Syncrude
Operated by Suncor

2024 Pit Lake Monitoring and Research Report (Base Mine Lake Demonstration Summary: 2012-2023)

Environmental Protection and Enhancement Act
Approval No. 26-03, as amended

Submitted to:

Alberta Energy Regulator

Submitted by:

Suncor Energy (Syncrude) Operating Inc. (SESOI)

July 31, 2024

LIMITATIONS

This report is provided to the Alberta Energy Regulator (AER) by Suncor Energy (Syncrude) Operating Inc. (SESOI) in its capacity as the operator of the Syncrude Project[1].

Findings and interpretations found in this report are superseded by any future Base Mine Lake (BML) Demonstration report. This report represents the data and interpretations from data collected from BML Demonstration commissioning (December 31, 2012) up to and including the year of the report. In future years, as more data are collected, understanding and interpretation of results may change. Please use the most current report for the most up-to-date information.

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[1] Referred to as Syncrude throughout the remainder of this submission.

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1 Executive Summary

Syncrude is committed to responsible oil sands development, which includes continuous improvement of our environmental performance and progressively reclaiming the land disturbed by our operations to meet mine decommissioning and closure objectives. Pit lakes are common closure landforms found in essentially all open pit mines throughout the world, including Alberta, regardless of the commodity extracted. The inherent nature of open pit mining lends itself to the creation of pit lakes once the mine pit has reached its end of life; therefore, they become critical components of all closure plans in the oil sands mining industry. Syncrude's Life of Mine Closure Plan (LMCP) includes planned pit lakes at the Mildred Lake site and the Aurora North site. These pit lakes are integral components of the Mildred Lake and Aurora North closure plans, regardless of whether they contain tailings since it is imperative that both industrial wastewater[2] and surface water run-off can be effectively managed in the future post-closure landscape in order to support the planned end land use objectives.

The materials remaining after bitumen is extracted from oil sands are called tailings. Tailings are a mixture of sand, water, silt, clay and some residual hydrocarbons and salts, which are found naturally in oil sands deposits. The tailings are distributed hydraulically via a network of pipelines and deposited into in-pit or out-of-pit tailings storage facilities. A primary fluid tailings (FT) management challenge is the long period of time it can take for some of the smallest solid components (fines) to settle within the FT[3]. As a result, application of FT management or treatment technologies is typically necessary to meet reclamation and mine closure objectives. To address this challenge, Syncrude has developed and successfully implemented several tailings technologies to manage its FT, including the Water-Capped Tailings Technology (WCTT). The principle of FT treatment for WCTT in Base Mine Lake (BML) Demonstration is self-weight consolidation to achieve fines sequestration. Water chemistry improvements occur after tailings deposition through natural processes (dilution, photo- and bio-degradation).

Syncrude first began investigating the WCTT in the early 1980's through the establishment of a research program founded on progressive scaled-up testing of water-capped FT. The reclamation technology involves the placement of FT below grade in a mined-out pit, followed by a layer of water of sufficient depth and volume; and allowing densification of the tailings to

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[2] The terms industrial wastewater, oil sands process-affected water (OSPW) and recycle water are used interchangeably throughout this report.

[3] The terms fluid tailings (FT) and Fluid Fine Tailings (FFT) are used interchangeably throughout this report.

occur without mechanical or chemical intervention, wherein the layer of water capping the tailings deposit develops over time into a lake habitable for plants and animals. Tailings treatment is self-weight consolidation without chemical treatment of the deposited tailings. The water layer becomes deeper as the tailings solids settle and pore water is expressed. As adequate water in-flows and out-flows are established, the water quality improves over time through low-energy water treatment processes (dilution and natural attenuation).

In 1994, Syncrude received endorsement from the Energy Resources Conservation Board (ERCB) for the proposed WCTT concept, as well as specific approval to develop BML as a full-scale demonstration of water-capped tailings in a pit lake. In 1995, Syncrude received *Environmental Protection and Enhancement Act* (EPEA) Approval No. 26-01-00 from the former Alberta Environmental Protection (AEP), which provided formal approval for the full-scale BML demonstration.

For the BML Demonstration, placement of FT into the mined-out pit began in 1995 and was completed in late 2012. The facility was removed from Syncrude’s active tailings network when it became commissioned as BML Demonstration on December 31, 2012. During 2013, additional fresh water and process-affected water were added to the existing upper water layer to attain the final elevation. Infrastructure has been installed to pump fresh water into BML Demonstration from Beaver Creek Reservoir and as required, water is pumped out of BML Demonstration to the closed-loop Industrial Wastewater Control System where it is utilized as recycle water in the bitumen extraction process. This flow-through process dilutes the water cap and will be in place until a more substantial upstream surface watershed is reclaimed and connected to BML Demonstration, and outflow is established to the receiving environment.

Syncrude submitted its first BML Demonstration Research and Monitoring Plan to AEP in 1996. An updated BML Demonstration Monitoring Plan and an updated BML Demonstration Research Plan were further submitted to the former Alberta Environment and Sustainable Resource Development (AESRD) in 2012 and 2013, respectively. Syncrude submitted its latest BML Demonstration Monitoring and Research Plan to the Alberta Energy Regulator (AER) on November 13, 2020, which was authorized on April 22, 2021. As indicated in EPEA Approval No. 26-03 (as amended), the objective of the BML Demonstration Monitoring and Research Plan is “to determine, by information collected through monitoring and research, whether or not water-capped fine tailings will be a viable tailings management, remediation and reclamation option at the Mildred Lake Plant Site."

Execution of the BML Demonstration monitoring and research program began upon commissioning and is ongoing. The various components comprising the monitoring and research program are closely linked. A key purpose of the program is to continue to support the adaptive management of BML Demonstration towards both the short- and long-term objectives. The monitoring and research program is designed to assess lake performance against key performance indicators and evaluate the need for management interventions. The initial focus of the monitoring and research program is to support the demonstration of the WCTT and to provide a body of scientific evidence which demonstrates that BML Demonstration is on a trajectory to become integrated into the reclaimed landscape.

Demonstrating the physical isolation of tailings fines beneath the water cap of BML Demonstration is considered a key performance outcome related to the validation of WCTT. To date, the results from the monitoring and research program indicate that the fine tailings is settling as forecasted by model predictions, the mudline is declining over time, the water cap is increasing in depth, and although the turbidity in the water cap fluctuates seasonally, there is generally a decrease in the suspended solids concentration over time, especially in the upper water layers. Surface water quality is also improving with time in BML Demonstration, as expected.

2 Introduction

2.1 Syncrude Project

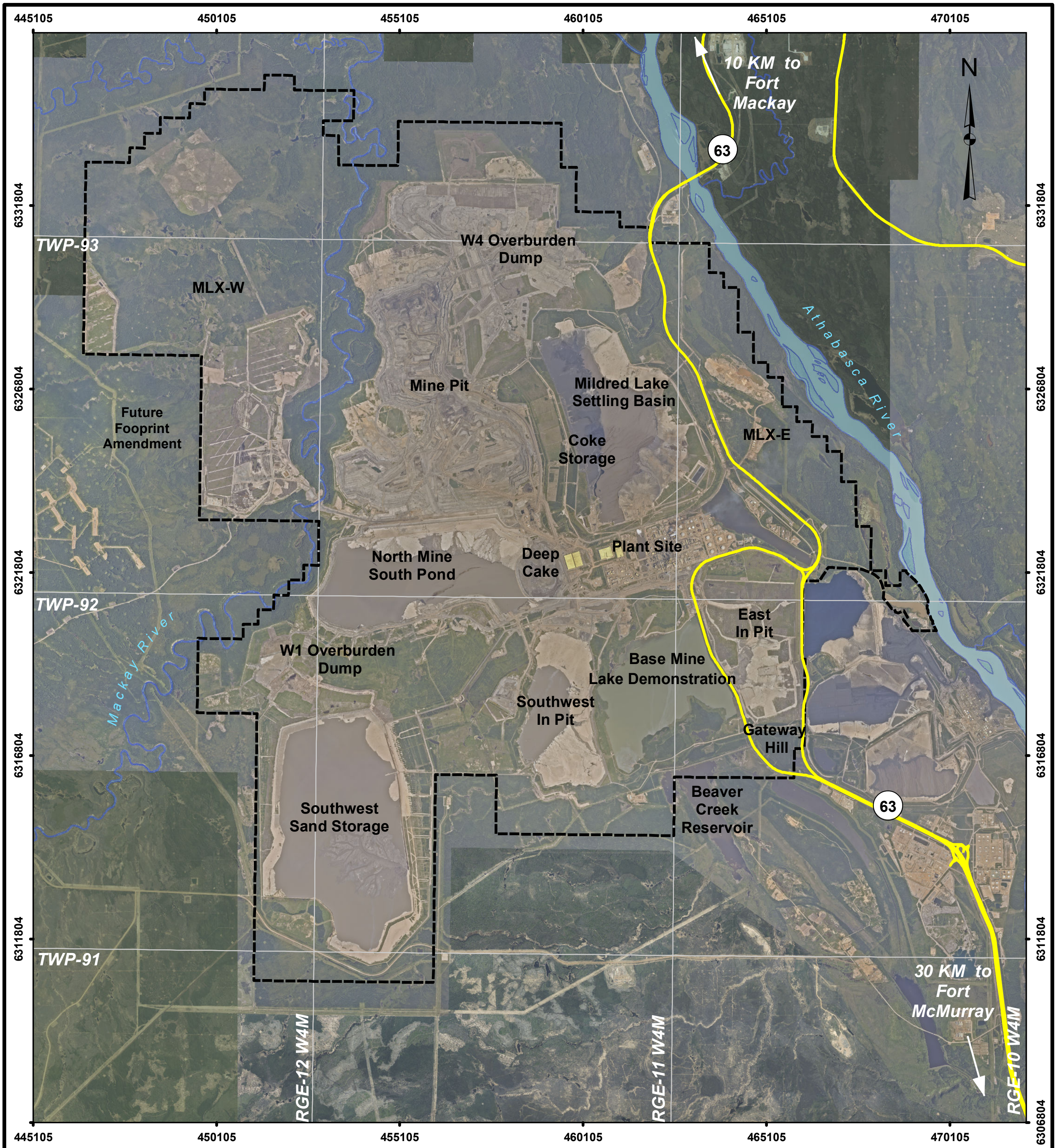
The Syncrude Project is a Joint Venture undertaking among Suncor Energy Inc., Imperial Oil Resources Limited; Sinopec Oil Sands Partnership; and CNOOC Oil Sands Canada. The Syncrude Joint Venture currently holds eight oil sands leases (OSLs) and two major production facilities, located north of Fort McMurray, Alberta in the Regional Municipality of Wood Buffalo (RMWB). Current Syncrude production facilities include the Mildred Lake and Aurora North mines and bitumen production facilities, and the Mildred Lake Upgrader and supporting infrastructure, known collectively as the Syncrude Project, and are operated by Suncor Energy (Syncrude) Operating Inc. Overviews of the Mildred Lake and Aurora North sites are provided in Figure 2-1 and Figure 2-2, respectively.

Oil sands mining is currently achieved through truck and shovel surface mining technology. The oil sands ore is mixed with warm water and delivered to a primary extraction facility using hydro-transport technology. The extraction facility’s role is to separate the bitumen from the oil sands. The produced bitumen froth is further processed at the Mildred Lake site through secondary extraction and upgrading.

The materials remaining after bitumen is extracted from oil sands are called tailings. Tailings are a mixture of sand and a fluid component which consists of water, silt, clay and some residual hydrocarbons and salts, which are found naturally in oil sands deposits. The tailings are distributed hydraulically via a network of pipelines and deposited into in-pit or out-of-pit tailings storage facilities. The tailings storage facilities serve two important purposes; firstly, they serve as the primary source of recycle water for use in bitumen processing, and secondly, they serve as temporary or permanent containment areas for tailings materials. As surface mining advances, new in-pit containment dykes are often constructed to establish additional in-pit tailings storage facilities, as required.

Syncrude is committed to responsible oil sands development, which includes continuous improvement of our environmental performance and progressively reclaiming the land disturbed by our operations to meet mine decommissioning and closure objectives. Due to the longevity of oil sands mining projects, reclamation and closure planning and execution needs to be undertaken throughout the life of the project, and in consideration of the various milestones along the way. Syncrude’s overarching objective is to develop a self-sustaining closure landscape, which attains the following fundamental goals:

- is integrated with the surrounding area
- yields water suitable for return to the natural environment
- has capability equivalent to that existing prior to development
- establishes boreal forest uplands, wetlands, and lake communities
- includes engagement with local, directly affected stakeholders



LEGEND

▬	Highway
⬚	OSCA Boundary
▭	River

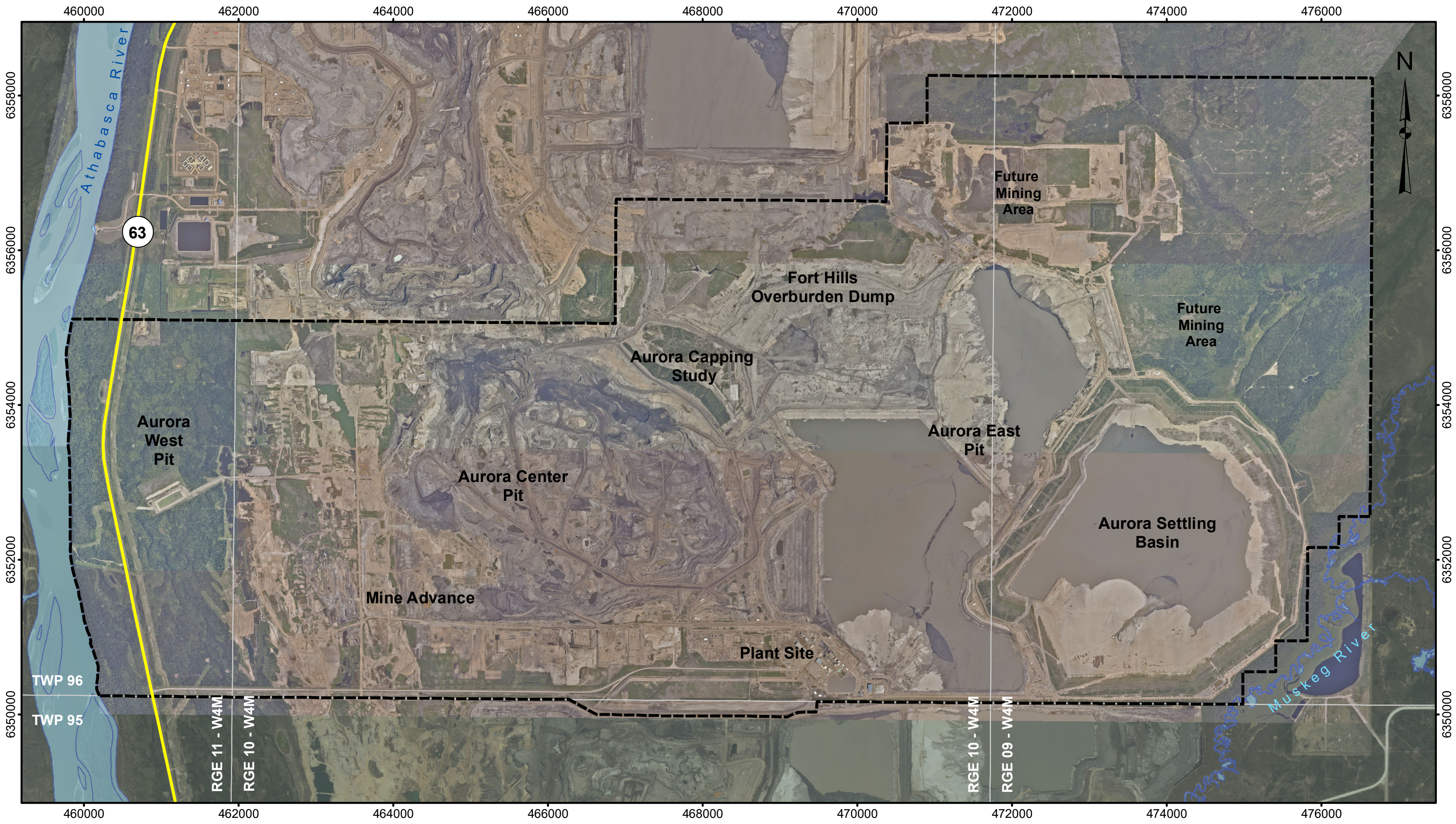
PROJECT:

TITLE:

Mildred Lake Site Overview

Syncrude
Operated by Suncor

AIR PHOTO DATE: 20220630			DATUM / PRJ: NAD 1983 UTM Zone 12N	
DESIGN			SCALE: 1:150,000	REV: 0
GIS	SL	May-2023	**Figure 2-1**	
REVIEW	AC	May-2023		
APPD	SR	May-2023		



1 0 1
Kilometers

LEGEND

- 🟨 Highway
- ⬚ OSCA Boundary
- 🟦 River

PROJECT:

TITLE:

Aurora North Site Overview

Syncrude Operated by Suncor

AIR PHOTO DATE: 20220630			DATUM / PRJ: NAD 1983 UTM Zone 12N
DESIGN			SCALE: 1:75,000 REV: 0
GIS	SL	May-2023	**Figure 2-2**
REVIEW	AC	May-2023	
APPD	SR	May-2023	

2.2 Regulatory Context

Syncrude received EPEA Approval 26-03-00 ("the EPEA Approval") from the AER on June 18, 2020. The following Pit Lake Monitoring and Research Report is submitted to the AER in accordance with the EPEA Approval, which requires Syncrude to submit an annual "End Pit Lake Research and Development Report" and an annual "Base Mine Lake Monitoring and Research Summary Report", as follows:

5.2.3 The approval holder shall submit an End Pit Lake Research and Development Report to the Director on or before February 28, 2021, and every year thereafter, unless otherwise authorized in writing by the Director.[4]

7.5.16 The approval holder shall submit a Base Mine Lake Monitoring and Research Summary Report to the Director annually on June 30, starting in 2021, unless otherwise authorized in writing by the Director.

BML Demonstration is Syncrude's first commercial scale demonstration of the WCTT within a pit lake; therefore, many of the research related reporting requirements under condition 5.2.3 are being addressed through the BML Demonstration. In accordance with EPEA Approval conditions 7.5.5 and 7.5.7, Syncrude submitted an updated BML Monitoring and Research Plan to the AER on November 13, 2020, which was authorized on April 22, 2021. As per EPEA Approval condition 7.5.9:

> *"The objective of the Base Mine Lake Monitoring Plan and Base Mine Lake Research Plan referred to in subsections 7.5.5 and 7.5.7 is to determine, by information collected through monitoring and research, whether or not water capped fine tailings will be a viable tailings management, remediation and reclamation option at the Mildred Lake Plant Site."*

In addition to internal research projects, Syncrude also participates in activities that support regional pit lake research initiatives through Canada's Oil Sands Innovation Alliance (COSIA). COSIA is an alliance of oil sands producers focused on accelerating the pace of improvement in

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[4] As per AER File No. 4101-00000026-0202, on July 24, 2023, Syncrude received authorization to extend the submission date of the End Pit Lake Research and Development Report and Baae Mine Lake Monitoring and Research Summary Report to Sept 30, 2023.

environmental performance in Canada's oil sands through collaborative action and innovation. Along with Syncrude’s BML Demonstration, there are two other key research programs that directly support building knowledge about pit lakes in the oil sands region supported through partnerships at COSIA: Suncor’s Lake Miwasin demonstration and the COSIA Demonstration Pit Lake Mesocosm study. A summary of these programs is provided in Section 3.7.

It is Syncrude’s interpretation that the annual report requirements listed under EPEA Approval condition 5.2.4 are primarily focused on pit lake designs and plans, rather than pit lake research. Many of these plans have been provided to the AER in previous EPEA and/or *Oil Sands Conservation Act* (OSCA) approval submissions or are subject to future submissions as required under Syncrude’s most recent EPEA and OSCA approvals. In alignment with ongoing efforts to improve regulatory efficiency, Table 2-1 lists the reporting requirements under EPEA Approval condition 5.2.4 and the relevant Syncrude submissions where the information has been or will be provided to the AER. Table 2-2 outlines the BML Demonstration monitoring and research reporting requirements, as per EPEA Approval condition 7.5.17, and the sections in this report which satisfy the requirements.

Table 2.1: Pit Lake Research and Development Report Concordance

Condition 5.2.4 Requirement	Submission
The End Pit Lake Research and Development Report referred to in subsection 5.2.3 shall address, at a minimum, all of the following with specific reference to the tailings technology used by approval holder:	
(a) a proposed schedule for all research and development undertaken, including a mechanism to track progress towards meeting the schedule over time;	Base Mine Lake Monitoring and Research Plan
(b) water budgets and solute mass balances for end pit lakes including quantities, sources, and quality of water to be used to fill the lake, and including groundwater recharge and seepage rates and quality;	2024 Pit Lake Monitoring and Research Report (Appendix 3)
(c) identification of key uncertainties in the water budget and solute mass balances and proposed research to address these uncertainties with particular attention to the hydrology of the effective catchment area and connectivity with groundwater;	2024 Pit Lake Monitoring and Research Report (Appendix 3)
(d) research assumptions, predictions, and validations to support fisheries, aquatic resources, and aquatic habitat: (i) as proposed in the closure landscape at various timeframes of end pit lake development for each the following: (A) chemical and physical behavior of untreated or treated tailings placed in an end pit lake; (B) water quality and toxicity; (C) geotechnical stability; and, (D) effects of long-term shoreline retrogression. (E) landform design; and (F) sustainable water levels and hydrological connectivity under a range of late 21st century regional climate change scenarios developed by the Intergovernmental Panel on Climate Change; (ii) for water release scenarios;	Base Mine Lake Monitoring and Research Plan 2024 Pit Lake Monitoring and Research Report
(e) estimates of water quality concentrations at closure for end pit lakes for parameters identified as substances of concern by the Director, including assumptions on decay rates and partitioning;	2024 Pit Lake Monitoring and Research Report
(f) confirmation of the assumptions and expectations for water quality release outlined in the application, including refinement, update, and validation of the predictive models;	Base Mine Lake Monitoring and Research Plan

Condition 5.2.4 Requirement	Submission
	2024 Pit Lake Monitoring and Research Report (Appendix 3)
(g) an indication of treatment efficiency required for end pit lakes to maintain suitable water quality given the quality of the source waters and the research;	Base Mine Lake Monitoring and Research Plan Pit Lake Monitoring and Research Annual Report
(h) the role of wetlands, riparian habitat, and littoral zone in creating continuity between the reclaimed landscape and end pit lakes;	Life of Mine Closure Plan
(i) identification of wetland/macrophyte research that will be required to ensure proposed end pit lakes provide sustainable habitat and achieve other functions such as enhanced water treatment, shoreline protection and flood buffering;	COSIA Annual Reports
(j) watershed hydrologic connections and associated closure goals and targets for fish and fish habitat;	2024 Pit Lake Monitoring and Research Report
(k) consideration of potential elevated contaminant influences on fish ecology, health, palatability, and consumption safety;	Base Mine Lake Monitoring and Research Plan
(l) consideration of long-term shoreline retrogression and related effects on littoral zone, adjacent wetlands, landforms, and water budget and solute mass balances (especially in relation to evaporation);	Base Mine Lake Monitoring and Research Plan
(m) identification of research that will be required to ensure end pit lakes adequately: (i) treats site drainage; (ii) provides a sustainable aquatic ecosystem and aquatic habitat; (iii) is geotechnically stable; and (iv) achieves other functions such as shoreline protection and flood buffering;	Base Mine Lake Monitoring and Research Plan
(n) lake design features which: (i) promote natural biodegradation and detoxification rates for toxic parameters; (ii) minimize erosion and protect shorelines; (iii) promote recreational, domestic, and commercial fisheries potential; and	Life of Mine Closure Plan Base Mine Lake Monitoring and Research Plan

Condition 5.2.4 Requirement	Submission
(iv) optimize water residence time with particular consideration of salinity;	
(o) biodegradation, detoxification, and dilution of parameters identified as substances of concern by the Director;	N/A
(p) research related to subsections 5.1.2(d) and 5.1.2(e) for end pit lakes;	Base Mine Lake Monitoring and Research Plan
(q) a review and assessment of other mitigative options for end pit lakes if water quality is a concern;	COSIA Annual Reports
(r) adaptive incorporation of any guidelines prepared or provided by the Director related to end pit lakes;	N/A
(s) identification of research or modelling limitations and uncertainties in achieving the targeted locally common boreal forest closure outcomes;	Base Mine Lake Monitoring and Research Plan
(t) plans and schedules to address research or modelling limitations and uncertainties in achieving the targeted locally common boreal forest closure outcomes;	Base Mine Lake Monitoring and Research Plan
(u) the applicability of Syncrude Canada Limited Base Mine Lake (BML) research to the other proposed water capped end pit lakes;	2024 Pit Lake Monitoring and Research Report
(v) how Syncrude will address uncertainties and risks where BML research is not applicable;	Base Mine Lake Monitoring and Research Plan
(w) the rationale for the siting of the proposed end pit lakes adjacent to the Athabasca River and McKay River escarpments, including: (i) the benefits and disadvantages of relocating the proposed pit lakes farther away from the Athabasca River and McKay River escarpments;	Life of Mine Closure Plan
(x) data submission and reporting schedule; and	Base Mine Lake Monitoring and Research Plan
(y) any other information as required in writing by the Director.	Table 2.2

Table 2.2: Base Mine Lake Monitoring and Research Summary Report Concordance

Condition 7.5.17 Requirement	Report Section
The Base Mine Lake Monitoring and Research Summary Report referred to in subsection 7.5.16 shall include the following, unless otherwise authorized in writing by the Director:	
(a) a summary of the results of monitoring for the previous year;	4.3.3, 6
(b) a summary of the results of research for the previous year;	7
(c) a description and presentation of trends across all timeframes;	4.3.3, 6, 7
(d) updates to the Base Mine Lake Monitoring Plan as necessary;	N/A
(e) updates to the Base Mine Lake Research Plan as necessary, including a description of research continuing and planned for the next five year period; and	N/A
(f) any other information as required in writing by the Director. As requested in 2023:	
• A discussion on end use goals for the proposed pit lakes;	3.6.1
• An overview of strategies to be employed or currently in research to prevent residual bitumen issues observed at Base Mine Lake;	3.6.3, 3.7.1, 5.6
• A discussion on what contributing factors may be leading to the differences observed in BCR and BML phytoplankton biomass.	5.4.1
• A discussion on what other factors may have contributed to the relatively constant chloride concentrations observed in 2022 and 2021, despite the larger volume of fresh water being pumped	5.2
• Based on monitoring to date, discuss when BML is expected to achieve the longer-term performance indicator of meeting	5.2.4

Condition 7.5.17 Requirement	Report Section
chronic guidelines for chloride concentrations (i.e. 120 mg/L); and	
• A discussion on strategies or alternatives to application of alum for control of suspended sediments in future pit lakes currently considered viable or being researched	4.3.3

The following Pit Lake Monitoring and Research Report summarizes the key findings from the BML Demonstration monitoring and research program for 2023. Background information is provided for additional context, in order to support the reader's understanding and interpretation of the information.

3 Background

3.1 Tailings Management and Closure Regulatory Overview

Reclamation and closure of industrial sites is a requirement under Alberta legislation; primarily under EPEA for the mineable oil sands. In order to meet the Province of Alberta's reclamation and closure objectives for oil sands mining projects, in 2015 the Government of Alberta (GoA) released the *Tailings Management Framework for the Mineable Athabasca Oil Sands* (TMF), which seeks to balance environmental protection and the associated risk of increasing FT volumes. The primary objective of the TMF is to reduce FT accumulation on the landscape by ensuring that FT are managed such that they can achieve a Ready-to-Reclaim state in a timely manner, which may reduce the potential for negative environmental effects. Requirements under the TMF are administered primarily through OSCA and EPEA:

- Under OSCA, *Directive 085: Fluid Tailings Management for Oil Sands Mining Projects* (Directive 085) sets out the requirements for managing and reporting FT volumes for oil sands mining projects to meet the intended outcomes set forth under the TMF.

- Under EPEA, *Specified Enactment Direction 003: Direction for Conservation and Reclamation Submissions Under an Environmental Protection and Enhancement Act Approval for Mineable Oil Sands Sites* (SED-003) outlines the requirements for the collection and reporting of conservation and reclamation information to the AER to fulfill the terms and conditions of the EPEA approval.

In addition, FT dam or impoundment requirements are managed through the *Water Act* and the *Alberta Dam and Canal Safety Directive* (Dam Safety Directive). The Dam Safety Directive contains requirements for dam owners that are applicable to the entire life cycle of a dam. *Manual 019: Decommissioning, Closure, and Abandonment of Dams at Energy Projects* (Manual 019) is a guide focused on section 9 of the Dam Safety Directive and provides additional guidance regarding decommissioning, closure, and abandonment plans and completion reports for tailings facilities with dams regulated by the AER.

In accordance with the legislation and requirements outlined above and in compliance with Syncrude's approvals and authorizations issued under EPEA, OSCA and the *Water Act*, Syncrude submits several plans and reports to the AER related to tailings management, dam abandonment, reclamation, and closure. Key submissions associated with tailings reclamation and closure are summarized below.

- Life of Mine Closure Plan

  A Life of Mine Closure Plan (LMCP) is a project-level plan required under EPEA (SED-003) for mineable oil sands projects. The LMCP functions as Syncrude's conceptual plan for the orderly and sustainable progression of reclamation activities to achieve a state of final closure and to accommodate all constituent requirements including FT management, as well as dam closure and abandonment. The LMCP is aligned with the goal of equivalent land capability and is designed to support commercial, recreational, and traditional end-land uses. As required under condition 7.3.8 of the EPEA Approval, Syncrude has submitted an updated LMCP to the AER in 2023. This submission is currently paused. An application update will be submitted in August 2024. Performance reporting is completed through the submission of Annual Reclamation Progress Tracking Reports, in accordance with SED-003 and Syncrude's EPEA Approval.

- Tailings Management Plan

  A Tailings Management Plan (TMP) is a project-level plan required under OSCA (Directive 085) for mineable oil sands projects. Syncrude submitted updated TMPs to the AER in 2023 for the Mildred Lake and Aurora North sites. The TMPs are aligned with the principles and objectives in the TMF and provide an overview of Syncrude's plans for managing and treating new and legacy FT throughout the life of the Mildred Lake and Aurora North projects. The 2023 TMP submission is currently paused. An application update will be submitted in August 2024. Performance reporting is completed through the submission of Annual Fluid Tailings Management Reports, in accordance with Directive 085 and Syncrude's OSCA Approvals.

- Dam Decommissioning, Closure, and Abandonment Plan

  A Dam Decommissioning, Closure and Abandonment Plan (DCAP) is a facility-level plan required under the *Water Act* (Dam Safety Directive) for tailings facilities with dams regulated by the AER, which have an accepted consequence classification of significant, high, very high or extreme. As required under the Dam Safety Directive, a DCAP must address all stages of decommissioning, closure, and abandonment of the dam. The scope of the DCAP is determined by qualified professionals and is based on the consequence classification or risk posed by the structures. Performance reporting is completed through the submission of Annual Performance Reviews, in accordance with the Dam Safety Directive and Syncrude's *Water Act* Approvals.

Figure 3-1 provides an overview of the key tailings management regulations referenced in this submission.

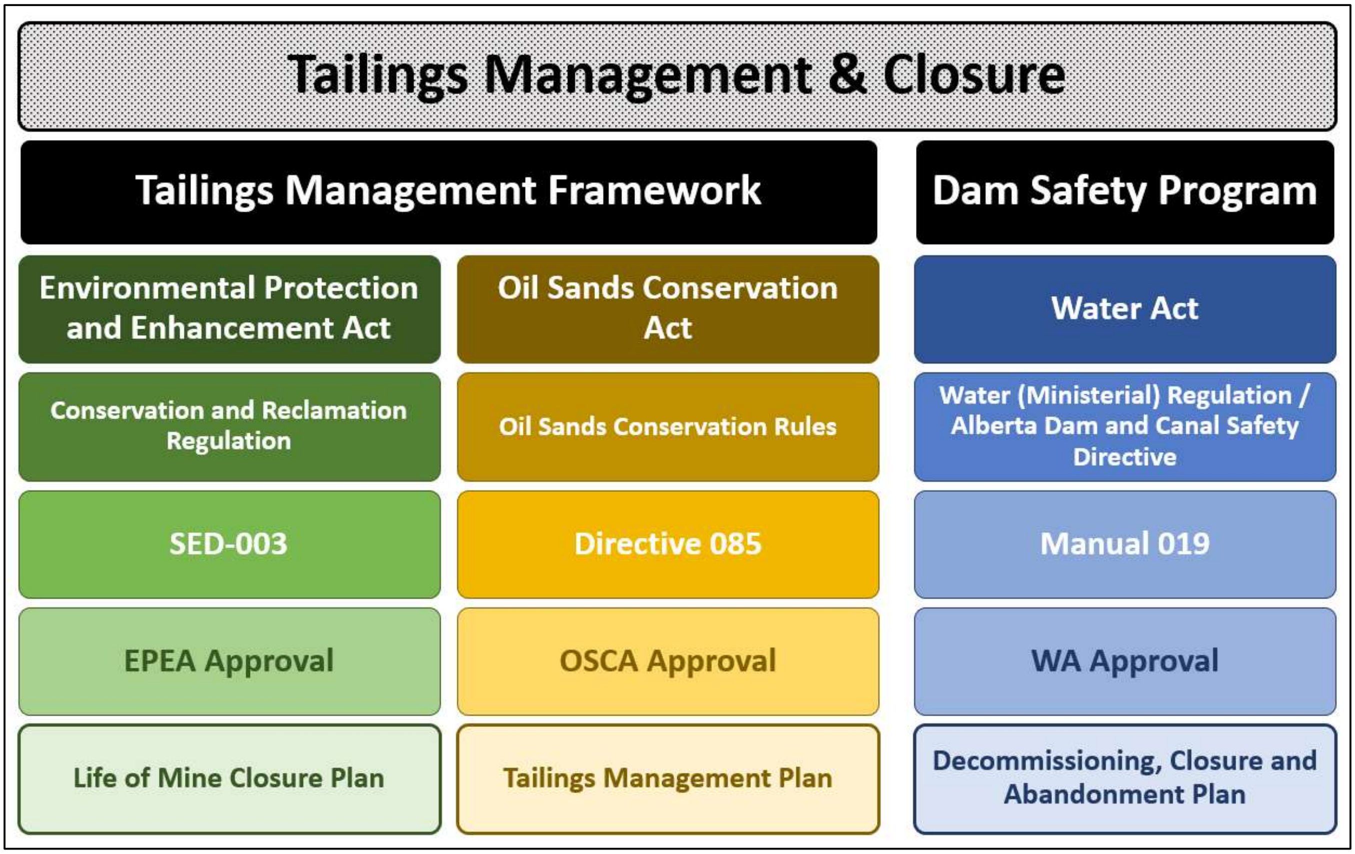


Figure 3-1: Tailings Management and Closure Regulatory Overview

3.2 Syncrude Fluid Tailings Management Technologies

Syncrude is committed to responsible oil sands development, which includes continuous improvement of our environmental performance, meeting or exceeding regulatory requirements, implementing cost effective tailings management technologies, and progressively reclaiming the land disturbed by our operations to meet mine closure objectives. In order to ensure the land can be returned to a stable, safe condition that can support biologically self-sustaining communities of plants and animals, Syncrude has a dedicated research and development department and specialized state-of-the-art facilities with a significant focus on tailings and reclamation. Syncrude undertakes environmental research in collaboration and partnership with academic institutions across Canada and North America. In addition to internal research and development projects, Syncrude also participates in activities that support regional research initiatives through Canada's Oil Sands Innovation Alliance (COSIA). COSIA is an alliance of oil sands producers focused on accelerating the pace of improvement in environmental performance in Canada's oil sands through collaborative action and innovation. The learnings from Syncrude and COSIA's research initiatives have been and will continue to be leveraged to ensure that the tailings technology options are well understood and can be successfully implemented at Syncrude, if selected. The advancement of tailings technology development is a priority. Therefore, Syncrude continues to assess tailings treatment options based on the latest research and development of all available technologies, as well as the sustainability (environment, economic, social) of alternative technologies on mining, tailings, and closure plans. Tailings technology development at Syncrude typically utilizes a progressive scale-up process beginning with bench scale laboratory testing, followed by field pilots (often multiple tests with increasing scale) and, if validated and selected, commercial implementation. This process has been successfully implemented for the tailings technologies currently approved for use or under commercial development at Syncrude, including:

- Water-Capped Tailings Technology (BML demonstration)
- Composite Tailings
- Centrifuge Cake
- Flocculated Tailings, and
- FT/Overburden Co-mixing

In addition, Syncrude has incorporated co-deposition of different tailings materials into its plan. Tailings co-deposition is a strategy which involves the deposition of more than one tailings product into a single containment structure, without separation by divider dykes. This approach to tailings deposition improves tailings storage efficiency by not requiring additional dykes or berms to separate each tailings product. While co-deposition in itself is not a technology, the depositional environment of the tailings product(s) has the potential to improve deposit performance through enhanced dewatering and consolidation by combining tailings materials with complementary properties.

Figure 3-2 provides an overview of Syncrude’s current and proposed FT management technologies, including the co-deposition placement.

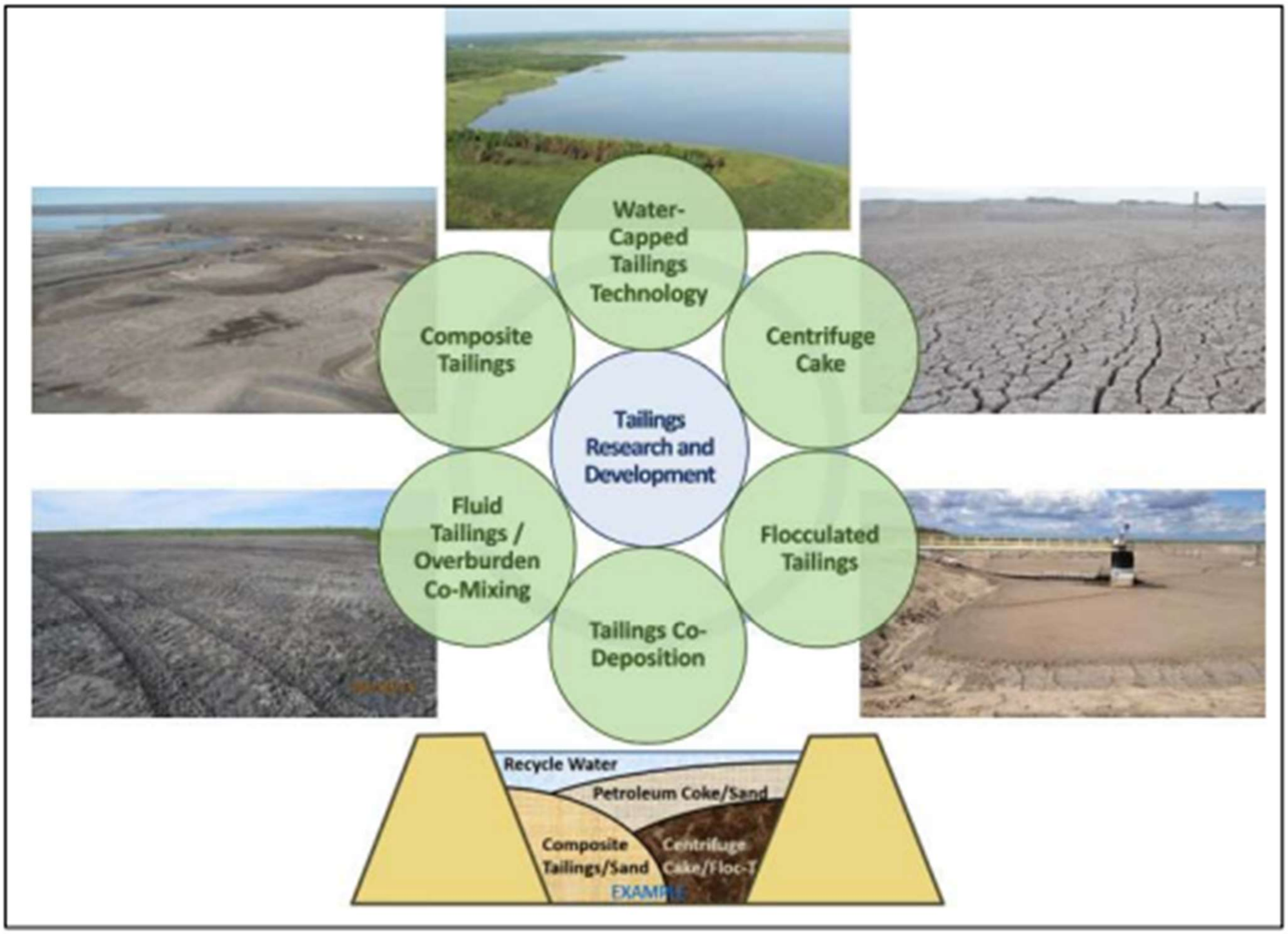


Figure 3-2: Overview of Syncrude Fluid Tailings Implemented Management Technologies

3.3 Water-Capped Tailings Technology Development

Pit lakes are used at mine sites around the world and are a mining industry best practice worldwide for reclamation and closure. Pit lakes support a variety of locally common terrestrial and aquatic species and are integrated into the reclaimed landscape.

Developing a successful pit lake requires effective planning and incorporation of research results. Pit lakes containing tailings have been part of oil sands mine closure plans since the first mine was opened in 1967 and are extensively researched components of closure plans for oil sands mines. Pit lake designs have changed over time to reflect the state of knowledge of oil sands mine waters and tailings, technology advances, changing regulations and inputs from local stakeholders and Indigenous communities.

Research has demonstrated that water capped tailings technology is a proven tailings treatment technology which has informed current pit lake designs and plans. Ongoing research and monitoring will further enhance pit lake designs and plans in the years to come. Ultimately, the intent is to develop pit lakes that meet environmental and end land use objectives and form an accepted part of the reclamation and closure landscape for local stakeholders and Indigenous communities (CAPP 2021).

Pit lakes in the mineable oil sands region are planned to cover approximately 8% of the landscape post-closure. There are a variety of lakes included in closure plans with a range of types and combinations of freshwater, oil sands process-affected water (OSPW) and/or tailings (treated chemically and/or through self-weight consolidation). Each lake is designed to meet unique site-specific opportunities and constraints.

WCTT is a method of tailings reclamation involving the deposition of tailings below grade into a mined-out pit, placing a layer of water of sufficient depth to prevent wind driven re-suspension of fines from beneath the mudline, and allowing the densification of the tailings to occur without mechanical or chemical intervention. The resulting landform features a layer of water that over time will support aquatic plants and animals. Tailings treatment is self-weight consolidation without chemical amendment to the tailings.

Based on extensive research, modelling, and experience, the expectation for WCTT is that the tailings solids remain sequestered below the water cap and the pit lake water quality improves with time. In simple terms, the water in the spaces between the finer (clay) particles moves to the surface as the particles settle. The water cap becomes deeper as the solids consolidate and release pore water. As adequate water in-flows and out-flows are established, the water cap quality improves over time.

A simplified overview of the FT settlement and increasing water cap depth over time is provided in Figure 3-3. Figure 3-4 provides a schematic of the WCTT concept.

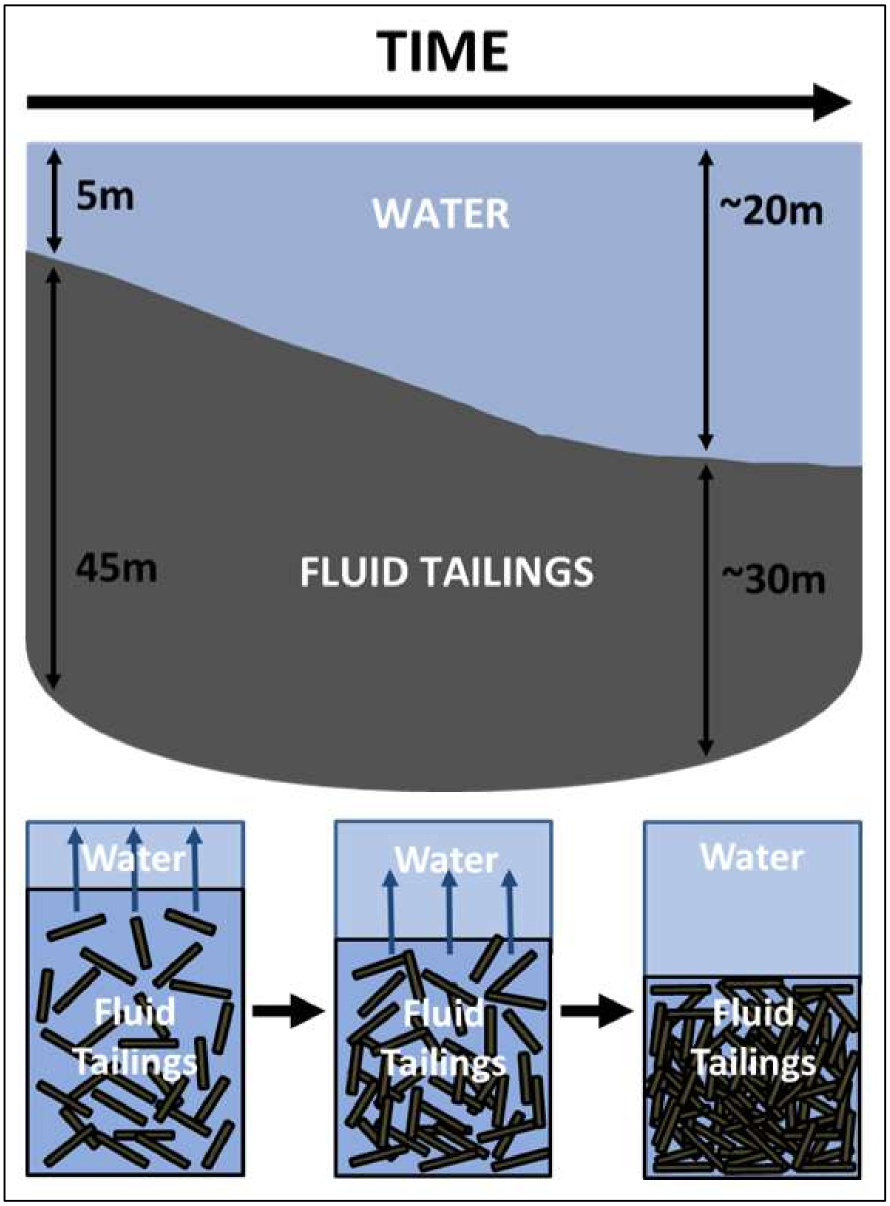


Figure 3-3: Simplified Depiction of Water-Capped Tailings Settlement over Time (not to scale)

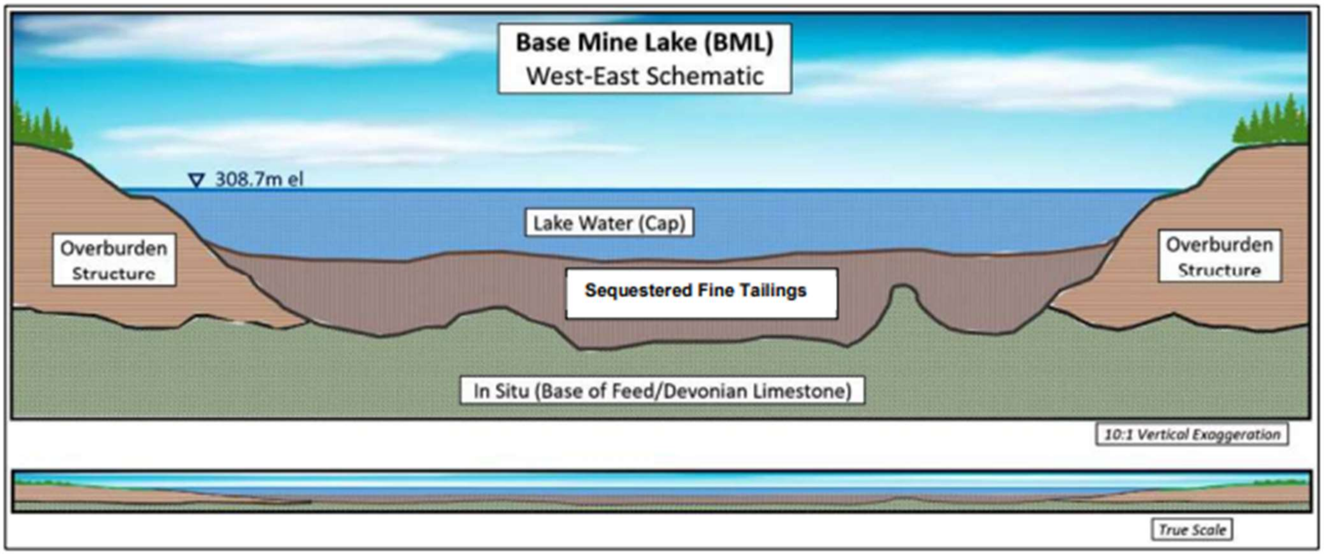


Figure 3-4: Water-Capped Tailings Technology Schematic (not to scale)

Syncrude first began investigating WCTT over four decades ago through the establishment of a research program founded on progressive scaled-up testing of water-capped FT. Research began in the early 1980’s with bench scale laboratory studies and from 1989 to 2012 the studies were scaled up to a series of ‘surrogate lake’ basins, consisting of 12 pilot test ponds ranging in size from roughly 0.5 to 4.0 hectares and from two thousand m^3 to 140 thousand m^3 total volume. Some ponds were filled with approximately three meters of FT and capped with water from a range of sources. Monitoring of the test ponds continued until 2012. Some key findings from the Syncrude Test Ponds and modelling activities include:

- FT has a low permeability to water, as do overburden clay and undisturbed lean oil sands deposits, and modelling and monitoring suggests negligible groundwater movement from pit lakes is expected;
- Naturally occurring bacteria can be relied upon to break down many compounds, such as ammonia, sulfate and dissolved organics;
- Oxygen in the water cap is important for degradation of organic compounds such as Naphthenic Acid;
- The relatively small-scale test ponds demonstrated that acute water toxicity dissipated quickly (weeks to months)
    - Within 2 months for fish and bacteria with 100% OSPW;
- The relatively small-scale test ponds demonstrated that chronic toxicity declined over time. These residual chronic effects may persist;

- The ponds containing FT were colonized by a variety of aquatic life rapidly
    - Diversity of these systems is influenced by water chemistry (eg. Naphthenic acid concentration and conductivity) and age (younger vs. older)
- These small ponds did not exhibit conventional boreal lake mixing dynamics (dimixis) that are important drivers of lake performance at full-scale
    - The water cap in the full scale demonstration is expected to turnover every fall;
- FT densifies over time as porewater is released;
- For the BML configuration, considering the lake size and orientation, the water cap must be at least five metres deep to prevent fines from the lake bottom from being resuspended by wind-generated waves (Lawrence, 1991).

Learnings from the decades of laboratory and field pilot research, monitoring and modelling were used to develop the BML demonstration, which was commissioned on December 31, 2012.

Figure 3-5 provides an overview of the WCTT research and development progression at Syncrude.

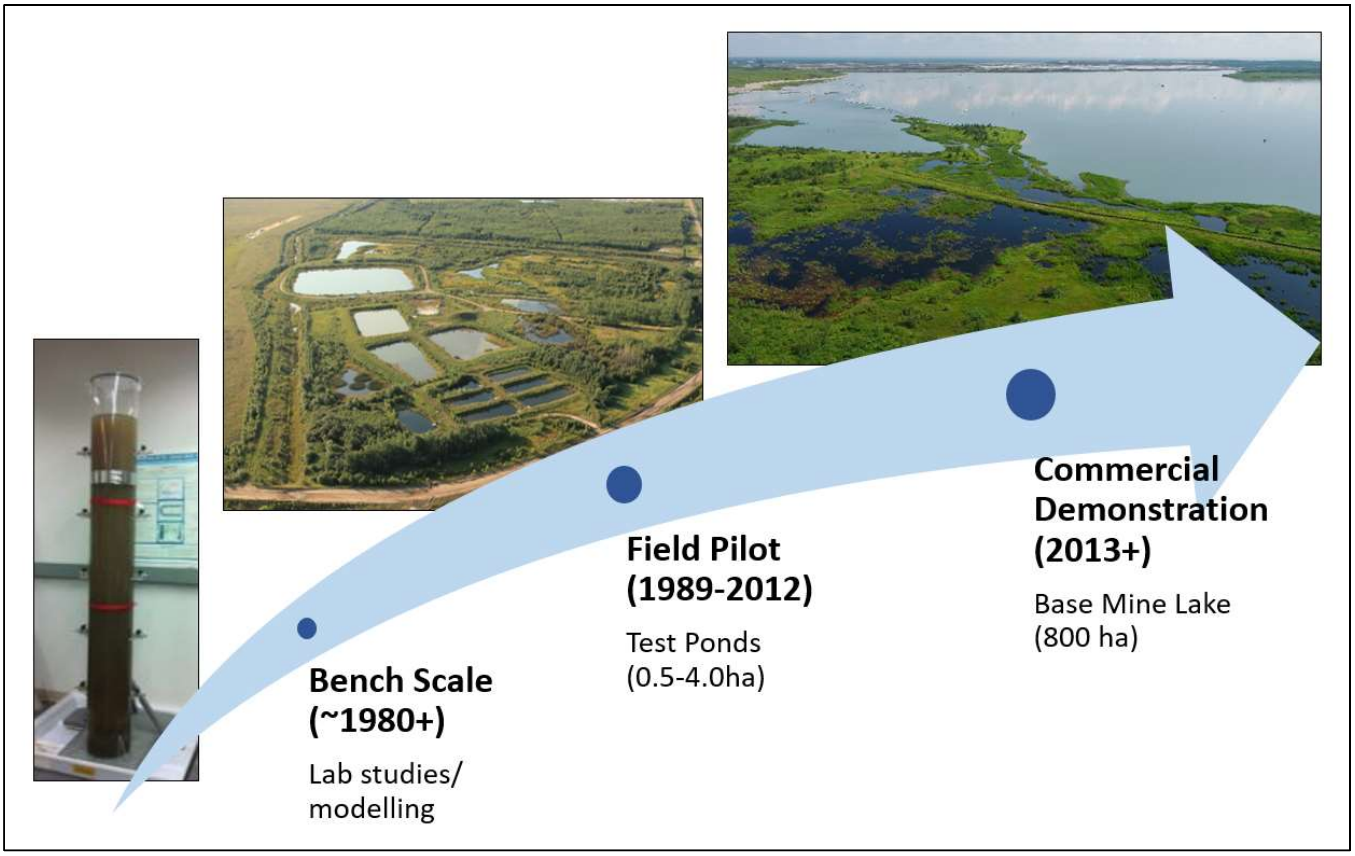


Figure 3-5: Progression of Water-Capped Tailings Research and Development

3.4 Water-Capped Tailings Approval History

Pursuant to the *Oil Sands Conservation Act* (OSCA), in September 1992 Syncrude submitted Application No. 921321 to the former ERCB to amend Mildred Lake Approval No. 5641. The application included plans for fluid fine tailings reclamation and identified water-capped fine tails as the preferred FT treatment option. In the response for additional information regarding Application No. 921321 issued by the ERCB on January 7, 1993, Syncrude indicated that a larger scale demonstration was under development which would more closely resemble the final water-capping scenario. The pilot plan included construction of a 200,000 m^3 Demonstration Pond into which 120,000 m^3 of fluid fine tailings (FT) would be transferred.

During the hearing for Application No. 921321 in 1993, some stakeholders questioned whether the 200,000 m^3 demonstration pond would be large enough to provide the necessary information to verify and implement the WCTT at full-scale. In response to stakeholder concerns, Syncrude proposed a commercial-scale test, which included the development of a lake containing roughly 150 Mm^3 of FT with a 5 meter water cap. This test became known as the Base Mine Lake Demonstration.

In July 1994, Syncrude received endorsement from the ERCB for the proposed WCTT concept, as well as specific approval to develop BML as a full-scale demonstration of WCTT in a pit lake; as indicated in the decision report for Application No. 921321 (Decision 94-5), as follows:

> 5. The conceptual mining, lease development and reclamation plans, including the proposed water-capped lakes technique for fine tails reclamation, are endorsed subject to:
>   - Syncrude developing the 'base mine lake' with a suitable monitoring program and successfully demonstrating the associated reclamation technique, and
>   - Syncrude continuing research and development efforts into alternative reclamation and tailings management technologies.
>
> 7. The development of the base mine demonstration lake is specifically approved subject to Syncrude developing associated comprehensive monitoring and scientific investigation programs in consultation with its stakeholders.

Pursuant to the EPEA, in March 1995, Syncrude submitted Application No. 002-26 to the former AEP to renew Mildred Lake Approval No. OS-1-78. The application included a conceptual life of mine closure and reclamation plan which included WCTT and the BML demonstration as key components, in alignment with the 1993 ERCB application and proceedings.

In December 1995, Syncrude received EPEA Approval No. 26-01-00 from AEP, which provided formal approval for the full-scale BML demonstration, as described below:

12.3.13 The Base Mine Lake described in the application is approved as a full-scale demonstration of the water-capped fine tails reclamation concept. Prior to June 30, 1996 the approval holder shall submit, for the approval of the Director of Land Reclamation, a detailed outline of a comprehensive research and monitoring program for the Base Mine Lake, addressing the objectives, methods, and schedule of the program. The program shall be developed in consultation with all stakeholders.

As required under clause 12.3.13 of EPEA Approval No. 26-01-00, Syncrude submitted its first Base Mine Lake Research and Monitoring Plan to AEP on June 26, 1996. An updated Base Mine Lake Monitoring Plan and an updated Base Mine Lake Research Plan were further submitted to Alberta Environment and Sustainable Resource Development in 2012 and 2013, respectively, in accordance with conditions 6.1.91 and 6.1.92 of EPEA Approval No. 26-02-05. Syncrude's most recent Base Mine Lake Monitoring and Research Plan was submitted to the AER on November 13, 2020, in accordance with conditions 7.5.5 and 7.5.7 of EPEA Approval No. 26-03-00; Syncrude received AER authorization for the plan on April 22, 2021.

3.5 Tailings Facility Progression into a Pit Lake

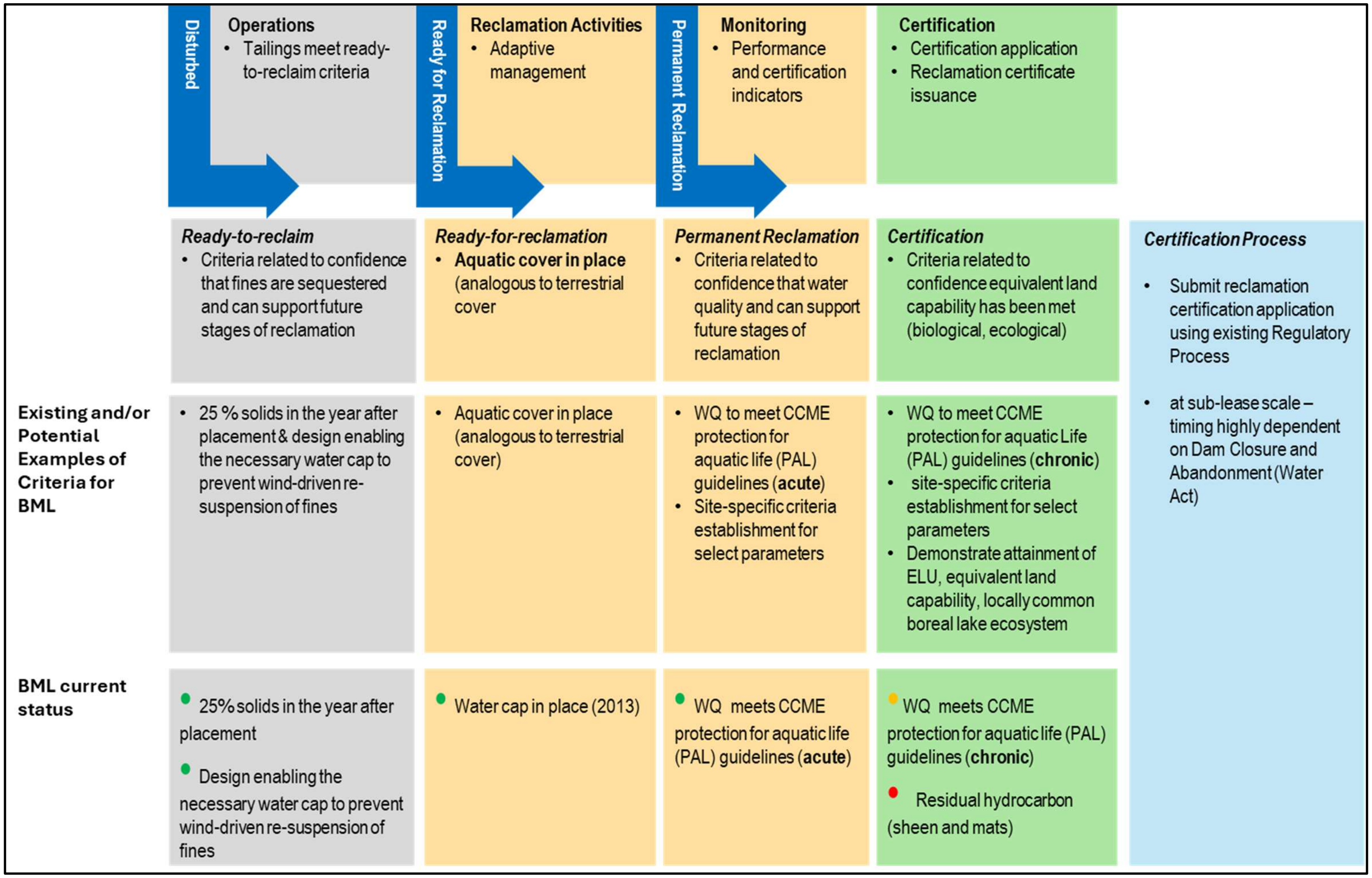
Disturbed land resulting from Syncrude's oil sands mining projects progresses through a number of defined stages towards ultimate reclamation certification, and transition from one stage to the next is typically separated by a defined progressive reclamation milestone. Reclamation stages are periods characterized by time and/or activities, and reclamation milestones are checkpoints that are characterized by the attainment of defined performance expectations.

For landforms containing FT, the first milestone is typically meeting Ready-to-Reclaim (RTR) criteria. Directive 085 defines RTR as the "state achieved when FT have been processed through an accepted technology, have been placed in their final landscape position, and have achieved necessary performance criteria." As described in the TMF, becoming RTR is just one stage in the process of progressive reclamation for FT deposits. Once a FT deposit meets its defined RTR criteria, it is considered to be on the trajectory towards being "ready for reclamation". SED-003 defines "ready for reclamation" as "areas that are no longer required for mine or project purposes and are available for reclamation but where reclamation has not yet started." As explained in Directive 085:

- "Ready to Reclaim" is used to track the performance of treated FT in active, operational tailings deposits; and
- "Ready for Reclamation" is used to identify project areas (inclusive of tailings deposits) that are no longer operational and are available for reclamation to begin.

For tailings facilities that transition into pit lakes, the pit lake is typically commissioned once tailings solids infilling is complete, and the facility is no longer utilized for active tailings management. It is at this stage that the facility is considered "ready for reclamation", although reclamation of the surrounding slopes, littoral zone and water-capping activities have likely already commenced.

Figure 3-6 illustrates the relationship between reclamation stages as presented in Directive 085 for pit lakes and adapted to support aquatic (pit lake) closure, as well as potential progressive reclamation and certification milestones and aquatic reclamation and current status of the BML Demonstration.



	Operations - Tailings meet ready-to-reclaim criteria	**Reclamation Activities** - Adaptive management	**Monitoring** - Performance and certification indicators	**Certification** - Certification application - Reclamation certificate issuance	
	Ready-to-reclaim - Criteria related to confidence that fines are sequestered and can support future stages of reclamation	***Ready-for-reclamation*** - **Aquatic cover in place** (analogous to terrestrial cover	***Permanent Reclamation*** - Criteria related to confidence that water quality and can support future stages of reclamation	***Certification*** - Criteria related to confidence equivalent land capability has been met (biological, ecological)	***Certification Process*** - Submit reclamation certification application using existing Regulatory Process - at sub-lease scale – timing highly dependent on Dam Closure and Abandonment (Water Act)
Existing and/or Potential Examples of Criteria for BML	- 25 % solids in the year after placement & design enabling the necessary water cap to prevent wind-driven re-suspension of fines	- Aquatic cover in place (analogous to terrestrial cover)	- WQ to meet CCME protection for aquatic life (PAL) guidelines (**acute**) - Site-specific criteria establishment for select parameters	- WQ to meet CCME protection for aquatic Life (PAL) guidelines (**chronic**) - site-specific criteria establishment for select parameters - Demonstrate attainment of ELU, equivalent land capability, locally common boreal lake ecosystem	
BML current status	🟢 25% solids in the year after placement 🟢 Design enabling the necessary water cap to prevent wind-driven re-suspension of fines	🟢 Water cap in place (2013)	🟢 WQ meets CCME protection for aquatic life (PAL) guidelines (**acute**)	🟠 WQ meets CCME protection for aquatic life (PAL) guidelines (**chronic**) 🔴 Residual hydrocarbon (sheen and mats)	

Figure 3-6: Conceptual Diagram of adapting the Alberta Progressive Reclamation Stages and Milestones for aquatic reclamation, and existing and/or potential examples for Pit Lake and Aquatic Reclamation, including current status of BML Demonstration (🟢 criteria achieved, 🟠 criteria on track and making progress, 🔴 not yet achieved)

3.6 Syncrude’s Planned Pit Lakes

Syncrude’s Water Modelling for the 2023 LMCP included three pit lakes at the Mildred Lake site and two at the Aurora North site:

- Base Mine Lake,
- North Mine Lake,
- West Mine Lake,
- Aurora North East Lake, and
- Aurora North West Lake.

These pit lakes are integral components of the Mildred Lake and Aurora North closure plans, regardless of whether they contain water-capped tailings since it is imperative that both industrial wastewater and surface water run-off can be effectively managed in the future post-closure landscape in order to support the planned end land use objectives. Water will not be released from any of Syncrude’s proposed pit lakes until it is proven to meet applicable water quality standards, which will be the subject of future regulatory submissions. The data that is being collected through the BML Demonstration integrated monitoring and research program will be helpful in ensuring that these future standards can be met.

3.6.1 End land use options for pit lakes

As described in Syncrude’s life of mine closure plan (Syncrude 2016), pit lakes will support ecological functions and lake specific wildlife habitat. This section outlines end land use (ELU) options for pit lakes in the mineable oil sands and the specific end land use goals adopted for each end pit lake in this plan. End land use options will be lake-specific and depend on a variety of factors including presence of tailings and resulting water chemistry, lake depth, oxygen and nutrient status and lake productivity. More work is needed to assess the productive capability in tailings containing pit lakes to understand the potential to support large-bodied fisheries. In the absence of specific pit lake policy or regulatory guidance, our targets for stewarding pit lake adaptive management to achieve outcomes have relied on existing guidelines (for example Environmental Quality Guidelines for Alberta Surface Waters (EQGASW) (ESRD, 2014)).

Option 1. Lake supports ecological functions

This pit lake is capable of supporting conventional boreal lake functions. It will achieve water quality capable of supporting aquatic plants, algae and macroinvertebrate communities.

Primary production will be sufficient to support primary and secondary consumers but may not be capable of support larger bodied sport fish. Although the water quality in the lake will likely not be acutely or chronically toxic to fish (using standard Environment Canada protocols), fish populations may be limited by available habitat to support their life history requirements and/or food availability. Depending on levels of primary production, oxygen levels may not be sufficient to support fish year-round, and there may be risk of winter fish kills. Any fish that may enter the lake through inflow or other means may not survive for these reasons. Any fish surviving in the lake will likely be lower trophic level, small-bodied species (minnows) and there is a low probability of the lake supporting large-bodied sport fish (e.g. pike, walleye). The lake will not pose limitations to other transient wildlife in and around the lake.

Existing guidelines that are appropriate to assess lake performance for this end land use option include: CCME Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2014a), CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2014c), EQGASW (ESRD, 2014), and CCME Canadian Tissue Residue Guidelines for the Protection of Wildlife that Consume Aquatic Biota (CCME, 2014b). Site specific standards for select parameters may need to be developed as provided for by the CCME and EQGASW.

For pit lake integration into the regional hydrology, the Government of Alberta, in the Water Quality Based Effluent Limits Procedures Manual, has outlined procedures necessary to screen and develop water quality-based effluent limits. The procedure estimates, using a mass balance dilution model, mixed downstream constituent concentrations that are based on effluent and stream-flow characteristics. The result is compared with applicable in-stream guideline values at the mixing zone boundary to permit calculation of acceptable effluent limits (AEP, 1995).

Attainment of the performance described in this option is the foundation for attainment of specific wildlife habitat outlines in Options 2 and 3.

Option 2. Lake supports ecological functions, including sustainable small-bodied fish populations

In addition to the basic biological functions specified in Option 1 (above), lakes in this category will be capable of supporting and sustaining small-bodied fish populations, and life cycle habitat requirements of the fish will be met. There should be sufficient primary production to sustain oxygen levels to support small-bodied fish year-round.

Existing guidelines that are appropriate to assess lake performance for this end land use option include: CCME (2014a), CCME (2014c), EQGASW (ESRD, 2014), CCME (2014b). The Water Quality Guidelines for Dissolved Oxygen will be particularly important for this ELU. Site specific standards for select parameters may need to be developed as provided for by the CCME and EQGASW.

Option 3: Lake supports ecological functions, including sustainable large-bodied fish populations

In addition, the biological functions in Options 1 and 2 (above), the lakes in this category will have water quality and productivity capable of supporting large-bodied fish populations. Existing guidelines that are appropriate to assess lake performance for this end land use option include: CCME (2014a), CCME (2014c), EQGASW (ESRD, 2014), and CCME (2014b). The Water Quality Guidelines for Dissolved Oxygen will be especially important for this ELU. Site specific standards for select parameters may need to be developed as provided for by the CCME and EQGASW.

Table 3-1 outlines the proposed end land use goals for each of Syncrude’s planned pit lakes.

Table 3.1: Proposed End Land Use Goals for Syncrude's Pit Lakes (Syncrude 2016)

End Land Use Goal		Description	Planned Pit Lakes
1	Pit lake supports ecological functions	Pit lake performs as a conventional boreal lake and water quality supports typical lake algae, plants, and macroinvertebrates.	
2	Pit lake supports ecological functions, including sustainable small-bodied fish populations	Small-bodied fish are able to survive in the lake. Food is present, oxygen is at appropriate levels, and no winter fish kills.	• Base Mine Lake • North Mine Lake • Aurora North West Pit Lake • Aurora North East Pit Lake • West Mine Lake
3	Pit lake supports ecological functions, including sustainable large-bodied fish populations	Same as above, but the lake is capable of supporting large-bodied fish populations.	

Landform design and water modelling are key components of Syncrude's mine closure planning process. Syncrude developed a hydrologic model to assess the simulations and predictions for the performance of the closure landscape under a wide range of late-21st-century climate scenarios. The results from the model are presented in Appendix 3.

Figure 3-7 and Figure 3-8 show the locations of each of the pit lakes and the planned drainage paths at closure for the Mildred Lake and Aurora North sites, respectively

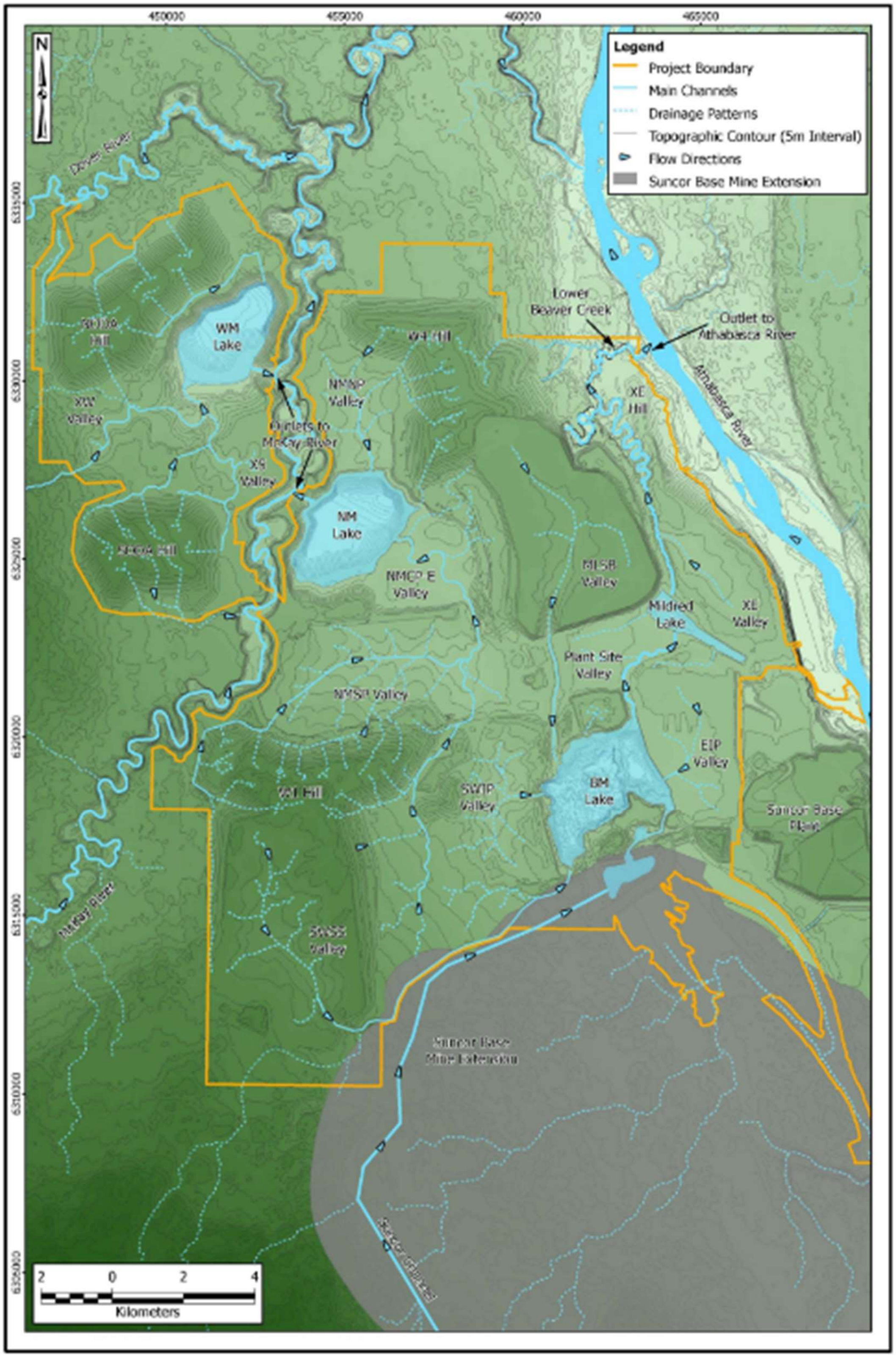


Figure 3-7: Mildred Lake Site Closure Overview (ARKK, 2023)

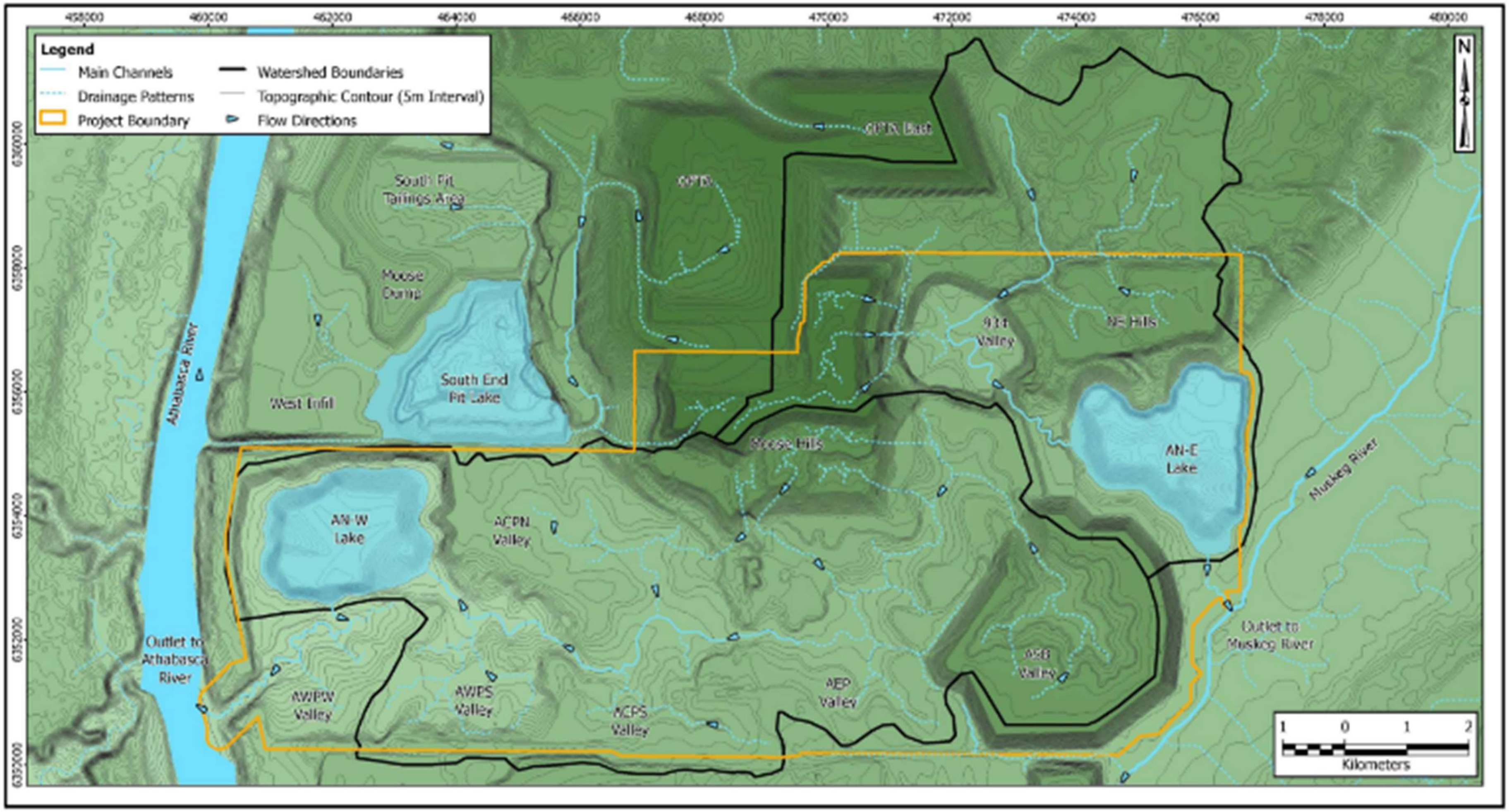


Figure 3-8: Aurora North Site Closure Overview (ARKK, 2023)

3.6.2 Base Mine Lake Demonstration overview

BML Demonstration is the first and currently the only full-scale commercial demonstration of water-capped tailings in a pit lake in the oil sands industry. The lake is located in the former West In-Pit (WIP) facility of the Base Mine at Syncrude's Mildred Lake site. It consists of a mined-out oil sands pit partially filled with fluid fine tailings (silt, clay, process-affected water, and residual bitumen) that sits below a cap of oil sands process-affected water and fresh/environmental water. The short-term objective is to successfully demonstrate the viability of the WCTT and the long-term objective is to integrate BML into the closure landscape and obtain reclamation certification.

Placement of FT into WIP began in 1995 and was completed in late 2012. The facility was removed from Syncrude's active tailings network when it became commissioned as BML Demonstration on December 31, 2012. During 2013, additional fresh water and process-affected water were added to the existing upper water layer to attain the final elevation of 308.7 meters above sea level (masl). BML Demonstration has a fluid surface area of roughly 800 hectares and a total volume of roughly 240 million meters cubed (Mm^3) (FT + water). An aerial overview of BML Demonstration within the Mildred Lake site is shown in Figure 3-9.

Infrastructure has been installed to pump fresh water into BML Demonstration from Beaver Creek Reservoir and as required, water is pumped out of BML Demonstration to the closed-loop Industrial Wastewater Control System, where it is utilized as recycle water in the bitumen extraction process. The Beaver Creek watershed will connect to BML at closure and the decision was made to connect Beaver Creek to BML Demonstration using active management from operation to closure. This flow-through process dilutes the water cap and active inflow management will be in place until a more substantial upstream surface watershed is reclaimed and connected to BML Demonstration, final inlet design for BML is constructed, and outflow is established to the receiving environment (i.e., Athabasca River). Design features incorporated into BML Demonstration include:

- Isolation from operational tailings inputs (no additional tailings transfer);
- Sufficient depth of water to minimize potential for wind-driven fine tailings re-suspension;
- Fresh (environmental) water flow-through system to improve water quality; and

- Construction of breakwaters and controlled water level elevation for protection and development of littoral zones.

The BML Demonstration monitoring and research program began upon commissioning and is ongoing. The initial focus of the monitoring and research program is to support the demonstration of the WCTT and to provide a body of scientific evidence which demonstrates that BML Demonstration is on a trajectory to become integrated into the reclaimed landscape.

Results from the BML Demonstration monitoring and research program have been shared with the AER through biennial/annual summary report submissions and annual update meetings. The last summary report (2023 Pit Lake Monitoring and Research Report) was submitted to the AER on September 29, 2023, in accordance with Syncrude’s EPEA Approval.

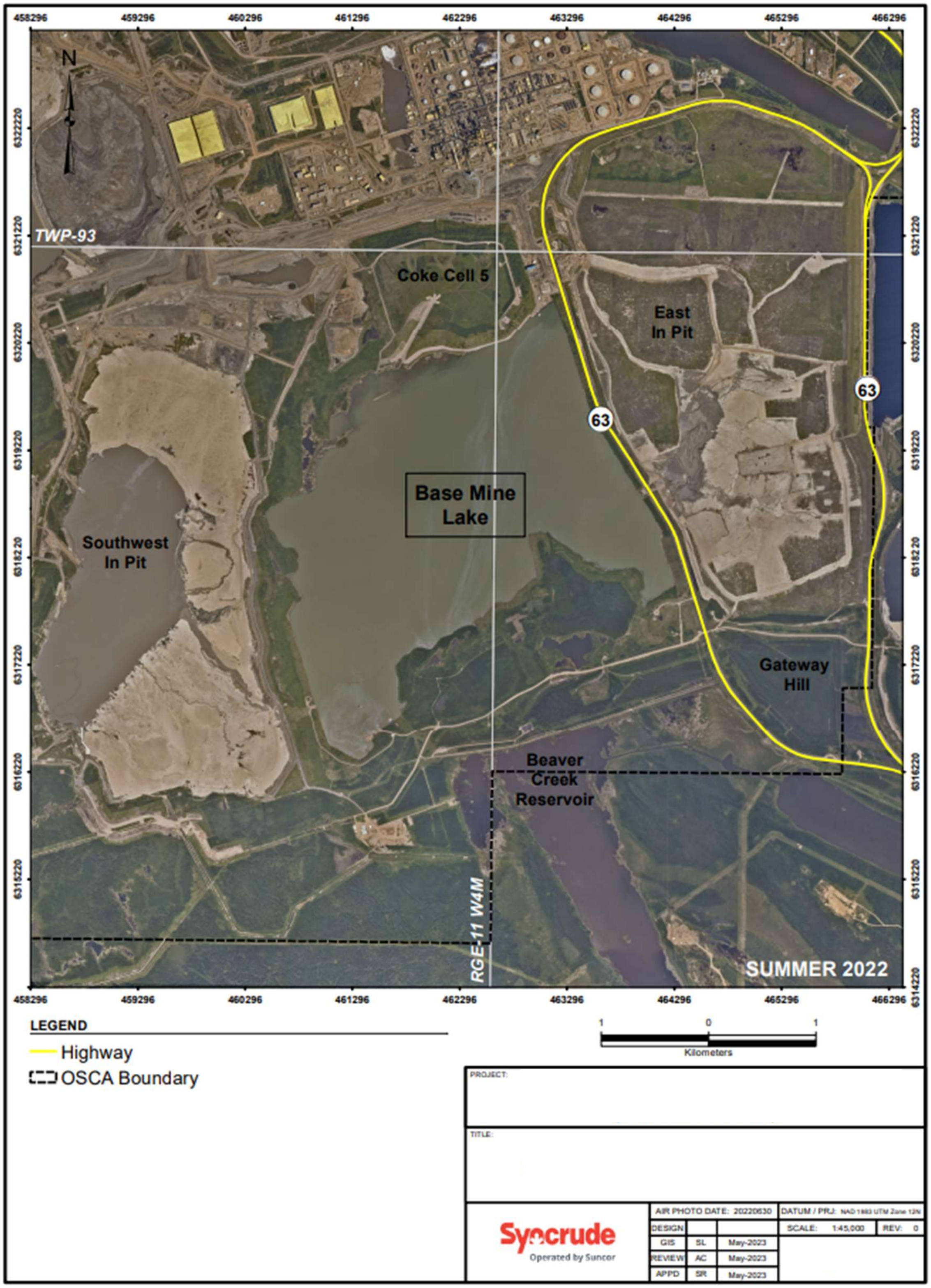


Figure 3-9: Aerial Overview of Base Mine Lake

3.6.3 Application of learnings from Base Mine Lake Demonstration to future pit lakes

BML Demonstration is a full-scale demonstration pit lake and has provided valuable learnings that can be leveraged for future pit lake planning, design and operation. Key considerations for pit lake performance evidenced through BML Demonstration performance are discussed below:

Water cap depth

Water cap depth is an important design consideration for pit lakes to ensure physical isolation of the fines beneath the water cap. The depth of water required to prevent wind-wave driven resuspension of sediments (e.g. tailings) is a function of four factors: the threshold velocity, wind velocity, fetch and a factor of wave heights (Lawrence et al. 1991). Using the expression derived by Lawrence *et al*. (1991) for BML Demonstration, a water cap depth of 6 m would prevent wind driven resuspension of fines from the sediment (i.e., below the mudline). The average water cap depth 10 months after commissioning was ~8 meters and has been consistently deeper than 9 meters since May 2015 (Lawrence *et al.* 2016). There is no evidence of wind-driven resuspension of mineral solids from beneath the mudline since BML Demonstration was commissioned. This provides confidence in the expression derived by Lawrence *et al* (1991). This equation has been used to inform water cap depth design in North Mine Lake (NML).

Mineral turbidity in the water cap

Turbidity resulting from residual fine solids in the water cap influences lake ecological development. In BML Demonstration, there is no evidence of fines resuspension from below the mudline influencing water clarity, however, residual fines suspended during tailings deposition created turbid water that influenced lake development. The one-time addition of alum to the water cap in 2016, was immediately effective at improving water clarity, and the water clarity improvements have been sustained since then (see Section 4.3.2.1). Alum addition is an effective option to manage water cap turbidity.

Self-weight consolidation of tailings solids

The rates and magnitude of the FT settlement are consistent with the expected self-weight consolidation as modelled by finite-strain consolidation theory (Carrier et al. 2019, and Dunmola *et al*. 2022). The tailings in BML Demonstration have undergone self-weight consolidation and remain sequestered under the water cap. Tailings settlement performance aligns well with modelled consolidation (Dunmola *et al*. 2022) and this gives confidence in modelling future lake tailings performance and pore-water flux estimates.

Lake water balance

The primary drivers of the water balance of BML Demonstration have been the managed in- and out- flows, and tailings porewater release to the water cap. The tailings porewater flux is the source of elevated chemical concentrations which influence water cap chemistry. As porewater fluxes decline with time, so will the influence of porewater flux on the water cap chemistry (see sections 5.1 and 5.1).

Bitumen

Bitumen loss to tailings and tailings depositional strategy influences the rate of pit lake performance and is a critical consideration for pit lake planning. Understanding bitumen dynamics and mitigation is a key focus of the BML Demonstration Research and Monitoring Program (see section 5.5).

Littoral zones

Littoral zones are important components in the ecological structure and function of lakes and are a consideration in pit lake designs.

Optimizing the Integrated Mine, Tailings and Closure plan is a priority. The learnings from BML Demonstration are informing operational considerations in the planning for NML and other pit lakes. These considerations are “levers” that can be used for each pit lake configuration in the plan. Syncrude continues to consider the latest research and development results, as well as the sustainability (environment, economic, social) of these “levers” on the plans.

Every pit lake begins as a mine pit, and plans consider optimization of mining benches and dump designs to support littoral zones while also meeting other plan objectives. The tailings deposition strategy is an important driver of bitumen dynamics in a pit lake. Optimizing the timing, source, and location of FT deposition is an important component of any pit lake plan. The 2024 clamshell dredging program in BML Demonstration will provide insight into the practical technical limits of commercially available technology for bitumen mat removal under a water cap. Other options for managing bitumen during in-filling of tailings (for example, skimming during deposition) are also being assessed (see section 5.5). These learnings will inform the plan for NML and other pit lakes. An integrated research portfolio is addressing the potential opportunities to minimize bitumen loss to tailings during extraction processes, and to reprocess bitumen that may be recovered post-deposition in-pit. Learnings from BML Demonstration will continue to be leveraged in the continuous improvement of our mining and tailings plans.

3.7 Research and Development

3.7.1 Syncrude Research and Development

The Syncrude joint venture began in 1964 and started mining at the Mildred Lake site in 1978. After more than 55 years of innovation, many of the processes used in the industry today were created by Syncrude, including an expanding suite of technologies to improve environmental and future economic performance. Syncrude has a dedicated Research and Development department and facility including a two-tonne per hour continuous extraction pilot. The cornerstones of the research portfolio are the Bitumen Production Technology and Mine Closure Research Programs.

- The objective of the Bitumen Production Technology Program is to create, develop and enhance methods for improving bitumen recovery, froth quality and increasing plant capacity. Improvements in these areas are essential to our business objectives of reducing unit cost, increasing revenue, and reducing our environmental impacts.
- The objective of the Mine Closure Research Program is to develop new technologies and improve existing technologies and best practices in the areas of tailings, reclamation and water management.

The objectives of these two programs are inherently linked in that any improvements in hydrocarbon recovery translate to downstream improvements for tailings, reclamation and closure. The key projects with a direct link to environmental aspects of tailings and reclamation are summarized in Table 3.2: Research and Development Projects Summary below.

Table 3.2: Research and Development Projects Summary

Project	Objective	Current Priorities
Extraction Fundamentals and Process and Equipment Optimization	Maximize bitumen recovery in primary extraction and minimize loss to straight coarse tailings (SCT) streams	Understanding the key ore attributes that impact recovery as a means to optimize process and operational variables to minimize hydrocarbon losses.
Froth Treatment Process and Equipment Optimization	Maximize bitumen recovery in froth treatment (secondary extraction) and minimize loss to froth treatment tailings (FTT) streams	Development of new equipment designs and process control instruments to improve equipment performance and minimize hydrocarbon losses.

Naphtha Recovery Unit (NRU) Improvement	Maximize naphtha recovery in the Naphtha Recovery Units (NRUs) and minimize naphtha loss to froth treatment tailings (FTT) streams.	Development of new equipment designs and process control instrumentation to enable improved unit reliability leading to reduced hydrocarbon losses.
Base Mine Lake Demonstration Research and Monitoring	Determine, by information collected through monitoring and research, whether or not water capped fine tailings will be a viable tailings management, remediation and reclamation option at the Mildred Lake Plant Site.	Base Mine Lake Demonstration Monitoring Plan and Base Mine Lake Research Plan referred to in subsections 7.5.5 and 7.5.7 and the focus of this submission.
Bitumen Recovery from Base Mine Lake Demonstration	Understand the hydrocarbon dynamics in the Base Mine Lake Demonstration and identify and test mitigation options.	Field test of bitumen removal from FFT/water interface in BML using environmental clamshell dredge planned for 2024.
Recovered Hydrocarbon Reprocessing	Assess technical viability of Pond skimmed bitumen reprocessing.	Plant test of bitumen recovered from tailings facilities planned for 2024 (including recovered bitumen from BML clamshell pilot, if possible).

More information is provided in the following sections for research projects in Table 3.2 that have a direct link to the Base Mine Demonstration.

3.7.1.1 Base Mine Lake Demonstration Research and Monitoring

The BML Demonstration Research and Monitoring Project is one project in this portfolio and the focus of this submission.

3.7.1.2 Bitumen Recovery from Base Mine Lake Demonstration

Some hydrocarbon, in the forms of naphtha and bitumen, is lost to various tailings and waste streams in the plant. Understanding the hydrocarbon dynamics in the BML Demonstration is one focus of the BML Demonstration Monitoring and Research Program. As summarized in Section 5.8, when FT was dredged and transferred into West In Pit to establish the BML

Demonstration, bitumen droplets were aerated, formed mats at the water surface and subsequently sank to form mats at the FT/water interface. Monitoring and research to date show that these bitumen mats are the primary driver of bitumen flux from the FT to the water surface in the BML Demonstration today.

In order to test this hypothesis, a technology scan was conducted for a method that could effectively physically remove bitumen mats in BML Demonstration. The environmental clamshell dredge has been identified as the best commercially available technology for heavy oil recovery from aquatic systems. There remain technical gaps for the specific application of clamshell dredge technology for bitumen mat removal in an oil sands pit lake containing FT.

In 2024, a field pilot of the environmental clamshell dredge is planned in BML Demonstration. Enabling technologies including bitumen mat detection, visualization and mapping are also being tested. Other work includes fundamental studies focused on understanding the environmental influence of dispersed bitumen droplets in the FT on pit lake performance.

3.7.1.3 Recovered Hydrocarbon Reprocessing

There is ongoing work to explore strategies and technologies to recover value from hydrocarbon loss to tailings streams to reduce the environmental and economic impacts of the hydrocarbon losses.

A study was performed where bitumen from pond froth skimmed from the surface of various tailings facilities over the last 20 years was characterized and compared to as-mined bitumen. The results showed that pond bitumen was not significantly different from as-mined bitumen, except for a few cases when the pond bitumen was weathered/oxidized or contained traces of naphtha from Froth Treatment tailings. Based on this information, various locations within the Mildred Lake Plant were considered for re-introduction of pond skimmed froth, and the best location identified was a re-circulation line in Plant 6.

Bench scale lab tests were conducted by adding various amounts of pond froth to Plant 6 feed, diluting it with naphtha at a naphtha to bitumen ratio of 0.7 and centrifuging it at 80°C to simulate the Froth Treatment process. It was found that up to 20wt% pond froth can be added to the froth without causing a detrimental impact to hydrocarbon recoveries or product quality.

Plans are in place to perform a field trial to re-introduce froth skimmed and/or dredged from tailings facilities to the Froth Treatment Plant in the summer of 2024 with a focus on integrating obtaining feed from the BML Demonstration clamshell dredge pilot (above).

3.7.2 Regional Pit Lake Initiatives

Syncrude participates in regional pit lake research initiatives through its membership with COSIA. In addition to BML Demonstration, two other key pit lake research programs with relevance to Syncrude are the Suncor Pit Lake Program and the COSIA Demonstration Pit Lake Mesocosm Study. Summaries of these research programs are provided below.

3.7.2.1 Suncor Pit Lake Program

An important component of Suncor Energy Inc. (Suncor)'s Pit Lake Program, is Lake Miwasin, a pilot-scale demonstration pit lake of the Permanent Aquatic Storage Structure (PASS) technology. This technology uses a coagulant and flocculant to dewater the FT, followed by water-capping to develop a pit lake. Lake Miwasin is a scaled representation of Suncor's aquatic closure plan for the East Bank Development Area. Lake Miwasin is located within an 18-hectare reclaimed demonstration area at Suncor's Base Plant site in Fort McMurray, Alberta, which includes the lake's surrounding watershed and a demonstration constructed wetland treatment system (CWTS). Construction and reclamation of Lake Miwasin and its watershed was completed in 2018 and an extensive research and monitoring program is underway to support the demonstration. Details from the Suncor Pit Lake Program, including Lake Miwasin, can be found in the pit lake research and development reports submitted to the AER by Suncor, in accordance with EPEA Approval No. 94-03 (as amended).[5]

3.7.2.2 COSIA Demonstration Pit Lake Mesocosm Study

Since 2017, the COSIA Demonstration Pit Lake (DPL) project is using aquatic mesocosms to inform pit lake research. The COSIA DPL mesocosm study is located at the InnoTech facility in Vegreville, Alberta. The research facility consists of 30 small (1.5 m deep x 3.6 m diameter) in-

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[5] Suncor (2024). Pit Lake Research and Development Report. In compliance with EPEA Approval 94-03, Clauses 5.2.1 - 5.2.5 Submitted to: Alberta Energy Regulator. 30 April 2024. 70 pp.

FORT HILLS ENERGY L.P. (2024) Fort Hills Oil Sands Project. Pit Lake Research and Development Report. In compliance with EPEA Approval 151469-01-00 (as amended) Clauses 6.2.1–6.2.4. Submitted to: Alberta Energy Regulator. 30 April 2024. 39 pp.

ground mesocosms, which can be experimentally manipulated to test a variety of pit lake hypotheses. Details can be found in the research and development reports shared by COSIA.[6]

4 Adaptive Management Approach

4.1 Mitigating Uncertainties

Syncrude recognizes that the amount, distribution, and quality of water in the closure landscape is critical to supporting the attainment of the closure goals defined in the LMCP and is committed to the successful implementation of WCTT in pit lakes as part of its overall mine, tailings, reclamation, and closure strategy. Syncrude utilizes an adaptive management approach to mitigate uncertainties and steward tailings management and reclamation activities towards meeting the desired closure outcomes. Adaptive management is an iterative process, including research and development, designing, planning, modelling, monitoring, analyzing, and adjusting in response to new information.

Monitoring of pit lakes throughout their progression from active deposition to end land use is a key component to compare actual performance to expectations. Plans are reconciled annually based on the previous year’s results to ensure that plans are optimized appropriately. Based upon the analysis of monitoring results, adaptive management strategies may be identified to improve performance. This type of activities not only address current issues but can also advance research and inform plans.

Critical information on the viability of WCTT is being provided through the BML Demonstration. The BML Demonstration monitoring and research program is providing data that improves our understanding of the design and operation of pit lakes, and the time required for each stage of development. The learnings from the BML Demonstration, combined with learnings from regional pit lake research initiatives, are being used to inform Syncrude’s future pit lake designs and plans.

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[6] Innotech Alberta, 2021. Densified Fluid Fine Tails and Oil Sands Process Water - an extension of the 2017 Study, Final Report, Prepared for COSIA’s Demonstration Pit Lakes Working Group. 169 pp. Available at: https://cosia.ca/sites/default/files/attachments/2018%20Mesocosm%20Research%20Report.pdf

4.2 A Decision-Making Framework

Under SED-003, the AER defines adaptive management as “a management approach that involves the monitoring and evaluation of performance followed by any necessary actions to achieve the intended performance objectives. Adaptive management also allows information to be fed back into the planning and design process so that future performance will meet the intended outcomes.” Furthermore, Directive 085 states that “the AER will include conditions in approvals that are outcomes based, manage risk and uncertainties, support flexibility and adaptive management, and are enforceable.”

Adaptive management is a decision-making process for natural resource management that emphasizes learning through management and allows for adjustments as outcomes from management actions and other events are better understood (Walters 1986, Allen *et al.* 2011, and others). This allows for learning from experience and modifying actions based on that experience (Stankey *et al.* 2005). It also permits management action in the face of the uncertainty, inherent in complex ecological systems. The process decreases ecological uncertainty and improves knowledge about potential management choices through direct comparisons of their performance in practice, allowing for flexible decision making (Walters 1986, Walters 2007).

Intended outcomes of an environmental management system include enhancement of environmental performance, fulfilment of compliance obligations, and achievement of environmental objectives (ISO 2016). In very simple terms, adaptive management ensures that objectives are understood, activities are planned and executed to achieve the objectives, results are measured to see what is working or not working, and information is used to make informed decisions on whether to implement additional actions to achieve the objectives and desired outcomes (Jones 2009). The iterative decision-making process is cyclical, as shown in Figure 4-1.

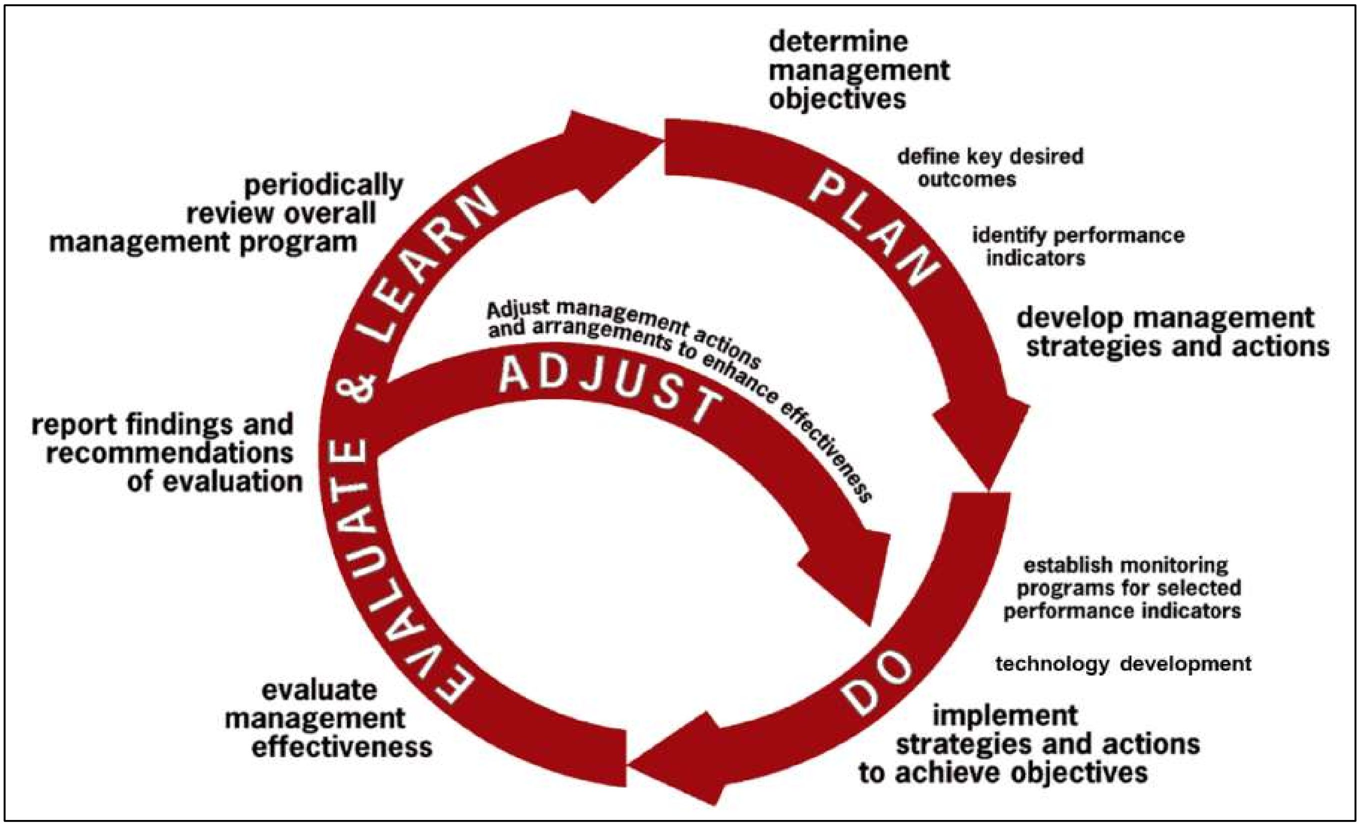


Figure 4-1: The Adaptive Management Cycle (after Jones 2005)

Adaptive management is a “learn by doing” approach; not a “trial and error” approach. There are four key components to the cycle:

- Plan
- Do
- Evaluate and Learn
- Adjust, as required

Each of these components are described more specifically for BML Demonstration in the following sections.

4.3 Adaptive Management Approach for Base Mine Lake Demonstration

The adaptive management approach for BML Demonstration has allowed for flexible decision making and management actions to steward the lake towards its short and long-term objectives. Some key components of the adaptive management framework as applied specifically to BML Demonstration are described herein.

4.3.1 Adaptive Management: Do, Evaluate and Learn

A key purpose of the BML Demonstration monitoring and research programs is to continue to support the adaptive management of the lake towards both the short and long-term objectives. The monitoring and research program is designed to assess lake performance against key performance indicators and evaluate the need for management interventions. The initial focus of the research program is to support the demonstration of the WCTT and to provide a body of scientific evidence which demonstrates that BML Demonstration is on a trajectory to become integrated into the reclaimed landscape. The outcomes from the BML Demonstration monitoring and research program will be used to inform the design and management of future pit lakes, including those that may contain treated or untreated tailings materials. At the same time, the program establishes a baseline of biophysical data to assess the changes in the lake through time, including water quality and other lake processes.

The monitoring program is designed to track trends in the lake both seasonally and annually, and measure these trends against key performance metrics, as previously outlined. The research program focuses on key scientific questions designed to elucidate the mechanisms and processes that govern the current state of BML Demonstration, and explain changes detected by the monitoring program. In other words, the monitoring program tracks the trends in the lake through time and the research program investigates why those changes are occurring. The BML Demonstration monitoring and research programs are integrated, such that lessons learned from research are used to inform future monitoring programs, as well as support validation and corrective/preventive measures. Trends and information obtained from the monitoring program further guides the priorities for the research program. This integrated BML Demonstration monitoring and research program supports the adaptive management of the lake's performance towards attainment of the key desired outcomes.

The BML Demonstration monitoring and research program also provides knowledge and guidance valuable to the integration of other pit lakes in the Athabasca mineable oil sands region. Syncrude will continue to share findings from the research and monitoring programs with its industry partners to advance understanding of a range of pit lake topics, including design, operation, modelling, and adaptive management.

4.3.1.1 Base Mine Lake Demonstration Monitoring Program

The specific objective of the BML Demonstration monitoring program is to provide information to support WCTT as a viable tailings management and reclamation option. In the early stages, the BML Demonstration monitoring program is demonstrating that the fine tailings are sequestered and that the water quality in the lake is improving. The monitoring program is designed to do this by tracking the physical, chemical, and biological changes in BML Demonstration. The program captures these changes both temporally and spatially, and eventually in the context of regional climate cycles. The monitoring program supports regulatory compliance, but also informs adaptive management of the lake. The physical, chemical, and biological components of the program are summarized in Table 4-1.

Table 4.1: Base Mine Lake Demonstration Monitoring Program Components

Physical	Chemical	Biological
FT Settlement	Water Balance Assessment	Aquatic Biology Assessment
FT Geochemistry Assessment	Surface Water Quality Assessment	Surface Water Toxicity
		Sediment Toxicity
Physical Limnology Assessment	Groundwater Assessment	
	Chemical Mass Balance	
Meteorological Monitoring		
FT Physical Assessment		

4.3.1.2 Base Mine Lake Demonstration Research Program

The BML Demonstration research program uses a multi-university, multi- and inter- disciplinary approach that focuses on the analysis and interpretation of monitoring data, hypothesis driven research activities, and integration and collaboration among and between research programs. Research results are integrated with monitoring results on an ongoing basis, with the goal of identification and quantification of the processes and properties in the lake that are responsible for the trends observed in the monitoring program. The various components comprising the BML monitoring and research programs are closely linked.

The current focus of the research program is to support the demonstration of the WCTT. The program also provides supporting information about key processes fundamental to the progression of BML Demonstration towards a functional component of the closure landscape. The current research programs were focused on key parameters influencing early BML Demonstration development.

The research program has two overarching themes. The first theme is validating the WCTT. Several research programs will determine the potential fluxes from the FT to the water column, including chemical, geochemical, mineral, gases, and heat. Physical, biological, and chemical mechanisms are being investigated. The second key (and related) theme relates to the long-term performance of BML Demonstration as a tailings reclamation option. These programs focus on the ecological development of the demonstration towards closure outcomes and understanding bitumen dynamics and mitigation. See section 7 for more information.

4.3.2 Adaptive Management: Adjust

The adaptive management framework allows for adjustments to lake management when an evaluation and assessment of performance does not match expectations. These management actions are undertaken to steward the lake to key desired outcomes. To date, there have been two adaptive management actions taken to improve BML Demonstration performance: application of alum to manage mineral turbidity, and hydrocarbon mitigation.

4.3.2.1 Alum Application to Reduce Turbidity

Since commissioning, turbidity in the lake was dominated by mineral solids. In response to the results of the first four years of monitoring, alum was added to the water cap for the management of the mineral turbidity in the BML Demonstration. This trial occurred in September 2016 during fall turnover to take advantage of lake mixis. Light penetration (water clarity) was determined to be an important parameter to track in the BML Demonstration monitoring and research program for several reasons. First, mineral turbidity in the lake is a result of suspended fine mineral particles; clear water could indicate that residual fines left in the water column from pit filling have settled out of suspension. In addition, a clear water column allows sunlight penetration, which is critical for algal primary production in the lake.

Monitoring results indicate that the single alum dosage in September 2016 was effective at reducing turbidity. Alum application is an effective tool for managing suspended solids in the water cap of pit lakes. The monitoring program will continue to track turbidity and the expectation is that turbidity will fluctuate with lake mixing events, but turbidity will continue to decline with time. If lake performance does not meet this expectation, further management actions may be considered as part of the ongoing adaptive management cycle presented previously in Figure 4-1.

4.3.3 Adaptive Management: Plan

The planning component of the adaptive management cycle is key to success. As such, Syncrude has defined two primary management objectives, which are to:

- Validate the viability of the Water-Capped Tailings Technology; and
- Ensure the lake becomes a functioning component of the closure landscape.

The key desired outcomes and performance indicators are described in more detail in the following sections.

4.3.3.1 Key Desired Outcomes

In general, pit lakes will support ecological functions and lake specific wildlife habitat. The specific end land use goal for BML Demonstration is that the lake will support lake ecological functions, including sustainable small-bodied fish populations (Syncrude 2016). BML Demonstration is expected to support conventional boreal lake functions, with water quality capable of supporting typical lake algae, plants, and macroinvertebrates. Small-bodied fishes will be able to survive in the lake; there will be enough biomass (food) and dissolved oxygen to support small-bodied fish populations (Syncrude 2016).

4.3.3.2 Performance Indicators

To support the adaptive management cycle, it is important to identify performance indicators that will help guide management decisions. There are two key milestones for BML Demonstration, each with unique performance indicators. In the absence of specific policy or regulatory guidance for pit lake performance milestones, the principle of comparing BML Demonstration results against modelling expectation for tailings performance and existing guidelines (for example EQGASW PAL guidelines) has been applied.

In the shorter-term, Syncrude has identified performance indicators that are associated with validation of the WCTT. In the longer-term, Syncrude has determined that performance indicators for reclamation certification are appropriate. It is important to identify longer-term performance indicators in the early planning stages so that management decisions are made with these progressive milestones in mind. BML Demonstration is expected to change over time and performance expectations for each milestone are necessarily different.

4.3.3.2.1 Shorter-Term Performance Indicators

Syncrude has identified the following BML Demonstration performance indicators for shorter-term assessment of BML Demonstration performance:

- The lake should have all solids in place and be filled to design elevation with a water cap sufficient to prevent wind driven resuspension of fines.
- The FT should be settling as it dewaters with time.
- Although total suspended solids (TSS) in the water column is expected to fluctuate seasonally with mixing events, TSS should show improvements over time or be in the range of natural variability.
- The water cap should not be acutely toxic, as demonstrated by appropriate standard acute lethality tests described in Environment Canada Biological Test Methods and Guidance Documents (Government of Canada).
- The water should also pass appropriate Canadian Water Quality (acute) Guidelines for the Protection of Aquatic Life (CCME 2014c) and Environmental Quality (acute) Guidelines for Alberta Surface Waters (AEP 2018).

4.3.3.2.2 Longer-Term: Performance Indicators to Support Reclamation Certification

Certification of BML will require demonstration that the lake is a functioning component of the closure landscape, with water quality appropriate to support the desired end land use and to provide lake specific wildlife habitat. Existing guidelines that may be appropriate as performance indicators to support certification of BML include:

- Environmental Quality (chronic) Guidelines for Alberta Surface Waters (AEP 2018)
- Canadian Water Quality (chronic) Guidelines for the Protection of Aquatic Life (CCME 2014c)
- Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2014a) and
- Canadian Tissue Residue Guidelines for the Protection of Wildlife that Consume Aquatic Biota (CCME, 2014b)

The dissolved oxygen guideline for the protection of aquatic life will be particularly important for ensuring the lake can support small-bodied fish populations. Science-based site-specific standards for select parameters may need to be developed, as provided for by the Environmental Quality Guidelines for Alberta Surface Waters (AEP 2018) and the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 2014c).

5 Summary of key performance results for Base Mine Lake Demonstration

The specific objective of the BML Demonstration monitoring program is to provide information to support WCTT as a viable tailings management and reclamation option. The monitoring program is designed to do this by tracking the physical, chemical, and biological changes in BML Demonstration. The program captures these changes both temporally and spatially, and eventually in the context of regional climate cycles. The monitoring program supports regulatory compliance, but also informs adaptive management of the lake. Results from the research and monitoring program have demonstrated that the tailings are settling through self-weight consolidation as predicted by numerical modelling. The mineral fines are physically isolated below the water cap and are not resuspending from below the mudline during annual lake water dimixis. Confidence in the tailings settlement modelling predictions provides confidence in predictions of FT porewater flux to the water cap over time. 90% of the tailings settlement will be complete by 2050, and at this time the porewater will have a small contribution to the water cap volume compared to other inputs of water (eg. freshwater inflow from BCR). The water quality in BML Demonstration continues to improve. In the absence of criteria for pit lake performance, the principle that has been applied to assess BML Demonstration performance in order to make adaptive management decisions is to compare water chemistry to existing guidelines (EQGASW PAL). The lake water shows no acute lethality response using conventional whole-effluent toxicity tests, however there is some residual chronic response. The lake ecology continues to develop in response to improving water quality, demonstrating progress towards potential certification outcomes. Residual bitumen mats that formed during tailings deposition may be limiting the lake’s ecological development. Comparison of BML Demonstration water quality to other existing guidelines is underway.

5.1 Fine Tailings prediction and performance

In order to understand WCTT performance, it is important to model and monitor tailings settlement, and confirm self-weight consolidation. Comparing model predictions to actual settlement performance provides an understanding of, and builds confidence in, predictions of settlement and resulting porewater flux over time. Results from BML Demonstration provide multiple lines of evidence that the fines are physically isolated below the water cap.

5.2 Tailings Settlement modelling predictions and monitoring results

In 2007, a numerical model of self-weight consolidation of the FT in BML Demonstration was developed. This numerical model is 1-D based on finite-strain consolidation theory. Because this modelling work was before BML Demonstration was commissioned, the model was based on a projected total filling volume of 104.6 million tonnes. Modelling using actual volume deposited in the lake is more informative, so the 1-D model was re-run in 2019 using the actual tonnage of FT deposited in BML Demonstration (98.4 million tonnes). The earlier model predicted a higher cumulative settlement because the assumed fines tonnage was higher (6.2 million tonnes higher) than actual conditions in BML at commissioning. Subsequently, a pseudo-3-D model was developed to provide a more accurate representation of the tailings and pond geometry. The field measurements of tailings settlement in BML Demonstration are shown against the model predictions for each iteration (2007 1-D, 2019 1-D with updated volumes, and 3-D model) in Figure 5-1. The field measurements of tailings settlement in BML Demonstration is aligned best with the 3-D model predictions which best represent the actual conditions in BML Demonstration. A complete description of this work is presented in Dunmola *et al.* (2022).

Since commissioning BML Demonstration, and as expected from modelling (Dunmola *et al.* 2022), the FT has been settling as indicated by decreasing mudline over time (Figure 5-2, and Figure 5-3), releasing pore water into the water cap. Contours of cumulative FT settlement between October 2012 and October 2023 highlight the spatial variability of observed settlement (Figure 5-3). Minimal settlement is observed around the perimeter (shoreline) of BML Demonstration, where underlying FT thickness is generally lower, and the pit bottom elevation is generally higher. Cumulative FT settlement across BML Demonstration between 2012 and 2023 is not constant and varies based upon the underlying thickness of FT and other factors. To illustrate this, a scatter plot of the original 2012 FT thickness versus the cumulative FT settlement from 2012 through 2023 is provided in Figure 5-4. The total volume of FT in BML Demonstration has decreased from 195.97 Mm^3 in 2012 to 166.78 Mm^3 in 2023, a volumetric decrease of 14.9 %. Figure 5.5 shows the solids content of the deposit. Figures 5.6 to 5.9 show the effective stress of the deposit.

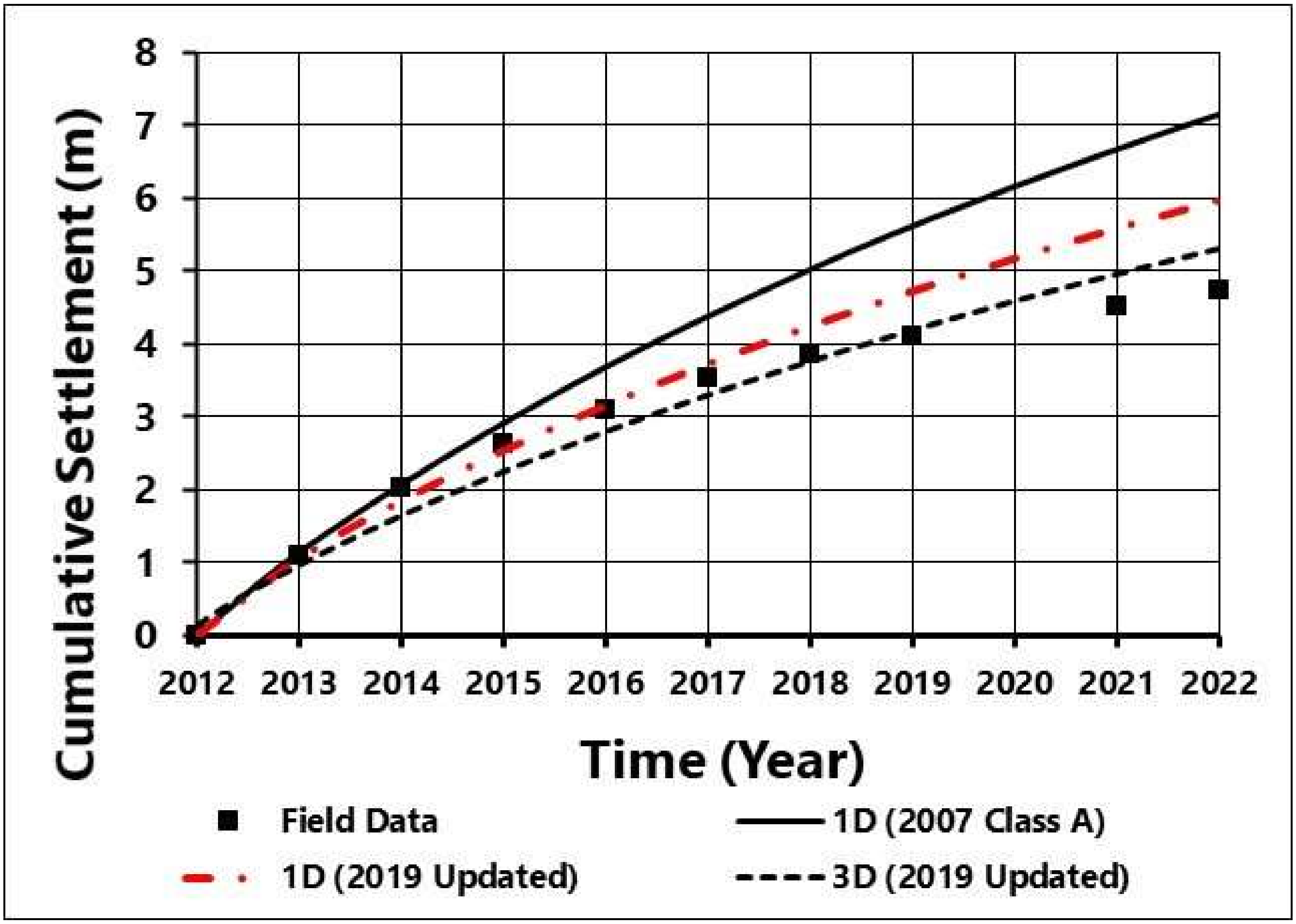


Figure 5-1: Cumulative settlement (m) as predicted by modelling and actual settlement measured in BML Demonstration.

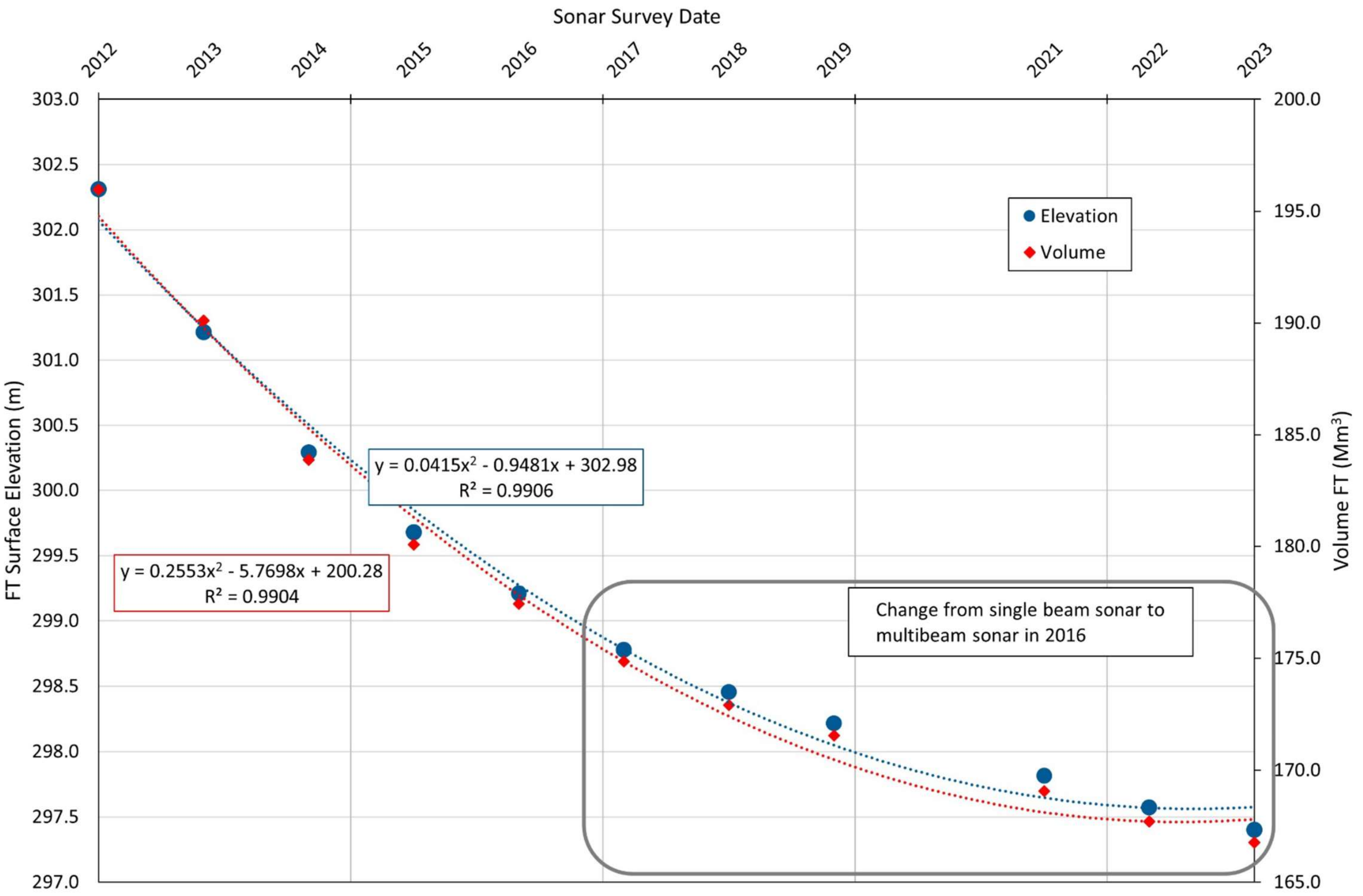


Figure 5-2: Field measurement of average FT mudline elevation (masl) and volume of FT (Mm^3) in BML Demonstration from 2012-2023

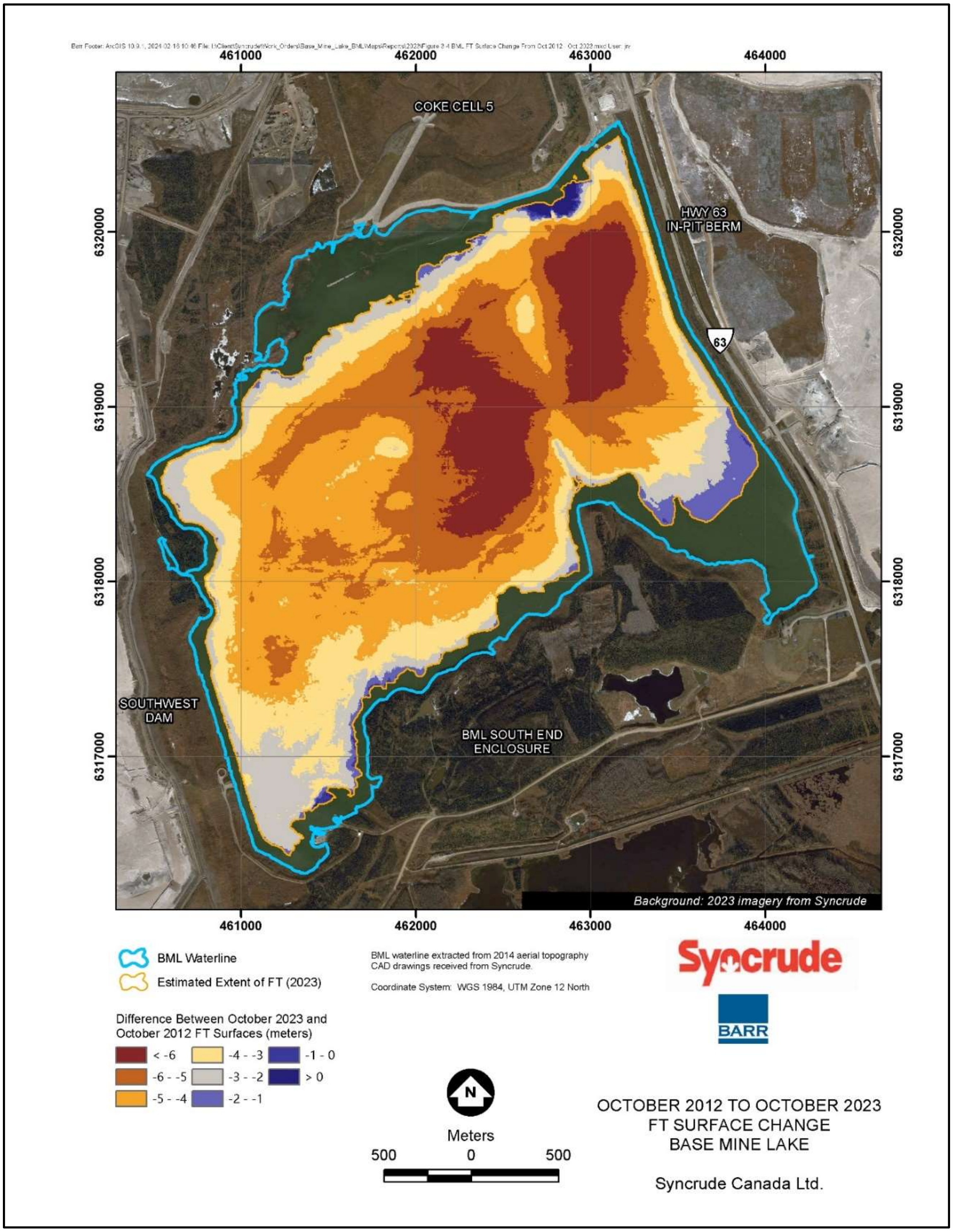


Figure 5-3: October 2012 to October 2023 FT surface elevation change in Base Mine Lake Demonstration.

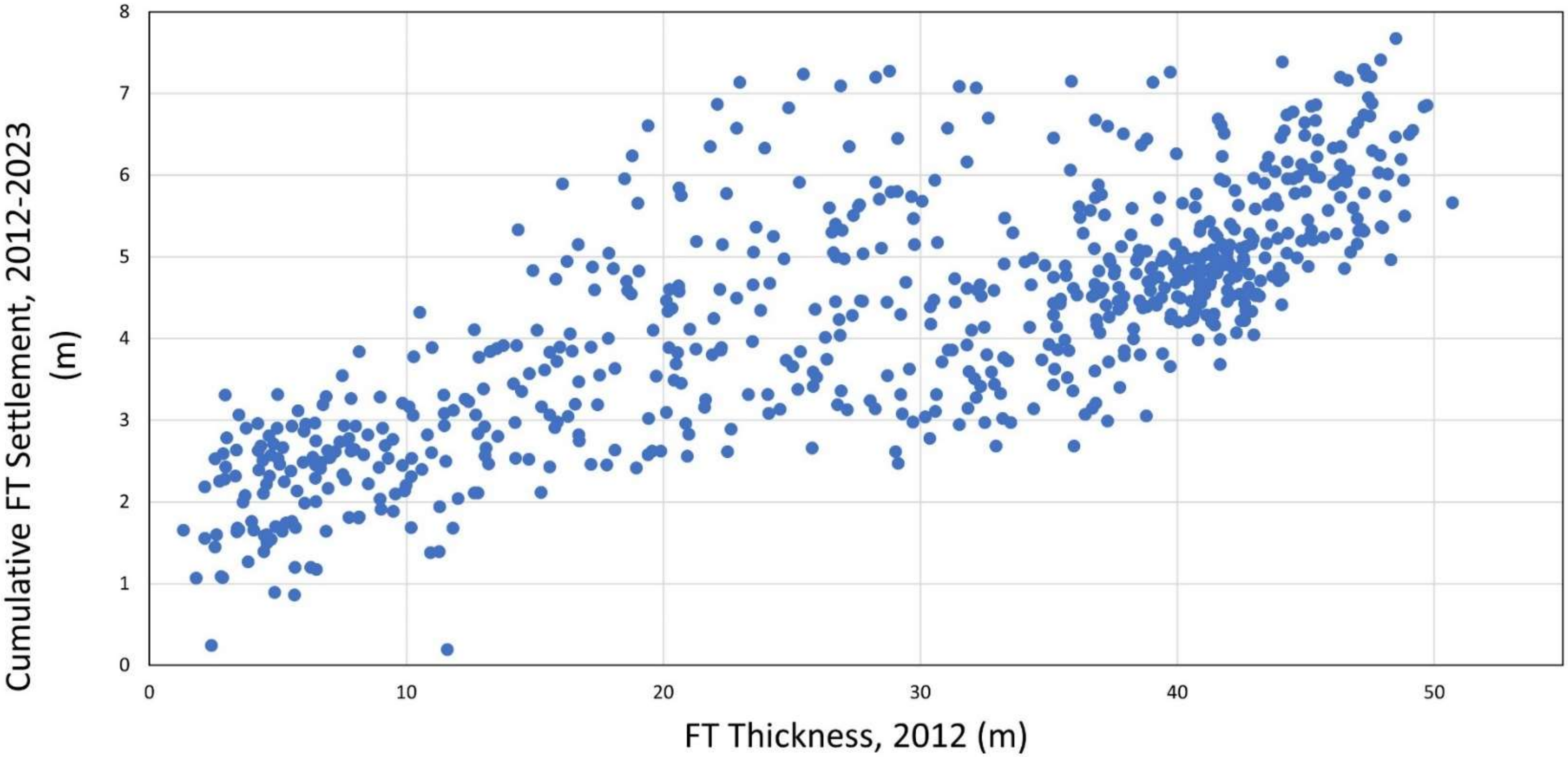


Figure 5-4: BML Demonstration Cumulative FT settlement from 2012 to 2023 versus original (2012) FT thickness demonstrating settlement increases with increasing FT thickness throughout BML Demonstration.

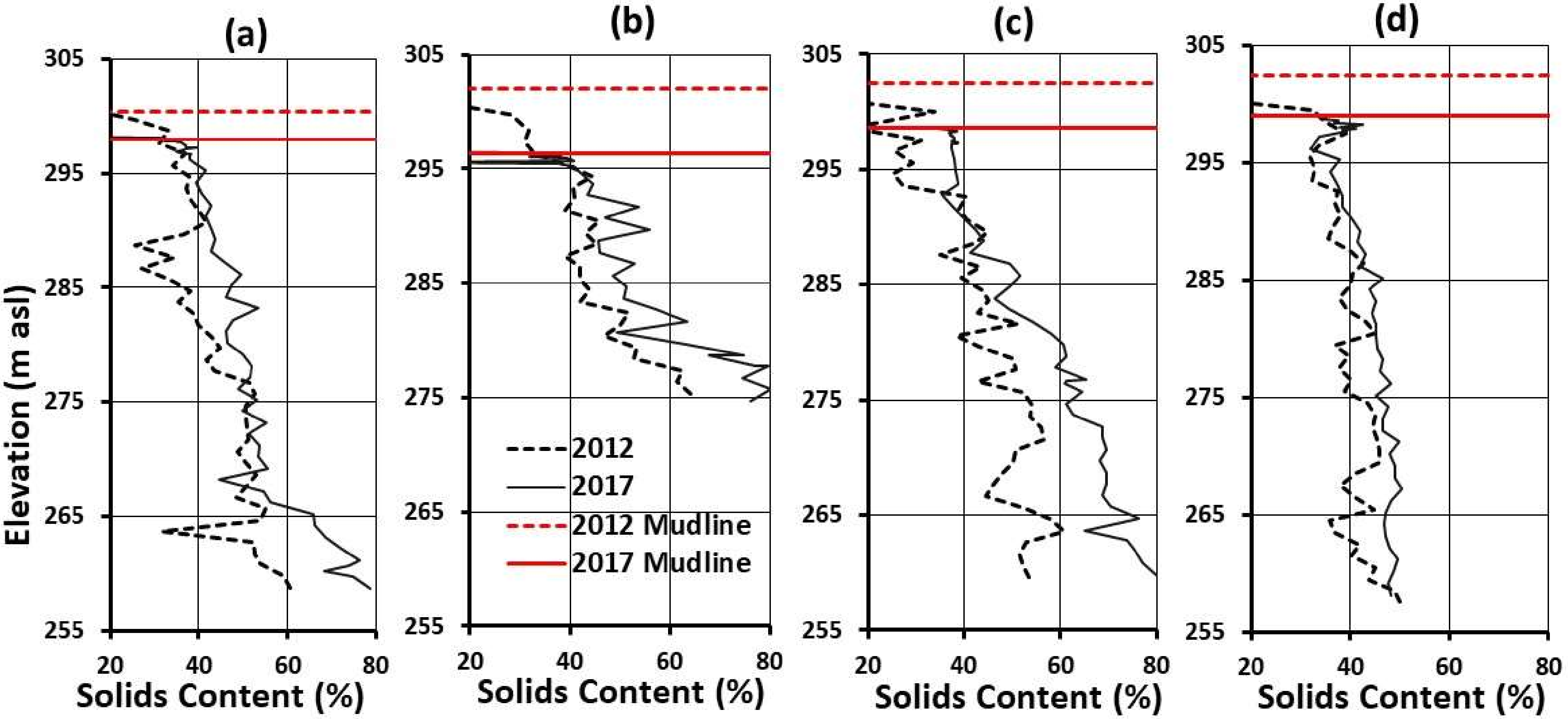


Figure 5-5: Profiles of solids content in 2012 and 2017 at sampling locations: (a) D11; (b) Platform; (c) D08; and (d) D38. Also shown are the respective mudlines (Dunmola et al. 2022).

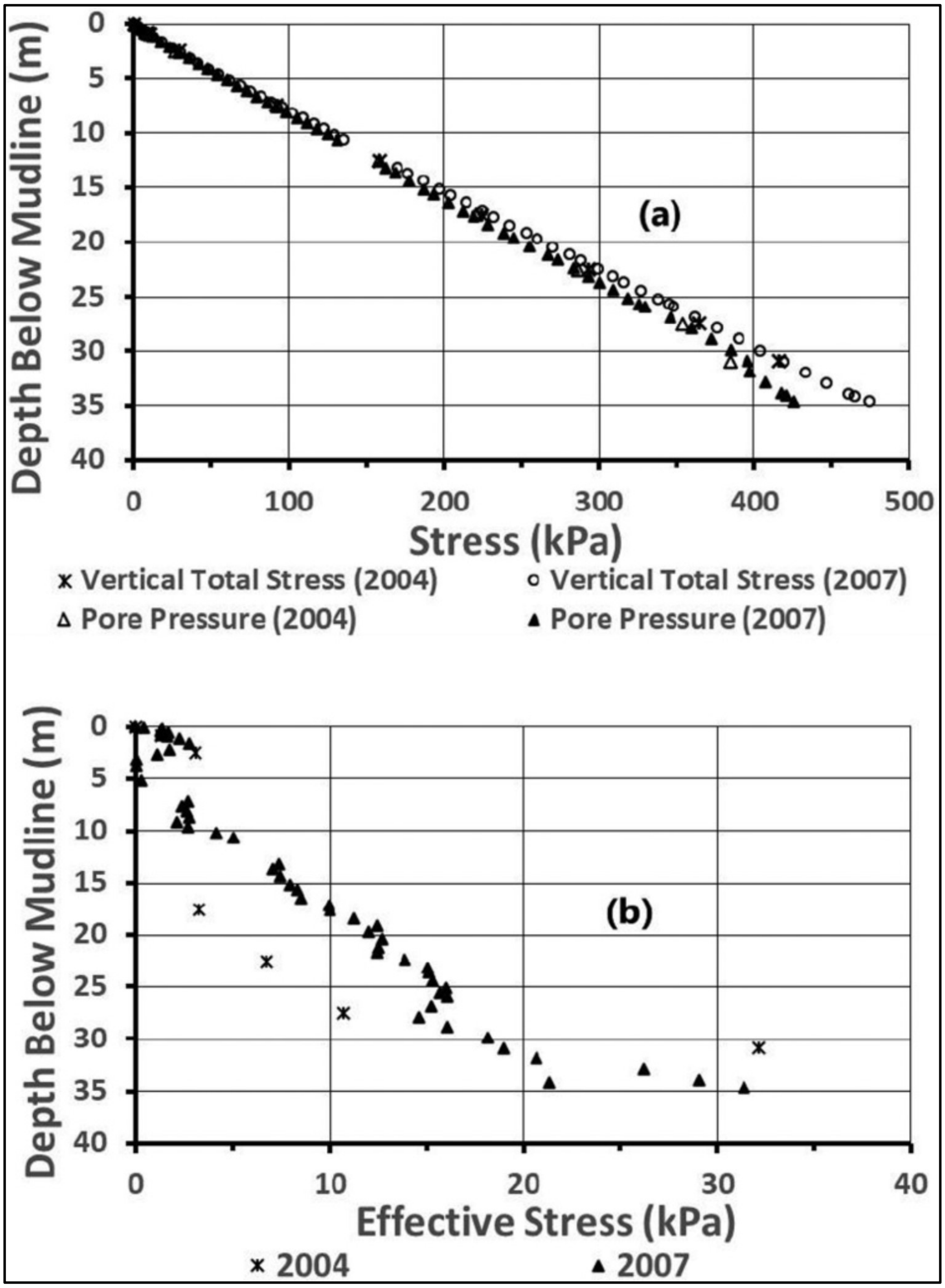


Figure 5-6: Profiles of a) vertical total stress and pore pressure and b) effective stress measured for FT in WIP during tailings infilling in 2004 and 2007 (after Dunmola et al. 2022)

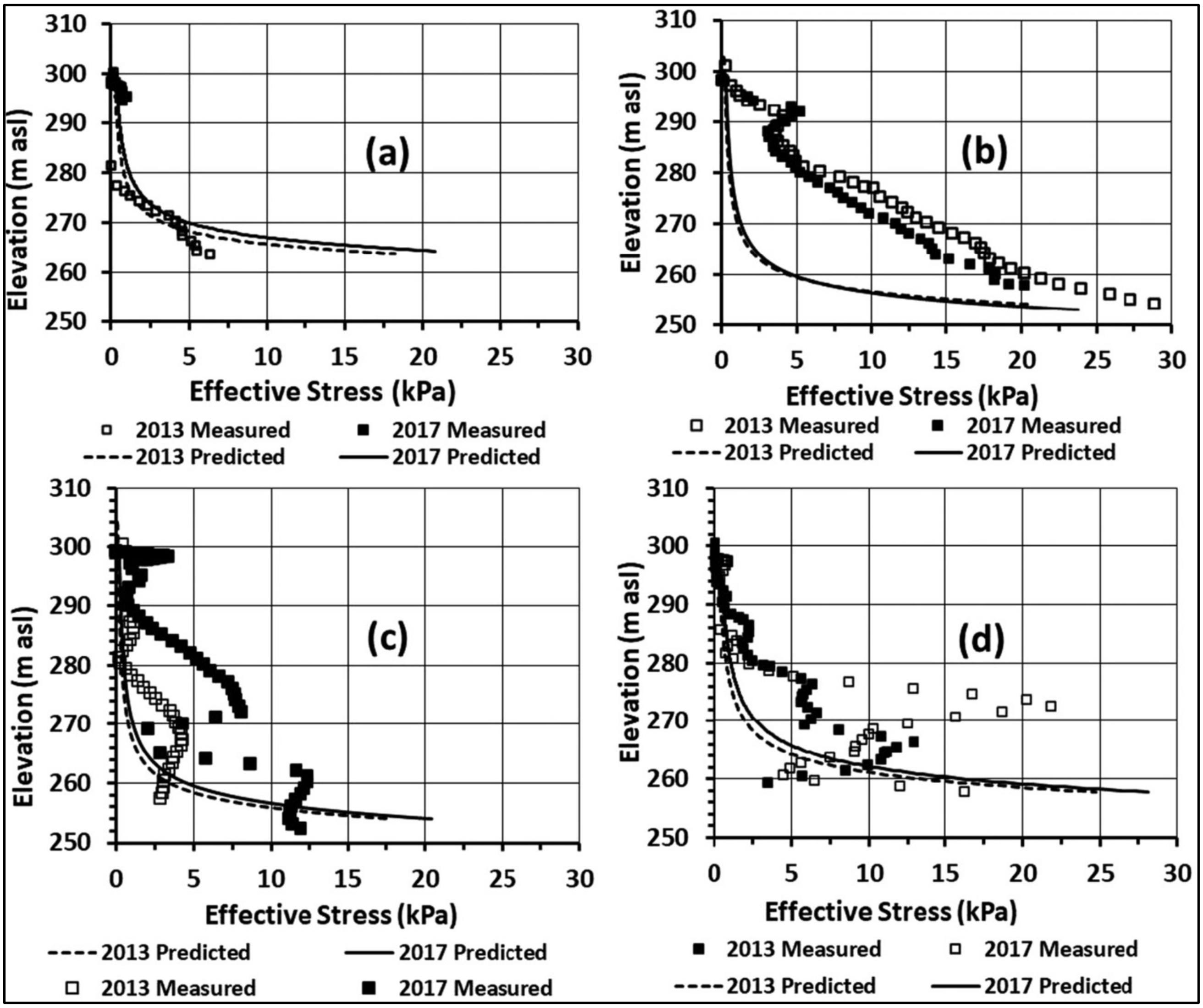


Figure 5-7: Predicted and measured profiles of effective stress in 2013 and 2017 at testing locations in Base Mine Lake Demonstration: a) Platform 3; b) Platform 1; c) D38; and d) D08 (after Dunmola et al. 2022)

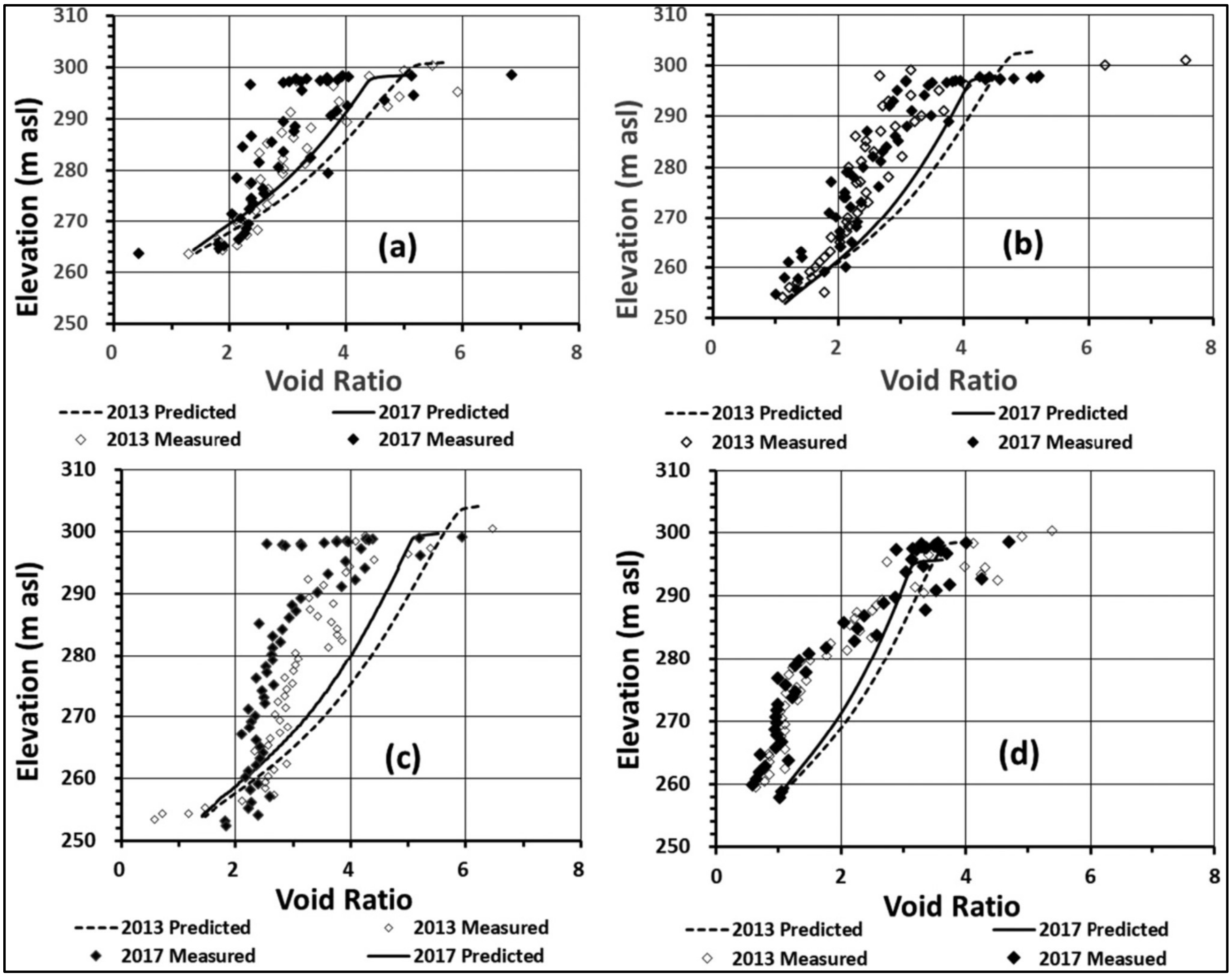


Figure 5-8: Predicted and measured profiles of void ratio in 2013 and 2017 at sampling locations in Base Mine Lake Demonstration: a) Platform 3; b) Platform 1; c) D38; and d) D08 (after Dunmola et al. 2022)

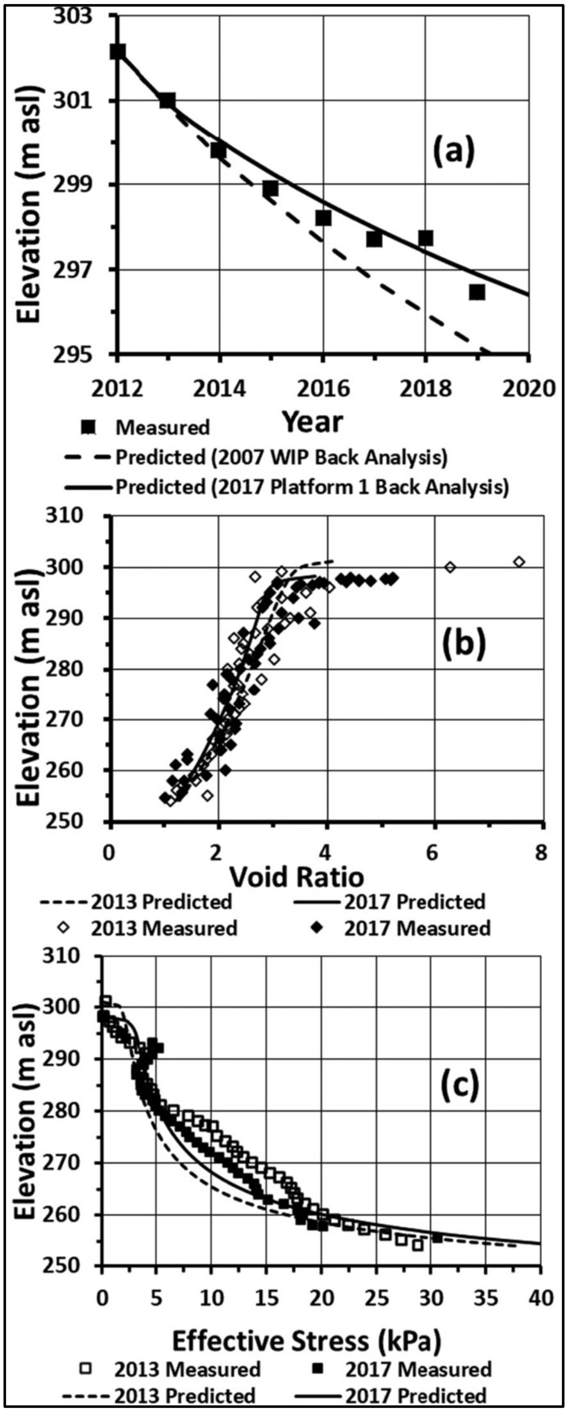


Figure 5-9: Predicted and measured: a) settlement; profiles of b) void ratio; and c) effective stress and Platform 1 in 2013 and 2017 using the compressibility and hydraulic conductivity function back-analyzed from 2017 in situ data (see Dunmola *et al*. 2022 for details).

Evidence of self-weight consolidation

The FT in BML Demonstration is settling, as the mudline decreases over time (Figure 5-1, Figure 5-2, Figure 5-3). This is complemented by profile increase in solids content (Figure 5-5) indicating FT dewatering and densifying with time. Multiple lines of evidence demonstrate that the FT settlement is driven by self-weight consolidation (see Dunmola *et al.* 2022 for discussion and details). Pore pressures and effective stress profiles measured during the tailings in-filling of WIP and after BML Demonstration commissioning confirm that self-weight consolidation is driving the FT's geotechnical performance (Dunmola *et al.* 2022). Secondly, numerical predictions of FT settlement, based on finite-strain consolidation theory, agree with field measurements of settlement, profiles of void ratio, and effective stress (Figures 5.7 to 5.9). Thirdly, field data show that cumulative settlement is correlated with initial FT thickness (Figure 5.4) and FT settlement is complemented by temporal increase in solids content profiles. This is consistent with the correlation of time-dependent decrease in FT water content (for initial water contents greater than 150%) to self-weight consolidation (Suthaker and Scott 1997). Hence, the long-term geotechnical performance of the FT in BML is driven by self-weight consolidation. The operational performance resulting from ~25 wt% solids density input into BML Demonstration (formerly WIP) is demonstrated through average deposit solids content increasing over time (As per Figure 5.5).

5.3 Fines are isolated below the mudline

The depth of water required to prevent wind-wave driven resuspension of sediments (e.g., FT) is a function of four factors: the threshold velocity, wind velocity, fetch and a factor of wave heights (Lawrence et al. 1991). Using the expression derived by Lawrence et al. (1991) for BML Demonstration, a water cap depth of 6 m would prevent wind driven resuspension of fines from the sediment (i.e., below the mudline). The average water cap depth 10 months after commissioning was ~8 meters and has been consistently deeper than 9 meters since May 2015 (Lawrence *et al.* 2016). There has been no evidence of wind-wave driven resuspension of sediment since BML Demonstration was commissioned. It is also expected that densification resulting from FT consolidation and increasing water cap depth with time will further reduce or eliminate the likelihood of wind-wave driven resuspension of FT (Dunmola *et al*. 2022).

TSS concentrations in BML Demonstration remained relatively high but declining in annual peak concentrations slightly from 2013 through 2015, before decreasing and becoming more stable after the 2016 alum treatment (Figure 5-10 and Figure 5-11). The fines in the water cap were residual fines liberated to the water cap during tailings deposition. If fines are re-suspended from below the mudline, the TSS concentration in the water cap would be expected to increase with time. Both pre- and post-alum addition, the peak TSS concentrations are generally declining with time or are stable (Figure 5-11). Seasonal trends in TSS concentrations connected to lake mixing events are evident but are dampened post-alum treatment. These seasonal dynamics represent residual fines in the water cap, not fines re-suspended from beneath the mudline, because there is no evidence of net increases over time. Also, as algal communities are developing post-alum addition, there are biological contributions to the TSS concentration. Before the alum addition, the TSS concentrations would peak during spring turnover, and when the lake was thermally stratified in summer the TSS concentration in the water cap generally declines as fines settle. The fines did not settle out of the water cap completely before fall turnover. These seasonal dynamics are present but dampened post-alum treatment.

Post alum dosage, high TSS concentrations are generally limited to <0.5m above tailings water interface for all sampling locations (Figure 5-11, Figure 5-12). In 2023, the greatest median TSS concentrations in BML Demonstration were found near bottom (within 3 m; 19 mg/L), with lowest median concentrations found at the surface (1.0 mg/L). The vertical variations in TSS concentrations are influenced by near-bottom sampling close to the water-FT interface (CTD sensor plunges into the FT surface to determine depth prior to sampling) or fines entrained in the wake of methane bubble ebullition events. These fines are not increasing the water column or the photic zone TSS concentrations or turbidity. The higher TSS concentrations are sporadic and are limited to the water cap near FT surface (<0.5 m), and the increased TSS near the mudline surface is not sustained over time.

Seasonal variations in TSS concentrations were less apparent in BML Demonstration in 2023 than prior to 2016, with median concentrations of 1 mg/L in each of the winter, fall, and summer. Median TSS concentrations in summer, fall, and winter 2023 were lower than the historical post-alum treatment (2017 through 2021) medians (2.9, 6.4, and 3.9 mg/L, respectively).

In 2023, TSS concentrations in BCR had a median concentration of 4.6 mg/L during the summer, which was lower than the historical median (7.0 mg/L) but still within the historical range. A comparison of BML Demonstration and BCR TSS concentrations over time is presented in Figure 5-12.

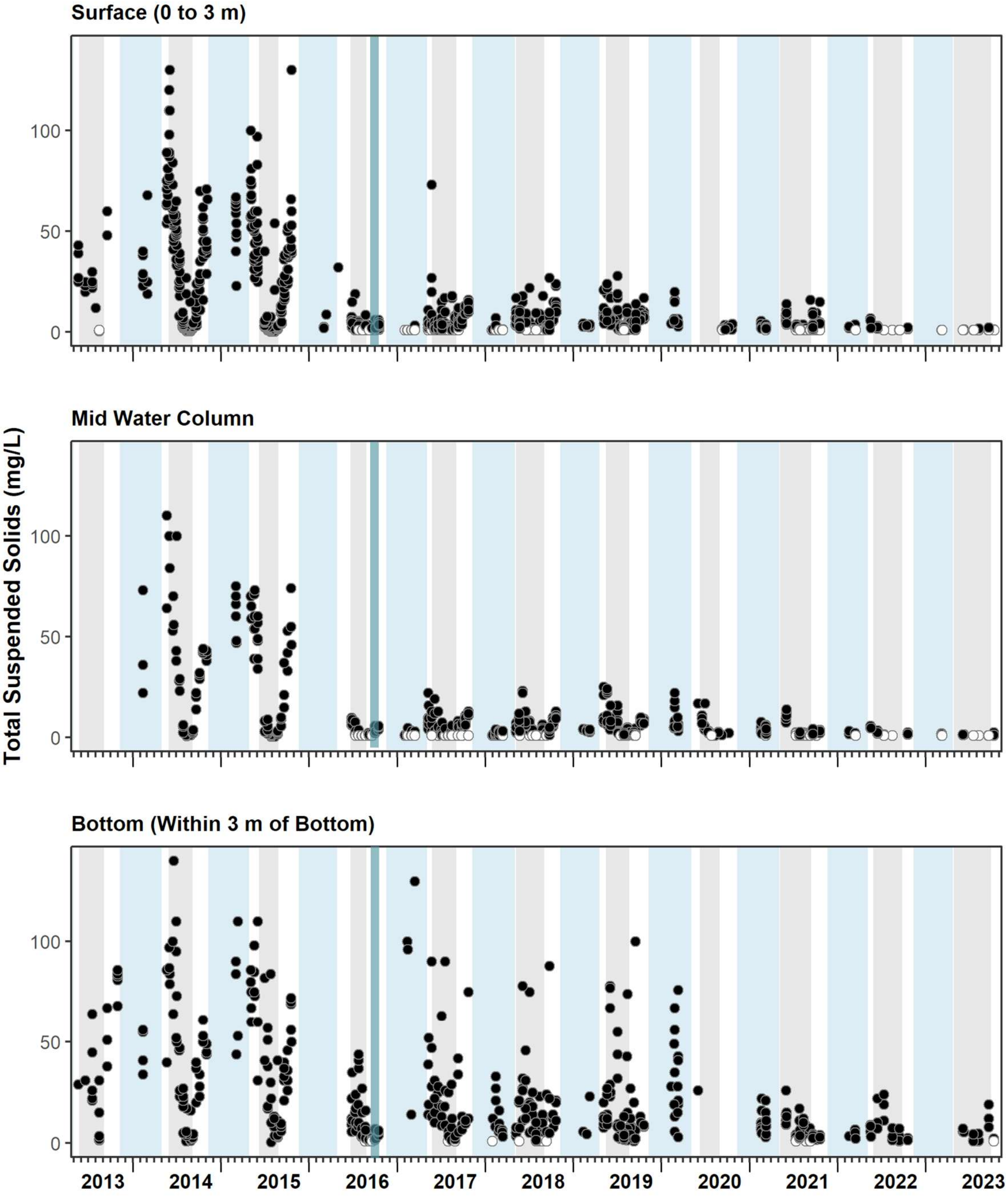


Figure 5-10: Total Suspended Solids (TSS) in BML Demonstration water cap in mg/L from 2013-2023.

Note: Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel. Green interval shows the period of the one-time alum treatment. The scale has been adjusted to focus on overall trends. Mid-water column depths range from 3 m to within 3 m of FT surface (bottom). Guideline for TSS is based on background condition, and therefore not presented. Scale is adjusted to focus on overall trends; 26 samples collected between 2014-02-12 and 2019-05-21 were greater than 150 mg/L which were excluded from the plot for presentation purposes. The full-scale plot with all data is shown in Appendix 1.

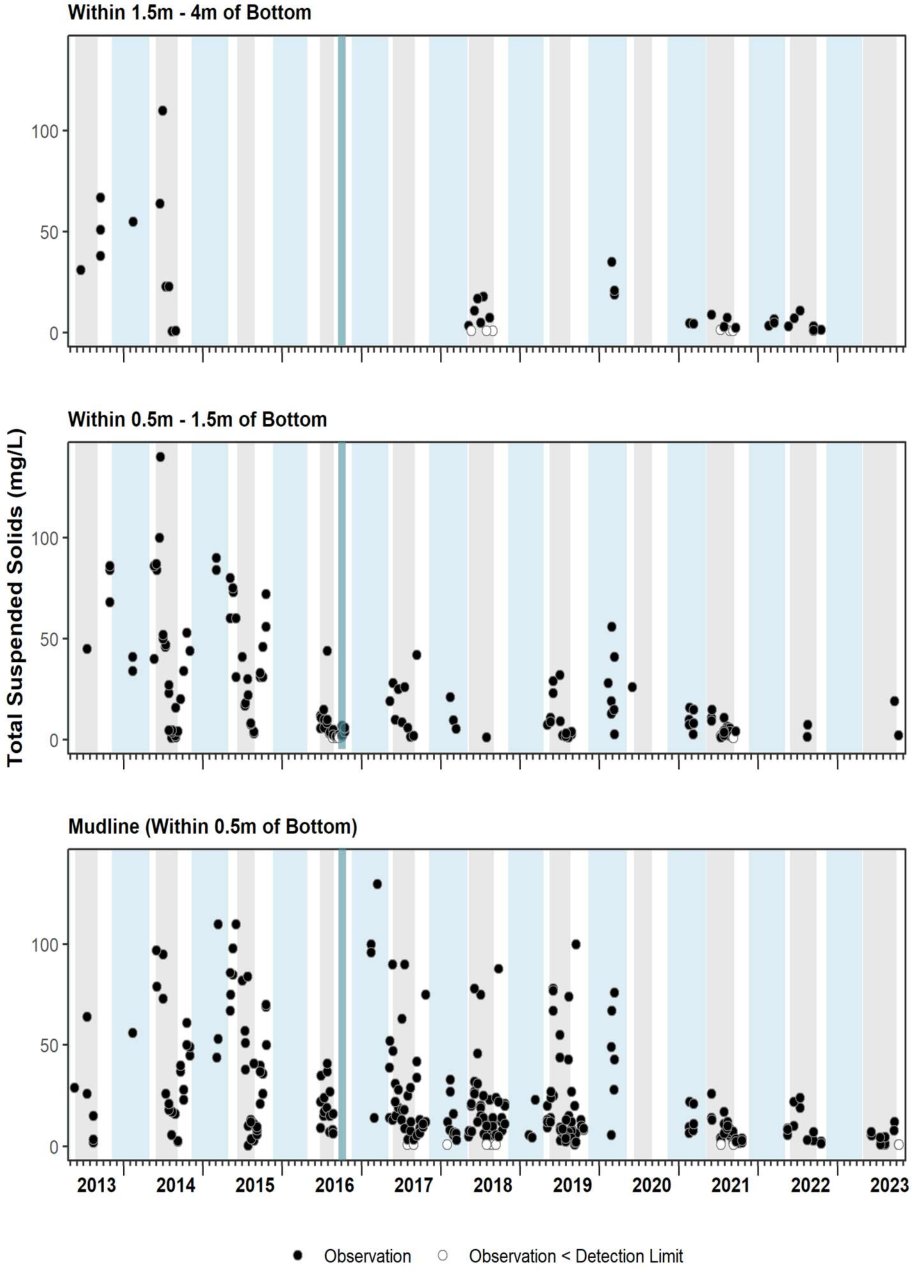


Figure 5-11: Temporal trend in total suspended solids (TSS) in BML Demonstration Water Cap in mg/L From 2013 to 2023 Within 4 m of the FT Water Interface (Scale Adjusted to Show Mudline Trend).

Note: Ice-covered (blue) and stratified (grey) periods are shown as filled areas on each panel. Darker interval shows the period of the alum addition in 2016. Scale is adjusted to focus on overall trends; 23 samples collected between 2014-02-12 and 2019-05-21 were greater than 150 mg/L which were excluded from the plot for presentation purposes.

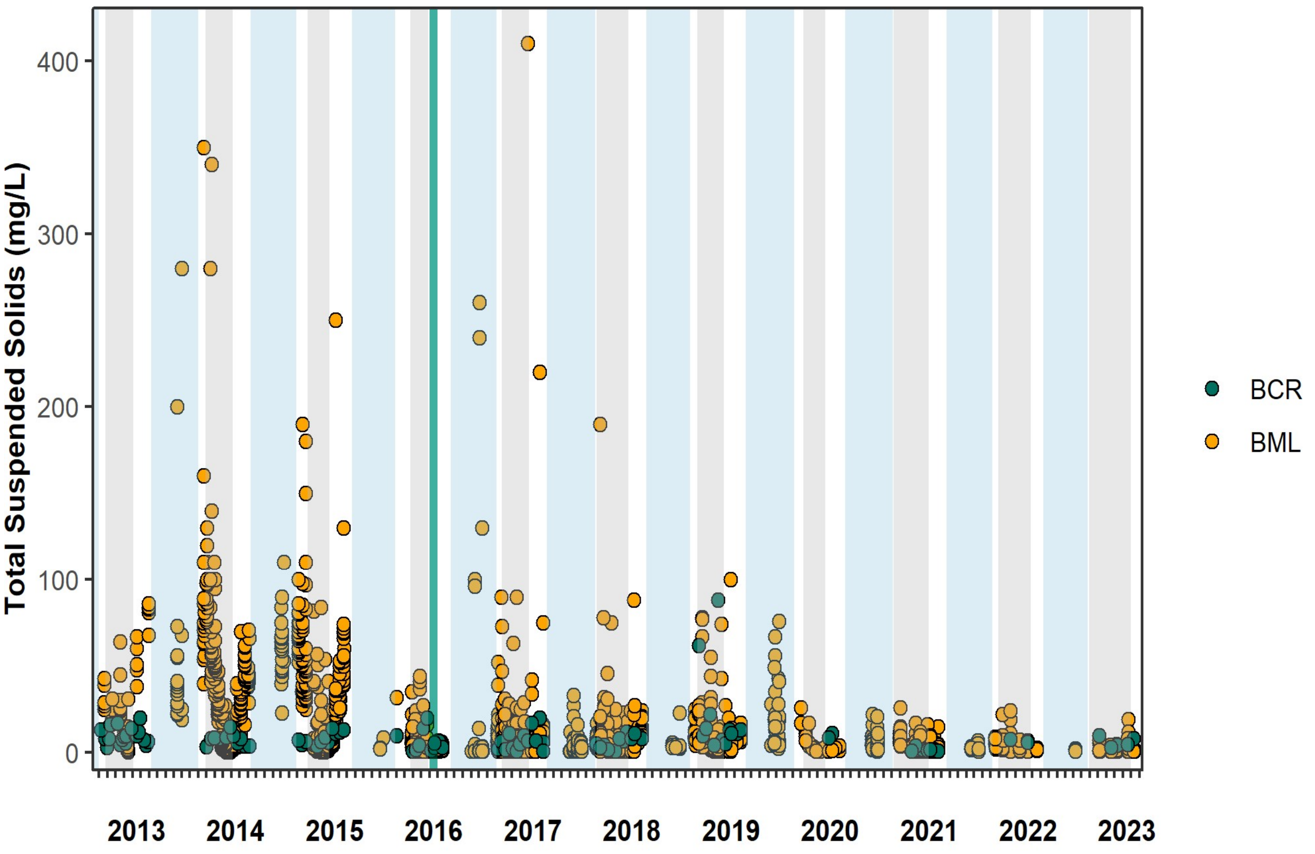


Figure 5-12: Temporal trend in total suspended solids (TSS in mg/L) in Base Mine Lake Demonstration water cap and Beaver Creek reservoir from 2013 to 2023.

Note: Ice-covered (blue) and stratified (grey) periods are shown as filled areas on each panel. Green interval shows the period of the alum addition in 2016. Scale is adjusted to focus on overall trends; 11 samples collected between 2014 and 2019 were greater than 500 mg/L which were excluded from the plot for presentation purposes.

As discussed in Dunmola *et al.* (2022), there are multiple lines of evidence that as the FT in BML Demonstration consolidates, densifies, and gains shear strength over time, the transition in geotechnical properties at the mudline becomes more distinct. The FT settlement is complemented by profile increases in solids content, indicating FT dewatering and densification with time. The transition in geotechnical properties at the mudline is also getting distinct over time. Features in the FT surface (e.g., cracks, pock marks) are further evidence that the mudline is distinct, and the FT is densifying (Figure 5-13). These are multiple lines of evidence that the fines are physically isolated below the water cap, and demonstrates that the fines continue to be physically sequestered below the water cap. Though the water cap in BML Demonstration, like other boreal dimictic lakes, undergoes seasonal mixing, there is evidence that the underlying FT is neither being scoured nor that fines are being liberated and re-suspended.

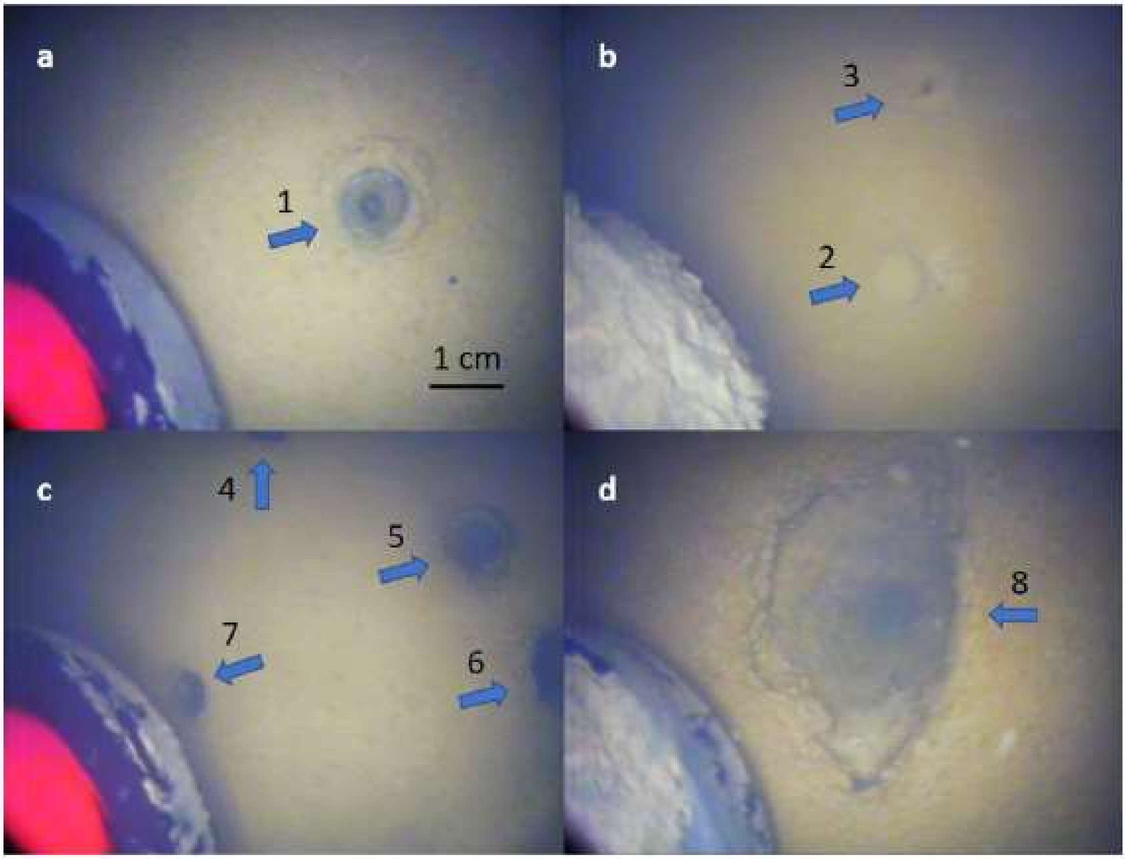


Fig. 4. Photographs taken from a camera suspended approximately 5 cm above the water-mud interface on 03 October 2019. (**a**) An active pockmark (#1) with a narrow conduit within. (**b**) Two pockmarks (#2–3) located close to each other. Pockmark 2 is backfilled with sediment, indicating bubbles did not rise through it in recent ebullition events. Pockmark 3 is particularly small, potentially because few bubbles have passed through it. (**c**) Four pockmarks (#4–7) in close proximity. (**d**) One large pockmark (#8). The instrument (red and black color) on the bottom-left corner of each image is an RBR concerto data logger. The rim of the black guard has a diameter of 8.6 cm. In (**b**) and (**d**), the instrument is covered by mud. The location of pockmark 1 is marked as white diamond in Fig. 1a; whereas, the location of pockmarks 2–8 is indicated with a white square in Fig. 1a.

Figure 5-13: Photographs taken from a camera suspended approximately 5 cm above the water-mud interface on 03 October 2019 (after Zhao et al. 2021).

5.4 Base Mine Lake Demonstration Water balance

A conceptual description of the BML Demonstration water balance is presented in Figure 5-14. The rate and volume of tailings porewater release from the tailings to the water cap is directly linked to the rate of FT settlement. As described in section 5.1, we have confidence in our modelling to predict FT settlement in BML Demonstration, which provides confidence in determining rates and volumes of porewater reporting to the water cap. The annual water balance estimation is provided in Mm^3 in Figure 5-15 and Table 5.1: Annual water balance for Base Mine Lake Demonstration since commissioning (Mm3) (Dredge Out is from the suction dredge piloted in 2019).
. Key drivers of the water balance are the porewater flux, freshwater flows into the lake, water flows out of the lake (back into the Recycle Water System). There is negligible groundwater flux in or out of BML Demonstration (see section 6.2.4). Currently, other than the freshwater inflow from Beaver Creek Reservoir, surface run-off into BML Demonstration has little influence on the water balance. Over time, as reclaimed watersheds are connected to BML Demonstration, that surface watershed will increase in size (see Appendix 3).

Numerical modelling predicts that FT settlement will reach 90% of ultimate consolidation by approximately 2050. Figure 5-15 shows the measured water balance for BML Demonstration since commissioning and a projected water balance for the lake at 2050 (t90 for settlement) for the range of climate scenarios modelled in our closure plan (see Appendix 3 for details of closure modelling). By 2050, the influence of porewater flux from FT settlement will have a small contribution to the water volume in the water cap. The porewater flux in 2050 is predicted to be reduced to 0.1 Mm^3, which is a 90% reduction from the 2023 porewater flux. The FT porewater is the source of elevated chemical concentrations, and as settlement reduces over time, so will the influence of FT porewater on the water cap volume and chemistry.

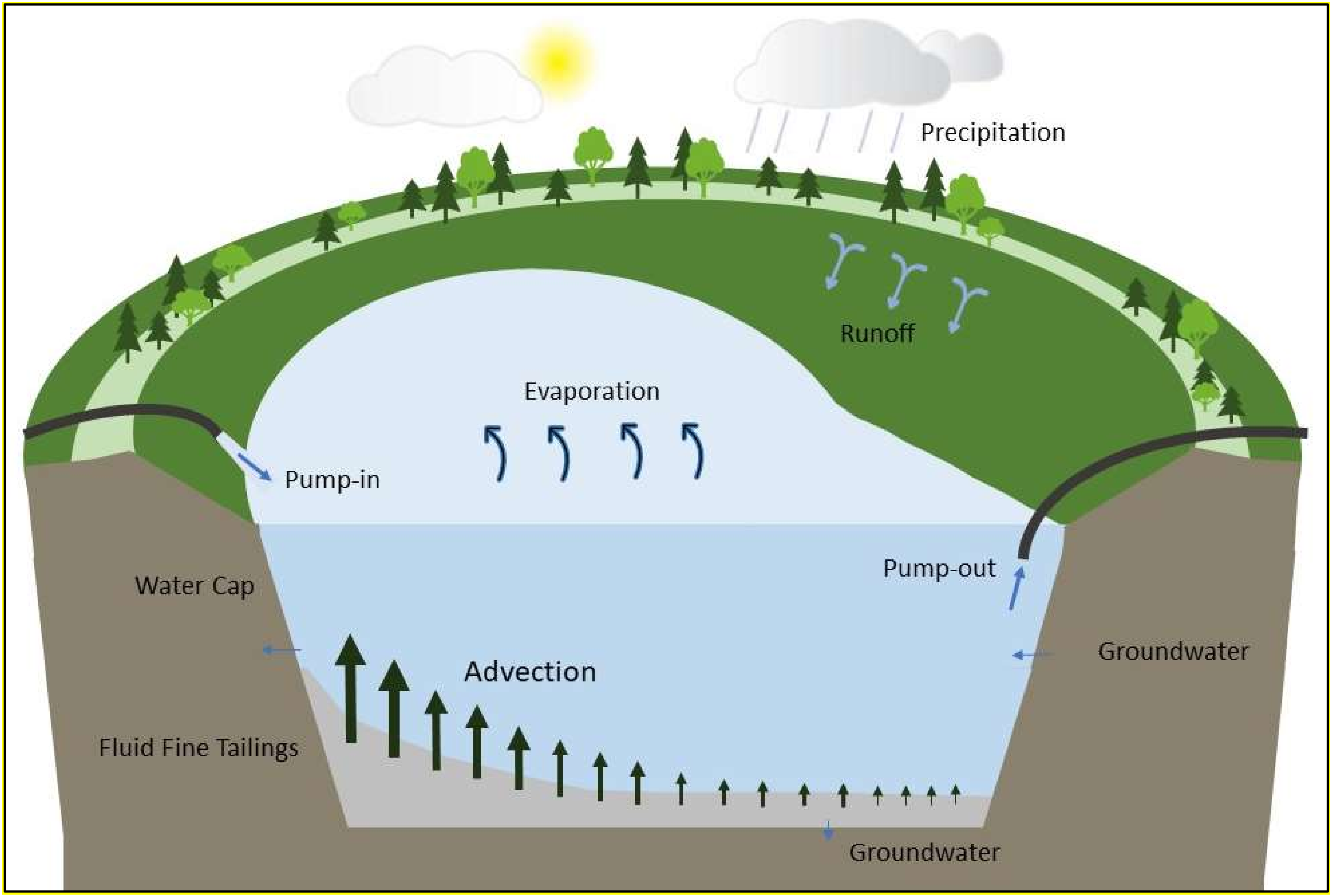


Figure 5-14 Conceptual BML Demonstration water balance illustrating declining influence of porewater advective flux from tailings settlement over time.

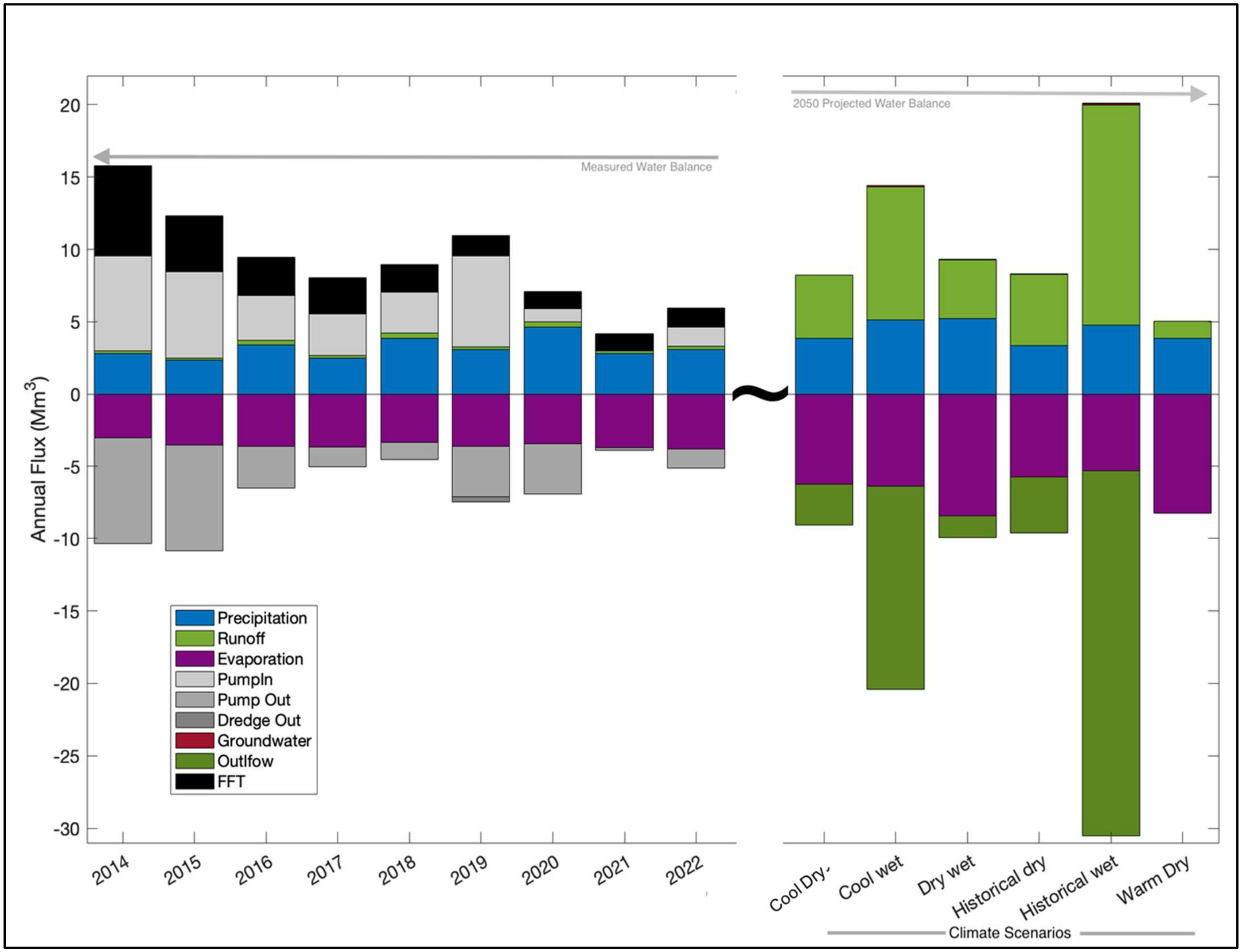


Figure 5-15: Annual measured water balance for BML Demonstration (Mm3) and projected 2050 (t90 settlement) water balance for range of climate scenarios used in LMCP modelling.

Table 5.1: Annual water balance for Base Mine Lake Demonstration since commissioning (Mm3) (Dredge Out is from the suction dredge piloted in 2019).

Year	Rain	Snow-water equivalent	Runoff	Evaporation	Pump In	Pump Out	Dredge Out	FT Settlement
2014	2.37	0.42	0.20	3.00	6.56	7.35	0.00	6.24
2015	1.96	0.39	0.13	3.50	6.01	7.34	0.00	3.84
2016	3.02	0.39	0.31	3.62	3.10	2.89	0.00	2.64
2017	2.20	0.31	0.17	3.64	2.84	1.40	0.00	2.52
2018	3.07	0.77	0.40	3.33	2.82	1.20	0.00	1.92
2019	2.54	0.54	0.20	3.59	6.25	3.55	0.34	1.44
2020	4.02	0.62	0.35	3.45	0.90	3.47	0.00	1.20
2021	2.02	0.77	0.19	3.71	0.00	0.18	0.00	1.20
2022	2.18	0.89	0.22	3.77	1.33	1.35	0.00	1.32
2023	2.13	0.75	0.25	3.96	4.56	3.14	0.00	1.08

Note: Dredge out is from the suction dredge piloted in 2019.

5.5 Water cap chemistry and toxicity

The water chemistry in the water cap is influenced strongly in the short-term by FT porewater flux as the tailings settle. The water chemistry in the lake is an important driver of ecological outcomes, and this chemistry is influenced over time by the chemistry of the water balance inputs. Water chemistry will change in tailings containing pit lakes through several mechanisms: reduction in porewater flux over time, dilution through in-and out-flow management during operations, and landform design for closure, and photo- and bio-degradation in the water cap. Comparison of water cap chemistry to existing EQGASW PAL guidelines is a good first step in screening, however it is important to acknowledge that plants and animals in the lake are not responding to each chemical parameter in isolation, but rather to the chemistry of the whole water. This is where standard whole-water toxicity tests can provide further understanding of water cap performance. These standard lab tests are a useful screening tool, but not all of these laboratory reared test organisms represent local flora and fauna, and therefore assessment of lake biological community structure and function is also an important step to understanding pit lake performance.

In the shorter-term, the water cap should not be acutely toxic, as demonstrated by appropriate standard acute lethality tests described in Environment Canada Biological Test Methods and Guidance Documents (Government of Canada). The water should also pass appropriate

Canadian Water Quality (acute) Guidelines for the Protection of Aquatic Life (CCME 2014c) and Environmental Quality (acute) Guidelines for Alberta Surface Waters (AEP 2018). BML should also demonstrate water quality improvements over time.

The longer-term objective for BML Demonstration is reclamation certification, which will require demonstration that the lake is a functioning component of the closure landscape, with water quality appropriate to support the desired end land use and to provide lake specific wildlife habitat. Key existing guidelines that may be appropriate as performance indicators to support certification of BML include Environmental Quality (chronic) Guidelines for Alberta Surface Waters (AEP 2018) and Canadian Water Quality (chronic) Guidelines for the Protection of Aquatic Life (PAL) (CCME 2014c).

5.5.1 Water chemistry comparison to chronic (long-term) Protection of Aquatic Life guidelines

The 2023 analytical results for the discrete water quality samples collected from BML Demonstration were screened against GoA (2018) surface water quality guidelines for the protection of aquatic life. The most conservative value was used for variables with multiple guidelines (e.g., for variables with GoA (2018) and CCME (2007) guidelines, or acute and chronic guidelines). Site-specific (e.g., hardness-dependent) guidelines were calculated for each sample, as applicable. One metric that historically has been used to track lake performance over time is the proportion that a water quality variable exceeds its guideline relative to the total number of samples collected in a year. Of all parameters measured in the water cap during the open water season with acute PAL guidelines, only the F2 hydrocarbons exceed acute guidelines. A study is underway through the Water EPA at COSIA to demonstrate the laboratory method implications for F2 exceedances, and results are expected later in 2023.

Table 5.2 summarizes the proportion of each analyte that exceeded chronic EQGASW PAL guideline values in each monitoring year. Caution should be taken when interpreting the 2020 results due to adjustments to the sampling design during the COVID-19 pandemic. Specifically, a higher proportion of winter samples were collected relative to open-water and a higher proportion of surface samples were collected relative to at-depth in 2020. In 2023, a lower percentage of samples exceeded the GoA chronic water quality guideline relative to the historical record, with chloride (100%), sulphide (54%), total ammonia (63%), total boron (66%), and F2 hydrocarbons (100%) exceeding guidelines consistently (> 50 % of samples) every year.

In 2023 only 2 other parameters exceeded chronic guidelines- total chromium (20%) and pyrene (3.9%).

Generic risk-based water quality guidelines have not yet been developed in Alberta or Canada for naphthenic acids (NA) quantified either as individual compounds or total concentrations of multiple NA. Thus, NA are not included in Table 5.2.

Table 5.2: Proportion (as %) of surface water quality samples from Base Mine Lake Demonstration that exceeded GoA chronic guidelines for surface water quality, 2013 to 2023.

Group/Variables	Year^a										
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Conventional Physico-Chemical Variables, Ions, and Nutrients											
Total Alkalinity (as $CaCO_3$)	0	0	0	0	0	0	0	0	0	0	0
Chloride	100	100	100	100	98	100	100	100	100	100	100
Sulphate	25	0	0	0	0	0	0	0	0	0	0
Sulphide^b	71	55	66	68	57	69	66	81	87	64	54
Nitrate (as N)	0	0	0	0	0	0	0	0	0	0	0
Nitrite (as N)	29	19	3.5	4.0	0	0.3	0	0	0	0	0
Total Ammonia (as N)	84	88	68	48	61	55	58	10^c	51	34	63
Dissolved and Total Metals											
Dissolved Aluminum	21	5.6	1.0	33	39	1.0	4.3	22	15	14	0
Dissolved Iron	2.3	0.4	2.0	0	0.3	0	6.2	7.8	1.0	0	0
Total Arsenic	0	1.6	0.8	0.5	1.4	0.6	0	2.5	0	1.5	0
Total Boron	100	100	95	86	96	100	95	83	67	93	66
Total Cadmium	0	0.4	0.4	0	0.6	0.6	0	2.5	0	1.5	0
Total Chromium	25	61	100	42	14	45	49	70	18	22	20
Total Cobalt	23	90	62	35	15	41	10	6.2	0.3	4.6	0
Total Copper	0	1.6	0	0	0.9	0.9	0	3.7	0	3.2	0
Total Lead	0	2.0	0.4	0	1.7	1.2	0	0	0	1.5	0
Total Mercury	7.5	3.6	0.7	1.0	1.3	0	0.9	0	0	0	0
Total Methyl Mercury	-	3.8	0	0	1.3	6.7	0	0	0	0	0
Total Molybdenum	9.1	0	0	0	0	0	0	0	0	0	0
Total Nickel	0	0	0	0	0.3	0	0	0	0	0	0
Total Selenium	51	1.2	0	0	0.3	0.3	0	0	0	1.7	0
Total Silver	0	0	0	0	0.3	0.3	0	0	0	1.5	0
Total Thallium	0	0	0	0	0	0.3	0	0	0	1.5	0
Total Uranium	0	0	0	0	0	0.3	0	0	0	1.5	0
Total Zinc	0	2.4	0.4	0	0.6	0.9	0	9.0	0.5	6.5	0

Organics										
Total Phenolics	100	71	52	50	15	79	46	35	11	0	0
Benzene	-	0.6	0	0	0	0	0	0	0	0	0
Ethylbenzene	-	0	0	0	0	0	0	0	0	0	0
F1 (C6-C10)	-	4.0	0.7	0	0.6	1.1	0	0	0	0	0
F2 (C10-C16)	-	100	99	100	100	97	99	98	100	100	100
Toluene	-	1.7	0	0	0.6	0	0	0	0	0	0
Total Xylenes	-	0.6	0	0	0	0	0	0	0	0	0
PAHs											
Acenaphthene	0	0	0	0	0	0	0	0	0	0	0
Acridine	0	0	0	0	0	0	0	0	0	0	0
Anthracene	0	0	0.7	0	5.7	1.1	0.7	0	0.6	0	0
Benzo(a)anthracene	0	4.2	1.4	1.0	1.3	0	0	0	0	0	0
Benzo(a)pyrene	0	3.5	1.4	1.0	0.6	0	0	0	0	0	0
Fluoranthene	0	4.2	0.7	0	0.6	0	0	0	0	0	0
Fluorene	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	0	0	0	0	0	0	0	0	0	0	0
Phenanthrene	0	3.5	0	0	0.6	0	0	0	0	0	0
Pyrene	54	61	67	15	23	17	10	14	3.6	6.2	3.9
Quinoline	0	0	0	0	0	0	0	0	0	0	0

Note: Percent exceedance values calculated across all locations, seasons, and depths; zero values presented in grey text to increase readability.

– = Variable not analyzed in a given sampling year.

[a] Based on calendar year.

[b] Sulphide guideline was equal to or less than the analytical DL from 2013 to 2020; the calculated proportion of exceedances includes measurable results only (i.e., values greater than DL).

[c] TAN exceedances have historically occurred most frequently in deep samples, while 2020 open-water sampling focused on shallow- to mid-water depths.

5.5.2 Whole water toxicity tests

Toxicity tests measure the biological response of test organisms exposed to a water or sediment sample for a controlled time period. This type of screening tools are useful because plants and animals are exposed to the whole water in the water cap- not just individual parameters. Organisms are exposed to BML Demonstration whole-water at various concentrations (serially diluted), and also to clean laboratory controls to determine differences in the biological responses to any toxicants present. Acute toxicity is determined by organism survival. Lethal responses are reported as LC50, which is the estimated concentration of exposure medium, diluted with a non-toxic control medium, that is lethal to 50% of the organisms in the short-term test period (usually within 96 hours).

Water toxicity samples are collected during the open water season. Each sample consists of a composite of multiple grabs from two discrete depths in the field-estimated euphotic zone (twice the Secchi depth), collected with a 4L horizontal Van Dorn sampler. The grab samples were composited in clean laboratory-supplied 20L carboys. At each of the three platform stations, 70 L of water was collected for testing. Samples were shipped immediately, unpreserved, to Nautilus Environmental (Nautilus) in Calgary, Alberta. Two standard acute toxicity tests were used:

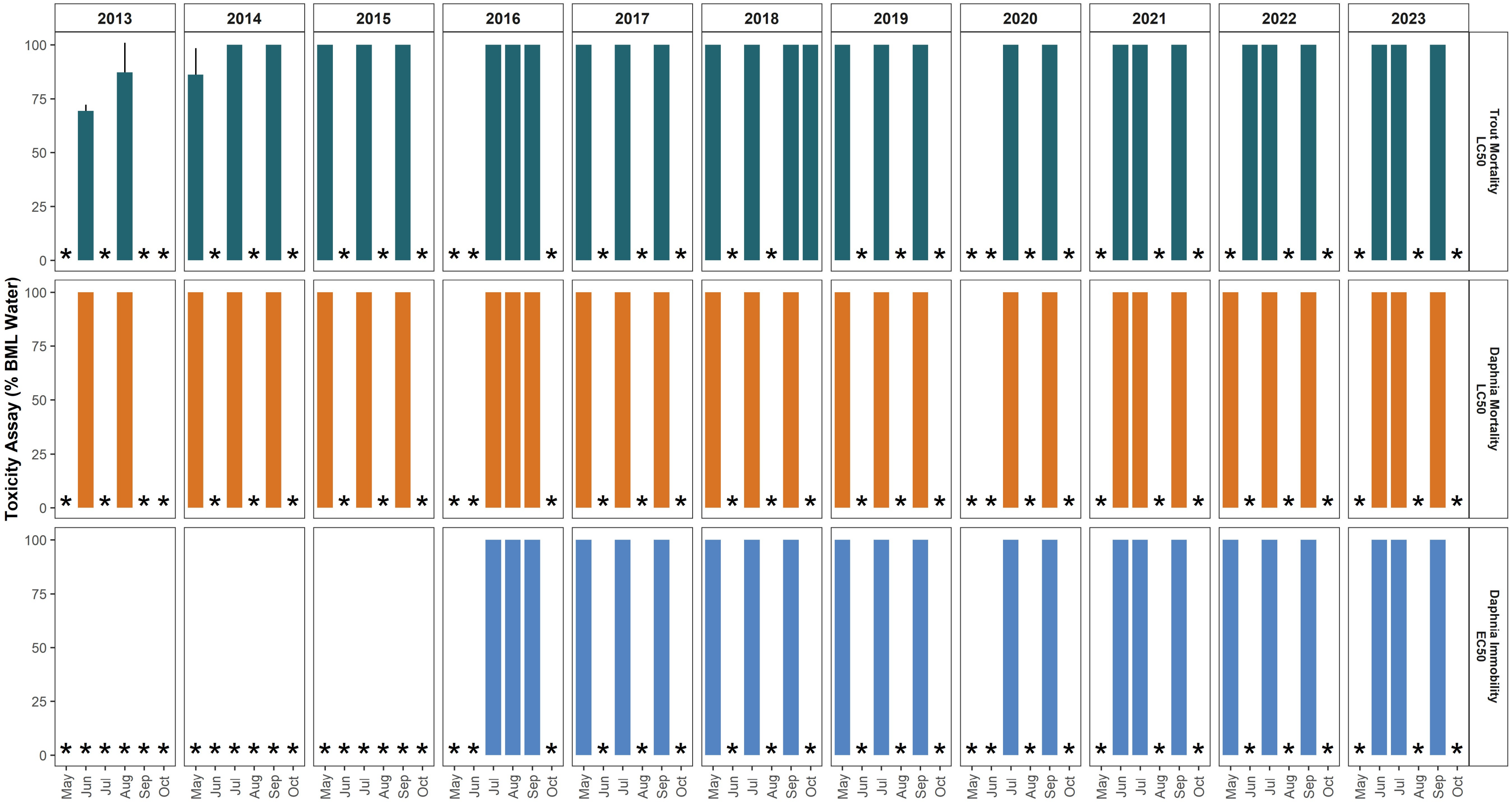
- EPS 1/RM/13: Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout (Environment Canada 2000, 2nd Edition); and

- EPS 1/RM/14: Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to *Daphnia magna* (Environment Canada 2000, 2nd Edition).

The 96-hour static acute test on rainbow trout (*Oncorhynchus mykiss*) did not show any effect on survival resulting from exposure to BML water in 2023, with all LC50 values >100% v/v BML Demonstration water (Figure 5-16). Historically, rainbow trout exposure to BML Demonstration water resulted in a mortality response until May 2014, with LC50 values ranging from 69% to 87% v/v; no survival effect has been observed in any subsequent rainbow trout test.

The 48-hour acute *Daphnia magna* test on BML Demonstration water has shown no survival effect since monitoring began in 2013, with all LC50 values >100% v/v BML (Figure 5-16). The 48-h *D. magna* acute test conducted since 2016 has similarly showed no toxicity of BML water on *D. magna* mobility, with EC50 values >100% v/v BML Demonstration in all three years.

Results from the standard Rainbow Trout and *Daphnia magna* tests indicate that there has been no evidence of acute toxicity in BML water cap since early 2014.



Shown are pooled averages of toxicity assay results across BML platform stations, with standard deviations shown as error bars where applicable. LC50 is the concentration of BML water, diluted by non-toxic medium, estimated to cause 50% mortality in exposed test organisms. EC50 is the concentration of BML water, diluted by non-toxic medium, estimated to cause immobility in 50% of the test organisms. Months without toxicity assay results for these endpoints are marked with asterisks. 2022 and 2023 values shown are toxicity assay results from a lake-wide composite sample.

Figure 5-16: Rainbow trout and Daphnia magna acute toxicity results for BML Demonstration whole water 2013-2023, showing absence of acute toxicity since early 2014.

5.5.3 Chloride concentrations over time

Active tailings infilling of WIP occurred from 1997-2012. During this time the tailings were also settling and porewater was released. The OSPW water cap on WIP was connected to the Recycle Water System (RCW), and as a result chloride concentration in the water cap during tailings infilling were influenced by the porewater chemistry of the tailings, but also RCW in- and out-puts. At the start of tailings infilling, the water in WIP had a chloride concentration of less than 400 mg/L. The practice of water recycling increased chloride concentration, peaking during 2001. After this time, Aurora North was integrated into the RCW system and because this ore had lower chloride concentrations, influencing the water cap chloride concentration in WIP. At the end of tailings infilling of WIP, the chloride concentration in WIP was above 600 mg/L (Figure 5-17). After this point, BML Demonstration was commissioned. No further tailings were input into the lake, and in 2013, freshwater and OSPW was pumped into BML Demonstration to bring the water cap to design elevation.

Chloride has remained the dominant anion in BML Demonstration since 2013, with absolute concentrations decreasing over time. Median chloride concentrations in 2023 were similar in all seasons, ranging from 340 to 390 mg/L, while falling below the historical seasonal median range of 390 mg/L in fall to 480 mg/L in winter (Figure 5-18). Chloride concentrations have exceeded the GoA (2018) long-term (chronic) surface water quality guideline for the protection of aquatic life since 2013 (Figure 5-18). Consistent with previous years, there were no vertical concentration gradients of chloride in BML in 2023 (Figure 5-18).

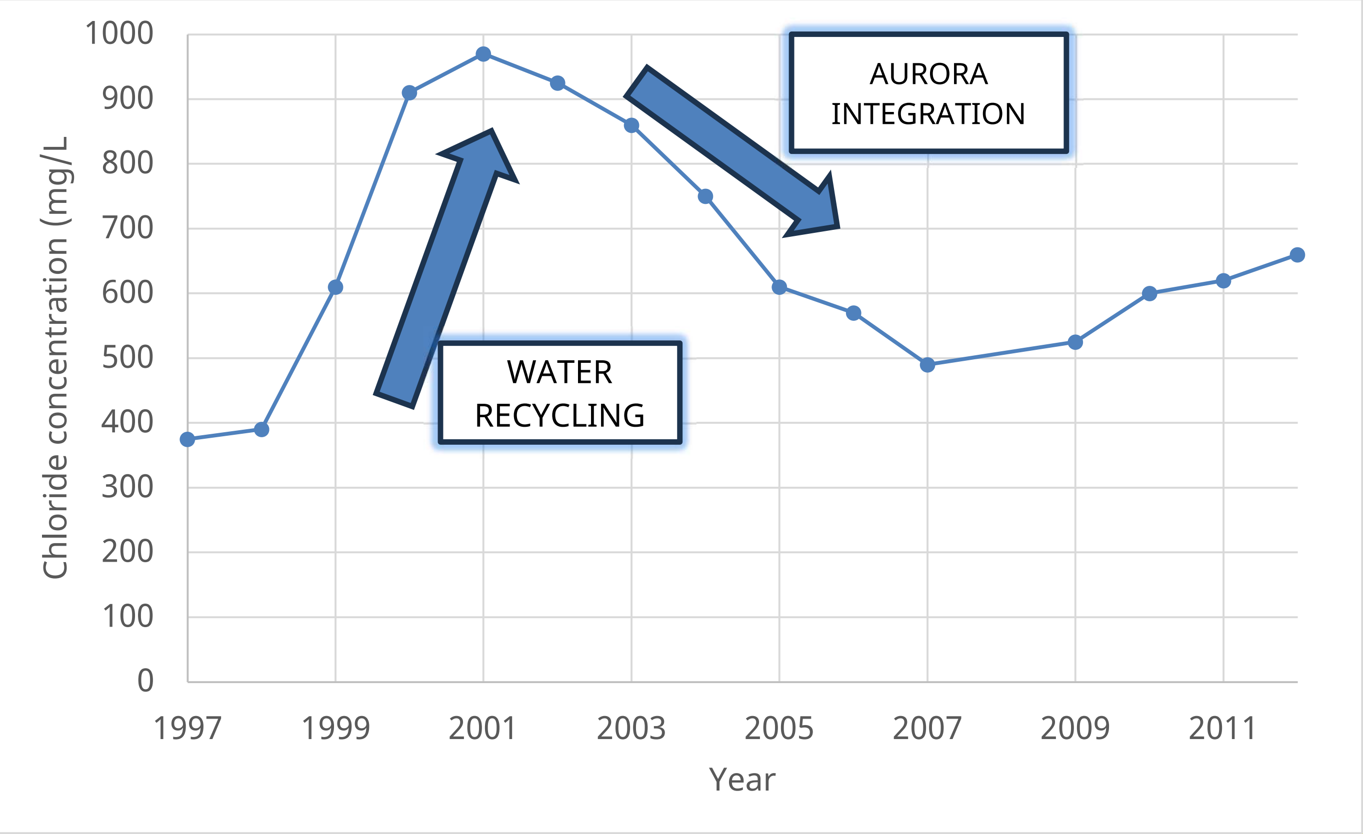


Figure 5-17: Water cap chloride concentrations of West-In Pit during tailings infilling (1997-2012). Base Mine Lake Demonstration was commissioned in 2012 and no more tailings solids were put in the lake after 31 December 2012.

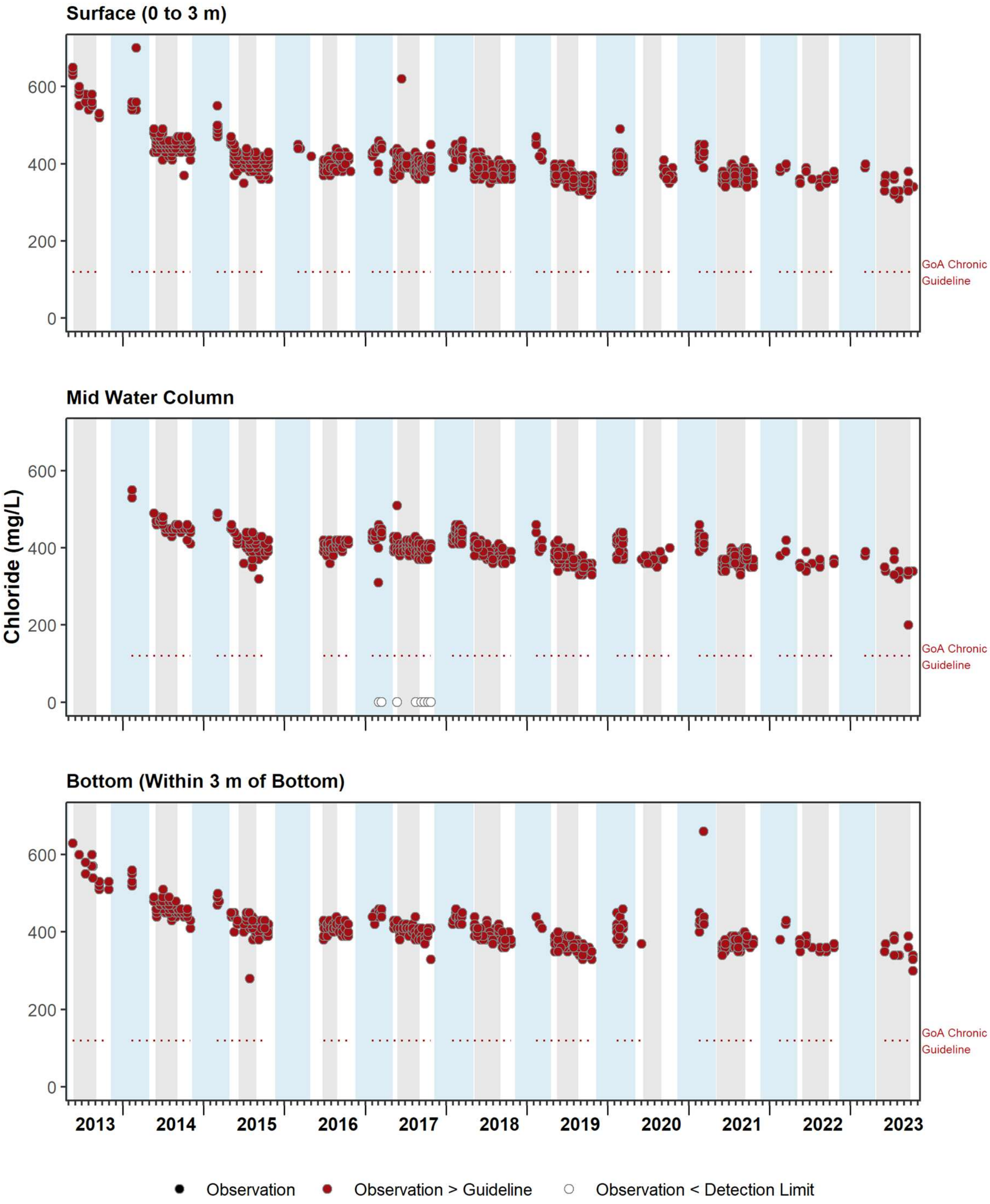


Figure 5-18: Chloride concentrations (mg/L) in BML Demonstration water cap 2013-2023.

Note: Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel. Mean weekly guideline values shown as dotted red line. Scale adjusted to focus on overall trends; 1 sample collected on 2014-03-03 was greater than 1100 mg/L which was excluded from the plot for presentation purposes.

5.5.4 Closure water chloride concentrations

An integrated surface and groundwater model for the Mildred Lake closure landscape, including BML Demonstration was undertaken to support the Life of Mine Closure Plan (Appendix 3). This model incorporates settlement and contributions of water from other landforms, including tailings containing landforms from 2040 to 2100. Four climate scenarios were modelled: Cool Dry (RCP 2.6), Warm Dry (RCP 8.5), Cool Wet (RCP 2.6), and Warm Wet (RCP 8.5). All scenarios demonstrated declining chloride concentrations compared to 2025 levels due to dilution and reduced porewater flux from tailings materials Figure 5-19. Some climate scenarios predict evapoconcentration occurring during dry climate cycles. All scenarios predict that chloride levels will remain below EQGASW PAL acute guideline (640 mg/L) but in some cases will exceed the chronic guideline (120 mg/L) The date that BML Demonstration water cap is projected to be below the EQGASW PAL chronic guideline is shown in Table 5.3.

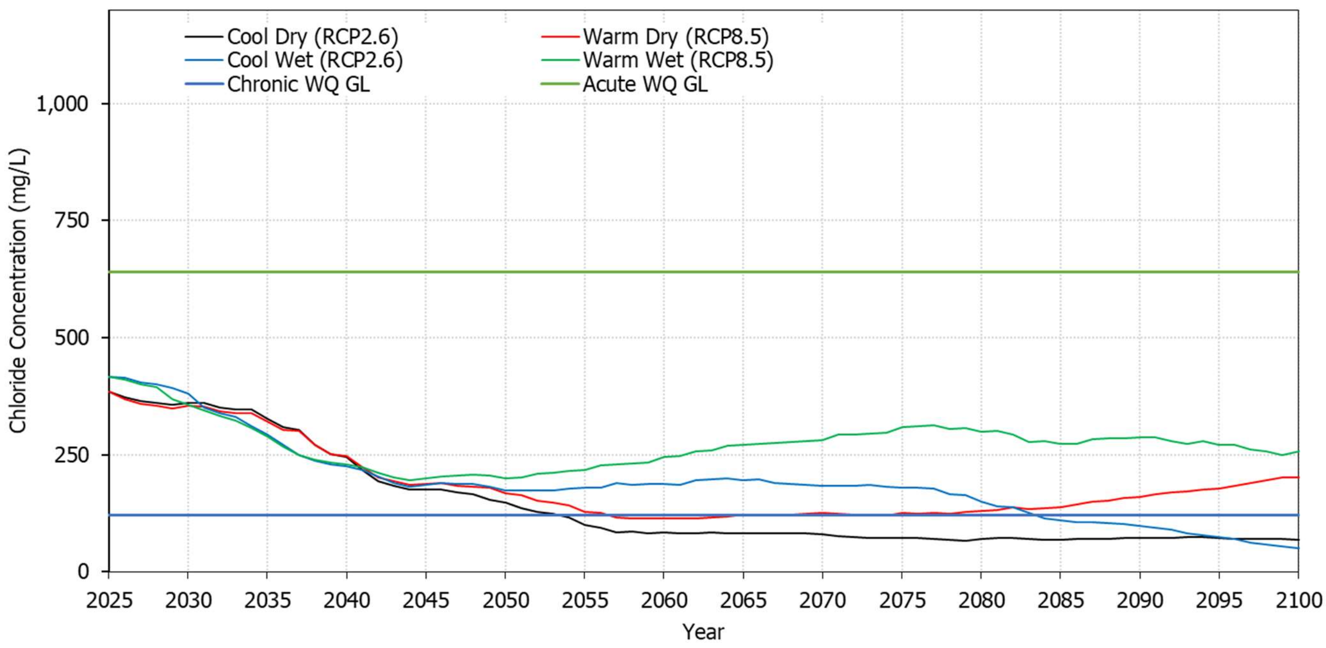


Figure 5-19: Life of Mine Closure Plan modelling predicted Chloride concentrations (mg/L) in BML Demonstration for a range of climate scenarios from 2025-2100.

Table 5.3: Predicted year chloride concentrations in Base Mine Lake Demonstration decline below 120 mg/L (EQGASW PAL chronic guideline) for each modelled climate scenario

Climate Scenario modelled	Year predicted for chloride <120 mg/L
Cool dry (RCP2.6)	2054
Warm Dry (RCP8.5)	2057*
Cool Wet (RCP2.6)	2084
Warm Wet (RCP8.5)	>2100

Note: chloride concentration declines below 120mg/L, but increases during dry climate conditions

5.6 Littoral and Shoreline ecological performance

The shallow lake areas in BML Demonstration are not in contact with FT. The largest littoral areas in BML Demonstration are reclaimed overburden areas (Figure 5-20). The shallow littoral areas are long shallow sloped areas that were part of BML Demonstration landform design (Figure 3-4). These areas were reclaimed using conventional terrestrial reclamation practices. These areas became flooded as the water cap was added to BML Demonstration over 2013. Some shoreline areas are parts of dams (east and west sides of the lake) and have steeper slopes. The water cap is nominally 10-12 m deep over the FT, but the water is shallower around the water's edge. Littoral zones are important areas for the ecological development of the BML Demonstration. Biological activity in the littoral zone is important for productivity and as aquatic habitat for plants and animals.

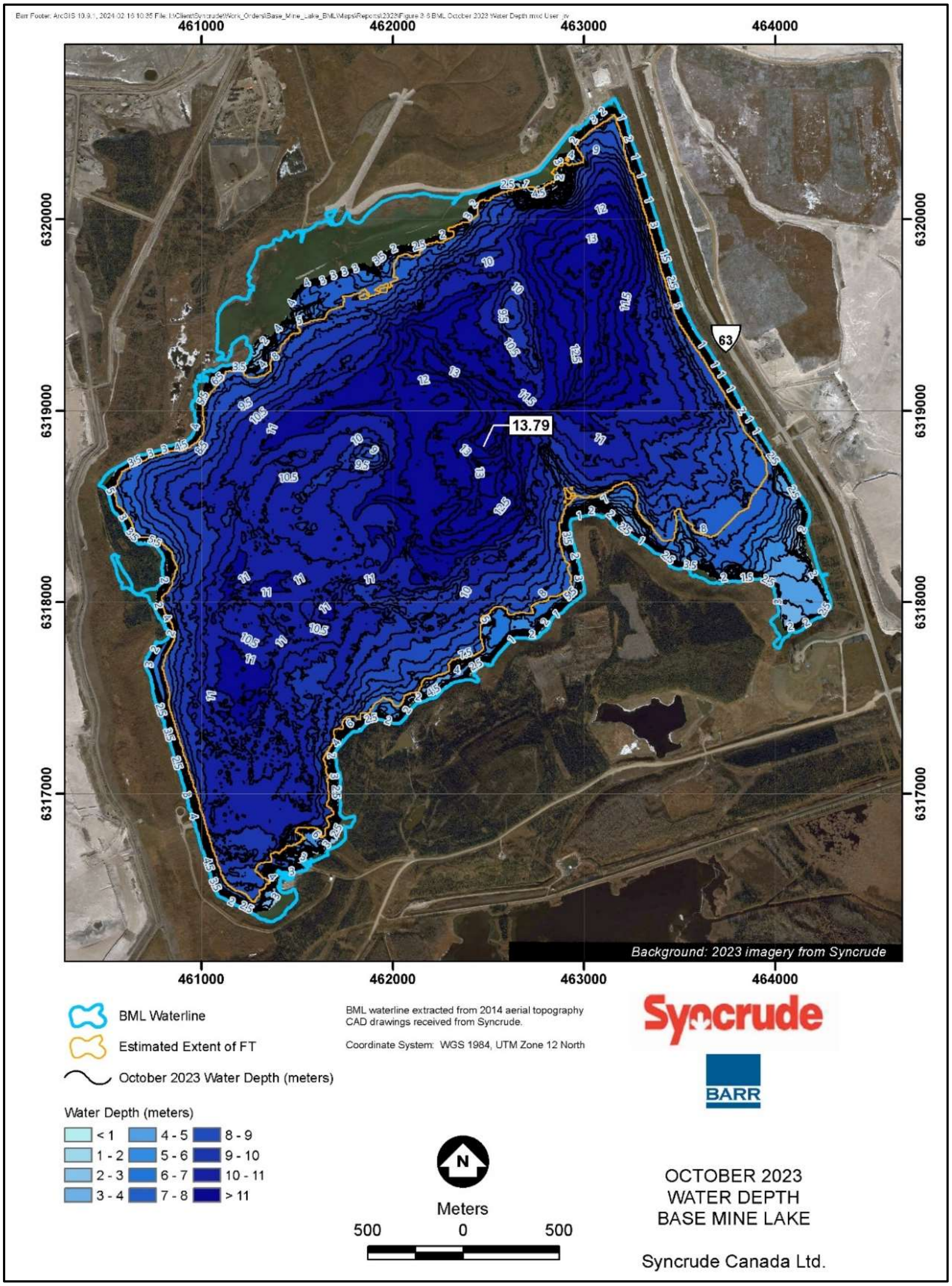


Figure 5-20: Base Mine Lake Demonstration water cap depth measured in October 2023 (orange line indicates extent of FFT, light blue line represents BML Demonstration waterline)

5.6.1 Sediment physics and chemistry

Sediment quality in the designed littoral areas (NW and SE of BML Demonstration). The physical and chemical composition of the sediments varies between these two areas. For example, the sediments in the NW are silty, whereas in the SE the sediments are sandy. This will influence the flora and fauna colonizing these areas. These physical characteristics do not change over time but there is spatial variation within these areas. In 2023, the only exceedances of EQGASW Sediment Quality PAL guidelines in the littoral were three PAHs: acenaphthene, acenaphthylene and dibenz[a,h]-anthracene (Table 5.4). This represents the fewest recorded sediment quality guideline exceedances since monitoring began. In 2021, a single FT sample from 3 locations in BML Demonstration was analyzed for sediment chemistry parameters (Table 5.5). FT sediment in the profundal zone exhibits more Parent PAH exceedances than the littoral zone sediments.

Table 5.4 Sediment quality percent exceedances of AB Sediment Quality guidelines in littoral sediments in NW and SE portions of BML (designed littoral areas)

Variable	NW Quadrant																										
	2014			2015			2016			2017			2018			2019			2021			2022			2023		
	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL
Total Metals																											
Arsenic (As)	25	0	-	50	0	-	27	0	-	13	0	-	0	0	-	0	0	-	13	0	-	0	0	-	0	0	-
Cadmium (Cd)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Chromium (Cr)	0	0	-	0	0	-	7	0	-	7	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Copper (Cu)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Lead (Pb)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Manganese (Mn)	-	-	0	-	-	0	-	-	7	-	-	20	-	-	0	-	-	0	-	-	7	-	-	0	-	-	0
Mercury (Hg)	0	0	-	0	0	-	0	0	-	7	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Molybdenum (Mo)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (Ni)	-	-	50	-	-	50	-	-	53	-	-	47	-	-	27	-	-	27	-	-	33	-	-	33	-	-	0
Selenium (Se)	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Zinc (Zn)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Parent PAHs																											
2-Methylnaphthalene	0	0	-	33	0	-	47	0	-	40	0	-	27	0	-	27	0	-	33	0	-	0	0	-	0	0	-
Acenaphthene	25	0	-	ns	ns	-	87	20	-	67	13	-	53	7	-	73	0	-	60	33	-	67	0	-	67	0	-
Acenaphthylene	0	0	-	ns	ns	-	80	7	-	67	0	-	53	0	-	73	0	-	53	13	-	67	0	-	67	0	-
Anthracene	0	0	-	ns	ns	-	13	0	-	40	7	-	0	0	-	20	0	-	33	27	-	0	0	-	0	0	-
Benzo[a]anthracene	25	0	-	ns	ns	-	47	0	-	27	0	-	27	0	-	53	0	-	40	13	-	0	0	-	0	0	-
Benzo[a]pyrene	25	0	-	ns	ns	-	53	0	-	53	0	-	40	0	-	53	0	-	40	0	-	17	0	-	0	0	-
Chrysene	25	0	-	ns	ns	-	27	0	-	7	0	-	0	0	-	7	0	-	33	0	-	0	0	-	0	0	-
Dibenz[a,h]anthracene	25	0	-	ns	ns	-	87	13	-	67	0	-	53	0	-	67	0	-	60	27	-	67	0	-	67	0	-
Fluoranthene	0	0	-	ns	ns	-	13	0	-	7	0	-	7	0	-	7	0	-	33	0	-	0	0	-	0	0	-
Fluorene	0	0	-	ns	ns	-	53	13	-	47	7	-	40	0	-	53	0	-	40	20	-	0	0	-	0	0	-
Naphthalene	0	0	-	ns	ns	-	20	0	-	13	0	-	7	0	-	0	0	-	33	0	-	0	0	-	0	0	-
Phenanthrene	25	0	-	ns	ns	-	67	20	-	40	0	-	33	0	-	33	0	-	40	0	-	0	0	-	0	0	-
Pyrene	25	0	-	ns	ns	-	80	13	-	53	0	-	47	7	-	67	0	-	47	27	-	83	0	-	0	0	-

Variable	SE Quadrant																				
	2016		2017				2018			2019			2021			2022			2023		
	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL	ISQG	PEL	LEL
Total Metals																					
Arsenic (As)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	33	0	-	0	0	-
Cadmium (Cd)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Chromium (Cr)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Copper (Cu)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Lead (Pb)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Manganese (Mn)	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0
Mercury (Hg)	0	0	-	7	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Molybdenum (Mo)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (Ni)	-	-	53	-	-	40	-	-	0	-	-	7	-	-	27	-	-	33	-	-	0
Selenium (Se)	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Zinc (Zn)	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Parent PAHs																					
2-Methylnaphthalene	60	0	-	13	7	-	7	0	-	7	0	-	20	7	-	0	0	-	0	0	-
Acenaphthene	93	40	-	67	27	-	40	7	-	20	7	-	33	20	-	33	33	-	67	0	-
Acenaphthylene	60	7	-	73	7	-	53	0	-	47	0	-	33	20	-	67	0	-	67	0	-
Anthracene	7	0	-	60	27	-	0	0	-	13	7	-	20	7	-	0	0	-	0	0	-
Benzo[a]anthracene	67	20	-	40	7	-	20	0	-	7	0	-	20	7	-	33	0	-	0	0	-
Benzo[a]pyrene	80	7	-	60	7	-	27	0	-	20	0	-	27	0	-	33	0	-	0	0	-
Chrysene	47	20	-	7	7	-	0	0	-	7	0	-	20	0	-	33	0	-	0	0	-
Dibenz[a,h]anthracene	93	27	-	80	7	-	53	7	-	53	0	-	33	13	-	67	0	-	67	0	-
Fluoranthene	60	0	-	33	0	-	7	0	-	7	0	-	20	0	-	33	0	-	0	0	-
Fluorene	67	27	-	47	13	-	7	0	-	13	7	-	20	13	-	33	0	-	0	0	-
Naphthalene	40	0	-	7	7	-	0	0	-	0	0	-	20	0	-	0	0	-	0	0	-
Phenanthrene	73	27	-	53	7	-	20	0	-	7	7	-	20	0	-	0	0	-	0	0	-
Pyrene	93	47	-	67	13	-	53	7	-	40	7	-	27	7	-	67	0	-	0	0	-

Sediment Quality Guidelines for the Protection of Aquatic Life - Government of Alberta. 2018. Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta.
Note: Percent exceedance calculations based on all replicate samples and stations within each quadrant; zero values presented in grey text to increase readability.

ISQG = Interim Sediment Quality Guidelines; PEL = probable effects level; LEL = lowest effect

- = no associated guideline
ns = no sample collected

Table 5.5: FT Sediment chemistry from 3 platform locations in 2021

Analyte	Unit	Guidelines[1]			BML12_PLATFORM 1_C	BML12_PLATFORM 2_NE	BML12_PLATFORM 3_SW
		ISQG	PEL	LEL			
Hydrocarbons and Organic Compounds							
Benzene	mg/kg	-	-	-	0.073	0.016	0.022
Ethylbenzene	mg/kg	-	-	-	0.120	0.078	0.044
Toluene	mg/kg	-	-	-	0.18	0.08	0.08
m,p-Xylene	mg/kg	-	-	-	0.72	0.13	0.18
o-Xylene	mg/kg	-	-	-	0.071	0.064	0.088
Xylene (Total)	mg/kg	-	-	-	0.72	0.14	0.20
Total Extractable Hydrocarbons (C11-C22)	mg/kg	-	-	-	14000	17000	9500
Total Extractable Hydrocarbons (C11-C60)	mg/kg	-	-	-	41000	50000	29000
Total Extractable Hydrocarbons (C23-C60)	mg/kg	-	-	-	27000	33000	20000
F1 (C6-C10)	mg/kg	-	-	-	1500	990	310
F1 (C6-C10) - BTEX	mg/kg	-	-	-	1500	990	310
F2 (C10-C16)	mg/kg	-	-	-	4600	5900	3200
F3 (C16-C34)	mg/kg	-	-	-	23000	27000	16000
F4 (C34-C50)	mg/kg	-	-	-	10000	13000	7000
Petroleum Hydrocarbons - F4 Gravimetric	mg/kg	-	-	-	68000	65000	45000
Parent PAHs							
1-Methylnaphthalene	mg/kg	-	-	-	0.17	0.25	0.16
2-Methylnaphthalene	mg/kg	**0.02**	0.201	-	**0.17**	**0.15**	**0.16**
Acenaphthene	mg/kg	**0.007**	0.089	-	**0.56**	**0.98**	**0.37**
Acenaphthylene	mg/kg	**0.006**	0.128	-	**0.17**	**0.16**	**0.16**
Acridine	mg/kg	-	-	-	0.33	0.27	0.32
Anthracene	mg/kg	**0.047**	0.245	-	**0.13**	**0.11**	**0.13**
Benzo[a]anthracene	mg/kg	**0.032**	0.385	-	**0.26**	**0.28**	**0.20**
Benzo[a]pyrene	mg/kg	**0.032**	0.782	-	**0.26**	**0.30**	**0.20**
Benzo[a]pyrene Total Potency Equivalence (TPE)	mg/kg	-	-	-	0.43	0.46	0.35
Benzo[b,j]fluoranthene	mg/kg	-	-	-	0.41	0.45	0.33
Benzo[c]phenanthrene	mg/kg	-	-	-	0.17	0.13	0.16
Benzo[e]pyrene	mg/kg	-	-	-	0.64	0.67	0.49
Benzo[g,h,i]perylene	mg/kg	-	-	-	0.21	0.22	0.18
Benzo[k]fluoranthene	mg/kg	-	-	-	0.17	0.13	0.16
Biphenyl	mg/kg	-	-	-	0.17	0.13	0.16
Chrysene	mg/kg	**0.057**	0.862	-	**0.34**	**0.45**	**0.30**
Dibenzo[a,h]anthracene	mg/kg	**0.006**	0.135	-	**0.17**	**0.13**	**0.16**
Dibenzothiophene	mg/kg	-	-	-	0.75	0.42	0.62
Fluoranthene	mg/kg	**0.111**	2.36	-	**0.34**	**0.50**	**0.32**
Fluorene	mg/kg	**0.021**	0.144	-	**0.30**	**0.46**	**0.19**
Indeno[1,2,3-cd]fluoranthene	mg/kg	-	-	-	0.17	0.13	0.16
Indeno[1,2,3-cd]pyrene	mg/kg	-	-	-	0.17	0.14	0.16
Naphthalene	mg/kg	**0.035**	0.391	-	**0.17**	**0.14**	**0.16**
Perylene	mg/kg	-	-	-	0.44	0.51	0.36
Phenanthrene	mg/kg	**0.042**	0.515	-	**0.17**	**3.00**	**0.16**
Pyrene	mg/kg	**0.053**	0.875	-	**1.20**	**1.50**	**0.96**
Retene	mg/kg	-	-	-	1.20	1.40	0.84
Alkylated PAHs							
C1 Substituted Acenaphthene	mg/kg	-	-	-	0.17	0.13	0.16
C1 Substituted Benzo[a]anthracene / Chrysene	mg/kg	-	-	-	4.70	5.60	3.90
C1 Substituted Benzo[b,j,k]fluoranthene / Benzo[a]pyrene	mg/kg	-	-	-	3.50	3.70	2.90
C1 Substituted Biphenyl	mg/kg	-	-	-	0.17	0.13	0.16
C1 Substituted Dibenzothiophene	mg/kg	-	-	-	12.0	18.0	9.2
C1 Substituted Fluoranthene / Pyrene	mg/kg	-	-	-	6.90	8.20	5.30
C1 Substituted Fluorene	mg/kg	-	-	-	2.60	4.60	1.80
C1 Substituted Naphthalene	mg/kg	-	-	-	0.17	0.40	0.16
C1 Substituted Phenanthrene / Anthracene	mg/kg	-	-	-	2.90	20.0	1.20
C2 Substituted Benzo[a]anthracene / Chrysene	mg/kg	-	-	-	18.0	21.0	14.0

C2 Substituted Benzo[b,j,k]fluoranthene / Benzo[a]pyrene	mg/kg	-	-	-	2.80	3.60	2.00
C2 Substituted Biphenyl	mg/kg	-	-	-	0.17	0.13	0.16
C2 Substituted Dibenzothiophene	mg/kg	-	-	-	58.0	84.0	45.0
C2 Substituted Fluoranthene / Pyrene	mg/kg	-	-	-	17.0	21.0	13.0
C2 Substituted Fluorene	mg/kg	-	-	-	8.40	13.00	5.80
C2 Substituted Naphthalene	mg/kg	-	-	-	0.85	1.40	0.52
C2 Substituted Phenanthrene / Anthracene	mg/kg	-	-	-	19.0	37.0	12.0
C3 Substituted Benzo[a]anthracene / Chrysene	mg/kg	-	-	-	7.90	9.20	6.40
C3 Substituted Dibenzothiophene	mg/kg	-	-	-	53.0	69.0	40.0
C3 Substituted Fluoranthene / Pyrene	mg/kg	-	-	-	33.0	40.0	27.0
C3 Substituted Fluorene	mg/kg	-	-	-	29.0	41.0	20.0
C3 Substituted Naphthalene	mg/kg	-	-	-	6.90	11.00	4.50
C3 Substituted Phenanthrene / Anthracene	mg/kg	-	-	-	56.0	75.0	40.0
C4 Substituted Benzo[a]anthracene / Chrysene	mg/kg	-	-	-	2.20	2.60	1.70
C4 Substituted Dibenzothiophene	mg/kg	-	-	-	38.0	49.0	32.0
C4 Substituted Fluoranthene / Pyrene	mg/kg	-	-	-	15.0	21.0	13.0
C4 Substituted Naphthalene	mg/kg	-	-	-	17.0	26.0	13.0
C4 Substituted Phenanthrene / Anthracene	mg/kg	-	-	-	25.0	31.0	19.0

Government of Alberta. 2018. Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta.

[1] ISQG: Interim Sediment Quality Guidelines PEL: Probable Effects Level LEL: Lowest Effects Level

Bold = guideline exceedance to ISQG

Underline = guideline exceedance to PEL

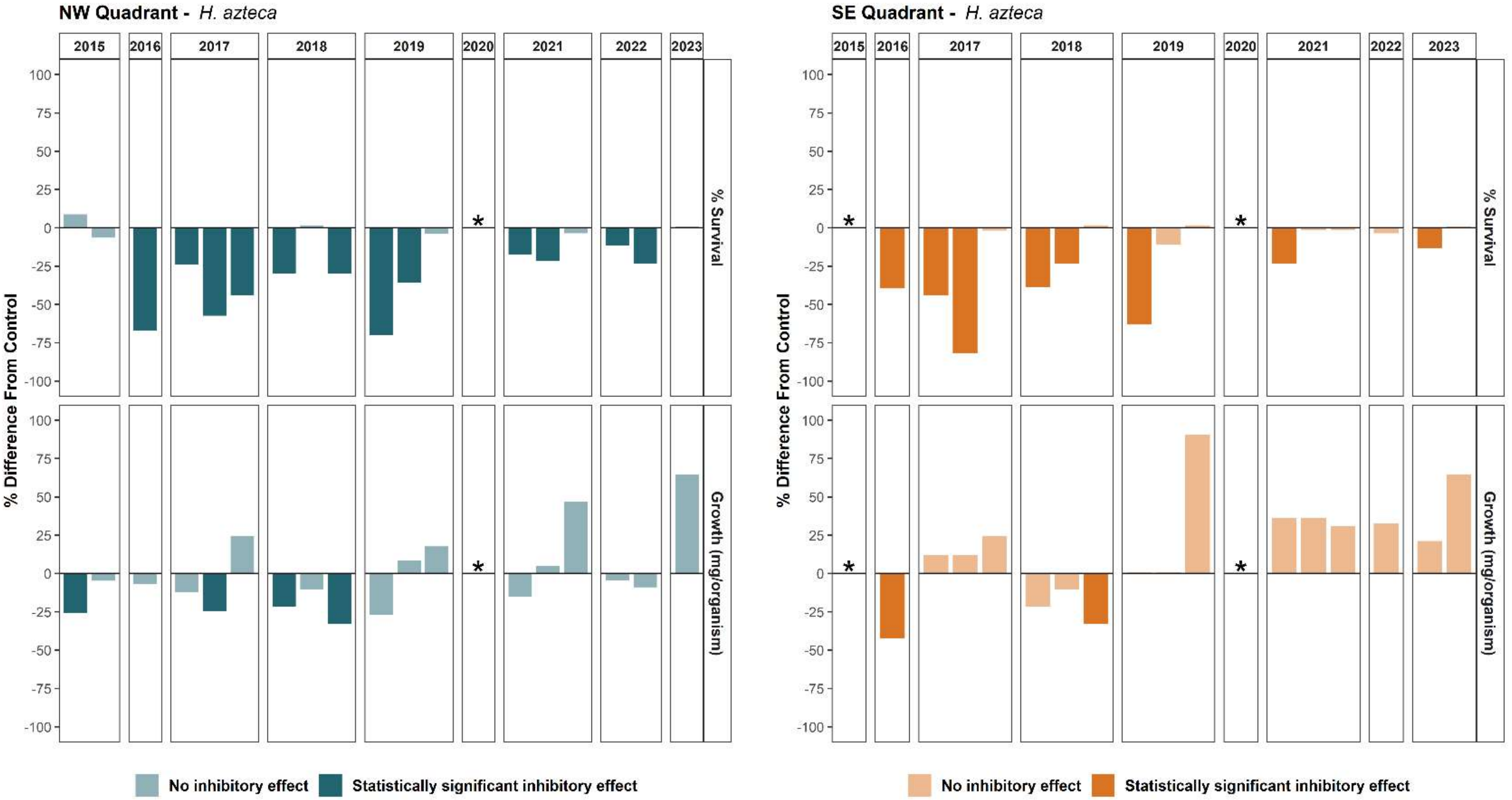
Double underline = guideline exceedance to LEL

5.6.2 Sediment toxicity

Sediment toxicity is used to assess the acute or chronic toxicity of the substrate in BML Demonstration to benthic invertebrates, and to provide information on the lake's ability to support colonization by benthic organisms. Sediment toxicity tests used the following methods:

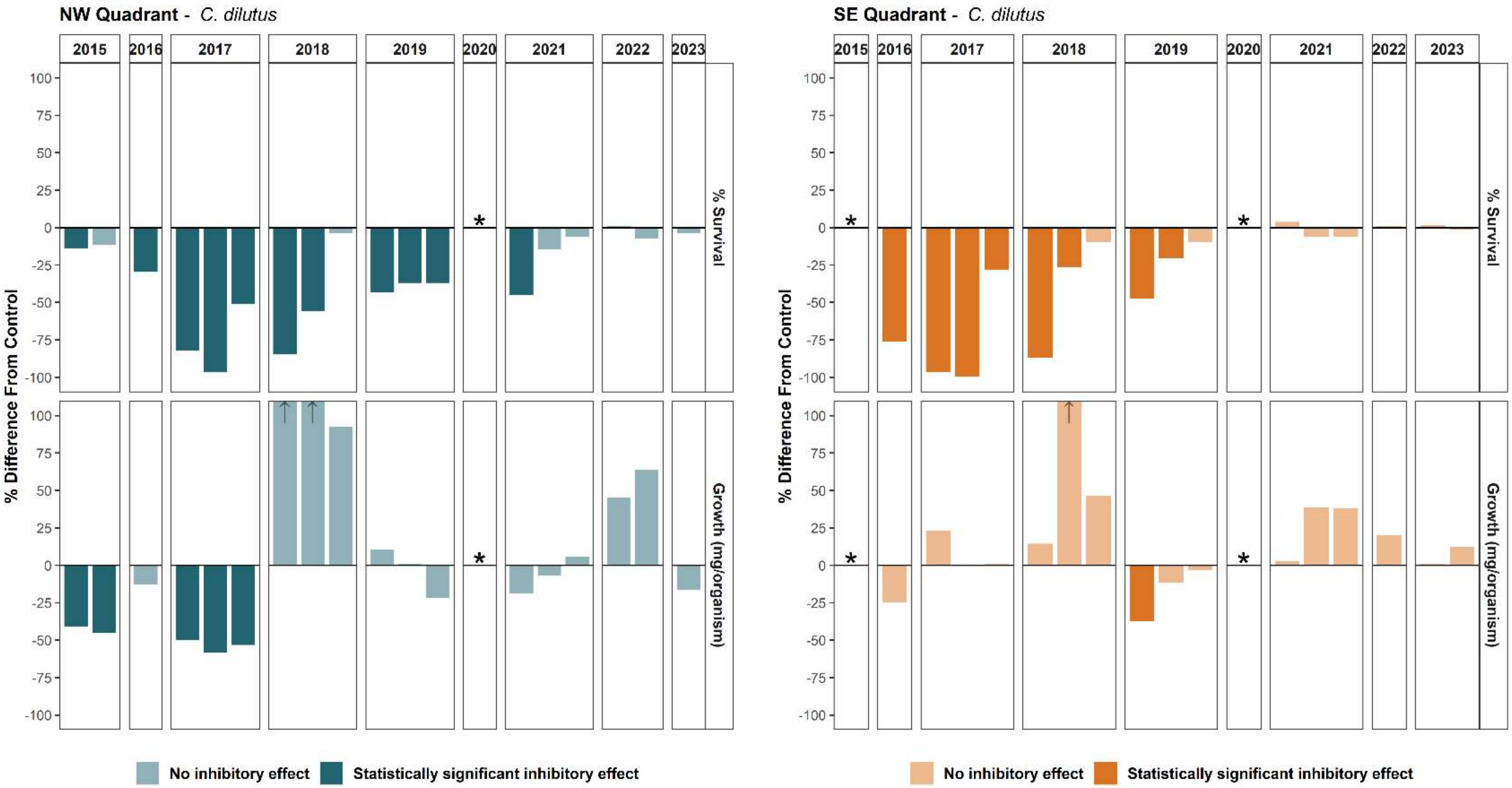
- EPS 1/RM/33: Biological Test Method: Test for Survival and Growth in Sediment Using the Freshwater Amphipod *Hyalella azteca* (Environment Canada 2013) – 14-day survival; and
- EPS 1/RM/32: Biological Test Method: Test for Survival and Growth in Sediment Using the Larvae of Freshwater Midges (*Chironomus dilutus* or *C. riparius*) (Environment Canada 1997) – 10-day survival.

Acute and chronic toxicity testing provide an effects-based assessment of sediment quality by comparing the survival and growth of amphipods *(Hyalella azteca)*(Figure 5-21) and chironomids *(Chironomus dilutus)* (Figure 5-22) exposed to lake sediment with the responses of test organisms exposed to laboratory-supplied control sediment. In 2023, negative effects on amphipod survival at one of two stations in the SE quadrant were evident. *Chironomus* growth was within +/- 16% of the control, and *Hyalella* growth was stimulated in both quadrants. In general, there are variable toxicity effects among years and also variability between sample stations. Survival and growth are improving over time, but toxicity response is still sometimes observed.



Percent difference in % survival (upper panels) and growth (mg/organism; lower panels) of H. azteca in BML sediment compared to control sediment across years in the NW (left panels) and SE (right panels) quadrants. Each bar represents an individual sampling station. Positive values indicate increased survival or growth from BML sediments while negative values represent a decrease in these endpoints. Test results significance from a one-tailed alternative hypothesis with a significance of $\alpha = 0.05$ is shown by bar colour, where lighter coloured bars show no statistically significant effect. No stations were sampled in the SE quadrant in 2015 and no samples were collected in 2020 (marked with an asterisk).

Figure 5-21: Results of *Hyalella* toxicity tests in NW and SE quadrant of BML 2015-2023



Percent difference in % survival (upper panels) and growth (mg/organism; lower panels) of H. azteca in BML sediment compared to control sediment across years in the NW (left panels) and SE (right panels) quadrants. Each bar represents an individual sampling station. Positive values indicate increased survival or growth from BML sediments while negative values represent a decrease in these endpoints. Test results significance from a one-tailed alternative hypothesis with a significance of $\alpha = 0.05$ is shown by bar colour, where lighter coloured bars show no statistically significant effect. High percent difference values in 2018 from the NW quadrant (116% and 238%) and SE quadrant (164%) are marked with an arrow. No stations were sampled in the SE quadrant in 2015 and no samples were collected in 2020 (marked with an asterisk).

Figure 5-22: Results of *Chironomus dilutus* sediment toxicity tests in NW and SE quadrants of BML Demonstration over time.

5.6.3 Shoreline plants

In 2019, aquatic plant communities were assessed in 238 plots along 41 transects around the entire perimeter of BML Demonstration. 25 of the 41 transects surveyed exhibited presence of aquatic vegetation. A total of 14 species were identified in BML Demonstration, including seven forb, three graminoid, one shrub, and three algal species; no rare plant species or weeds were recorded in the transects surveyed. A complete list of the species recorded in 2019 is presented in Table 5.6. Species richness, vegetation cover, and vigor were highest along transects with higher quality littoral habitat, organic substrates, and shelter from wave action (e.g., in the flooded bay behind the breakwater and the southwest corner and west shore of BML Demonstration). These are areas that were designed as littoral areas- with shallow slopes. Transects located in areas with bank erosion, steeper slopes, and coarse substrates had little to no aquatic vegetation present (e.g., the east and south shorelines). Overall visual health of plant communities in BML Demonstration was predominantly classified as fair to excellent. Figure 5-24 shows selected images from the aquatic plant survey in 2019. The aquatic plant community in BML has not been assessed since 2019. Figure 5.23 shows images from BML Demonstration shoreline including adjacent reclaimed wetland.

Figure 5-23: Some images from BML Demonstration shoreline including an adjacent reclaimed wetland.

Table 5.6: Aquatic plant species identified in the littoral zone of BML Demonstration in 2019.

Species Code	Scientific Name	Common Name
Forb		
EQUIARV	*Equisetum arvense*	Common horsetail
STUCFIL	*Stuckenia filiformis*	Thread-leaved pondweed
POTAGRA	*Potamogeton gramineus*	Various-leaved pondweed
SPARANG	*Sparganium angustifolium*	Narrow-leaved bur-reed
SCHOTAB	Schoenoplectus tabernaemontaini	Common great bulrush
TYPHLAT	*Typha latifolia*	Common cattail
UTRIINT	*Utricularia intermedia*	Flat-leaved bladderwort
Graminoid		
PHALARU	*Phalaris arundinacea*	Reed canary grass
CAREAQU	*Carex aquatilis*	Water sedge
HORDJUB	*Hordeum jubatum*	Foxtail barley
Shrub		
SALIX spp.	*Salix spp.*	Willow
Algae		
CHARA (ALGAE)	*Chara spp.*	Stonewort
EUGLENA (ALGAE)	*Euglena spp.*	Euglena algae
STIGE (ALGAE)	*Stigeoclonium spp.*	Stigeoclonium algae

Figure 5-24: Some images of the 2019 littoral vegetation survey showing rake used for sampling, quadrats and some examples of shoreline appearance.

5.6.4 Benthic Invertebrates

Benthic invertebrates have been sampled in the littoral zone using petite ponar grabs. The samples are sorted and identified using standard Canadian Aquatic Biomonitoring Network (CABIN) protocols.

Invertebrate abundance was similar in both the NW and SE littoral areas, but biomass was 2.7 times greater in the SE. Chironomid (Diptera: Chironomidae) larvae continue to be the most abundant benthic invertebrates, accounting for 75% of abundance in the NW and 95% of abundance in the SE littoral. Oligochaetes (Oligochaeta) and amphipods (Amphipoda) were the next most abundant. Biomass in the SE littoral is dominated by snails (Gastropoda) and in the NW biomass is dominated by chironomid larva. Although there is variability in abundance and biomass of invertebrates among monitoring years, the chironomids are consistently the most abundant invertebrates. Species richness is increasing over time. Sensitive taxa- EPT (Ephemeroptera, Plecoptera, Trichoptera) and Odonata (dragonflies and damselflies) are present in samples, but they are making up a relatively limited portion of the invertebrate community.

Shoreline invertebrate communities are qualitatively sampled via D-net sampling along the shoreline in the NW littoral area of BML Demonstration (Table 5.7, Figure 5-25). This sampling demonstrates a more diverse invertebrate community is present than that sampled via the quantitative approaches described above. These invertebrates are consistently present, and the range of life stages present indicates that the lake is colonized by these taxa. There are established populations. The leech was a new detection in 2023.

Table 5.7 List of invertebrate taxa detecting during ad-hoc D-net sampling along the NW shoreline of BML Demonstration

Dragonfly (Odonata)
Damselfly (Odonata)
Caddisfly (Trichoptera)
Dytiscid (predaceous diving beetles)
Hydrophilid (water scavenger beetles)
Leech (Hirudinea)
Midge larva (Chironomidae)
Mayflies (Ephemeroptera)
Freshwater shrimp (Amphipoda)
Water mite (Acari)
Zooplankton (Copepoda and Cladocera)
Water boatmen (Corixidae)
Backswimmer (Notonectidae)
Snail (Gastropoda)

Figure 5-25: Examples of invertebrates collected by D-net sampling along the shoreline of BML Demonstration

5.7 Water cap ecological performance

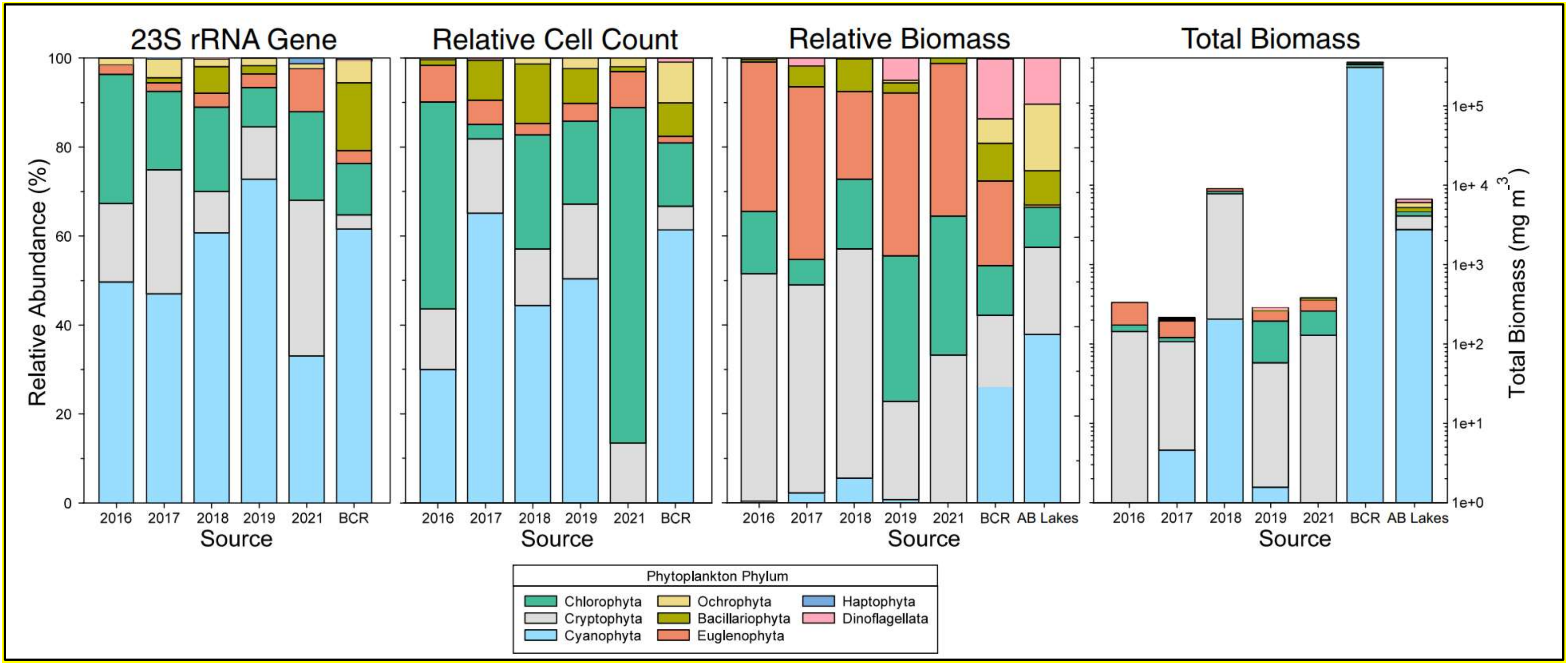
The ecological communities in the water cap include algae and zooplankton. Algae are important as primary producers in lakes- they form the base of the food chain and produce oxygen in the water cap. Zooplankton are also important as primary consumers in lakes. Zooplankton and algal communities have been monitored in BML Demonstration throughout the water cap.

5.7.1 Phytoplankton community development

A comprehensive assessment of BML Demonstration algal community development and comparison to BCR and Mildred Lake Settling Basin (MLSB) has been completed and is described in Furgason *et al.* (2024). Key results from this assessment include the following:

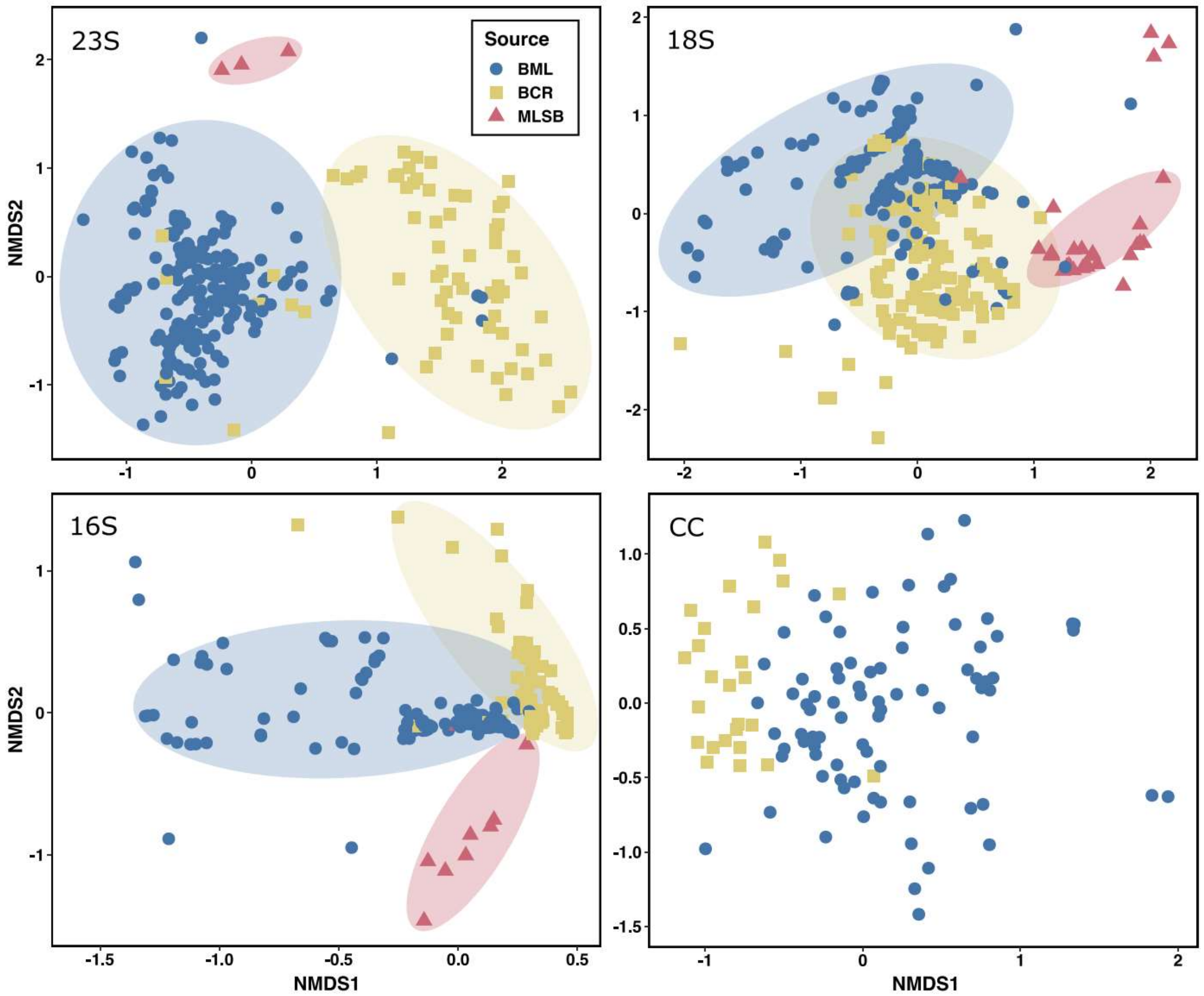
- Dominant taxa in BML Demonstration and its freshwater source (BCR) are Chlorophyta (green algae) and Cyanophyta (blue-green algae) (Figure 5-26)
- BML Demonstration and BCR have a higher proportion of Euglenophytes than other Alberta boreal lakes (Figure 5-26)
- Haptophytes have been documented in BML Demonstration and BCR but not in other Alberta boreal lakes (Figure 5-26)
- BML Demonstration has a phytoplankton community that is distinct from BCR and MLSB (Figure 5-27)
- The BML Demonstration phytoplankton community is different from BCR, demonstration that conditions in BML select for certain taxa.
- Algal community composition is dynamic over time- some genera decline in dominance, others increase (Figure 5-28).
- Indicators of algal abundance demonstrate similar seasonal patterns- 3 of the 4 most abundant general showed consistent seasonality (peaks at similar times each year)
- Total phytoplankton abundance is consistently higher in BCR than in BML Demonstration (Figure 5-29).

Generally, the results indicate that phytoplankton taxa in BML Demonstration are comparable to those found in natural boreal lakes. Phytoplankton in BML Demonstration are performing primary producer functions. BML Demonstration shows distinct seasonal patterns in some phytoplankton taxa consistent with natural boreal lakes. Phytoplankton abundance and alpha diversity did not increase notably between 2016 to 2021. The diversity of phytoplankton in BML Demonstration was intermediate between the freshwater (BCR) and tailings (MLSB) controls. Phytoplankton abundance and seasonality in BML Demonstration were not merely a product of the freshwater inflow- specific phytoplankton strains established and continued to exhibit seasonal patterns when there was no freshwater input into BML Demonstration (see Furgason *et al.* 2024). The results of this work indicate that BML Demonstration is supporting a developing algal community that contributes to lake ecosystem food web structure and function.



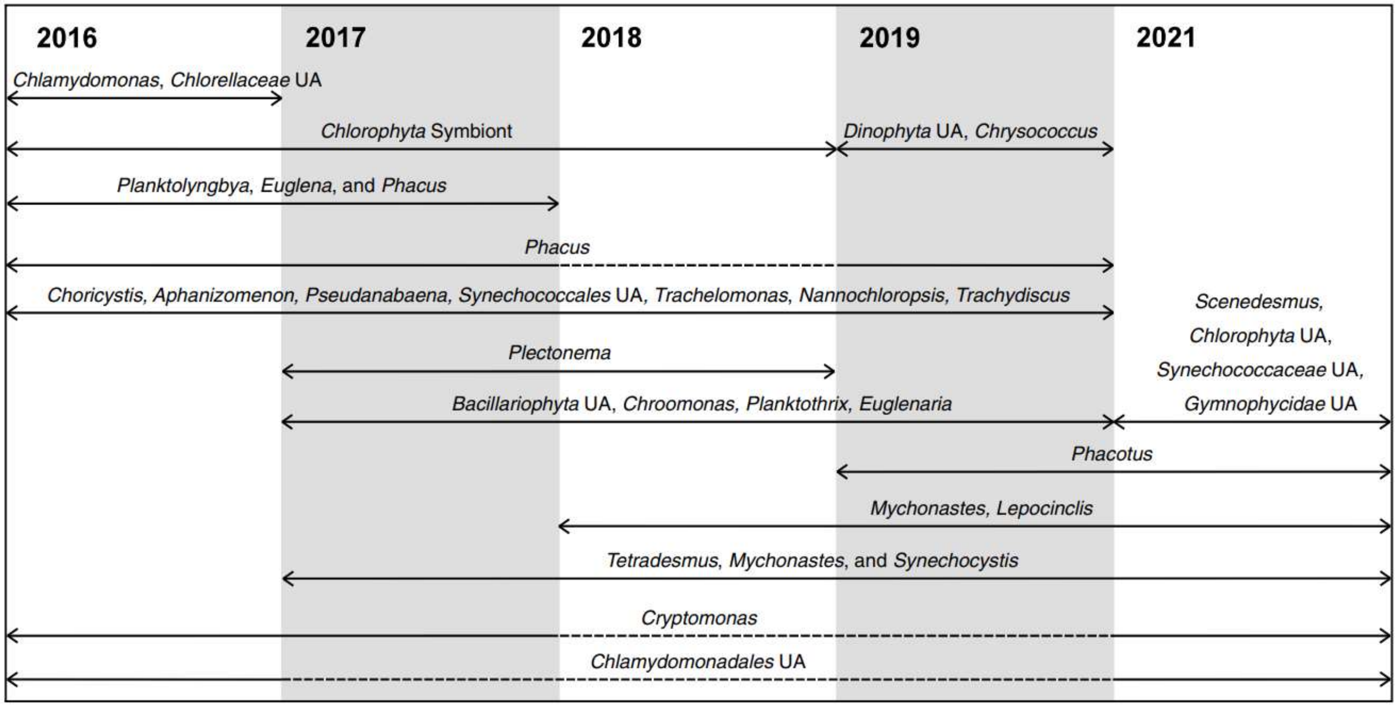
Note: Total biomass (mg/m3) is also given as a logarithmic scale. For direct comparison of the different sites, only samples from July through September were included (after Furgason *et al.* 2024).

Figure 5-26: Relative abundances (%) of the major phytoplankton phyla in surface waters of BML Demonstration (0.3-0.6 m for 23S rRNA gene data and 0.6-0.8 m for cell count and biomass data) for each sampling year, shown in comparison to freshwater reservoir BCR (averaged for all years) and to relative biomass estimated in Alberta boreal headwater lakes.



Note: Data were normalized using scaling with ranked subsampling (SRS) to 4000, 1000, 100 and 10000 for the 23S, 18S, and 16S rRNA gene and cell count datasets, respectively. (After Furgason *et al.* 2024).

Figure 5-27: Non-metric multi-dimensional scaling ordination (NMDS) plots in BML Demonstration, BCR, and MLSB surface waters based on Bray-Curtis dissimilarities of phytoplankton communities.



Note: Gaps are given by dashed lines to show that a genus was not indicative for that year (although most genera were always present at some level). UA = unassigned at any taxonomic level below the taxon shown. No sampling was done in 2020 (COVID-19) (After Furgason *et al.* 2024).

Figure 5-28: Summary of genus-level Indicator Species Analysis (ISA) results for BML Demonstration surface water over 6 years.

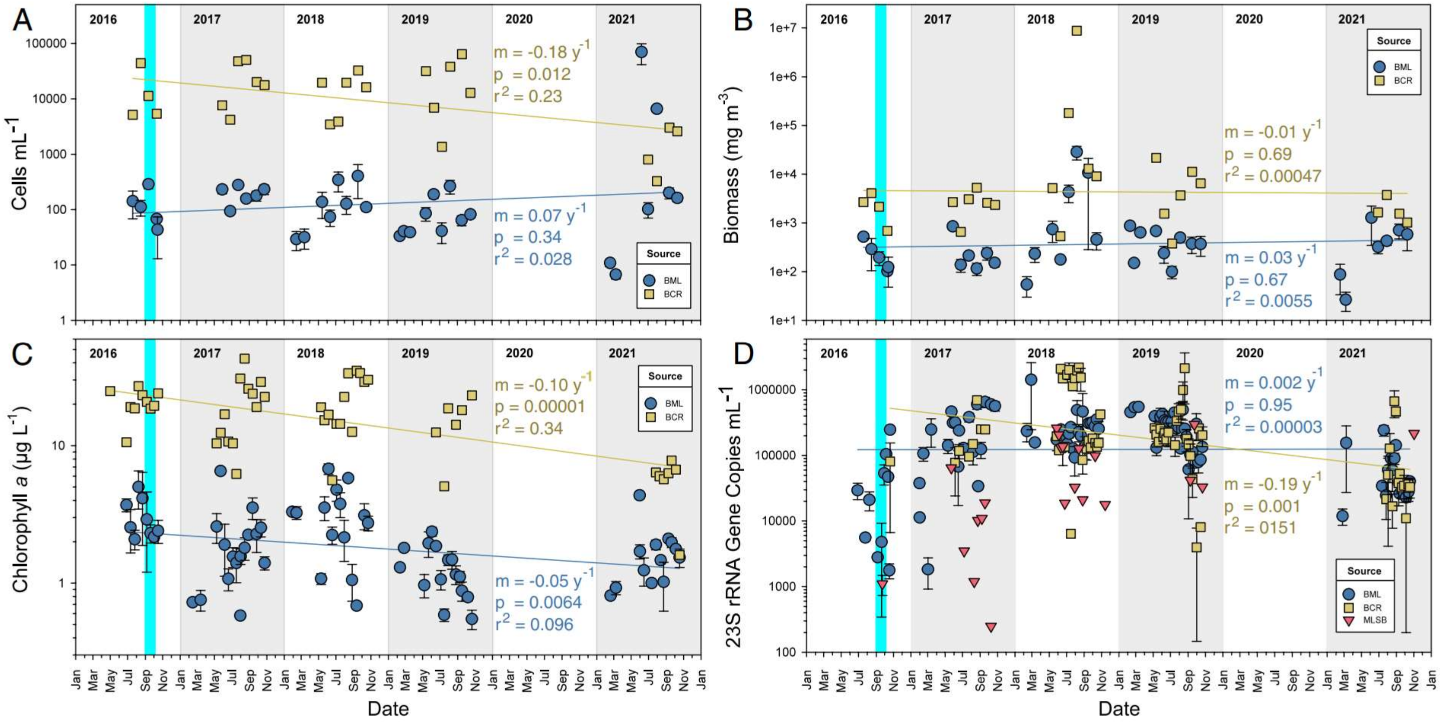


Figure 5-29: Quantification of phytoplankton for 2016-2021 based on cell counts (A), biomass (B), chlorophyll *a* (C) and qPCR quantification of the 23S rRNA gene (D) for surface water samples in BML Demonstration and BCR (after Furgason *et al.* 2024).

5.7.2 Water Cap Chronic Whole-Effluent toxicity tests

Another way to assess the water quality in BML Demonstration with respect to ecological performance is standard whole effluent toxicity tests. Chronic toxicity trends provide an understanding of the longer-term lake trajectory to support end land use expectations. Chronic toxicity tests were performed using the following tests:

- EPS 1/RM/21: Biological Test Method: Test of Reproduction and Survival Using the Cladoceran *Ceriodaphnia dubia* (Environment Canada 2007a);

- EPS 1/RM/22: Biological Test Method: Test of Larval Growth and Survival Using Fathead Minnow *Pimephales promelas* (Environment Canada 2011);

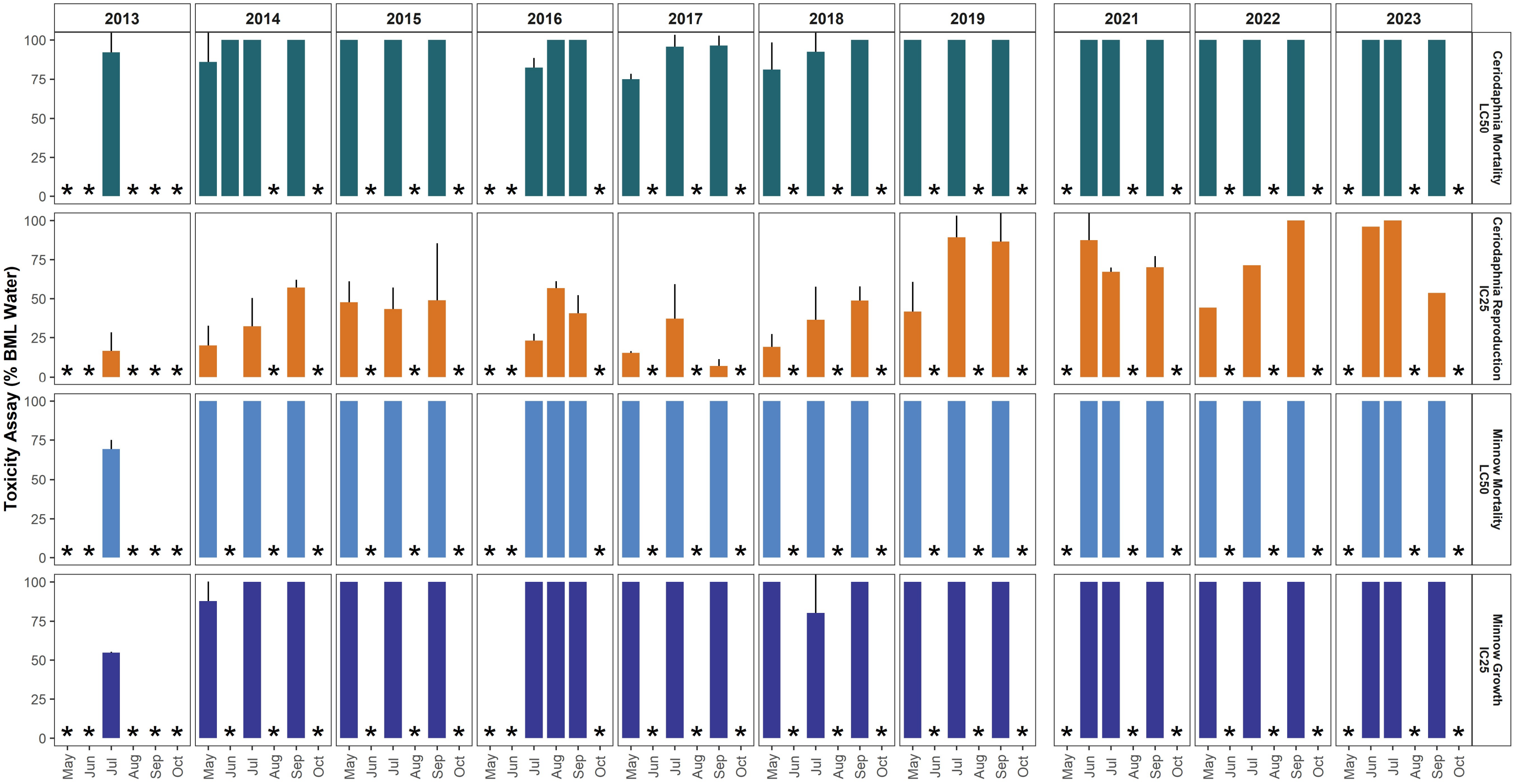
- EPS 1/RM/25: Biological Test Method: Growth Inhibition Test Using the Freshwater Alga *Raphidocelis subcapitata* (formerly *Selenastrum capricornutum* and *Pseudokirchneriella subcapitata*) (Environment Canada 2007b, 2nd Edition);

- EPS 1/RM/37: Biological Test Method: Test for Measuring the Inhibition of Growth Using the Freshwater Macrophyte *Lemna minor* (Environment Canada 2007c, 2nd Edition); and

- EPS 1/RM/24: Biological Test Method: Toxicity Test Using Luminescent Bacteria (*Vibrio fischeri*) (Environment Canada 1992).

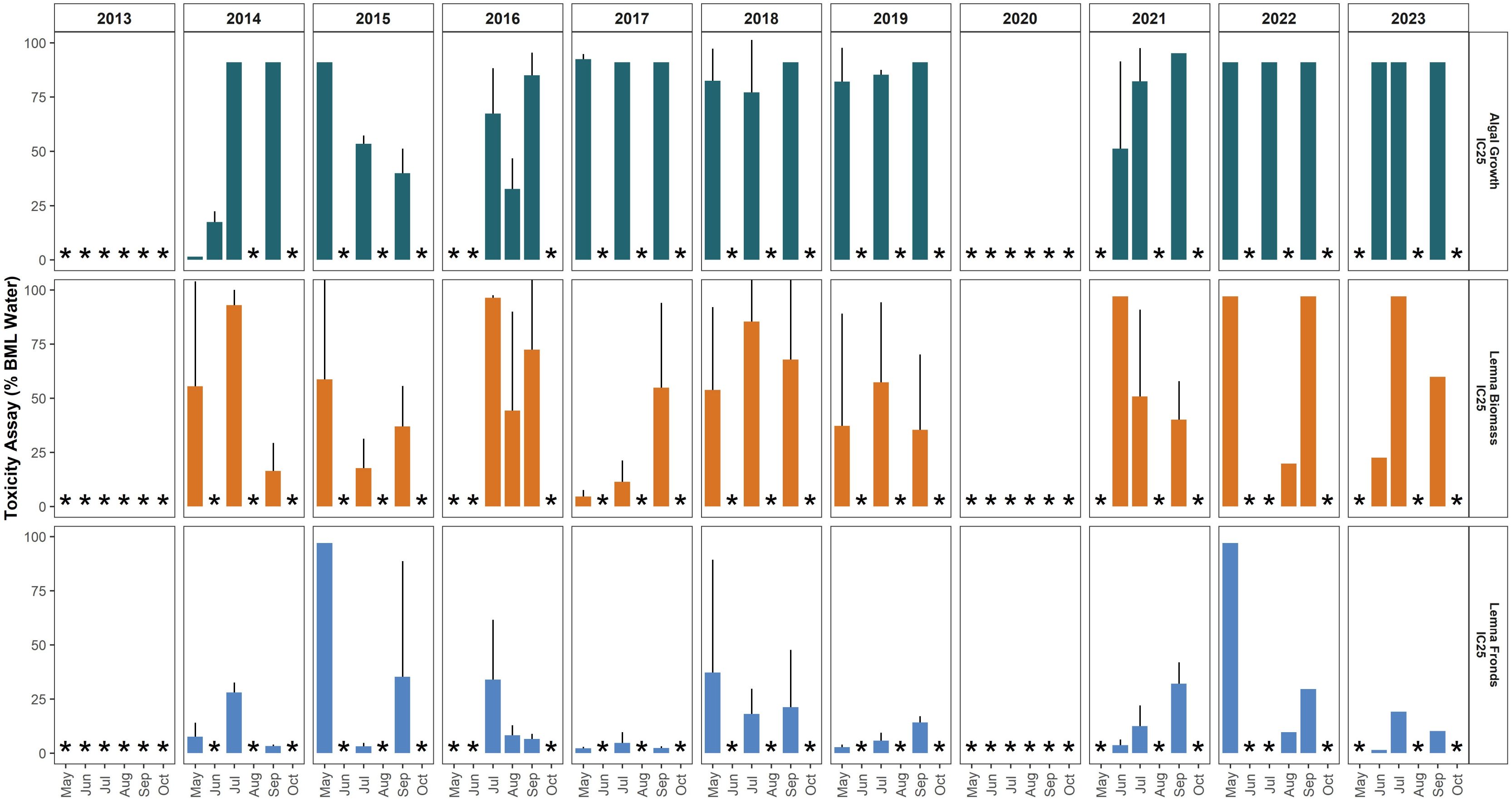
Water toxicity testing provides proxy measures of the potential for BML Demonstration water to reduce the survival of or have inhibitory effects on representative aquatic organisms. These tests are laboratory assays that use standardized methods to assess the relative toxicity of a water sample on cultured plants, algae and animals. Measurement endpoints (e.g., EC50) are estimates of the concentration of exposure medium (i.e., BML Demonstration water) that results in a sub-lethal effect on test organisms (in this example, 50%), with increasing concentrations representative of decreasing effects.

Chronic toxicity responses to BML Demonstration water have decreased since monitoring began in 2013 (Figure 5-30, Figure 5-31), with no chronic responses observed from 2019 onwards except for *C. dubia* reproduction and *L. minor* growth. Although toxicity responses have varied seasonally as evidenced by changes in endpoints from month to month, no consistent seasonal trends in toxicity have been observed across monitoring years. Since monitoring was initiated in 2013, chronic toxicity has been observed for some test organisms. No clear seasonal trends in chronic toxicity have been evident since the onset of monitoring. In 2023, toxicity of BML Demonstration water was similar to what has been documented previously.



Shown are pooled averages of toxicity assay results across BML platform stations, with standard deviations shown as error bars where applicable. LC50 is the concentration of BML water, diluted by non-toxic medium, estimated to cause 50% mortality in exposed test organisms.LC50 is the concentration of BML water, diluted by non-toxic medium, estimated to cause 50% mortality in exposed test organisms. The IC endpoints are the concentrations of BML water, diluted by non-toxic medium, estimated to impair the physiology and reproduction of exposed test organisms. Months without toxicity assay results for these endpoints are marked with asterisks.
2022 and 2023 values shown are toxicity assay results from a lake-wide composite sample

Figure 5-30: Chronic toxicity responses of invertebrates and fish exposed to BML Demonstration waters, 2013-2023.



Shown are pooled averages of toxicity assay results across BML platform stations, with standard deviations shown as error bars where applicable.The IC endpoints are the concentrations of BML water, diluted by non-toxic medium, estimated to impair the physiology and growth of exposed test organisms. Months without toxicity assay results for these endpoints are marked with asterisks.
2022 and 2023 values shown are toxicity assay results from a lake-wide composite sample.

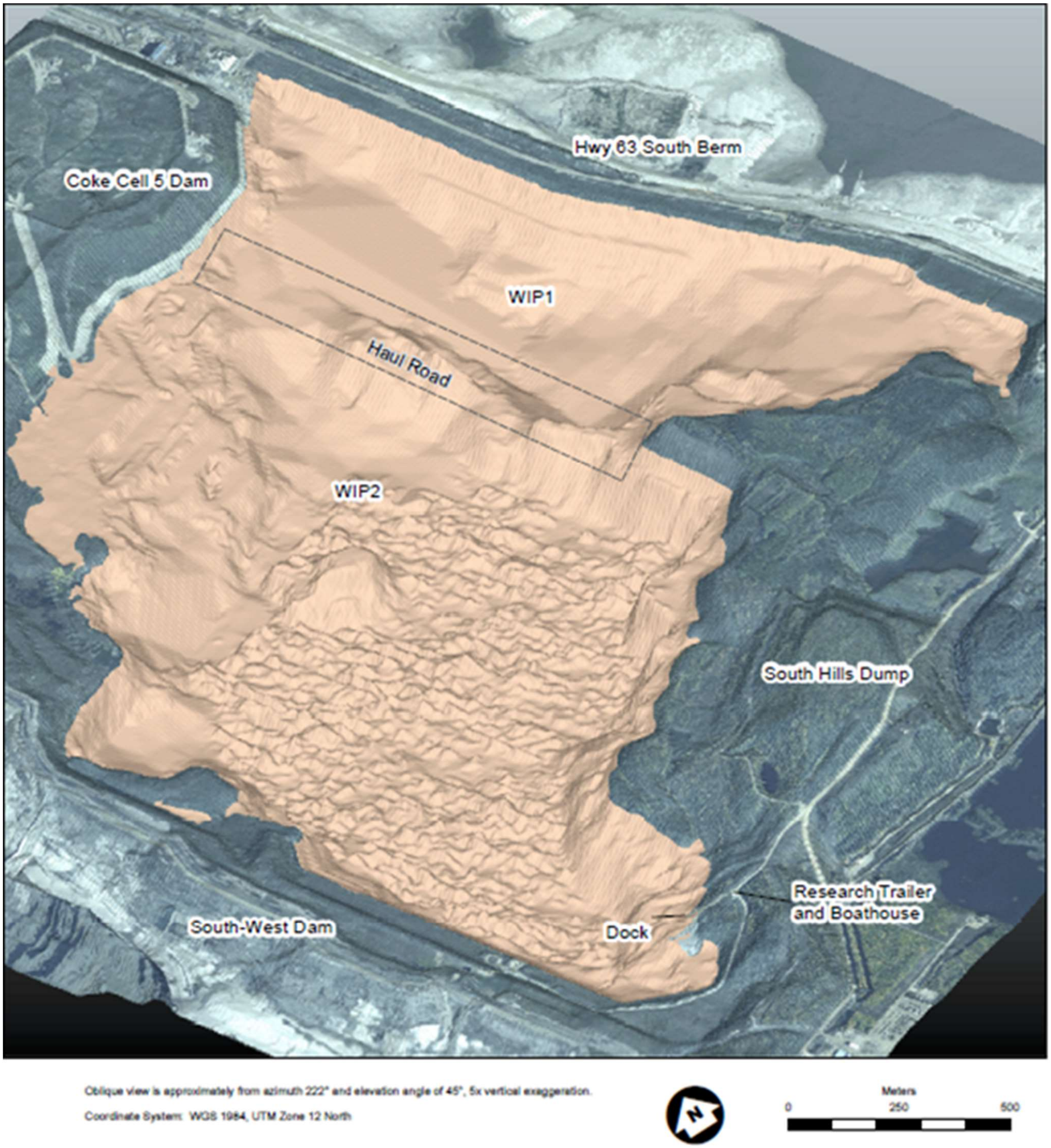
Figure 5-31: Chronic toxicity response of primary producers exposed to BML Demonstration water, 2013-2023

5.8 Hydrocarbons

Understanding the hydrocarbon dynamics and performance in the BML Demonstration is one focus of the BML Monitoring and Research Program.

5.8.1 Filling history of the Base Mine Lake Demonstration

Mining began in WIP in 1977 and was completed in 1995. Following the end of mining, WIP was decommissioned. WIP was originally separated by a north-south haul road (Figure 5-32) into WIP1 (east of haul road) and WIP2 (West of haul road). At the end of excavation in 1995, transfer of fine tailings from several tailings facilities into WIP at the Syncrude Mildred Lake site began and continued until Fall 2012. On 31st December 2012, WIP was commissioned as the BML Demonstration of water-capped tailings technology.



Oblique view is approximately from azimuth 222° and elevation angle of 45°, 5x vertical exaggeration.

Coordinate System: WGS 1984, UTM Zone 12 North

Figure 5-32: Original pit bottom surface of WIP showing the north-south haul road, as well as WIP1 and WIP2.

Table 5.8 summarizes the transfer of FT into and out of WIP after the excavation ended in 1995. Initial infilling of WIP started in 1995 with FT transferred from Mildred Lake Settling Basin (MLSB) into the northeastern section of WIP1 until WIP1 became full in 1996. Subsequently, a breach was cut through the central haul road to allow FT to spill from WIP1 into WIP2. However, to mitigate any geotechnical impacts that the “waterfall” of FT from WIP1 into WIP2 through the breach might have had, the FT pipeline was relocated to the west side of the central haul road to facilitate direct discharge into WIP2. FT transfer from MLSB continued until the last year of infilling WIP (2012).

Table 5.8:Summary of FT flows in and out of WIP (after Shaw and Carrier, 2019).

(Month/Season) Year	Event	
West In-Pit (WIP)		
1977	Mining	Initial excavation of Base Mine.
1995		Final excavation of WIP complete.
1995	Infilling	FT transfer from MLSB to WIP1 mined-out void (transfer restricted largely to ice-free periods on MLSB).
1996		WIP1 full (at elevation 275 m asl). Filling WIP2 started.
(August) 2000		FT withdrawal from WIP2 for CT production started. COF discharge into SWSS.
2001		TFT transfer from SWSS to WIP. FT transfer from SEP to WIP.
(August) 2002		FT transfer from SEP to WIP.
(May) 2003		COF discharge moved from SWSS to WIP2.
(May) 2008		FT transfer from WIP to SWIP (Phase 1).
(Fall) 2012		Completion of FT transfer to WIP. Mudline is at 302.31 m asl.
Base Mine Lake (BML)		
(Fall) 2012	BML	Filling of BML with FT complete.
(December) 2012		BML commissioned.

Notes:
COF = Cyclone Overflow
BML = Base Mine Lake
FT = Fine Tailings
SWSS = Southwest Sand Storage
TFT = Thin Fine Tailings
MLSB = Mildred Lake Settling Basin
WIP = West In-Pit
Outflow from WIP indicated in red font.

Apart from MLSB, FT was transferred at different times from other tailings facilities at the Mildred Lake mine. Between 2000 and 2011, FT was transferred from East in-Pit (Southeast Pond -SEP) into WIP. Between 2004 to 2006 and 2011 to 2012, beaching coarse tailings started from the southeast corner of WIP. Starting in 2003 until 2011, cyclone overflow (COF) from the composite tailings (CT) plant was deposited into WIP at the same northeast location as FT from MLSB. Between 2009 and 2012, recycle water and thin fine tailings (TFT, with low solids contents, typically less than 20 %) was transferred from Southwest In-Pit (SWIP) into WIP. At various times between 2001 and 2009, FT was also transferred from Southwest Sands Storage (SWSS) into WIP.

Apart from infilling, there were several events where FT was pumped from WIP during the 1995 – 2012 timeline. From 2000 to 2012, FT was dredged from WIP and sent to produce CT. Also, in 2008, FT was dredged from WIP and sent to SWIP. In addition, from 1998 to 2012, WIP was integrated into the site-wide recycle water circuit for extraction. This necessitated maintaining a minimum of 3 m deep water cap on the FT. In total, at commissioning (December 31st, 2012), the facility contained 196 Mm^3 of FT, and 12 Mm^3 of CT COF and coarse tailings, and 24 Mm^3 of free water (Dunmola *et al*. 2022). The cumulative volumes of the different materials stored in BML Demonstration are shown in Figure 5-33. Post commissioning in 2013, water flow through BML Demonstration from the adjacent Beaver Creek Reservoir (BCR) began and the lake water elevation is maintained by pumping out water into the recycle water system.

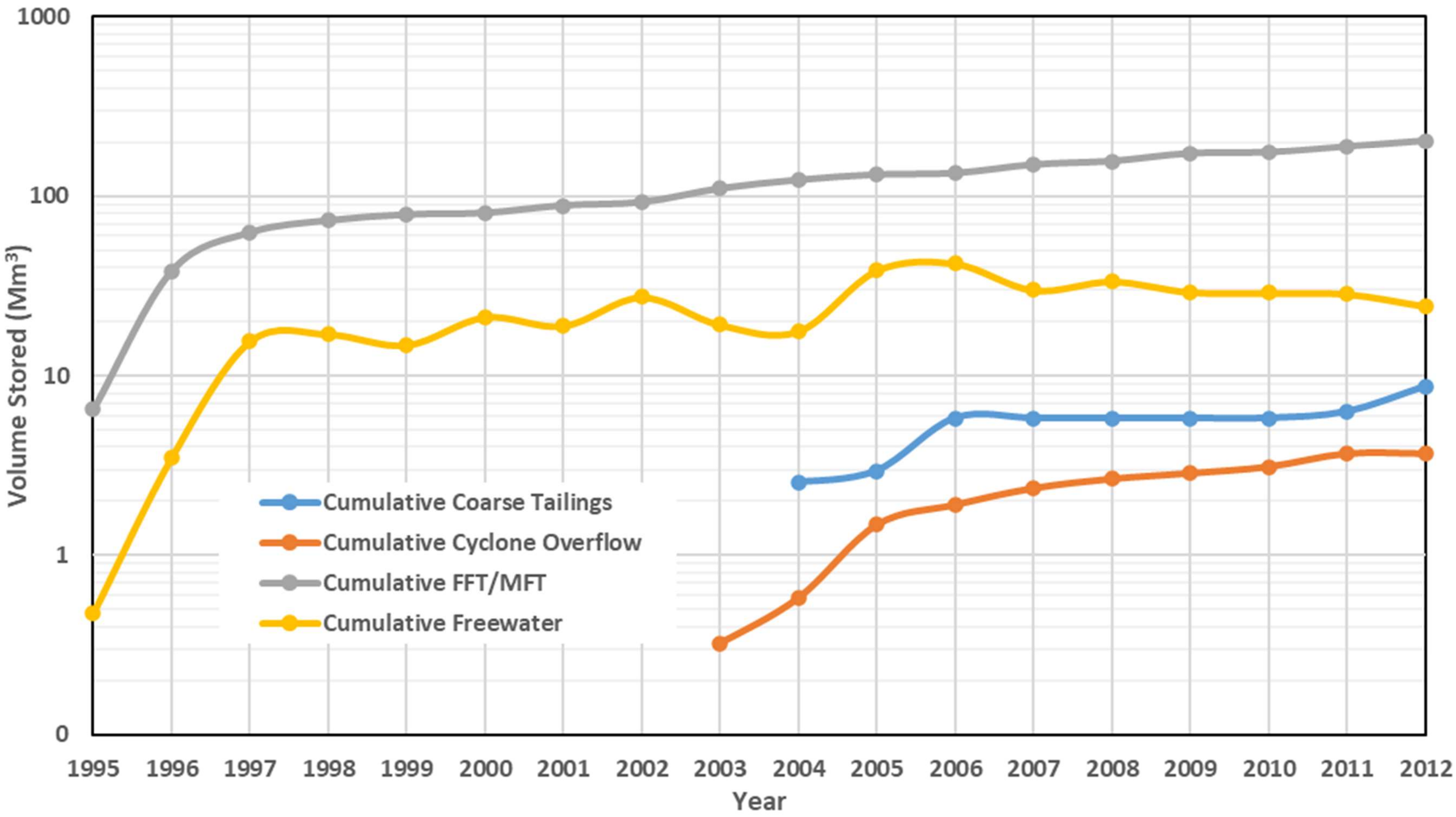
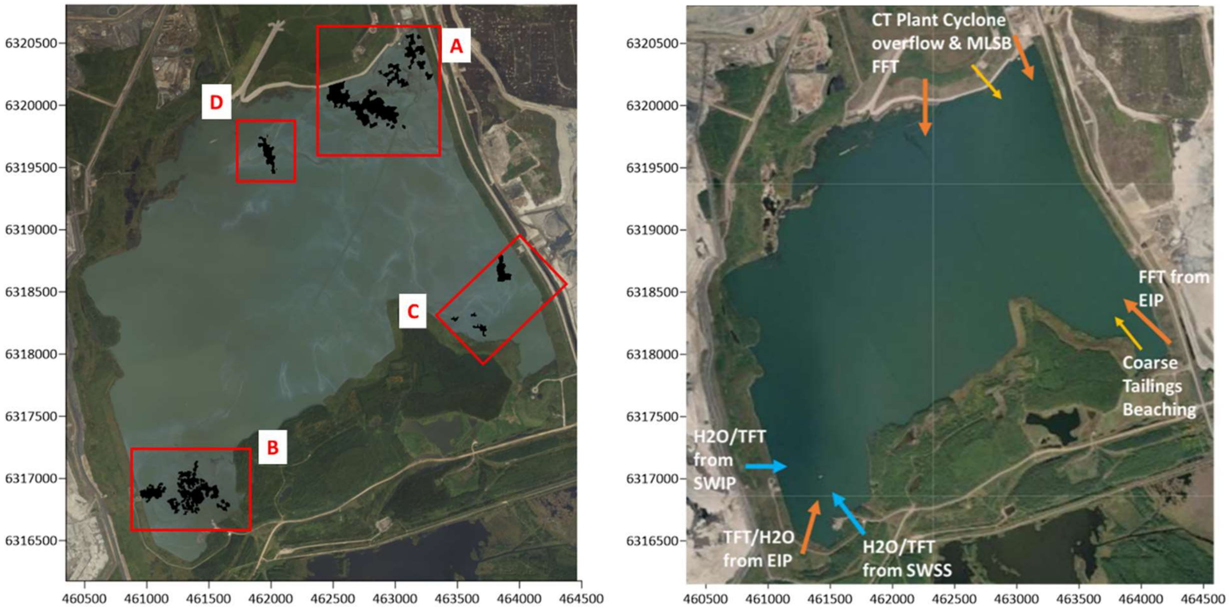


Figure 5-33: Cumulative volume of materials accumulated in the Base Mine Lake facility up to commissioning in 2012.

5.8.2 Developing and validating conceptual model of bitumen dynamics in the Base Mine Lake Demonstration

Some hydrocarbon, in the forms of naphtha and bitumen, is lost to various tailings and waste streams in the plant. As part of the filling of West In Pit, some hydrocarbons were transferred from the source tailings facility along with the tailings and water. When the FT was placed in West In Pit, the FT and the constituent residual bitumen were aerated during deposition. This led to the separation of the residual bitumen from the discharged slurry which further coalesced, de-aerated, sank, and formed the bitumen mats at the mudline. This occurred primarily in areas of the pit of where tailings were discharged as shown in Figure 5-34.



(a) (b)

Figure 5-34: Bitumen mat delineation map (a) and tailings input streams (b).

Some residual bitumen is also present as a hydrocarbon sheen on the water surface, some of which has accumulated along the shoreline. Shoreline protection and bird deterrent systems remain in place for the facility.

This sheen is a result of methanogenic bacterial consumption of residual hydrocarbon in the bitumen mat producing methane bubbles with bitumen attached being released to the air-water interface.

Research and monitoring to date indicated that the bitumen mats at the FT/water interface are the primary driver of bitumen flux from the FT to the water surface in the BML Demonstration today. The influence of dispersed bitumen in the FT in bitumen dynamics, specifically the flux of bitumen to the surface, is significantly less and potentially negligible.

Observations and empirical data from both the research and monitoring program has led to the development of a conceptual model (Figure 5-35). The conceptual model is being tested empirically through several research and monitoring programs (see also section 3.7.1)

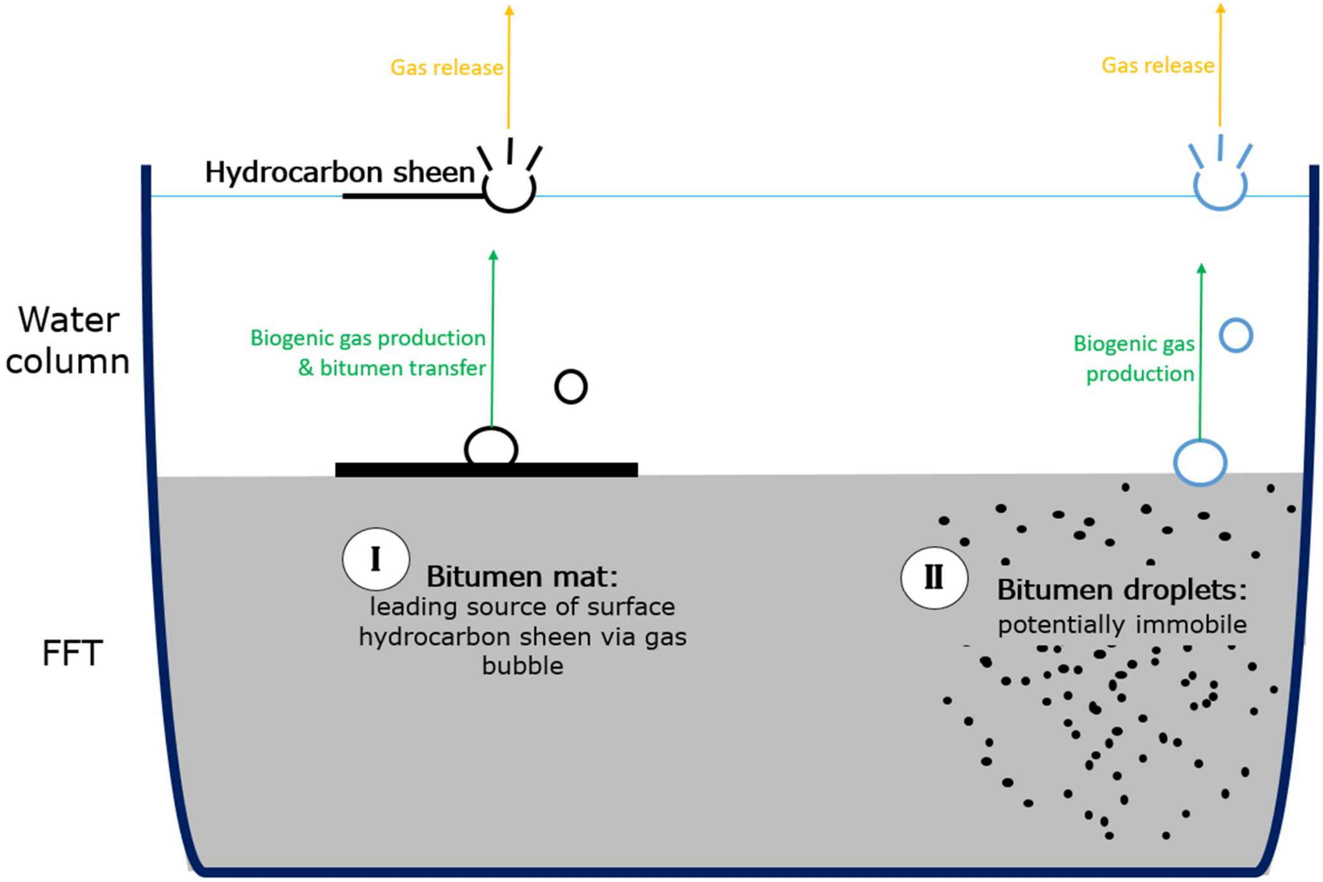


Figure 5-35: Conceptual model of bitumen dynamics in the Base Mine Lake Demonstration.

Several lines of evidence have supported an understanding of bitumen dynamics in BML Demonstration. Observations from the research and monitoring program have indicated that ice cores from BML Demonstration can show both gas bubbles and bitumen (Figure 5-36) and could be a useful method for tracking changes in bitumen liberation resulting from removal of the bitumen mats through dredging. The challenge was making these qualitative assessments quantitative. A CT scanning method was developed for the ice cores which allows quantification of gas voids and bitumen. A method for reliable analysis of the Oil-Water-Solids content of the cores was also developed. This ice core method has become a key component of monitoring bitumen flux to the water cap in BML Demonstration.

Ice core data from 2020 (Figure 5-37) and 2021 (Figure 5-38) were used to generate contour plots of the gas and bitumen content per unit area generated from the ice core data. The data shows similar gas and bitumen patterns for both 2020 and 2021. Two features that stand out are the high bitumen content in the south-west and north-east corners of BML, and areas with elevated gas volume measured in regions of low bitumen content. The bitumen content quantified with ice core analysis in 2021 displayed as a contour map, compared to the bitumen mat location map is shown in (Figure 5-39). The location of the bitumen mats strongly correlates with the location of the high bitumen measured in ice cores. This provides confidence that the sunken bitumen mats are the primary source of the hydrocarbon reaching the surface of BML.

There is also evidence validating that the primary source of bitumen flux to the surface of the water cap are the bitumen mats. Figure 5-40 and Figure 5-41 show surface plots of bitumen and gas volumes measured in ice cores in BML for 2020 and 2021. In both 2020 and 2021 there are regions in the lake that have high gas bubble volume but corresponding very low bitumen flux. The areas with high bitumen flux are areas of the lake where mats have been detected. This suggests that the gas bubbles generated in the FT are not transporting significant hydrocarbon to the surface of BML. This supports the conceptual model that bitumen mats are the primary source of bitumen flux to the water cap, and that the bubbles that may be generated in the FT are not transporting significant hydrocarbon to the water cap.

In 2018 and 2019, a horizontal auger dredge was deployed in BML Demonstration to target removal of bitumen mats on the FT surface. To determine the extent and location of bitumen mats on the surface of the FT, sonar acoustic imagery, ponar grab sampling of the mudline, and visual observations of bitumen on the water surface and at the FT surface were used together to determine the location and extent of bitumen mats. Sampling efforts identified bitumen mats on the surface of the FT in areas of the lake where the FT was poured, and evidence indicates these mats are not very thick (i.e., centimetres in thickness). This preliminary dredging effort provided valuable information to design and pilot a more efficient dredging technology, and a mechanical clam-shell environmental dredge was piloted in 2021. This clamshell dredging pilot focused on the bitumen mats identified through ponar sampling in the southwest corner of BML Demonstration. The clamshell dredge targeted bitumen mats on the FT surface, and each clamshell grab contains bitumen and some water and FT. Learnings from these pilots are informing a field test of the environmental clamshell dredge planned in BML Demonstration in 2024. Enabling technologies including bitumen mat detection, visualization and mapping are also being tested. Other work includes fundamental studies focused on understanding the environmental influence of dispersed bitumen droplets in the FT on pit lake performance.

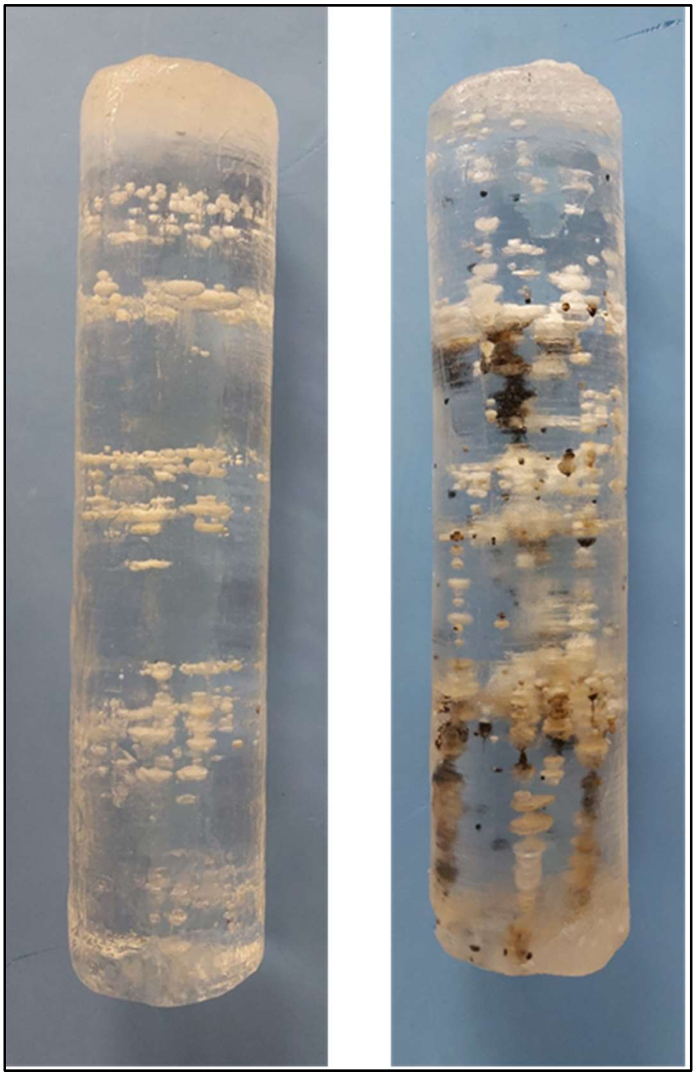


Figure 5-36: Ice core samples from two different areas in Base Mine Lake Demonstration with gas and no visible bitumen on the left, and gas and visible bitumen on the right

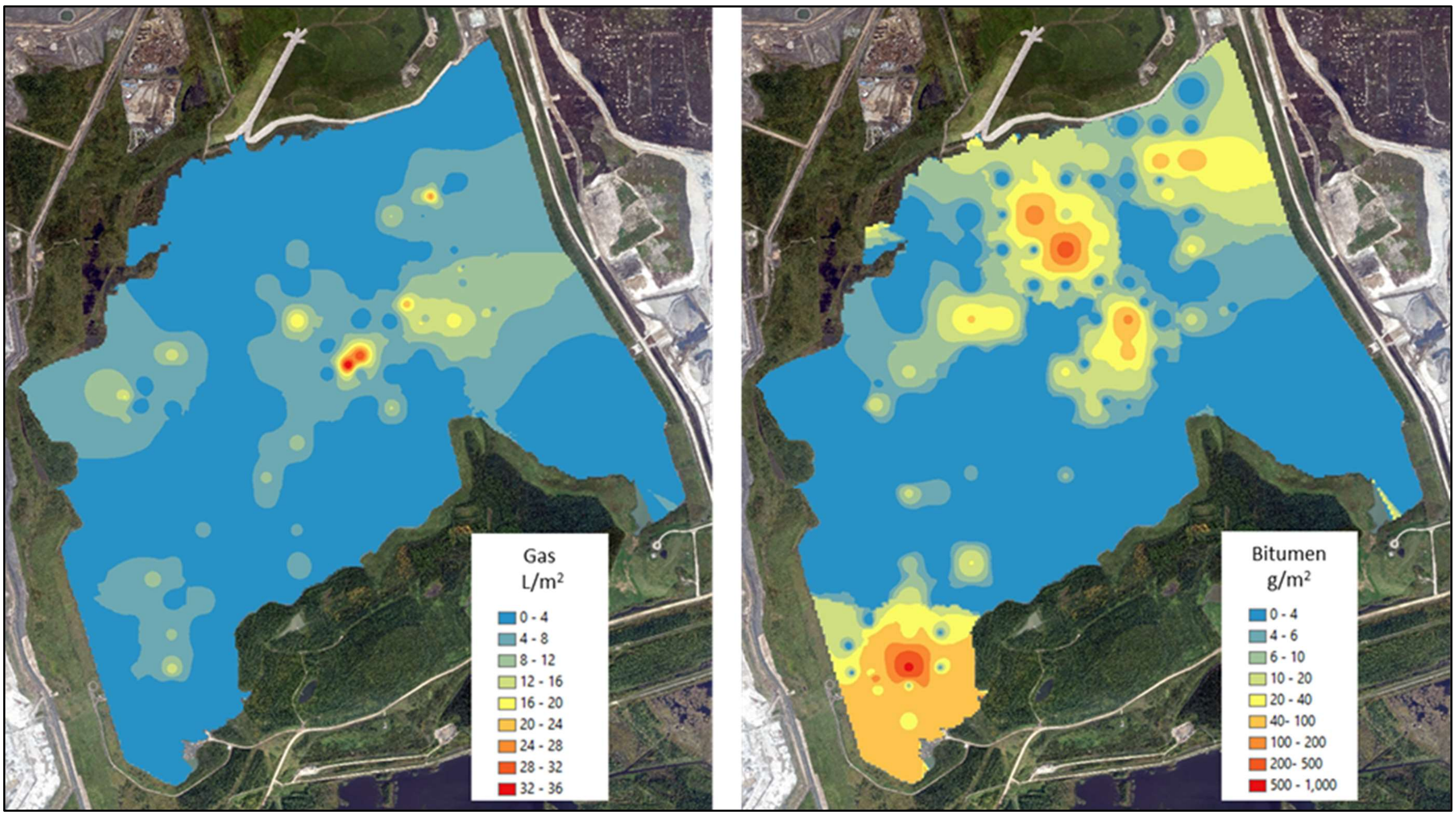


Figure 5-37: Contour maps of gas volume and bitumen mass per unit area contained in the ice cap generated from the 2020 ice core program field data

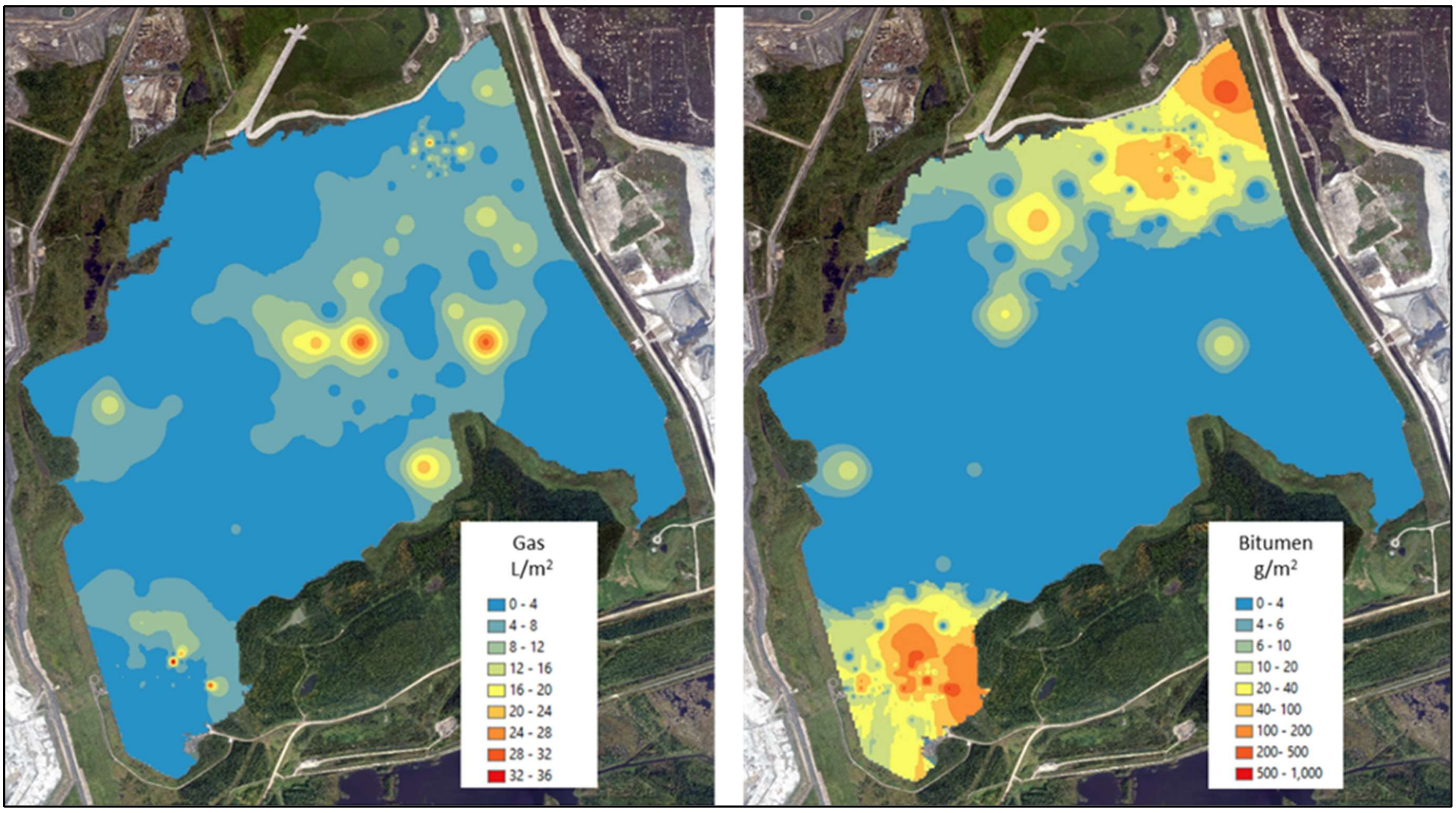


Figure 5-38: Contour maps of gas volume and bitumen mass per unit area contained in the ice cap generated from the 2021 ice core program field data

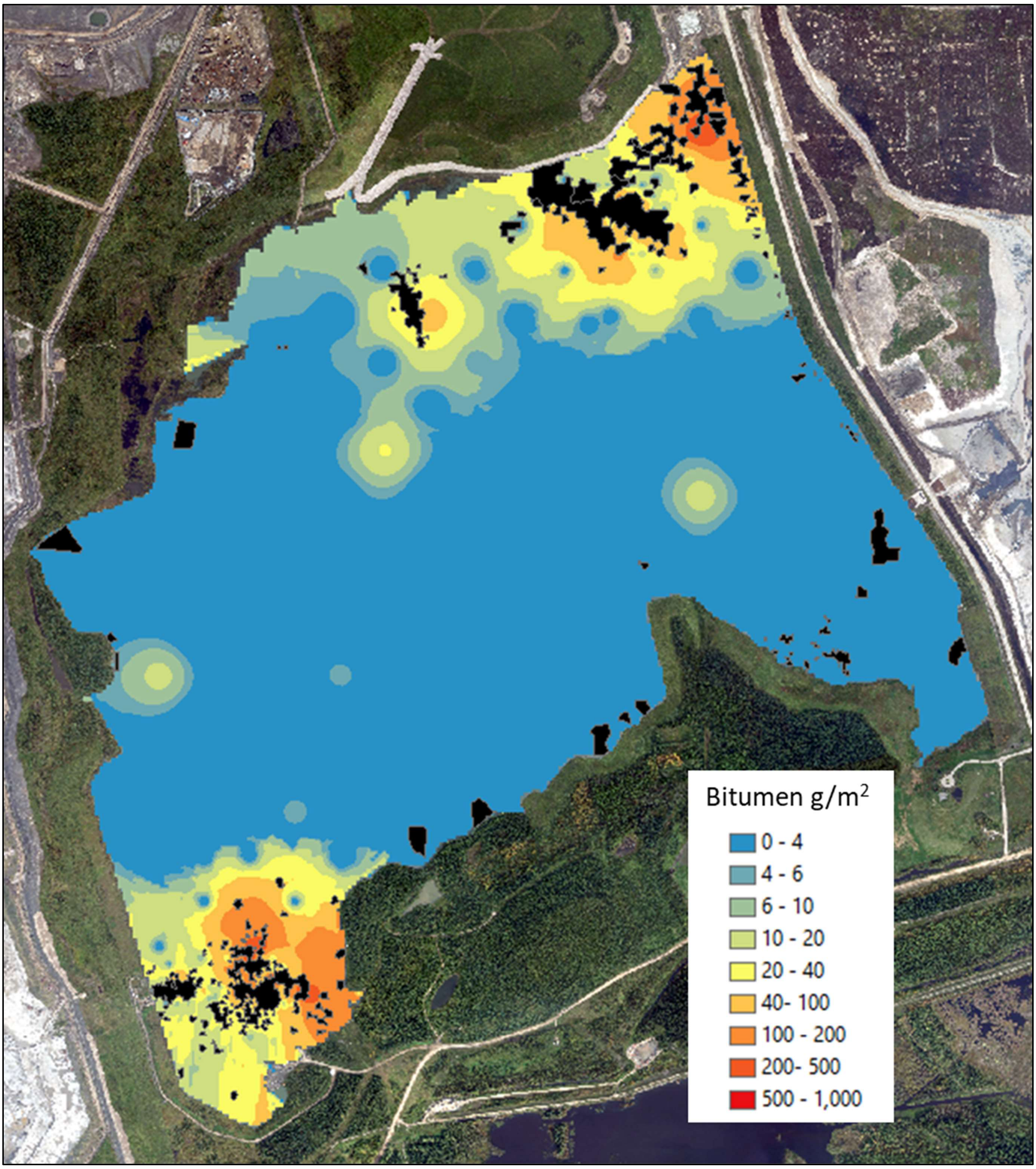


Figure 5-39: Contour plot of bitumen mass per unit area contained in the ice cap generated from the 2021 ice core program field data compared to bitumen mats determined from 2019 ponar grab sampling

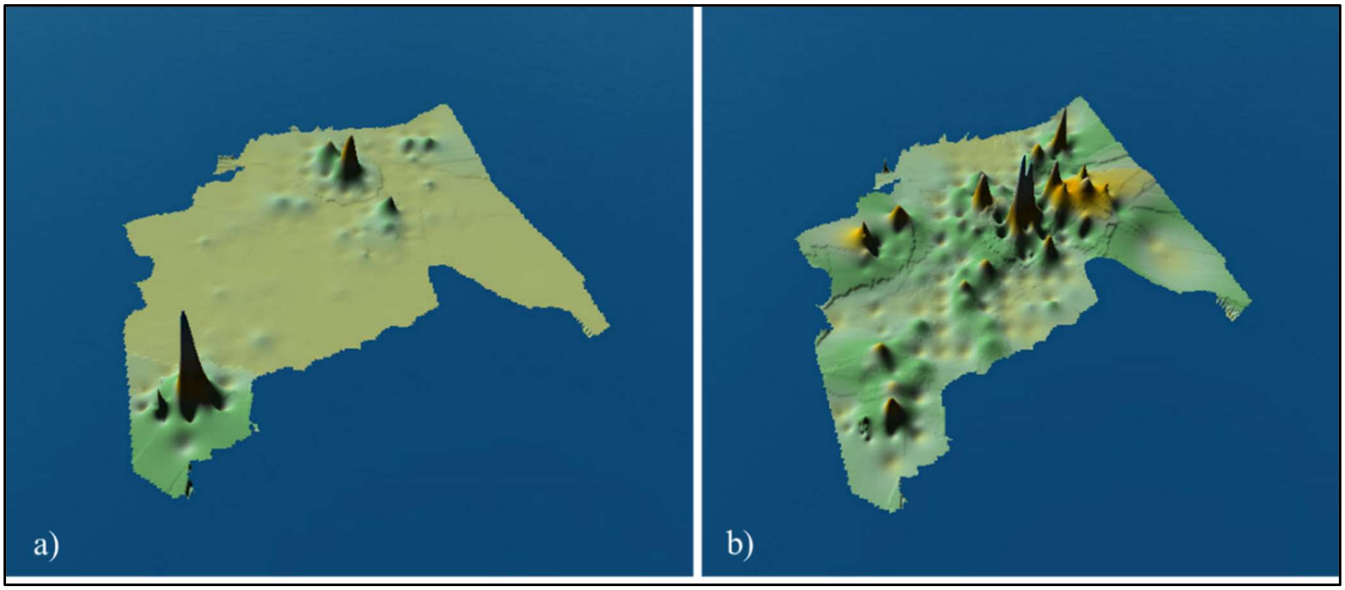


Figure 5-40: a) surface plot of the bitumen content from ice core analysis for 2020, b) surface plot of the gas content measured in ice cores in 2020

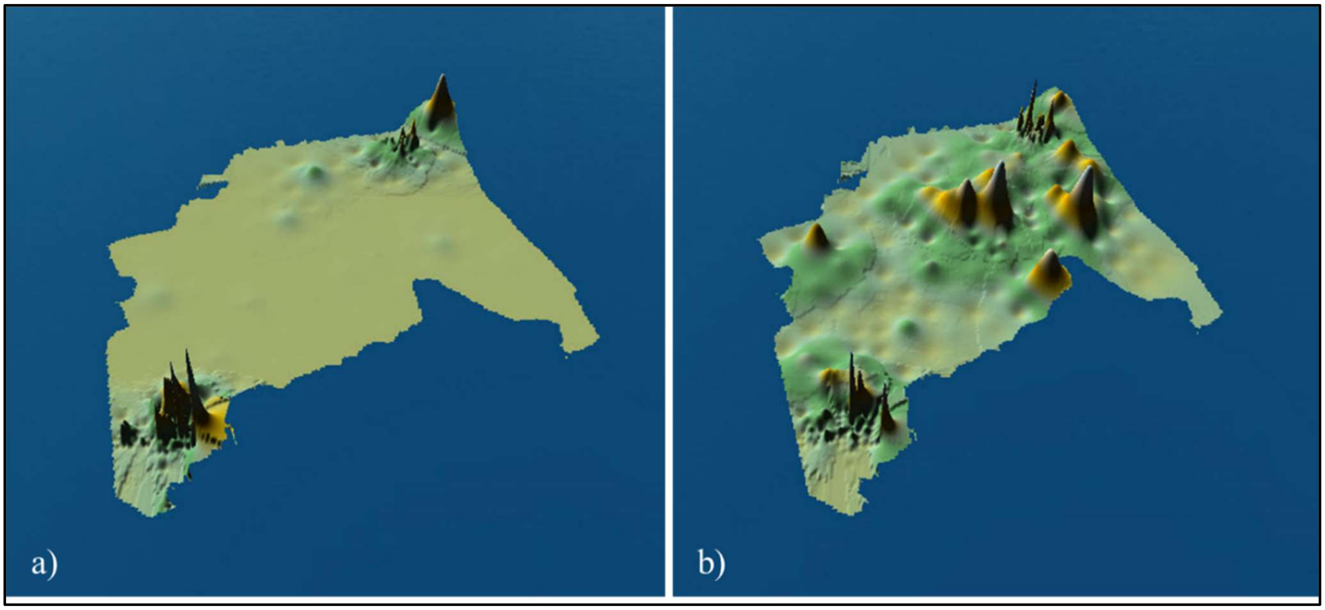


Figure 5-41: a) surface plot of the bitumen content measures in ice cores in 2021, b) surface plot of the gas content measured in ice cores collected in 2021.

6 Summary of results from the 2023 Base Mine Lake Demonstration Monitoring Program

6.1 Physical Components of the Base Mine Lake Demonstration Monitoring Program

The physical components of the BML Demonstration monitoring program primarily relate to understanding trends in FT consolidation and conventional lake mixing dynamics. The physical components of the lake are the key drivers of lake chemistry (especially with respect to lake water and chemical mass balance) and lake biology. An understanding of key physical limnological aspects in the lake is crucial for putting the lake chemistry and biology into context. Monitoring the FT mudline provides an understanding of the FT consolidation behavior, and pore water volume and chemistry flux from the FT into the water cap. This monitoring provides support for the shorter-term performance indicators associated with demonstrating physical isolation of the fines beneath the water cap.

6.1.1 Fluid Tailings Settlement

Table 6.1 below provides a summary of the key findings from the FT settlement assessment.

Table 6.1: FT Settlement Assessment Key Findings

FT Settlement Assessment Key Findings
• The top of the FT surface is not flat. There is considerable variability in the mudline surface across the lake that generally corresponds to the original pit topography.
• FT is settling, up to approximately 8 m between October 2012 and October 2023.
• The volume of FT in BML Demonstration has decreased from 167.71 Mm^3 in September 2022 to 166.78 Mm^3 in October 2023
• The volume of FT is BML Demonstration has decreased from 195.97 Mm^3 in October 2012 to 166.78 Mm^3 in October 2023, a cumulative settlement of 29.19 Mm^3 (a volumetric decrease of 14.9%)
• The FT surface changes observed in the 2023 FT program are consistent with historic changes since 2012.
• The rates and magnitude of the FT settlement are consistent with the expected self-weight consolidation as modelled by finite-strain consolidation theory (Carrier et al. 2019, and Dunmola *et al*. 2022).

A complete sonar survey of BML Demonstration was conducted in October 2023. Since the fall of 2012, complete sonar surveys have been completed in the fall of each year, with the exception of 2020 due to COVID-19 pandemic site restrictions. FT surface contour maps were completed for each fall sonar survey. FT surface contour maps for 2012 and 2023 are shown in Figure 6-1. A map of cumulative settlement since commissioning is presented in Figure 5-2.

The FT surface shows more bathymetric variation than in the early years since commissioning. This is a result of several factors, including:

- Single beam sonar methods and patterns of data acquisition were improved between 2012 and 2015,
- During the first sonar assessment in October 2012, tailings were still actively being deposited and this may have affected detection of mudline settlement,
- In 2016, sonar methods switched from single beam echosounder to swath bathymetry (multi-beam) providing full bathymetric coverage at high resolution,
- Cumulative FT settlement in BML Demonstration from 2012-2023, including differential settlements, variation in pit-bottom topography, and varying initial thicknesses of FT creates variation in the mudline elevation.

The FT surface is not flat across BML Demonstration. As shown on Figure 6-1, the FT surface in October 2023 generally varies spatially by over 6.8 m, from elevation 294.3 m just southeast of Platform 1, to approximately 301.2 m off the south shore. Based upon the sonar survey isopachs, the FT settled between 0 m and approximately 8.0 m between October 2012 and October 2023. Minimal settlement is observed around the perimeter (shoreline) of BML Demonstration, where underlying FT thickness is generally lower, and the pit surface is generally higher.

Comparing the FT surface over time, the FT surface is much flatter in 2012, when the FT was not as consolidated. As the FT consolidated, the topography of the FT surface has become more pronounced. The FT surface contours generally exhibit more bathymetric variability year after year, indicating that the FT surface has developed distinct topography. Based on this trend, it is anticipated that the variability of the FT surface will continue to become further pronounced with time as the FT continues to consolidate below the BML Demonstration water cap.

Cumulative FT settlement across the lake between 2012 and 2022 is not constant but varies across the lake generally based upon the underlying thickness of FT. To illustrate this, a scatterplot of the original 2012 FT thickness versus the cumulative FT settlement from 2012 through 2023 is provided in Figure 5-4. The individual scatterplot points are spaced at 5 m. These points are referenced and summarized within 100 m x 100 m grid ‘cells.’ The overall trend of this dataset is that settlement increases with increasing FT thickness throughout the lake. There is quite a bit of scatter in the data for several factors, in addition to original FT thickness, which may include variations in the physical characteristics of the FT. Overall settlement of the FT continues and the maximum settlement is approximately 8.0 m.

A cross-section through the three permanent platforms (P1, P2, and P3) in BML Demonstration showing both the 2012 and 2022 water elevations and the 2012 and 2023 FT surfaces, demonstrates that overall settlement is in part related to FT thickness, as discussed above (Figure 6-2).

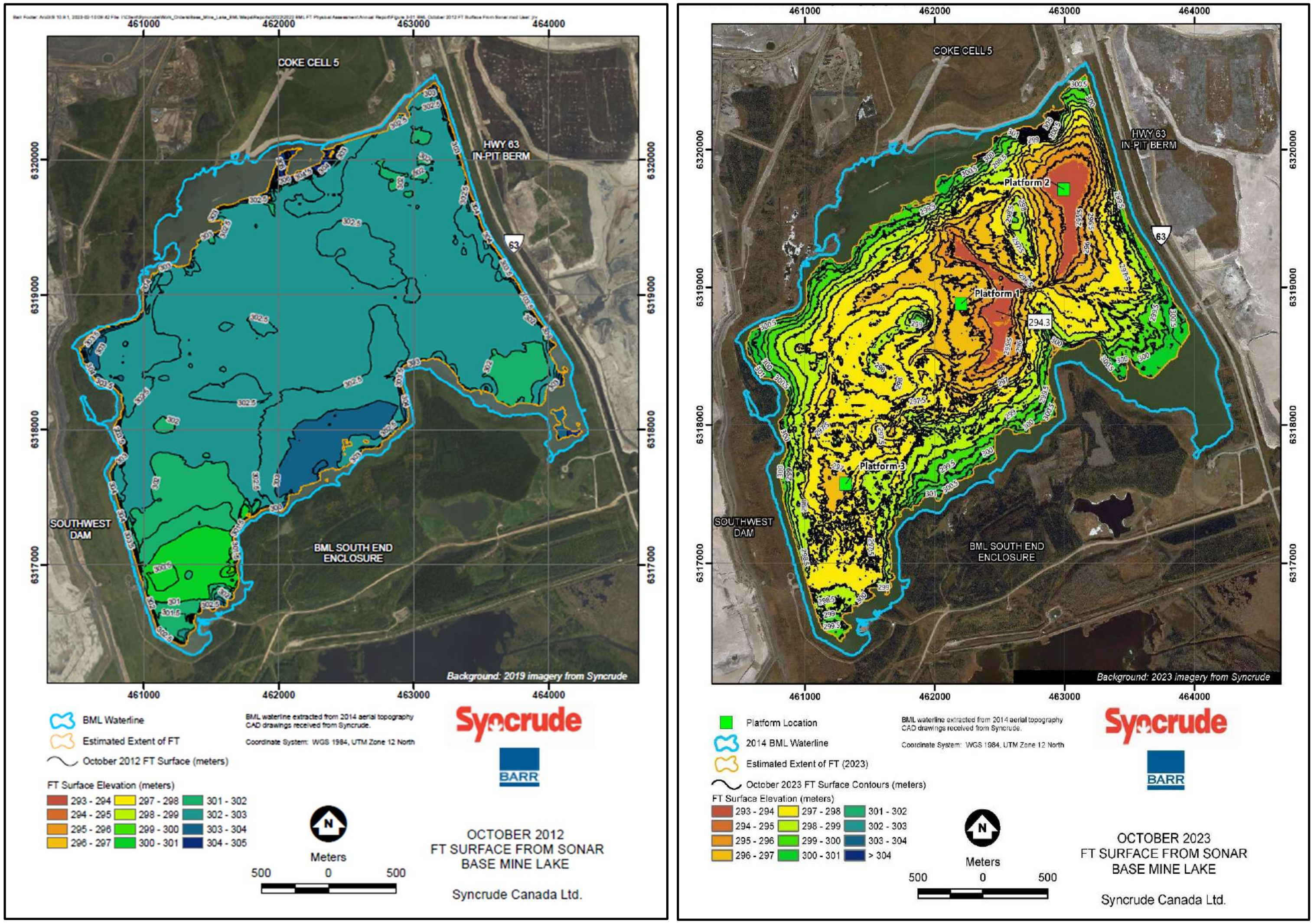


Figure 6-1: Surface contour maps of FT mudline from October 2012 (at left) and October 2023 (at right) showing variation in mudline bathymetry.

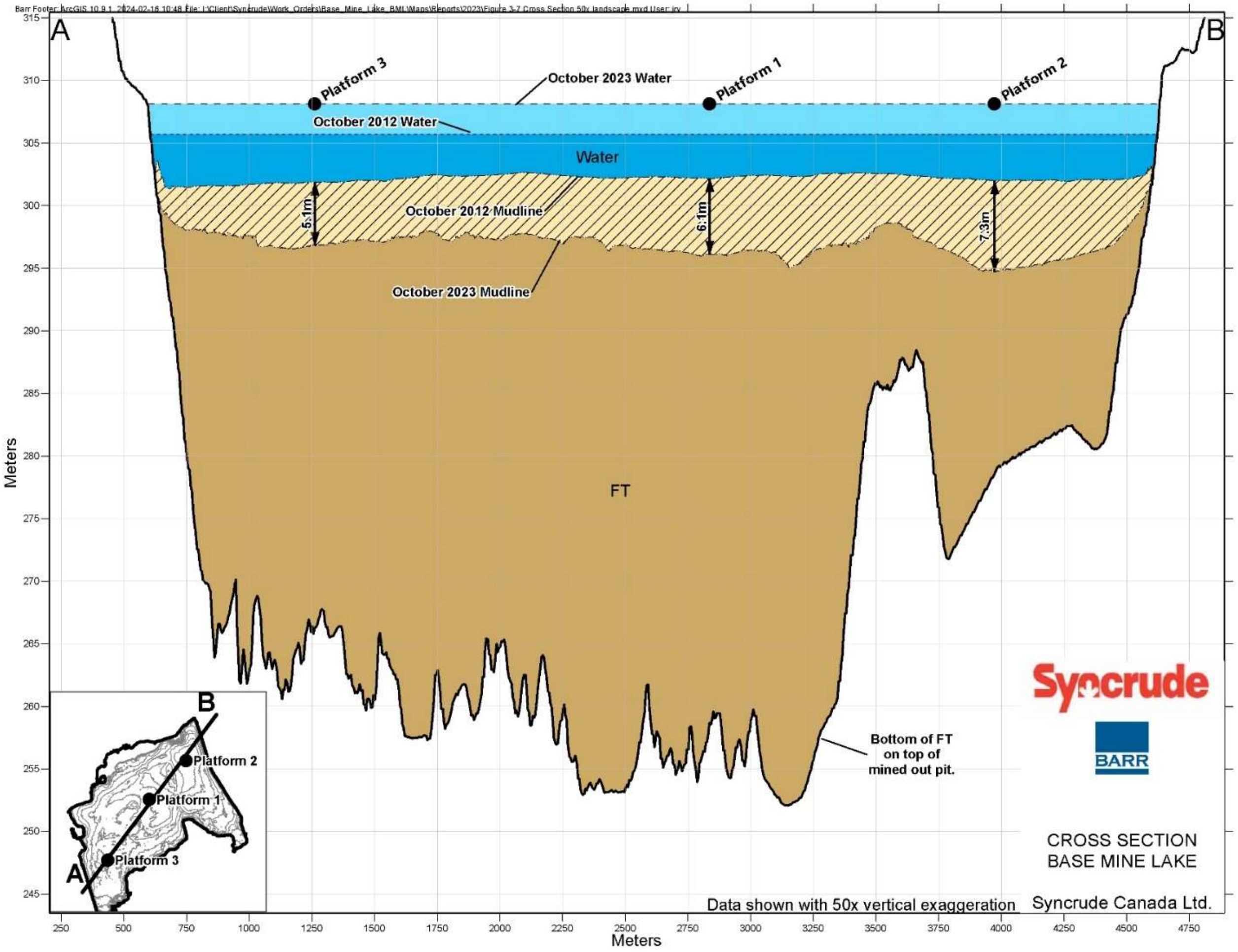


Figure 6-2: Cross-section of BML Demonstration showing mudline elevation changes since 2012, with 50x vertical exaggeration

6.1.2 Physical Limnology Assessment

Table 6.2 below highlights the key findings from the physical limnology assessment.

Table 6.2: Physical Limnology Assessment Key Findings

Physical Limnology Assessment Key Findings
Physical Limnological processes that were similar in 2023 to 2014-2022
• Similar to previous years, BML Demonstration underwent many of the same physical processes that are generally observed in natural lakes including: summer thermal stratification, fall turnover, reverse thermal stratification in the winter, wind driven thermocline tilting and wind driven mixing.
• Turbidity had a strong seasonal cycle; increasing during the fall, decreasing under ice, increasing during the spring, and decreasing again during the summer.
• Significant exclusion of salt from the ice resulting in a nearly 10% increase in water salinity under the ice.
• As the winter progressed, dissolved oxygen concentrations gradually declined at both 2 and 6 m depths, from 75% to 40% saturation.
• Increasing turbidity at depth in the spring from ice-off until mid-June
• Gradually declining turbidity during the summer thermal stratification period. The decline begins in the epilimnion at the onset of the summer stratification and starts approximately a month later at depth.
• In the summer, weekly wind events (filtered wind > 4 m/s) cause large oscillations of the thermocline (internal seiches) and large fluctuations in turbidity and oxygen in and below the thermocline
• Complete vertical mixing during fall turnover results in uniform temperature, salinity, turbidity throughout
• There was continuation of the general trend of declining turbidity observed in previous years
Physical Limnological processes that were varied from previous years or newly observed

Physical Limnology Assessment Key Findings
• There was very limited spring turnover, resulting in the earliest onset of persistent summer stratification yet (April 29)
• The turbidity in 2022 and 2023 was generally less than the turbidity in previous years.
• The turbidity at depth, under ice, is higher than the peak at the end of fall turnover and is approximately as high the peak in late spring. The source of this turbidity remains unknown. The under-ice turbidity peaks were observed in years previous to the winter of 2021-2022 but were generally earlier, before January. With the addition of deeper turbidity sensors, the under-ice peaks have become more obvious
• The addition of dissolved oxygen sensors at 11 m (the maximum depth was previously 6 m) has made it possible to identify low oxygen periods under ice and in the hypolimnion during the summer
• Profiles collected before alum dosing (September 2016) often indicated the presence of a region at the base of the water column up to approximately 0.5 m thick with very high turbidity that was intermediate in temperature between the temperature of the FT and the water above (e.g. this layer was warmer than the water above in the fall and cooler than the water above in the spring). This intermediate region has become smaller and smaller since 2016 and in 2023, for the first time, was not observed at all (e.g. no warm layer at the bottom of the profiles in Figure 3.4).

Physical limnology is the study of water circulation and mixing within lakes, examining specific physical processes such as temperature and salinity stratification, and the formation and breakdown of ice cover. These processes are driven largely by atmospheric forcing at the surface of a lake and play a critical role in biological and geochemical processes within the lake. BML Demonstration has consistently exhibited conventional boreal lake physical processes since commissioning. Annually, during the winter, the BML Demonstration forms ice. When the ice melts in the spring, temperature driven density changes in the BML Demonstration results in the water cap mixing, or spring turnover. During the summer, the water cap is thermally stratified. In the fall, thermal stratification diminishes as a result of cooling temperatures and wind. This results in the water cap mixing again or fall turnover. Key lake physical events since commissioning are indicated in the Table 6.3 below. Figure 6-3 shows turbidity data measured at platform 3 over the years.

Table 6.3: Summary of ice-on, ice-off, stratification and turbidity maxima from moored sensors at Platform 3 (P3) at 2.5 m depth

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Winter Min. (NTU)	-	*180*	*169*	53	2	23	28	28	18[c]	16	14
Ice-off	-	May 1	Late April	April 27	May 5	May 5	April 20	May 6	May 6	May 7	April 25
Spring Max. (NTU)	*99*[a]	*177*	221	153	55	70	55	70	24[d]	28	15
Strat. Onset	Late May[b]	May 30	June 9	June 23	May 26	May 10	May 17	June 9	May 28	May 29	April 29
Summer Min NTU	*5*	*10*	36	16	3	6	7	6	4	4	2[e]
Fall Turnover	Early Sept.	Sept. 7	Aug. 28	Aug. 27	Sept. 3	Sept. 3	Aug. 21	Aug. 30	Sept. 14	Sept. 27	Sept. 30
Fall Max. (NTU)	*260*	*138*	308	40	100	100	51	30	27	30	24[e]
Ice-on	Nov. 10	Nov. 11	Nov. 20	Nov. 18	Nov. 8	Nov. 8	Nov. 11	Nov. 10	Nov. 21	Nov. 10	Nov. 20

a Italics mark turbidity measured from bottle samples before the continuous moored turbidity loggers were installed

b Estimate only

c Based on platform 2 at 2.5m (the instrument at P3 drifted off of calibration)

d Based on Hatfield YSI ProDSS profiler data collected June 2 (Spring maximum) at P3 at 2.5m.

e Based on P3 at 5m (2.5m instrument had excessive gaps).

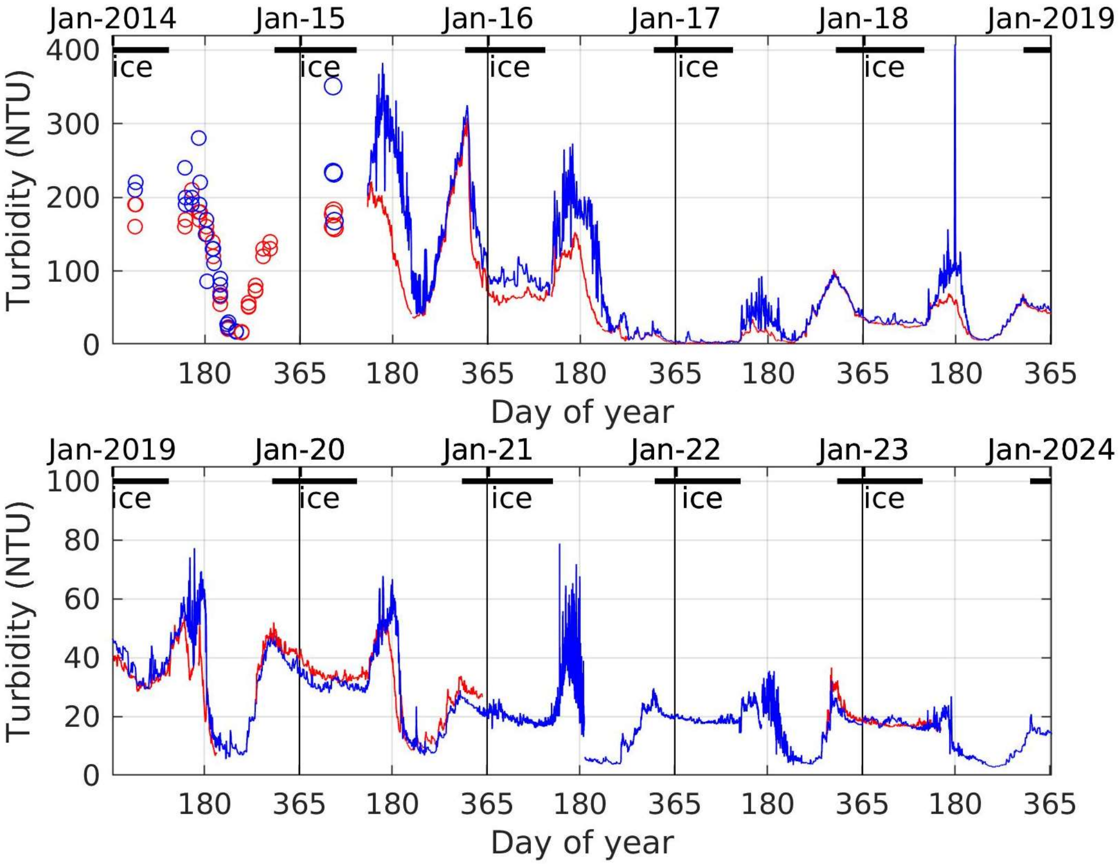


Figure 6-3: Daily average turbidity measured at Platform 3 at a depth of 2.5m and 7.5m from March 2013 to December 2023. Due to platform instability during 2022 data from platform 2 is plotted. *Note: difference in NTU scales in upper and lower graphs*

6.1.2.1 Ice and Winter Reverse Thermal Stratification in 2022 (Nov. 20, 2022 – April 25, 2023)

Air and water temperature, turbidity, specific conductivity, and dissolved oxygen concentration (as a percentage of the saturation concentration) from BML Demonstration before, during and after the period of ice-cover in 2022-2023 is presented in Figure 6-4. Once ice cover occurred (day -51, November 10, 2022), notable changes were observed in the water column: throughout most of the depth the water warmed until December 2, 2022 (day -29), the top 6 m then cooled until January 1, 2023; (Figure 6-4); the conductivity increased due to salt exclusion from the ice (day –50 to day 60, November 11, 2022 to March 1, 2023, Figure 6-4d); the oxygen concentration in the top 6 m declined from approximately 75% to 40% until ice-off on April 25, 2023 (day 115). The new oxygen sensor deployed at P2 at 11m showed the oxygen concentration reached zero on approximately January 30 (day 30).

Following ice-on, reverse temperature stratification (warmer water below cooler water) was established, indicating that mixing associated with atmospheric forcing (wind and solar radiation) was not occurring (Figure 6-4b). The patterns in the water temperature under ice are qualitatively similar to what is observed in many natural lakes and nearly identical to previous winters in BML Demonstration; the near bottom water gained heat from the bottom FT or sediment, and the near surface water lost heat through the ice to the cold atmosphere.

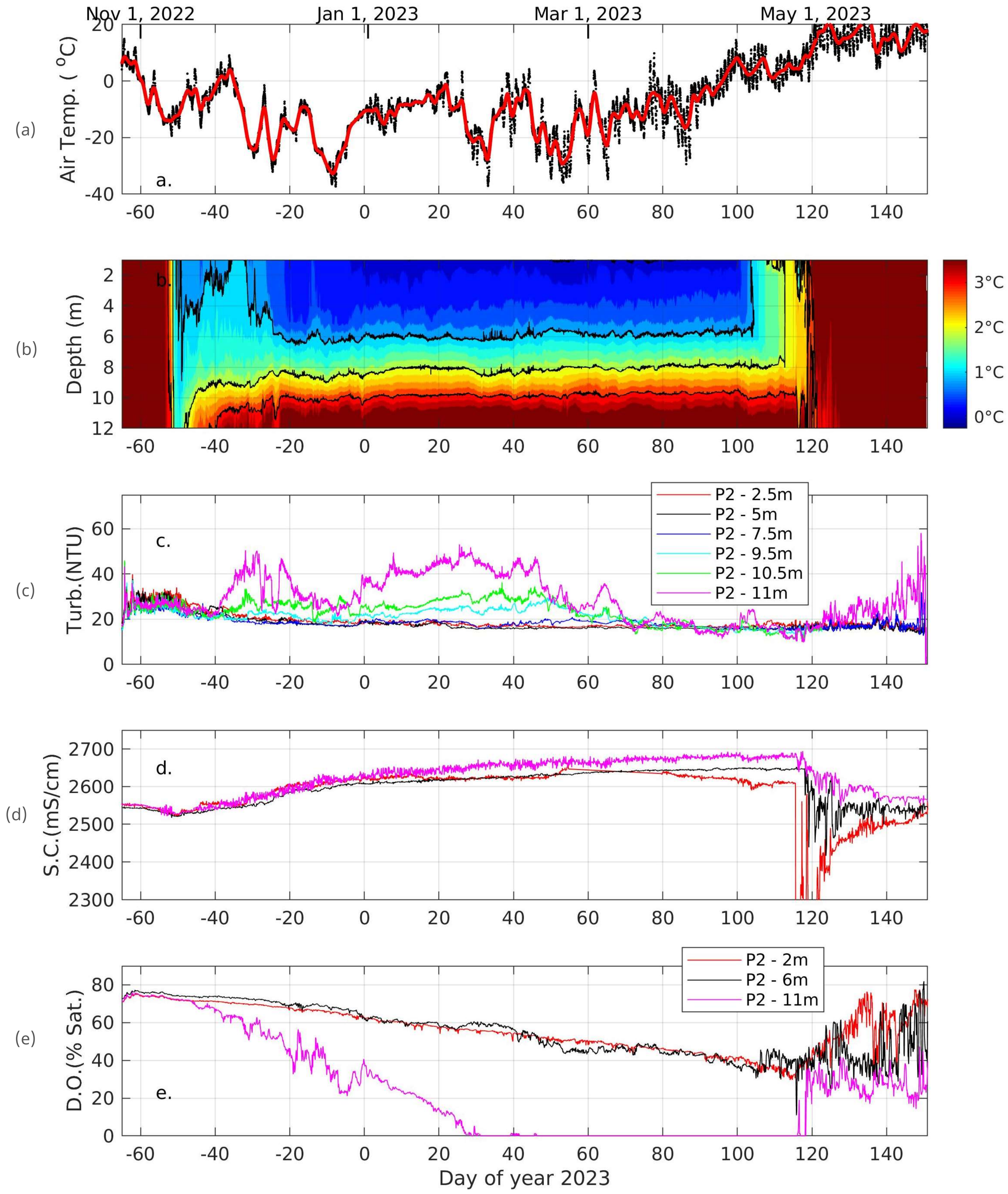


Figure 6-4: Measurements during winter 2023-2024. (a) Air temperature at P1. (b) Water temperature profiles measured at P2, the black contours are at 1, 2 and 3°C. (c) Turbidity measured at P2 and P3. (d) Specific conductivity (mS/cm) measured at various locations indicated. (e) Oxygen concentration expressed as a percentage of the saturated concentration i.e., adjusted for water temperature, depths match panel (d).

6.1.2.2 Under-Ice Turbidity

There are four noteworthy features in the under-ice turbidity data collected at P2:

1. Similar to previous years, at 2.5 m and 5 m, the maximum turbidity occurred at the end of fall turnover, at the start of ice formation.

2. The turbidity throughout the ice-covered period above 7.5 m was similar to the winters of 2020-2021 and 2021-2022.

3. Similar to winter 2021-2022, the peak in turbidity below 7.5 m (9.5 m, 10.5 m and 11 m) occurred several weeks after ice-on. The under-ice peak in turbidity was particularly late at 9.5 m, occurring on approximately February 24 (day 55).

4. The minimum under-ice turbidity occurred at the deepest sensors (below 7.5 m) in the spring before ice-off (see day 95, Figure 6-4 c). This deep, slightly clearer, water was first noticed during the winter of 2021-2022. The source of this clearer water remains unknown; it may, for example, result from the melting of salt-laden white ice.

6.1.2.3 Under-Ice Profiles of Temperature, Specific Conductivity and Turbidity

As was the case in the winter of 2021-2022, limited ice access restricted profiling to only one station which was between the shore and D04. The vertical profiles of temperature were consistent with those observed in natural lakes under ice: water temperature increased with depth (reverse thermal stratification, Figure 6-5 a.). Unlike previous winters, the profiles did not exhibit a thermally homogeneous, near-surface water-layer. Salinity profiles collected at this location were stratified similar to profiles collected during winters prior to 2022 (Figure 6-5 a.). The turbidity profiles collected at this location were similar to profiles collected during previous winters (approximately homogeneous down to 7.5 m). Due to their proximity to the shore, the profiles collected during the winter of 2022-2023 may not well represent the whole lake.

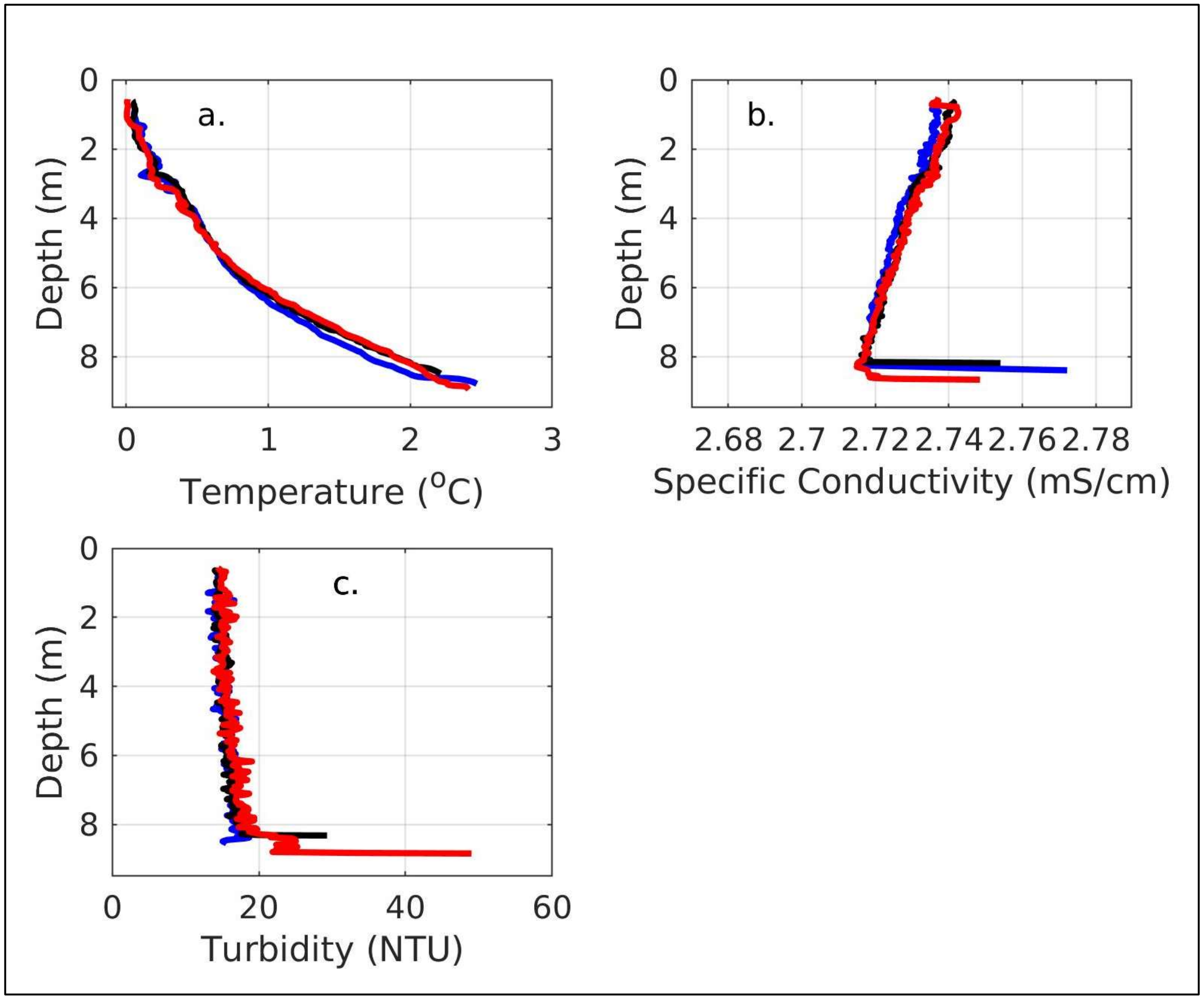


Figure 6-5: Winter 2022-2023 Seabird profiles of (a.) temperature, (b.) specific conductivity and (c.) turbidity. Due to limited access all winter profiles were collected near D04

6.1.3 2022 Spring Turnover (April 25-April 29, 2023)

Once the ice melts, solar heating warms the near surface water that is cooler than the temperature of maximum water density (TMD). This heating of the cool near-surface water increases the water density near the air-water interface, destabilizing the water column (dense water on top of less dense water) and drives convection. In the absence of salinity or suspended solids, the unstable water column will continue to warm from top to bottom until the temperature of maximum density is reached. In the BML Demonstration, melted ice and snow can leave a freshwater cap at the surface. The fresh, less dense, water at the surface tends to stabilize the water column and, provided there are no large wind events, can prevent complete spring turnover.

In 2023, ice-off was estimated to occur on April 25 (day 115). A 5 m/s wind event on April 28 (day 118) resulted in a brief period (<1 day) when BML Demonstration nearly homogenized but close inspection of the temperature records throughout the depth at P2 indicate temperature stratification persisted. Similarly, small horizontal variations in specific conductivity and dissolved oxygen also indicate the lake did not homogenize horizontally (Figure 6-4 d. and e.). While the dissolved oxygen at 11 m had been 0% saturation since late January, the wind event just after ice-off on April 28 (day 118), resulted in a notable increase in dissolved oxygen in the deep water to approximately 30% saturation (Figure 6-4 e.).

6.1.4 2023 Summer Stratified Period (April 29 – Sept. 30, 2023)

Like previous summers, BML Demonstration exhibited summer thermal stratification that is typical of temperate and northern lakes. In this section, the evolution and structure of temperature, turbidity and dissolved oxygen are described.

6.1.5 Wind Forcing and Thermal Evolution During the Summer Period

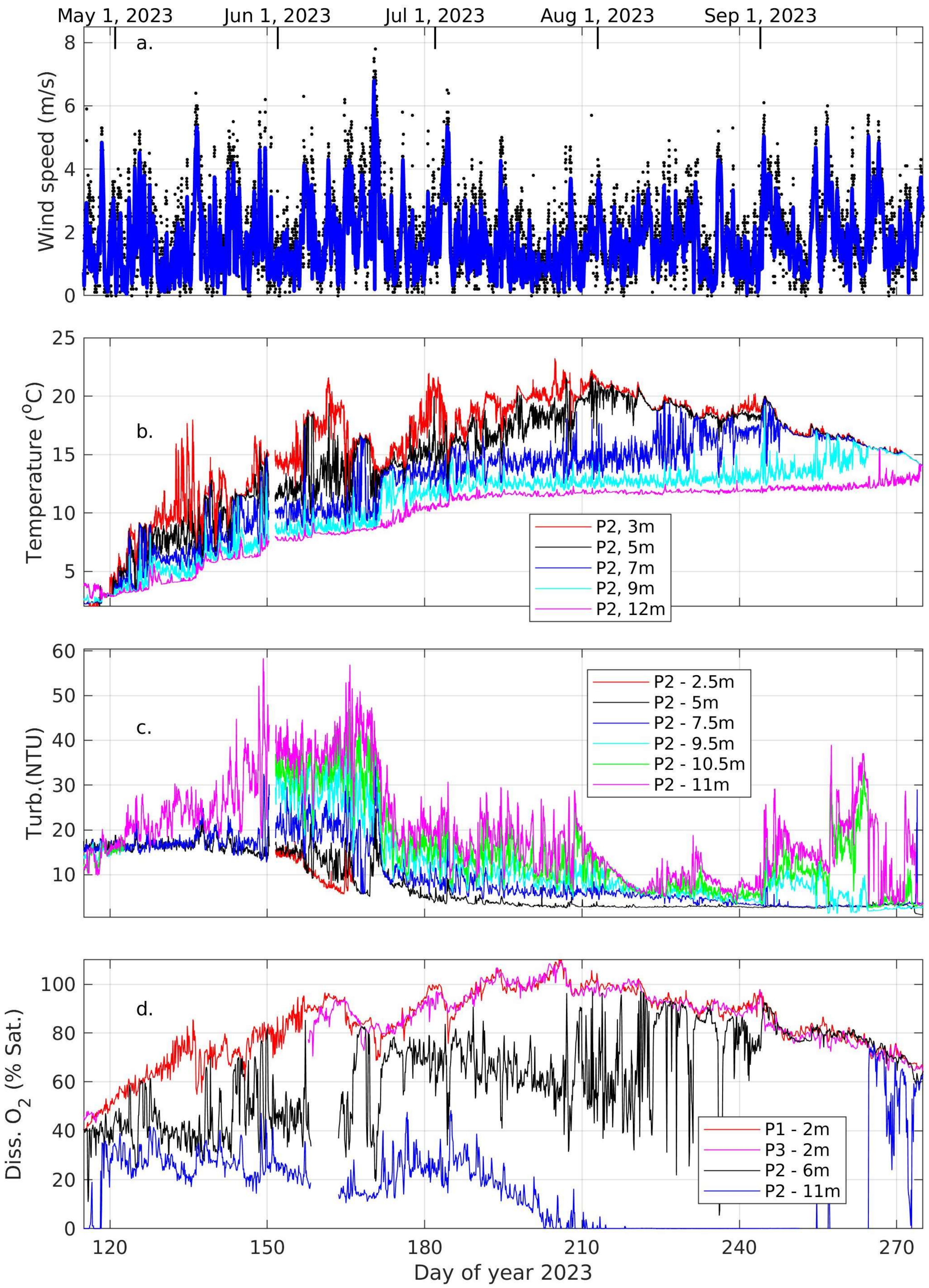
In Figure 6-6, wind speed is plotted with the water temperature records from P2, turbidity from P2 and dissolved oxygen (as a percentage of the saturation concentration) from P1, P2 and P3. The heavy blue line in Figure 6-6 a. is a low pass filtered representation of the scalar wind speed. This filter removes the wind variance at frequencies faster than 8 cycles per day (periods less than 3 hours) to emphasize winds that are persistent enough to have a lake-wide impact on the thermocline (i.e. upwelling of deeper cold water at the upwind end of the lake and downwelling of warmer near-surface water at the downwind end of the lake). It takes at least 3 hours of sustained winds in the same direction to begin to significantly impact the thermocline lake-wide.

The period of persistent summer thermal stratification began on approximately day 119 (April 29) and ended on approximately day 273 (September 30). The epilimnion (the upper water layer above the thermocline, represented by the temperature at 3 m depth as shown by the red line in Figure 6-6 *b. and c.*) warmed from the beginning of this period until approximately day 212 (July 31). From day 212 until turnover on day 270 (September 30) the epilimnion gradually cooled and deepened. The deepest water warmed between days 119 and 190 in four steps associated with wind driven mixing (Figure 6-6 *a. and b.* days 135, 150, 170, 185). After day 190 (July 10) the bottom water temperature remained nearly constant, warming very slowly until just before turnover.

6.1.5.1 Turbidity in BML Demonstration During the Summer Period

Turbidity data was only available at 2.5 m for early June, which declined during this time. At 5 m, turbidity remained relatively stable in May (day 121 to 152), then decreased until the end of July, and then remained close to 2 NTU until fall turnover. The 5 m sensor was in the epilimnion for most of the summer (Figure 6-6 b). Turbidity below 5 m increased until mid-June (approx. day 170) when it reached a maximum of approximately 50 NTU at 11 m. Turbidity then decreased until the end of August (day 240). Large variations in turbidity at 7.5 and 9.5 m depth during this period (day 170 to 240) are generally correlated with wind driven oscillations of the thermocline (as discussed in Tedford et al 2019). After day 240, turbidity at the deepest sensors (10.5 m and 11 m) increases sporadically until fall turnover. These sporadic increases in turbidity at the two deepest sensors at the end of summer but before turnover occur every year and are not yet understood.

The weak or non-existent spring turnover resulted in divergence of the deep (11 m at P2), mid-depth (6 m at P1) and shallow dissolved oxygen (DO), starting April 29 (Figure 6-6 d), much earlier than previous years (typically mid-May to early June). After this date the shallower measurements showed DO increasing to approximately 100% saturation on day 195 (July 14) and then, due to cooling and mixing, declining after day 220 (August 8). The DO at the deepest sensor (11 m at P2) reached 0% saturation on approximately day 180 (June 29) and remained low until day 270 (Sept. 27). These trends are similar to those observed in previous years albeit with low DO at depth occurring earlier and lasting longer due to the early onset of persistent summer stratification and the late start of fall turnover.



Note that temperatures at 9.5 and 11m in panel (b.) are interpolated from 212 to 225 (August 1 to 14) during a period of excessive motion at P2.

Figure 6-6: (a.) Wind speed at P1 (b.) Water temperature in BML Demonstration at P2. (c.) Turbidity measured at P2(d.) Dissolved oxygen concentration in percent of saturation concentration

6.1.5.2 Examination of Summer Profiles

Vertical and horizontal variability of temperature, specific conductivity, and turbidity from profiles collected on day 227 (August 14th) is shown in Figure 6-7. The thermal stratification during this period is typical of BML Demonstration or any other temperate lake on a mid-summer day. There are three layers within the water column as indicated in Figure 6-7 a.; an upper layer (epilimnion), a middle layer (metalimnion, also called the thermocline), and a lower layer (hypolimnion). The temperature, specific conductivity and turbidity profiles from August 2023 were generally similar to previous years. The bottom water was slightly cooler than typically in August (12°C vs 13°C). The specific conductivity (salinity) was more stratified in August than it has been since 2014, a summer when a very large volume of fresh water was pumped in. The turbidity was similar to 2022 and less than previous years particularly in the hypolimnion (5 to 12 NTU in 2023 vs >20 NTU in summers previous to 2022).

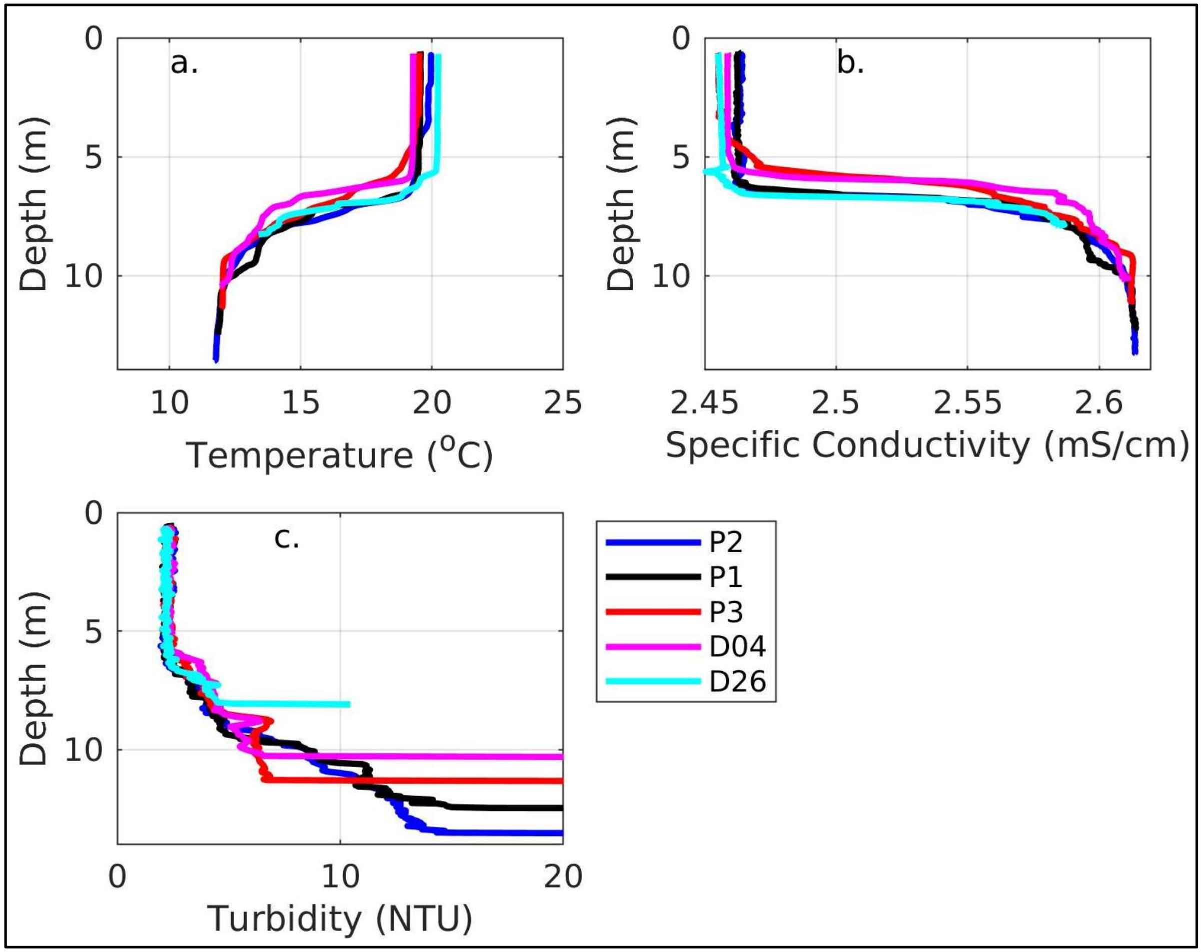


Figure 6-7: Seabird profiles of (a.) temperature, (b.) specific conductivity and (c.) turbidity on 14 August 2023 at stations indicated in the legend

6.1.6 2022 Fall Turnover (Sept. 23 – Nov. 10, 2023)

6.1.6.1 Temperature and Turbidity Evolution

Relatively mild temperatures and calm winds in September resulted in the latest fall turnover observed since the commissioning of BML Demonstration (approximately day 273, September 30, Figure 6-6 b). Profiles of temperature, specific conductivity and turbidity collected on day 276 (October 3rd, 2023) – three days after turnover - are plotted in Figure 6-8. In general, all three parameters are nearly uniform at all five stations. Turbidity remained relatively low (<10 NTU) throughout October 2023 (data not shown).

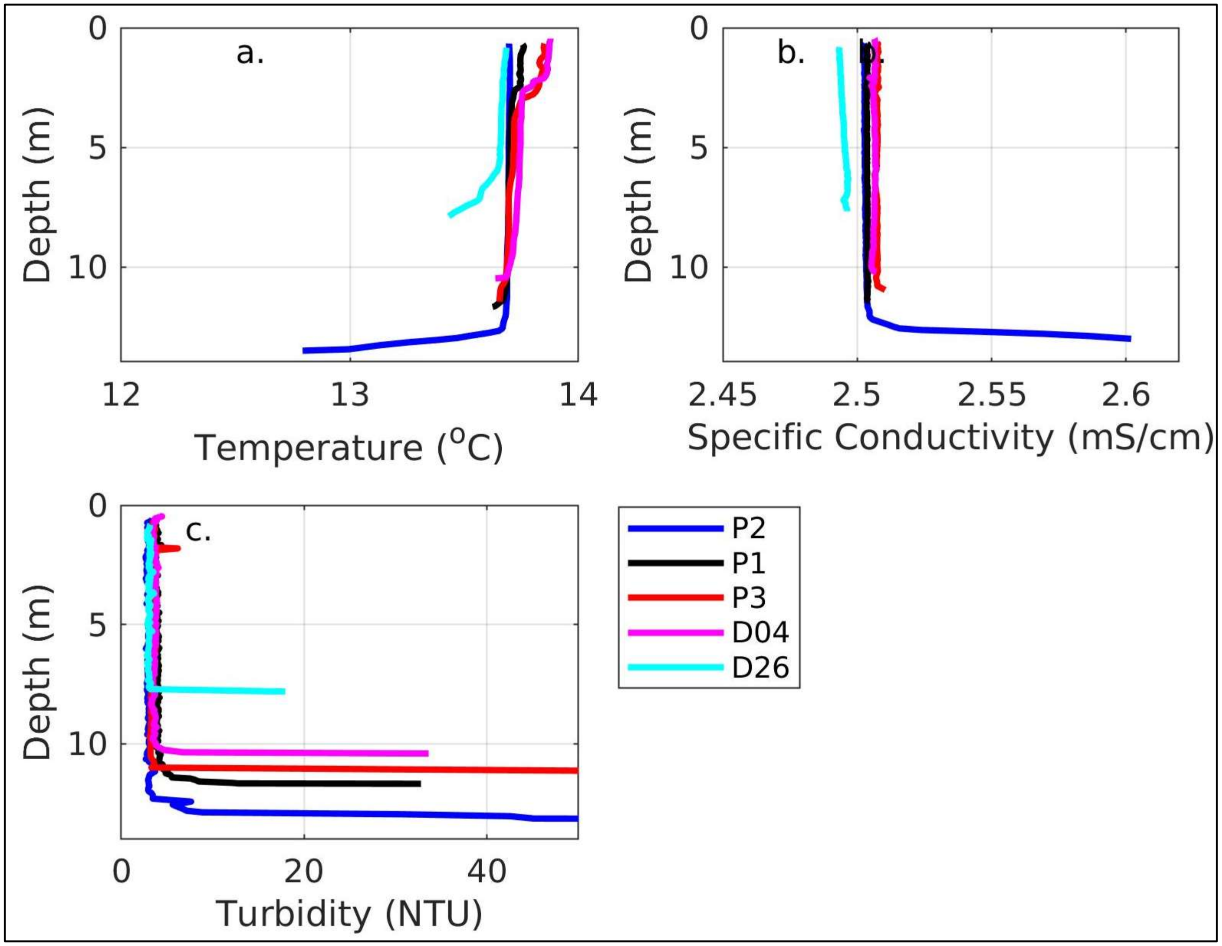


Figure 6-8: Fall 2023 (Oct 03) Seabird profiles at the 5 locations indicated in the legend of (a) temperature, (b) specific conductivity and (c) turbidity.

6.2 Chemical Components of the Base Mine Lake Demonstration Monitoring Program

The chemical components of the BML Demonstration monitoring program focus on understanding surface water quality and changes through time. These monitoring components contribute to the validation of the shorter-term expectation of water quality improvements over time. Understanding the lake water balance is important for developing the water column chemical mass balance.

6.2.1 Water Balance Assessment

Table 6.4 below summarizes the key findings from the water balance assessment.

Table 6.4: Water Balance Assessment Key Findings

Water Balance Assessment Key Findings
• The primary drivers of the water balance since commissioning have been inflows in and out of the BML Demonstration, and pore water release to the water cap.
• The water balance is being closed and is well constrained.
• Runoff has been challenging to measure, and an estimation is required to close the water balance.

Estimating the water balance of BML Demonstration has important implications for the chemical, energy, and constituent mass balance of the lake, and provides information to support modelling of pit lakes in the closure landscape. The water balance is complete from January 1, 2014, to December 31, 2023, on a daily basis in terms of both volumes of water and mm of water (depth per unit area).

6.2.1.1 Air Temperature

Since commissioning, air temperatures at BML Demonstration have fluctuated by approximately 5 degrees in the open water season on an annual basis with the exception being an anomalously cool September 2018 (Figure 6-9). Open water air temperatures were above the 30-year Fort McMurray climate normal (1991-2020) whereas winter temperatures were above/below normal during ice-on periods. 2023 had an exceptionally warm May.

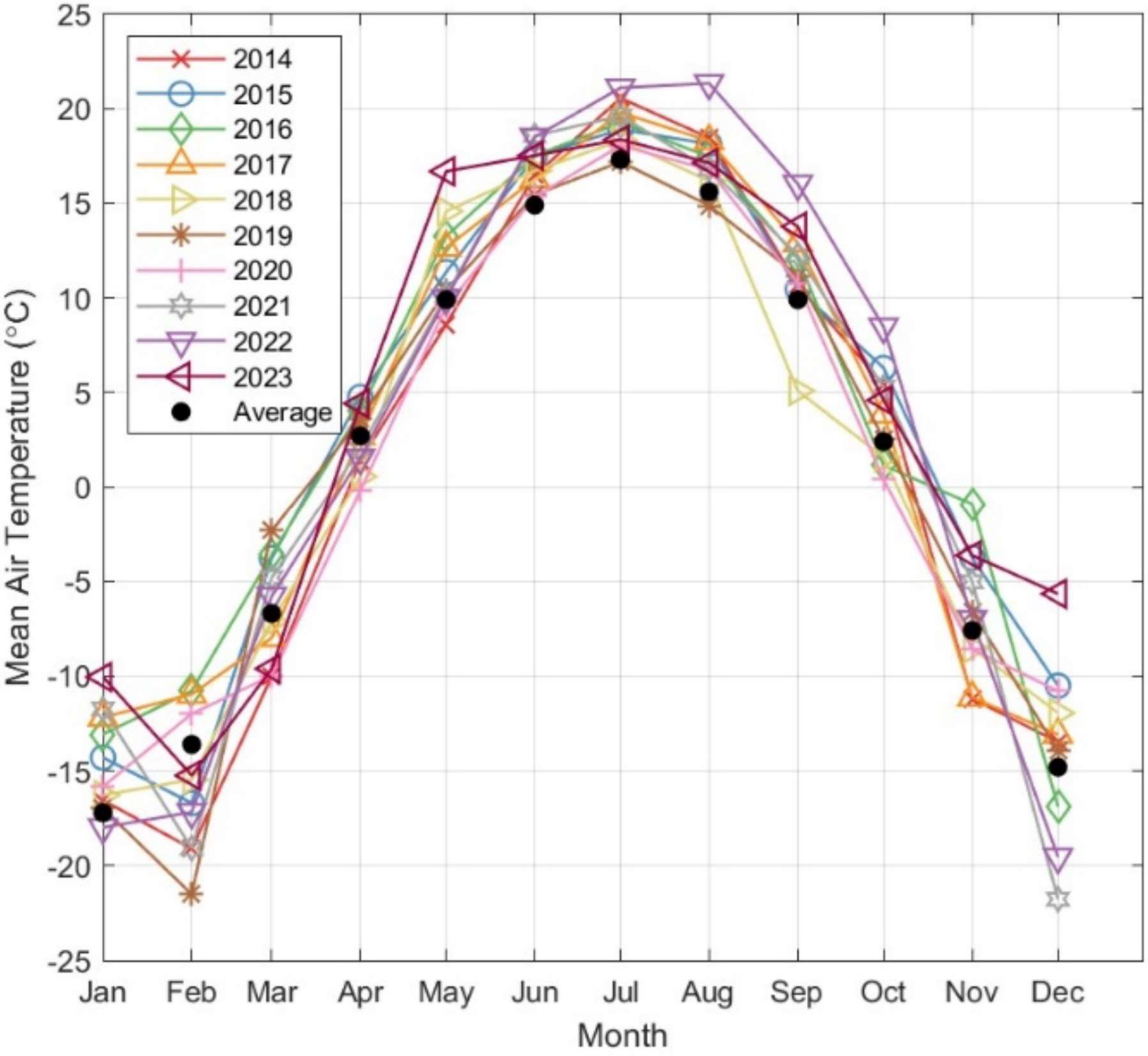


Figure 6-9: Air temperature from 2014-2023. Black circles are the 30-year climate normal for Fort McMurray (1991-2020).

6.2.1.2 Total Precipitation

Annual total precipitation has ranged from approximately 300 mm in 2015 to 600 mm in 2020, highlighting the considerable variability in local climate conditions (Figure **6-10**). The climate normal for Fort McMurray A is ~405 mm, and the past three years have been a bit drier that the three years prior.

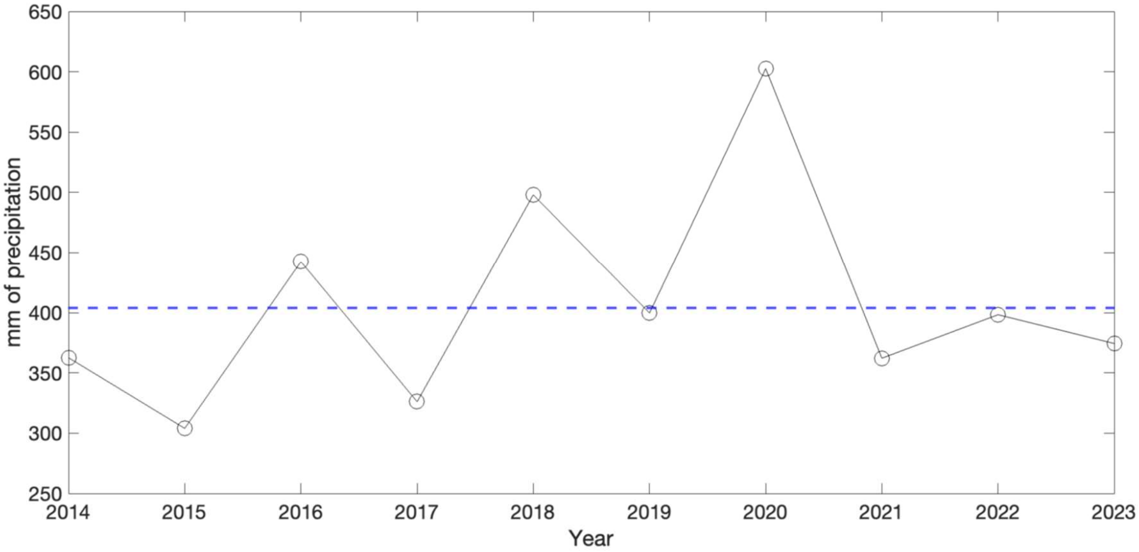


Figure 6-10: Total precipitation from 2014 to 2023.

6.2.1.3 Snow

The input of snow to BML Demonstration is handled in a rudimentary manner. Each year snow surveys at BML Demonstration and other sites are compared with total SWE gauges at the Sandhill Fen. There is considerable correspondence among these measurements, and a 'representative' BML snow water equivalent (SWE) is determined. This SWE is then added to the lake on the day the lake estimated to become ice-free. While there are obvious errors in this (most notably snowmelt will contribute to the lake water budget prior to ice-off), it is a reasonable estimate on a monthly basis yet may result in storage variances in the April and May.

In all years, cumulative melt expressed as SWE is lower than the Fort McMurray average SWE of 102 mm. 2015 and 2017 were exceptionally low-snow years, whereas 2021 and 2022 were the only years with a snowpack approaching normal. Note that SWE is taken as the maximum measured via surveys and continuous measurements. Figure 6-11 shows the cumulative melt added to the BML Demonstration on the day of ice-off.

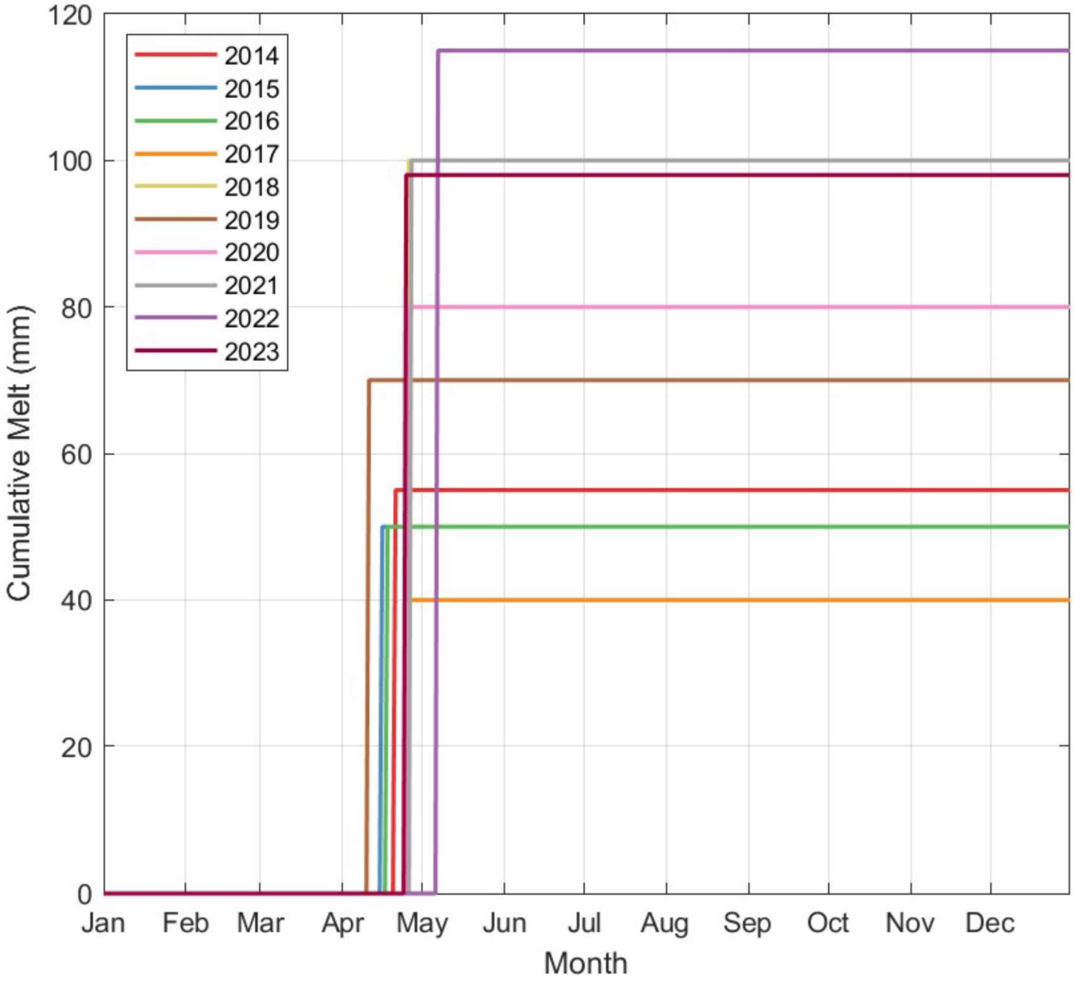


Figure 6-11: Cumulative melt added to the BML on the day of ice-off.

6.2.1.4 Rain

Rainfall is obtained by comparing daily totals from five gauges adjacent to BML Demonstration and the tipping bucket gauge on Platform 1 for quality assurance. Gaps are filled and under-catch is assessed based on windspeed and gauge type. Daily cumulative rainfall (Figure 6-12) indicates that approximately 6 years are below and 4 are above the 30-year climate normal (1991-2020). Cumulative rainfall in the 10 years of this work, appears to lag the climate average, and in wet years late-summer large intensity events are responsible for considerable gains in water. In terms of total precipitation, rainfall is responsible for much more water, and a much greater variance in the water balance compared with snow.

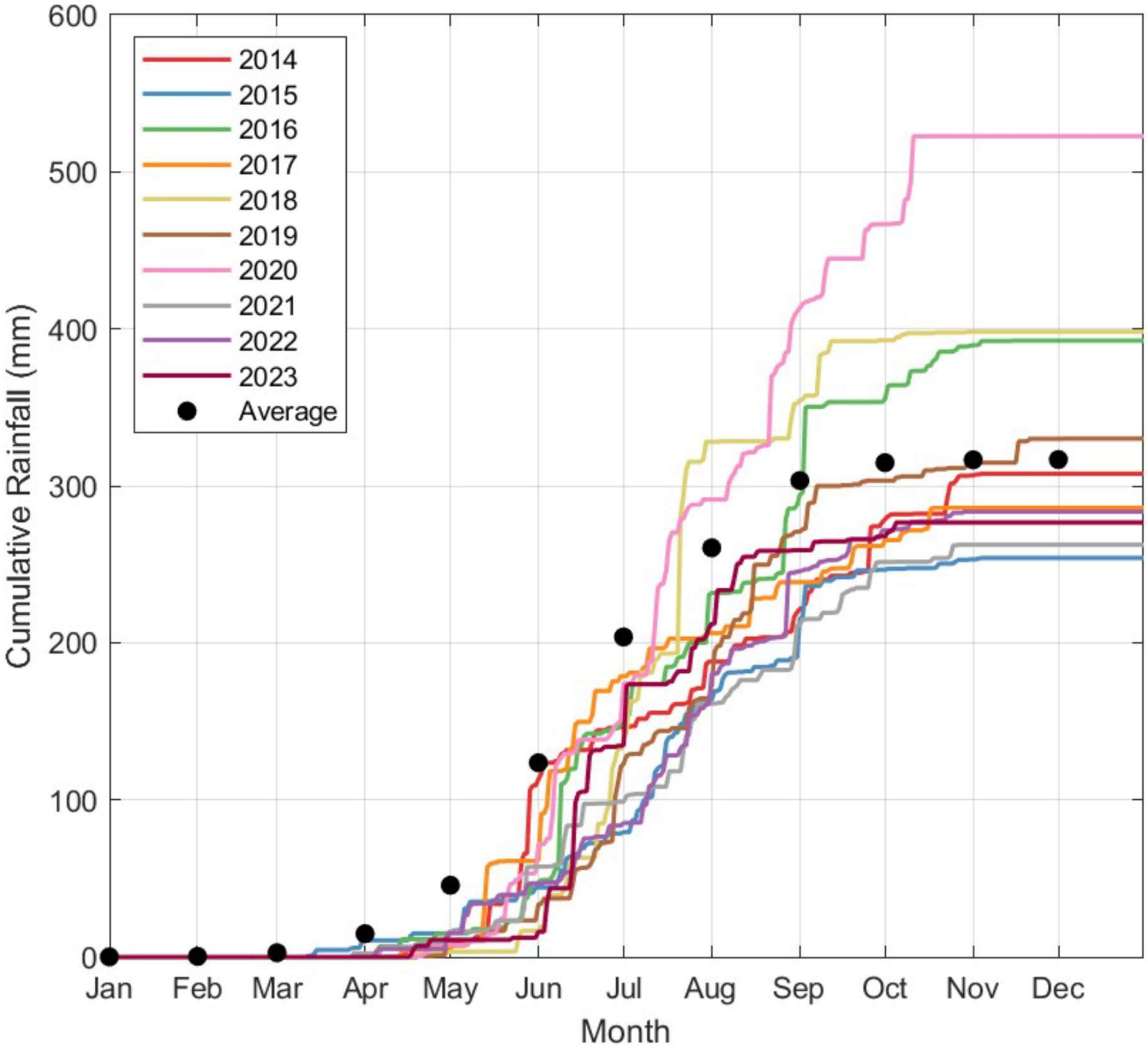


Figure 6-12: Cumulative daily rainfall. Black circles are the Fort McMurray cumulative monthly rainfall normal (1991-2020).

6.2.1.5 Runoff

Previous runoff data from the weir prior to 2014 was reviewed, and a 'rule of thumb' developed to estimate runoff from precipitation events. A literature review helped to place this in context of previous reviews of runoff ratios form the boreal plains. The rule of thumb is:

For a given day:

- If Precipitation is < 10 mm, there is no runoff
- If Precipitation is > 10 mm and < 20 mm, the runoff ratio is 0.05
- If Precipitation is > 20 mm and < 40 mm, the runoff ratio is 0.1
- If Precipitation is > 40 mm, the runoff ratio is 0.2

These rules are applied for both rain and snow and occur the day of precipitation without lag. As discussed in previous reports, there was a gradual decrease of water over the 8 years. Figure 6-13 shows the annual estimated runoff, and while total fluxes were small, they ranged from 17 to 52 mm.

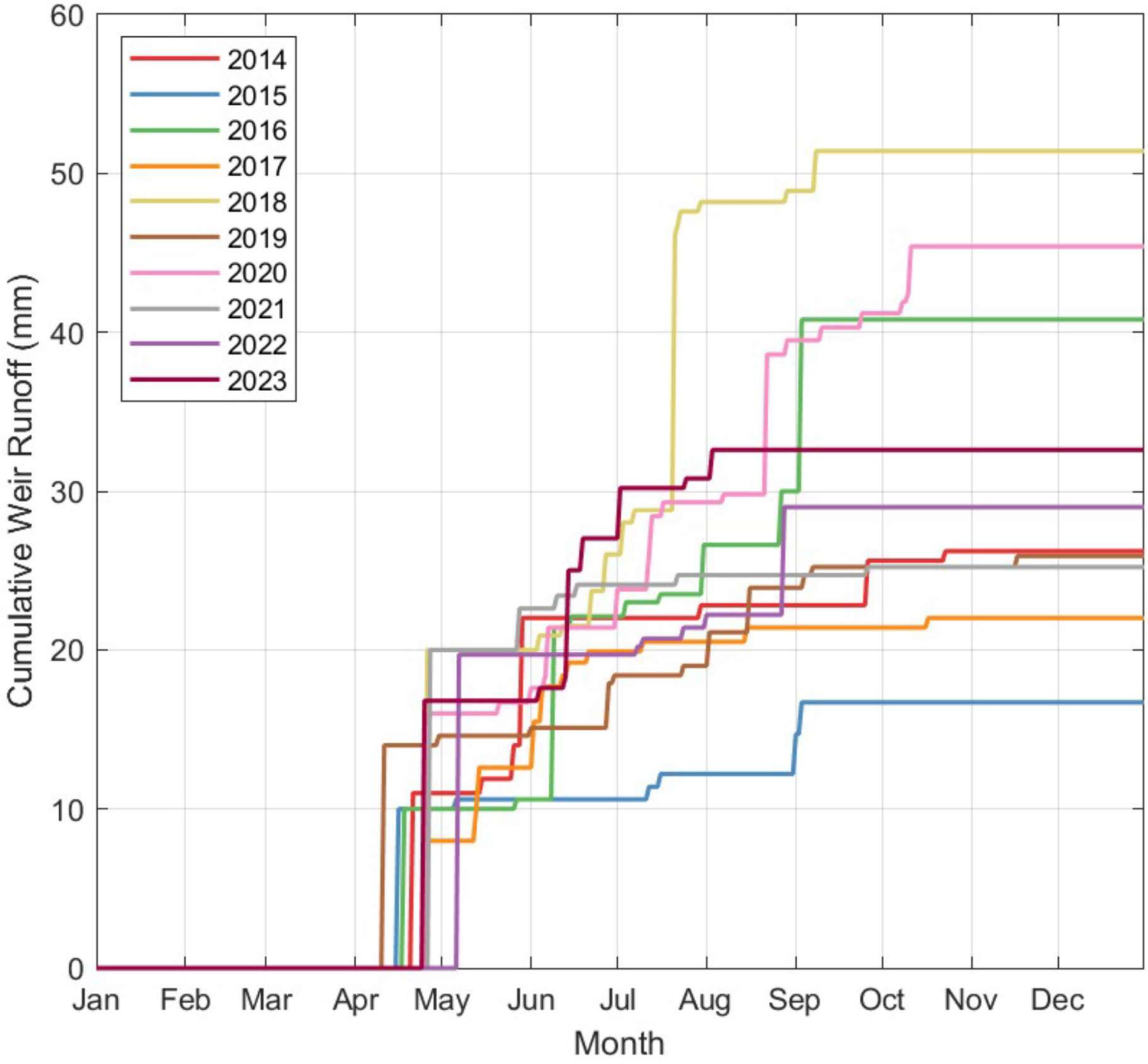


Figure 6-13: Cumulative calculated daily runoff from 2014-2023.

6.2.1.6 Pumping

When there is inflow or outflow, volumes of both the additions (Figure 6-14) and removals (Figure 6-15) of water from BML Demonstration from pump operation are determined daily. In the early years of commissioning, there were very large inputs/outputs from BML Demonstration which have gradually declined over time. In 2019, dredging of bitumen removed and estimated 45 mm of water. In 2021, to support operational water management on-site, no water was added to BML Demonstration and very little (~23 mm) was removed. In 2022, 172 mm was pumped in, and 176 mm pumped out.

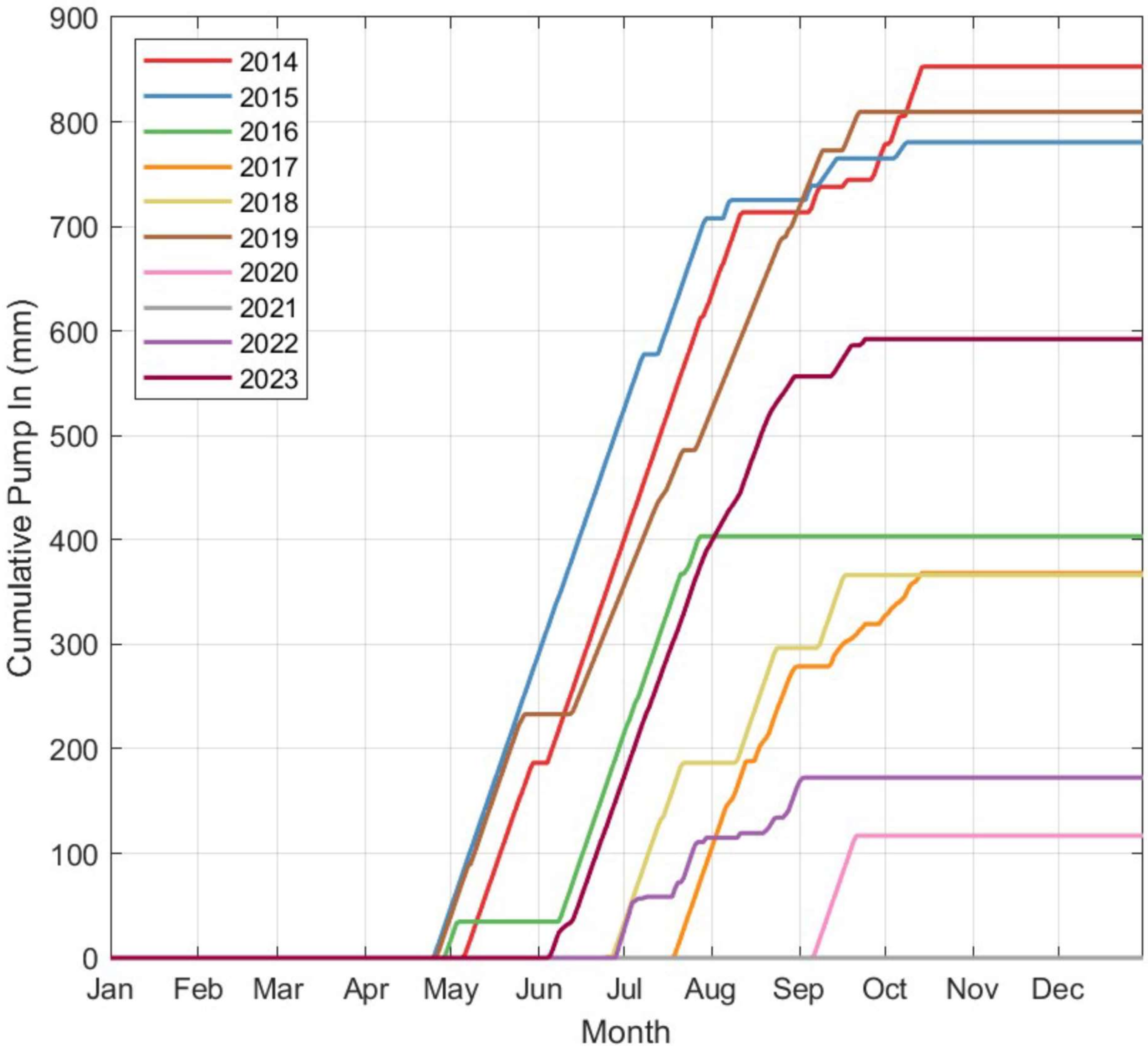


Figure 6-14: Total pump volume in from Beaver Creek Reservoir.

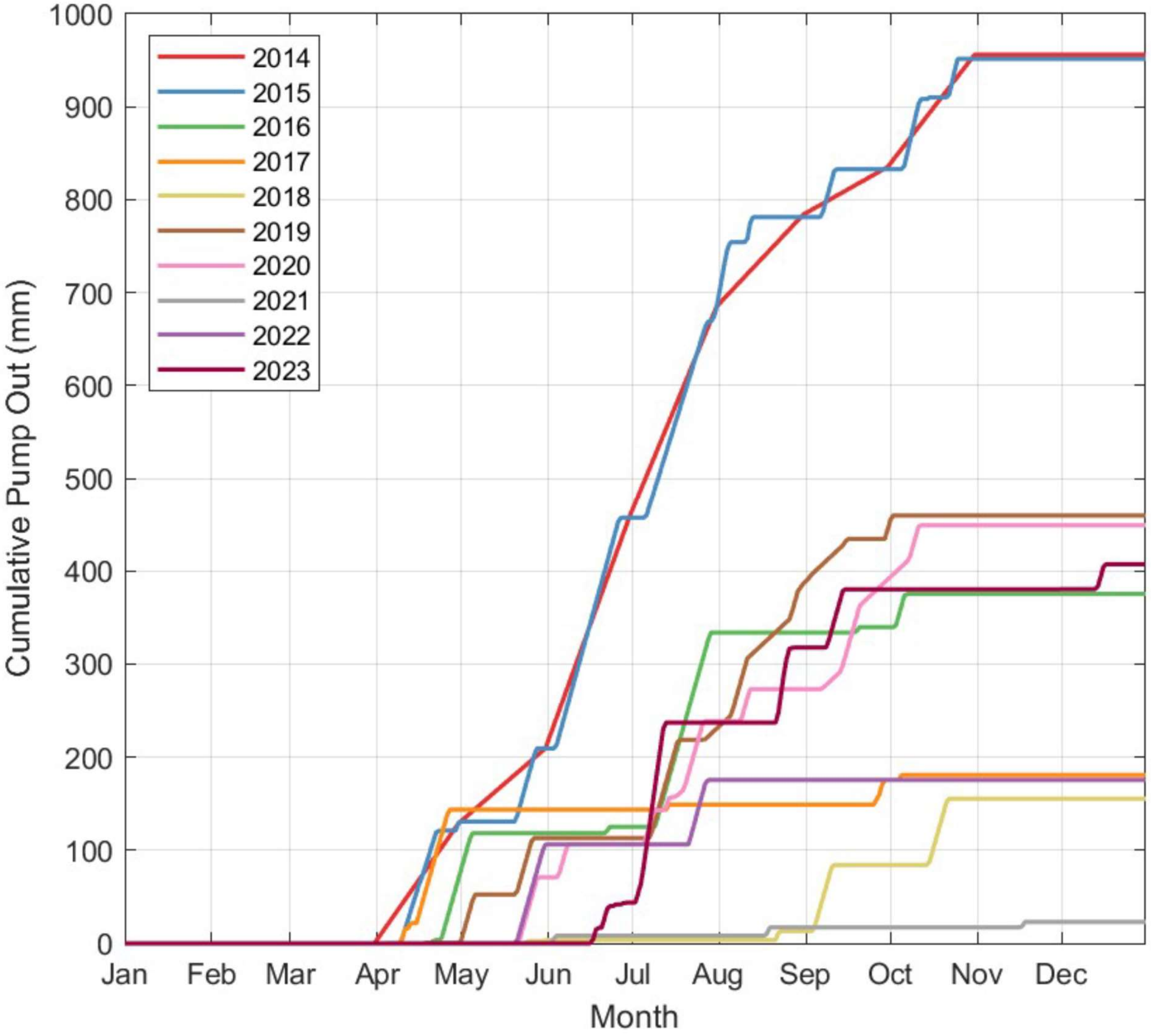


Figure 6-15: Total pumped removal of water from BML Demonstration.

6.2.1.7 Evaporation

Evaporation is measured typically during the open water season (setup is in February/March and takedown in October). To interpolate missing data, artificial neural networks are now trained using BML Demonstration data. This is also compared with the publicly available several models (Air Sea Toolbox and Canadian Small Lakes Model). Note, in 2023, the Eddy Covariance systems were not functional due to logistical constraints and 2023 fluxes were modelled. Values in 2023 were slightly greater than previous years (Figure 6-16).

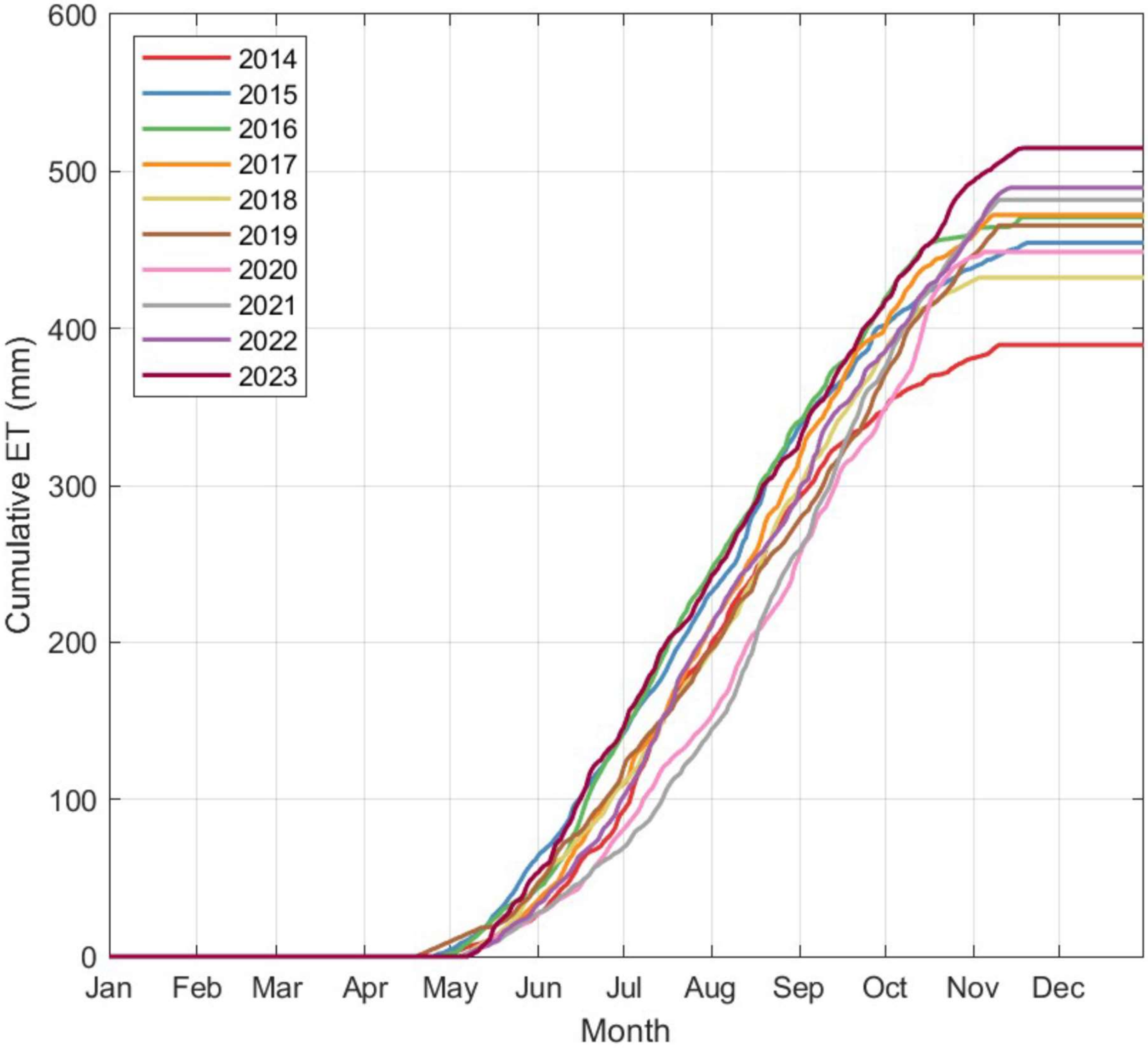


Figure 6-16: Cumulative evaporation from Base Mine Lake Demonstration measured at Platform 1 from 2014-2023.

6.2.1.8 Multi-year Water Balances

Cumulative monthly totals in terms of mm and Mm^3 of water are presented in Figure 6-17 an d Figure 6-18; annual totals are presented in Table 6.5 and Table 6.6, and Figure 6-19. The volumetric totals include the water expressed from the FT as determined by the annual FT mudline elevation surveys.

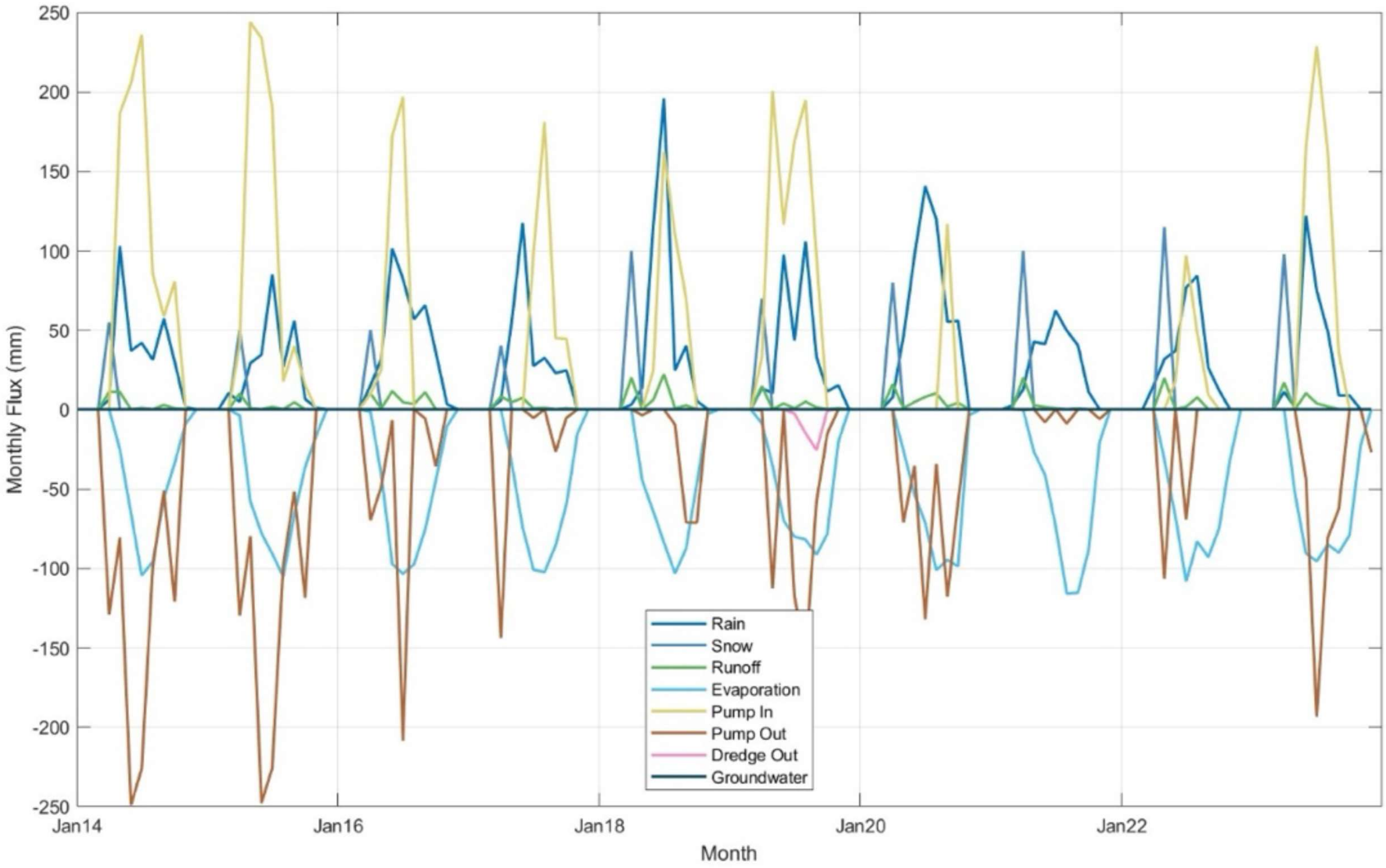


Figure 6-17: Monthly BML Demonstration water balance in mm.

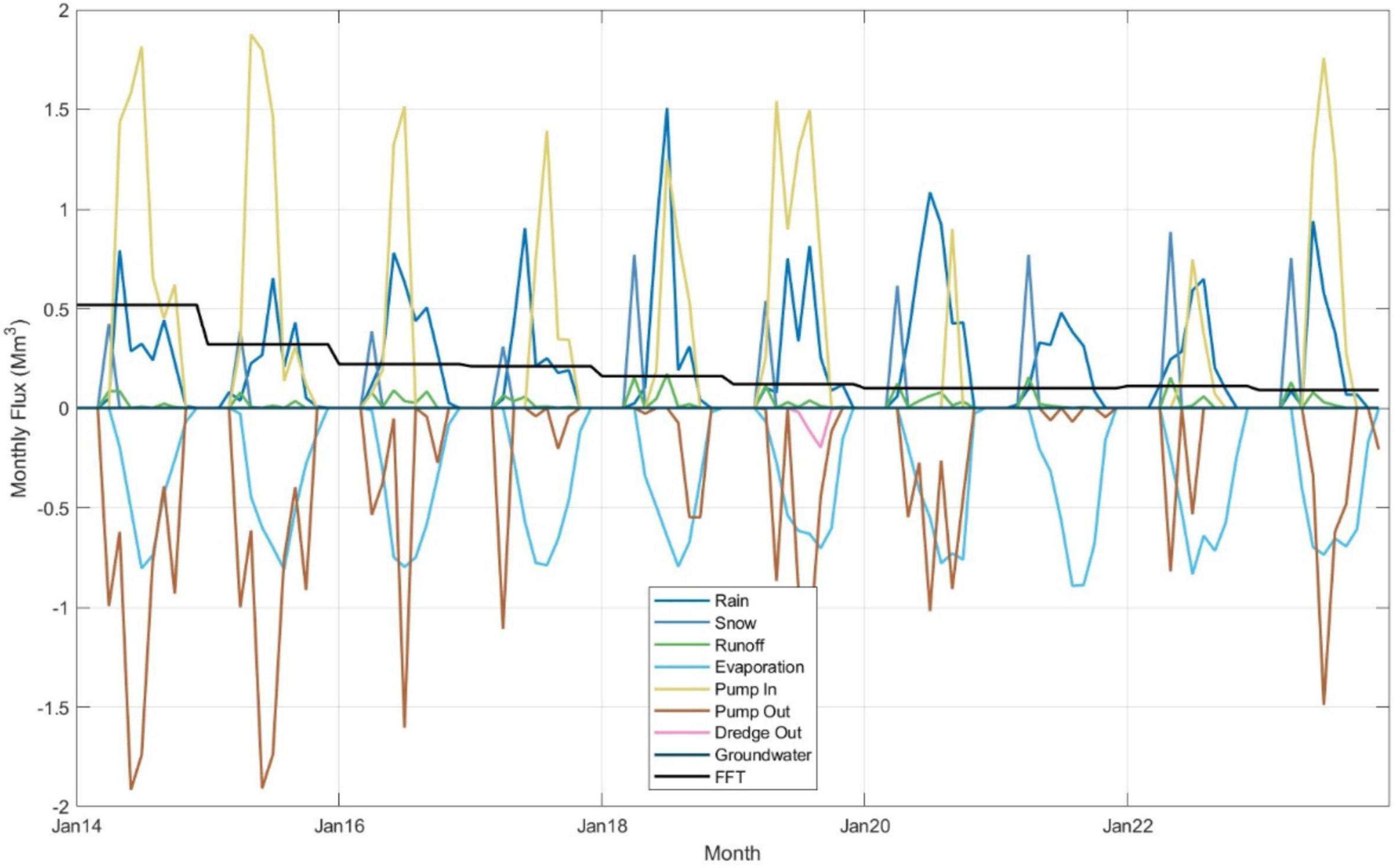


Figure 6-18: Monthly BML Demonstration water balance in Mm^3.

Table 6.5: Annual BML Demonstration water balance (in mm)

Year	Rain	SWE	Runoff	Evap	Pump_In	Pump_Out	Dredge_out
2014	307.6	55.0	26.1	389.7	852.0	954.5	0.0
2015	254.0	50.0	16.7	455.2	780.2	952.6	0.0
2016	392.5	50.0	40.8	470.3	402.1	375.9	0.0
2017	286.1	40.0	22.1	472.8	368.4	181.2	0.0
2018	398.1	100.0	51.3	432.2	366.1	155.6	0.0
2019	329.7	70.0	26.0	466.3	811.4	461.1	43.6
2020	522.6	80.0	45.4	448.2	117.1	450.0	0.0
2021	262.2	100.0	25.2	481.9	0.0	23.1	0.0
2022	283.3	115.0	29.0	489.9	172.5	175.7	0.0
2023	276.4	98	32.6	514.8	0	407.3	0

Table 6.6: Annual BML Demonstration water balance (in Mm^3)

Year	Rain	SWE	Runoff	Evap	Pump In	Pump _Out	Dredge _ Out	FT Settlement
2014	2.37	0.42	0.20	3.00	6.56	7.35	0.00	6.24
2015	1.96	0.39	0.13	3.50	6.01	7.34	0.00	3.84
2016	3.02	0.39	0.31	3.62	3.10	2.89	0.00	2.64
2017	2.20	0.31	0.17	3.64	2.84	1.40	0.00	2.52
2018	3.07	0.77	0.40	3.33	2.82	1.20	0.00	1.92
2019	2.54	0.54	0.20	3.59	6.25	3.55	0.34	1.44
2020	4.02	0.62	0.35	3.45	0.90	3.47	0.00	1.20
2021	2.02	0.77	0.19	3.71	0.00	0.18	0.00	1.20
2022	2.18	0.89	0.22	3.77	1.33	1.35	0.00	1.32
2023	2.13	0.75	0.25	3.96	4.56	3.14	0.00	1.08

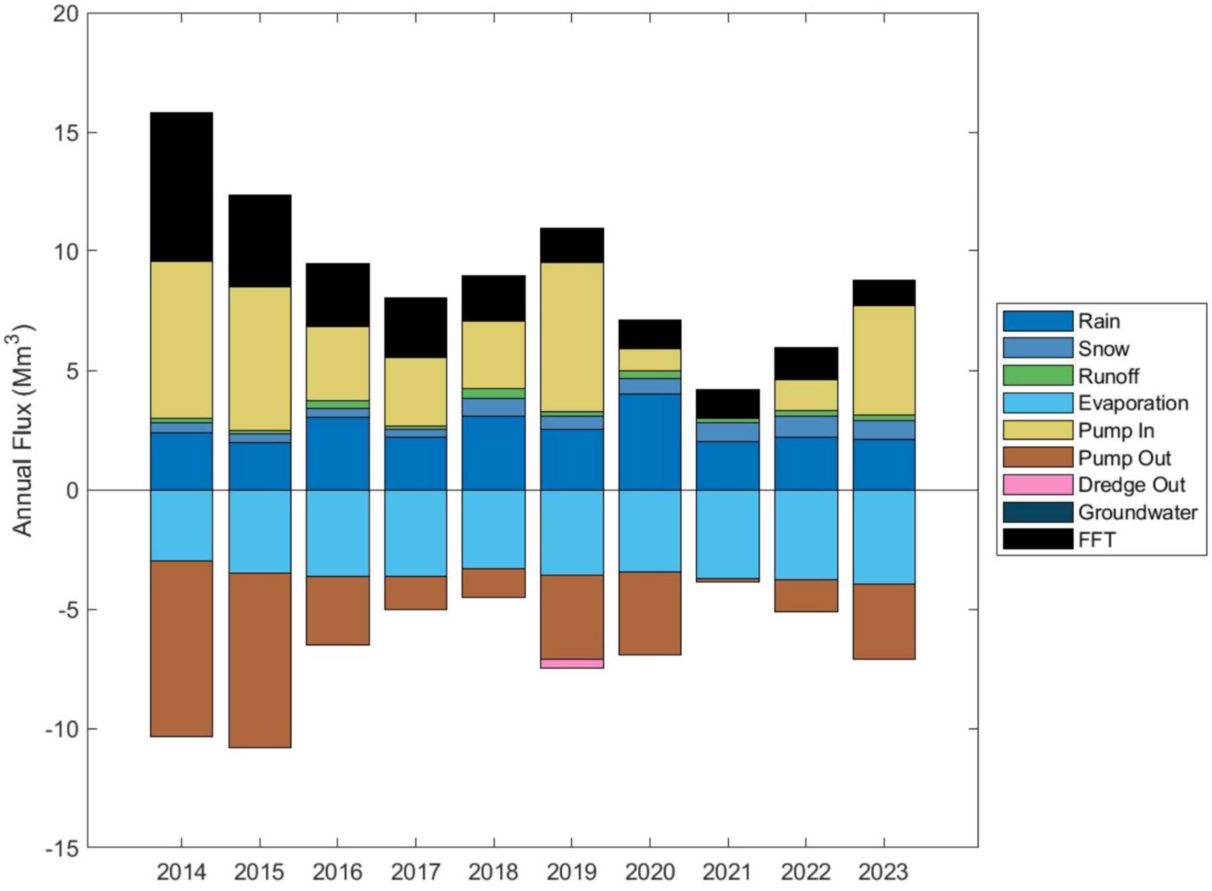


Figure 6-19: Annual BML Demonstration water balance in Mm^3.

6.2.2 Methane and Carbon Dioxide fluxes

In 2023, unfortunately, issues with infrastructure and logistical constraints resulted in no CO_2 and CH_4 fluxes on the lake were directly measured. Existing results are shared below (Figure 6-20, Figure 6-21).

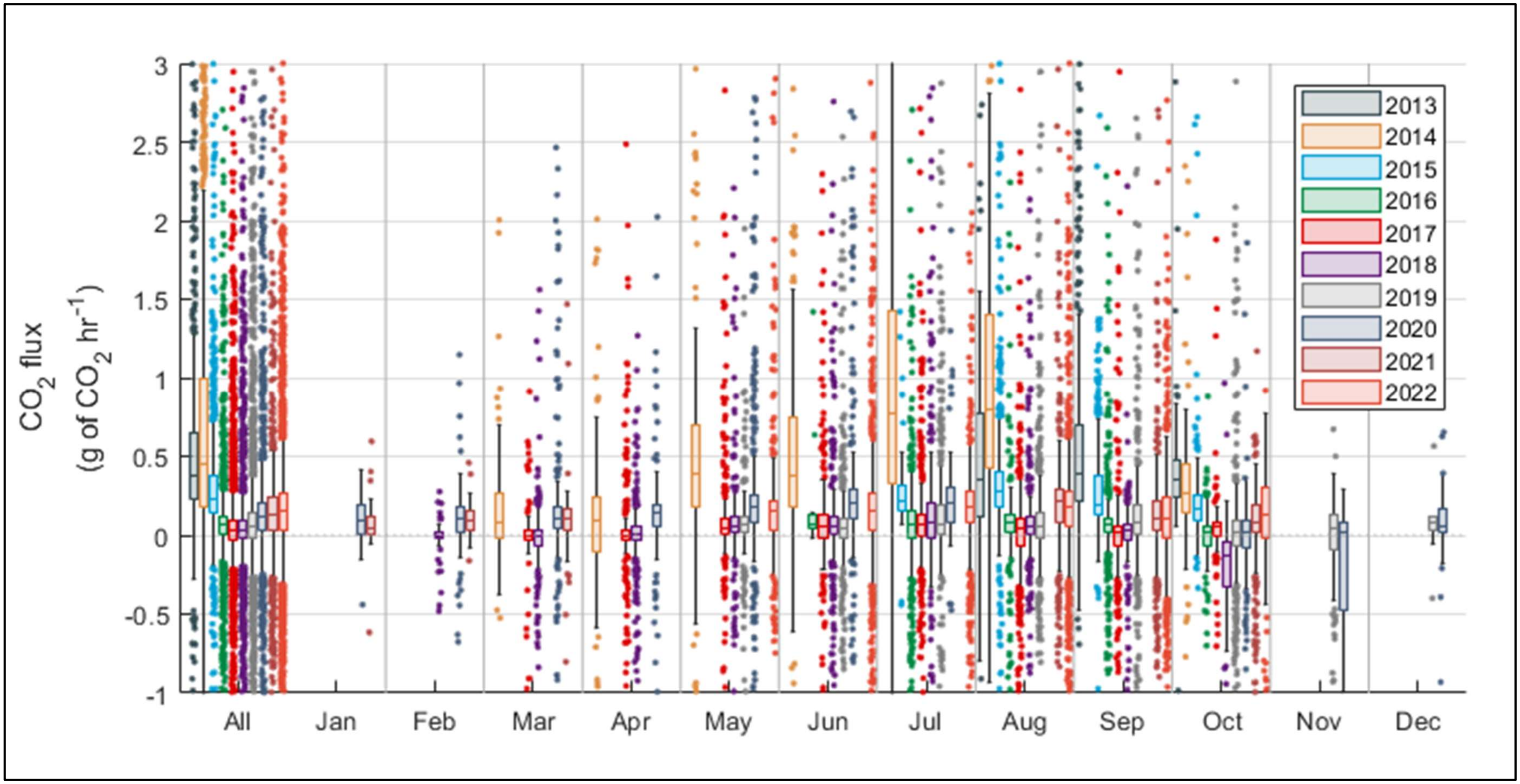


Figure 6-20: Annual and monthly binned CO₂ fluxes from BML Demonstration.

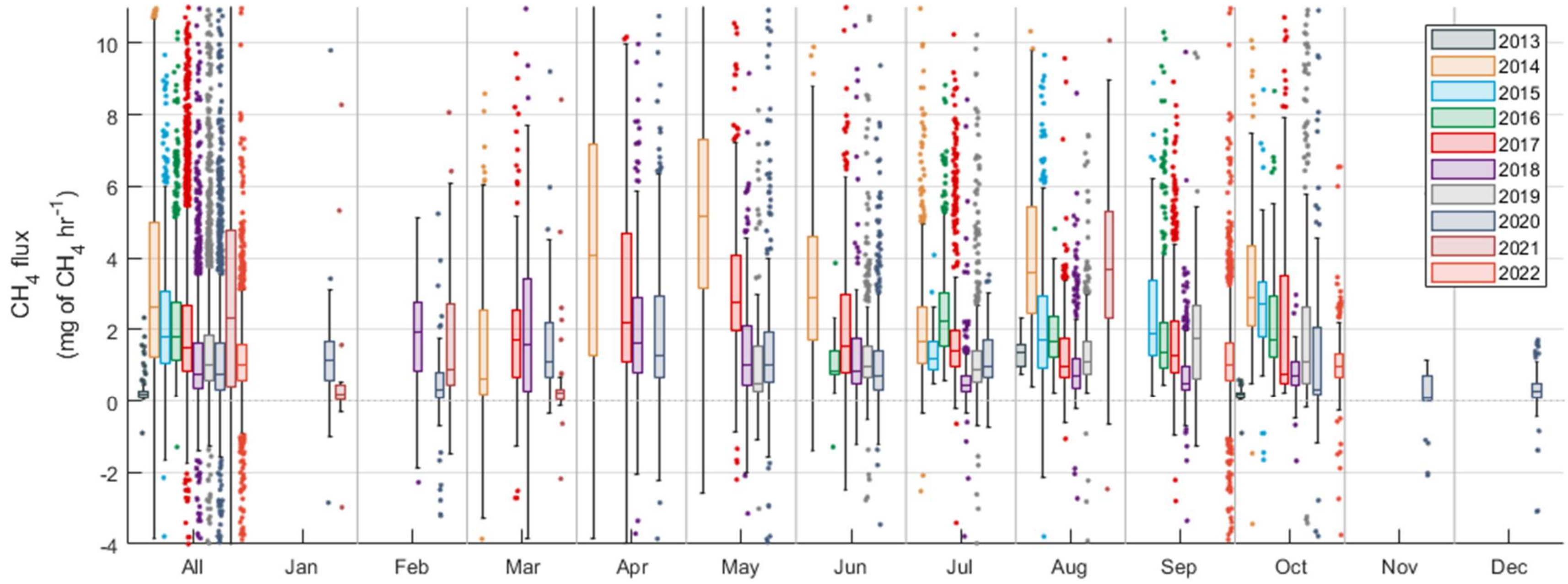


Figure 6-21: Annual and monthly binned CH₄ fluxes from BML Demonstration.

6.2.3 Surface Water Quality Assessment

Table 6.7 below summarizes the key findings from the BML Demonstration surface water quality assessment.

Table 6.7: BML Demonstration Surface Water Quality Assessment Key Findings

BML Demonstration Surface Water Quality Assessment Key Findings	
In-situ and Conventional Physico-Chemical Variables	
Summary of Observations	• Dimictic water cap with typical patterns of mixing in spring and fall and stratification in winter and summer. • Elevated concentrations of monovalent anions (e.g., chloride and sulphate) and cations (sodium) compared to fresh water. • Slightly alkaline pH.
Temporal Trends	• Climate-driven seasonal patterns are evident; formation of ice-cover in winter, turnover in spring and fall, and summer stratification. • Cation composition has been dominated by sodium. Anion composition indicates no dominant water type; however, chloride is relatively more abundant than the other anions. Both ratios in BML Demonstration have shifted gradually over the years, while remaining comparable with OSPW originating from the WIP • Decreased concentrations of major anions, cations, and TDS since 2013. • Decreased concentrations of suspended sediments have occurred since the alum treatment in 2016, particularly within the surface and mid-strata. Concentrations also decrease at the bottom depth strata with continuing consolidation of FT at the mudline.
Spatial Trends	• Seasonal suboxic conditions in deep waters, during periods of stratification. • Higher turbidity in the BML Demonstration water cap near the FT surface.
Guideline Exceedances (long-term)	• Dissolved oxygen concentrations less than minimum guideline requirements in the hypolimnion during winter, through summer stratification and into the beginning of the fall season. • Chloride and sulphide concentrations remained greater than long-term guideline for protection of aquatic life.
Nutrients	
Summary of Observations	• Primary nutrients (i.e., nitrogen- and phosphorus-containing compounds) are available in BML Demonstration in sufficient concentrations to support primary production.

BML Demonstration Surface Water Quality Assessment Key Findings	
	• Variation in nutrient concentrations observed among seasons and depth strata within BML Demonstration, related to expected biogeochemical processes. • Nutrient concentrations and associated variables indicate BML Demonstration is an “oligo-mesotrophic” lake on the aquatic productivity scale.
Temporal Trends	• Seasonal variations of nitrate and nitrite observed, both with concentrations during winter. • Similar to 2022, nutrient concentrations in 2023 were lower than in previous years.
Spatial Trends	• Depth-related variation in nutrient concentrations: • BML Demonstration bottom layer potential source of ammonia. • Total phosphorus concentrations greater within the surface and bottom depth strata.
Guideline Exceedances (long-term)	• Ammonia concentrations often lower than guidelines. Generally, the frequency of exceedances has decreased since 2013.
Metals	
Summary of Observations	• Concentrations of total and dissolved bismuth, cadmium, silver, thallium, and tin, and dissolved beryllium, chromium, and titanium were often near or below analytical detection limits. • Seasonal variability present, with concentrations generally higher in winter.
Temporal Trends	• Concentrations of most metals have decreased in BML Demonstration since commissioning. • Metals that showed the steadiest declines are molybdenum, antimony, selenium, and sulphur.
Spatial Trends	• Metal concentrations were relatively homogenous through the water column, except for total chromium and manganese, which are greater in the bottom depth strata.
Guideline Exceedances (long-term)	• Boron concentrations consistently greater than long-term guidelines. • Sporadic observations of concentrations greater than guidelines for several metals e.g., total chromium, however, unlike in 2022 dissolved aluminum and total zinc were below guidelines in 2023. • Many metals display decreasing trends, with concentrations moving towards guideline compliance or more frequently falling within guideline compliance compared to historical proportions of sample exceedances.
Organics	
Summary of Observations	• Some petroleum-associated compounds continued to be measurable in BML Demonstration:

BML Demonstration Surface Water Quality Assessment Key Findings	
	○ Naphthenic acids, total phenolics, alkylated and parent PAHs, and F2 and F3 hydrocarbons. • Most volatile organics (e.g., F1 hydrocarbons, benzene, ethylbenzene, xylene, toluene) were near or below analytical detection limits.
Temporal Trends	• Highest concentrations of PAH, F2 and F3 hydrocarbons were in summer. • Improvements to the extraction method for NA in 2016 have resulted in higher concentrations being reported from 2016 onwards. However, a decreasing trend is observed in 2023.
Spatial Trends	• Limited depth-related variation, with PAH concentrations marginally higher in bottom water samples.
Guideline Exceedances (long-term)	• F2 hydrocarbons consistently greater than guidelines. [NOTE: F2 hydrocarbons have only a short-term guideline.] • A few exceedances of total phenolics in 2023. • No anthracene exceedances in 2023 and very few pyrene exceedances.

The surface water quality component of the 2023 program consisted of both winter and open-water sampling events. During winter, samples were collected from immediately below the ice shelf, at 4 m increments through the water column, and from near bottom (within 0.2 m of the FT mudline). During open water, the following depth determination protocols were established for analytical sampling according to station type:

- BML Demonstration platform stations:
    - When the relation between dissolved oxygen and depth was approximately linear, water samples were collected from near-surface (0.3 m), mid depth (arithmetic midpoint of the water column), and near-bottom (within 0.2 m of the FT mudline); and
    - When the relation between dissolved oxygen and depth was more strongly sigmoidal (indicative of the presence of a chemocline), water samples were collected from near-surface (0.3 m), mid-depth (inflection point of sigmoidal curve), and near-bottom (within 0.2 m of the FT mudline).
- BML Demonstration Pump-Out: one set of samples was collected from the pump intake depth of 2.0 m.
- BCR Pump-In: one set of samples was collected from the pump intake depth of 1.5 m.

Samples were collected from each sample depth for all water quality variables except chlorophyll *a* and phaeophytin *a*, which were collected only at the surface depth, and methylmercury, which was collected at the near-bottom depth from the platform stations and deep station D04 during winter. Water samples were collected by lowering an appropriately pre-cleaned and rinsed Van Dorn bottle to the desired depth and triggering the sampler by releasing a messenger down the cable line; multiple grabs were required to fill all the sample containers for each station, to measure the sampling variables. Containers for discrete depth samples were filled directly from the sampler.

Analytical water quality samples from BML Demonstration stations were collected with a 4.2-L horizontal Van Dorn sampler. BCR Pump-In samples were collected with a 2.2-L horizontal Van Dorn sampler, to avoid any potential for cross-contamination between BML and BCR.

Water quality samples were collected and preserved according to protocols specified by BV Labs. Nitrile gloves were worn during collection. Water samples were stored and shipped to BV Labs in coolers containing ice packs. Samples submitted for analysis of dissolved variables were filtered by the laboratory and not in the field. In situ profile data were collected using a YSI multi-meter probe, water clarity was measured using a Secchi disk, and light penetration profiles were completed using a Li-Cor light sensor. A summary of the sampling program is provided in Table 6.8 to Table 6.10.

Table 6.8: Locations, analyses, and frequency of snow, ice, and water quality sampling at Base Mine Lake Demonstration, winter 2023

Media Sampled	Station ID	In Situ Water Quality[1] and PAR[2]	Conventional Variables	Ions	Nutrients and Biological Indicators	General Organics	Total and Dissolved Metals	Total and Methylmercury	Hydrocarbons	PAHs	Dissolved Gasses
Water (🌢)[3]	BML12_PLATFORM 1_C[4]	-	-	-	-	-	-	-	-	-	-
Ice (◊)[3]	BML12_PLATFORM 2_NE[4]	-	-	-	-	-	-	-	-	-	-
Snow (❄)[3]	BML12_PLATFORM 3_SW[5]	🌢	🌢	🌢	🌢	🌢	🌢	🌢	🌢	🌢	🌢
	BML13_D04	🌢	🌢❄◊	🌢❄◊	🌢❄◊	🌢❄	🌢❄◊	🌢❄◊	🌢❄	🌢❄	🌢
	BML15_D26[4]	-	-	-	-	-	-	-	-	-	-

[1] Temperature, pH, specific conductivity, dissolved oxygen concentration and saturation, and turbidity depth profiles.

[2] Photosynthetically active radiation (PAR) depth profile using a Li-Cor.

[3] Surface water, ice, and snow samples collected between March 7 and March 9.

[4] Platform stations 1 and 2 and deep station D26 were not accessible during winter 2023.

[5] Platform station 1 was not sampled for ice and snow during winter 2023 due to time and access constraints.

- = not sampled

Table 6.9: Locations, analyses, and frequency of surface water sampling at Base Mine Lake Demonstration, open-water 2023

Station Type	Station ID	In Situ Water Quality[1]	PAR[2]	Conventional Variables	Ions	Nutrients and Biological Indicators	Total and Dissolved Metals	General Organics	Hydrocarbons and PAHs	Oil and Grease	Total and Methylmercury
Deep Stations	BML12_PLATFORM 1_C	💧	💧	💧	💧	💧	💧	💧	💧	-	💧
	BML12_PLATFORM 2_NE	💧	💧	💧	💧	💧	💧	💧	💧	-	💧
	BML12_PLATFORM 3_SW	💧	💧	💧	💧	💧	💧	💧	💧	-	💧
	BML13_D04[3]	💧	💧	-	-	-	-	-	-	-	-
	BML15_D26[4]	💧	💧	-	-	-	-	-	-	-	-
Lake Pump-out	BML_PUMP_OUT	💧	💧	💧	💧	💧	💧	💧	-	💧	-
Reservoir Pump-in	BCR_PUMP_IN	💧	-	💧	💧	💧	💧	💧	-	-	-

[1] Temperature, pH, specific conductivity, dissolved oxygen concentration and saturation, turbidity, and light penetration depth profile.

[2] Photosynthetically active radiation (PAR) depth profile measured using a Li-Cor.

[3] Deep station D04 was visited in July and October 2023.

[4] Deep station D26 was visited in October 2023.

💧 = water measurement/sample collection

Table 6.10: Total number of analytical water quality samples collected from Base Mine Lake Demonstration and Beaver Creek Reservoir, 2013 to 2023.

Sample location and season	Number of samples collected per year										
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Winter sampling											
Base Mine Lake	0	26	30	3	63	79	21	72	48	23	18
Open-water sampling											
Base Mine Lake	74	356	358	223	349	335	339	56	272	66	65
Beaver Creek Reservoir	19	26	22	29	37	25	23	2	8	3	5

6.2.3.1 Trends in conductivity profiles through time

Lake-wide specific conductivity has decreased progressively in BML Demonstration (Figure 6-22); median specific conductivity at the BML Demonstration platform and deep stations in 2013 was approximately 3,600 µS/cm, which has decreased to a median value of approximately 2,500 µS/cm in 2023. Consistent with results from previous years, specific conductivity also was seasonally variable in 2023, with a median value of 2,746 µS/cm at platform stations in winter relative to around 2,400 µS/cm median at deep stations in the open-water season. Major ions have been relatively equally distributed throughout the water column since monitoring began in 2013, with no evidence of vertical variation among depth strata.

6.2.3.2 Sodium

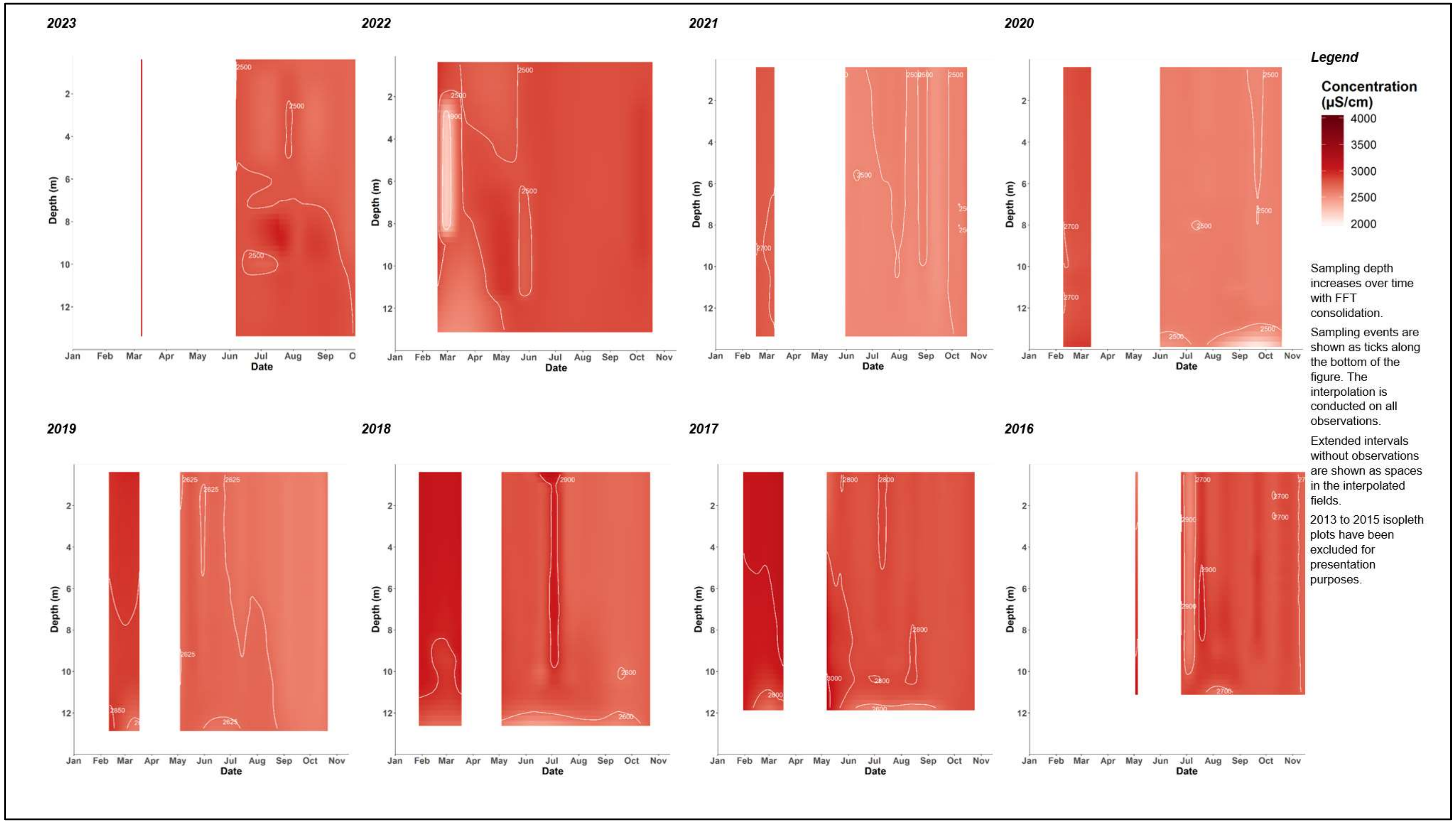
Sodium has remained the dominant cation in BML Demonstration since monitoring began in 2013, although concentrations have declined slightly in recent years (Figure 6-23). The seasonal median concentrations of sodium in 2023 ranged from 488 mg/L in fall to 569 mg/L in winter, which were slightly lower than the historical seasonal medians (544 to 697 mg/L). Sodium has remained evenly distributed throughout the water column since 2014.

6.2.3.3 Chloride

Chloride has remained the dominant anion in BML Demonstration since monitoring was initiated in 2013, with absolute concentrations decreasing over time. Median chloride concentrations in 2023 were similar in all seasons, ranging from 340 to 390 mg/L, while falling below the historical seasonal median range of 390 mg/L in fall to 480 mg/L in winter (Figure 6-24). Chloride concentrations have exceeded the GoA (2018) long-term surface water quality guideline for the protection of aquatic life since 2013. Consistent with previous years, there were no vertical concentration gradients of chloride in BML in 2023.

6.2.3.4 Sulphate

Sulphate continued to be the second-most abundant anion in BML Demonstration in 2023, exhibiting only minor variation among seasons and across depth strata (Figure 6-25). Seasonal median sulphate concentrations in 2023 ranged from 140 to 155 mg/L, which were slightly lower than the seasonal medians from previous years (ranged from 170 to 230 mg/L). Sulphate concentrations were below the long-term surface water quality guideline for the protection of aquatic life in 2023 (Figure 6-25).



Sampling depth increases over time with FFT consolidation.

Sampling events are shown as ticks along the bottom of the figure. The interpolation is conducted on all observations.

Extended intervals without observations are shown as spaces in the interpolated fields.

2013 to 2015 isopleth plots have been excluded for presentation purposes.

Figure 6-22: In situ specific conductivity (µS/cm) profiles measured at Base Mine Lake Demonstration platform and deep stations, 2016 to 2023.

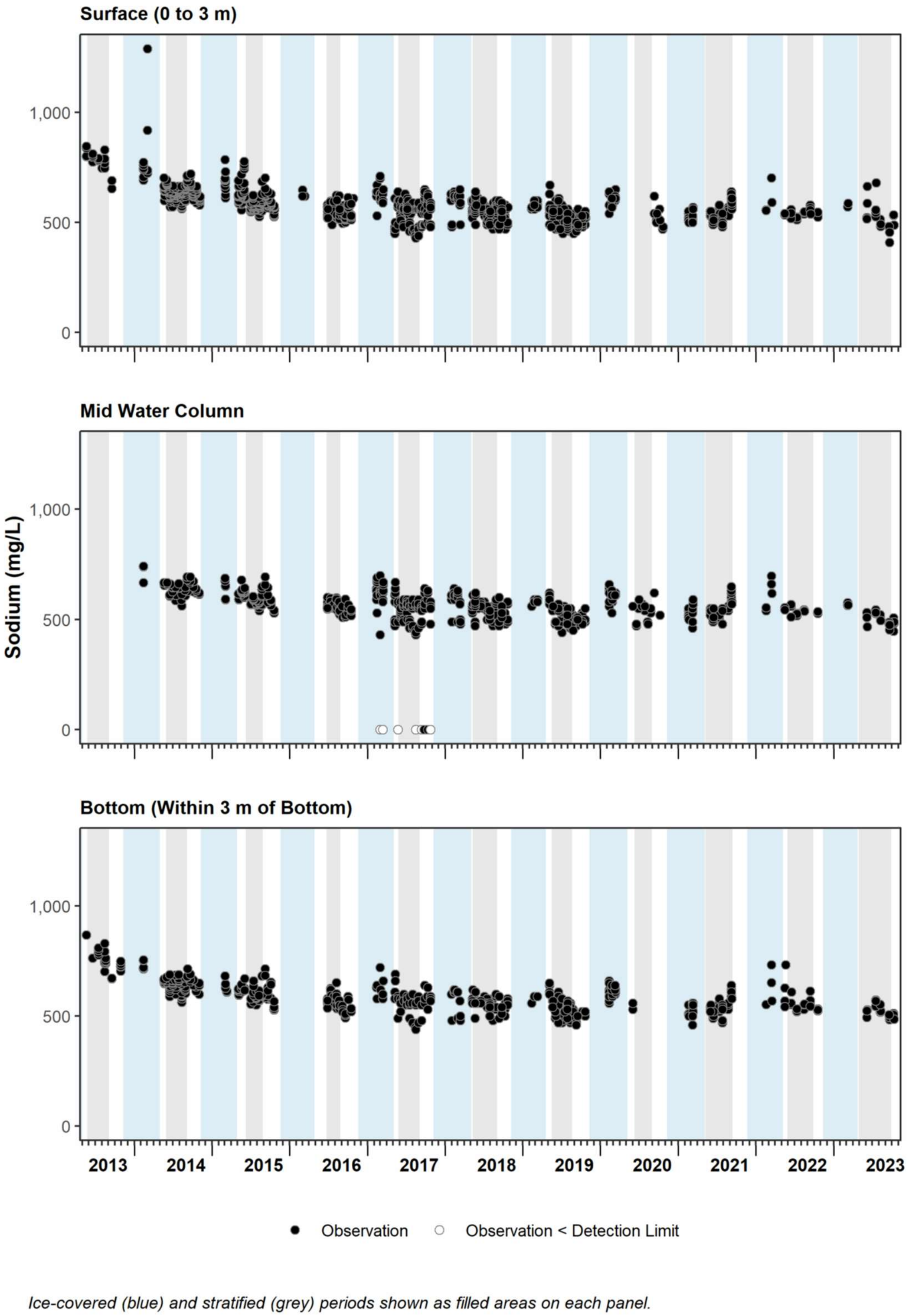


Figure 6-23: Sodium in Base Mine Lake Demonstration, 2013 to 2023.

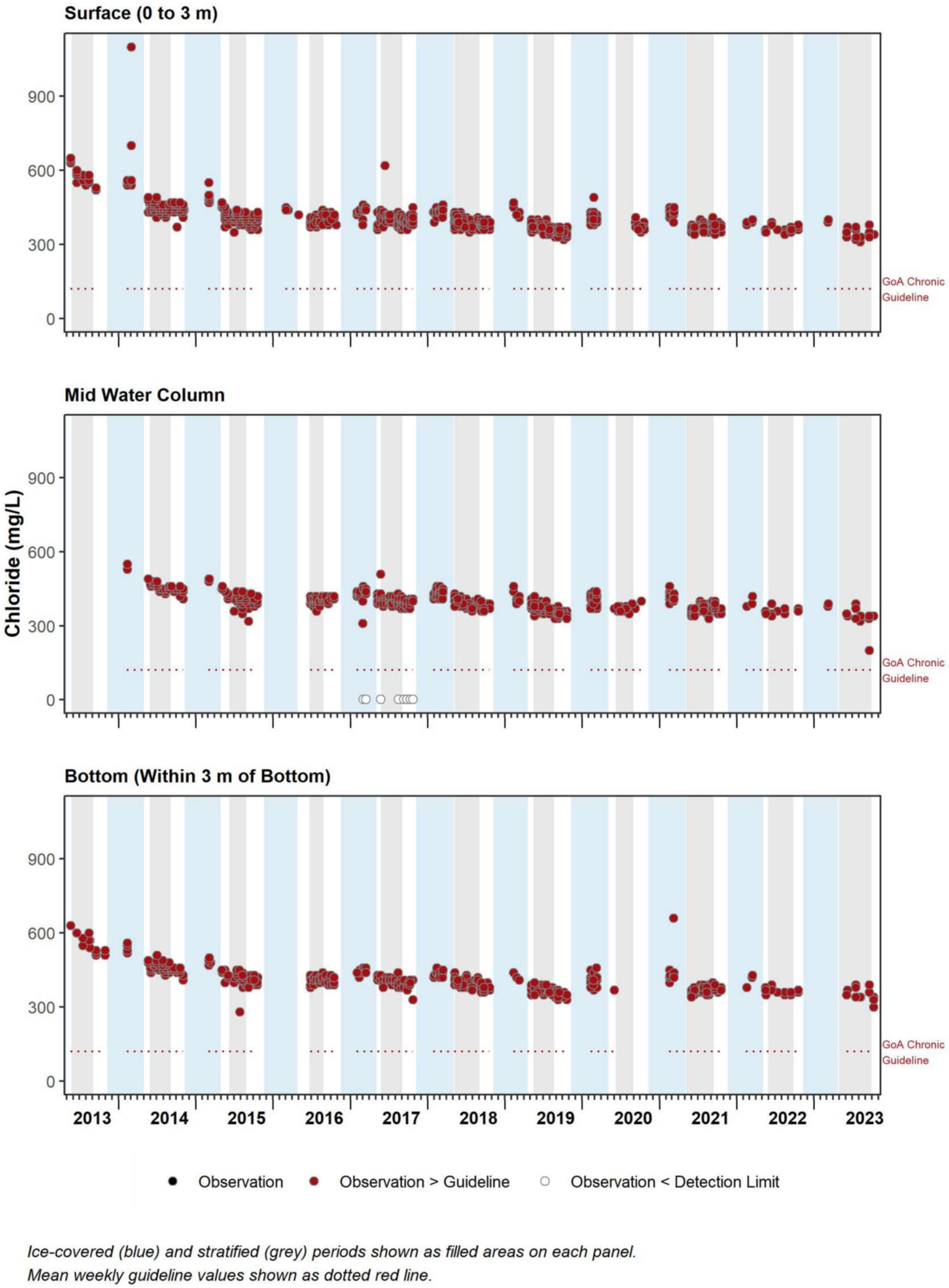
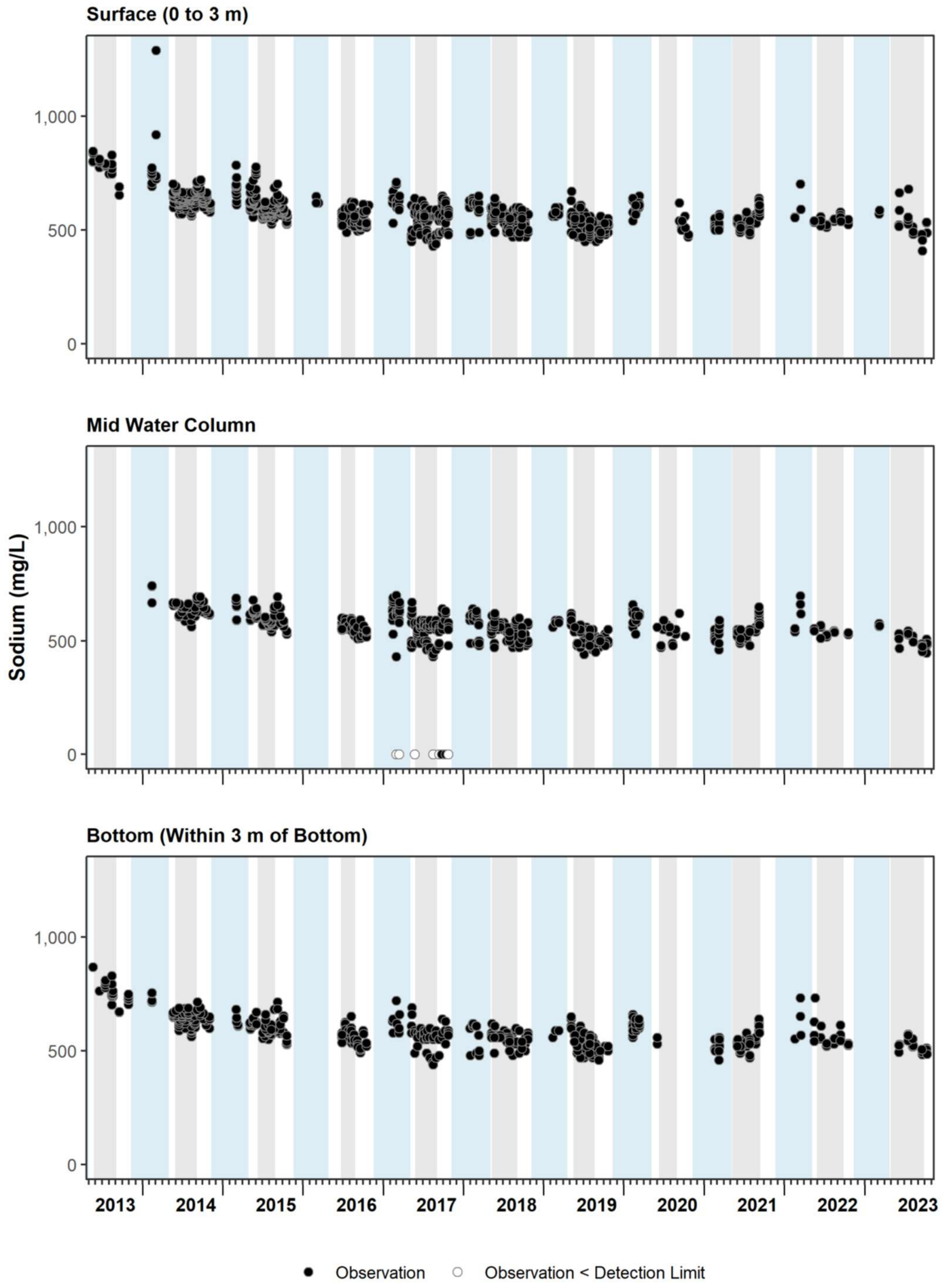


Figure 6-24: Chloride in Base Mine Lake Demonstration, 2013 to 2023.

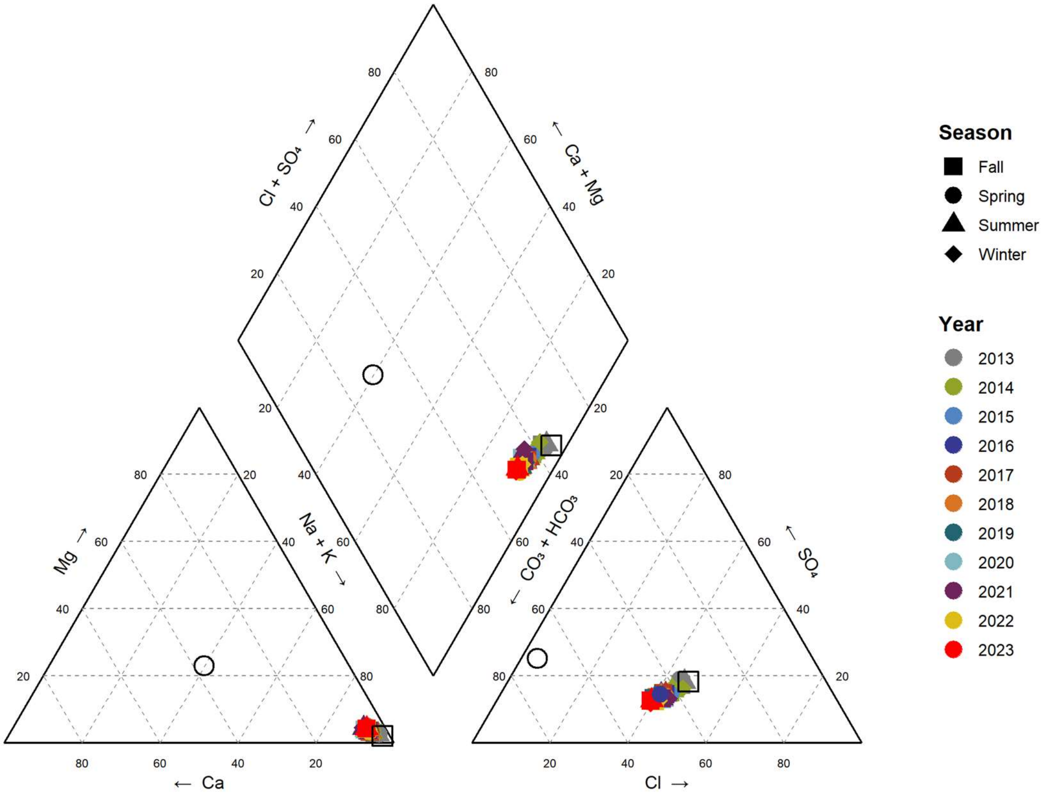


Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.

Figure 6-25: Sulphate in Base Mine Lake Demonstration, 2013 to 2023.

6.2.3.5 Water cap Ionic Composition

The major ion composition of BML Demonstration water has been relatively stable since 2013 (Figure 6.26). The composition of cations is strongly dominated by monovalent cations, especially sodium, which comprised over 90% of the cation composition. Divalent magnesium and calcium ions occurred at very low concentrations. The total equivalent concentrations of anions should be approximately equal to the total cation concentration in natural waters; however, all of bicarbonate, chloride, and sulphate contribute appreciably to the anionic concentration with a percent composition of 59:29:13, respectively. Cation and anion ratios in BML Demonstration have shifted gradually over the years, while remaining comparable to OSPW originating from the WIP; the ionic signatures of OSPW and BML Demonstration have been, and continue to be, substantially different than BCR.



Note: OSPW from the West In-Pit (WIP) is presented as mean ionic composition pre-commissioning and represented as open square, BCR (2013-2023) represented as open circle

Figure 6-26: Piper plots of major ion composition in BML.

6.2.3.6 Metals

Total and dissolved forms of 29 metals, total ultra-low-level mercury, and methylmercury were analyzed in support of the 2023 program. Temporal trends among individual metals vary, but focusing on those with detectable concentrations in >50% of the collected samples (Table 6.11, and Table 6.12), the following dominant temporal patterns have been observed in BML since commissioning:

- Those metals/metalloids with the greatest decrease in concentration from 2013 through 2022 include: antimony, molybdenum (Figure 6-29), selenium (Figure 6-30), uranium and sulphur.

  For these, the inter-annual variation in concentration was much less obvious than the consistent decrease over the ten-year monitoring period.
- Concentrations of several other metals/metalloids have declined discernibly but to a lesser degree from 2013 through 2023, including arsenic (Figure 6-27), boron (Figure 6-28), cadmium, and chromium. For arsenic and boron, there has been an approximate 40% decrease in concentration over the ten-year time span, while the average annual chromium concentration in BML Demonstration water has decreased approximately eight-fold.
- A longer-term trend, from 2013 through 2023, was not readily discernible for many of the metals, including copper, lead, mercury and methylmercury, nickel, zinc, and total and dissolved iron.
- Dissolved aluminum increased in response to the September 2016 alum treatment but returned to pre-treatment levels the following year and has remained stable through 2023.

Metal concentrations were relatively homogenous through the water column in 2023, except for total manganese, which was present in higher concentrations in the bottom 3 m of the water cap. Most metals also exhibited some seasonal variability, with median concentration generally highest during winter in 2023; this result was consistent with the historically higher medians observed during winter and spring.

Table 6.11: Proportion (as %) of surface water quality total metals from Base Mine Lake Demonstration that were above detection limit, 2013 to 2023.

Analyte	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Total Metals											
Aluminum (Al)-Total	100	100	100	100	100	100	100	100	99	100	100
Antimony (Sb)-Total	100	99	100	100	99	100	97	100	99	99	97
Arsenic (As)-Total	100	100	100	100	100	100	100	100	100	100	100
Barium (Ba)-Total	100	100	100	100	100	100	100	100	100	100	100
Beryllium (Be)-Total	41	88	100	53	27	56	31	92	68	61	34
Bismuth (Bi)-Total	5	3	50	10	2	3	5	5	4	17	1
Boron (B)-Total	100	100	100	100	100	100	100	100	100	100	100
Cadmium (Cd)-Total	50	39	76	15	7	10	4	10	12	14	7
Calcium (Ca)-Total	-	-	-	100	100	100	100	100	100	100	100
Chromium (Cr)-Total	68	64	100	59	34	94	79	100	86	84	49
Cobalt (Co)-Total	100	100	100	100	100	100	100	100	100	100	100
Copper (Cu)-Total	98	56	100	92	40	78	74	97	89	98	67
Iron (Fe)-Total	100	100	100	100	98	100	100	100	99	100	100
Lead (Pb)-Total	98	97	100	93	80	100	99	100	99	99	82
Lithium (Li)-Total	100	100	100	100	100	100	100	100	100	97	100
Manganese (Mn)-Total	100	100	100	100	100	100	100	100	100	100	100
Magnesium (Mg)-Total	-	-	-	100	100	100	100	100	100	100	100
Mercury (Hg)-Total	55	100	99	74	99	96	91	93	98	100	100
Methyl Mercury-Total	-	88	66	46	61	100	100	100	100	82	45
Molybdenum (Mo)-Total	100	100	100	100	100	100	100	100	99	99	100
Nickel (Ni)-Total	100	100	100	100	100	100	100	100	100	100	100
Potassium (K)-Total	-	-	-	100	100	100	100	100	100	98	99
Selenium (Se)-Total	100	99	100	94	99	99	87	100	96	97	57
Silicon (Si)-Total	100	100	100	100	100	100	100	100	100	100	100
Silver (Ag)-Total	23	28	99	18	4	10	5	2	9	1	3
Strontium (Sr)-Total	100	100	100	100	100	100	100	100	100	100	100
Sodium (Na)-Total	-	-	-	100	100	100	100	100	100	100	100
Sulphur (S)-Total	100	98	100	85	100	100	100	100	99	97	100
Thallium (Tl)-Total	9	63	100	27	7	20	17	59	37	49	25
Tin (Sn)-Total	0	2	14	1	6	1	0	0	0	43	3
Titanium (Ti)-Total	82	51	91	23	11	50	50	83	59	65	3
Uranium (U)-Total	100	100	100	100	100	100	100	100	100	100	100
Vanadium (V)-Total	100	91	100	100	100	100	97	100	100	99	97
Zinc (Zn)-Total	98	53	94	24	12	16	15	46	75	87	46
Zirconium (Zr)-Total	96	100	100	100	100	100	100	100	100	100	100

All numbers rounded to the nearest percent except for those between 99.5 and 99.9, which were rounded down.

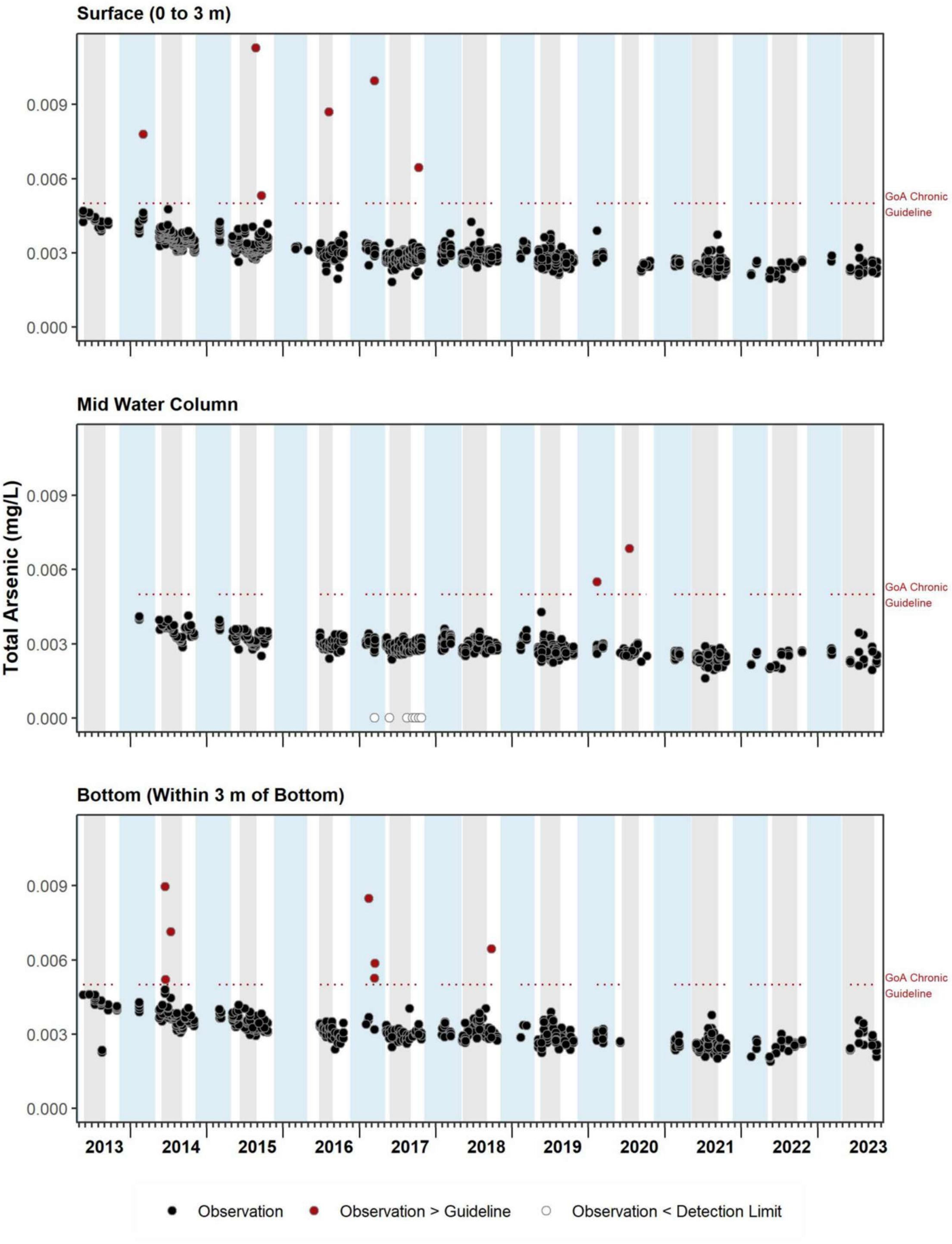
🟩	Metals present above RDLs in all water samples
🟧	Metals present above RDLs in 50 to 99% of water samples
🟨	Metals present above RDLs in less than 50% of water samples
⬜	Not sampled

Table 6.12: Proportion (as %) of surface water quality dissolved metals from Base Mine Lake Demonstration that were above detection limit, 2013 to 2023.

Analyte	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Dissolved Metals											
Aluminum (Al)-Dissolved	84	77	99	100	100	97	87	99	100	100	100
Antimony (Sb)-Dissolved	100	100	100	100	100	100	99	98	100	98	93
Arsenic (As)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Barium (Ba)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Beryllium (Be)-Dissolved	9	0	5	1	0	4	5	38	10	10	1
Bismuth (Bi)-Dissolved	0	0	13	3	1	2	2	8	1	9	0
Boron (B)-Dissolved	100	100	100	100	100	100	100	100	100	100	99
Cadmium (Cd)-Dissolved	32	6	6	7	0	6	2	6	7	2	1
Calcium (Ca)-Dissolved	-	-	-	100	100	100	100	100	100	100	100
Chromium (Cr)-Dissolved	16	3	23	5	1	13	9	49	37	45	6
Cobalt (Co)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Copper (Cu)-Dissolved	93	75	99	89	50	76	83	94	94	100	82
Iron (Fe)-Dissolved	68	85	99	33	10	29	65	80	82	100	100
Lead (Pb)-Dissolved	41	51	50	26	20	26	27	85	62	59	61
Lithium (Li)-Dissolved	100	100	100	100	100	100	100	100	100	98	99
Magnesium (Mg)-Dissolved	-	-	-	100	100	100	100	100	100	100	100
Manganese (Mn)-Dissolved	100	100	90	93	82	76	80	100	90	100	100
Molybdenum (Mo)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Nickel (Ni)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Potassium (K)-Dissolved	-	-	-	100	100	100	100	100	100	100	100
Selenium (Se)-Dissolved	100	96	100	99	100	96	88	97	94	95	63
Silicon (Si)-Dissolved	100	100	100	100	100	100	100	100	100	98	100
Silver (Ag)-Dissolved	21	1	39	8	0	12	5	9	7	3	0
Sodium (Na)-Dissolved	-	-	-	100	100	100	100	100	100	100	100
Strontium (Sr)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Sulphur (S)-Dissolved	100	100	100	100	100	100	100	97	100	97	97
Thallium (Tl)-Dissolved	25	7	48	13	0	12	2	21	26	19	100
Tin (Sn)-Dissolved	0	0	3	0	2	0	0	0	0	16	3
Titanium (Ti)-Dissolved	16	1	12	1	1	7	6	43	31	41	6
Uranium (U)-Dissolved	100	100	100	100	100	100	100	100	100	100	100
Vanadium (V)-Dissolved	100	95	99	100	100	100	95	97	92	99	97
Zinc (Zn)-Dissolved	89	50	88	44	50	55	77	100	72	85	52
Zirconium (Zr)-Dissolved	96	100	100	100	100	100	100	100	100	99	97

All numbers rounded to the nearest percent except for those between 99.5 and 99.9, which were rounded down.

🟩	Metals present above RDLs in all water samples
🟧	Metals present above RDLs in 50 to 99% of water samples
🟨	Metals present above RDLs in less than 50% of water samples
⬜	Not sampled



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.

Figure 6-27: Total arsenic in Base Mine Lake Demonstration, 2013 to 2023.

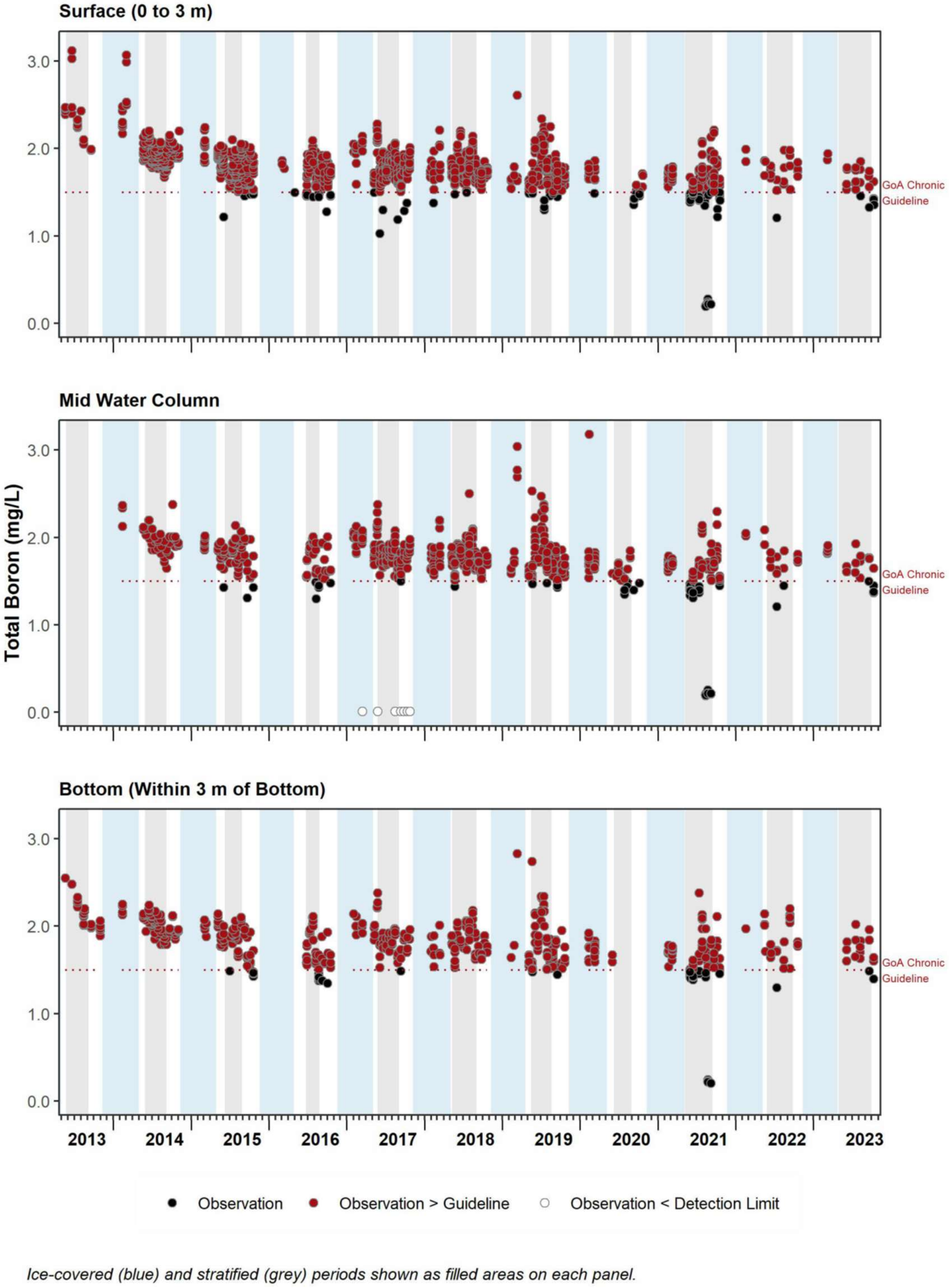


Figure 6-28: Total boron in Base Mine Lake Demonstration, 2013 to 2023.

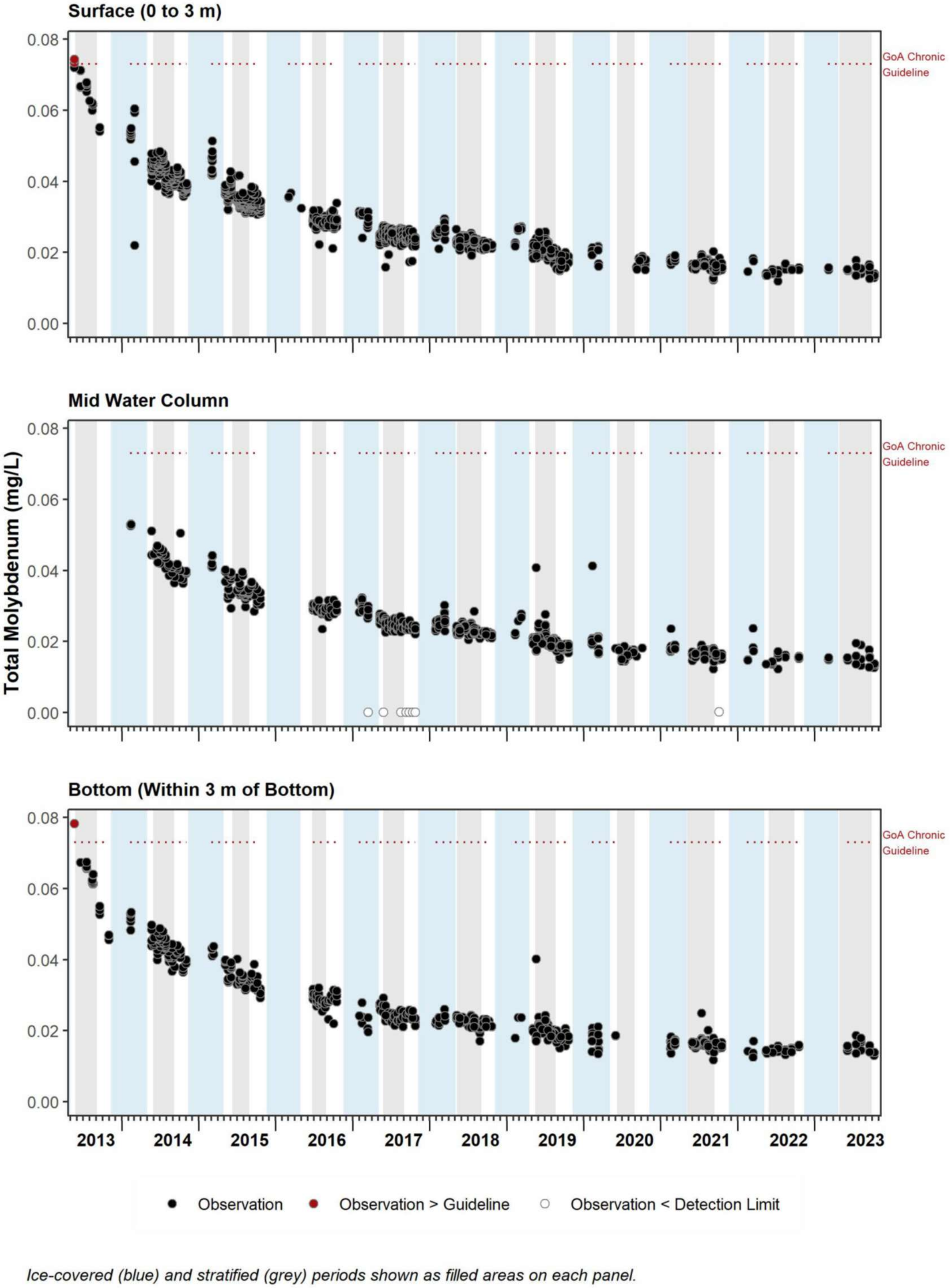


Figure 6-29: Total molybdenum in Base Mine Lake Demonstration, 2013 to 2023.

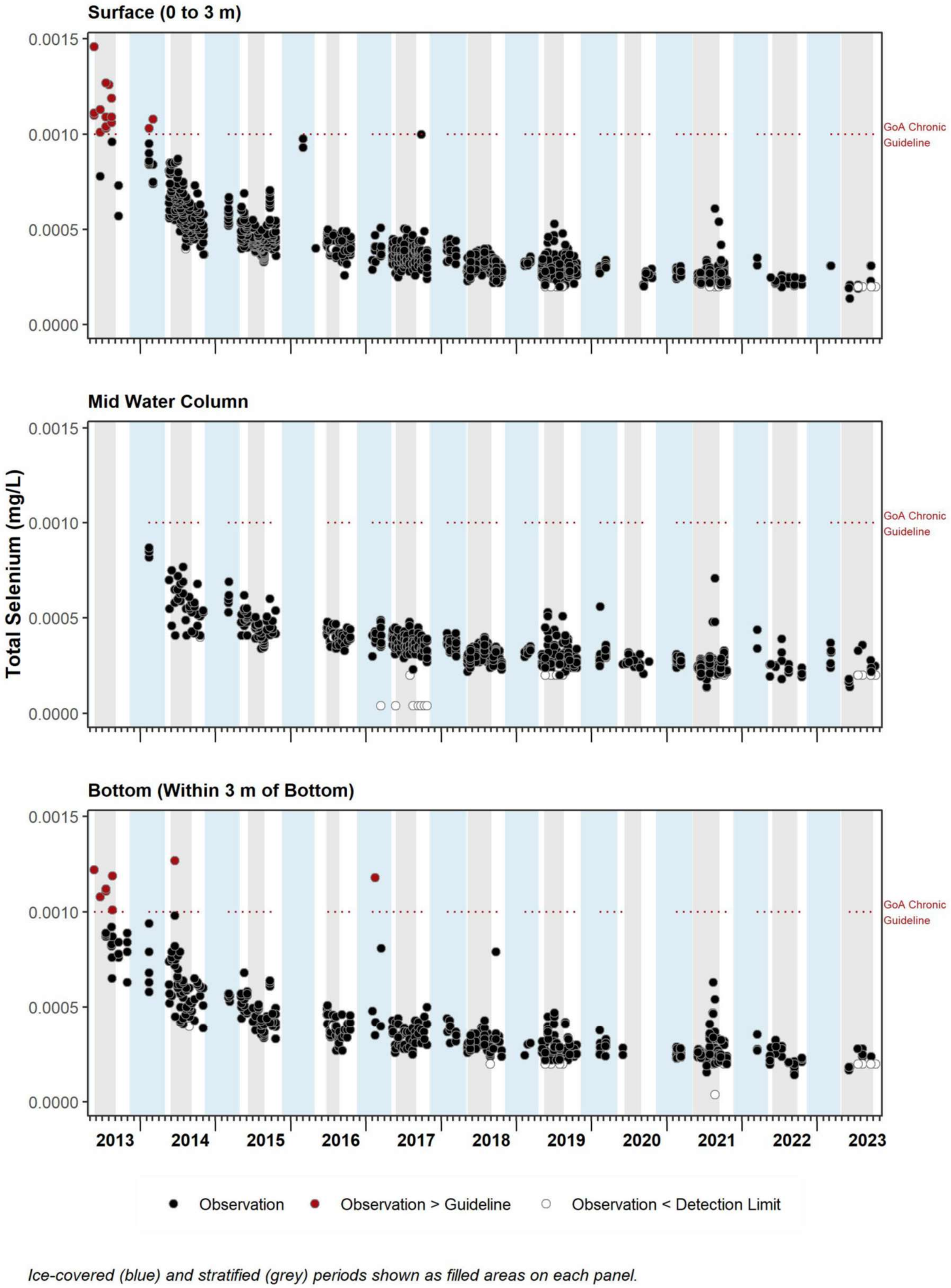


Figure 6-30: Total selenium in Base Mine Lake Demonstration, 2013 to 2023.

6.2.3.7 Organics

Oil sands extractable acids, more commonly known as naphthenic acids (NA), are one of the principal components of OSPW and are associated with OSPW toxicity (Allen 2008). Classic naphthenic acids are limited to those compounds with the formula $C_nH_{2n+z}O_2$, but OSPW also consists of related compounds containing sulphur and nitrogen. Given the high diversity of acid extractable organic acids, quantification is challenging and method dependent. Analysis and reporting of NA results were adjusted in 2016, which should be considered when comparing observations from 2016 onwards with previous years. Specifically, discrepancies between NA concentrations analyzed by the Syncrude R&D Analytical Services laboratory and those reported by the contracted commercial laboratory (BV Labs) during a 2016 review of concurrently analyzed NA samples (Ripmeester and Duford 2019). This review determined that all BV Labs analyses conducted prior to 2016 had used a method that deviated from the requested Syncrude 1995 method[7]. The change in NA concentrations that are apparent between the pre-2016 and 2016-to-present results (Figure 6-31) are an artifact of the laboratory adjustment to the correct Syncrude 1995 method.

The NA median concentrations in BML Demonstration have remained relatively stable since 2013 (Figure 6-31). The greatest seasonal median concentration in 2022 was recorded in winter (29 mg/L) while the lowest seasonal medians were observed in summer and fall (27 mg/L). This seasonal trend of marginally higher winter medians was consistent with the historical dataset. The decrease in naphthenic acid concentrations from the late winter period in a calendar year through summer and fall was clearly evident in 2013, 2014, and 2019, but not apparent for many other years. A small decrease in naphthenic acid concentrations over the calendar year was observed in 2022. No discernible vertical variations in NA concentrations have been observed in BML to date. NA concentrations in BCR have remained below detection limits (1 to 2 mg/L) since 2016.

Total polycyclic aromatic hydrocarbons (PAH) concentration is calculated by summing concentrations of 27 parent and 28 alkylated PAH species. Approximately 89% of the total PAH in BML consisted of alkylated species in 2022, whereas most of the parent PAH species were below detection limits (<0.005 µg/L) in over 50% of all samples Total PAH concentrations in BML Demonstration have shown within-year variation, as well as variation at different depths of the water column (Figure 6-32). Of the 10 parent PAH species with guidelines, only pyrene exceeded the GoA (2018) long-term surface water quality guidelines for the protection of aquatic life in

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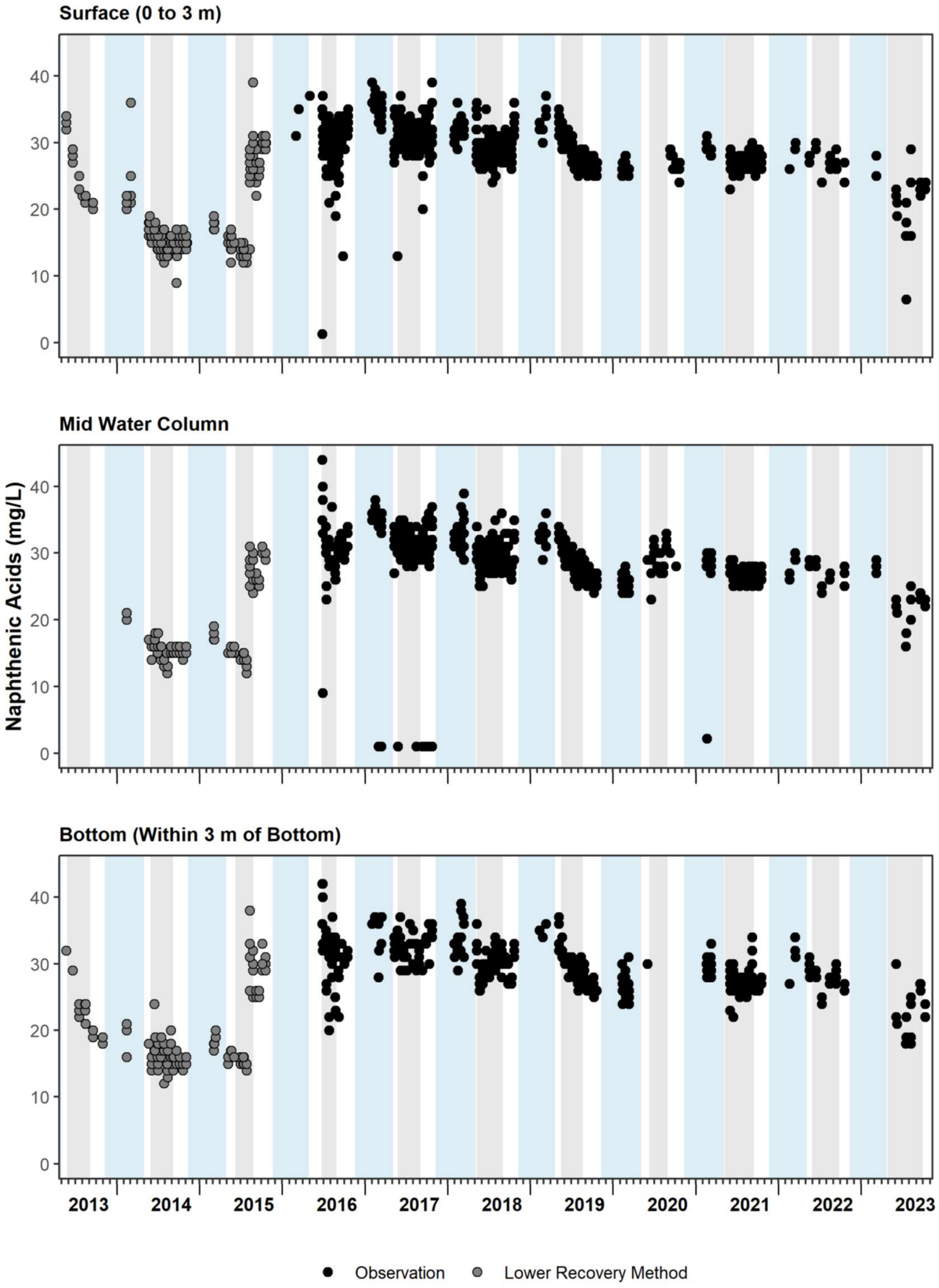
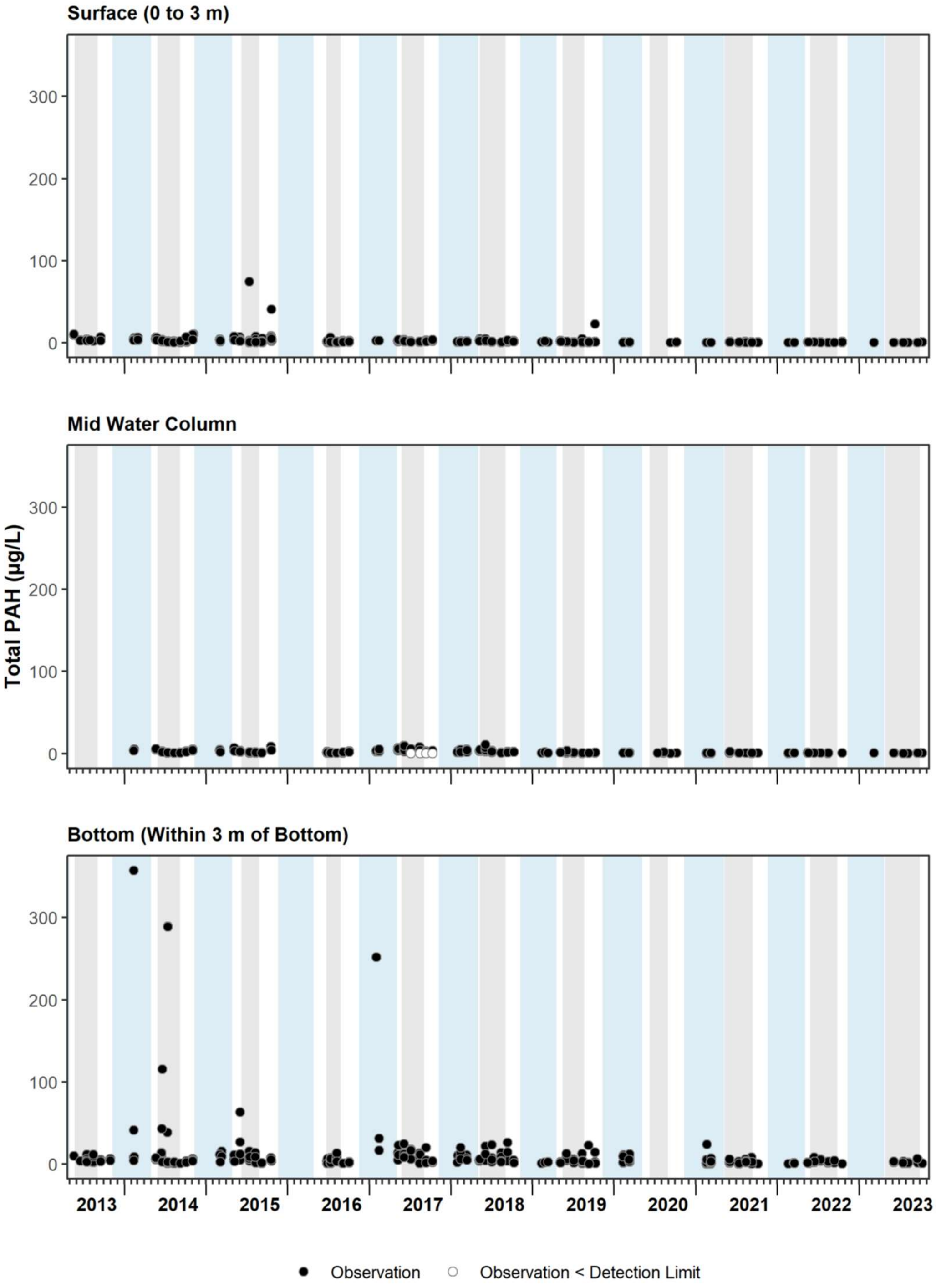
[7] Syncrude 1995 method (Jivraj et al. 1995) requires acidification of the water sample followed by extraction in dichloromethane (DCM), while commercial laboratory methods use hexane for extraction; the use of hexane results in a less efficient extraction process that does not recover all acid extractable organics from the water sample.

2023. 3.9% of samples exceeded pyrene guidelines, which is lower than 2022 exceedances (6.2%).



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.

Figure 6-31: Naphthenic acids in Base Mine Lake Demonstration, 2013 to 2023



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.

Figure 6-32: Total polycyclic aromatic hydrocarbons in Base Mine Lake Demonstration, 2013 to 2023.

6.2.4 Groundwater Quality Assessment

Table 6.13 below summarizes the key findings from the BML Demonstration groundwater assessment.

Table 6.13: BML Demonstration Groundwater Assessment Key Findings

BML Demonstration Groundwater Assessment Key Findings
• Overall, groundwater level and quality results for 2023 appear to be following consistent trends with or fall within previously measured ranges of the historical data collected between 2013 and 2022.
• Groundwater levels, and inferred flow directions, exhibit similar trends to prior years and indicate the presence of both groundwater inflow and discharge zones around BML's perimeter.
• Comparison with site-wide data suggest that the BML Demonstration water elevation of about 308.5 masl and currently recorded BML Demonstration area groundwater levels, which are in the 280 to 325 masl range, are overall relatively low compared to immediate surrounding areas (i.e., the BML Demonstration area acts as a zone of groundwater convergence) which likely reflects residual effects from historical mine operations (i.e., groundwater level recovery).
• Once groundwater levels have fully equilibrated, it may be expected that groundwater inflows to BML Demonstration will occur from the south and west and that groundwater losses from BML Demonstration may occur towards the northeast. In the shallow zone, the rate of these groundwater exchanges with the freshwater cap may be controlled by the hydraulic conductivity of overburden deposits and/or shallow bedrock while in the intermediate and deep zones these groundwater exchanges are likely limited by the low hydraulic conductivity of the FT (i.e., are likely small).
• The key indicator variables evaluated do not suggest any significant adverse changes since BML Demonstration was filled. Groundwater flow in and out of the lake is negligible.
• The ionic composition (piper diagrams) and isotopic plots indicate distinct groundwater geochemical differences between the shallow, intermediate, and deep sediments around BML Demonstration. There were no notable changes in the ionic composition of the groundwater from prior years.
○ Among the monitoring wells, there were 94 statistically significant trends detected among 20 water quality variables (particularly for major ions). ○ Major ions (bicarbonate, calcium, chloride, magnesium, sodium, and sulphate) comprise 32 of the 94 identified trends. ○ There was a net increase of 8 significant increasing trends and a net increase of 10 significant decreasing trends compared to the 2022 groundwater assessment
• The monitoring program results suggest that the infilling of the lake has altered subsurface pressures and groundwater flows, and that there is ongoing evolution in groundwater geochemistry. The evolution in chemistry is likely related to

BML Demonstration Groundwater Assessment Key Findings
chemical evolution processes (e.g., ion exchange) which may be associated with groundwater movement.
• Groundwater levels appear to be stabilizing over time (i.e., rates of change are diminishing in recent monitoring), and significant geochemical change may be occurring in only about 23% of instances (i.e., the significant trends) while 77% of the 408 trend analyses conducted suggest relatively stable groundwater quality.

From 2013 to 2020, groundwater monitoring has been conducted at 27 wells in 11 well nests on the north, east, and west sides of BML Demonstration. In October 2021, 14 groundwater wells in 4 existing Syncrude well nests on the southern edge of BML (South Bison Hills) were inspected and 8 were added to the Groundwater program to provide a more complete picture of groundwater levels and quality around BML Demonstration. There are now 41 monitoring wells in the BML network which are classified as shallow, intermediate, or deep (Figure 6-33). The wells are classified using isotope analysis and grouping the screened unit by depositional material. The monitoring well location information, formations, and well status in 2022 are indicated in Table 6.14. Continuous groundwater elevations are being recorded at seven deep well locations with dataloggers. Well status is discussed below.

For 2023 the spring (June 2023) and fall (November 2023) groundwater monitoring events consisted of verifying the status of the 41 monitoring wells that are now a part of the BML Program as well as conducting groundwater level measurements and collecting groundwater samples in active monitoring wells. Fourteen of the 41 wells cannot be sampled due to gas concerns, obstructions, bitumen presence, damage, or insufficient water. Monitoring wells are classified as active if sufficient water is available to fill sampling bottles to the minimum volume required for laboratory testing. There were 27 monitoring wells classified as active and sampled during the spring sample event. Only 26 wells could be sampled for the fall even as BML12_MW04 was frozen. Monitoring and sampling activities at the active wells included:

- Observation of well condition and status;
- Measurement of casing stickup, depth to bottom, and groundwater levels;
- Measurement of field variables (pH, temperature, specific conductivity, and dissolved oxygen);
- Downloading of datalogger data if a transducer is present; and
- Collection and submission of groundwater samples for analysis of conventional physicochemical variables, nutrients, dissolved metals, organics and hydrocarbons, and stable isotopes.

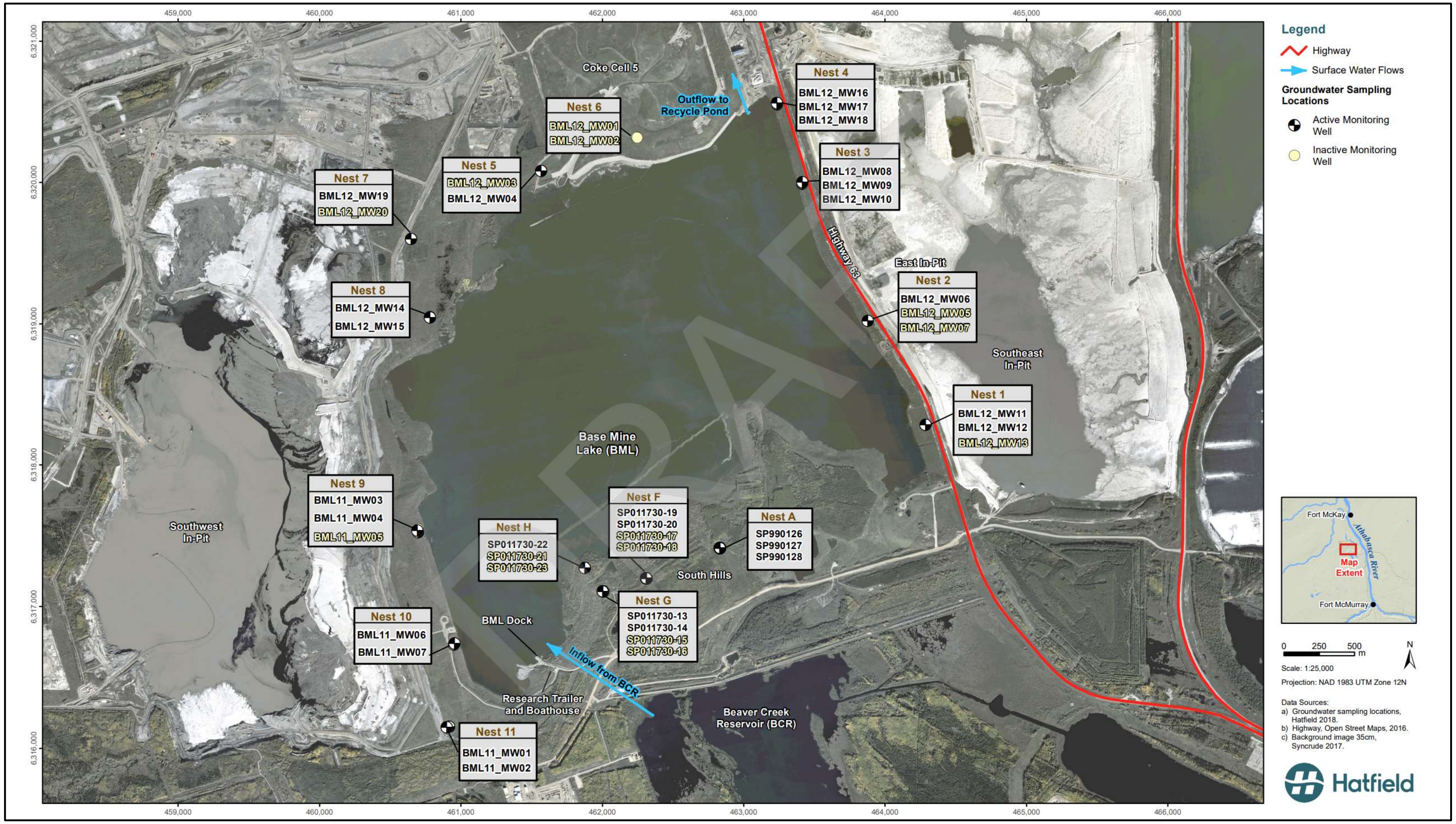


Figure 6-33: Groundwater sampling locations for the 2023 Base Mine Lake Demonstration Monitoring Program.

Table 6.14: Groundwater sampling locations for the 2022 Base Mine Lake Demonstration Monitoring Program

Nest	Location	Monitoring Well ID	Well Grouping	Screened Unit	Ground Elevation (masl)	Screen Elevation (masl)		Location (UTM NAD 83 12V)		Well Status and Water Level Logger Installation
						Top	Bottom	Easting	Northing	
1	Hwy 63 Berm	BML12_MW13	-	Dam Core	311.6	293.2	290.1	464285	6318277	Inactive[1]
		BML12_MW12	3	Dam Core	311.7	272.1	269.0	464286	6318282	Active
		BML12_MW11	3	Basal Water Sands	311.6	251.0	247.9	464286	6318284	Active & Logger Installed
2	Hwy 63 Berm	BML12_MW06	2	Dam Shell	311.5	296.6	293.6	463878	6319022	Active
		BML12_MW07	-	Dam Core	311.3	272.8	269.7	463880	6319013	Inactive[2]
		BML12_MW05	-	Basal Water Sands	311.5	245.7	242.6	463879	6319017	Inactive[2]
3	Hwy 63 Berm	BML12_MW10	2	Dam Shell	311.0	295.1	292.1	463415	6320002	Active
		BML12_MW08	1	Dam Core	311.0	274.4	271.4	463413	6319991	Active
		BML12_MW09	3	Basal Water Sands	311.1	245.6	242.5	463414	6319997	Active & Logger Installed
4	Hwy 63 Berm	BML12_MW18	1	Dump	310.7	287.9	284.8	463234	6320561	Active
		BML12_MW17	1	Dump	310.9	267.8	264.8	463236	6320557	Active
		BML12_MW16	3	Km Pond Mud	310.8	241.7	238.6	463237	6320553	Active & Logger Installed
5	Coke Cell 5	BML12_MW04	1	Dragline Rejects	319.3	284.4	281.3	461567	6320080	Active
		BML12_MW03	-	Dragline Rejects	319.3	265.9	262.9	461571	6320082	Inactive[2]
6	Coke Cell 5	BML12_MW02	-	Dragline Rejects	331.5	305.9	302.8	462247	6320317	Inactive[3]
		BML12_MW01	-	Dragline Rejects	331.5	267.5	264.4	462242	6320320	Inactive[3]
7	Southwest Dam	BML12_MW20	-	Dump	326.4	300.6	297.5	460654	6319600	Inactive[4]
		BML12_MW19	2	Devonian Limestone	326.6	256.6	253.6	460648	6319603	Active & Logger Installed
8	Southwest Dam	BML12_MW15	1	Kc Fill	313.7	303.6	300.6	460782	6319045	Active
		BML12_MW14	2	Devonian Limestone	313.7	246.8	243.8	460782	6319048	Active & Logger Installed
9	Southwest Dam	BML11_MW05	-	Dam Shell	309.5	290.6	287.6	460697	6317546	Inactive[5]
		BML11_MW04	2	Dam Shell	309.7	281.4	278.3	460693	6317537	Active
		BML11_MW03	3	Dragline Rejects	309.8	265.5	262.4	460696	6317526	Active
10	Southwest Dam	BML11_MW07	2	Dam Shell	308.9	295.8	292.7	460955	6316740	Active
		BML11_MW06	2	Dam Core	309.0	275.3	272.3	460952	6316732	Active & Logger Installed
11	In-situ south of Southwest Dam	BML11_MW02	2	In-situ Kc	333.7	316.3	313.3	460901	6316150	Active
		BML11_MW01	2	In-situ Kcw	333.7	305.8	302.8	460917	6316153	Active & Logger Installed[6]
A	South Bison Hills Shore	SP990126	1	Kc Fill	325.8	313.0	311.5	462832	6317411	Active
		SP990127	1	Kc Fill	324.9	321.9	320.4	462830	6317416	Active
		SP990128	1	Kc Fill	325.4	317.8	316.3	462832	6317413	Active
F	South Bison Hills Mid-East	SP11730_17	-	Kc Fill	328.9	325.5	324.0	462307	6317208	Inactive[5]
		SP11730_18	-	Kc Fill	328.9	320.7	319.1	462308	6317206	Inactive[5]
		SP11730_19	1	Kc Fill	328.8	315.1	313.1	462310	6317204	Active
		SP11730_20	1	Kc Fill	328.8	260.2	258.7	462315	6317199	Active
G	South Bison Hills Mid-West	SP11730_13	1	Kc Fill	319.5	316.4	314.9	462003	6317106	Active
		SP11730_14	1	Kc Fill	319.5	311.3	309.7	462005	6317106	Active
		SP11730_15	-	Kc Fill	319.5	305.8	304.3	462008	6317105	Inactive[5]
		SP11730_16	-	Kc Fill	319.5	260.0	258.5	462012	6317104	Inactive[3]
H	South Bison Hills East	SP11730_21	-	Kc Fill	316.6	312.0	310.5	461874	6317269	Inactive[5]
		SP11730_22	1	Kc Fill	316.6	308.4	306.8	461875	6317471	Active
		SP11730_23	-	Kc Fill	316.5	302.8	301.3	461877	6317273	Inactive[5]

[1] Gas concerns

[2] Obstruction in well

[3] Heavy bitumen presence in well

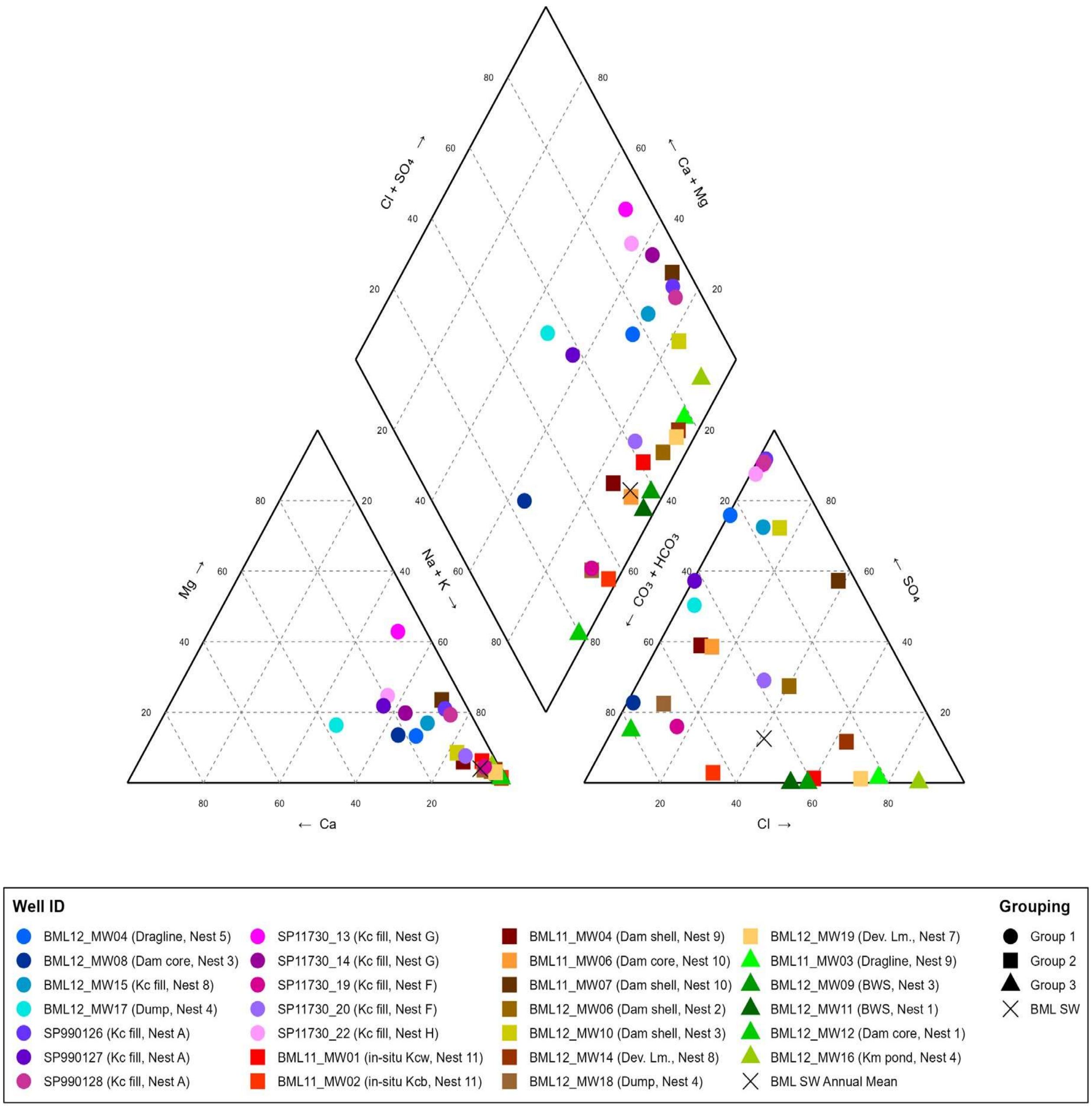
[4] Damaged well

[5] Insufficient water for sample collection

[6] Water level and barometric pressure loggers installed.

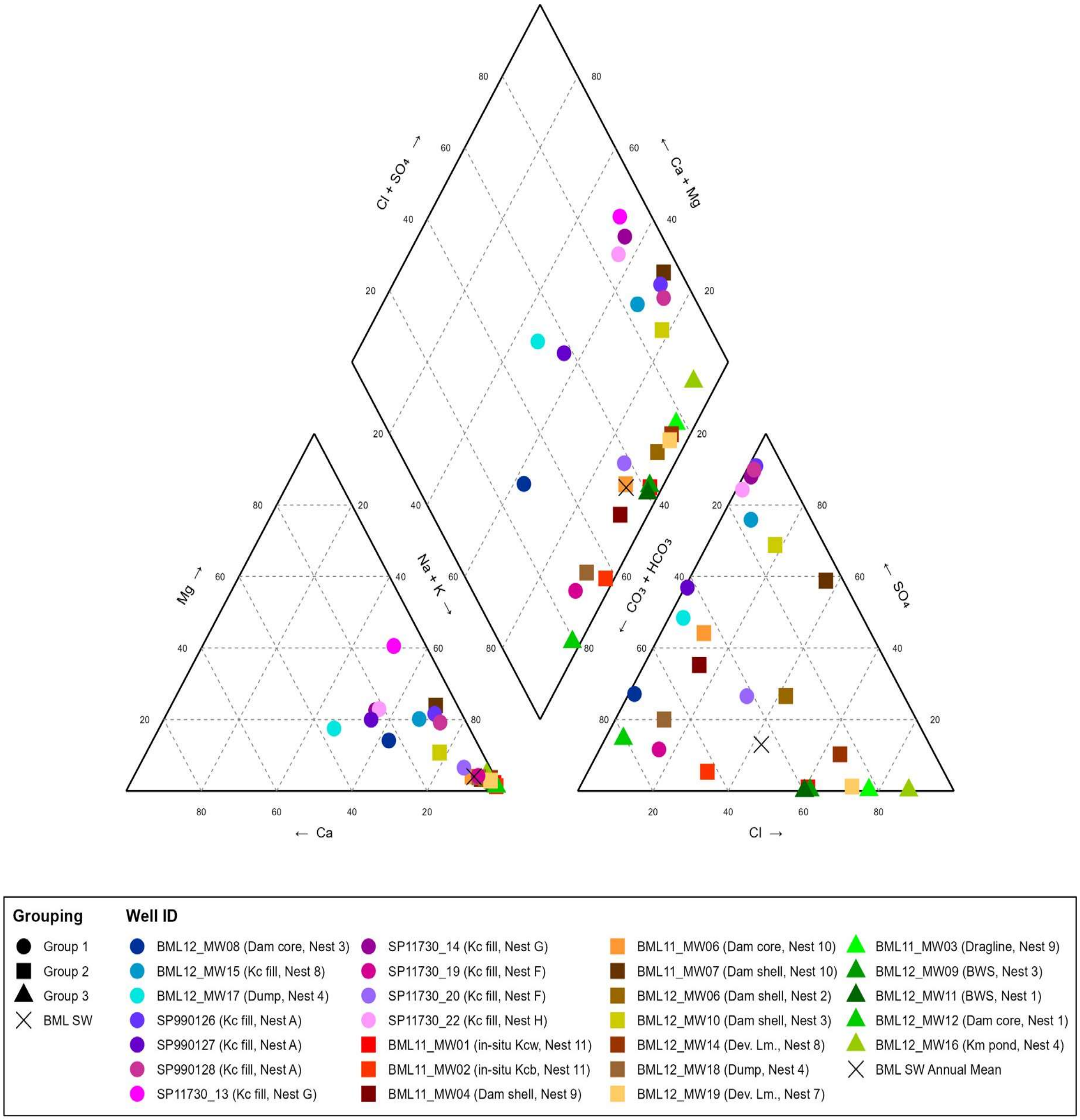
Ground and screen elevations are in metres above sea level (masl)

Piper diagrams were prepared for the June and November monitoring events and are presented in Figure 6-34 and Figure 6-35, respectively. The ionic characterization did not materially change between spring and fall and is consistent with historical results. From the piper diagrams, groundwater from wells in Group 1 would generally be characterized as a sodium potassium and sulphate type water and Group 3 as sodium potassium chloride. Sodium and potassium are the predominant cations and appear to be generally higher in the Group 2 and 3 wells. The predominance of anions varies more than the cations by group. Sulphate anions are higher in Group 1 wells and chloride in Group 3 wells. The Group 2 wells have no dominant anion type.



Discrete water chemistry for wells in Group 1 are shown in pink/purple (South Bison Hills) and blue shades, wells in Group 2 are shown in warm (red, yellow, orange, etc.) shades, and wells in Group 3 are shown in green shades.

Figure 6-34: Piper plot of ionic composition in BML Demonstration groundwater zones (Spring 2023).



Discrete water chemistry results for wells in Group 1 are shown in pink/purple (South Bison Hills) and blue shades, wells in Group 2 are shown in warm (red, yellow, orange, etc.) shades, and wells in Group 3 are shown in green shades.

Figure 6-35: Piper plot of ionic composition in BML Demonstration groundwater zones (Fall 2023).

7 Summary of Key Results from the Base Mine Lake Demonstration Research Program

The BML research program uses a multi-university, multi- and inter- disciplinary approach that focuses on the analysis and interpretation of monitoring data, hypothesis-driven research activities, and integration and collaboration among and between research programs. Research results are integrated with monitoring results on an ongoing basis, with the ultimate goal of identification and quantification of the processes and properties in BML Demonstration that are responsible for the trends observed in the monitoring program. The various components comprising the BML Demonstration monitoring and research programs are closely linked.

As mentioned previously, the current focus of the research program is to support the demonstration of the WCTT. The program also provides supporting information about key processes fundamental to the progression of BML Demonstration towards becoming a functional component of the reclaimed closure landscape. The current research programs are focused on key parameters influencing early BML development. Recently, research and technology development has been underway to build tools for detection of bitumen mats, and to monitor gas bubble driven bitumen liberation from the bitumen mats to the water surface.

Objectives of each program and key findings are outlined in the following sections. It is important to note that much of this work is underway and the results described below should be considered preliminary until the work is complete and published. The BML Demonstration monitoring and research program has a good record of publication to date, and many scientific papers are in preparation. The next five years of research will continue to focus on similar activities that have been addressed previously, however the focus of the work will primarily be to understand the dynamics of methane ebullition, turbidity, and hydrocarbon (bitumen) dynamics in the lake. Other research may be undertaken to assess potential mitigation strategies for turbidity and hydrocarbon in BML when necessary.

In 2020 and 2021, all research program activities were adapted in response to the COVID-19 pandemic and resulting safety measures. Due to site access restrictions, inter-provincial travel restrictions, and university work restrictions, all research programs were limited by sample procurement, as well as lab and office access to progress work.

7.1 Physical limnology of BML Demonstration and the potential for meromixis (Lawrence, Tedford, Pieters: University of British Columbia)

The objective of this program is to understand the circulation of BML Demonstration and its potential for meromixis. Some results are described below.

Seasonal turbidity continues a gradual decline with the exception of near the summer minimum, which has remained relatively low over the last four years. Ebullition (bubbling) is modulated by pressure throughout the year. Three more bubble traps were built and deployed in 2023 giving a total of four bubble traps. The additional bubble traps have provided new information on the spatial variability of ebullition. These new traps were lengthened to increase their capacity and modified to allow sampling the trapped gas for laboratory analysis. This work involves a complete qualitative, and in some cases quantitative, description of bathymetric/mudline features, for example, describing distribution of pock marks in space and size.

Epilimnetic dissolved oxygen concentrations are generally increasing. In late 2022, new sensors were deployed below 6 m, an essential step in tracking dissolved oxygen. Note, as the FT settles, and the water cap deepens the stability of the lake is expected to increase and the hypolimnetic dissolved oxygen near the FT interface may decrease.

Preliminary analysis of the data collected in 2023 indicates BML Demonstration did not completely mix during spring turnover. The spring of 2023 had the least mixing of any spring since 2013. The reasons for the limited mixing are a focus of investigation. Profiles collected during the winters beginning in 2017 have evidence of FT sourced salts. Beginning in the summer of 2021 there are indications of evaporation driven increases in salinity. While the salinity of BML has either decreased or remained constant the flux from settling FT has resulted in an increase in the volume of the water cap and the total mass of salt in the water cap. The salt water entering at depth may be more effective at stabilizing the lake as the depth increases. The locations of at least two potential ground water seeps have been identified and will be further investigated to determine their potential impact on salinity.

Commercial modelling packages have limited ability to capture several physical processes that are of importance in BML Demonstration. We have been working on understanding these processes, (20 or so potential mixing mechanisms identified in Lawrence *et al*. 2016) particularly waves, under ice processes, and heat transport across the water-FT interface. This work includes using and developing numerical models. Other research groups associated with BML Demonstration (University of Saskatchewan, McMaster University, University of Toronto, and Syncrude Research and Development) are also working on modelling one or more of these processes. These focused modelling efforts are the foundation for a more comprehensive model of transport in the water cap.

In 2022, a physics-based model was developed for predicting the response of ebullition to changes in atmospheric pressure, and this work has been ongoing. Future modelling will investigate the impact heat and salt flux on turbidity.

7.2 Characterization of controls on mass loading to an oil sands end pit lake (Barbour, Lindsay: University of Saskatchewan)

The objective of this program is to define mass loading to BML Demonstration by characterizing the mechanisms and distribution of heat and mass transfer from the tailings column to the overlying water column. This program examines processes controlling physical mass-transport and chemical mass-transfer across the FT-water interface in BML Demonstration. Recent findings offer insight on processes controlling mass-loading across this interface. Most of the work in this program is completed and published.

Key research topics include:

- identifying the dominant mechanisms of mass and heat transfer within the tailings and determining how the rates associated with these mechanisms change with time.
- determining if the rate of pore water release defined by FT settlement measurements adequately describe heat and mass fluxes from the fine tailings into the water cap.
- elucidating if mass transport is enhanced by other mechanisms occurring in the lake, for example, overturning of the water cap, ebullition of dissolved gases; and

- determining how pore water release affects the chemical and thermal conditions across the FT-water interface.

The principal research activities undertaken during 2020/2021 were the development, testing and refinement of gas pressure sensors to understand gas pressure in the FT. The gas pressure sensors were deployed in spring 2022 and will collect data over the open water season. Results will be shared when that work is complete.

A key paper (Francis *et al.* 2022) was published from this research that demonstrates a positive relationship between $CH_{4(aq)}$ saturation and enhanced mixing, showing that ebullition enhances internal mass loading.

7.3 Laboratory studies investigating chemical flux across tailings-cap water zones, simulating an end pit lake in the Athabasca oil sands region (Ulrich, Flynn, Siddique: University of Alberta)

This project used an experimental approach to quantify physical and biogeochemical processes in a laboratory system simulating an end pit lake. The experiments are quantifying the flux of chemicals from underlying FT to overlying cap water, mediated by advection, diffusion, ebullition, and biogeochemical reactions transforming clay minerals. This work was completed and has been summarized in previous reports and theses and scientific journal articles.

7.4 Field investigation of BML water cap oxygen concentrations, consumption rates and key BOD/COD constituents affecting oxic zone development (Warren, Slater: University of Toronto, McMaster)

This program focuses on field investigation of the BML Demonstration water cap, characterizing spatial and temporal in-situ variations in depth dependent: (1) physico-chemistry, (2) oxygen concentrations, (3) real-time oxygen consumption rates (OCR), (4) potential oxygen consuming constituents (OCC), (5) redox reactive geochemical species and (6) microbial communities. This program will establish temporal and spatial variability in in-situ BML water cap oxygen concentrations, oxygen consumption rates and identify the biogeochemical processes linked to its consumption from the FT-water interface to the BML Demonstration water surface. The outcomes will identify the key OCC and processes affecting oxygen status throughout the BML Demonstration water cap as well as any early developmental stage trends in water cap dissolved oxygen dynamics. Focus more recently has been on sulfur biogeochemistry in BML Demonstration. The program has provided evidence of sulfur cycling (both reduction and oxidation) occurring in BML Demonstration which then influences water cap oxygen concentrations. Results indicate that rates of sulfur reduction (SRR) and oxidation (SOR) are seasonally and spatially variable in BML Demonstration resulting in differential impacts on linked OCR.

Activities in 2023 were focused on addressing the main objective of this project; namely to identify important controls on oxygen consuming processes in BML Demonstration through the in-depth examination of the interaction of sulfur-reducing and sulfur-oxidizing pathways. Improved understanding of these processes will also shed light on the key controls, outcomes and rates of sulfur cycling and how these may impact the BML Demonstration water cap oxygen trajectory over both seasonal and annual scales as it continues to develop supporting an accurate determination of possible sulfur influences on BML Demonstration success. Analysis and interpretation of results is ongoing.

7.5 Microbial communities and methane oxidation processes in Base Mine Lake Demonstration (Dunfield: University of Calgary)

This project has been ongoing for a number of years and has provided much insight into the development of the microbial (bacterial and microbial eukaryotes) community. The project has three main objectives:

1) To monitor the development of the microbial community (bacteria and microbial eukaryotes) in BML Demonstration over time, and compare it to adjacent natural habitats (e.g., Beaver Creek Reservoir) and active tailings facilities (e.g., Mildred Lake Settling Basin).
2) To understand the role of algae in the carbon cycle of BML Demonstration. The lake may be transitioning from a primarily organotrophic system based on hydrocarbon degradation to a primarily phototrophic system based on algal primary productivity. This may change parameters such as oxygen status and nutrient cycling.

3) To understand the roles of some abundant microbial groups (methanotrophic bacteria and phototrophic algae) in bioremediation of organic pollutants. This may inform adaptive management strategies to maximize biodegradation activity.

Key results from this work are shared in Section 5.7.1, and are published in Furgason *et al.* (2024).

7.6 Understanding Air-Water Exchanges and the long-term hydrological viability of Base Mine Lake Demonstration (Carey, Humphreys: McMaster, Carleton)

This research has three main focus areas: determining factors that control evaporation from BML, understanding long-term water balance for BML Demonstration, and will measure and improve the understanding of the physical mechanisms controlling CH_4 and CO_2 fluxes across the air-water interface using the eddy covariance technique. Detailed results from the evaporation and water balance components of this work contribute to the water balance estimates (see section 6.2.1)

7.7 Characterization of organic compounds and naphthenic acids in Base Mine Lake Demonstration: Implications to methane production, transport, oxygen consumption and naphthenic acid persistence (Slater, Mumford: McMaster)

This laboratory based study focuses on an experimental approach to characterize the impacts of methane ebullition from sediment on gas exchange and potential for organic transport within the overlying water column in laboratory analogues relevant to BML Demonstration. Results of experiments in large-scale columns (bubble towers), will be used to understand fundamental processes related to bubble size and release frequency during ebullition, and to provide detailed datasets of water column gas exchange.

These laboratory experiments have three main objectives: 1) to investigate the relationship between sediment depth and gas release characteristics, including gas bubble size, bubble release frequency and gas pressure, 2) to measure the mass exchange between rising bubbles and dissolved gases in the water column, and 3) assess the potential for gas bubbles to facilitate the transport of other organic compounds out of the sediment. This work will be linked to other research and monitoring programs on the full-scale lake.

The results so far have confirmed that dissolved methane concentrations in the upper FFT remain at or near saturation. Microcosm results have confirmed ongoing methane production from the FFT at shallow depths (less than 5 m depth). Methane production varies with depth and location. Methane production correlates to some extent with naphtha concentrations.

Analysis of phospholipid fatty acids (PLFA) from BML Demonstration FFT indicated that at some sites, an isotopic signature of methanotrophy could be identified in the upper 0.5 m of FFT. However, given the absence of oxygen within the FFT, this is not expected. The PLFA distributions and isotopic compositions observed are consistent with what is observed in the water column, so this signature may indicate transport of water column microbes into the upper FFT, or potentially transport of oxygen into the upper FFT to fuel similar aerobic methanotrophs. This would be consistent with the mixing in the upper circa 1 m of FFT proposed by Dompierre *et al*.

Identification of naphtha range compounds in the headspace above FFT samples indicates dominance of less degradable compounds and low concentrations or absence of compounds considered more biodegradable. This does not imply they are entirely absent, but they are potentially being utilized at a greater rate than they are supplied. Partitioning modelling, including that based on bitumen/water partition coefficients, indicates that more than 99% of naphtha range compounds will be present in bitumen at equilibrium, and more than 95% of even the most soluble compounds. This implies a long-term source of naphtha range compounds from bitumen. Quantification of naphtha range compounds using GC backflush FID indicated varying concentrations of naphtha within the FFT. There is a correlation, though not exact, between quantified naphtha and methane production rates, consistent with naphtha being the carbon source, but also with other factors influencing the process.

High resolution mass spectrometry (FTICR MS) has identified a wide array of naphthenic acid fraction compounds in surface water and FFT porewater. Some trends identified between the epilimnion and hypolimnion in 2019 water samples were as follows:

- Indication of photodegradation of large, aromatic hydrocarbons in surface water.
- Indication of increased oxygenation and decreased size of NAFC consistent with biodegradation in the water column.
- Support for biodegradation in upper FFT as well.

Samples from the largest test pond "Demo Pond" were taken, and initial results show low abundances of methane in water samples, low methane production rates and low concentrations of naphtha. These preliminary results are consistent with decreased methane production if low concentration of low molecular weight (naphtha range) hydrocarbons are present. Ongoing analysis of radiocarbon and PLFA samples will further explore this aspect.

Bubble tower results indicate that the release of gas bubbles from FFT has the potential to enhance the transport of both conservative and surface-active solutes, alongside the enhancement of bitumen transport. Further experimentation will assess bitumen transport in more detail.

7.8 List of Peer Reviewed Publications Produced by Base Mine Lake Demonstration Research Programs

Research Project: University

Physical limnology of BML Demonstration and the potential for meromixis: University of British Columbia

Publications:

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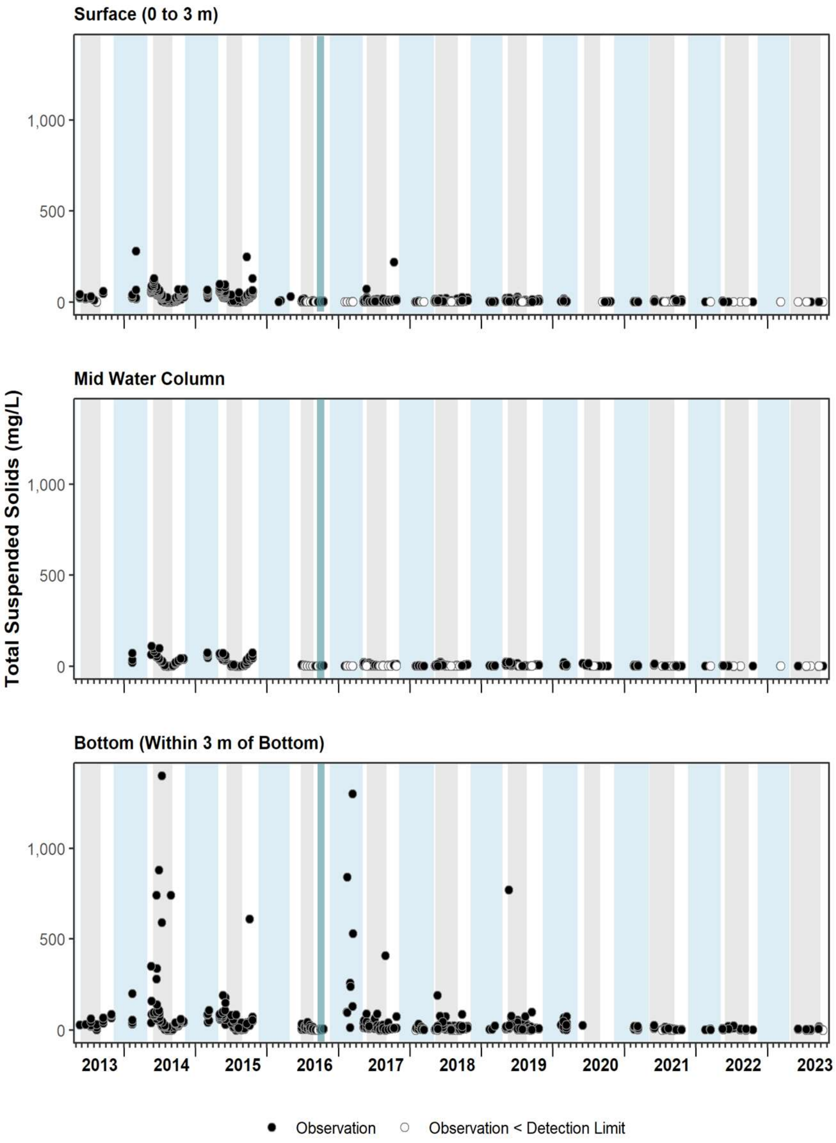
Appendix 1

Water Quality Temporal Trends of Total Suspended Solids in Base Mine Lake Demonstration

Water quality temporal trends of total suspended solids in Base Mine Lake, 2013 to 2023. Full Scale Figure.



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.
Mid water column depths range from 3m to within 3m of bottom.
Green interval shows the period of the alum treatment.
Guideline for TSS is based on background condition, and therefore not presented.
One TSS observation was considered an outlier at station BML12-PLATFORM 3-SW on 2017-02-01 at 9.1m and was excluded

Appendix 2

Base Mine Lake Demonstration Water Quality Summary

Base Mine Lake Demonstration Water Quality Summary

	Unit	DL	BML12_PLATFORM 1_C	BML12_PLATFORM 1_C
			2023-07-18	2023-09-20
			0.3 m	0.3 m
General				
Field pH	pH	-	8.68	8.67
Field Specific Conductivity	µS/cm	-	2445	2409
Field Temperature		-	20.3	15.7
Total Dissolved Solids (Calculated)	mg/L	10	1500	1400
Total Alkalinity (as CaCO3)	mg/L	1	620	620
Chemical Oxygen Demand	mg/L	10	139	166
Biochemical Oxygen Demand	mg/L	2	<2	<2
Total Phenolics	µg/L	1.5	<1.5	<1.5
Sulphide (as S)	mg/L	0.0018	<0.0018	<0.0018
Sulphide (as H2S)	mg/L	0.002	<0.002	<0.002
Total Mercury	µg/L	0.0001	0.00091	0.00086
Total Methyl Mercury (Samples from depth: 11.8 - 12.2 m)	µg/L	0.00005	<0.00005	<0.00005
Total Arsenic	mg/L	0.0001	0.00322	0.00223
Total Selenium	mg/L	0.0002	<0.0002	<0.0002
Total Boron	mg/L	0.05	1.53	1.56
Total Recoverable Hydrocarbons	mg/L	2	<2	<2
Total PAHs	µg/L	-	0.7268	0.8957
Total Parent PAHs	µg/L	-	0.1479	0.1512
Total Alkylated PAHs	µg/L	-	0.5789	0.7445
Total Organic Carbon	mg/L	1	34	29
Naphthenic Acids	mg/L	1 - 2	16	22
Total Hardness (as CaCO3)	mg/L	0.5	120	100
Acute Toxicity				
Rainbow Trout Survival (96 hr) - LC50	% Vol. Water	-	>100	>100
Daphnia magna Survival (48 hr) - LC50	% Vol. Water	-	>100	>100
Daphnia magna Immobility (48 hr) - EC50	% Vol. Water	-	>100	>100
Bacterial Luminescence Light Inhibition (15 min) - IC50	% Vol. Water	-	>91	>91
Bacterial Luminescence Light Inhibition (15 min) - IC20	% Vol. Water	-	>91	63.1
Nutrients				
Phosphorus, Total Orthophosphate (as P)	mg/L	0.001	0.0018	<0.001
Phosphorus, Total (as P)	mg/L	0.001	0.0037	0.007
Phosphorus, Total Inorganic (as P)	mg/L	0.002	0.0033	0.0031
Phosphorus, Total Organic (as P)	mg/L	0.002	<0.002	0.0039
Nitrite (as N)	mg/L	0.001	0.011	0.013
Nitrate (as N)	mg/L	0.003	0.13	0.054
Nitrate plus Nitrite (as N)	mg/L	0.003	0.14	0.067
Nitrogen, Total (as N)	mg/L	0.02	0.96	1.1
Nitrogen, Total Kjeldahl	mg/L	0.02	0.814	1.03
Silicon (Si)-Total	mg/L	0.25	3.5	2.82
Major Ions				
Cations				
Sodium	mg/L	0.25	527	456
Potassium	mg/L	0.25	8.52	7.45
Magnesium	mg/L	0.25	14.1	12
Calcium	mg/L	0.25	24.6	22.2
Anions				
Fluoride	mg/L	0.05	1.1	1.4
Chloride	mg/L	5	370	330
Sulphate	mg/L	5	160	150
Carbonate	mg/L	1	32	48
Bicarbonate	mg/L	1	690	660

	Unit	DL	BML12_PLATFORM 1_C	BML12_PLATFORM 1_C
			2023-07-18	2023-09-20
			0.3 m	0.3 m
Field Specific Conductivity	µS/cm	-	2445	2409
Dissolved Major Elements				
Sodium	mg/L	0.25	527	456
Potassium	mg/L	0.25	8.52	7.45
Magnesium	mg/L	0.25	14.1	12
Calcium	mg/L	0.25	24.6	22.2
Silicon (Si)	mg/L	0.25	2.65	2.38
Boron (B)	mg/L	0.05	1.7	1.41
Strontium (Sr)	mg/L	0.00025	0.521	0.463
Sulphur (S)	mg/L	15	54	44
Dissolved Trace Elements				
Aluminum (Al)	mg/L	0.0025	0.0069	0.0057
Antimony (Sb)	mg/L	0.0001	0.0002	0.00018
Arsenic (As)	mg/L	0.0001	0.00201	0.0019
Barium (Ba)	mg/L	0.0001	0.201	0.184
Beryllium (Be)	mg/L	0.00005	<0.00005	<0.00005
Bismuth (Bi)	mg/L	0.000025	<0.000025	<0.000025
Boron (B)	mg/L	0.05	1.7	1.41
Cadmium (Cd)	mg/L	0.000025	<0.000025	<0.000025
Chromium (Cr)	mg/L	0.0005	<0.0005	<0.0005
Cobalt (Co)	mg/L	0.000025	0.000368	0.000263
Copper (Cu)	mg/L	0.00025	0.00033	0.0004
Lead (Pb)	mg/L	0.000025	0.000028	0.000041
Lithium (Li)	mg/L	0.0025	0.123	0.114
Molybdenum (Mo)	mg/L	0.00025	0.0143	0.0133
Nickel (Ni)	mg/L	0.0001	0.00424	0.00348
Selenium (Se)	mg/L	0.0002	0.00023	<0.0002
Silicon (Si)	mg/L	0.25	2.65	2.38
Silver (Ag)	mg/L	0.000025	<0.000025	<0.000025
Strontium (Sr)	mg/L	0.00025	0.521	0.463
Sulphur (S)	mg/L	15	54	44
Thallium (Tl)	mg/L	0.00001	<0.00001	<0.00001
Tin (Sn)	mg/L	0.001	<0.001	<0.001
Titanium (Ti)	mg/L	0.0025	<0.0025	<0.0025
Uranium (U)	mg/L	0.00001	0.00204	0.00187
Vanadium (V)	mg/L	0.001	0.0019	0.0014
Zinc (Zn)	mg/L	0.0005	0.00167	<0.0005
Zirconium (Zr)	mg/L	0.0005	0.00168	0.00168

	Unit	DL	Mol. Weight	BML12_PLATFORM 1_C	BML12_PLATFORM 1_C
				2023-07-18	2023-09-20
				0.3 m	0.3 m
Polycyclic Aromatic Hydrocarbons					
Total Parent PAHs	µg/L	-	-	0.1479	0.1512
Total Alkylated PAHs	µg/L	-	-	0.5789	0.7445
Alkylated PAHs as % of Total PAHs	%	-	-	80	83
PAH Compounds					
Quinoline	µg/L	0.005	129	0.017	0.018
Naphthalene	µg/L	0.005	128	0.0054	0.0072
1-Methylnaphthalene	µg/L	0.005	142	<0.005	<0.005
2-Methylnaphthalene	µg/L	0.005	142	0.0055	<0.005
C1 Naphthalene	µg/L	0.005	142	<0.005	0.0059
C2 Naphthalene	µg/L	0.005	156	0.04	0.046
C3 Naphthalene	µg/L	0.005	170	0.073	0.094
C4 Naphthalene	µg/L	0.005	184	0.094	0.13
Acenaphthylene	µg/L	0.005	152	<0.005	<0.005
Acenaphthene	µg/L	0.005	154	<0.005	<0.005
Fluorene	µg/L	0.005	166	<0.005	<0.005
C1 Fluorene	µg/L	0.005	180	0.016	0.025
C2 Fluorene	µg/L	0.005	194	0.031	0.04
C3 Fluorene	µg/L	0.005	208	0.057	0.064
Biphenyl	µg/L	0.005	154	<0.005	<0.005
C1 Biphenyl	µg/L	0.005	168	<0.005	<0.005
C2 Biphenyl	µg/L	0.005	182	0.0077	0.011
Phenanthrene	µg/L	0.005	178	<0.005	0.006
C1 Phenanthrene / Anthracene	µg/L	0.005	192	0.019	0.027
C2 Phenanthrene / Anthracene	µg/L	0.005	206	0.027	0.038
C3 Phenanthrene / Anthracene	µg/L	0.005	220	0.027	0.039
C4 Phenanthrene / Anthracene	µg/L	0.005	234	0.016	0.017
Anthracene	µg/L	0.005	178	<0.005	<0.005
Acridine	µg/L	0.005	179	<0.005	<0.005
Dibenzothiophene	µg/L	0.005	184	<0.005	<0.005
C1 Dibenzothiophene	µg/L	0.005	198	0.0082	0.026
C2 Dibenzothiophene	µg/L	0.005	212	0.037	0.048
C3 Dibenzothiophene	µg/L	0.005	226	0.031	0.031
C4 Dibenzothiophene	µg/L	0.005	240	<0.005	<0.005
Fluoranthene	µg/L	0.005	202	<0.005	<0.005
Pyrene	µg/L	0.005	202	<0.005	<0.005
C1 Fluoranthene / Pyrene	µg/L	0.005	216	<0.005	0.0096
C2 Fluoranthene / Pyrene	µg/L	0.005	230	0.012	0.016
C3 Fluoranthene / Pyrene	µg/L	0.005	244	0.023	0.027
C4 Fluoranthene / Pyrene	µg/L	0.005	258	<0.005	<0.005
Benzo[a]anthracene	µg/L	0.005	228	<0.005	<0.005
Chrysene	µg/L	0.005	228	<0.005	<0.005
C1 Benzo[a]anthracene / Chrysene	µg/L	0.005	242	<0.005	<0.005
C2 Benzo[a]anthracene / Chrysene	µg/L	0.005	256	<0.005	<0.005
C3 Benzo[a]anthracene / Chrysene	µg/L	0.005	270	<0.005	<0.005
C4 Benzo[a]anthracene / Chrysene	µg/L	0.005	284	<0.005	<0.005
Retene	µg/L	0.005	234	<0.005	<0.005
Benzo[e]pyrene	µg/L	0.005	252	<0.005	<0.005
Benzo[b,j]fluoranthene	µg/L	0.005	252	<0.005	<0.005
Benzo[k]fluoranthene	µg/L	0.005	252	<0.005	<0.005
C1 Benzo[b,j,k]fluoranthene / Benzo[a]pyrene	µg/L	0.005	266	<0.005	<0.005
C2 Benzo[b,j,k]fluoranthene / Benzo[a]pyrene	µg/L	0.005	280	<0.005	<0.005
Benzo[c]phenanthrene	µg/L	0.005	252	<0.005	<0.005
Benzo[a]pyrene	µg/L	0.005	252	<0.005	<0.005
Benzo[a]pyrene (equival.)	µg/L	0.01	252	<0.01	<0.01
Perylene	µg/L	0.005	252	<0.005	<0.005
Benzo[g,h,i]perylene	µg/L	0.005	276	<0.005	<0.005
Indeno[1,2,3-cd]pyrene	µg/L	0.005	276	<0.005	<0.005
Indeno[1,2,3-cd]fluoranthene	µg/L	0.005	276	<0.005	<0.005
Dibenz[a,h]anthracene	µg/L	0.005	278	<0.005	<0.005

	Unit	DL	BML12_PLATFORM 1_C	BML12_PLATFORM 1_C
			2023-07-18	2023-09-20
			0.3 m	0.3 m
BTEX Compounds				
Benzene	µg/L	0.4	<0.4	<0.4
Ethylbenzene	µg/L	0.4	<0.4	<0.4
m,p-Xylene	µg/L	0.8	<0.8	<0.8
o-Xylene	µg/L	0.4	<0.4	<0.4
Toluene	µg/L	0.4 - 0.43	<0.43	<0.4
Total Xylenes	µg/L	0.89	<0.89	<0.89
Hydrocarbon Fractions				
F1 (C6-C10)	µg/L	100	<100	<100
F2 (C10-C16)	µg/L	100	450	470
F3 (C16-C34)	µg/L	100	1200	1400
F4 (C34-C50)	µg/L	200	<200	<200

	Unit	BML12_PLATFORM 1_C	BML12_PLATFORM 1_C
		2023-07-18	2023-09-20
		0.3 m	0.3 m
General			
Field pH	pH	8.68	8.67
Field Specificic Conductivity	µS/cm	2445	2409
Naphthenic Acids	mg/L	16	22
Total Ammonia (as N)	mg/L	0.13	0.14
Toxicity Bioassay Results			
Rainbow Trout (96 h) Acute Toxicity: Mortality - LC50	% Vol. Water	>100	>100
D. magna (48 h) Acute Toxicity: Mortality - LC50	% Vol. Water	>100	>100
D. magna (48 h) Acute Toxicity: Immobility - EC50	% Vol. Water	>100	>100
Bacterial Luminescence (15 m) Acute Toxicity: Light Inhibition - IC50	% Vol. Water	>91	>91
Bacterial Luminescence (15 m) Acute Toxicity: Light Inhibition - IC20	% Vol. Water	>91	63.1
Algal (72 h) Chronix Toxicity: Growth Inhibition - IC25	% Vol. Water	>91	>91
C. dubia (7 d) Chronic Toxicity: Mortality - LC50	% Vol. Water	>100	>100
C. dubia (7 d) Chronic Toxicity: Reproduction - IC25	% Vol. Water	>100	53.7
Fathead Minnow (7 d) Chronic Toxicity: Mortality - LC50	% Vol. Water	>100	>100
Fathead Minnow (7 d) Chronic Toxicity: Growth - IC25	% Vol. Water	>100	>100
L. minor (7 d) Chronic Toxicity: Growth Dry Weight - IC25	% Vol. Water	>97	60
L. minor (7 d) Chronic Toxicity: Growth Frond Number - IC25	% Vol. Water	19.2	10.1

Appendix 3

Water Modelling for 2023 Life of Mine Closure Plan

WATER MODELLING FOR 2023 LIFE OF MINE CLOSURE PLAN

Mildred Lake and Aurora North

Presented to
Syncrude Canada Ltd.

March 3, 2023
Issued for Use
21-003-RPT-001

171 Pembina Road
Sherwood Park, AB T8H 2W8 Canada
Telephone: +1 780 306 3100
Fax: +1 780 306 3101
www.arkkeng.ca

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21-003-RPT-001 – WATER MODELLING FOR 2023 LIFE OF MINE CLOSURE PLAN

Rev	Description	Originator	Review	Corporate Approval	Date	Client Approval	Date
0	Issued For Use	R. Nagare	R. Wirtz	F. Quintanilha	3-Mar-2023	D. Heisler	

EXECUTIVE SUMMARY

Syncrude Canada Ltd. (Syncrude) contracted ARKK Engineering Corporation (ARKK) to undertake water modelling of the proposed closure conditions of Mildred Lake (including Mildred Lake Extension (MLX)) and Aurora North Mines in support of Syncrude's 2023 Life of Mine Closure Plan (LMCP). The assessment uses an integrated surface water and groundwater flow and solute transport model ("integrated model") to provide an understanding of water and solute (chloride) movement throughout the proposed reclaimed landforms of the mine sites. The models were developed to represent conditions from the completion of mining to the end of this century (year 2090 to 2100). Historical wet/dry climate conditions were simulated to allow model validation with regional runoff data. Future climate scenarios were based on upper and lower bounds of assumed future emissions scenarios. It is anticipated that the future climate will fall in between the scenarios modelled in this study. Key model results and limitations are summarized below.

Water Balance

Water balance results for historical climate conditions were similar to regional reference values. Results of climate change scenarios suggest runoff from the watershed would be reduced due to increased temperature and evapotranspiration.

Results suggest that the pit lakes will perform as locally common boreal lakes. For historical climate scenarios the water levels of pit lakes are maintained near the sill elevation. For the climate change scenarios, lake levels drop below the sill for all pit lakes. The lake levels increase during wet cycles. It is important to recognize that the lower and upper bounds of climate change projections were estimated.

Groundwater

The elevation of the water table closely follows the topography of the ground surface, indicating flow from topographic highs to topographic lows. Groundwater was estimated to be near surface throughout topographic lows, along closure valleys, and at the base of the hills. Wetlands are expected to form at these locations. The extent of wetlands fluctuates in response to wet and dry conditions. Groundwater flow into and out of pit lakes is not a significant component of the water balance other than for AN-E Lake, which receives groundwater inflow approximately equal to 50% of the direct precipitation over the lake.

Water Quality

Chloride concentrations were simulated as an indicator parameter of oil sands process water (OSPW).

Chloride concentrations at the outlet of the valleys suggests higher flows are associated with lower concentrations due to dilution of porewater with fresh surface water. Lower flows result in higher concentrations. The concentration and flow dynamic demonstrates an inherent mechanism within the landforms that limits discharge of solute mass from the site during low flow periods.

Model results suggests chloride mass loading generally trends downward; however, the loading is primarily influenced by climatic conditions (wet and dry cycles). Variation in the magnitude of mass loads released from a given landform is a function of landform scale, topography, stratigraphy, and initial OSPW within the pore space.

Comparison of the initial mass and the mass mobilized over the simulations suggests the majority of the OSPW will remain within the pore space of the sand capped CT landforms beyond year 2100; however, mass is readily mobilized from coke cap portions of landforms. Rapid displacement of OSPW from tailings pore

space is beneficial from a landform water quality perspective but would increase mass loading to downstream areas.

Within pit lakes, dilution of OSPW occurs during wet cycles; however mass loads from upstream landforms and fine tailings (FT) enter the lakes keeping chloride concentrations elevated. During dry cycles, especially when the lake level drops below the sill, chloride mass accumulates within the lake resulting in concentrations that exceed that of the initial OSPW. The model results suggest that elevated chloride concentrations will persist beyond year 2100 and are highly dependant on the assumed future climate conditions. Consolidation release water from FT within in the pit lakes has potential to contribute significant mass loads to pit lakes in the years following placement.

An approximate mixing calculation was developed to estimate the chloride concentration in each river downstream of the proposed runoff release from the sites. The mixed concentrations are all below chloride guidelines except in the McKay River under the scenarios with the highest estimated loads. Most mass loading from pit lakes is expected to occur during wet periods, when McKay River flows are higher. During the lowest McKay River flows, the water level in pit lakes would likely be below sill (i.e., no outflow or loading).

Limitations

Climate conditions (i.e., wet, and dry cycles) dominate the water balance and solute migration from reclaimed landforms. Future climate conditions are unknowable. The climate scenarios simulated in this study used upper and lower bounds of assumed future emissions, as defined by RCP2.6 (stringent GHG mitigation) and RCP8.5 (very high GHG emission).

The scale of sitewide models requires simplification of ground topography and subsurface discretization given computational limitations. Landform scale models are required to close gaps related to discretization and computational limitations, and better understand sitewide model performance.

Frozen ground conditions affect seasonal water and solute movement in the boreal region; however, these processes were not included in the model due to computational limitations. Including frozen ground could potentially result in 10 to 20% reduction in solute mass released from landforms (ARKK 2021a).

Effectively capturing the transition of landforms from operation to closure is challenging as described throughout this report. The modelling approach in this study sets the groundwork for future assessments. Achieving closure objectives will require multiple iterations of closure and operational plans fed by additional closure experience, evolution of technology, and development of acceptable water release criteria by the regulators. Ongoing monitoring and refinement of models will be important to better understand water balance and solute transport of the closure landscape.

This study is not intended to provide a comprehensive evaluation of water quality evolution under reclaimed conditions. However, this study provides groundwork for future monitoring and modelling (to occur over the next 10 years) to predict the evolution of comprehensive water quality over closure timeframes and provide information that can inform refinements to tailings and operational plans that will achieve the desired closure outcomes.

ACRONYMS

Acronym	Description
ACPN Valley	Aurora Centre Pit North Valley
ACPS Valley	Aurora Centre Pit South Valley
AEP Valley	Aurora East Pit Valley
AER	Alberta Energy Regulator
AET	Actual Evapotranspiration
ASB Valley	Aurora Settling Basin Valley
AN-E Lake	Aurora North - East Lake
AN-W Lake	Aurora North - West Lake
AWPS Valley	Aurora West Pit South
AWPW Valley	Aurora West Pit West
ARKK	ARKK Engineering Corporation
BC	Boundary Condition
BM Lake	Base Mine Lake
CT	Composite Tailings
CNUL	Canadian Natural Upgrading Limited
ECCC	Environment and Climate Change Canada
EIP Valley	East In-Pit Valley
EPEA	Environmental Protection and Enhancement
FFT	Fluid Fine Tailings
FT	Fine Tailings
GHG	Greenhouse Gas
HGS	HydroGeoSphere
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
LMCP	Life of Mine Closure Plan
MLSB Valley	Mildred Lake Settling Basin Valley
MLX	Mildred Lake Extension
MLX-E	Mildred Lake Extension East
MLX-W	Mildred Lake Extension West
NECD	Northeast Closure Dyke

Acronym	Description
NM Lake	North Mine Lake
NMNP Valley	North Mine North Pit Valley
NMCP	North Mine Centre Pit
NMCP-E Valley	North Mine Centre Pit
NMSP Valley	North Mine South Pit Valley (includes NMSP-E and NMSP-W)
NMSP-E Valley	North Mine South Pit East Valley
NMSP-W Valley	North Mine South Pit West Valley
NODA Hill	North Out of Pit Dump Area Hill
NRCAN	Natural Resources Canada
OPTA	Out of Pit Tailings Area
OSPW	Oil Sand Process Water
PET	Potential Evapotranspiration
RCP	Representative Concentration Pathway
RCW	Recycle Water
RD	Root Depth
RDF	Relative Root Density
SCD	South Closure Dyke
Syncrude	Syncrude Canada Ltd.
SHBC	Specified Head Boundary Condition
SODA Hill	South Out of Pit Dump Area Hill
Suncor	Suncor Energy Inc.
SWIP Valley	Southwest In-Pit Valley
SWSS Valley	Southwest Sand Storage Valley
WM Lake	West Mine Lake
XE Hill/Valley	(Mildred Lake) Extension East Hill/Valley
XS Valley	(Mildred Lake) Extension South Valley
XW Valley	(Mildred Lake) Extension West Valley

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APPENDICES

1. INTRODUCTION

Syncrude Canada Ltd. (Syncrude) contracted ARKK Engineering Corporation (ARKK) to undertake water modelling of the proposed closure conditions of Mildred Lake (including Mildred Lake Extension (MLX)) and Aurora North Mines. The Mildred Lake and Aurora North mine sites are located approximately 40 km and 70 km north of Fort McMurray, Alberta, respectively. The primary objective of this assessment is to support Syncrude's 2023 Life of Mine Closure Plan (LMCP), under Environmental Protection and Enhancement Act (EPEA) Approval 26-03 and SED-003 (AER 2018). The assessment uses an integrated surface water and groundwater flow and solute transport model ("integrated model") to provide an understanding of water and solute (chloride) movement throughout the proposed reclaimed landforms of the mine sites, specifically:

- water balance and water movement through the proposed closure landscapes (on a landform and sitewide basis including pit lakes);
- surface water and groundwater flow regimes;
- wetland locations and extents;
- movement of solutes through landforms and pit lakes; and
- the influence of climate change on the water balance of the closure landscapes and pit lakes.

HydroGeoSphere (HGS) was used to model the closure landscape under a wide range of late-21st-century climate scenarios. HGS is a fully integrated hydrological model that provides the necessary detail for simulations of the above noted aspects of the proposed closure landscape. The modelling is based on the closure surfaces and plans provided by Syncrude (Aquanty 2017). Three sitewide integrated models were developed (Mildred Lake, MLX-W, and Aurora North).

The sitewide models were used to simulate water balance and solute (chloride) transport for a range of climate conditions. Chloride is a conservative solute in surface water and groundwater (i.e., does not degrade) and is indicative of worst-case solute migration and mass-loading under given surface water and groundwater flow fields. Annual runoff and chloride mass loads were estimated throughout the closure landscapes that characterize conditions at individual landforms and the pit lakes. Depth to water table and surface ponding were also mapped to illustrate spatial variations of wetland conditions throughout the model simulations. Water levels and chloride mass load balances were estimated for each individual pit lake.

The models were developed to represent conditions from the completion of mining to the end of this century (year 2090 to 2100). The scenarios include:

- historical wet/dry decades for validation with regional runoff data; and
- four climate scenarios based on combinations of historic wet and dry decades adjusted for Natural Resources Canada (NRCAN 2019)/Intergovernmental Panel on Climate Change (IPCC 2014) climate change projections. Modelling was completed using upper and lower bounds of assumed future emissions, as defined by Representative Concentration Pathway (RCP)2.6 (stringent mitigation) and RCP8.5 (very high GHG emission). It is anticipated that the future climate will fall in between the scenarios modelled in this study.

2. OVERVIEW OF CLOSURE DRAINAGE PLANS

Closure plans for the Mildred Lake site, MLX-W, and the Aurora North site used in this study were developed by Syncrude along with the operational mining and tailings plans. Mining materials used to construct the closure landscape following oil sands (ore) extraction consists broadly of overburden (rock, clay, sand, soil that lies on top of an oil sands deposit and is removed to allow it to be mined), tailings (sand and fines), coke, and reclamation soils. During operations, overburden is excavated to access the ore and placed in dumps and mined-out-pits. Tailings result from processing ore and are hydraulically placed within mined-out-pits and out-of-pit tailings facilities. Fluid tailings and oil sand process water (OSPW) are contained by dams. Water within the mine site is contained and recycled as mining and ore processing progresses throughout the life of the mines. Appendix 1 through 3 provide cross sections of the reclaimed site that show insitu stratigraphy as well as mining and tailings material throughout the sites.

The closure landscapes were developed to balance mining material volumes, mimic regional topographic features, and achieve closure and abandonment/deregistration of dams. Dam closure (AEP 2018) is generally achieved by infilling the tailing facilities with solids and excavating drainage channels through the dams to limit impoundment of water. Terrestrially-reclaimed tailings facilities are gently sloped upland/wetland complexes herein referred to as valleys. Note that the external tailings facilities are also considered valleys although they are elevated features. At closure these landforms will be sloped toward a central axis and outlet. Overburden dumps are elevated relative to the surrounding topography and are herein referred to as hills. Pit lakes are located toward the downstream portion of the sites and collect runoff from the site and direct it into the surrounding watercourses. The valleys and hills connect to the surrounding topography of undisturbed areas and topography of adjacent reclaimed mines. The topography is also heavily influenced by the undisturbed ground elevations where closure drainage features connect to upstream and downstream natural watercourses. The overall topography results in a network of closure drainage features (wetlands and channels) where groundwater and surface water collect at topographic lows and move throughout the reclaimed topography toward the pit lake and into the surrounding watercourses.

Figure 1 illustrates the proposed closure topography and drainage features for the Mildred Lake site and MLX-W. The closure plans at the Mildred Lake site feature two pit lakes: Base Mine (BM) Lake and North Mine (NM) Lake. Water from BM Lake would flow into the Athabasca River, while water in NM Lake would flow into the McKay River. MLX-W mine has a single pit lake, West Mine (WM) Lake. Water from WM Lake would also flow into McKay River. Water discharge from the closure landscape to natural watercourses would occur once the discharge water quality meets release criteria that is acceptable to stakeholders. Figure 2 shows the watershed boundaries of BM Lake, NM Lake, and WM Lake. Both BM Lake and WM Lake would receive runoff from undisturbed watersheds and reclaimed mine areas, while the watershed of NM Lake would be primarily reclaimed mine areas. Figure 3 compares pre-mining, operating, and closure watershed boundaries for the Mildred Lake site and MLX-W. The key information on this figure is the diversion of Beaver Creek into Poplar Creek at mining and the proposed reconnection of Beaver Creek at closure via the BM Lake outlet channel. It should be noted that the southeastern portion of Beaver Creek watershed (approximately

50%) was excluded as part of the Suncor Energy Inc. (Suncor) future Base Mine Extension; at closure, this portion of the Beaver Creek watershed is assumed to flow into the Athabasca River via Poplar Creek.

Figure 4 provides an overview of the closure topography, drainage patterns and pit lake watersheds for Aurora North. Two pit lakes are proposed: Aurora North west (AN-W) Lake, which would receive runoff from the majority of the reclaimed mine prior to flowing into the Athabasca River, and Aurora North East (AN-E) Lake, which would receive runoff from the east-most reclaimed mine areas prior to flowing into the Muskeg River. It should be noted that closure topography and drainage has been integrated with the Suncor Fort Hills mine to the north, and the Canadian Natural Upgrading Ltd. (CNUL) Albian mine to the south. Figure 5 illustrates pre-mining and closure watersheds at Aurora North in the context of regional watersheds. A summary of the pit lake data is provided in Table 1.

Table 1 – Summary of Pit Lake Data

Pit Lake	Sill (Outlet) Elevation (m)	Lake Surface Area (km^2)	Watershed Area (km^2)	Watershed to Lake Area Ratio
BM Lake	309.1	9.2	243	25
NM Lake	304.0	6.9	100	13
WM Lake	285.2	5.2	91	17
AN-W Lake	251.0	5.0	65	12
AN-E Lake	283.1	5.7	44	7

Note:
The design water level of BM Lake is 308.7 m; however, the elevation of the sill used in the model grid was 309.1 m. The 0.4 m difference in sill elevation would have little to no influence on the results presented in this report. The detailed configuration of the BM Lake outlet is to be determined and is expected to vary over closure timeframes.

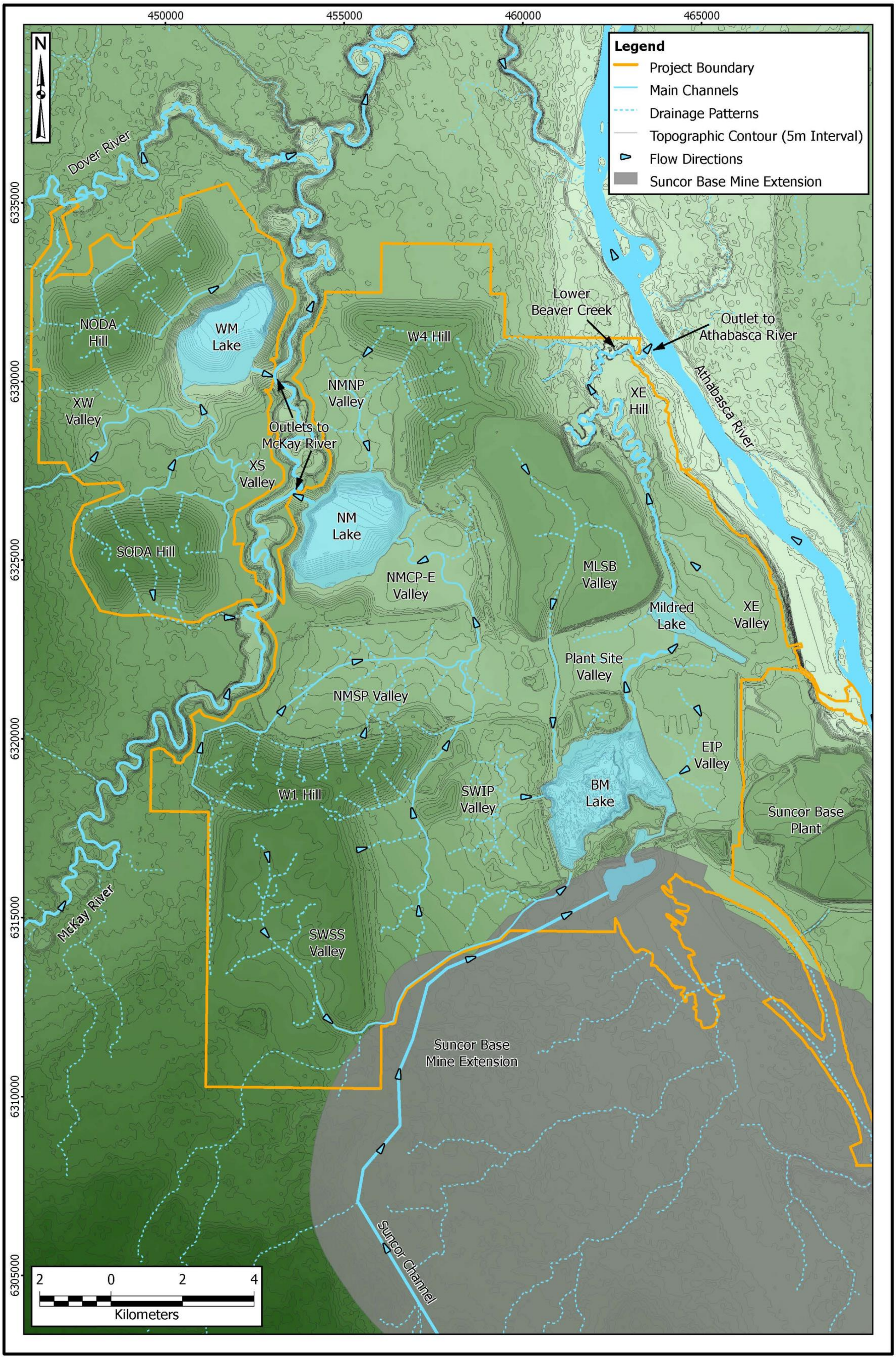


Figure 1 – Closure Drainage Plan Overview – Mildred Lake and MLX-W

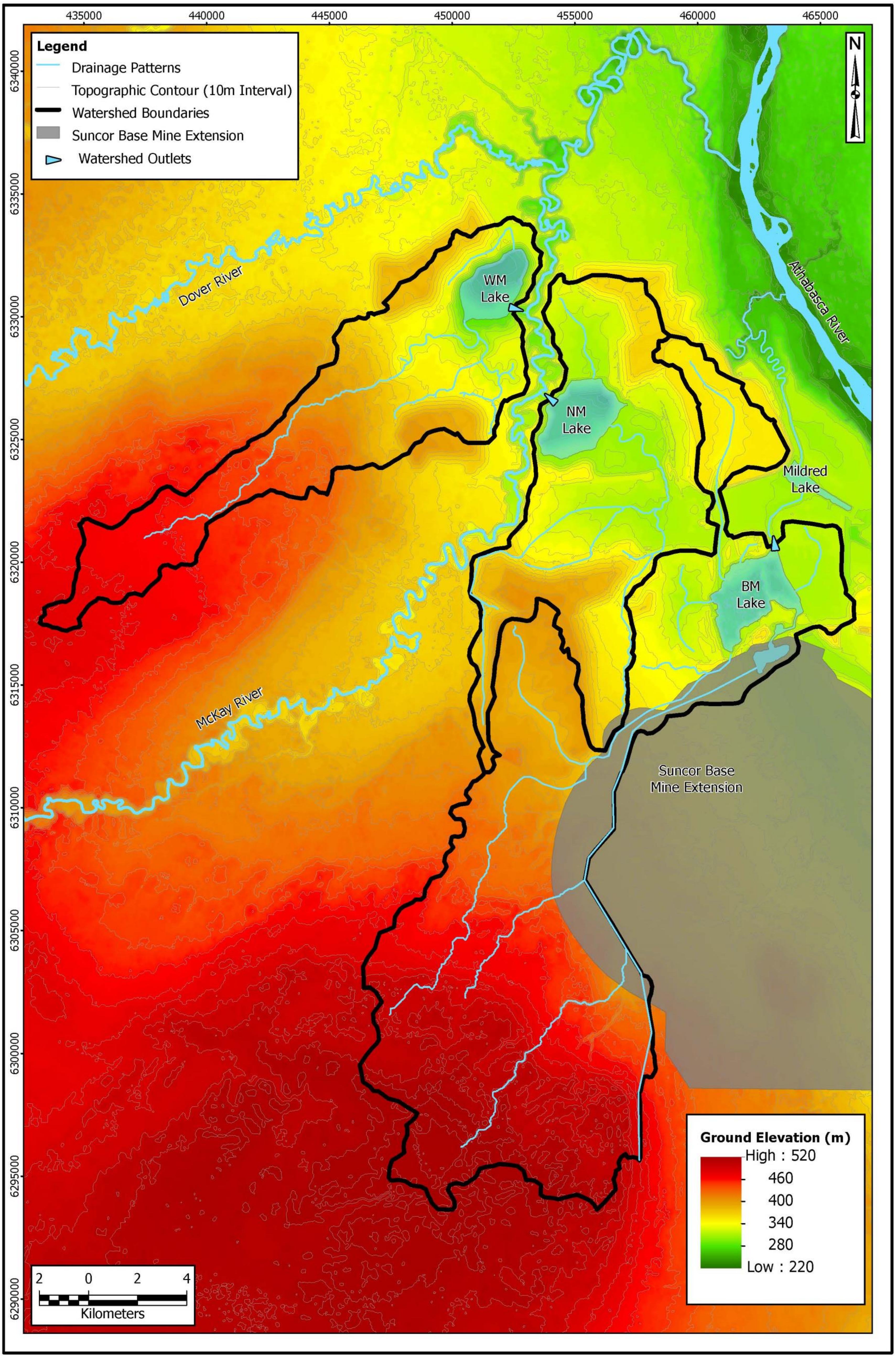


Figure 2 – Watersheds for BM Lake, NM Lake, and WM Lake

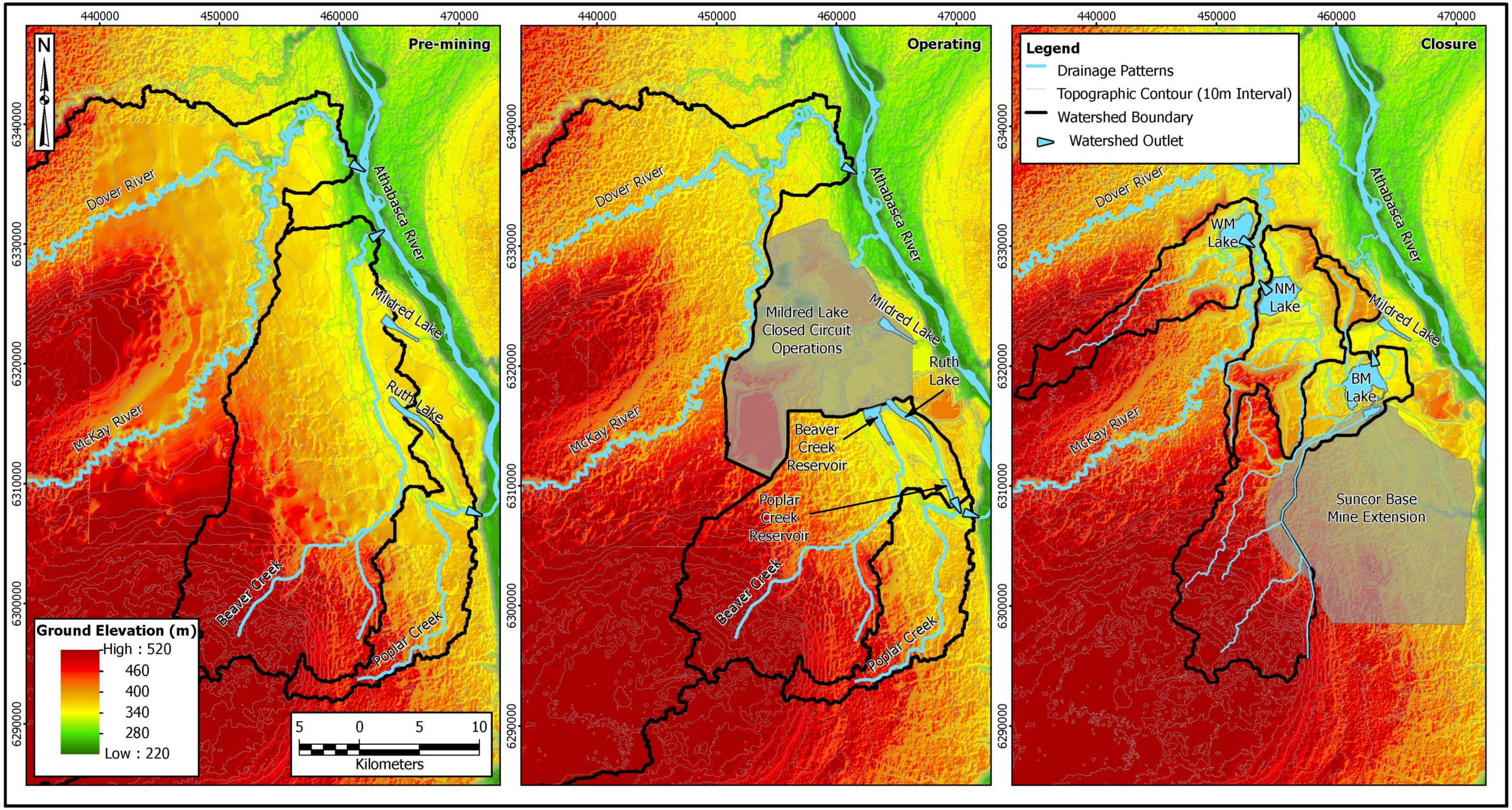


Figure 3 – Pre-mining, Operation, and Closure Watershed Boundaries at Mildred Lake and MLX-W

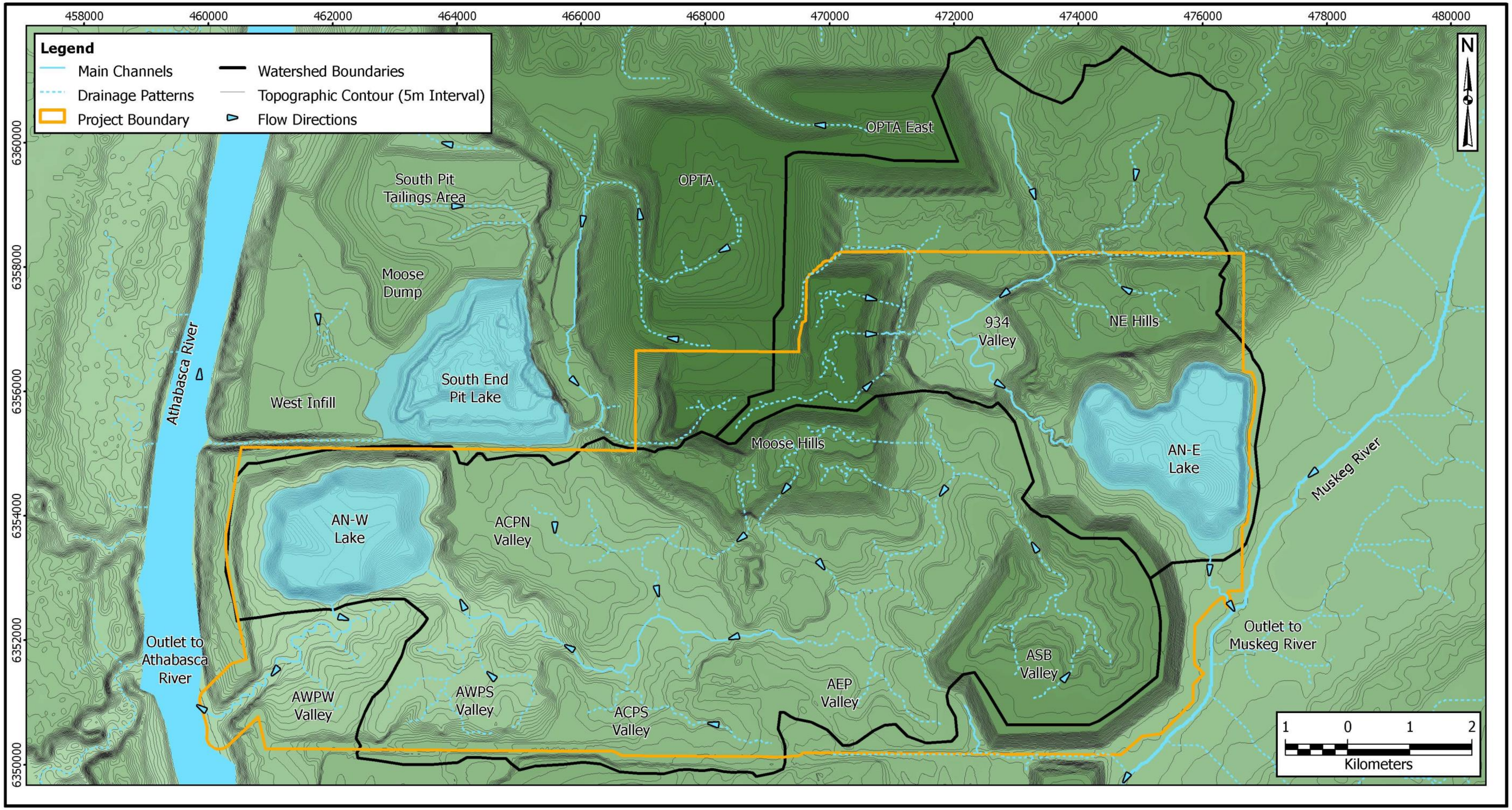


Figure 4 – Closure Drainage Plan Overview – Aurora North and Watersheds of AN-E Lake and AN-W Lake

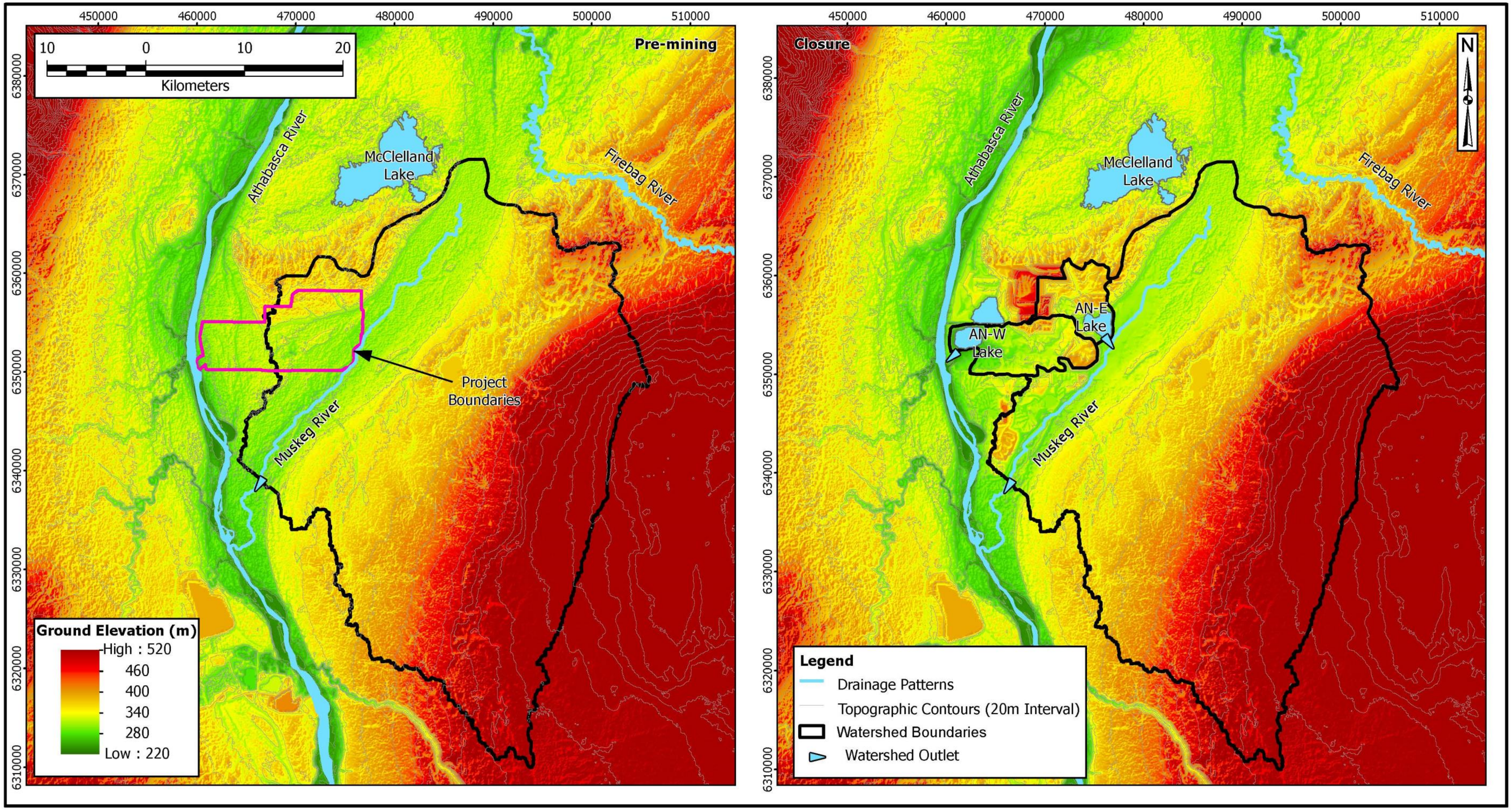
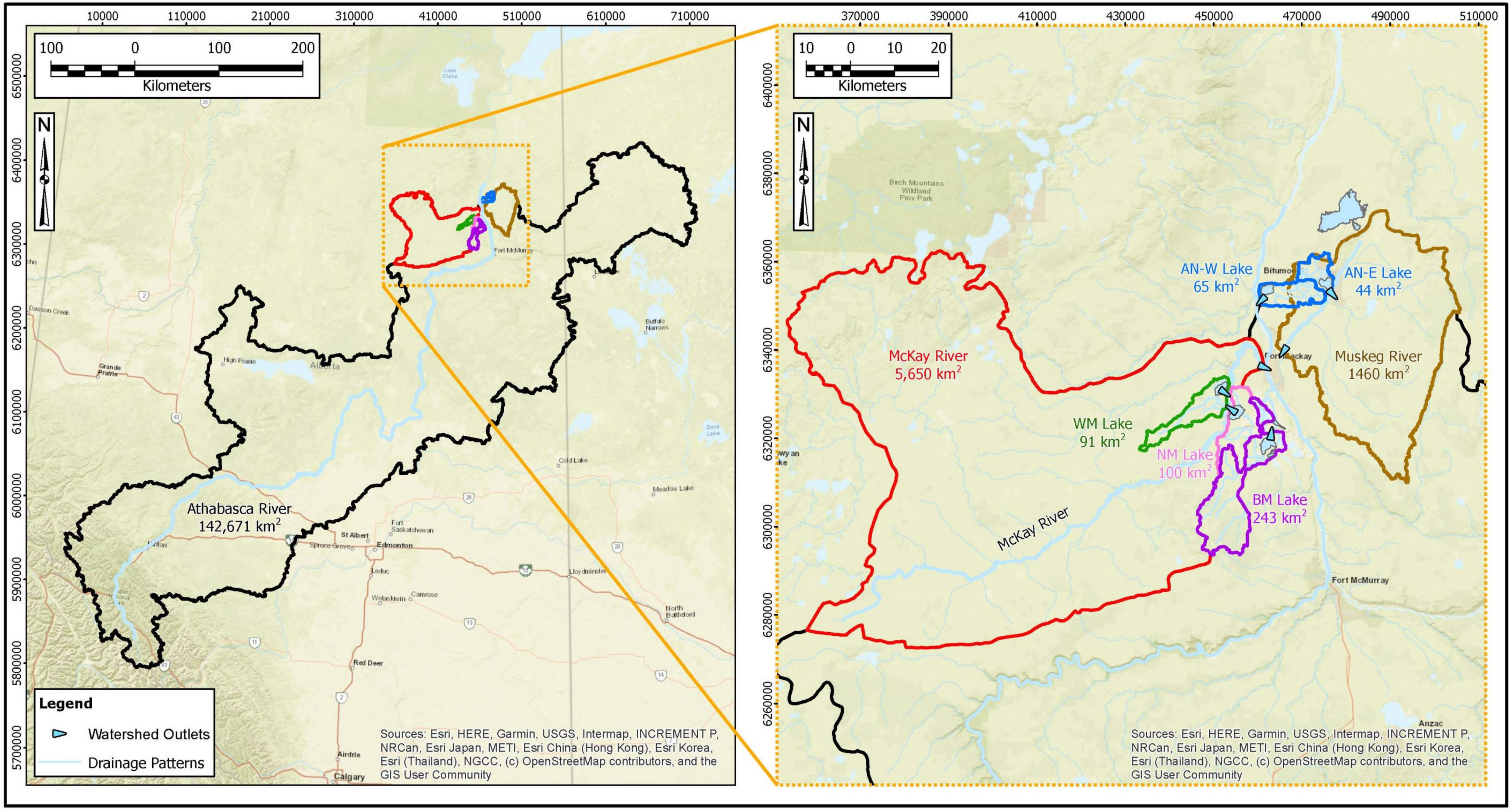


Figure 5 – Pre-mining and Closure Watersheds – Aurora North



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 6 – Closure Drainage Watersheds with Athabasca River, McKay River, and Muskeg River Watersheds

3. CONCEPTUAL MODEL

3.1 GENERAL WATER AND SOLUTE MOVEMENT AND TIMEFRAMES

Conceptualizing water and solute movement throughout the closure landscape requires an understanding of operational water management, the progression from operations to closure, and the conditions at closure. The modelling is focused on both water balance (quantity) and mass loading (quality) of the closure landscape around year 2100. Mine closure and reclamation are anticipated to be largely complete by year 2040. Presently, most of the area within the leases is in an operational state. Some landforms are at advanced stages of closure and reclamation while mining has not yet begun in other areas.

The Athabasca Oil Sands Region (AOSR) is located in the boreal region wherein the landscape is made up of treed (deciduous and coniferous) uplands surrounded by wetlands (primarily peatlands). Water movement in the boreal region is characterized by tight surface water and groundwater coupling (Hayashi et al. 1998, Devito et al. 2012, Ketcheson et al. 2017, Nagare et al 2022). The general stratigraphic sequence of interest in the AOSR, with increasing depth, consists of Holocene sediments comprised of peat, sands and clays followed by Pleistocene deposits comprised of sands, silts and clays, which are underlain by Clearwater Formation clays and shale, Bitumen/water filled clays and sands of the McMurray Formation; and Shales and Carbonates of the Upper (Waterways/Beaverhill Lake Group) and Middle (Keg River and Prairie Evaporites) of the Devonian Formation.

Under terrestrial closure conditions, mined out areas and out-of-pit tailings ponds will generally be backfilled by moderate to thick fine tailings deposits and covered by shallow to moderate thickness, relatively permeable sand tailings or granular caps then reclaimed with mineral and organic cover soils. In addition, elevated overburden dumps are reclaimed with a similar yet generally thicker reclamation soil prescription. Natural land existing throughout the leases may or may not require reclamation soil placement, depending on whether or not it was previously stripped. Under aquatic closure conditions, areas will generally consist of mined out pits with riparian and littoral geometry created out of pit walls and in-pit overburden dumps, filled with fine tailings capped with water (pit lakes). Water will mostly flow on the overland and through the permeable tailings caps and shallow Holocene and Pleistocene sand deposits.

The climate in the boreal systems is characterized by water deficit and pronounced annual and decadal cycles of water availability wherein potential evapotranspiration (PET) exceeds precipitation on an annual time scale (Devito et al. 2005, Devito et al. 2012). The annual average precipitation and PET for the 1944-2020 period in the region is 429 mm and 578 mm, respectively. The functioning of the hydrologic system in the Boreal Plains has evolved to store and redistribute water during dry climate cycles and transmit large amounts of water in wet climate periods (Devito et al. 2005, Devito et al. 2012). Such functioning ensures water availability during the prolonged decadal scales of dry periods making ecosystems resilient to the water deficit climate. Field measurements of total annual runoff in the Boreal Plains in Alberta ranges from 0 mm to 90 mm under dry climate conditions and 50 mm to 269 mm under wet climate conditions (Devito et al. 2012).

At closure, water will enter the reclaimed landscape by precipitation and overland flow from upstream areas. Water will exit the reclaimed landscape via surface evaporation, evapotranspiration, and overland flow through the closure drainage network. Groundwater seepage will also occur at topographic lows where it will mix with surface runoff and be conveyed to downstream landforms or into a pit lake before discharging to the surrounding watercourses. Within a given landform (hill or valley), surface and groundwater interactions will dominate the water and solute movement before the water exits the landforms by mechanisms described above. The surface water and groundwater interactions will include evaporation, evapotranspiration, deep percolation through topographic highs, interflow and seepage toward topographic lows, and overland flow, infiltration, and exfiltration from topographic and in topographic lows. Porewater expressed due to tailings consolidation would mix with runoff within landforms and pit lakes.

Throughout this report, the term “runoff” is used to define the combined surface water and groundwater discharge from the individual landform watersheds. When referring to runoff water quality, it is implied that water quality of the runoff will be a product of surface water and groundwater interactions within the individual landforms and at points of interest within the closure drainage channels (overland runoff mixing with the shallow and deeper groundwater discharge and consolidation release water).

It is critical to understand that the surface and shallow subsurface water movement is dominated by climate. Historical climate shows a high degree of variability in precipitation, which is known to result in variable runoff from natural and reclaimed landforms (Nagare et al. 2015). This variation drives variable solute mass loading through processes of evapoconcentration (during periods of no runoff) and dilution (as concentrated runoff and/or porewater mixes with fresh runoff).

3.2 TRANSITION FROM OPERATION TO CLOSURE

The analysis in this report is focused on estimating the water balance and solute transport of the mine’s closure drainage systems at the end of this century. The analysis is primarily focused on this timeframe; however, consideration must also be given to the transition from operations to closure. Understanding the differences between operation and closure and the transition to closure is critical to conceptualization of the model and the selection of initial conditions.

Closure and reclamation of the sites is expected to progress incrementally and be complete at about year 2040. The maturity of reclamation for different landforms across the sites in year 2100 will vary. At year 2100, some landforms will have been reclaimed for over 100 years (Gateway Hill), while others will only be reclaimed for 60 years or less. Landform maturity will influence the depth to groundwater table, vegetation characteristics, and porewater chemistry (i.e., displacement of OSPW from tailings pore space with fresh water).

During operations, fluid tailings and OSPW is contained in tailings facilities by dams. Runoff from the disturbed areas is collected within the closed-circuit drainage system and recycled through the ponds. Runoff from undisturbed areas upstream of the mines is generally directed away from the closed-circuit system. Water levels within the ponds are balanced through operational pumping systems. No water is released to the surrounding watercourses. Presently, the majority of runoff from the reclaimed areas of the site (overburden dumps, BM Lake, and East In-Pit [EIP]) is collected within a closed-circuit system. At site-wide closure, it is assumed all tailings facilities are in a closed state with final surficial drainage regimes established with runoff conveyed passively through the landforms, into the pit lakes, and the surrounding watercourses.

As the sites transition toward closure, landforms will be progressively connected to the closure drainage system and dam structures will be abandoned as facilities enter a closed state. Runoff release from the site is expected to occur in stages. It is anticipated that release of runoff to the surrounding watercourses will initially be controlled based on conditions such as flow rate in the downstream watercourses. Controlled releases might initially occur through pumped outlets or gravity systems with control structures. Ultimately, final closure drainage channels will be constructed to passively release runoff to the surrounding watercourses.

The incremental transition from operations to closure has been, and will continue to occur over decades as facilities are closed and abandoned, converted to landforms which are reclaimed,, and connected to closure channels to drain runoff to downstream areas. Capturing this transition in an integrated model is impractical. Instead, the sites were conceptualized to have static topography that represents the complete final passive closure drainage network. Tracking of flow and solute mass between each landform provides information on individual landform evolution and isolates the quantity and quality of runoff discharged from each landform. The geology of the sites and nature of the mining materials allows the in-pit tailings facilities to be conceptualized as a series of interconnected “bath-tubs”, each with a finite initial solute concentration within the pore space at the start of model simulations. The solute moves throughout the landscape along with water moving through landforms and mixing within pit lakes.

The water quantity and quality estimates from each landform can be used to provide feedback into future tailings plans as more detailed operational plans are developed. It is understood that Syncrude plans to use these results, along with water release criteria, to refine tailings and operational plans such as commissioning plans for pit lakes that will achieve the desired closure outcomes.

3.3 EVOLUTION OF INDIVIDUAL LANDFORMS

The timing, magnitude, and quality of runoff from the hills (overburden dumps) and valleys (tailings facilities) are expected to differ. The quantity of runoff from the hills is anticipated to be relatively low, based on monitoring data from Syncrude's South Bison Hills which shows that vegetation utilizes the majority of water (Huang et al. 2018). Evapotranspiration rates at South Bison Hills are similar to locally common boreal forest. Given the limited runoff from the hills, mass loading is assumed to be insignificant compared to landforms with OSPW in the pore space. Conversely, the valleys are expected to produce solute loads due to presence of OSPW within the pore space of tailings. The valleys also have increased surface water and groundwater interactions due to the geometric configuration that mimics pre-disturbance conditions; tightly coupled upland/wetland complexes.

Each tailings landform will evolve over time with runoff from these landforms being dominated by different transient factors. The consolidation release water from the various tailings facilities will have different magnitudes and timing and will produce different water volumes and quality as the sites transition from operations to closure. The surface water and groundwater interaction within each landform will also differ. For example, shallow and deep groundwater pathways within each landform will be unique and would lead to different mass loading rates at different times.

Tailings landforms are typically comprised of tailings sand, composite tailings (CT) capped with tailings sand, or fine tailings (FT) capped with coke. Tailings undergo consolidation during and following placement into the mined-out pits. Consolidation results in a reduction in volume and corresponding release of porewater. Consolidation, and the release of porewater, diminishes with time. Consolidation rates and magnitudes are expected to differ between CT, fluid fine tailings (FFT) and flocculated tailings. Note that use of FT in this report refers to consolidated FFT and flocculated tailings and is synonymous in with densified tailings.

Based on the experience of EIP work (ARKK 2021a), the majority of porewater release from CT is expected to occur during placement into the pit and construction of the sand cap. The expressed porewater is assumed to be captured in the operational closed-circuit system. Ongoing residual consolidation was also assumed to be negligible within the timeframe of this study. Therefore, consolidation release water from CT is not included in the model or the assessment.

Based on research conducted by Syncrude, consolidation of FFT and flocculated tailings is anticipated to be of greater magnitude and occur over a longer time horizon compared to CT. The initial consolidation is expected to occur rapidly and diminish over decades. For the purpose of the modelling, it is assumed some consolidation occurs during placement and operations and the related water release is captured within the closed-circuit system. The remaining consolidation and associated release water was assumed to occur within the timeframe considered in this study. It is impractical to include time variable consolidation within the integrated model. Instead, estimated consolidation release volumes and chemistry were approximated outside of the model and merged with the modelling results in a separate mass balance assessment for the pit lakes.

Once reclamation matures, runoff quantity and quality are expected to be dominated by transient climate. Evapotranspiration would be the major water outflow under these conditions. OSPW would be largely displaced from soil pores in the shallow sand and coke capping material. Runoff would be gravity drained to pit lakes and then flow to a receiving stream (i.e., Athabasca River, McKay River, and Muskeg River).

3.4 MODELLING ASSUMPTIONS

The main assumptions made in the conceptualization of the models are summarized below.

- A traditional model calibration and validation is not possible given much of the reclaimed landscape does not exist. Model results were "validated" based on regional and site-specific historical runoff and evapotranspiration values.
- At the start of the simulation, pit lakes were assumed to be full (i.e., the initial lake water level was assumed to be at lake sill, and all closure drainage channels were assumed to be in place). This condition simulates water drainage to the surrounding watercourses when the lake water level rises above the sill. As simulations progress, fresh water from precipitation and runoff from upstream areas moves through the sites. Solutes are transported from the subsurface of tailings landforms driven by hydraulic gradients (i.e., recharge at topographic highs and discharge at topographic lows). Solute mass is carried to the downstream pit lakes. The water balance dictates the lake levels and movement of water and solute off-site; if the lake level is above the sill there would be discharge and when the lake level is below the sill, the solutes would accumulate in the lake water. Given the uncertainties with the transition from operation to closure, it is challenging to define the point in time when closure channels will be in place. Therefore, it is necessary to interpret the results as potential releases from landforms and pit lakes to the environment. As landforms and the overall sites are transitioning from operation to closure it is likely that various forms of water management will be required. (i.e., interim channels, pumping, etc.)
- Given the constraints in simulating the temporal and spatial complexities of the water and solute movement as the mine transitions from operation to closure, the HGS model results for pit lake water balance and chloride mass loading were used as input to a spreadsheet model that tracks volume and chloride mass within the water cap of pit lakes. Consolidation release water from FT is estimated outside the HGS model for application to the pit lake model. Estimates for the degree of FT consolidation are shown in Figures 7 through 11 for each of the modelled lakes.
- Only chloride is modelled and was assigned within the pore space of tailings landforms (valleys) and pit lakes (both in FFT and water caps) of Syncrude mines. Other areas were assigned a chloride concentration of 0 mg/L. Chloride is a conservative solute in surface water and groundwater (i.e., does not degrade) and is indicative of worst-case solute migration and mass-loading under given surface water and groundwater flow fields.
- The initial flow conditions of the model account for unsaturated zones within the tailings deposit by spinning up the model with historical climate until a pseudo steady-state flow condition was achieved. The initial flow conditions were developed by spinning up the models using the representative dry (2011-2019) and wet (1966-1978) climate conditions. A minimum of two spin-up cycles were required before representative flow depths and groundwater elevations were reached.

An approximate calculation was used to estimate the increase in chloride concentration in the receiving watercourses due to release of runoff from the reclaimed sites. Modelling these releases in detail is an important next step to determine suitability and timing of release to the surrounding watercourses.

4. INTEGRATED HYDROLOGICAL MODEL DEVELOPMENT

4.1 GENERAL

This assessment applies an integrated flow and solute transport model to provide an understanding of water movement throughout the reclaimed closure landscape. Integrated modelling was used for the assessment because water and solute cycling from reclaimed oil sands mines and natural boreal ecosystems are governed by strong coupling between surface and groundwater processes (Devito et al. 2012; Nagare et al. 2022). The modelling was conducted using HGS, a fully integrated surface water and groundwater flow, and solute and heat transport modelling code (Aquanty 2017).

The conceptual model for the integrated model is described in Section 3. Inputs to an integrated model are climate time series, surface, and subsurface properties (digital elevation data, surface roughness, hydrogeologic parameters, etc.), vegetation properties (e.g., time varying leaf area index (LAI), root depth, etc.), and water quality data. This section describes the model development including model domain, model grid and layering, model boundary conditions and model parameterization followed by a description of model verification and simulation cases.

4.2 CLIMATE DATA

For the integrated modelling, transient precipitation, and potential evapotranspiration (PET) were developed at daily input time steps for days with non-zero precipitation. For days with no precipitation, the input time step equals the number of days with no precipitation up to a maximum time step of 14 days. For days with no precipitation, PET rate equalled the average PET over the number of days with no precipitation. Snowmelt was incorporated into the input by adding snowmelt water equivalent to the precipitation time series using a temperature-index approach. Any precipitation falling as snow is assumed to be stored on below freezing (<0°C) air temperature days. On days with above freezing (≥0°C) air temperature, the snowmelt process is simulated and the resulting meltwater is added to the rainfall component of the precipitation time series.

The modelling included simulation of historical climate and potential future climate which incorporated the effects of climate change. The historical climate scenarios were used to assess model performance and future climate scenarios were used to evaluate the closure landscape.

Historic climate data is primarily based on 1944-2020 precipitation and air temperature measured at Environment Canada's Fort McMurray Airport weather station. The future climate data sets were developed on the basis of the historical climate time series and NRCAN (2019) climate change projections as described below.

- The integrated modelling was focused on representing conditions at approximately year 2100. This timeframe coincides with the planned sitewide closure and future climate scenarios requested by the Alberta Energy Regulator (AER) (i.e., "*Provide a water budget…after surface water and groundwater systems are re-established…include a range of regional late-21st-century climate-change scenarios*").
- IPCC (2014) and NRCAN (2019) reported probable climate change outcomes in terms of increases in precipitation and air temperature for different emission scenarios or the Representative

Concentration Pathways (RCPs). The RCPs describe different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use (IPCC 2014). The RCP2.6 (stringent mitigation of GHG emissions) and RCP8.5 (very high GHG emission) scenarios provide upper and lower bounds for the emissions assumptions. NRCAN (2019) downscaled and summarized the IPCC climate model projections for Canada based on RCP2.6 and RCP8.5. The projected winter and summer temperature and precipitation increases for oil sands region based on NRCAN (2019) for both RCP2.6 and RCP8.5 scenarios were used to develop the model input precipitation and PET time series for 2024-2100 period.

4.2.1 HISTORICAL PRECIPITATION

Historical precipitation data at the Fort McMurray Airport weather station is available from 1944-2020 (76 years). The recorded annual total precipitation in the hydrological year timeframe (October 1 to September 30), is shown in Figure 7. The 76-year mean annual precipitation is 429 mm with annual minimum of 252 mm (1998) and annual maximum of 702 mm (1973). The climate data shows multiple cycles of wet and dry periods, longest of which occur from 1966 to 1978 (wet cycle) and 2006 to 2017 (dry cycle). The recorded average precipitation over the wet and the dry cycles are 504 mm and 357 mm, respectively. The wet and dry cycles with their corresponding mean values are also shown in Figure 7.

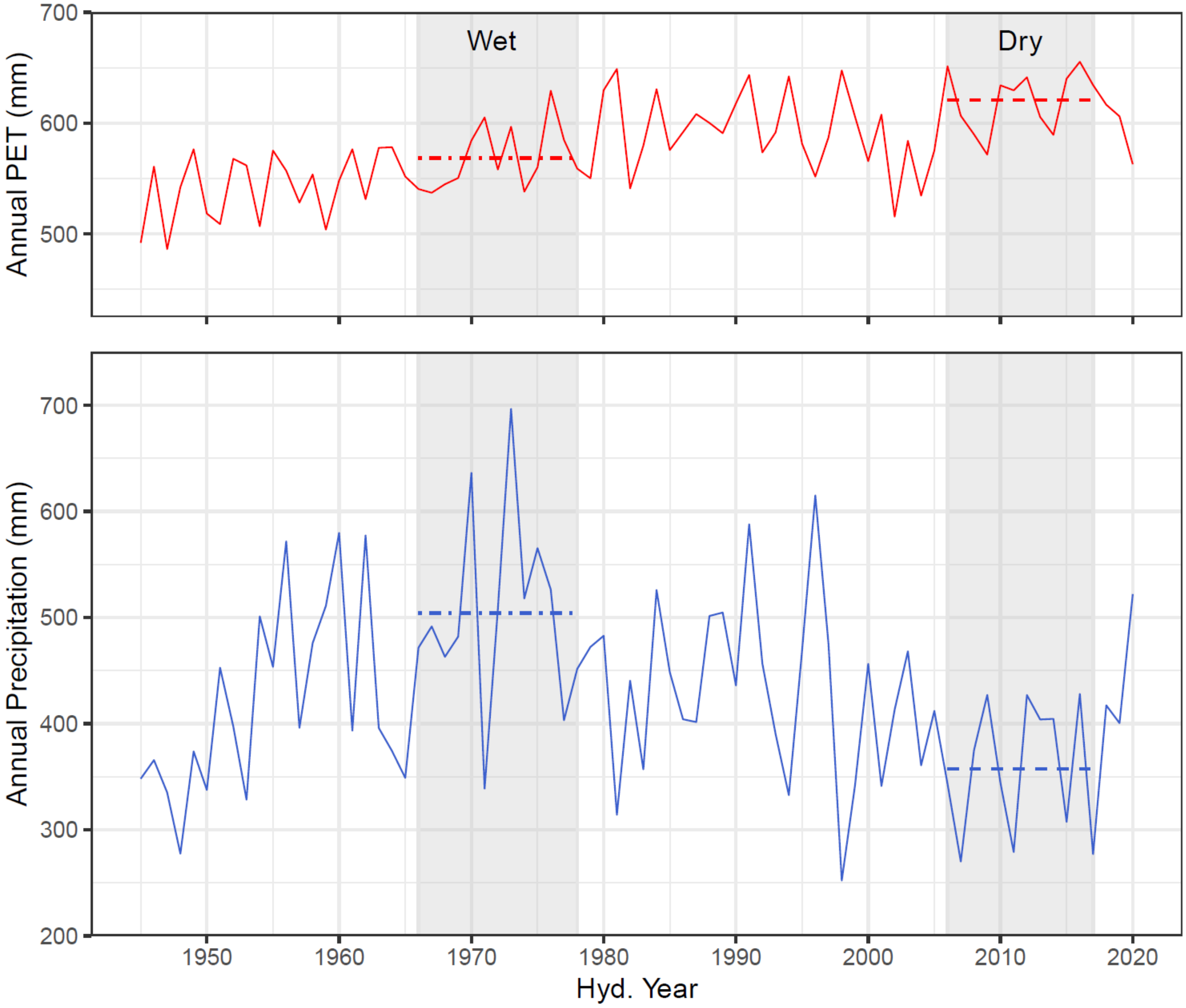


Figure 7 – Annual Precipitation and PET at Fort McMurray Airport Weather Station

4.2.2 HISTORICAL POTENTIAL EVAPOTRANSPIRATION (PET)

Evapotranspiration losses account for a significant portion of the water balance (i.e., the largest sink term) in the northern Alberta region. The HGS model simulates interception and actual evapotranspiration (AET) using the approach of Kristensen and Jensen (1975). The transpiration rate depends (1) on linear LAI functions that account for seasonal LAIs; (2) on a root distribution function which distributes root extraction among the root zone confined by the maximum root depth (RD); (3) on the difference between PET and canopy evapotranspiration and (4) nonlinearly on the current soil moisture. The PET can be estimated using energy balance or empirical approaches depending on the available meteorological data at a given location. The energy balance methods (e.g., Penman-Monteith (Allen et al. 1998)) need extensive meteorological data and their application is limited when required climate data is not available. Empirical approaches (e.g., Hamon 1961, Thornthwaite 1948) use easily measurable meteorological variables (e.g., air temperature) for PET calculation and can provide reliable estimates of PET especially for locations where empirical methods have been developed or calibrated. The Penman-Monteith method is a generally recommended approach for calculating PET (Allen 1998), however long-term time series of required meteorological data (e.g., net radiation, wind speed, and humidity) are not available for Penman-Monteith application in the Fort McMurray region. Carey (2011) reported meteorological data and PET values estimated using Penman-Monteith method for 2001–2011 period at a reclamation site near Fort McMurray. In addition, monthly PET and shallow lake evaporation for different locations in Alberta, including Fort McMurray (1972-2009) are available (Alberta Government 2013). These were calculated using Morton's (1983) complementary relationship for areal evapotranspiration.

Hamon's (1961) temperature-based empirical method was used to generate a continuous PET time series for the LMCP modelling. The Hamon (1961) equation (Dingman 2002) is given below:

$$ET\ (\frac{mm}{day}) = 29.8D\frac{e_a^*}{T_a + 273.15}$$

where e_a is the saturation vapor pressure (kPa) at mean daily temperature T_a (°C), and D is day length (hours). The calculated PET using Hamon's empirical method was adjusted using a correlation between Fort McMurray monthly PET data for 1972-2009 (Alberta Government 2013). The adjustments were applied to the PET time series from 1944 to 2020. The adjustment factors for different months are given in Table 2. The time series of adjusted annual PET for Fort McMurray for 1944-2020 is shown in Figure 7. The annual average of calculated PET for 1944-2020 period is 578 mm.

Table 2 – Adjustment Factors of Calculated PET for Each Month

Month	Adjustment Factor
January	1.0
February	1.0
March	2.2
April	1.8
May	1.5
June	1.4
July	1.3
August	1.2
September	0.9
October	0.7
November	0.1
December	1.0

4.2.3 CLIMATE CHANGE – TEMPERATURE AND PRECIPITATION ANOMALY CALCULATIONS

Statistically downscaled climate change scenario data (NRCAN 2019) were used to construct the projected input precipitation and PET time series. The downscaled climate time series were constructed using output from 24 global climate models, with 10 km grid resolution, available for 1951-2100 (ECCC 2021). The median (50th percentile) monthly total precipitation and mean air temperature at three locations, Syncrude's Mildred Lake and Aurora North sites, and Fort McMurray Airport, for RCP2.6 and RCP8.5 were downloaded from the Environment and Climate Change Canada website (ECCC 2021) and considered for this study.

The 1986-2005 period was used as the reference period for calculating precipitation and temperature anomalies for future climate scenarios (NRCAN 2019). Anomalies represent the difference between the value of a climate variable for a season in a given year and the average value of the reference period (Charron 2016). Based on the reference period of 1986-2005 in the downscaled climate data, anomalies for air temperature and precipitation were calculated for each season within the 2024-2100 period as shown in Figure 8 and Figure 9, respectively. Different seasons were defined in a manner analogous to NRCAN (2019): spring - March, April, and May; summer - June, July and August; fall - September, October and November; and winter - December, January, and February. The anomalies are reported as differences in degrees Celsius for air temperature and percentage for precipitation. Calculated anomalies for the three locations were found to be very similar. Therefore, the calculated anomalies for Fort McMurray Airport were used for climate change projection. As discussed earlier, the historic climate data is also from the same location.

The average seasonal total changes in temperature and precipitation for RCP2.6 and 8.5 scenarios for two selected future periods (2031-2050 and 2081-2100) relative to the reference period of 1986-2005 are summarized in Table 3 and Table 4. Winter temperature anomalies are expected to be greater than other seasons (NRCAN 2019) as shown in Figure 8 and Table 3. A 7.7°C change in winter temperature is projected by end of the century for RCP8.5 as compared to a 2.9°C change for RCP2.6 scenario. A relative (1986-2005) winter precipitation increase of 17.6% is projected for RCP8.5 scenario at the end of the century as compared to 9.5% increase for RCP2.6 scenario. This increase in winter precipitation however does not lead to a comparable annual increase because most precipitation in Fort McMurray area falls as rain in summer (Figure 9).

Table 3 – Average Projected Temperature Change (°C) Relative to 1986-2005

Time Period	Season	RCP2.6	RCP8.5
2031-2050	Spring	1.5	2.1
	Summer	1.4	2.1
	Fall	1.8	2.4
	Winter	1.6	2.9
2081-2100	Spring	1.8	5.4
	Summer	1.5	5.9
	Fall	1.9	5.9
	Winter	2.6	7.7

Table 4 – Average Projected Precipitation Change (%) Relative to 1986-2005

Time Period	Season	RCP2.6	RCP8.5
2031-2050	Spring	5.5	7.3
	Summer	3.2	2.2
	Fall	3.2	7.3
	Winter	6.1	8.1
2081-2100	Spring	7.7	18.7
	Summer	7.0	2.3
	Fall	6.4	12.8
	Winter	9.5	17.6

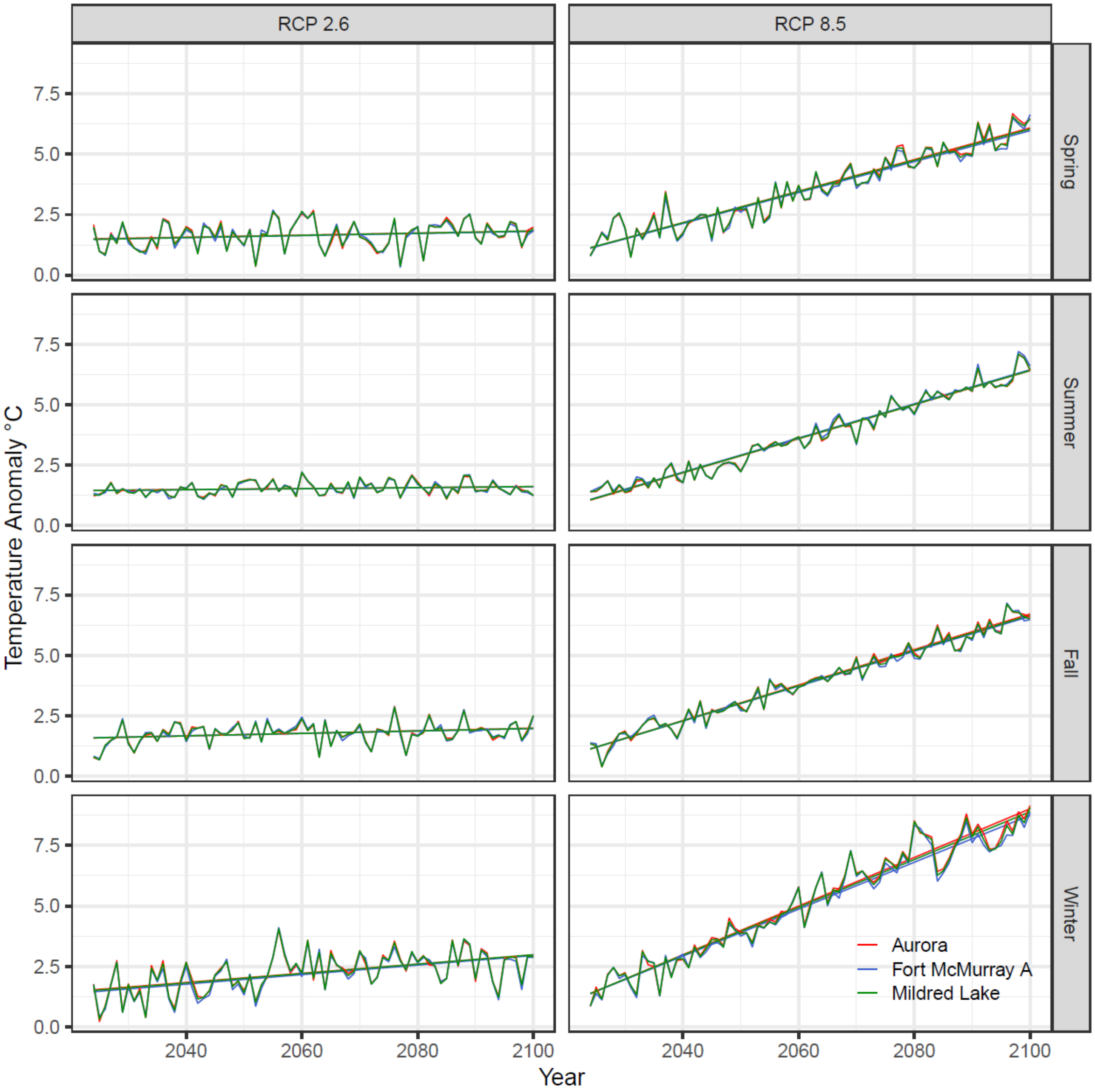


Figure 8 – Seasonal Temperature Anomaly of Climate Scenarios Relative to 1986-2005

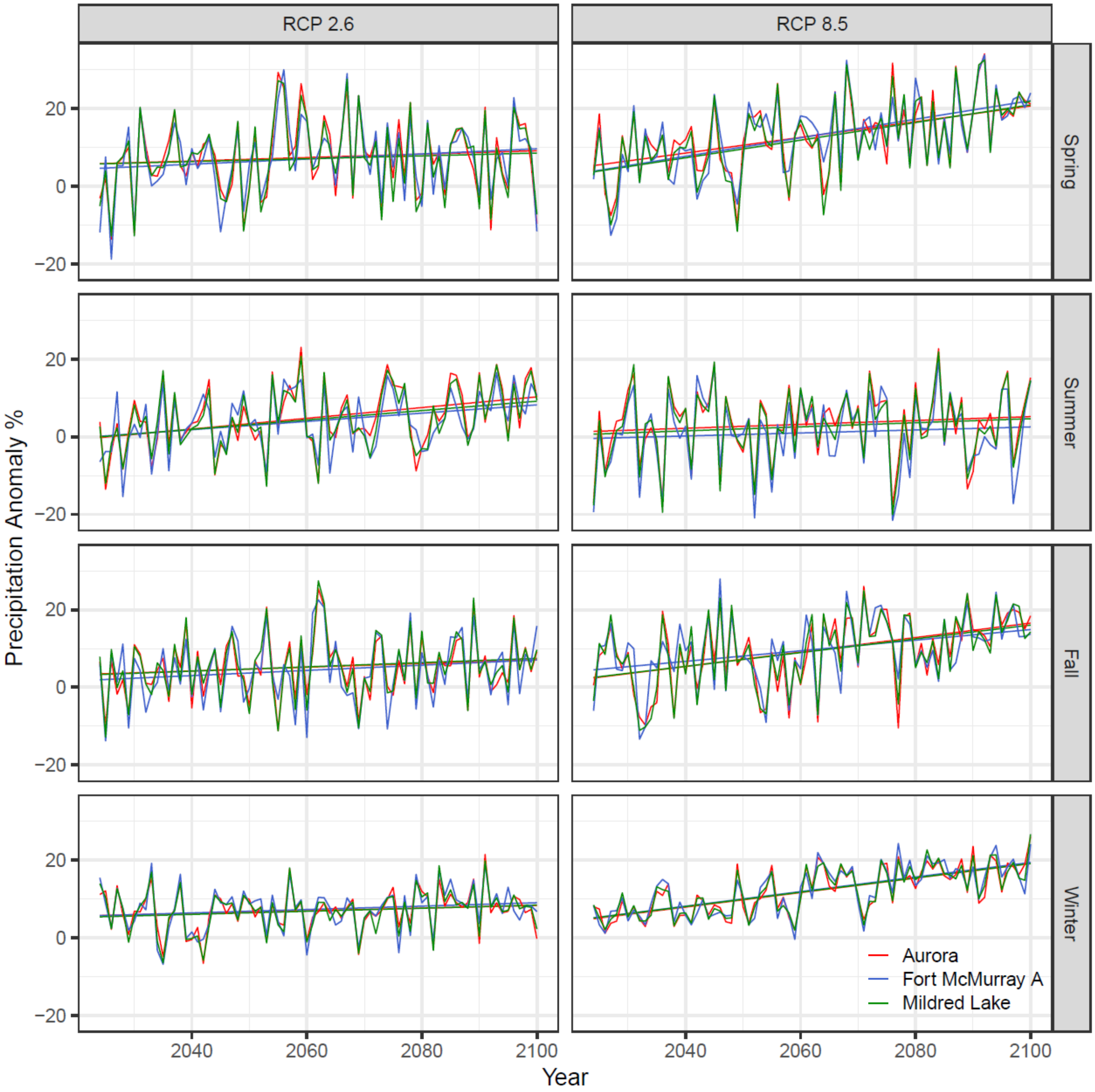


Figure 9 – Seasonal Precipitation Anomaly of Climate Scenarios Relative to 1986-2005

4.2.4 CLIMATE CHANGE PROJECTION

The anomalies for air temperature and precipitation described in Section 4.2.3 were applied to the historical precipitation data from the Fort McMurray Airport (1944-2020) climate data to develop four sets of PET and precipitation time series for years 2024-2100. The objective of developing the four sets of climate times series is to provide end of the century climate scenarios that represent probable warm-wet, cool-wet, warm-dry, and cool-dry conditions. The last 15 years (2006-2020) of 1944-2020 precipitation time series represents a dry climate cycle with respect the 76-year average conditions (see Figure 7). The projected dry-cold and dry-warm time series were developed by applying RCP2.6 and RCP8.5 anomalies to historic climate data. Historic data from 1944 to 2020 was projected in sequence to years 2024 to 2100. Given the dry climate cycle from 2006-2020, this provides a dry condition at the end of the 21st century. To construct projected wet conditions at the end of the century, the historical climate data was rearranged such that the first portion of the time series comprises the data from 1979 to 2020 and the later portion of the time series comprises the data from 1944 to 1978. This provides a wet condition at the end of 21st century (i.e., 1966-1978 historic wet cycle). This approach generally honours the historic variability and decadal cycles. The resulting time series provide a plausible and broad range of climate input that are well suited to testing the robustness of the closure landforms.

As PET is calculated using the mean air temperature time series, the historical air temperature of Fort McMurray Airport station in 1944-2020 was detrended prior to applying the anomalies and reordering the data to construct the above noted four time series. To detrend the timeseries, the mean temperature of each season in 1986-2005 was selected as the reference value and the rest of the time series was adjusted by adding the residuals of the linear regression. The detrended air temperature time series in each season has a mean value similar to the seasonal mean value in 1986-2005. The linear trend lines of both historical and detrended air temperature are shown in Figure 10. The historic precipitation time series was not detrended because there is no consistent trend in the precipitation data. In addition, detrending the data would reduce the magnitudes of the historical wet and dry cycles. Simulation of the wet and dry extremes is important in order to understand landform performance, such as sustainability of pit lakes.

The mean annual projected air temperature time series of 2024-2100 for RCP2.6 and RCP8.5 climate scenarios are shown in Figure 11 (dry condition) and Figure 12 (wet condition). The reference time series are the detrended 1944-2020 temperature data. The projected air temperature was used to calculate PET using the methodology presented in Section 4.2.2. The annual PET time series of 2024-2100 for RCP2.6 and RCP8.5 are shown in Figure 13 (dry condition) and Figure 14 (wet condition). The reference PET time series shown in the figures is the PET calculated using the detrended air temperature time series. The time series of annual precipitation for RCP2.6 and RCP8.5 scenarios are shown in Figure 15 (dry condition) and Figure 16 (wet condition). The reference is the time series of historic precipitation (1944-2020) measured at the Fort McMurray Airport weather station.

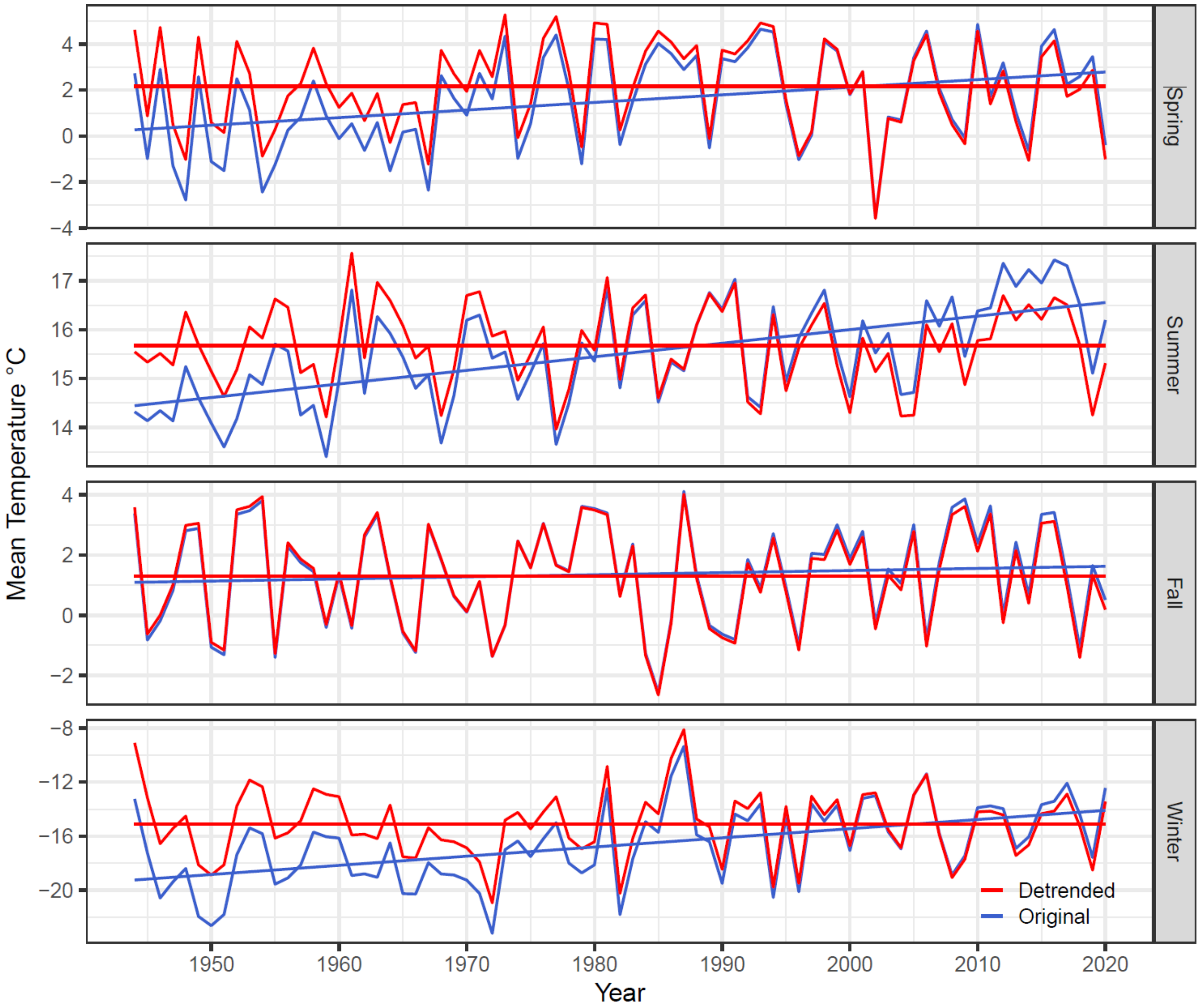


Figure 10 – Mean Annual Detrended Historical Temperature Time Series in 1944-2020

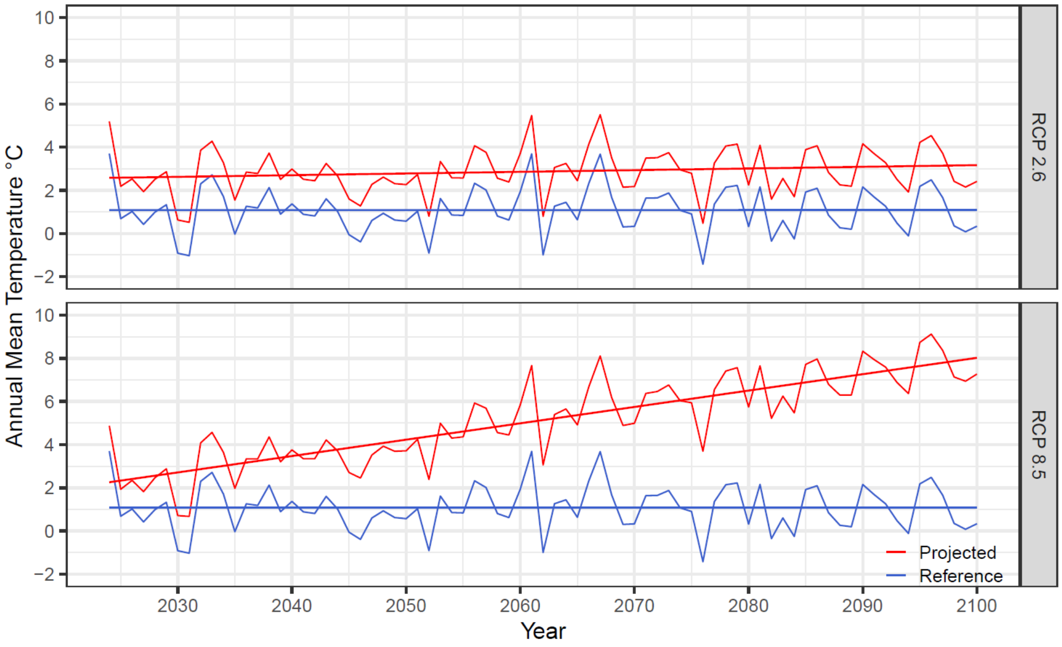


Figure 11 – Projected Dry Temperature (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

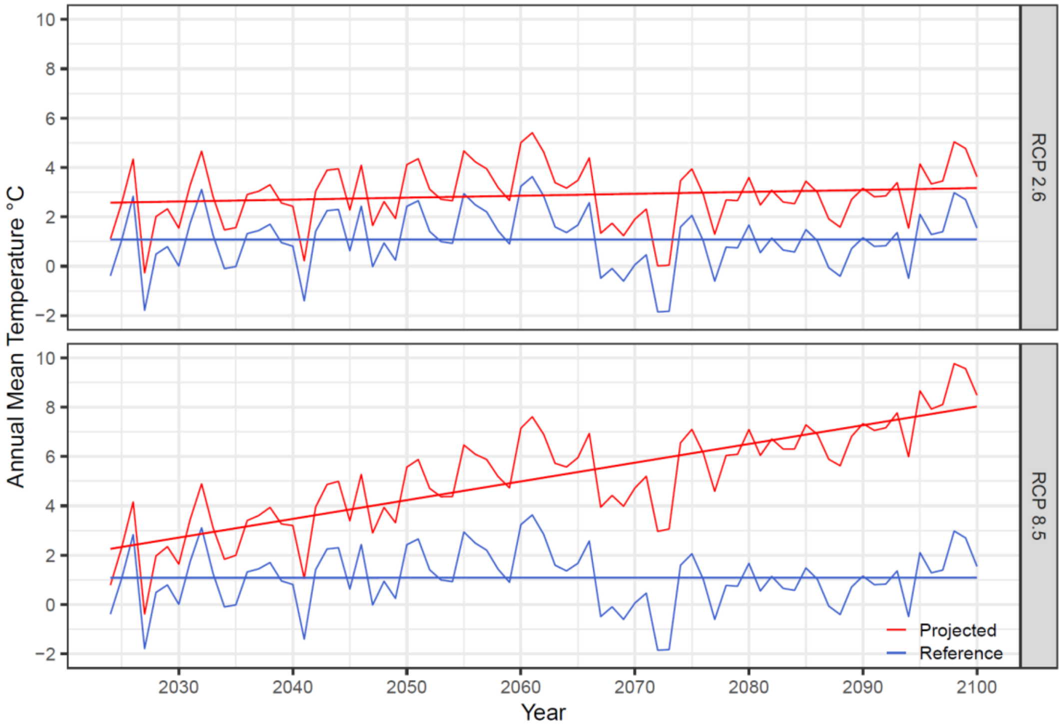


Figure 12 – Projected Wet Temperature (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

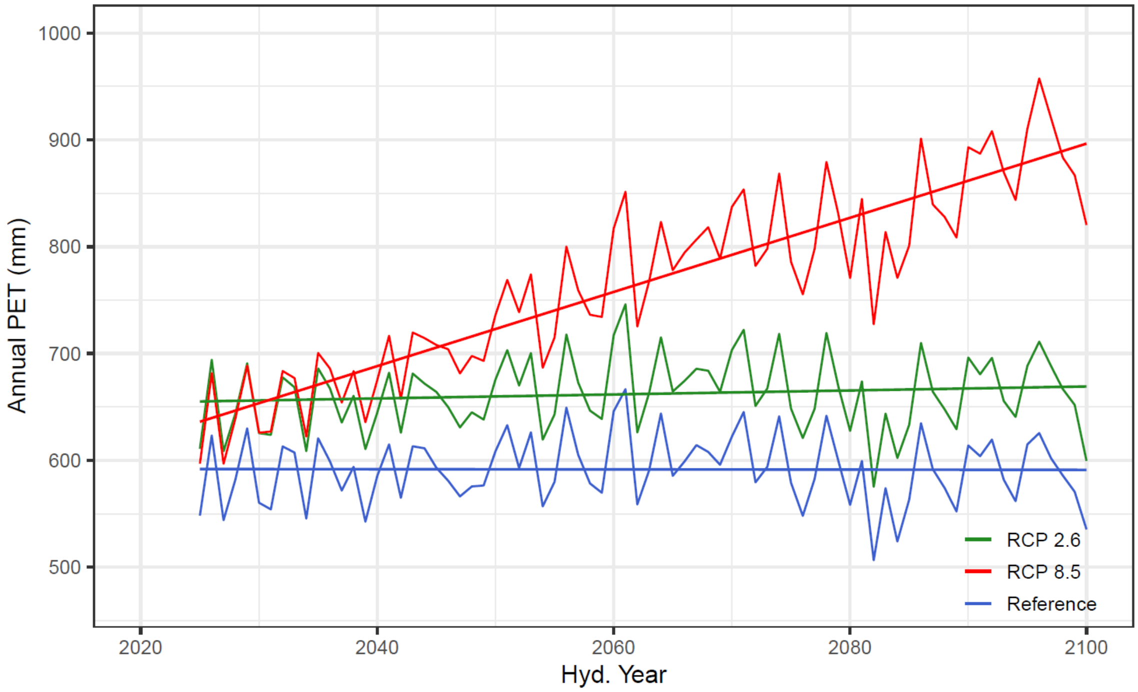


Figure 13 – Projected Dry PET (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

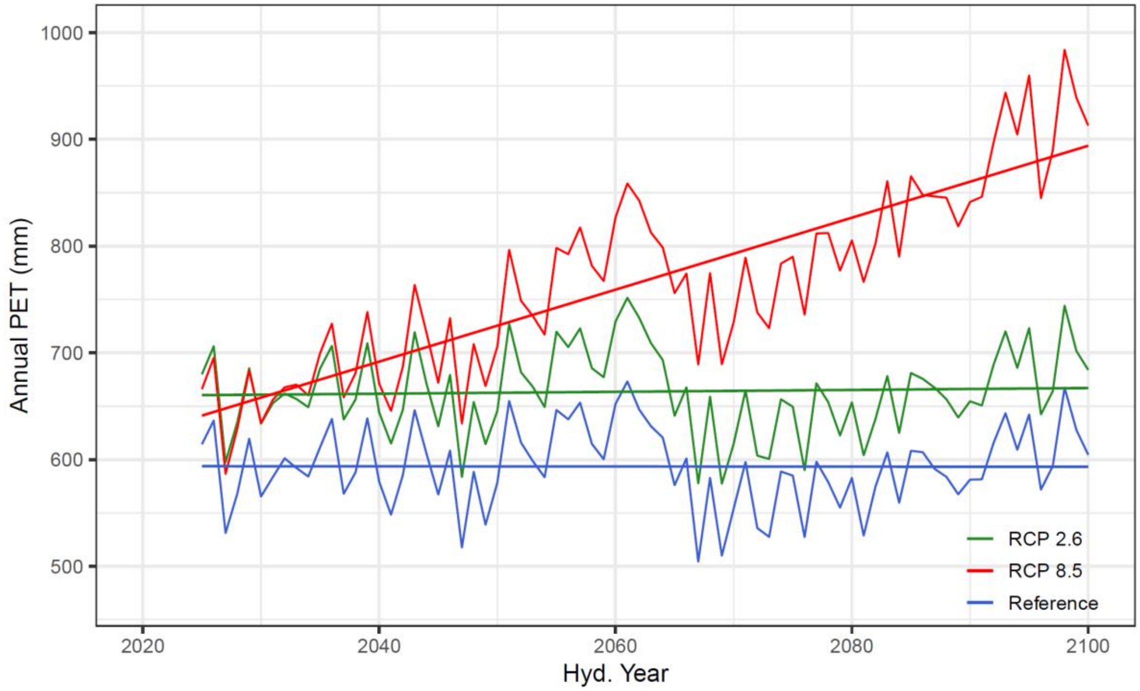


Figure 14 – Projected Wet PET (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

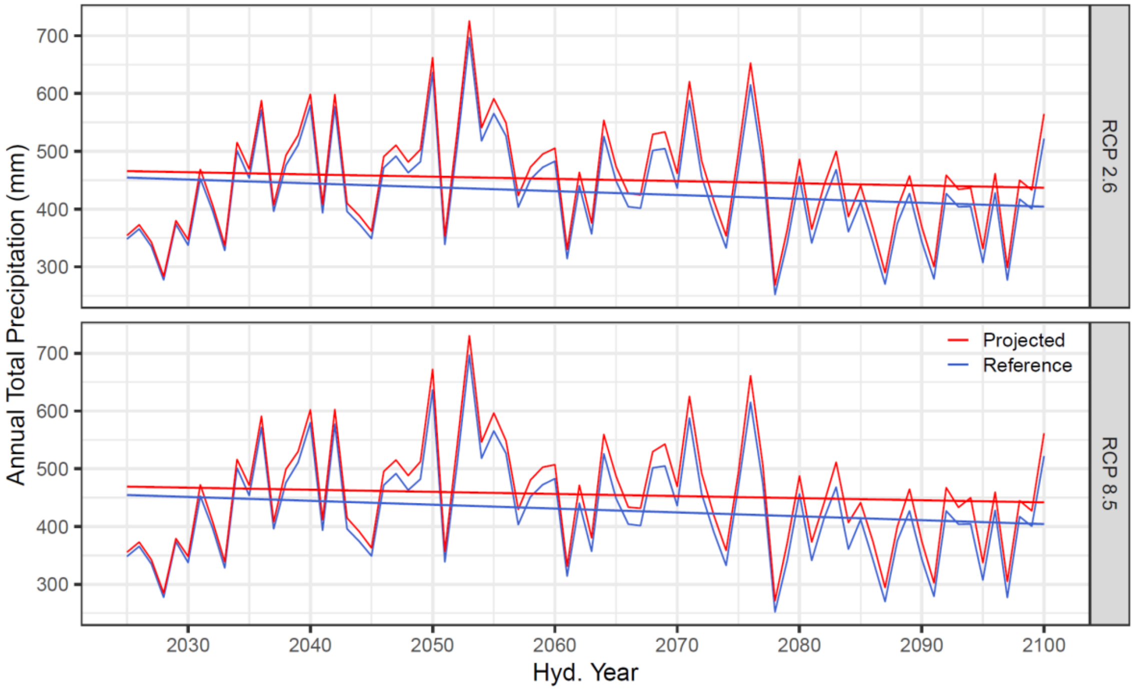


Figure 15 – Projected Dry Precipitation (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

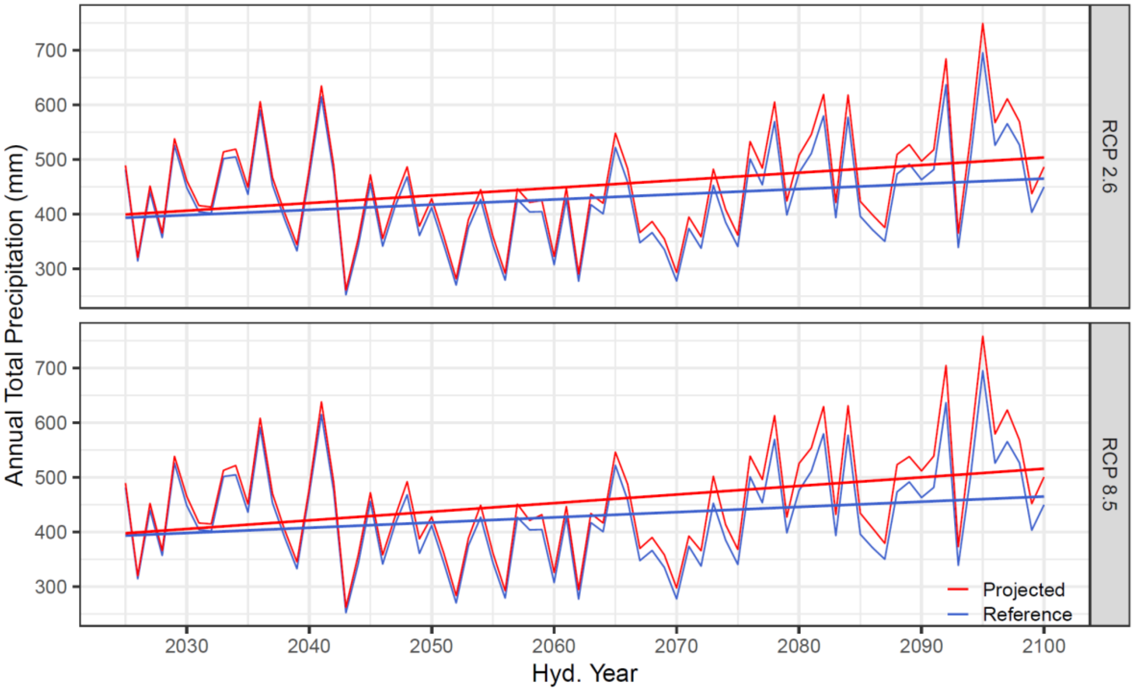


Figure 16 – Projected Wet Precipitation (2024-2100) for RCP2.6 (Cool) and RCP8.5 (Warm)

4.2.5 CLIMATE SCENARIOS

The integrated modelling scenarios are aimed at representing conditions at approximately year 2100. This timeframe coincides with closure plans and future climate scenarios requested by the AER (i.e., "*Provide a water budget…after surface water and groundwater systems are re-established…include a range of regional late-21st-century climate-change scenarios"*).

The integrated models were validated by simulating historical wet (1966-1978) and dry (2006-2017) cycles and comparing the model results to regional observed data. The simulations are summarized below:

- Historical dry decade (2006-2017, Figure 7)
- Historical wet decade (1966-1978, Figure 7)
- Cool Dry – RCP2.6 for 2024-2100 with final decade in dry cycle (Figure 13 and Figure 15)
- Cool Wet – RCP2.6 for 2024-2100 with final decade in wet cycle (Figure 14 and Figure 16)
- Warm Dry – RCP8.5 for 2024-2100 with final decade in dry cycle (Figure 13 and Figure 15)
- Warm Wet – RCP8.5 for 2024-2100 with final decade in wet cycle (Figure 14 and Figure 16)

The above scenarios are expected to provide a wide range of results that will be interpreted to understand potential water balances and solute transport (chloride) through the sites.

4.3 REGIONAL HYDROSTRATIGRAPHY

The regional stratigraphic sequence is shown in Table 5. The sequence (Mossop and Shetsen 1994) of interest, with increasing depth, consists of:

- Holocene sediments comprised of peat, sands, silts, and clays;
- Pleistocene deposits comprised of sands, silts, and clays;
- Clearwater Formation clays and shales of the Cretaceous Period;
- Bitumen/water filled clays and sands of the McMurray Formation of the Cretaceous Period; and,
- Shales and Carbonates of the Upper (Waterways Formation) and Middle (Keg River and Prairie Evaporites Formations) Devonian Period.

The stratigraphic units were divided by Bachu et al. (1993), WorleyParsons (2012) and AESRD (2013) into aquifers (geologic layers with potential to transmit water) and aquitards (geologic layers of low permeability). The reported hydrostratigraphic sequence is shown in Table 6. The aquifers of interest are:

- Quaternary and Holocene deposits (sands and gravel) including sand and gravel buried channels as mapped regionally by Andriashek and Atkinson (2007), and Atkinson et al. (2013);
- Clearwater Wabiskaw Member;
- Water-bearing sand at the base of the McMurray Formation (Basal Aquifer);
- Weathered Beaverhill portion of the Upper Devonian sequence;
- Lower Prairie Evaporite Formation collapse features from the Middle Devonian interval; and,
- Keg River Formation aquifer system.

4.4 HYDROSTRATIGRAPHY OF SYNCRUDE MINE SITES

4.4.1 NATURAL MATERIALS

The predevelopment hydrostratigraphic units for the Syncrude mine sites are shown in Table 6. The units are described in more detail in the sections below.

HOLOCENE AND PLEISTOCENE SURFICIAL DEPOSITS

The surficial deposits in the AOSR consist of Holocene and Pleistocene sediments deposited by glacial and fluvial processes. The extensive boulder gravels along Athabasca and Clearwater rivers were deposited ~10,000 years ago by the paleoflood of the Glacial Lake Agassiz (Fisher and Smith, 1994). The valleys of many creeks and rivers in the region also consist of varying thicknesses of recently deposited aeolian and fluvial sand and gravel sediments.

At the Mildred Lake site and MLX-W, Holocene deposits (muskeg, sand, clay, peat, and organic soil) (Ho) are generally thin and range from 1-2 m in thickness. Thicker alluvial and aeolian sand (Hf and Ha) may occur along the west bank of the Athabasca River (e.g., T-Pit and MLX-East (MLX-E) Pit areas). Pleistocene deposits at the Mildred Lake site are thin (generally 5-10 m in thickness). The Pleistocene layer consist of glaciolacustrine deposits (Pl), made up primarily of interbedded silt and clay with minor sand, overlying till (Pg). Fluvial (Pf) sand and gravel may occur along the banks of Athabasca, McKay, and Dover Rivers. The buried North and South Spruce Channels located along the east side of the McKay River are made up of thin sand and gravel layers interbedded with thicker till deposits with a total thickness ranging from 15-40 m (Andriashek and Atkinson 2007, BGC 2011, ARKK 2021b). The buried Birch Channel located to the south of MLX-W is made up of fine silty sand and is between 0 and 15 m thick in the area of interest (WorleyParsons 2012, Wood 2021). The Birch Channel is made up of cleaner sands and gravels to the west further away from MLX-W with total thickness ranging from 15-100 m (Andriashek and Atkinson 2007, WorleyParsons 2012).

At Aurora North the Holocene deposits could be up to 12 m thick. These are underlain by 1-90 m Pleistocene sediments consisting of Pleistocene glaciofluvial sands and gravels (Pf), glaciolacustrine clays (Pl) and tills (Pg). The thicker sequences of Pleistocene deposits occur in the Fort Hills area. The Fort Hills is a major thrust moraine complex that covers an area of ~180 km^2. The southern portions of the Fort Hills could partly be hydraulically disconnected in the subsurface from the southern low-lying areas (ARKK 2020a). This was interpreted to be due to an impermeable or leaky barrier formed by clay (Pl) and till (Pg) layers as a result of glacial thrusting (Bruce Geotechnical Consultants 1998, Andriashek and Atkinson 2007) and/or reduction in hydraulic conductivity of the glaciofluvial sands (Pf) due to higher oil/bitumen content (ARKK 2020a).

CRETACEOUS

The Grand Rapids Formation (Kg) is characterized by a “salt and pepper” texture of fine to coarse grained, uncemented sand. The Grand Rapids is absent throughout much of the Mildred Lake site, ML-X, and Aurora North. The known occurrence of the formation is under the Southwest Sand Storage (SWSS) at the Mildred Lake Site (ARKK 2021c).

The Clearwater Formation (Kc), where present, conformably overlies the McMurray Formation and is composed of a sequence of marine shales and siltstones. The Clearwater Formation (Kc) is mostly eroded at the Aurora North. At the Mildred Lake Site and MLX-W, the Clearwater Formation (Kc) is continuous and could be as thick as 60 m, except over the footprint of the North and South Spruce buried channels (Syncrude 2014). The Wabiskaw Member (Kcw) of the Clearwater Formation (Kc) directly overlies the McMurray formation and is composed of glauconitic sand and silt. The Wabiskaw Member (Kcw) is saturated with bitumen in the eastern portions of the Athabasca Oil Sands Deposit (BGC 2010).

McMurray Formation (Km) underlies the Clearwater Formation (Kc). The middle and lower members of the formation are composed of bitumen-saturated fine to coarse grained sands with interbeds of clay and host most of the hydrocarbon reserves in the region. The McMurray Formation is the lowermost geological formation of the Cretaceous period overlying the Devonian erosional surface in the area. The McMurray Formation is often divided into three members: lower continental, middle estuarine, and upper near shore marine environments.

The Basal Aquifer comprises water bearing sands and is typically found at the base of the Lower McMurray Member. The thickness and presence of the basal water sands is largely controlled by the topography of the erosional surface of the Devonian. The Basal Aquifer is discontinuous at the Mildred Lake site and MLX-W with a maximum thickness of ~13 m under the Mildred Lake Settling Basin (Syncrude 2014). The Basal Aquifer is more continuous and thicker at Aurora North and reaches a maximum thickness of ~47 m. Lake and pond muds, sometimes referred to as basal clays, are often present above the Basal Aquifer within the Lower McMurray Member (Km).

DEVONIAN

The Devonian Waterways Formation (Dw) is the main Upper Devonian unit present within the Syncrude mine leases. The upper 3-5 m thick weathered portion of the erosional top of the Waterways Formation of the Devonian Beaverhill Group may act as a leaky aquifer. Where present, the overlying McMurray basal water sands are directly hydraulically connected to this weathered layer. The Waterways Formation is composed of shales and argillaceous carbonates and acts as an aquitard. The Prairie Evaporite Formation underlies the Waterways Formation and is composed of anhydride and salt. The Prairie Evaporites may contain highly permeable collapse features (ARKK 2020b) that could act as aquifers but are likely not continuous. The Prairie Evaporite Formation is underlain by the fossiliferous carbonates of the Keg River Formation. The Keg River Formation has been characterized as an aquifer/aquitard system (Bachu et al. 1993).

The different Devonian units may possibly be hydraulically connected, but data is sparse. There may be locations of fractured zones within the Waterways Formation that may act as connection between McMurray Formation Basal Aquifer and Lower Prairie and Keg River Formation aquifers. However, little data exists on such connections.

4.4.2 MINING AND RECLAMATION MATERIALS

Post 2008, mining materials at Syncrude sites have been classified into hydrostratigraphic units to represent conditions at the mine sites and for closure modelling. Tailings sand, CT, FT, coke, engineered dam fills and unengineered dump fill materials were defined as unique hydrostratigraphic units at the Mildred Lake site and MLX-W. Tailings sand, CT, FT, engineered dam fills, and unengineered dump fill materials were defined as unique hydrostratigraphic units at Aurora North. Beach deposits, reclamation covers, and hummocks made up of tailings sand could function as units transmitting water in the subsurface in the post reclamation landscape. Other materials would act as aquitards due to their low potential to transmit water.

Table 5 – Stratigraphic[1] Column for the Athabasca Oil Sands Region

ERA	PERIOD		GROUP	FORMATION	MEMBER	LITHOLOGIC DESCRIPTION	REGIONAL HYDROSTRATIGRAPHIC UNITS[2]
Cenozoic	Holocene					Muskeg/organic soils, alluvium	Quaternary aquifer and aquitard system
	Pleistocene					Sand, gravel, silt, clay	
	Erosional Unconformity (major gap in geologic sequence)						
Mesozoic	Cretaceous	Lower	Mannville	Grand Rapids (Kg)		Lithic sand and sandstone	Grand Rapids aquifer
				Clearwater (Kc)		Lower and upper estuarine sand, silt, and clay	Clearwater aquitard
					Wabiskaw (Kcw)	Glauconitic sandstone	Wabiskaw aquifer
				McMurray (Km)	Upper	Marine sand, silt, and clay	McMurray aquifer/aquitard system
					Middle	Lower and upper estuarine sand, silt, and clay	
					Lower	Continental fluvial sand, floodplain, and lagoon clay	
	Erosional Unconformity (major gap in geologic sequence)						Beaverhill Lake aquifer and Upper Devonian aquitard systems
Paleozoic	Devonian	Upper	Beaverhill Lake	Waterways (Dw)	Moberly		
					Christina	Alternating sequence of argillaceous limestone, calcareous shale, and clastic limestone	
					Calumet		
					Firebag		
				Paraconformity			
		Middle/Lower		Slave Point		Dolomitic Limestone	
				Paraconformity			Prairie-Watt Mountain aquiclude system Dissolution features and Prairie Evaporite aquifer system
				Fort Vermillion		Anhydrite and dolomite	
			Elk Point	Watt Mountain		Shale, siltstone, and anhydrite	
				Muskeg		Anhydrite and dolomite	
				Prairie Evaporite		Salt and anhydrite	
				Keg River		Dolomite, claystone and evaporite	Keg River aquifer- aquitard system
				La Loche		Claystone and arkosic sandstone	Basal Aquifer
	Erosional Unconformity (major gap in geologic sequence)						
Proterozoic	Precambrian					Metasedimentary rocks and granite	Aquiclude

Notes: [1,2]Adopted and modified from Bachu et al. (1993), BGC (2010), WorleyParsons (2012) and AESRD (2013)

Table 6 – Pre-development Hydrostratigrahic Units for Mildred Lake, MLX-W, and Aurora North Groundwater Models

Hydrostratigraphic Unit	Description	Mildred Lake and MLX-W	Aurora North
Remaining Holocene and Pleistocene surficial deposits (Ho, Hl, Pl, Pg)	Lower permeability organic soils (Ho), lacustrine (Hl) and glaciolacustrine clays (Pl), silts and tills (Pg); undifferentiated; aquitards	Present throughout	Present throughout
Grand Rapids Formation Sandstone (Kg)	Salt and pepper sandstone; aquifer	Not present within lease except under SWSS	Not Present within lease
Clearwater Formation Clay Shale (Kc)	Marine shales and siltstone; aquitard	Present throughout, but eroded east of Beaver River	Mostly eroded
Wabiskaw Member of the Clearwater Formation (Kcw)	Thin sandier member of Kc, glauconitic sand and silt, potential water bearing zone, i.e., potential aquifer	Present throughout, but eroded east of Beaver River	Mostly eroded; sporadic and discontinuous
McMurray Formation (Km) Bituminous Sands	This includes the Upper, Middle, and Lower members; aquitard	Present throughout	Present throughout
Water Sands of the McMurray Formation	Water filled sand at the base of McMurray Formation; aquifer	Present but very thin and discontinuous	Present throughout
Devonian Bedrock Formations	Top of Devonian (Waterways - Dw) expected to act as aquitard and will form the base of each model; surficial eroded layer may act as leaky aquifer	Present throughout	Present throughout

4.5 HYDROGEOLOGY AND GROUNDWATER FLOW SYSTEM

The study area is situated within the glacially-derived terrain of Alberta's northeastern boreal plains. Low lying areas are occupied by shallow lakes and extensive muskeg and peat deposits, while uplands are generally forested by species such as aspen poplar and white spruce. Climate within the study area is strongly seasonal, with long, cold winters and short, moderately warm summers. On an annual basis, the climate is sub-humid, with synchronized peaks in potential evapotranspiration and precipitation occurring in the warmest month of July (ARKK 2021c). As a result, annual streamflow hydrographs are dominated by the spring freshet and most groundwater recharge is derived during the freshet and outside of the growing season.

Prior to mining at the Mildred Lake site, principal groundwater flow directions in the region in stratigraphic units above the Devonian were from the topographic highs to the west and southwest (Thickwood Hills) of the mining area towards the deeply incised river valleys of the Dover River to the north, the McKay River between the Mildred Lake site and MLX-W, and the Athabasca River to the east. Groundwater flow was focused in the permeable horizons of the surficial soils, with lesser flow in the permeable horizons of the Cretaceous deposits (e.g., the Clearwater Wabiskaw Member (Kcw) and the Basal Aquifer) due to the generally low permeability of the intervening Clearwater Formation clays and bitumen saturated McMurray Formation.

Within the area of the Mildred Lake site, groundwater flow directions in the overburden material were controlled by local topography, thick muskeg deposits that blanketed the area, and variations in permeability. Significant groundwater flow occurred through the discontinuous deposits of permeable sands and gravels across the lease. Recharge water that entered the overburden generally discharged to local creeks and the Beaver Creek, which ran from the south to the north through the lease, where it discharged to the Athabasca River. Groundwater flow through the Clearwater and McMurray formations occurred at a slow rate and was generally downward due to its low permeability. Small amounts of vertical seepage that passed through these formations are thought to recharge the patchy permeable Basal Aquifer at the base of the McMurray Formation (Wallick and Dabrowski 1982). The hydraulic conductivity of the surficial Holocene and Quaternary deposits varied between 1.0×10^{-9} m/s (fine grained glacial deposits) and 5.0×10^{-5} m/s (muskeg deposits) (Golder 2012, ARKK 2021c). The hydraulic conductivity of the buried channel deposits within North Spruce and South Spruce channels was reported to range from 5.0×10^{-8} m/s (fine grained glacial deposits) and 6.7×10^{-4} m/s (sand and gravels) (ARKK 2021c). The hydraulic conductivity of the sand within the Birch Channel extent within the MLX-W area was found to be on the order of 3.0×10^{-6} to 1×10^{-5} m/s (Wood 2021).

Pre-mining groundwater elevations in the Quaternary deposits at Aurora North and the surrounding areas closely followed the ground topography. The highest measured groundwater levels of 340 metres above sea level (masl) occurred under the Fort Hills (Clifton Associates 2001). The lowest groundwater level of 270 masl was measured in the western region close to the escarpment of Athabasca River (Clifton Associates 2001). Groundwater flow occurred radially away from the elevated Fort Hills area. The radial flow may partly be interrupted towards the south of the Fort Hills due to presence of leaky or impermeable thrust sediments.

Under pre-mining conditions, the steepest lateral groundwater gradients of ~0.01 m/m occurred from the Fort Hills towards the Athabasca River. Much flatter hydraulic gradients of ~5.0 x 10^{-4} m/m occurred on the low-lying wetland areas to the south of the Fort Hills (Clifton Associates 2001). The hydraulic conductivity of the Quaternary deposits at Aurora North varies between 1.0 x 10^{-8} m/s (fine grained glacial deposits) and 3.0 x 10^{-4} m/s (outwash sand) (ARKK 2021c).

The predevelopment groundwater heads in the Basal Aquifer at Aurora North and the surrounding area varied between 230 masl and 280 masl (WorleyParsons 2012). The groundwater flow was in general towards the Athabasca River (east to west in the project area). The hydraulic conductivity of the Basal Water Sands varied from on the order of 2 x 10^{-5} m/s to 1 x 10^{-4} m/s. Storativity of the Basal Aquifer ranged from on the order of 8 x 10^{-6} to 1 x 10^{-4} (ARKK 2021c).

The predevelopment groundwater heads in the Beaverhill Lake unit in the area varied between 235 masl and 270 masl (WorleyParsons 2012). The groundwater flow within the area of interest was in general from east to west towards the Athabasca River. The predevelopment groundwater heads in the Keg River unit of the Devonian Formation within the area of interest varied between 245 masl and 260 masl (WorleyParsons 2012). The groundwater flow was in general towards the Athabasca River, i.e., from east to west. The hydraulic conductivity of the different horizons of the Devonian was in general found to be on the order of 1.0 x 10^{-13} to 1.0 x 10^{-9} m/s, except for discrete zones of significant permeability (e.g., open fractures) inferred from circulation loss zones in drilling records within the Prairie Evaporites where hydraulic conductivity has been estimated to be as high as on the order of 1.0 x 10^{-4} m/s (ARKK 2021c).

4.6 MODEL DOMAIN, GRID AND LAYERING

4.6.1 MODEL DOMAIN

Model domains were developed based on natural features and watershed boundaries and/or conceptual surface water and groundwater flow considerations. Figure 17, Figure 18, and Figure 19 show the model domains for the Mildred Lake, MLX-W and Aurora North closure models, respectively.

Mildred Lake Model

The Mildred Lake model is bound by the Athabasca and McKay Rivers to the east and to the north and west, respectively. The southwest boundary of the model domain was chosen along an unnamed creek. The south boundary of the Mildred Lake model domain was chosen based on the Beaver Creek watershed boundary. The southeast boundary of the model domain was chosen along the clean water diversion channel of Suncor's Base Mine Expansion, which was assumed to occur over the Mildred Lake mine closure timeframe. Suncor Base Mine Expansion diverts approximately 50% of the Beaver Creek watershed from upstream of the Mildred Lake mine lease.

MLX-W Model

The MLX-W model domain is bound by McKay River to the east and Dover River on the north and west sides. The southern border of the domain follows the watershed boundary of WM Lake. The southern border diverges from the watershed boundary and meets the east and west borders of the model domain along paths perpendicular to the topographic contours.

Aurora North Model

The Aurora North model domain is bound by Athabasca and Muskeg Rivers to the west and east, respectively. The northern border of the domain follows the southern boundary of the McClelland Lake and McClelland Fen. The southern boundary of the model domain was chosen along a wetland.

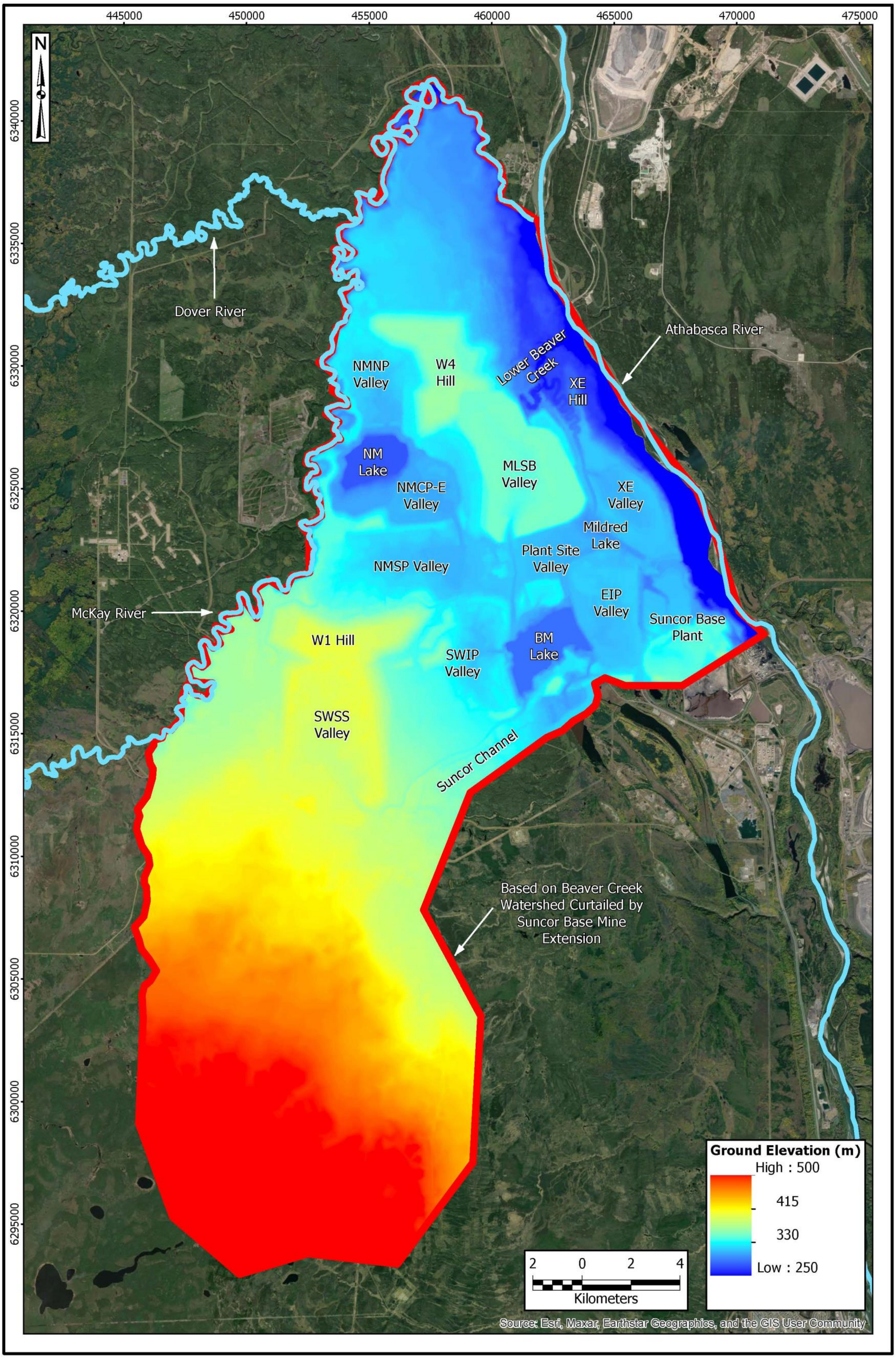
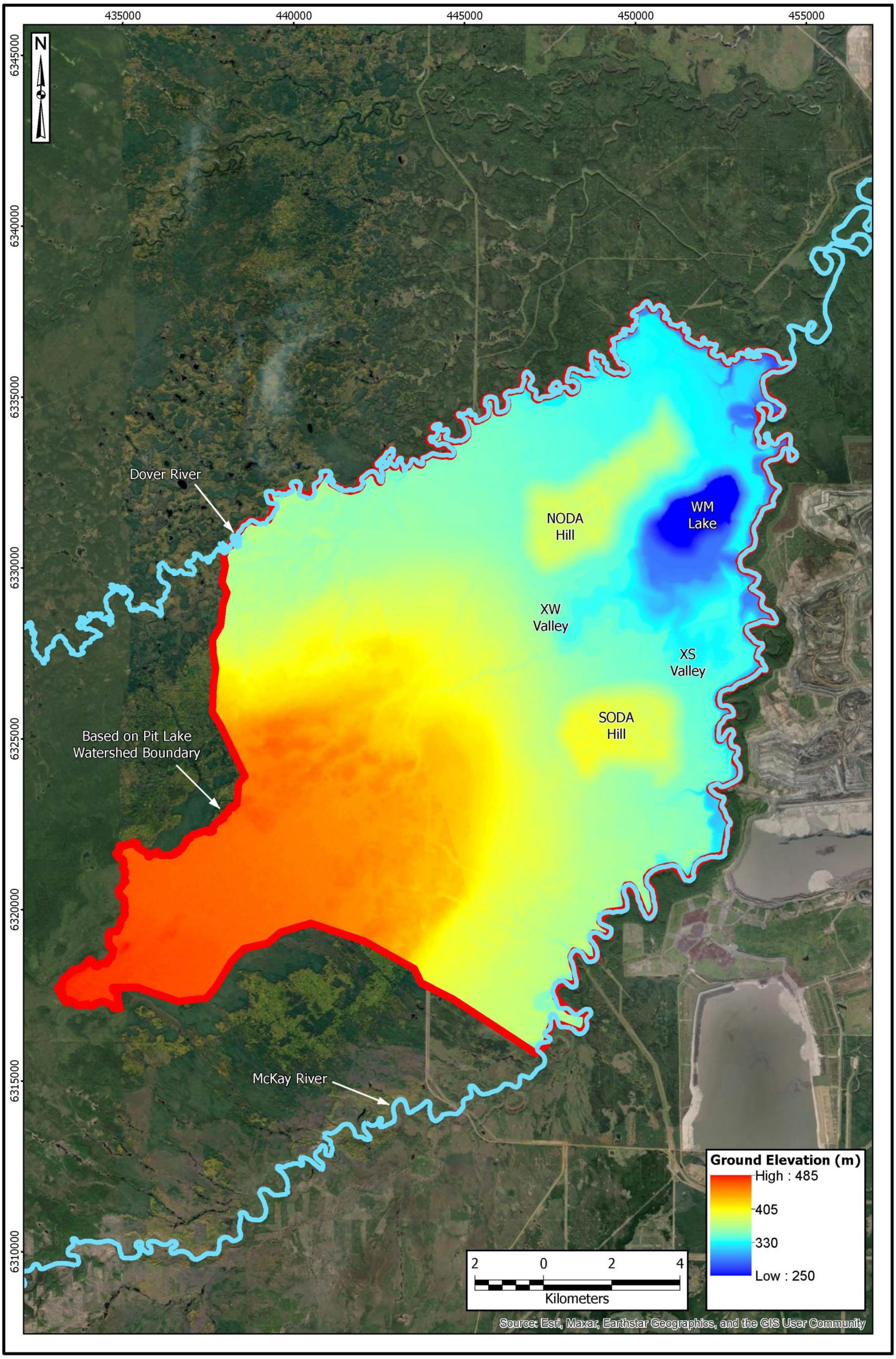


Figure 17 – Mildred Lake Model Domain



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 18 – MLX-W Model Domain

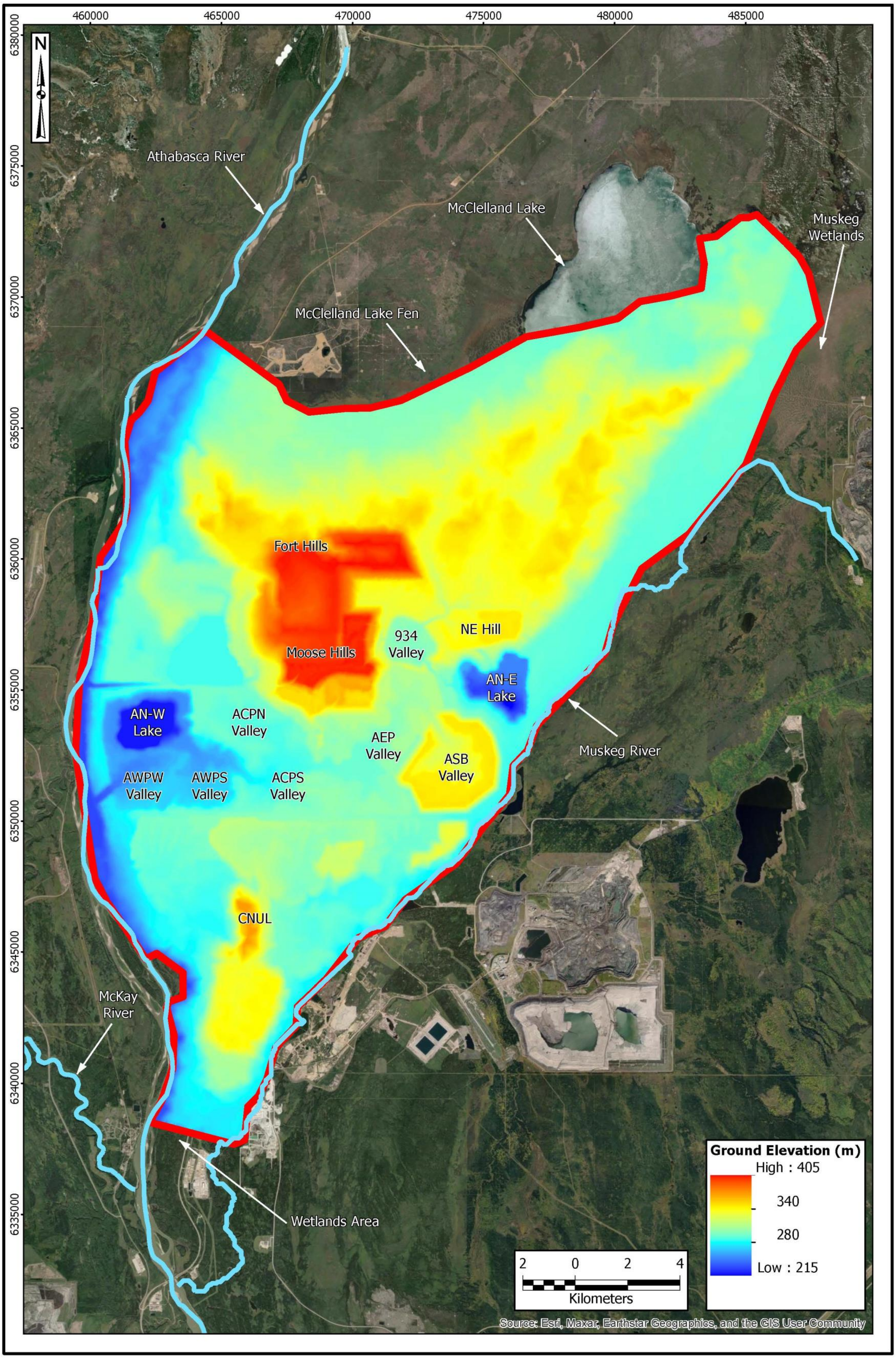


Figure 19 – Aurora North Model Domain

4.6.2 MODEL GRID AND LAYERING

HGS uses unstructured model grids to spatially discretize the area of interest. This allows local refinement of irregular features such as river and closure channels. The uppermost model surface (slice) is shared by surface water and groundwater domains in HGS. The surface and subsurface domains were separated by a coupling length of 0.001 m. Triangular prisms were used to discretize the model layers. The model grid was refined in the footprints of reclaimed dumps, in-pit, and out-of-pit landforms and along the closure channels. The details of the model grid for each model are summarized below. Model layer elevations were developed by combining the geological model surfaces with the closure surfaces, mine pit elevations, and overburden structure surfaces provided by Syncrude. Syncrude provided the geological model surfaces within the mine lease areas. The geological model surfaces were extended outside the mine leases using regional geological surfaces from WorleyParsons (2012).

Mildred Lake Model

The Mildred Lake mine model grid (Figure 20) consists of 58,414 nodes and 115,993 triangular elements/prisms in the surface domain (and per slice/layer in the subsurface domain) with a smallest node spacing of on the order of 25 m along the closure channels and 100 m node spacing within the reclaimed landforms, including the littoral zone around the pit lakes. The pit lakes were discretized using a node spacing on the order of 200-450 m and the natural areas outside the mine site using a node spacing of 400-500 m.

A total of 14 model layers (15 slices) of varying thicknesses were used to vertically discretize the reclaimed and natural materials. Thus, the subsurface model grid consisted of 876,210 and 1,623,902 total nodes and triangular prisms, respectively. The model layering and the corresponding natural and mining and reclamation materials each layer represents is summarized in Table 7.

Table 7 – Mildred Lake Model Layering

Layer	Natural Materials	Mining and Reclamation Materials	Mining and Reclamation Materials Landforms	Notes
1	Natural Forest Floor, Fibric Peat, Pleistocene Fluvial Sand[1], McMurray Formation[2]	Peat, Peat Mineral Mix, FT[3]		[1] Pleistocene Fluvial Sand exposed in Mildred Lake [2] McMurray Formation is exposed in Mildred Lake [3] FT is exposed in NM Lake and BM Lake
2				
3	Fibric Peat, Pleistocene Fluvial Sand[1], Quaternary Deposits, McMurray Formation[2]	Subsoil, Peat Mineral Mix, FT[3]		
4	Sapric Peat, Pleistocene Fluvial Sand[1], Quaternary Deposits, McMurray Formation[2]			
5				
6	Sapric Peat, Pleistocene Fluvial Sand, Quaternary Deposits, McMurray Formation	Tailings Sand, Tailings Sand Infill, Cell Sand, Coke, Unengineered Dump Fills, Engineered Dam Fills, FT	Tailings Sand in Suncor Pond 6, EIP, North Mine North Pit (NMNP), North Mine South Pit-West (NMSP-W), Southwest In-Pit (SWIP), SWSS Tailings Sand Infill in Mildred Lake Settling Basin (MLSB) Cell Sand in EIP, MLX-E, SWSS Coke in MLSB, MLX-E, North Mine Centre Pit (NMCP), North Mine South Pit East (NMSP-E) Unengineered Dump Fills in Gateway and South Bison Hills, W1 Dump, W2 Dump Engineered Dam Fills in NMCP, South Bison Hills FT as minimum thickness	
7	Pleistocene Fluvial Sand, Quaternary Deposits, McMurray Formation	Tailings Sand, Cell Sand, Unengineered Dump Fills, Engineered Dam Fills, CT, FT	Tailings Sand in MLX-E Pit Cell Sand in EIP Unengineered Dump Fills in W4 Dump Engineered Dam Fills as minimum thickness CT in EIP, SWIP FT in NMSP-E, BM Lake, NMCP, NM Lake, MLSB	
8	Pleistocene Fluvial Sand, Quaternary Deposits, McMurray Formation	Tailings Sand, Cell Sand, Unengineered Dump Fills, Engineered Dam Fills	Tailings Sand in MLSB Cell Sand in MLSB, North Toe Berm, W4 Dump Unengineered Dump Fills as minimum thickness Engineered Dam Fills as minimum thickness	
9	Pleistocene Fluvial Sand, Quaternary Deposits, McMurray Formation	Unengineered Dump Fills, Engineered Dam Fills	Unengineered Dump Fills in SWIP and BM Lake Engineered Dam Fills in MLSB Starter Dyke, MLX-E Pit, NMCP, SWIP, BM Lake	
10	Pleistocene Fluvial Sand, Quaternary Deposits, Clearwater Formation McMurray Formation			
11	Buried Channel Sand, Quaternary Deposits, Clearwater Formation, McMurray Formation			
12	Clearwater Formation, McMurray Formation			
13	McMurray Formation			
14	Devonian Formation			

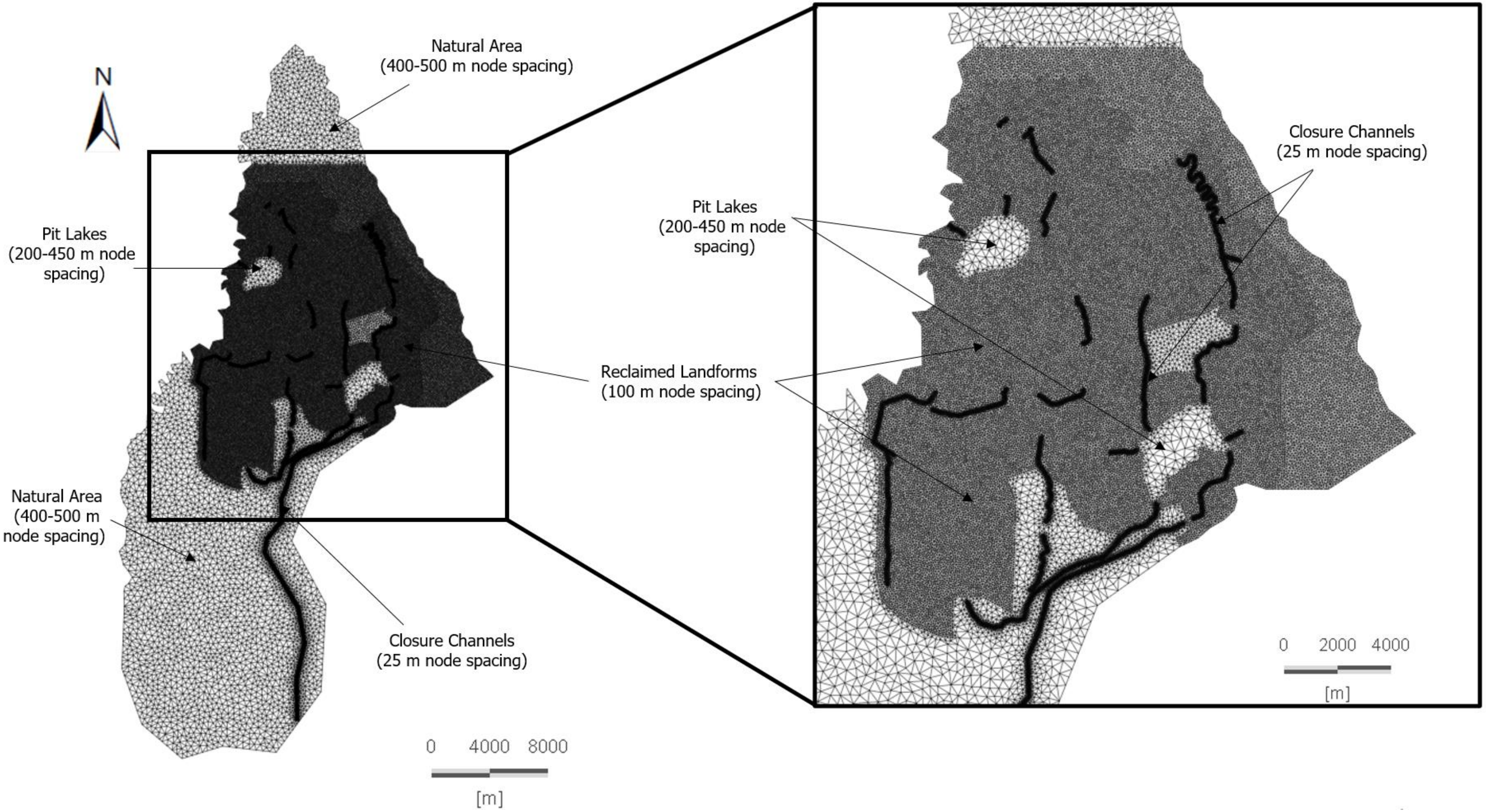


Figure 20 – Mildred Lake Model Grid

MLX-W Model

The MLX-W model grid (Figure 21) was developed using 47,126 nodes and 93,635 triangular elements/prisms in the surface domain (and per slice/layer in the subsurface domain) with a smallest node spacing of 15-25 m along the closure channels and natural creeks passing through the area of interest. The in-pit features XW and XS Valleys were discretized using a node spacing of on the order of 30 m, while the grid node spacing in the littoral zone of the pit lake was ~50-75 m. The area of the overburden dumps was discretized using an approximately 100-150 m node spacing. The node spacing in the pit lake was on the order of 75 to 240 m from littoral zone to the lake interiors. The other areas within the mine footprint were discretized with a node spacing of ~100 m and a grid node spacing of 200 m was used in the natural areas immediately adjacent to the mine area. The larger natural areas to the southwest of the area of interest was discretized using a node spacing of ~300-350 m.

A total of 10 model layers (11 slices) of varying thicknesses were used to vertically discretize the reclaimed and natural materials. Thus, the subsurface model grid consisted of 518,386 and 936,350 total nodes and triangular prisms, respectively. The model layering and the corresponding natural and mining and reclamation materials each layer represents is summarized in Table 8.

Table 8 – MLX-W Model Layering

Layer	Natural Materials	Mining and Reclamation Materials	Mining and Reclamation Materials Landforms
1	Forest Floor Organics, Fibric Peat, McMurray Formation[1]	Peat, FT[2]	
2			
3	Fibric Peat, Quaternary Deposits, McMurray Formation[1]	Subsoil, FT[2]	
4			
5			
6	Sapric Peat, Buried Channel Sand - Regional, Buried Channel Sand - Local, Quaternary Deposits, McMurray Formation	Coke, Unengineered Dump Fills, Engineered Dam Fills, FT	Coke in XW Valley and XS Valley Unengineered Dump Fills in NODA[3] and SODA[3] Engineered Dam Fills as minimum thickness
7	Buried Channel Sand - Regional, Buried Channel Sand - Local, Quaternary Deposits, McMurray Formation	Engineered Dam Fills, FT	FT in XW Valley and XS Valley Engineered Dam Fills as minimum thickness
8	Clearwater Formation, McMurray Formation	Engineered Dam Fills	Engineered Dam Fills between WM Lake and XW and XS Valleys
9	McMurray Formation		
10	Devonian Formation		

Notes:

[1] McMurray Formation exposed in pit lake

[2] FT exposed in pit lake

[3] NODA/SODA: North/South Out of Pit Dump Area

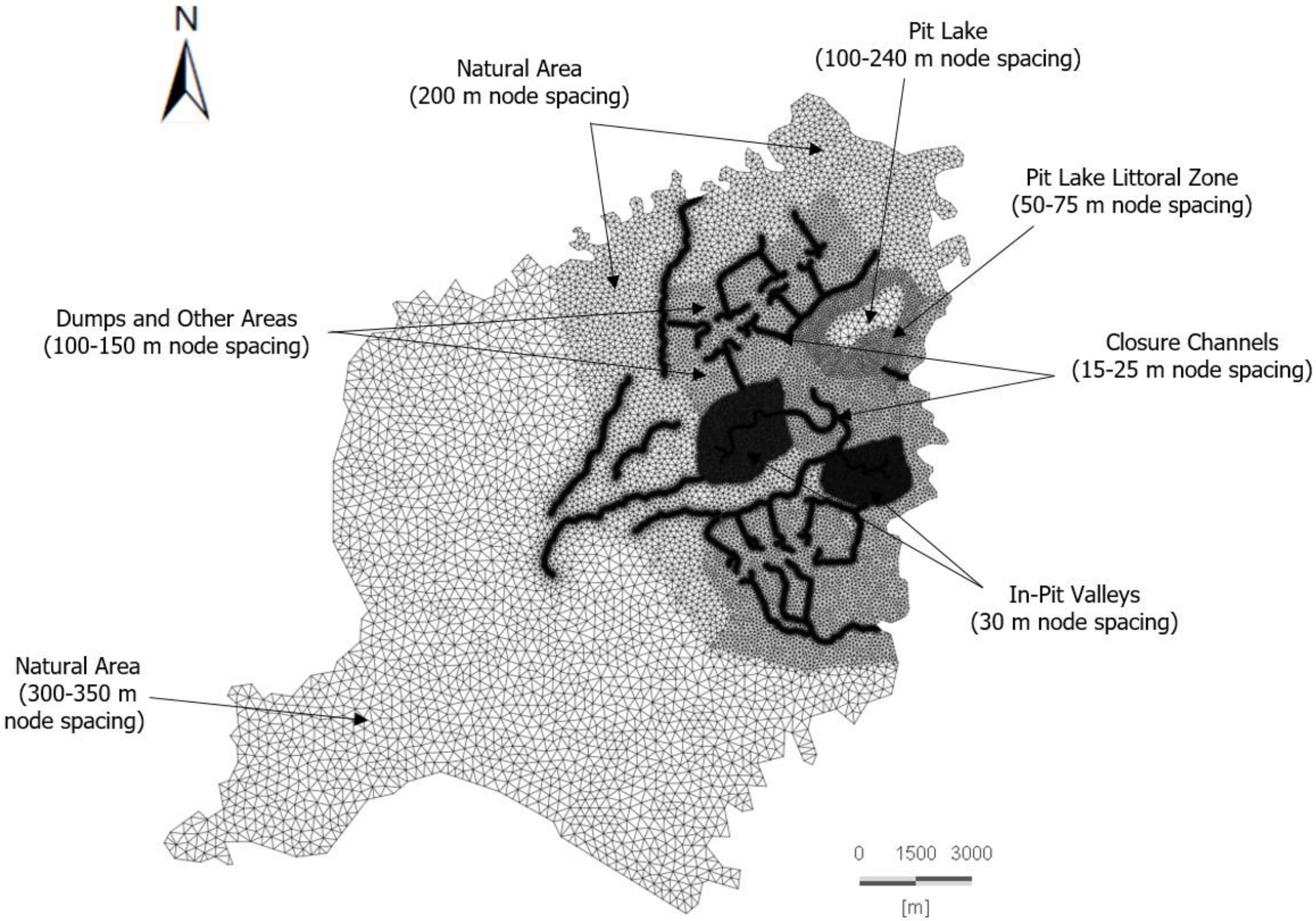


Figure 21 – MLX-W Model Grid

Aurora North Model

The Aurora North Mine model grid (Figure 22) consists of 39,904 nodes and 79,322 triangular elements/prisms in the surface domain (and per slice/layer in the subsurface domain). The closure channels and natural creeks were discretized using the smallest node spacing of on the order of 15-25 m. The grid in the reclaimed areas made up of in-pit and out of pit tailings areas and overburden dumps has an approximate node spacing of 50-100 m. The pit lakes were discretized using a node spacing of 100-200 m and the natural areas were discretized using a node spacing of on the order of 275-450 m.

A total of 20 model layers (21 slices) of varying thicknesses were used to vertically discretize the reclaimed and natural materials. Thus, the subsurface model grid consisted of 837,984 and 1,586,440 total nodes and triangular prisms, respectively. The model layering and the corresponding natural and mining and reclamation materials each layer represents is summarized in Table 9.

Table 9 – Aurora North Layering

Layer	Natural Materials	Mining and Reclamation Materials	Mining and Reclamation Materials Landforms
1, 2	Forest Floor Organics, Fibric Peat, McMurray Formation[1]	Peat, Engineered Dam Fills[2], FT[3]	
3, 4, 5	Fibric Peat, Coarse Pleistocene Fluvial or Outwash Sand, McMurray Formation[1]	Subsoil, Engineered Dam Fills[2], FT[3]	
6	Fibric Peat, Coarse Pleistocene Fluvial or Outwash Sand, McMurray Formation	Tailings Sand, Cell Sand, Unengineered Dump Fills, Engineered Dam Fills, FT	Tailings Sand in Aurora Settling Basin (ASB) Cell Sand as minimum thickness Unengineered Dump Fills in 934 Pit, Fort Hills Dump, Northeast Dump, West Infill and Moose Dump Engineered Dam Fills as minimum thickness FT in East Pit Lake
7			Tailings Sand in Out of Pit Tailings Area (OPTA) and South Pit Tailings Area Cell Sand as minimum thickness Unengineered Dump Fills as minimum thickness Engineered Dam Fills in East Pit Lake and OPTA FT in ASB
8			Tailings Sand in Aurora East Pit and ASB Cell Sand in ASB Unengineered Dump Fills in Fort Hills Dump Engineered Dam Fills in ASB FT in ASB
9	Sapric Peat, Coarse Pleistocene Fluvial or Outwash Sand, McMurray Formation		Tailings Sand in all Mine Pits Cell Sand in Dyke 1N Unengineered Dump Fills as minimum thickness Engineered Dam Fills in all Dykes and South Closure Dyke (SCD) FT in West Pit Lake
10	Coarse Pleistocene Fluvial or Outwash Sand, McMurray Formation	Tailings Sand, Cell Sand, Unengineered Dump Fills, Engineered Dam Fills, CT, FT	Tailings Sand in CNUL Cell Sand in Dyke 1N and Northeast Closure Dyke (NECD) Unengineered Dump Fills in CNUL Engineered Dam Fills as minimum thickness CT in Aurora Centre Pit – North (ACPN), ACP – South (ACPS), Aurora East Pit (AEP), Aurora West Pit South (AWPS), AWP West (AWPW) FT as minimum thickness
11	Coarse Pleistocene Fluvial or Outwash Sand, Buried Channel Sand - Regional, Clearwater Formation, McMurray Formation	Tailings Sand, Unengineered Dump Fills, Engineered Dam Fills	Tailings Sand in CNUL Unengineered Dump Fills as minimum thickness Engineered Dam Fills in all Dykes and Inpit Structures and CNUL
12	Pleistocene Fluvial Sand, Buried Channel Sand - Regional, Quaternary Deposits, Clearwater Formation, McMurray Formation		Tailings Sand as minimum thickness Unengineered Dump Fills as minimum thickness Engineered Dam Fills as minimum thickness
13			
14	Buried Channel Sand - Regional, Quaternary Deposits, McMurray Formation		
15	Clearwater Formation, McMurray Formation	Tailings Sand, Engineered Dam Fills	

Layer	Natural Materials	Mining and Reclamation Materials	Mining and Reclamation Materials Landforms
16	McMurray Formation		Tailings Sand as minimum thickness Engineered Dam Fills as minimum thickness
17	Basal Water Sands, Devonian Formation		
18	Basal Water Sands, Continental Mud, Devonian Formation		
19	Basal Water Sands, Devonian Formation		
20	Devonian Formation		

Notes:

[1] McMurray Formation found in pit lakes

[2] Engineered Dam Fills found in pit lakes

[3] FT found in pit lakes

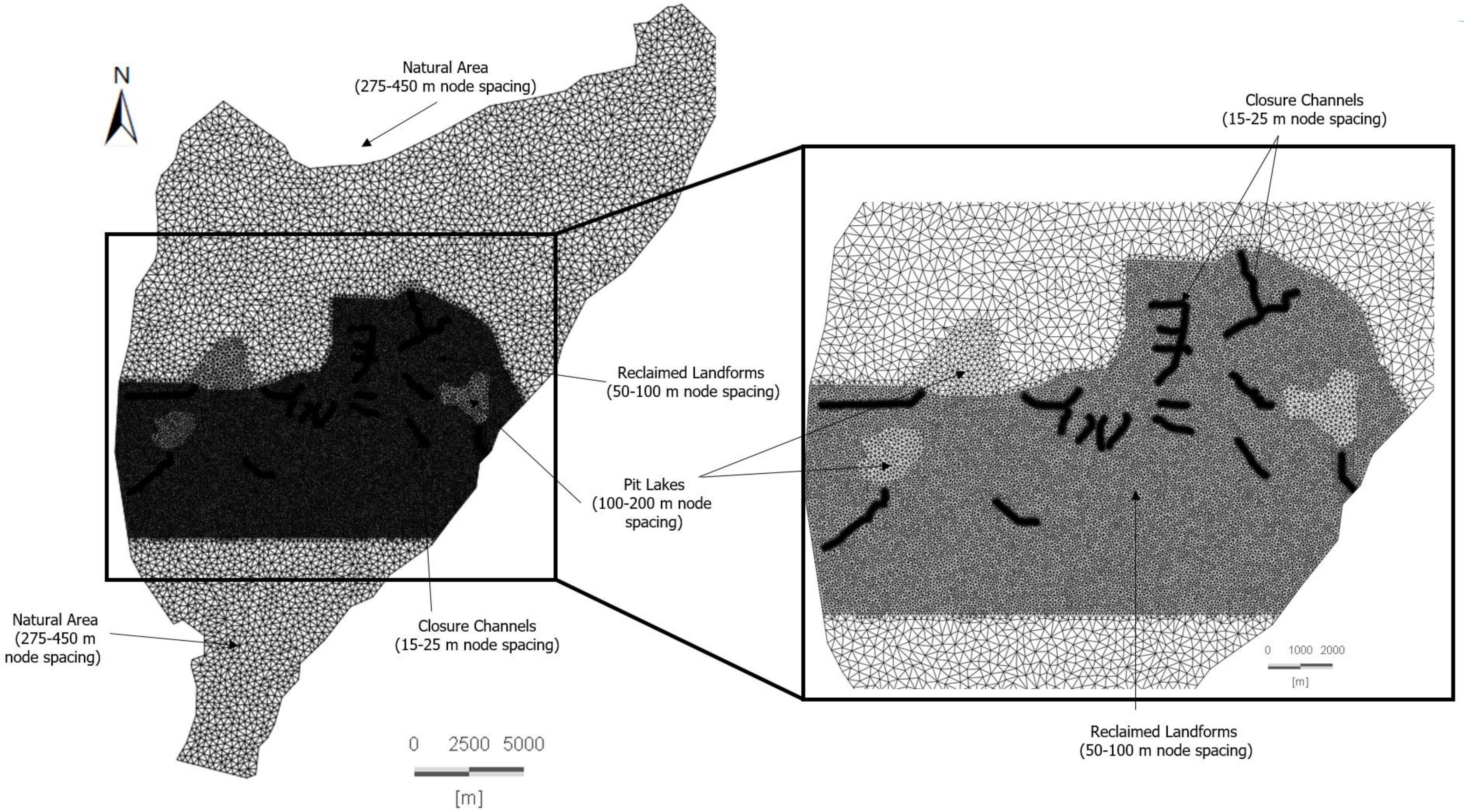
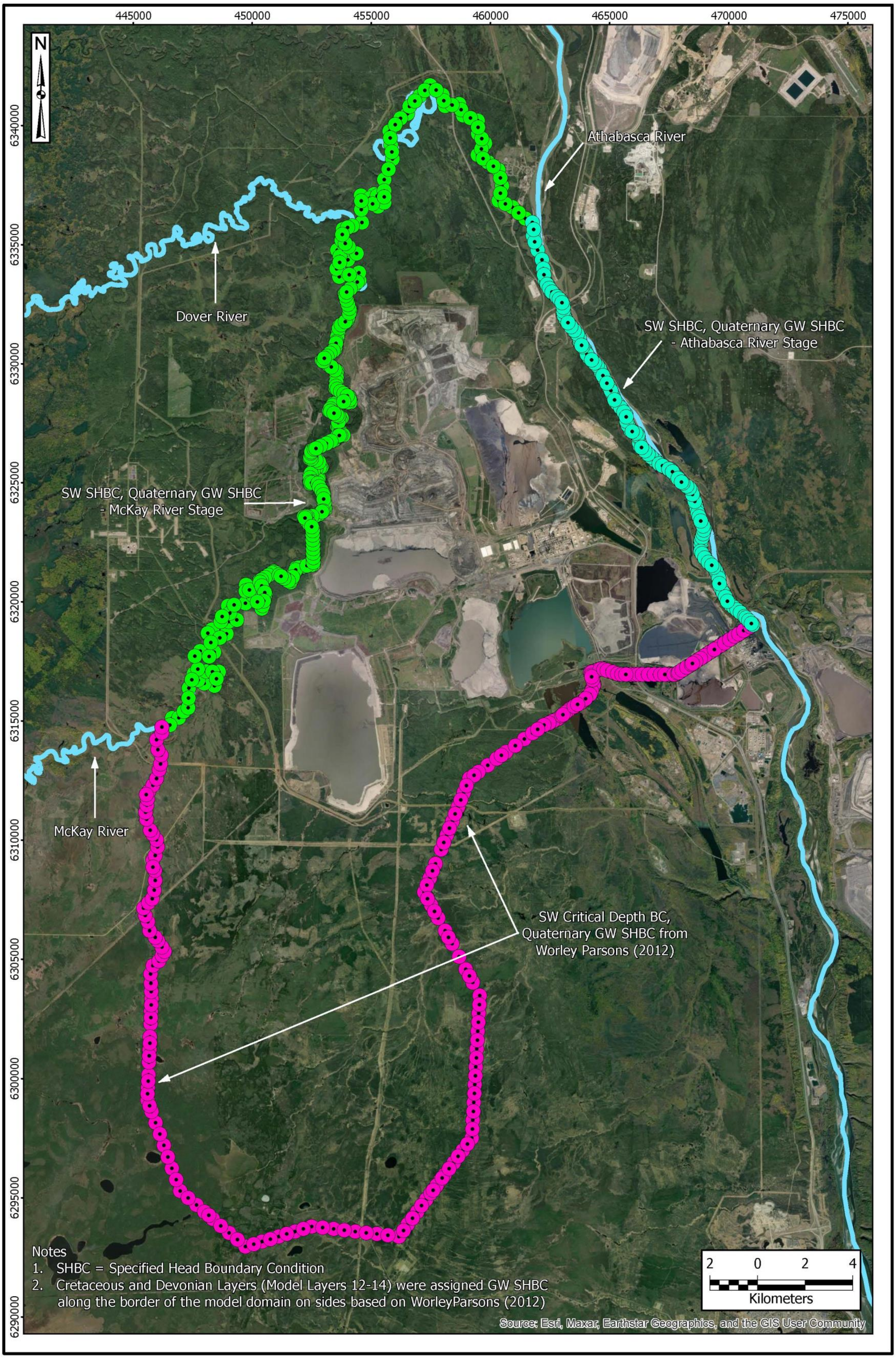


Figure 22 – Aurora North Model Grid

4.7 MODEL BOUNDARY CONDITIONS

Model boundary conditions were defined along the model edges and top to represent specified hydraulic conditions at different model boundaries. The entire model top was assigned transient precipitation and PET as a flux boundary condition to the model top faces. The precipitation and PET rates were applied at daily input time step for days with non-zero precipitation. For days with no precipitation, the input time step equalled the number of days with no precipitation up to a maximum time step of 14 days. For days with no precipitation, PET rate equalled the average PET over the number of days with no precipitation. Snowmelt was incorporated into the model by adding snowmelt water to the precipitation time series using a temperature-index approach. Any precipitation falling as snow is assumed to be stored, the snowmelt process is simulated, and the resulting meltwater is added to the rainfall component of the precipitation time series.

In addition to the flux boundary condition at the model top, critical depth (overland domain) and specified head boundary conditions (overland and subsurface domains) were applied to model edges as shown in Figure 23, Figure 24, and Figure 25 for the Mildred Lake, MLX-W and Aurora North closure models, respectively. The critical depth boundary condition allows water in the overland domain to exit the model when surface water depth at nodes where the boundary condition is applied exceeds the specified critical depth. Specified head boundary condition maintains the hydraulic head value at any given node where it is applied at the prescribed specified head value throughout the model simulation. Specified head boundary condition can be applied as time-constant (i.e., one value at each node throughout entire model simulation) or as time-varying values at specified intervals. Time-constant values were used for all simulations. The model bottom was assumed to be a no-flow boundary condition owing to the negligible hydraulic interaction between Devonian and overlying units.



Notes
1. SHBC = Specified Head Boundary Condition
2. Cretaceous and Devonian Layers (Model Layers 12-14) were assigned GW SHBC along the border of the model domain on sides based on WorleyParsons (2012)

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 23 – Mildred Lake Model Boundary Conditions

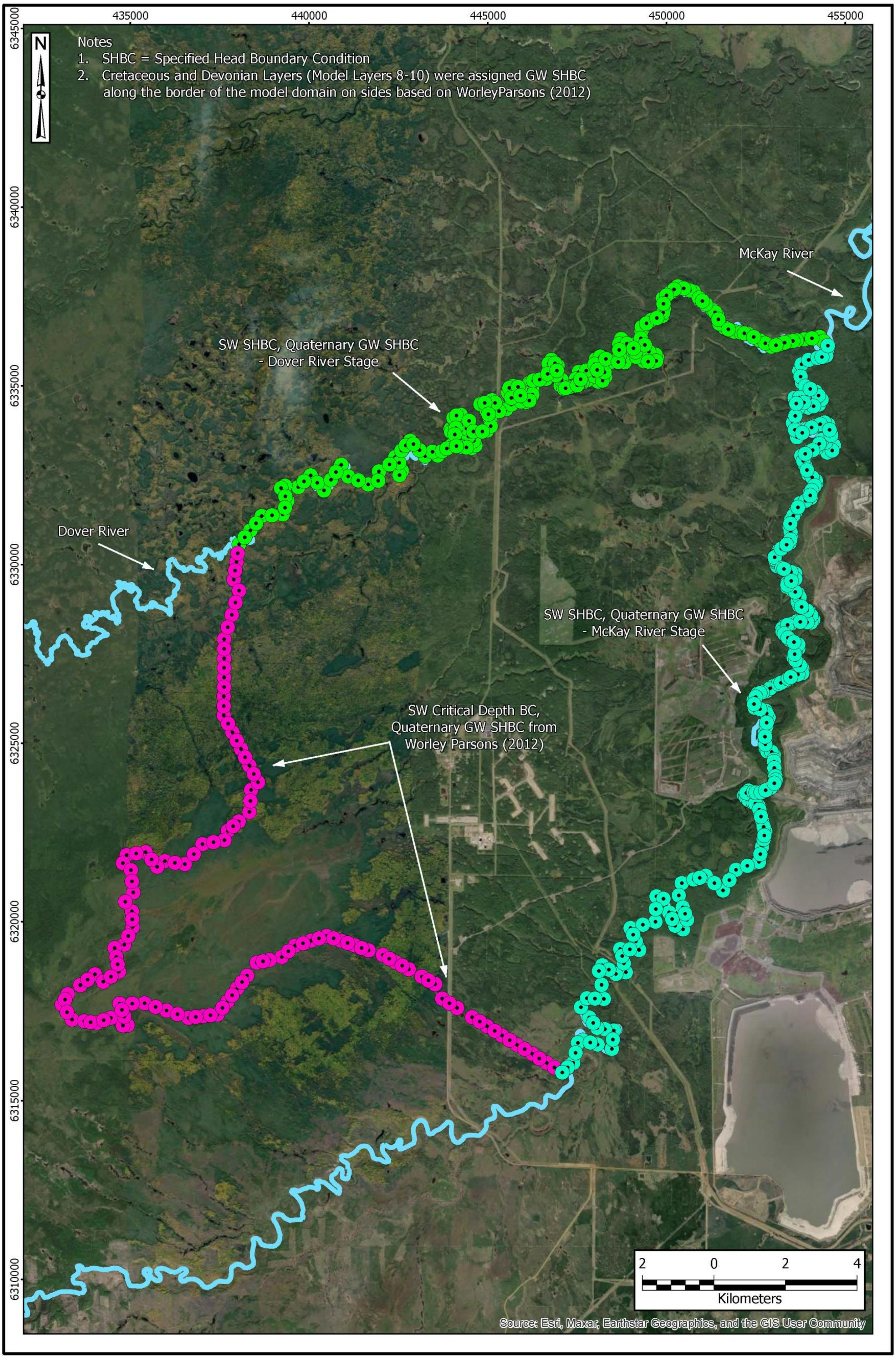
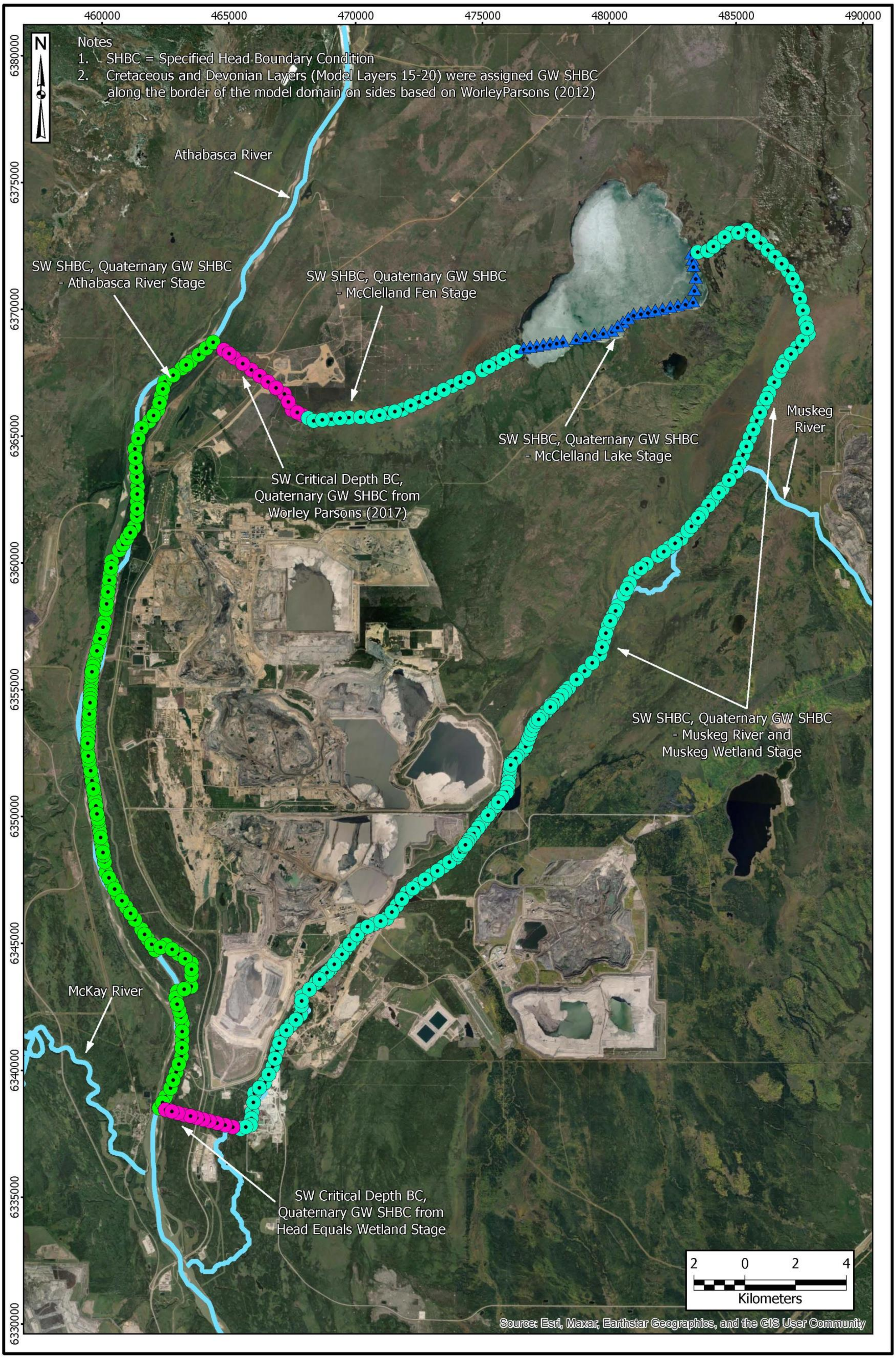


Figure 24 – MLX-W Model Boundary Conditions



Notes
1. SHBC = Specified Head Boundary Condition
2. Cretaceous and Devonian Layers (Model Layers 15-20) were assigned GW SHBC along the border of the model domain on sides based on WorleyParsons (2012)

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 25 – Aurora North Model Boundary Conditions

4.8 MODEL PARAMETERIZATION

4.8.1 OVERLAND FLOW PARAMETERS

The overland model parameters consist of Manning's roughness coefficient, depression/rill storage height, and vegetation obstruction storage height. These parameters (Table 10) were based on previous modelling experience (ARKK 2018, 2021a, 2021c; WorleyParsons 2013, 2014) and literature values.

Table 10 – Summary of Overland Flow Parameterization

Parameter	Uplands	Lowlands	Open Water
Manning's Coefficient (-)[1]	0.095	0.055	0.25
Rill Storage Height (m)[2]	0.0015	0.0015	N/A
Obstruction Storage Height (m)[2]	0.01	0.01	N/A

Notes:

[1] Chow (1988), Dingman (2002).

[2] WorleyParsons (2013, 2014), ARKK (2018, 2021a, 2021c)

4.8.2 SUBSURFACE FLOW MODEL PARAMETERS

The key subsurface model parameters for each natural and mining and reclamation materials include saturated horizontal and vertical hydraulic conductivities (K_H and K_V), specific storage (S_s) and unsaturated zone parameters (porosity, residual water content, and Van Genuchten (Van Genuchten 1980) parameters α, n and m). Regional and Syncrude mine sites specific hydrogeological parameters were reviewed and were summarized by ARKK (2021c). The parameters from the ARKK (2021c) review were used to parameterize the Mildred Lake (Table 11), MLX-W (Table 12) and Aurora North (Table 13) models.

Table 11 – Summary of Hydrogeologic Parameterization – Mildred Lake Model

Material	Material Type	K_H (m/s)	K_V (m/s)	S_s (m^{-1})	Porosity (m^3/m^3)	θ_r (m^3/m^3)	α (m^{-1})	n	m
Peat	Mining and Reclamation Materials	5.0 x 10^{-5}	5.0 x 10^{-5}	5.0 x 10^{-5}	0.59	0.05	6.00	1.41	0.29
Subsoil		4.3 x 10^{-6}	4.3 x 10^{-6}	5.0 x 10^{-4}	0.50	0.02	2.80	2.22	0.55
Peat Mineral Mix		1.0 x 10^{-5}	1.0 x 10^{-6}	1.0 x 10^{-4}	0.66	0.16	9.41	1.95	0.49
Tailings Sand		5.0 x 10^{-6}	5.0 x 10^{-7}	1.0 x 10^{-5}	0.41	0.05	1.90	5.00	0.80
Tailings Sand Infill		2.0 x 10^{-5}	2.0 x 10^{-6}	1.0 x 10^{-5}	0.41	0.05	1.90	5.00	0.80
Cell Sand		2.0 x 10^{-5}	2.0 x 10^{-6}	1.0 x 10^{-5}	0.37	0.05	2.50	8.50	0.88
Coke		5.0 x 10^{-5}	5.0 x 10^{-6}	1.0 x 10^{-5}	0.41	0.05	2.75	4.00	0.75
Unengineered Dump Fills		2.6 x 10^{-7}	3.5 x 10^{-8}	1.0 x 10^{-5}	0.39	0.21	1.22	1.94	0.48
Engineered Dam Fills		3.3 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.39	0.21	1.22	1.94	0.48
CT		1.0 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.46	0.01	1.12	1.25	0.20
FT		1.0 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.65	0.25	1.50	1.60	0.38
Forest Floor Organics	Natural Materials	5.0 x 10^{-5}	1.0 x 10^{-5}	5.0 x 10^{-2}	0.75	0.05	6.00	1.41	0.29
Fibric Peat		3.0 x 10^{-4}	3.0 x 10^{-5}	5.0 x 10^{-2}	0.88	0.05	6.00	1.41	0.29
Sapric Peat		5.0 x 10^{-6}	5.0 x 10^{-7}	5.0 x 10^{-2}	0.83	0.05	6.00	1.41	0.29
Pleistocene Fluvial Sand		5.0 x 10^{-5}	5.0 x 10^{-6}	1.0 x 10^{-5}	0.35	0.05	2.50	8.50	0.88
Buried Channel Sand		1.0 x 10^{-4}	1.0 x 10^{-6}	1.0 x 10^{-5}	0.35	0.21	1.22	1.94	0.48
Quaternary Deposits		5.0 x 10^{-6}	5.0 x 10^{-7}	1.0 x 10^{-5}	0.41	0.21	1.22	1.94	0.48
Clearwater Formation		8.0 x 10^{-9}	1.4 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43
McMurray Formation		5.0 x 10^{-9}	3.0 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43
Devonian Formation		2.0 x 10^{-9}	1.0 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43

Table 12 – Summary of Hydrogeologic Parameterization – MLX-W Model

Material	Material Type	K_H (m/s)	K_V (m/s)	S_s (m^{-1})	Porosity (m^3/m^3)	θ_r (m^3/m^3)	α (m^{-1})	n	m
Peat	Mining and Reclamation Materials	5.0×10^{-4}	5.0×10^{-5}	5.0×10^{-2}	0.59	0.05	6.00	1.41	0.29
Subsoil		4.3×10^{-6}	4.3×10^{-6}	5.0×10^{-4}	0.50	0.02	2.80	2.22	0.55
Coke		5.0×10^{-5}	5.0×10^{-6}	1.0×10^{-5}	0.41	0.05	2.75	4.00	0.75
Unengineered Dump Fills		2.6×10^{-7}	3.5×10^{-8}	1.0×10^{-5}	0.39	0.21	1.22	1.94	0.48
Engineered Dam Fills		3.3×10^{-8}	1.0×10^{-8}	1.0×10^{-5}	0.39	0.21	1.22	1.94	0.48
FT		1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-5}	0.65	0.25	1.50	1.60	0.38
Forest Floor Organics	Natural Materials	1.0×10^{-4}	1.0×10^{-5}	5.0×10^{-2}	0.75	0.05	6.00	1.41	0.29
Fibric Peat		3.0×10^{-4}	3.0×10^{-5}	5.0×10^{-2}	0.88	0.05	6.00	1.41	0.29
Sapric Peat		5.0×10^{-6}	5.0×10^{-7}	5.0×10^{-2}	0.83	0.05	6.00	1.41	0.29
Buried Channel Sand - Regional		1.0×10^{-4}	1.0×10^{-6}	1.0×10^{-5}	0.35	0.21	1.22	1.94	0.48
Buried Channel Sand – Local		1.0×10^{-5}	1.0×10^{-6}	1.0×10^{-5}	0.35	0.21	1.22	1.94	0.48
Quaternary Deposits		5.0×10^{-6}	5.0×10^{-7}	1.0×10^{-5}	0.41	0.21	1.22	1.94	0.48
Clearwater Formation		8.0×10^{-9}	1.4×10^{-9}	1.0×10^{-5}	0.25	0.17	2.15	1.75	0.43
McMurray Formation		5.0×10^{-9}	3.0×10^{-9}	1.0×10^{-5}	0.25	0.17	2.15	1.75	0.43
Devonian Formation		2.0×10^{-9}	1.0×10^{-9}	1.0×10^{-5}	0.25	0.17	2.15	1.75	0.43

Table 13 – Summary of Hydrogeologic Parameterization – Aurora North Model

Material	Material Type	K_H (m/s)	K_V (m/s)	S_s (m^{-1})	Porosity (m^3/m^3)	θ_r (m^3/m^3)	α (m^{-1})	n	m
Peat	Mining and Reclamation Materials	5.0 x 10^{-5}	5.0 x 10^{-5}	5.0 x 10^{-2}	0.59	0.05	6.00	1.41	0.29
Subsoil		1.0 x 10^{-5}	1.0 x 10^{-5}	5.0 x 10^{-5}	0.36	0.02	2.80	2.22	0.55
Tailings Sand		5.0 x 10^{-6}	5.0 x 10^{-7}	1.0 x 10^{-5}	0.41	0.05	1.90	5.00	0.80
Cell Sand		2.0 x 10^{-5}	2.0 x 10^{-6}	1.0 x 10^{-5}	0.37	0.05	2.50	8.50	0.88
Unengineered Dump Fills		2.6 x 10^{-7}	3.5 x 10^{-8}	1.0 x 10^{-5}	0.39	0.21	1.22	1.94	0.48
Engineered Dam Fills		3.3 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.39	0.21	1.22	1.94	0.48
CT		1.0 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.46	0.01	1.12	1.25	0.20
FT		1.0 x 10^{-8}	1.0 x 10^{-8}	1.0 x 10^{-5}	0.65	0.25	1.50	1.60	0.38
Forest Floor Organics	Natural Materials	5.0 x 10^{-5}	1.0 x 10^{-5}	5.0 x 10^{-2}	0.75	0.05	6.00	1.41	0.29
Fibric Peat		3.0 x 10^{-4}	3.0 x 10^{-5}	5.0 x 10^{-2}	0.88	0.05	6.00	1.41	0.29
Sapric Peat		5.0 x 10^{-6}	5.0 x 10^{-7}	5.0 x 10^{-2}	0.83	0.05	6.00	1.41	0.29
Coarse Pleistocene Fluvial or Outwash Sand		5.0 x 10^{-5}	5.0 x 10^{-6}	1.0 x 10^{-5}	0.39	0.05	2.50	8.50	0.88
Pleistocene Fluvial Sand		7.5 x 10^{-5}	7.5 x 10^{-6}	1.0 x 10^{-5}	0.35	0.05	2.50	8.50	0.88
Buried Channel Sand – Regional		1.0 x 10^{-4}	1.0 x 10^{-6}	1.0 x 10^{-5}	0.35	0.21	1.22	1.94	0.48
Quaternary Deposits		5.0 x 10^{-6}	5.0 x 10^{-7}	1.0 x 10^{-5}	0.41	0.21	1.22	1.94	0.48
Clearwater Formation		8.0 x 10^{-9}	1.4 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43
McMurray Formation		5.0 x 10^{-9}	3.0 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43
Basal Water Sands		7.5 x 10^{-5}	7.5 x 10^{-6}	1.0 x 10^{-5}	0.35	0.05	2.50	8.50	0.88
Continental Mud		5.0 x 10^{-9}	3.0 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43
Devonian Formation		2.0 x 10^{-9}	1.0 x 10^{-9}	1.0 x 10^{-5}	0.25	0.17	2.15	1.75	0.43

4.8.3 SOLUTE TRANSPORT PARAMETERS

The longitudinal, transverse, and vertical transverse dispersivity values used in the model were 1 m, 0.1 m, and 0.01 m, respectively. These values are based on previous EIP models (ARKK 2018, ARKK 2021a, Nagare et al. 2018, Nagare et al. 2022, WorleyParsons 2013, 2014). Uncertainty related to dispersivity assumptions was in part addressed in WorleyParsons (2014) and Nagare et al. (2018).

4.8.4 EVAPOTRANSPIRATION PARAMETERIZATION

For integrated surface and subsurface flow and transport simulations, the rates of plant interception, transpiration, and surface water flow are directly influenced by spatially (e.g., uplands and lowlands) and temporally (e.g., LAI) varying vegetation characteristics. In the HGS model, interception storage (maximum capacity water can be retained by plants before it reaches ground surface) is determined by the canopy storage parameter (c_{int}) and the LAI (area covered by plants over unit ground surface area); the rate of transpiration is a function of root depth (RD), relative root density (RDF) with depth, soil saturation, and the leaf area index (Kristensen and Jensen, 1975; Wigmosta et al., 1994). Table 14 summarizes the ranges of the values for these parameters. Two types of vegetation were assumed – (1) treed vegetation growing in elevated natural and reclaimed areas (e.g., overburden dumps, hummocks in reclaimed in-pit and out of pit reclaimed mine pits) or upland vegetation and (2) vegetation growing in low-lying areas (wetland vegetation, shrubs, etc. growing in wetland areas, swales and within lake littoral zones) or lowland vegetation. Optimized vegetation parameters developed in the past studies (ARKK 2018, 2021a, Nagare et al. 2022) were used for upland and lowland vegetation for all three models (i.e., Mildred Lake, MLX-W and Aurora North Models). Vegetation was assumed to be fully developed or fully grown at the start of each simulation.

Table 14 – Vegetation Dependant Model Parameters

Vegetation	Transpiration and Evaporation Parameters	References
Uplands	Evaporation depth: 0.5 m RDF: quadratic RD: 1.5 m Transpiration fitting parameters: $c_1 = 0.12$, $c_2 = 0.2$, $c_3 = 2$	Dingman (2002), Van Rees (1997), Straker et al. (2019)
Lowlands	Evaporation depth: 0.5 m RDF: quadratic RD: 0.375 m Transpiration fitting parameters: $c_1 = 0.075$, $c_2 = 0.2$, $c_3 = 2$	

Note: Typical values for oxic and anoxic limits of soil saturation of 0.9 and 1.0 for transpiration were derived from the literature. Saturation limits of 0.78 and 0.33 were used as field capacity and permanent wilting point based on Huang et al. (2015).

Figure 26 shows the annual LAI distribution used for all model scenarios. The annual LAI distribution was repeated annually throughout the simulations. The peak LAI values are based on measurements at several reference and reclaimed sites at the Syncrude and Suncor Leases (Straker et al. 2019). The distribution of the LAI over the growing season was based on Barr et al. (2004) for uplands and Bonneville et al. (2008) and Nagler et al. (2004) for lowlands. Higher LAI values would result in increased evapotranspiration and deeper depths to water table. Therefore, the lower LAI values are likely conservative in terms of estimating runoff volumes and water table elevation. However, evapotranspiration would also be affected by available soil water.

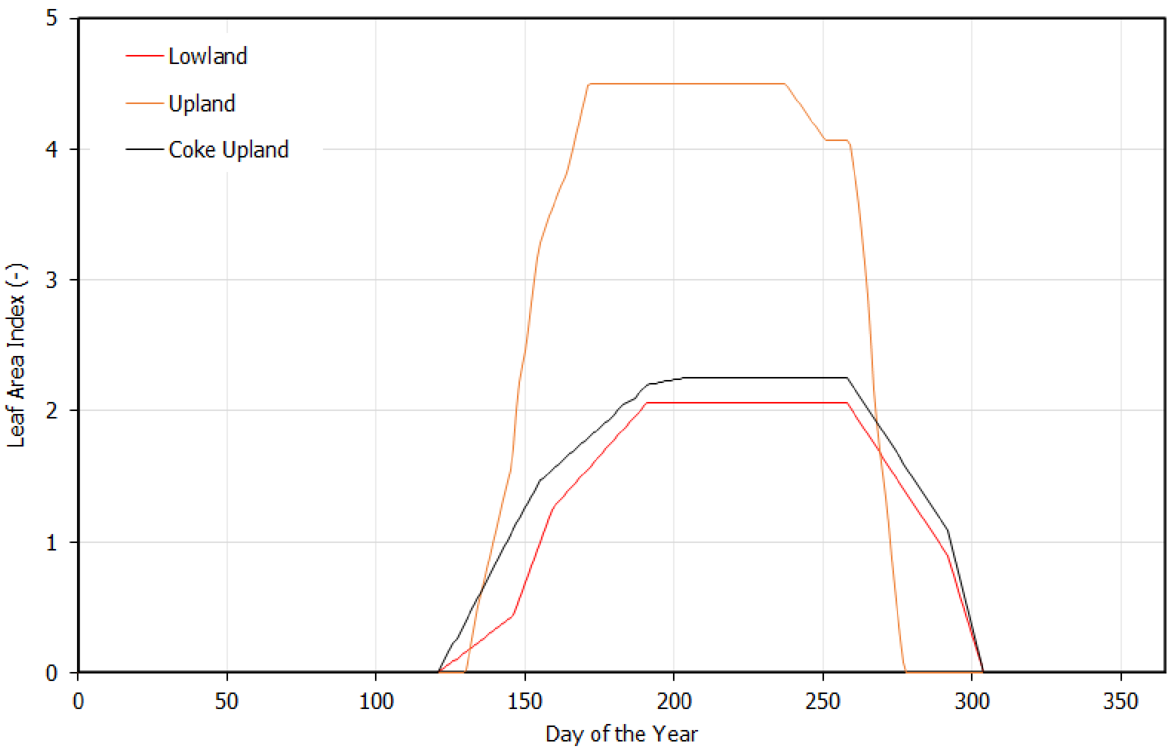


Figure 26 – Annual LAI Time Series. Uplands with Coke Substrate (MLSB and NMSP-E Valley in the Mildred Lake site and XW and XS Valleys in MLX-W) was applied lower LAI to account for lower water retention in Coke.

4.9 WATER QUALITY

The initial chloride concentration in the porewater of each landform was estimated based on data provided by Syncrude that aligns with the 2023 tailings management plan. Estimated historical and forecasted chloride concentration in the operational recycle water (RCW) systems of the Mildred Lake site (including MLX-W) and Aurora North is shown in Figure 27. The chloride concentration ranges from 400 to 1,250 mg/L. The chloride concentration in the porewater of each landform was estimated based on the years of tailings placement and the corresponding average chloride concentration in OSPW.

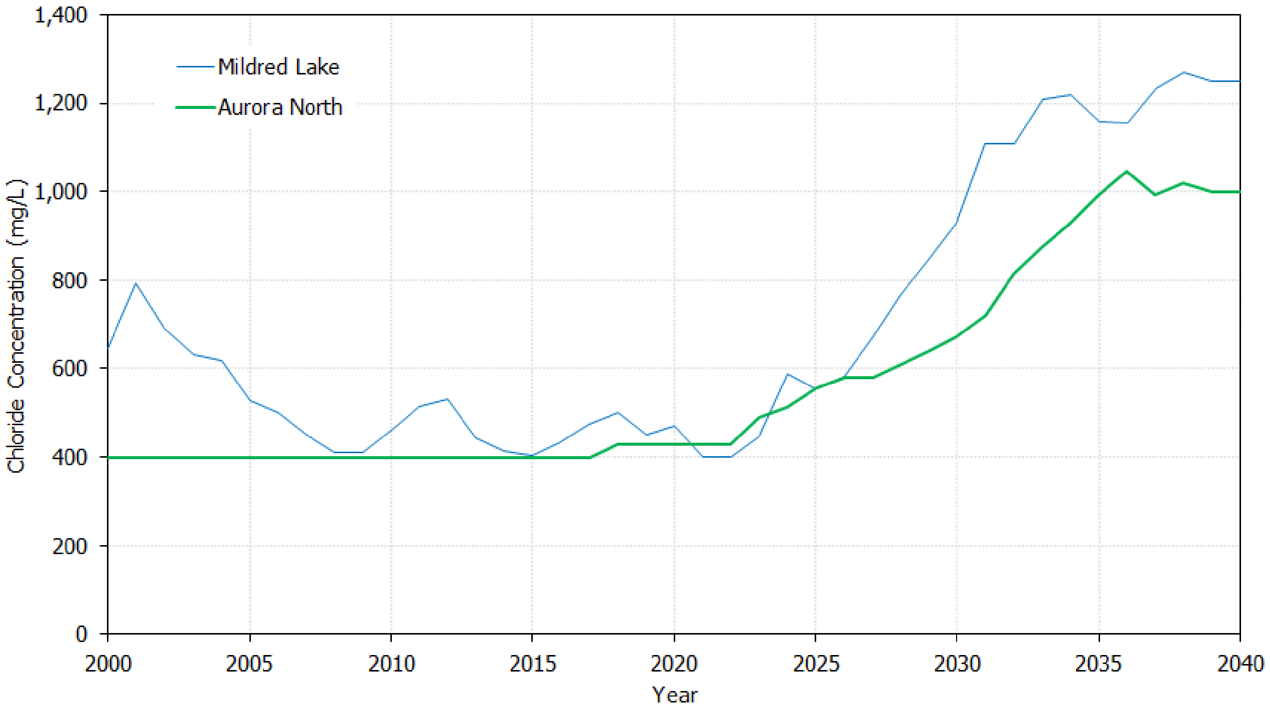


Figure 27 – OSPW Chloride Concentration - Mildred Lake and Aurora North Sites

Table 15 through Table 18 provide an overview of the approximate start and end of tailings deposition for each landform based on information provided by Syncrude. The assumed initial year and chloride concentration in the HGS model simulations is also included. The HGS simulations represent transport of chloride with water flow through the surface and subsurface of landforms as well as into and out of pit lakes. The topography of the HGS model is static. From model time zero, the pit lakes are assumed to be full (water level at the lake sill elevation), and the entire closure watershed and drainage system is constructed allowing runoff to flow from the landforms into and out of pit lakes. The pit lakes release water to the downstream when the water level exceeds the sill elevation. It is understood that landform maturation and pit lake commissioning will be required prior to fully constructing the closure drainage network and connecting the pit lakes to the downstream watercourses. The model results would be representative of pumping water between landforms and from the pit lakes in early years following reclamation.

The HGS simulations were used to characterize mass loading from each landform and to develop MS Excel spreadsheet models for pit lake water caps that allow incorporation of consolidation fluxes from FT and corresponding growth of water cap volumes. The combination of the HGS models and the spreadsheet models can be used to refine pit lake commissioning plans and work towards release of water to the surrounding watercourses.

Table 15 – Summary of Initial Chloride Concentration at Mildred Lake Site - BM Lake and Watershed

Landform	Year Deposition Starts	Year Deposition Ends	Comments from Tailings Plan	Initial Year in Model Simulations	Initial Chloride Concentration in HGS Model (mg/L)
EIP Valley	1999	2022	Tailings placement almost complete in 2022	2024	600
SWIP Valley	2009	2028	FFT and water removed by 2029	2024	500
SWSS Valley	1991	2039	FFT and water removed by 2040, no inflow from 2022 to 2028	2040	750
MLSB Valley	1978	2039	FFT and water removed by 2041, with high density FT left in place	2040	750
BM Lake	1996	2013	FFT capped with freshwater demonstration underway.	2024	400
XE Valley	2040	2040	Infilling starts in 2040	2040	1,250

Notes:
For the Mildred Lake model, the model simulation began in year 2024 with initial chloride concentrations assigned to BM Lake, EIP Valley, and SWIP Valley. The simulation was halted and restarted at year 2040 with initial chloride concentrations assigned within the remaining landforms. Chloride concentrations within BM Lake, EIP Valley, and SWIP Valley were not altered and continued from end of 2039 time point.

The above assumed dates are approximate and suitable for the level of detail in this study. It should be noted that the dates are not in exact alignment with other Syncrude planning documents.

Table 16 – Summary of Initial Chloride Concentration at Mildred Lake Site - NM Lake and Watershed

Landform	Year Deposition Starts	Year Deposition Ends	Comments from Tailings Plan		Initial Year in Model Simulations	Initial Chloride Concentration in HGS Model (mg/L)
NMSP- E Valley	2015	2028	Cake capped with coke by 2028		2040	500
NMSP-W Valley	2013	2039	FFT and water removed by 2040		2040	750
NMNP Valley	2025	2039	FFT and water removed by 2040		2040	1,000
NMCP-E Valley	2022	2040	Flocculated tailings capped with coke by 2040		2040	950
NM Lake	2028	2040	Filled with FFT to elevation 302 m and capped with 100% OSPW		2040	1,250

Note: The above assumed dates are approximate and suitable for the level of detail in this study. It should be noted that the dates are not in exact alignment with other Syncrude planning documents.

Table 17 – Summary of Initial Chloride Concentration at MLX-W - WM Lake and Watershed

Landform	Year Deposition Starts	Year Deposition Ends	Comments from Tailings Plan	Initial Year in Model Simulations	Initial Chloride Concentration in HGS Model (mg/L)
XS Valley	2030	2037	Flocculated tailings deposition completed in 2037, water cap removed in 2041	2040	1,250
XW Valley	2037	2043	Flocculated tailings at Mildred Lake operations treated by 2043	2040	1,250
WM Lake	2040	2040	Flocculated tailings to elevation 255 m and the remainder of the lake filled with 100% OSPW in Year 2040	2040	1,250

Note: The above assumed dates are approximate and suitable for the level of detail in this study. It should be noted that the dates are not in exact alignment with other Syncrude planning documents.

Table 18 – Summary of Initial Chloride Concentration at Aurora North

Landform	Year Deposition Starts	Year Deposition Ends	Comments from Tailings Plan	Initial Year in Model Simulations	Initial Chloride Concentration in HGS Model (mg/L)
AEP Valley	2020	2029		2035	466
ACPN Valley	2023	2034		2035	665
ASB Valley	2001	2037	FFT and water removed from 2038 to 2041	2035	536
ACPS Valley	2029	2038		2035	871
AWPS Valley	2033	2041		2035	984
AWPW Valley	2036	2041		2035	1,000
AN-W Lake	2039	2041	Contains only FFT and water. FFT transfer done 2041 to elevation 245 m. In 2042 is topped up with RCW as AWPW is emptied.	2035	1,000
AN-E Lake	2042	2058 full	No direct tailings deposition, assumption is that in 2058. The water make up is 50/50 (fresh/OSPW).	2035	Simulation started at 1,000 mg/L in 2035 to target dilution to about 500 mg/L by year 2058. Lake concentration calculation based of initial concentration of 500 mg/L in 2058.

Note: The above assumed dates are approximate and suitable for the level of detail in this study. It should be noted that the dates are not in exact alignment with other Syncrude planning documents.

4.10 TAILINGS CONSOLIDATION RELEASE WATER

OSPW will be released during consolidation of FFT and flocculated tailings and is expected to mix with surface and groundwater in the closure landscape. The consolidation process and associated OSPW release was not included within the HGS model. The topography and stratigraphy within the HGS model are static throughout the duration. The top elevation of FT was estimated to represent conditions at year 2090, when most consolidation is complete, given the focus of the modelling. For example, FFT will be placed in NM Lake to elevation 301 m in year 2040. By year 2090 the top of FT is estimated to have settled to elevation 277 m. For closure valleys, the capping/FT interface was assumed to be at the top of FT at year 2090. Figure 28 to Figure 32 show conceptual cross sections of each pit lake. Note the settled top of FT at year 2090 was implemented in the model as a flat surface. The surface of FT in pit lakes is variable depending on the depth of tailings and initial pit floor. This surface is represented as a conceptual realistic settled surface of FT in the Figures. Table 19 provides a summary of the landforms that contain FFT and flocculated tailings along with the assumed placement thickness, consolidated thickness, and assumed initial chloride concentration. It should be noted that Syncrude potentially plans to place flocculated tailings in some tailings facilities at Aurora North; however, this information was not included in the model as the details of placement were not available.

The chloride mass released from consolidation was estimated for comparison to mass loading from landforms modelled in HGS. Where appropriate, the consolidation mass loading estimates were added to mass loads applied to the pit lake concentration estimates. The magnitude and rate of FT consolidation was based on research data from Syncrude for FFT and flocculated tailings. Figure 33 provides the estimated consolidation mass loads based on the consolidation magnitude and rates provided by Syncrude. The mass loads from the closure valleys were added to the mass balance of BM Lake, NM Lake, WM Lake, and AN-W Lake and used to estimate chloride concentration within the water cap of pit lakes. Growth of the pit lake water caps with consolidation of FT was also estimated within the spreadsheet model.

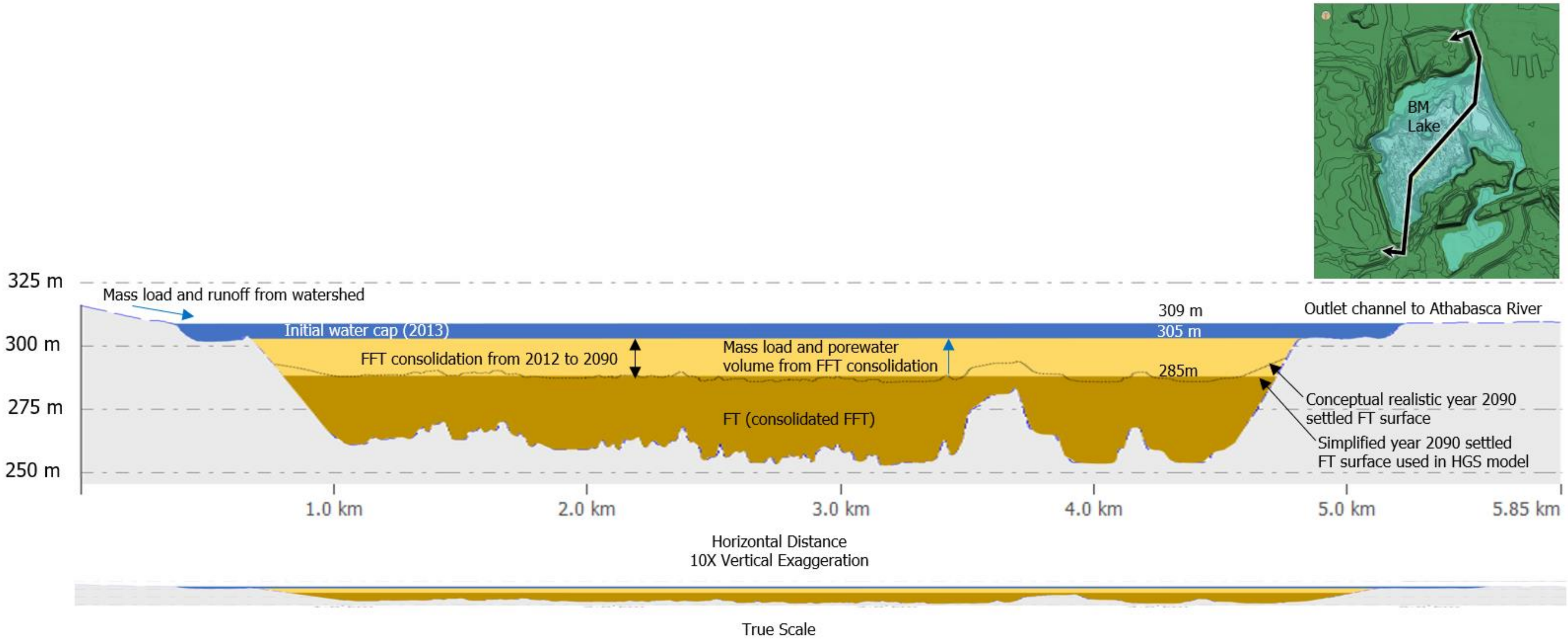


Figure 28 – Conceptual Cross Section – BM Lake

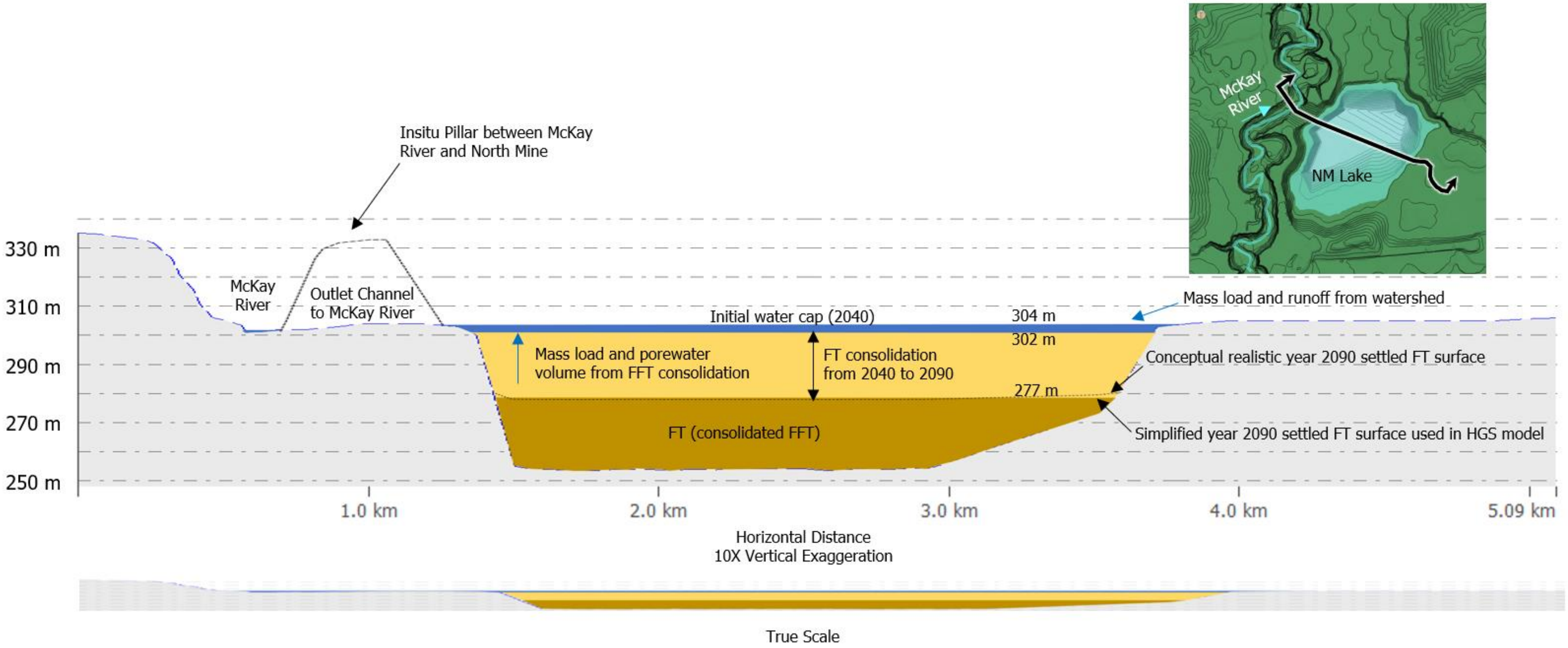


Figure 29 – Conceptual Cross Section – NM Lake

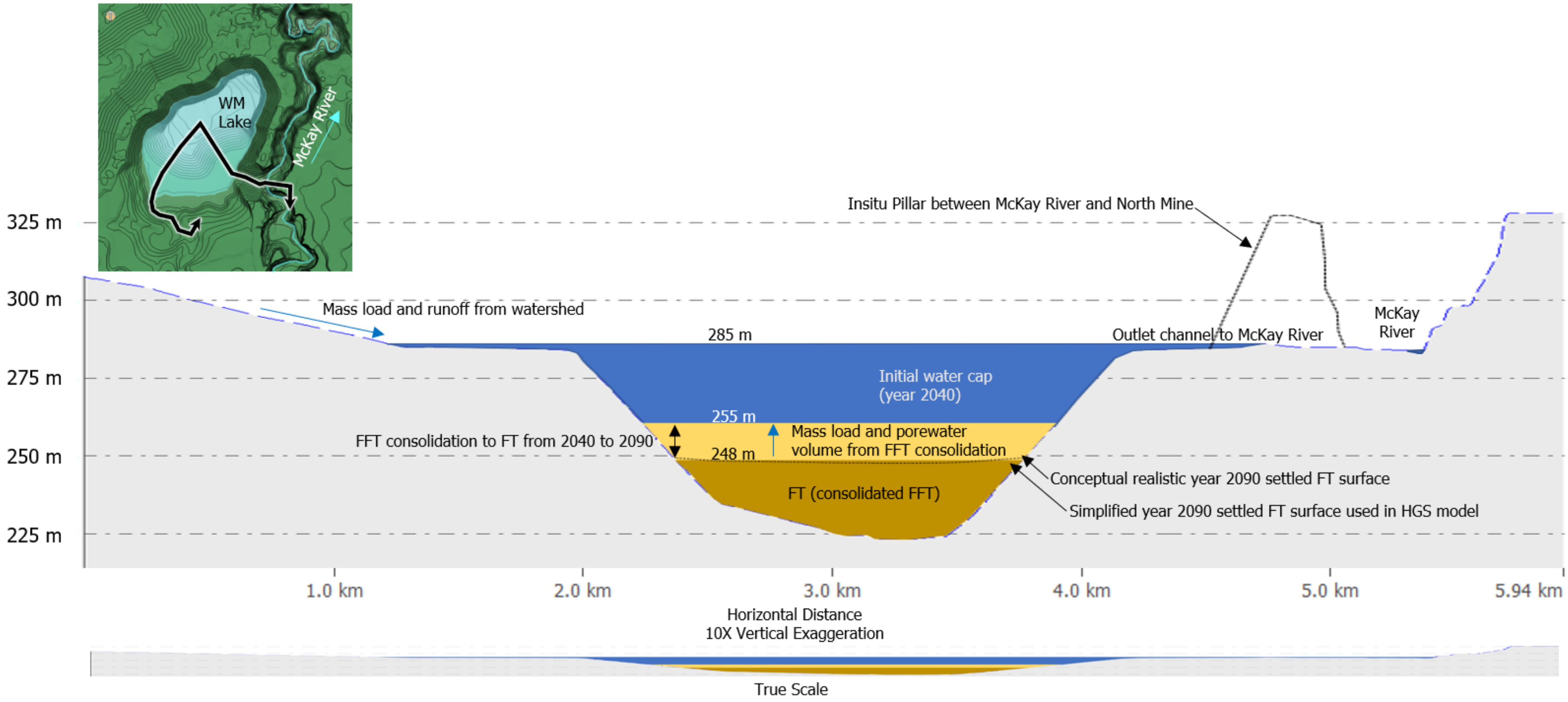


Figure 30 – Conceptual Cross Section – WM Lake

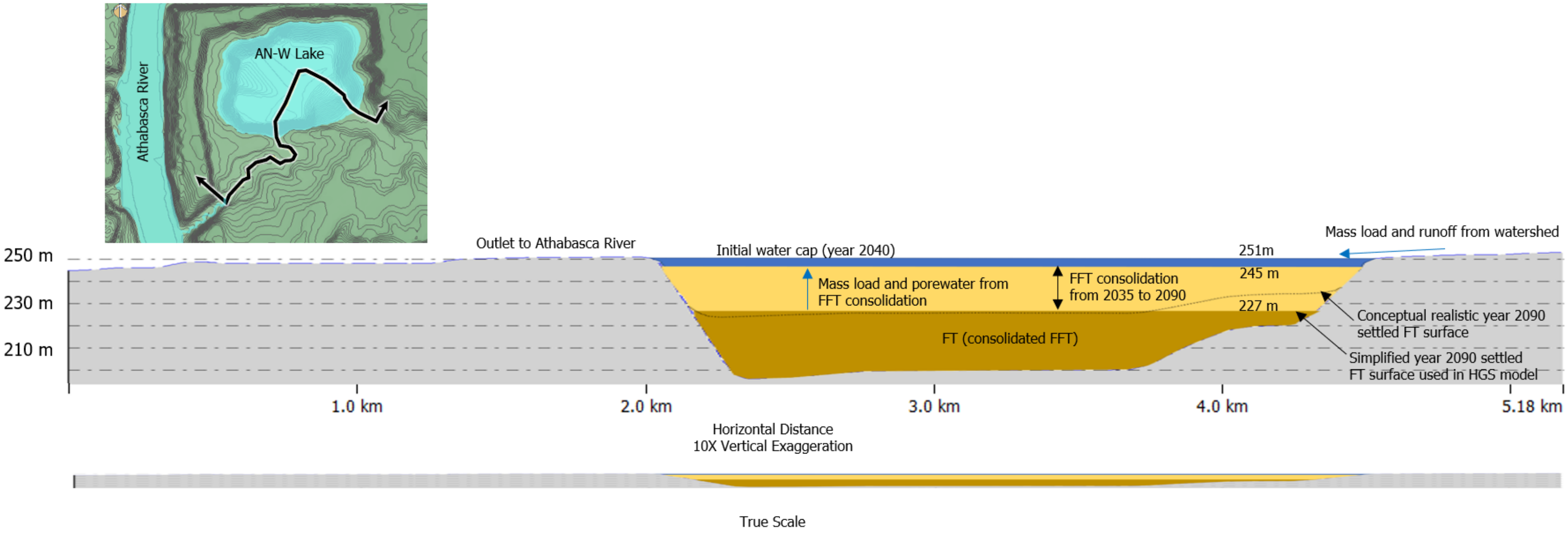


Figure 31 – Conceptual Cross Section – AN-E Lake

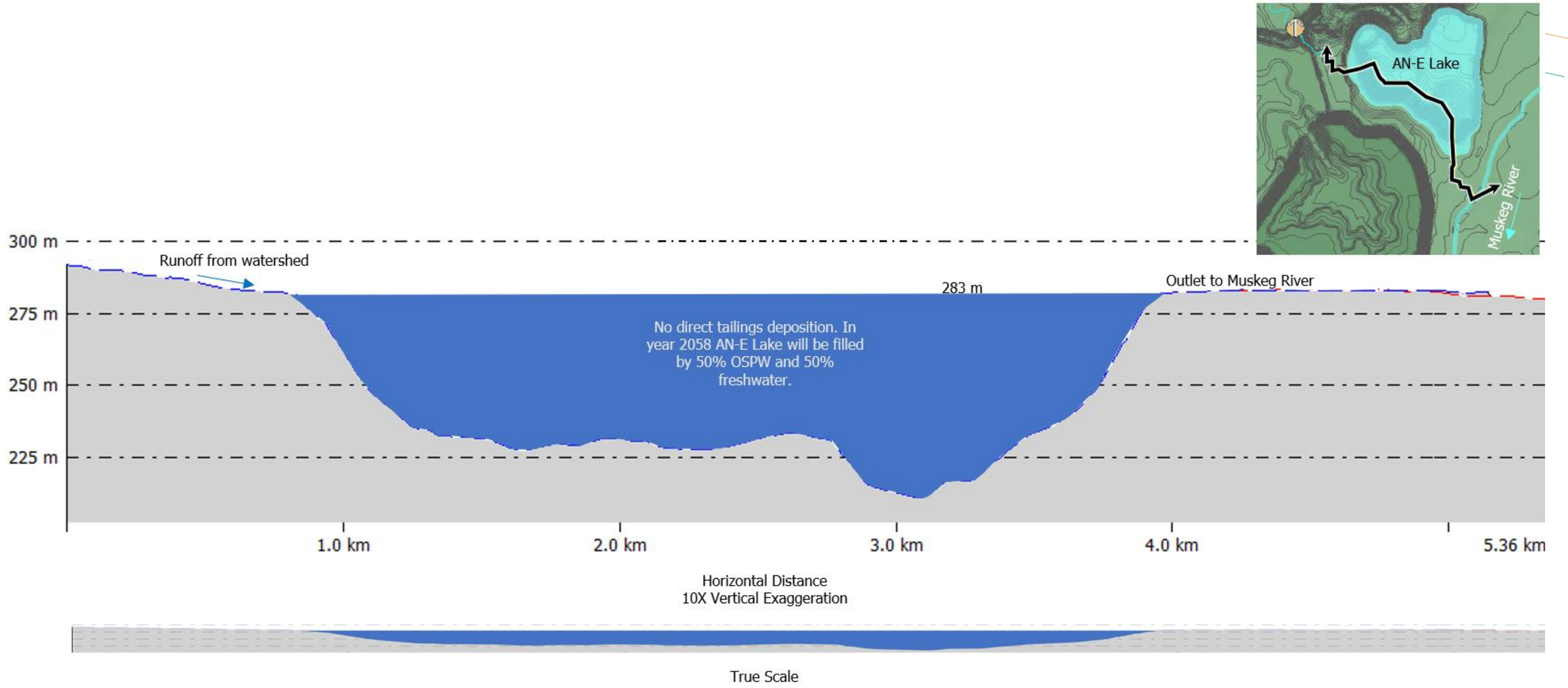


Figure 32 – Conceptual Cross Section – AN-W Lake

Table 19 – Summary of Fine Tailings Deposit Consolidation

	BM Lake	NMSP-E	NMCP-E Valley	NM Lake	XW Valley	XS Valley	WM Lake	AN-W Lake
Type	FFT	See Note	See Note	FFT	See Note	See Note	FFT	FFT
Initial Chloride Concentration in Pore Space (mg/L)	400	500	950	1,250	1,250	1,250	1,250	1,000
Year Tailings Placement Complete	2013	2025	2040	2040	2040	2040	2040	2035
Age of Tailings at Year 2090 (years)	77	65	50	49	50	50	50	55
Elevation of Fine Tailings at Placement (m)	305	310	299	302	327	322	255	245
Elevation of Fine Tailings at Year 2090 (m)	285	301	290	277	320	310	248	227
Approximate Thickness at Placement (m)	45	40	45	60	44	57	30	45
Approximate Thickness at Year 2090 (m)	25	31	36	35	37	45	23	27

Note: flocculated tailings

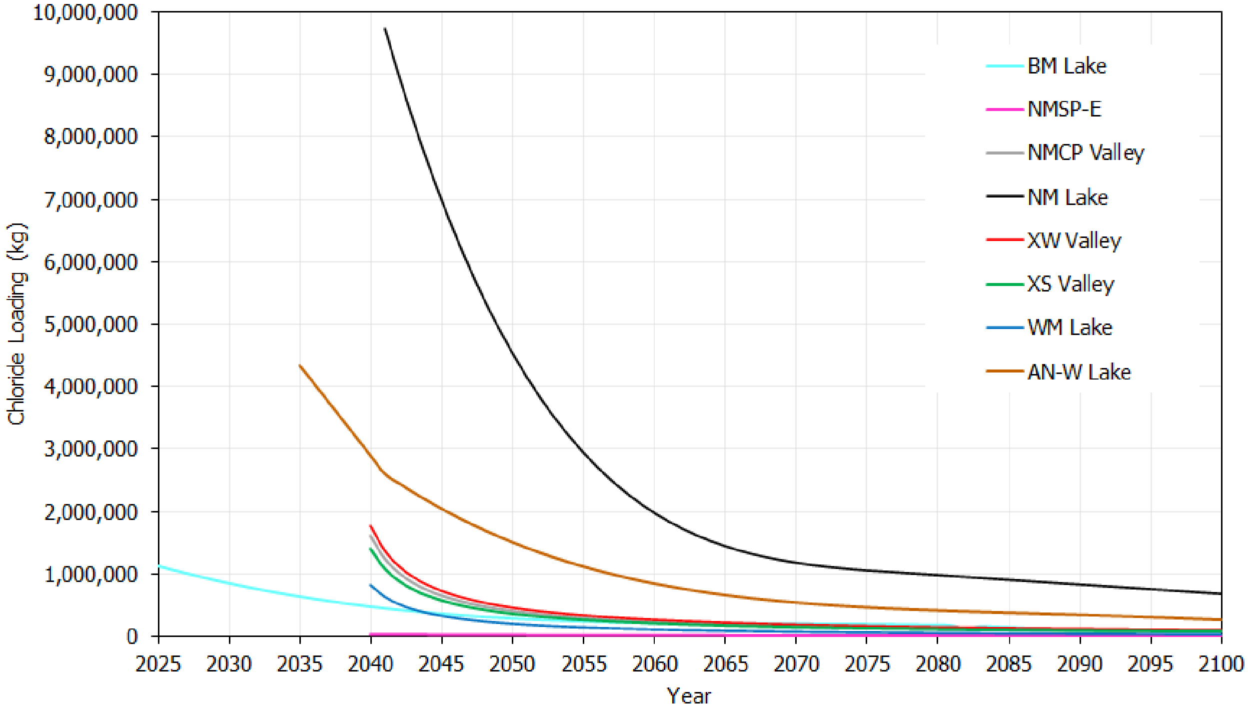


Figure 33 – Fine Tailings Consolidation Mass Loads

5. RESULTS

5.1 WATER BALANCE RESULTS

The water balance components for simulation cases are summarized in sections below. Assessing the water balance is important in understanding water movement through the landforms and pit lakes. The results are presented for each of the main reclaimed landforms (i.e., tailings facilities converted to closure valleys, overburden dumps, and pit lakes). Runoff for a given landform is based on volume of surface runoff tracked at the outlet of the landform divided by the watershed area of the landform at the outlet. For landforms that have inflow, an additional surface water tracking line was established upstream of the landform. The runoff for these landforms was calculated by taking the difference in surface runoff volume between the upstream and downstream flow tracking lines divided by the increase in watershed area from the downstream to upstream flow tracking line. This approach isolates runoff contributions for each distinct landform. Runoff upstream and downstream of pit lakes was calculated using the upstream and downstream flow track volumes divided by the upstream and downstream watershed areas. This approach illustrates the impact of lake evaporation on runoff.

The results are compared to the historical values as a point of reference when reviewing the climate change scenarios and to assess model performance against regional runoff and AET values. The modelled runoff and AET compare reasonably well to historical regional reference values. Reference values for runoff range from 0 to over 250 mm/year (ARKK 2021c). Reference values for AET range from about 250 mm to 425 mm (Straker et al. 2019).

5.1.1 MILDRED LAKE SITE WATER BALANCE RESULTS

The water balance at Mildred Lake site is described in terms of runoff and AET depths in Table 20 for BM Lake landforms and in Table 22 for NM Lake landforms. Flow tracking lines used to track runoff volumes in the model are shown in Figure 34. The model results suggest that little to no runoff is anticipated from overburden dumps (W1 Hill and W4 Hill) under all conditions. The water balance of the closure valleys is characterized by relatively lower AET and higher runoff. It is anticipated that closure valleys adjacent to overburden dumps have higher runoff depths due to interflow. Runoff depths upstream and downstream of the pit lakes suggest limited inflow and outflow from the lake will occur during dry periods. The model results suggest that moderate inflow and outflow will occur during wet periods. The results also indicate reduced runoff and increased AET due to the assumed climate change scenarios, relative to the historical wet and dry decades.

Table 21 and Table 23 provide a summary of the annual volume balance for BM Lake and NM Lake, respectively. During wet periods, the water balance is dominated by surface runoff into and out of the lake. During dry periods the water balance components of precipitation, PET, and runoff are similar. The results suggest reduced inflow and increased evaporation due to the assumed climate change scenarios, especially for NM Lake, which has a smaller watershed compared to BM Lake. Groundwater has little influence on the water balance of the lakes at the Mildred Lake site.

The simulated water level of the BM Lake is shown in Figure 35. The water level is maintained near or at the sill for the historical and cool (RCP2.6) scenarios. For the warm (RCP8.5) climate change scenarios, the water level drops about 5 m below the sill of the lake. The warm wet climate change scenario suggests the lake level can recover from these drops during wet cycles. NM Lake water levels are shown in Figure 36 and show a similar pattern; however, the reduction in water level is slightly more pronounced due to the smaller watershed area. It is important to recognize that the RCP2.6 and RCP8.5 represent the lower and upper bounds of climate change projections.

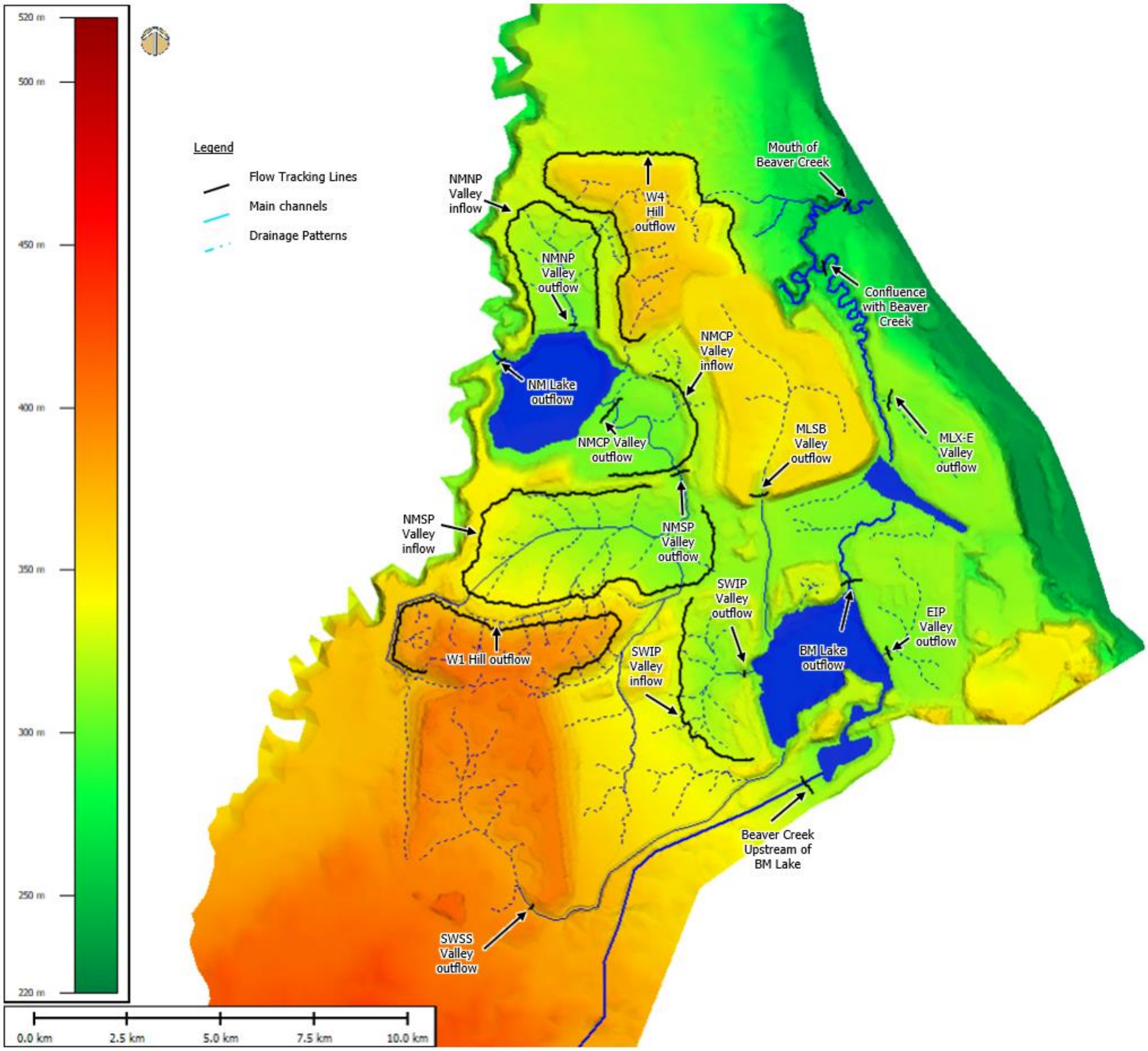


Figure 34 – Mildred Lake Flow Tracking Lines

Table 20 – Average Annual Runoff and AET Depth for BM Lake

Simulation (Averaging Period)	P (mm)	PET (mm)	P-PET (mm)	EIP Valley		SWIP Valley		SWSS Valley		MLSB Valley		XE Valley		Beaver Creek Upstream of BM Lake	BM Lake Outlet	Confluence with Beaver Creek	Mouth of Beaver Creek
				Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	Runoff (mm)	Runoff (mm)	Runoff (mm)
Historical Dry Cycle (2007 to 2017)	358	618	-260	6	388	44	390	6	379	0	288	2	318	33	17	18	24
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	3	409	34	420	5	386	0	340	5	352	29	12	12	17
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	0	419	1	453	1	406	0	375	0	380	8	0	1	4
Historical Wet Cycle (1967 to 1978)	508	574	-66	138	367	221	335	142	366	7	340	101	344	61	109	112	121
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	44	454	104	432	57	443	0	376	75	400	48	60	63	69
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	2	535	10	556	9	527	0	436	23	475	26	7	8	14

Note: P = Precipitation, PET = Potential Evapotranspiration, AET = Actual Evapotranspiration

Table 21 – Average Annual Water Balance for BM Lake

Simulation (Averaging Period)	Climate Conditions			Volumes (m^3)				
	Precipitation (mm)	Lake Evaporation (mm)	P - PET (mm)	Precipitation Over Lake	Runoff Into Lake	Net Groundwater Inflow to Lake	Evaporation from Lake	Outflow from Lake
Historical Dry Cycle (2007 to 2017)	358	615	-257	3,341,617	4,939,663	18,986	5,736,780	3,892,472
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	3,846,687	4,364,187	20,408	6,251,042	2,842,136
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	3,866,629	1,155,614	18,309	8,273,364	0
Historical Wet Cycle (1967 to 1978)	512	570	-59	4,771,172	15,197,028	112,606	5,317,416	25,203,934
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	5,108,176	9,211,313	82,113	6,408,625	14,020,582
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	5,230,127	4,026,288	30,307	8,445,978	1,511,327

Table 22 – Average Annual Runoff and AET Depth for NM Lake Watershed

Simulation (Averaging Period)	P (mm)	PET (mm)	P-PET (mm)	W1 Hill		W4 Hill		NMSP Valley		NMCP-E Valley		NMNP Valley		NM Lake Outlet	Lake AET (mm)	Natural Wetland AET	Natural Upland AET (mm)
				Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)			
Historical Dry Cycle (2007 to 2017)	358	618	-260	0	343	0	339	47	386	41	371	66	390	19	612	417	344
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	0	378	0	376	35	418	37	620	39	420	6	664	434	378
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	0	399	0	398	-8	490	-2	679	3	483	0	861	448	429
Historical Wet Cycle (1967 to 1978)	508	574	-66	1	384	35	371	214	336	209	352	228	343	171	569	423	323
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	0	441	6	441	100	431	158	652	92	439	91	683	507	401
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	0	506	0	499	18	554	55	821	14	558	0	896	569	503

Note: P = Precipitation, PET = Potential Evapotranspiration, AET = Actual Evapotranspiration

Table 23 – Average Annual Water Balance for NM Lake

Simulation (Averaging Period)	Climate Conditions			Volumes (m^3)				
	Precipitation (mm)	Lake Evaporation (mm)	P - PET (mm)	Precipitation Over Lake	Runoff Into Lake	Net Groundwater Inflow to Lake	Evaporation from Lake	Outflow from Lake
Historical Dry Cycle (2007 to 2017)	358	615	-257	2,639,100	3,722,152	3,657	4,530,721	1,849,579
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	3,037,988	2,544,182	4,947	4,936,868	589,869
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	3,053,737	50,551	10,452	6,534,032	0
Historical Wet Cycle (1967 to 1978)	507	569	-62	3,768,116	17,220,527	28,022	4,199,521	16,992,862
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	4,034,270	9,898,109	23,357	5,061,322	9,032,841
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	4,130,583	2,626,041	33,343	6,670,357	7,254

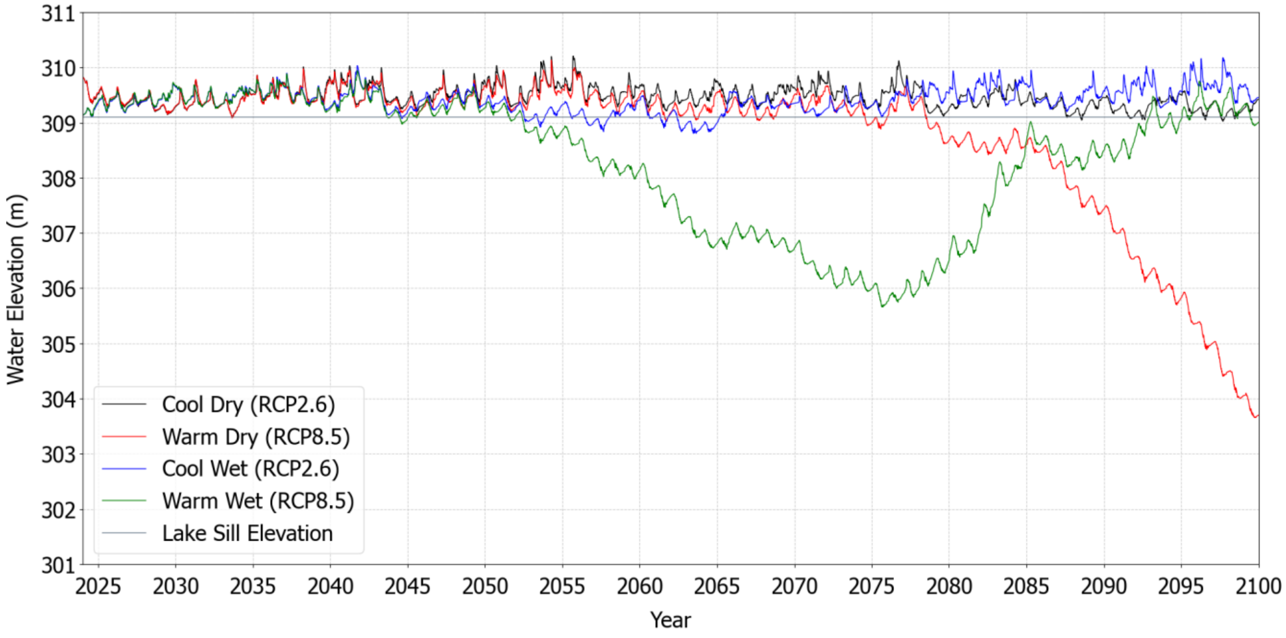


Figure 35 – Simulated BM Lake Water Levels

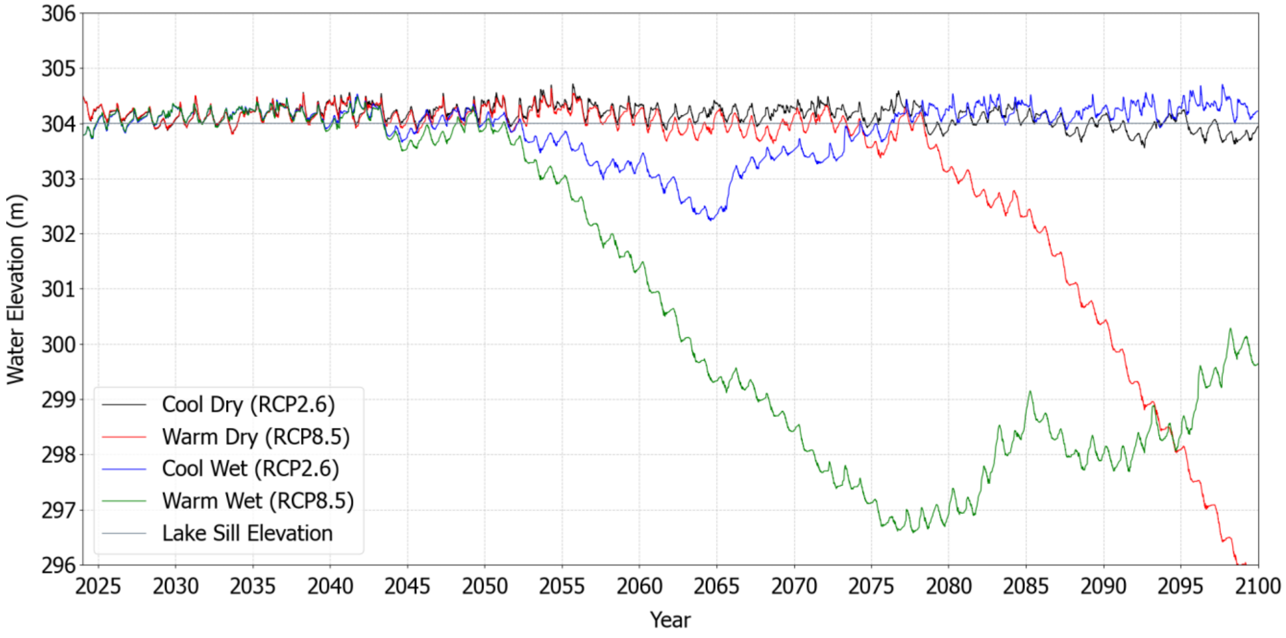


Figure 36 – Simulated NM Lake Water Levels

5.1.2 MLX-W WATER BALANCE RESULTS

Flow tracking locations for the MLX-W landforms are shown in Figure 37. The water balance of MLX-W mine landforms is described in terms of runoff and AET depths in Table 24. The results suggest that little to no runoff is anticipated from overburden dumps (NODA Hill and SODA Hill) on an annual basis. The water balance of the XW Valley and XS Valley are characterized by relatively lower AET, and higher runoff yields given the relatively higher permeability of coke substrates. It is anticipated that the XW Valley has higher runoff depths compared to the XS Valley due to interflow from the natural watercourse that flows through the landform. Runoff depths upstream and downstream of WM Lake suggest limited inflow and outflow from the lake will occur during dry periods. The model results suggest that moderate inflow and outflow will occur during wet periods. The results also indicate reduced runoff and increased AET due to the assumed climate change scenarios, relative to the historical wet and dry decades.

Table 25 provides a summary of the annual volume balance of WM Lake. During wet periods the water balance is dominated by surface runoff into and out of the lake. During dry periods the water balance components of precipitation, PET, and runoff are similar. The results suggest reduced inflow and increased evaporation due to the assumed climate change scenarios. Groundwater flow into and out of the landforms is minimal compared to flow through the landform outlets.

The simulated water level of the WM Lake is shown in Figure 38. The level is maintained near or at the sill for the historical and cool (RCP2.6) scenarios. For the warm (RCP8.5) climate change scenarios, the water level drops about 5 m below the sill of the lake. The warm wet climate change scenario suggests the lake level can recover from these drops during wet cycles. It is important to recognize that the RCP2.6 and RCP8.5 represent the lower and upper bounds of climate change projections.

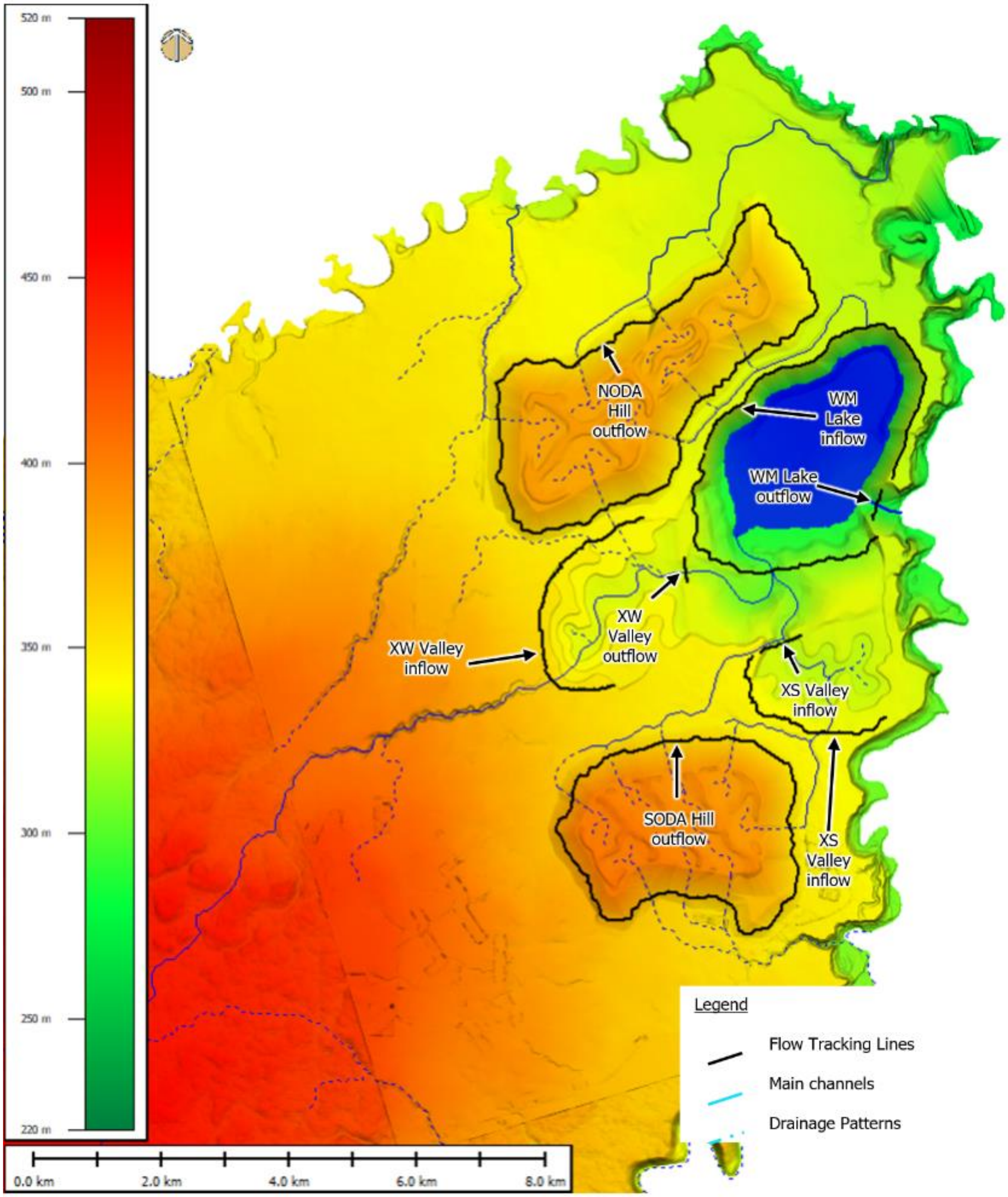


Figure 37 – MLX-W Flow Tracking Lines

Table 24 – Average Annual Runoff and AET Depth for WM Lake Watershed

Simulation (Averaging Period)	P (mm)	PET (mm)	P-PET (mm)	NODA Hill		SODA Hill		XW Valley		XS Valley		WM Lake Upstream	WM Lake Downstream	WM Lake AET (mm)	AET Natural Wetlands (mm)	AET Natural Uplands (mm)
				Runoff (mm)	AET Uplands (mm)	Runoff (mm)	AET Uplands (mm)	Runoff (mm)	Blended AET (mm)	Runoff (mm)	Blended AET (mm)	Runoff (mm)	Runoff (mm)			
Historical Dry Cycle (2007 to 2017)	358	618	-260	3	288	2	286	164	271	127	273	41	22	615	358	353
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	0	388	0	389	108	372	51	379	21	8	667	389	374
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	0	410	0	411	38	438	21	431	4	0	867	426	429
Historical Wet Cycle (1967 to 1978)	508	574	-66	27	360	31	360	311	299	217	305	121	111	572	430	406
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	7	449	9	451	329	409	127	417	90	95	685	466	400
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	0	526	0	528	187	495	97	506	28	1	899	523	512

Note: P = Precipitation, PET = Potential Evapotranspiration, AET = Actual Evapotranspiration

Table 25 – Average Annual Water Balance for WM Lake

Simulation (Averaging Period)	Climate Conditions			Volumes (m^3)				
	Precipitation (mm)	Lake Evaporation (mm)	P - PET (mm)	Precipitation Over Lake	Runoff Into Lake	Net Groundwater Inflow to Lake	Evaporation from Lake	Outflow from Lake
Historical Dry Cycle (2007 to 2017)	358	615	-257	1,792,136	2,816,433	208,036	3,076,681	1,691,707
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	2,063,009	1,651,625	99,900	3,352,484	593,854
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	2,073,705	245,349	31,798	4,437,072	0
Historical Wet Cycle (1967 to 1978)	507	569	-62	2,533,708	8,435,326	299,610	2,845,648	8,654,891
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	2,739,556	7,048,587	206,413	3,436,997	7,455,877
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	2,804,959	2,196,681	120,834	4,529,646	81,883

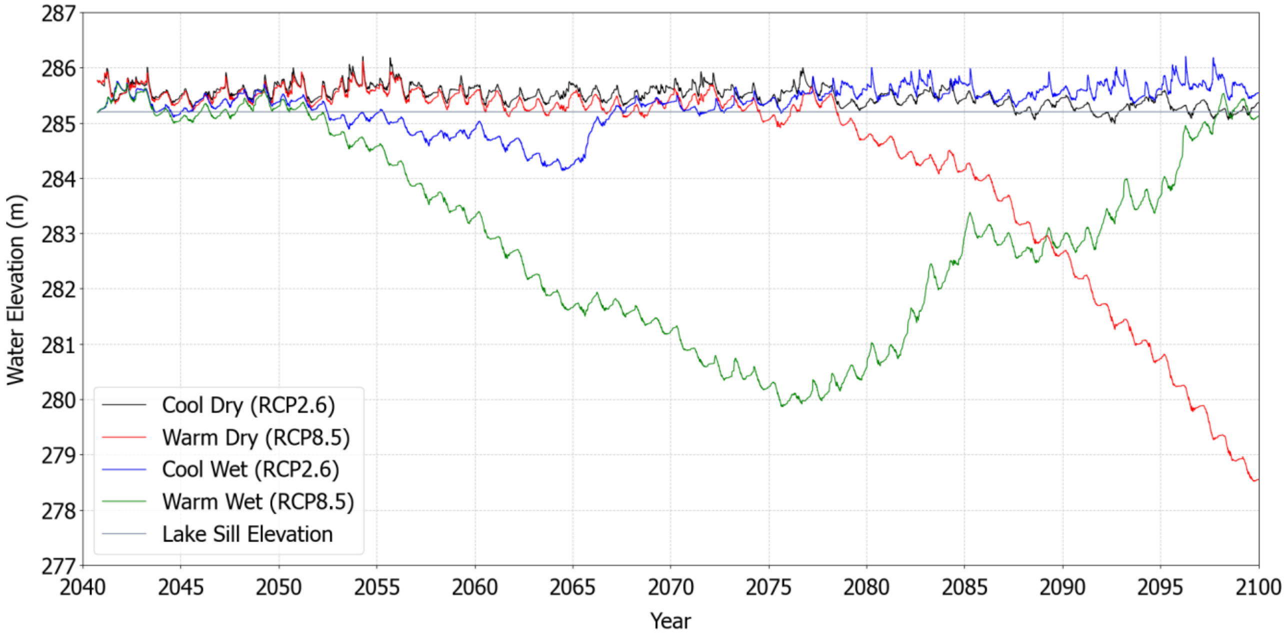


Figure 38 – Simulated WM Lake Water Levels

5.1.3 AURORA NORTH WATER BALANCE RESULTS

Flow tracking lines for Aurora North landforms are shown on Figure 39. The water balance of AN-E Lake watershed landforms is described in terms of runoff and AET depths in Table 26. The runoff and AET for the watershed of AN-W lake are provided in Table 28. The results suggest that little to no runoff is anticipated from overburden dumps (Moose Hills and NE Hills) under all conditions. The water balance of the closure valleys is characterized by relatively lower AET and higher runoff yields. It is anticipated that closure valleys adjacent to overburden dumps have higher runoff depths due to interflow. Runoff depths upstream and downstream of the pit lakes suggest limited inflow and outflow from the lakes will occur during dry periods. The model results suggest that moderate inflow and outflow will occur during wet periods. The results also indicate reduced runoff and increased AET due to the assumed climate change scenarios, relative to the historical wet and dry decades.

Table 27 and Table 29 provide summaries of the annual volume balance of AN-E Lake and AN-W Lake, respectively. During wet periods, the water balance is dominated by surface runoff into and out of the lakes. During dry periods the water balance components of precipitation, PET, and runoff are similar. The results suggest reduced inflow and increased evaporation due to the assumed climate change scenarios, especially for AN-W Lake. Groundwater inflow to AN-E Lake is about equal to 50% of the inflow due to direct precipitation over the lake. The groundwater inflow approximately balances the net evaporation losses over the lake for most scenarios. Groundwater has little influence on the water balance of the AN-W Lake; however, the model results show a loss to groundwater when the lake levels are elevated and a gain when lake levels drop.

The simulated water level of the AN-E Lake is shown in Figure 40. The level is maintained near or at the sill for all scenarios. AN-W Lake water levels are shown in Figure 41 and follow a similar pattern to NM Lake where the water level drops under climate change scenarios.

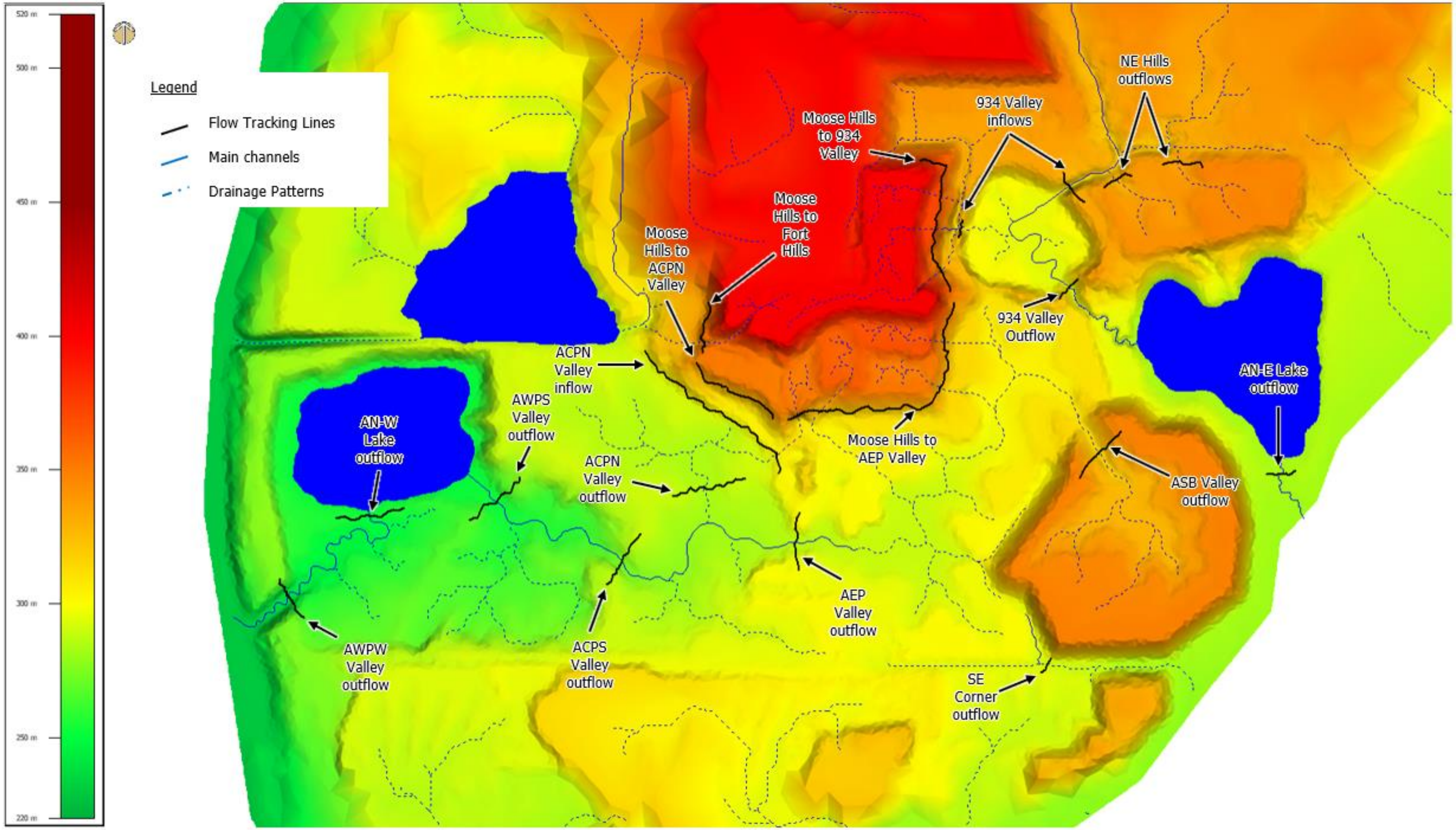


Figure 39 – Aurora North Flow Tracking Lines

Table 26 – Average Annual Runoff and AET Depth for AN-E Lake Watershed

Simulation (Averaging Period)	P (mm)	PET (mm)	P-PET (mm)	SE Corner		FHD to Fort Hills		ASB Downstream Slope		NE Hill		934 Valley		AN-E Lake at Inlet	AN-E Lake at Outlet	Lake AET (mm)	AET Natural Wetland (mm)	AET Natural Upland (mm)
				Runoff (mm)	AET Upland (mm)	Runoff (mm)	AET Upland (mm)	Runoff (mm)	AET Upland (mm)	Runoff (mm)	Blended AET (mm)	Runoff (mm)	Blended AET (mm)	Runoff (mm)	Runoff (mm)			
Historical Dry Cycle (2007 to 2017)	358	618	-260	3	327	0	318	0	320	0	322	309	294	48	50	612	424	286
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	3	368	0	359	0	359	0	362	198	333	29	34	669	462	321
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	0	394	0	387	0	388	0	386	92	418	13	0	885	562	370
Historical Wet Cycle (1967 to 1978)	508	574	-66	156	328	0	364	0	347	0	369	550	297	104	153	571	402	314
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	63	397	0	409	0	395	0	421	285	358	41	79	686	488	359
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	13	482	0	464	0	458	0	488	165	456	24	30	903	629	423

Note: P = Precipitation, PET = Potential Evapotranspiration, AET = Actual Evapotranspiration

Table 27 – Average Annual Water Balance for AN-E Lake

Simulation (Averaging Period)	Climate Conditions			Volumes (m3)				
	Precipitation (mm)	Lake Evaporation (mm)	P - PET (mm)	Precipitation Over Lake	Runoff Into Lake	Net Groundwater Inflow to Lake	Evaporation from Lake	Outflow from Lake
Historical Dry Cycle (2007 to 2017)	358	615	-257	2,032,283	1,872,744	1,111,424	3,488,957	2,246,670
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	2,339,453	1,132,211	1,053,774	3,801,717	1,521,938
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	2,351,581	522,524	1,059,384	5,031,640	4
Historical Wet Cycle (1967 to 1978)	507	569	-62	2,901,700	4,080,911	1,445,263	3,233,911	6,911,597
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	3,106,656	1,620,801	1,255,690	3,897,555	3,546,159
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	3,180,824	931,875	1,134,782	5,136,619	1,346,950

Table 28 – Average Annual Runoff and AET Depth for AN-W Lake Watershed

Simulation (Averaging Period)	P (mm)	PET (mm)	P-PET (mm)	Moose Hills		ASB Valley		AEP Valley		ACPN Valley		ACPS Valley		AWPS Valley		AWPW Valley		AN-W Lake at Inlet	AN-W Lake at Outlet
				Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	AET (mm)	Runoff (mm)	Runoff (mm)
Historical Dry Cycle (2007 to 2017)	358	618	-260	0	323	0	333	20	346	84	355	25	345	49	345	25	353	23	9
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	0	364	0	371	21	382	64	394	37	381	61	380	36	389	25	9
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	0	391	0	400	1	426	13	453	-4	444	10	454	4	443	2	0
Historical Wet Cycle (1967 to 1978)	508	574	-66	0	369	0	367	182	336	303	331	200	324	208	330	185	342	132	147
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	0	414	0	419	88	411	175	419	113	406	147	401	105	419	75	80
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	0	469	0	488	19	503	56	531	28	509	59	508	34	508	22	0

Note: P = Precipitation, PET = Potential Evapotranspiration, AET = Actual Evapotranspiration

Table 29 – Average Annual Water Balance for AN-W Lake

Simulation (Averaging Period)	Climate Conditions			Volumes (m3)				
	Precipitation (mm)	Lake Evaporation (mm)	P - PET (mm)	Precipitation Over Lake	Runoff Into Lake	Net Groundwater Inflow to Lake	Evaporation from Lake	Outflow from Lake
Historical Dry Cycle (2007 to 2017)	358	615	-257	1,788,552	1,652,790	-72,636	3,070,528	570,890
Cool Dry (RCP2.6, 2090 to 2100)	413	670	-258	2,058,883	1,762,678	-74,955	3,345,779	612,101
Warm Dry (RCP8.5, 2090 to 2100)	415	887	-473	2,069,557	158,197	60,802	4,428,198	0
Historical Wet Cycle (1967 to 1977)	512	570	-59	2,553,701	9,461,502	-33,731	2,846,069	9,682,891
Cool Wet (RCP2.6, 2090 to 2100)	548	687	-139	2,734,077	5,341,495	-62,472	3,430,123	5,223,386
Warm Wet (RCP8.5, 2090 to 2100)	561	906	-345	2,799,350	1,582,423	79,024	4,520,587	157

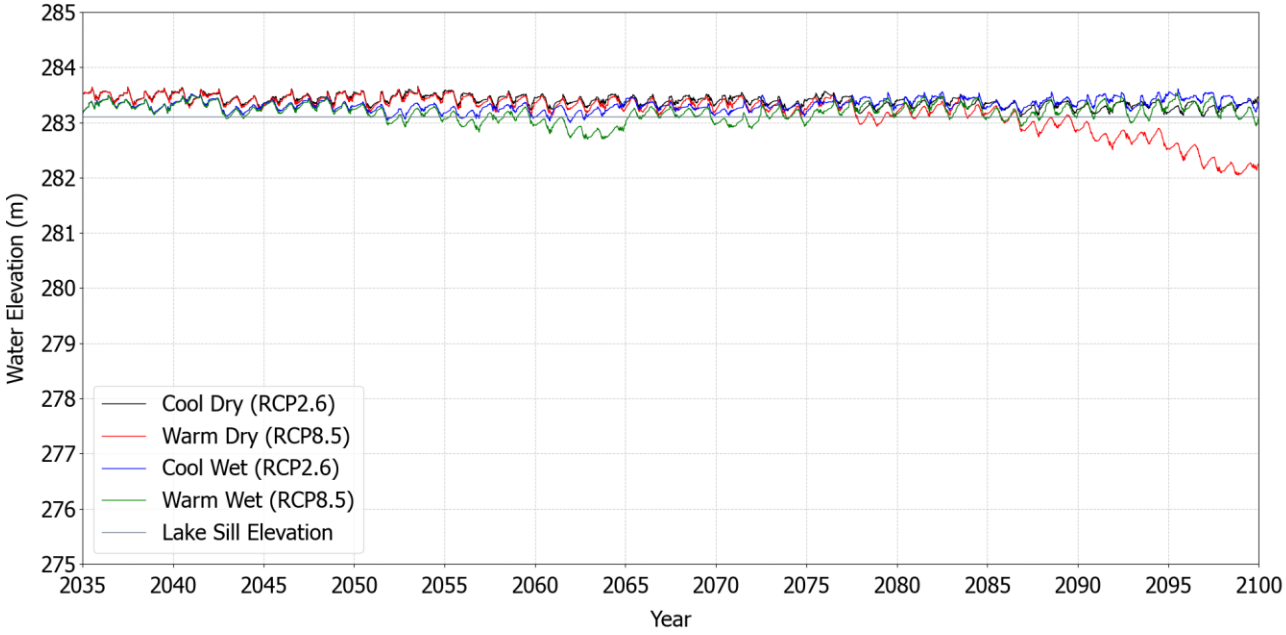


Figure 40 – Simulated AN-E Lake Water Levels

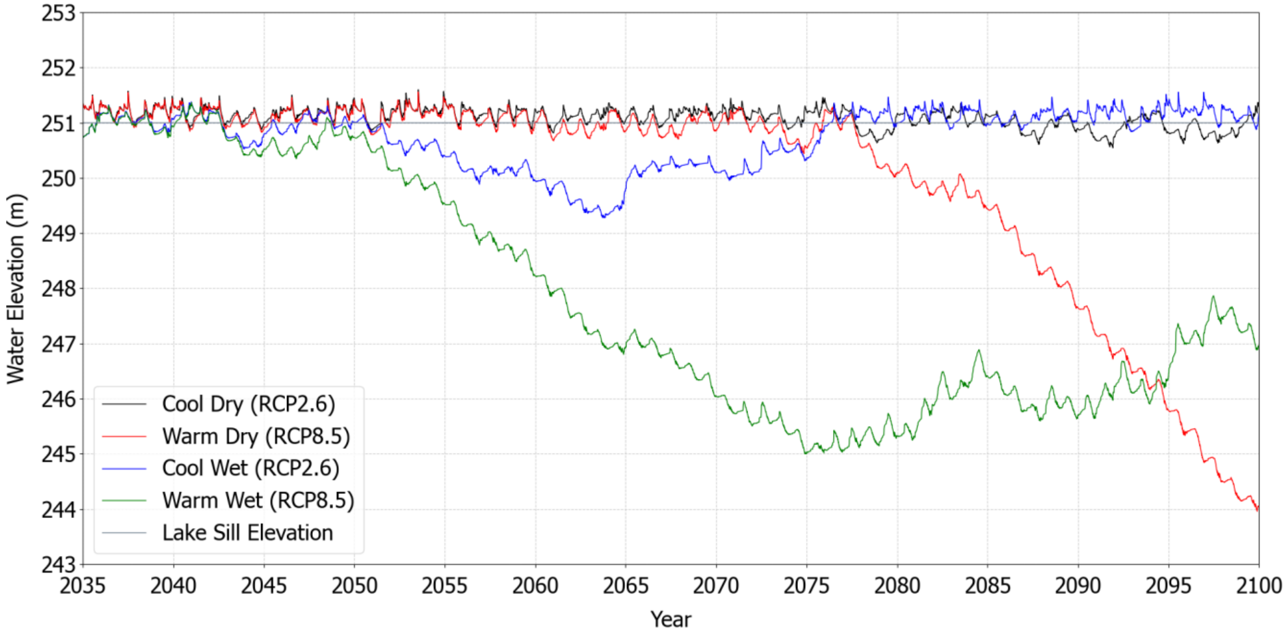


Figure 41 – Simulated AN-W Lake Water Levels

5.2 GROUNDWATER TABLE AND SURFACE WATER PONDING

Estimating the location of the water table and extents of ponded surface water is important for estimation of wetland extents and prediction of ecosite types. Water table and surface ponding were selected for historic dry and wet conditions by selecting a single point in time from the simulation that was considered representative of the general conditions for the wet and dry historic decade.

Figure 42 shows shallow groundwater depth 0 to 0.3 m below ground surface and ponding surface water extents for Mildred Lake site and MLX-W. Figure 43 shows groundwater flow directions for Mildred Lake and MLX-W. Similar information is provided for Aurora North on Figure 44 and Figure 45.

The results generally indicate:

- The water table would be at or near the ground surface along the valley bottoms, the toes of slopes, and watercourses.
- The elevation of water table closely follows the topography of the ground surface.
- The extents of groundwater within 0.3 m of the surface changes with wet and dry conditions.

The modelled wetland extents generally align with observed wetland areas, where data is available for conditions as modelled (i.e., natural areas and reclaimed areas). These results provide an understanding of water movement throughout the lease. Additionally, the results provide an indication of potential soil moisture and wetland extents for use in ecological modelling of the closure landscape.

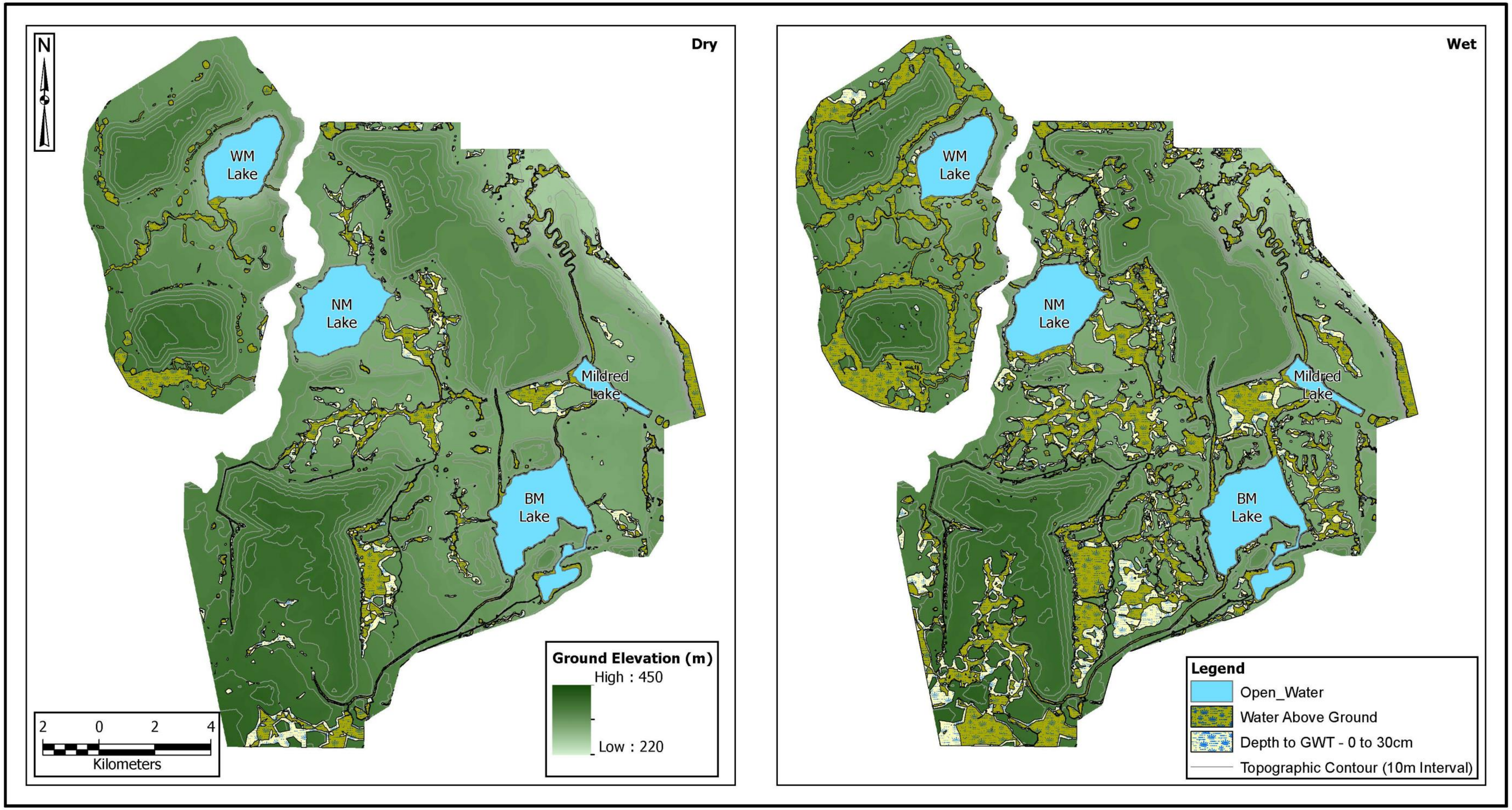


Figure 42 – Depth to Water Table 0 to 0.3 m and Surface Water Ponding – Mildred Lake and MLX-W

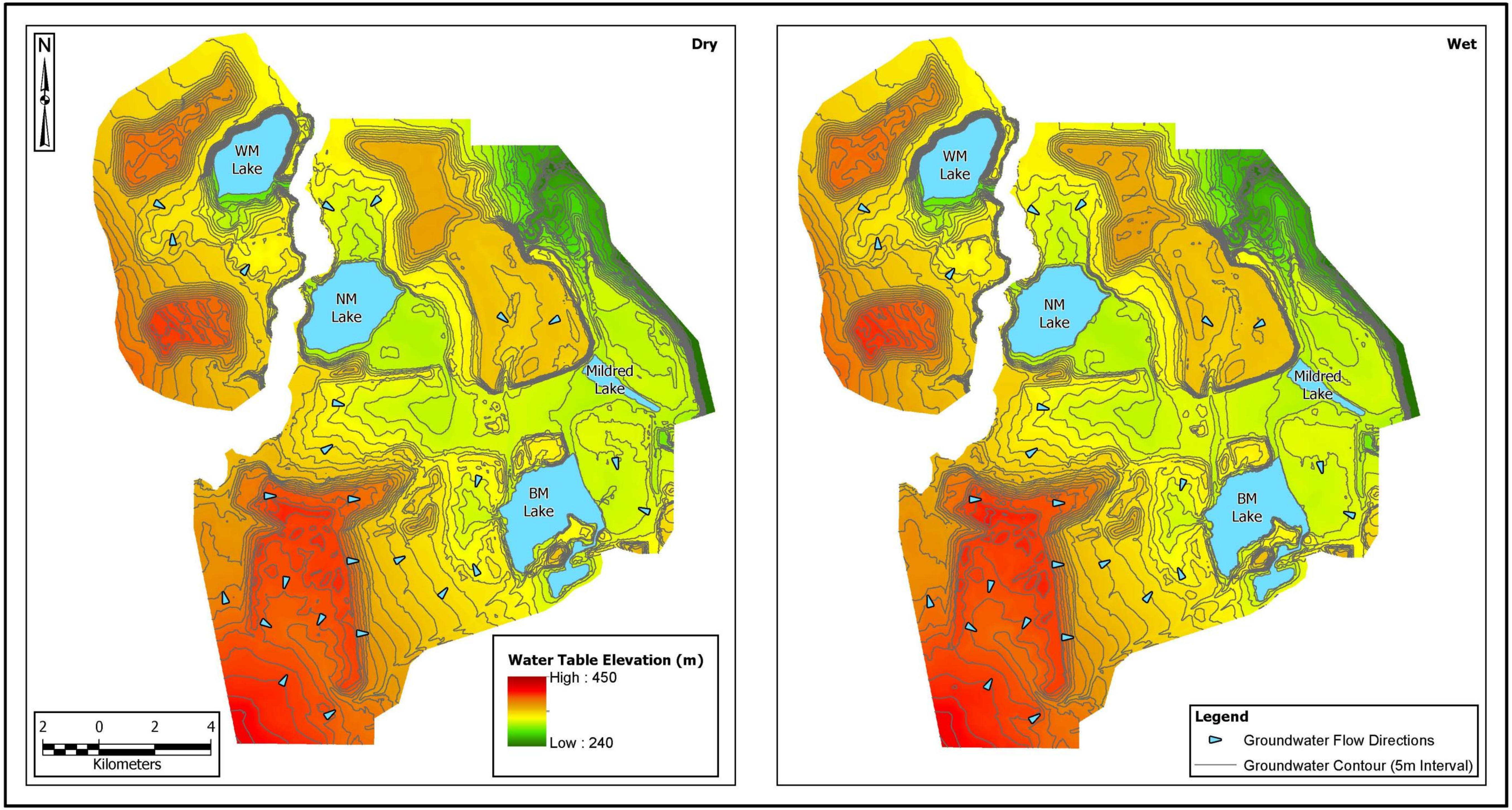


Figure 43 – Water Table Elevation and Flow Directions – Mildred Lake and MLX-W

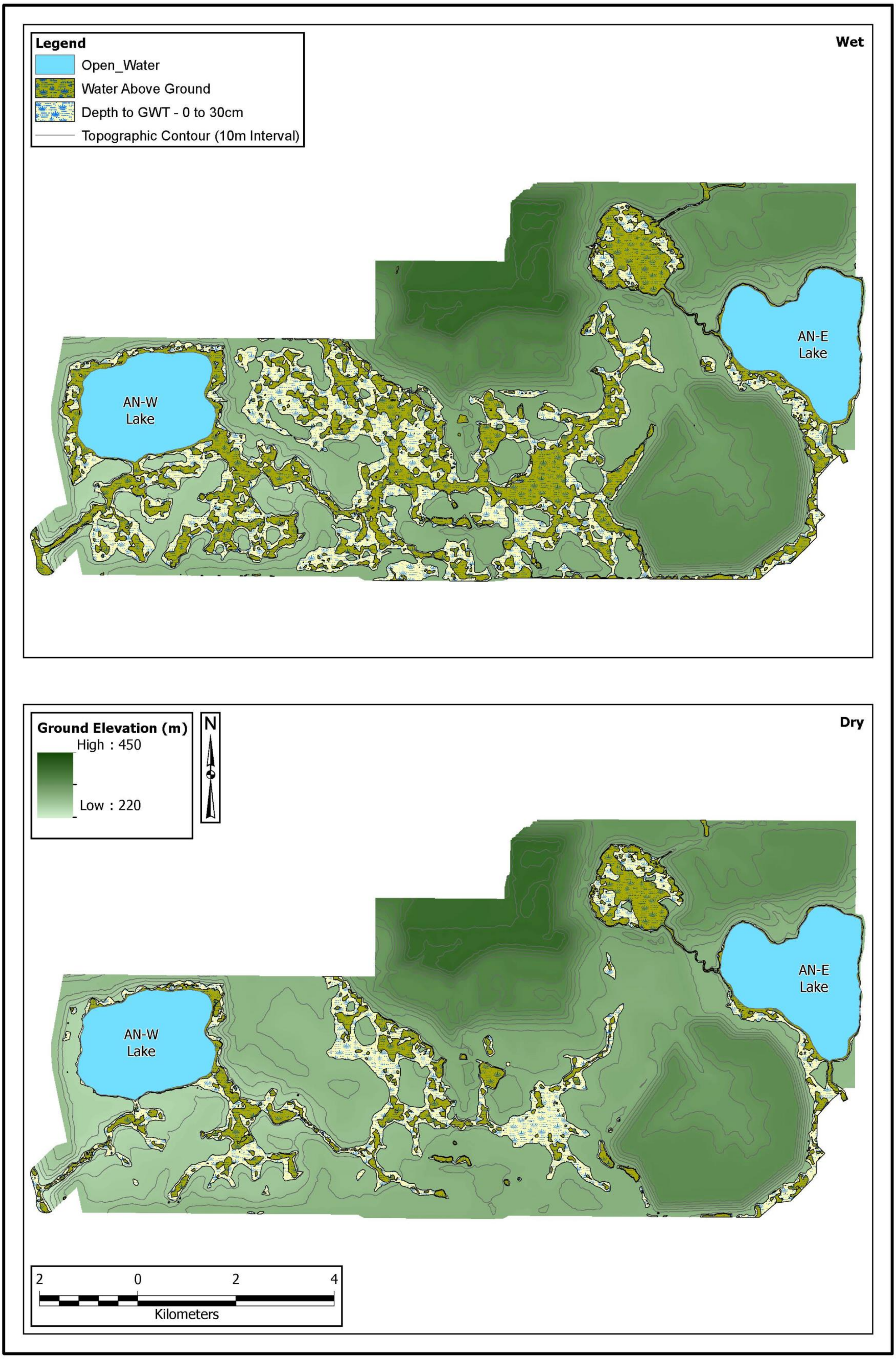


Figure 44 – Depth to Water Table – Aurora North

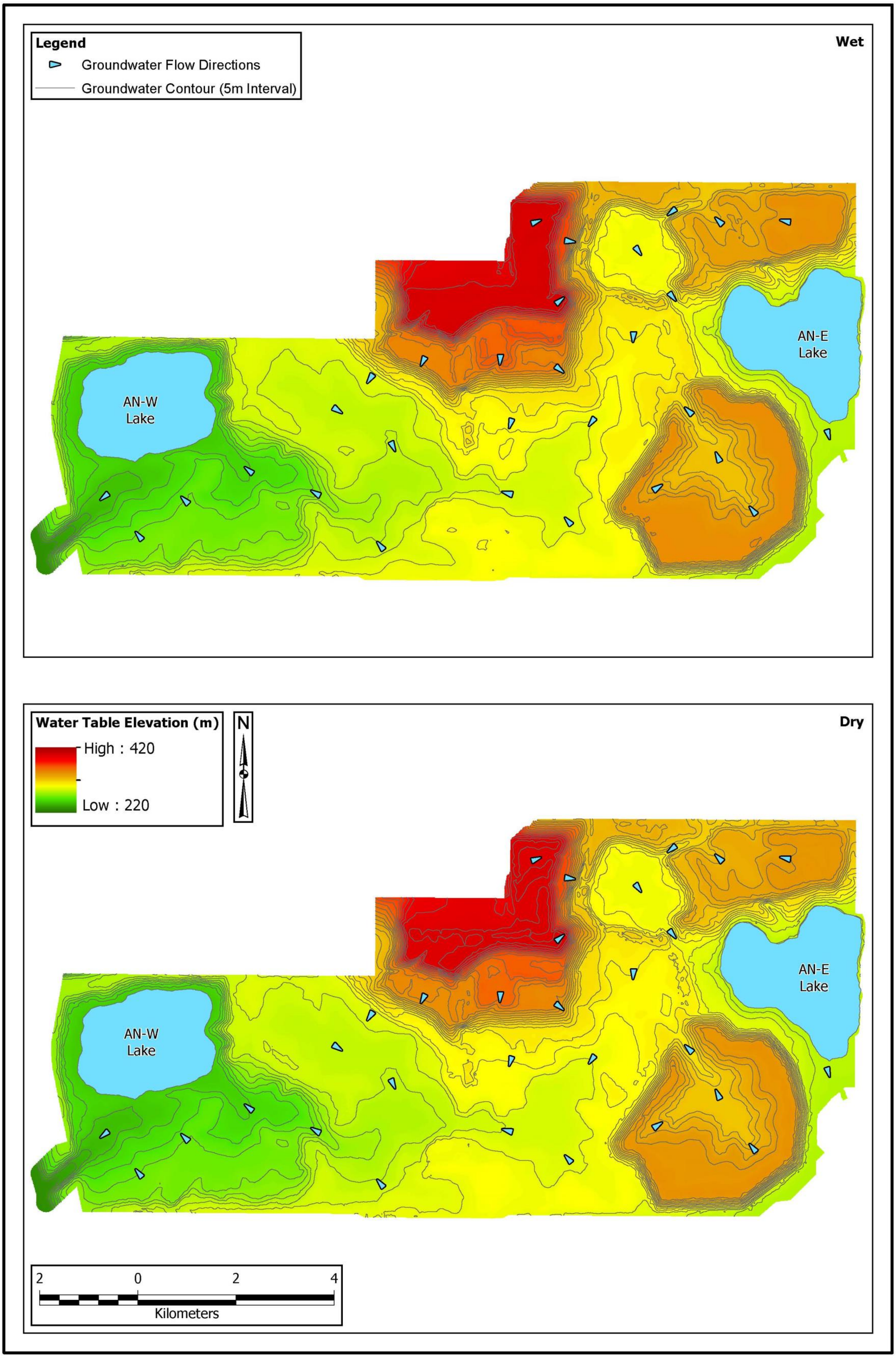


Figure 45 – Water Table Elevation and Flow Directions – Aurora North

5.3 WATER QUALITY RESULTS

The water quality is expected to vary in response to wet and dry climate cycles as well as movement of solutes from and within the landforms. During dry conditions, AET exceeds precipitation (water deficit) resulting in little to no runoff, lowering of the water table, and evaporation of ponded surface water. This leads to increases in solute concentrations and accumulation of solutes in ponded water. During wet conditions, precipitation exceeds AET (water surplus) resulting in runoff and groundwater recharge that dilutes the accumulated solutes and mobilizes them to zones of groundwater discharge and downstream areas.

Water quality across the closure landscape is evaluated using chloride as a conservative indicator parameter. The initial concentration of chloride was assigned throughout the pore space of tailings landforms and within pit lakes. The concentration and mass of chloride is tracked throughout the model simulation at the outlets of each landform in terms of concentration and mass loading. These data along with the flow data provide insights into the evolution of water quality throughout the closure landscape with time and in response to the climate change scenarios. The water balance and mass loading are used as input to spreadsheet models that track volume, mass, and concentration within the pit lake water cap and mass release to downstream areas.

5.3.1 MILDRED LAKE WATER QUALITY

Water quality was tracked at the outlet of each tailings landforms for the four climate change scenarios. The landforms contribute chloride mass to downstream areas. The model results are used to track the movement of solutes from the landforms overtime and assess mixing within the pit lakes. This information can inform management plans to commission the lakes and ultimately release the runoff into the McKay and Athabasca Rivers.

CHLORIDE CONCENTRATION – MILDRED LAKE

Figure 46 through Figure 52 show the outflow rate vs. chloride concentration relationships at the outlets of the tailings landforms. The initial porewater chloride concentration for each landform is shown in the title of each figure. Chloride concentration below the initial value suggests dilution due to precipitation and mixing. Concentration above the initial value represents evapoconcentration. Outflow rate vs. concentration plots help understand the dynamics of the potential mass loading under various climatic cycles. The plots show that for the valleys, higher flows are associated with lower concentrations due to dilution of porewater with fresh surface water. The concentration and flow dynamics demonstrate an inherent mechanism within the landforms that limits discharge of solute mass from the site during low flow periods.

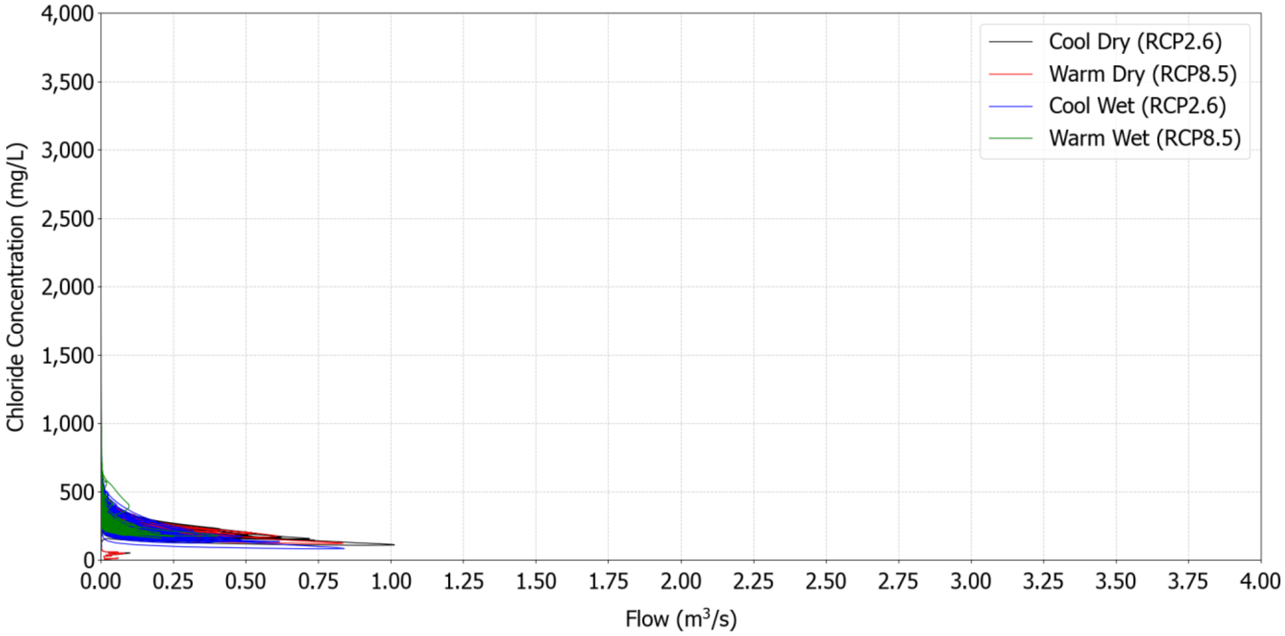


Figure 46 – Concentration vs. Flow Discharged from EIP Valley (C_0 = 600 mg/L)

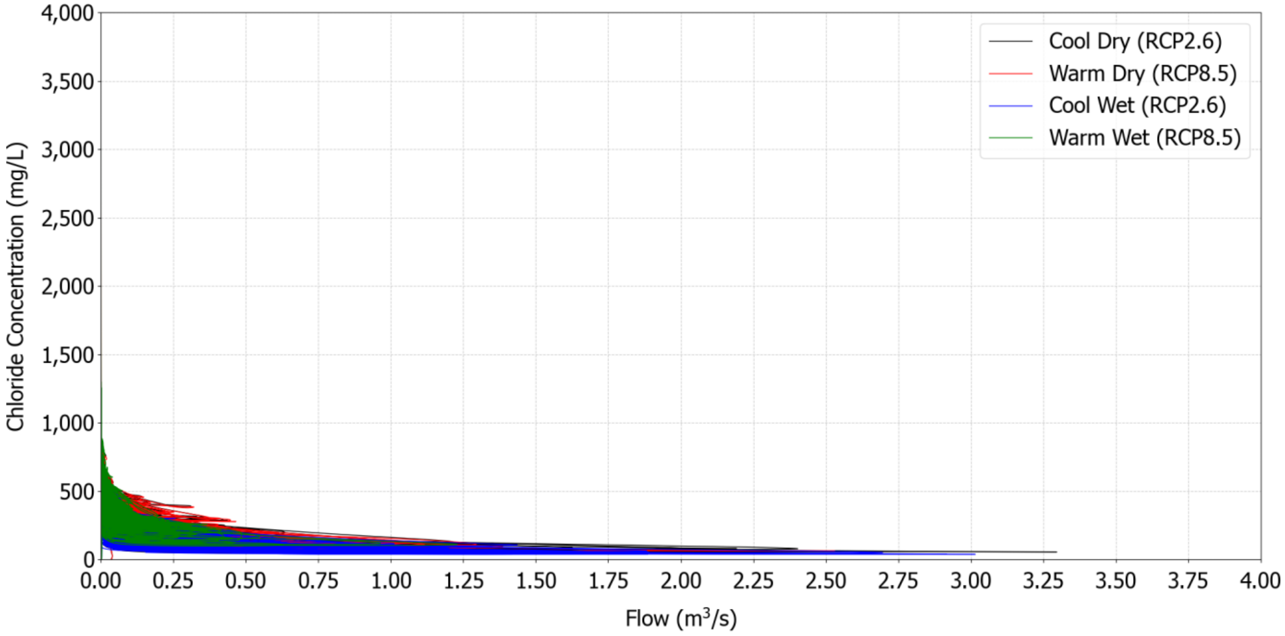


Figure 47 – Concentration vs. Flow Discharged from SWIP Valley (C_0 = 500 mg/L)

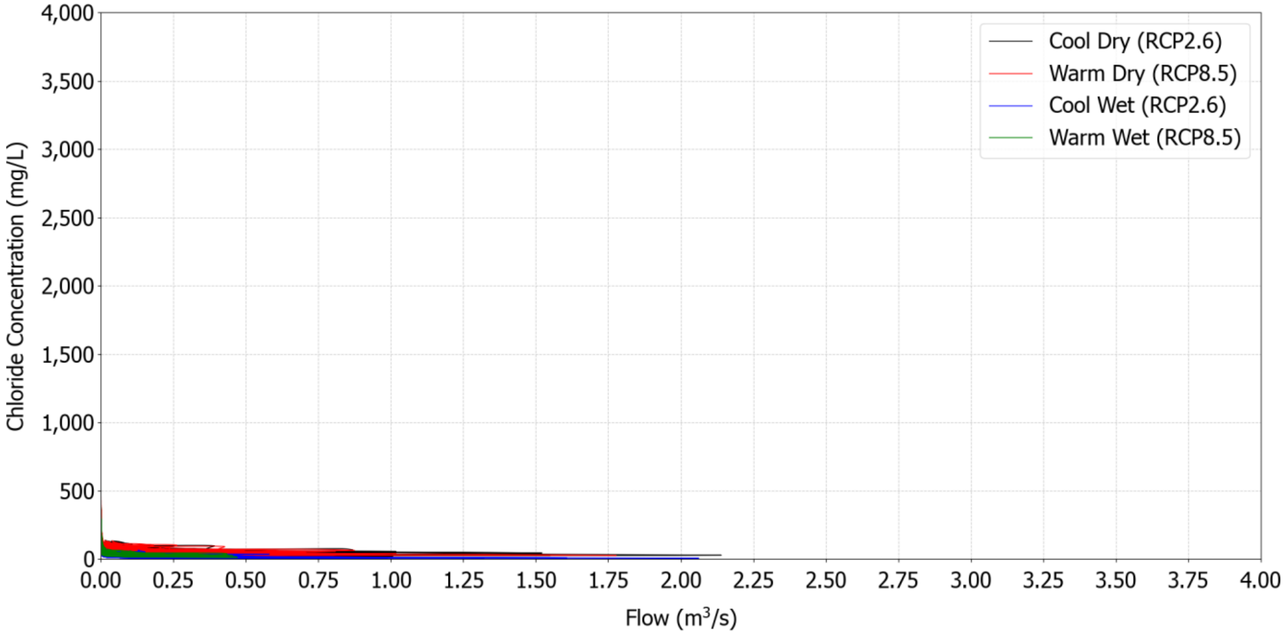


Figure 48 – Concentration vs. Flow Discharged from SWSS Valley (C_0 = 750 mg/L)

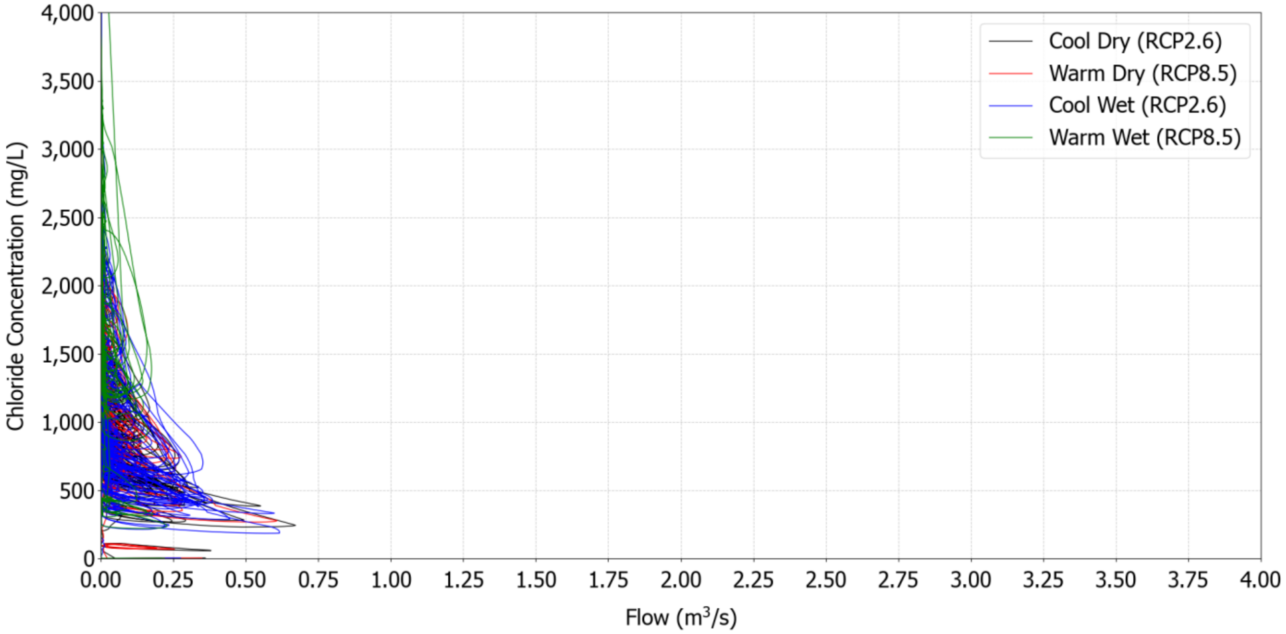


Figure 49 – Concentration vs. Flow Discharged from MLX-E Valley (C_0 = 1,250 mg/L)

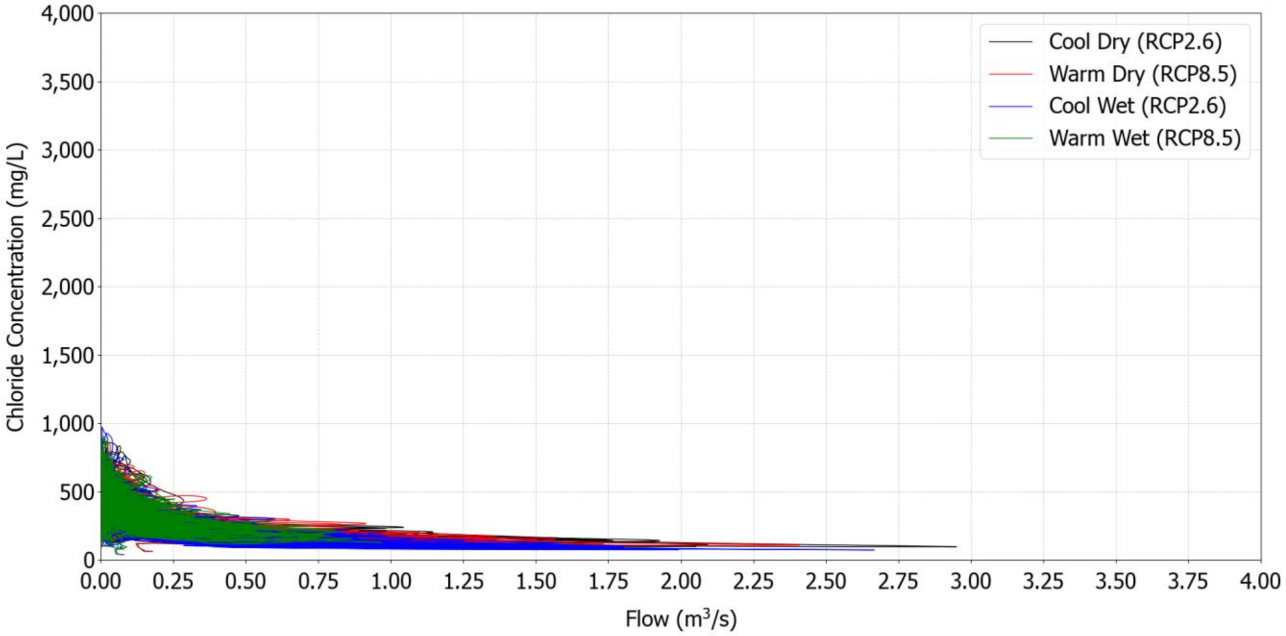


Figure 50 – Concentration vs. Flow Discharged from NMSP Valley (C_0 = 750 mg/L)

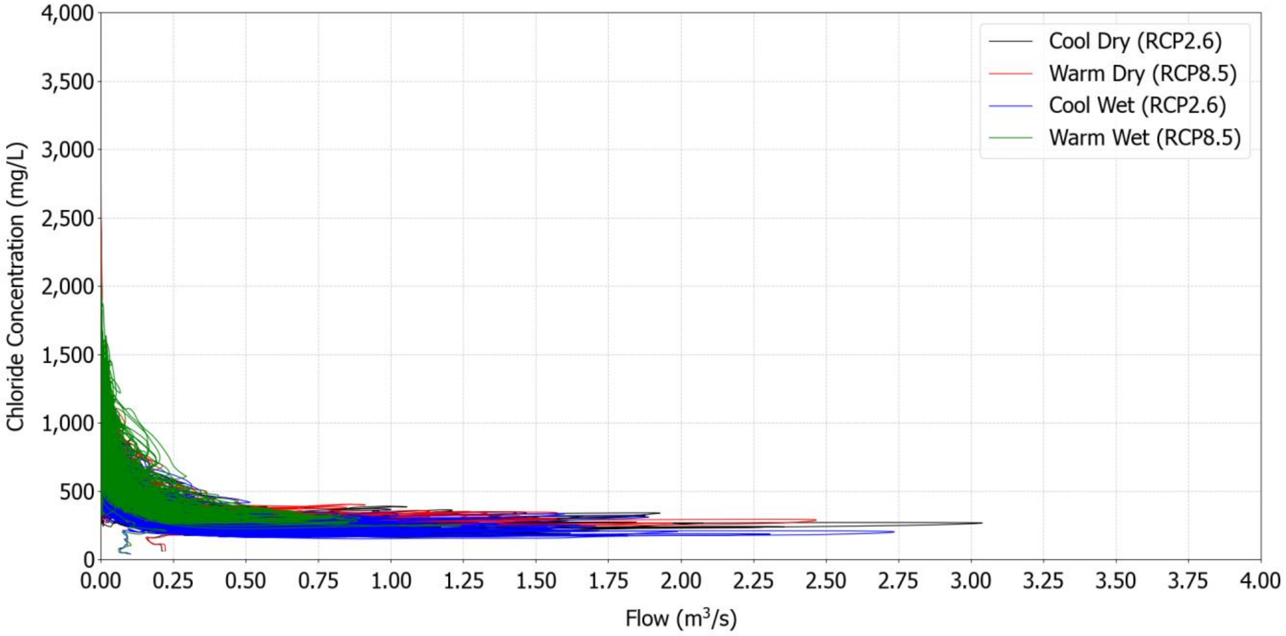


Figure 51 – Concentration vs. Flow Discharged from NMCP-E Valley (C_0 = 950 mg/L)

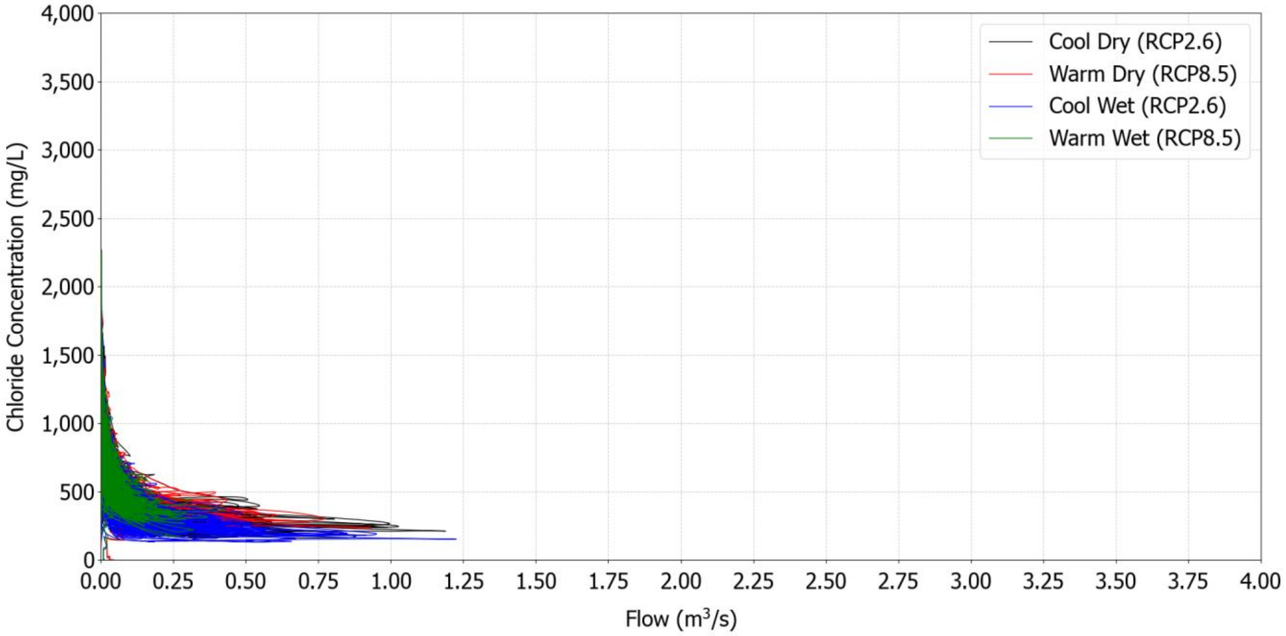


Figure 52 – Concentration vs. Flow Discharged from NMNP-E Valley (C_0 = 1,000 mg/L)

CHLORIDE MASS LOADING – MILDRED LAKE LANDFORMS

Mass loading is the product of runoff volume and chloride concentration and is useful to understand the relative magnitude of chloride contributions from various landforms, mixing in pit lakes, management of water during the transition to closure, and the potential effects of eventual release of runoff from the reclaimed site to downstream watercourses. Modelled annual chloride mass loading at each tailings landform outlet are shown in Figure 53 through Figure 60. Cumulative mass loads over the simulation are shown in Table 31. For context the initial chloride mass is provided in Table 30.

Table 30 – Initial Chloride Mass in Landforms – Mildred Lake

Landform	Material	Initial Chloride Mass (x10^6 kg)
EIP Valley	Tailings Sand	37
	CT	65
SWIP Valley	Tailings Sand	40
	CT	23
SWSS Valley	Tailings	144
MLSB Valley	Tailings	294
BM Lake	OSPW Cap	61 (400 mg/L)
	FT	26
MLX-E Valley	Coke	17
	Tailings Sand	95
NMSP-W Valley	Tailings Sand	178
NMSP-E Valley	Coke	10
	FT	10
NMCP-E Valley	Coke	84
	FT	74
NMNP Valley	Tailings	119
NM Lake	OSPW Cap	73 (1,250 mg/L)
	FT	65

Table 31 – Chloride Mass Loading from Landforms Simulation – Mildred Lake

Landform	Mass Load from FT Consolidation (x10^6 kg)	Chloride Mass Loading at Outlet from 2024 to 2100 (x10^6 kg)			
		Cool Dry (RCP2.6)	Warm Dry (RCP8.5)	Cool Wet (RCP2.6)	Warm Wet (RCP8.5)
EIP Valley	NA	4	2	3	1
SWIP Valley	NA	17	11	11	6
SWSS Valley*	NA	2	1	0.6	0.3
MLSB Valley*	NA	18	18	15	15
BM Lake	26	mass load is considered in initial conditions			

Landform	Mass Load from FT Consolidation (x10^6 kg)	Chloride Mass Loading at Outlet from 2024 to 2100 (x10^6 kg)			
		Cool Dry (RCP2.6)	Warm Dry (RCP8.5)	Cool Wet (RCP2.6)	Warm Wet (RCP8.5)
MLX-E Valley	NA	10	6	9	5
NMSP Valley*	3	58	36	43	23
NMCP-E Valley	17	38	26	34	20
NMNP Valley	NA	21	13	15	7
NM Lake	149	mass load is considered in initial conditions			

Notes:

Seepage from SWSS toe is collected into NMSP Valley.
Seepage from MLSB west toe is collected in NMCP-E Valley.
Seepage from MLSB east toe is collected in BM Lake outlet channel.

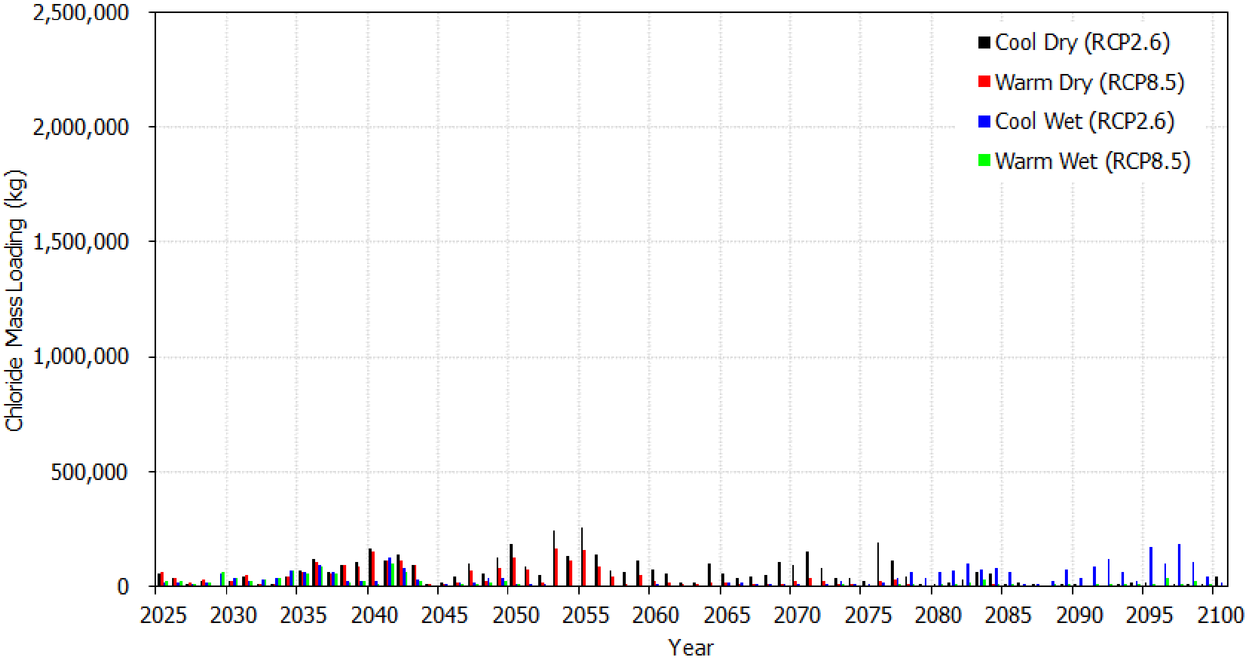


Figure 53 – Annual Chloride Mass Loading from EIP Valley

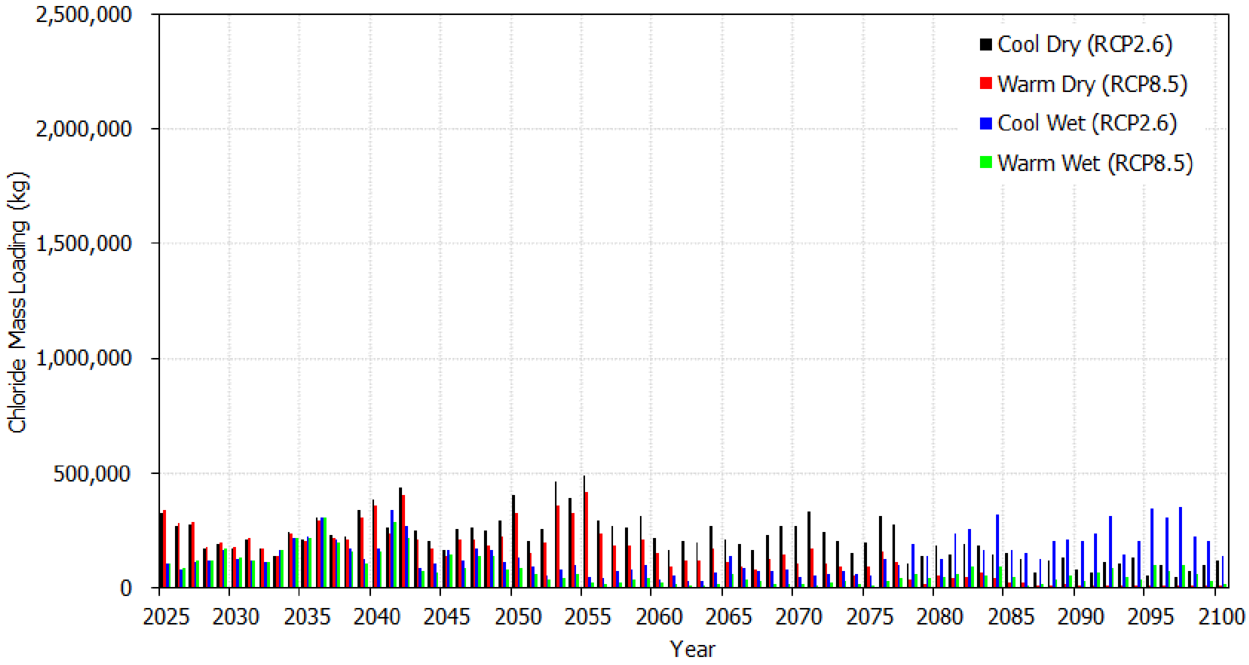


Figure 54 – Annual Chloride Mass Loading from SWIP Valley

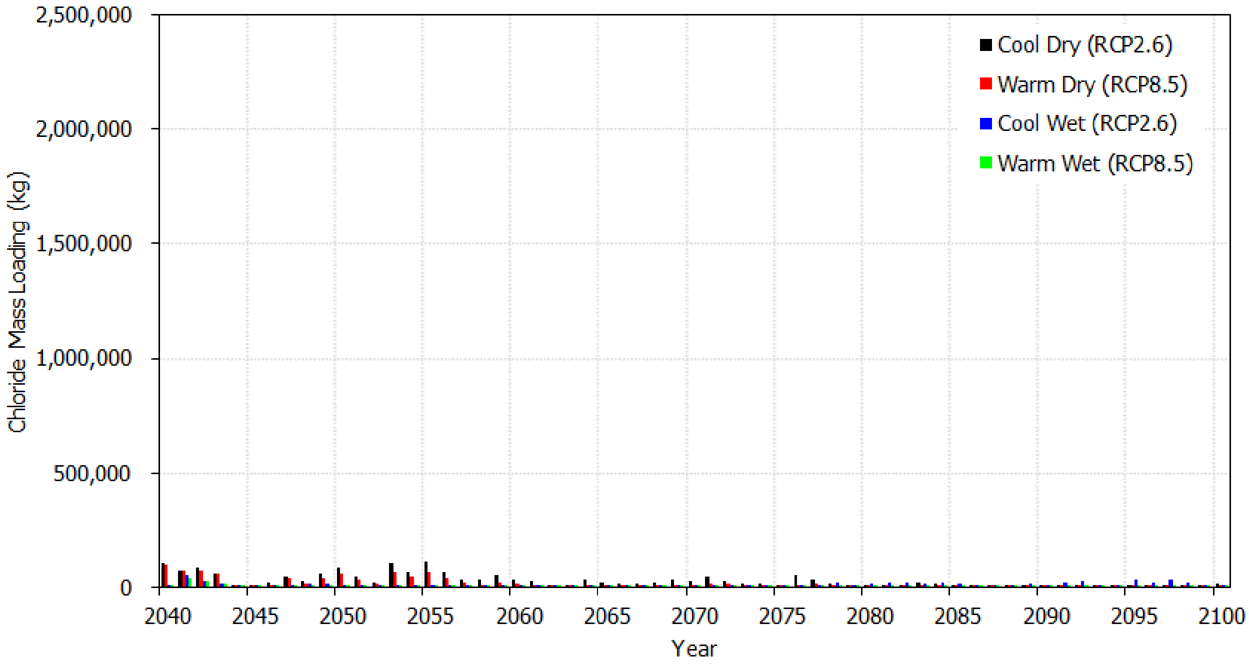


Figure 55 – Annual Chloride Mass Loading from SWSS Valley

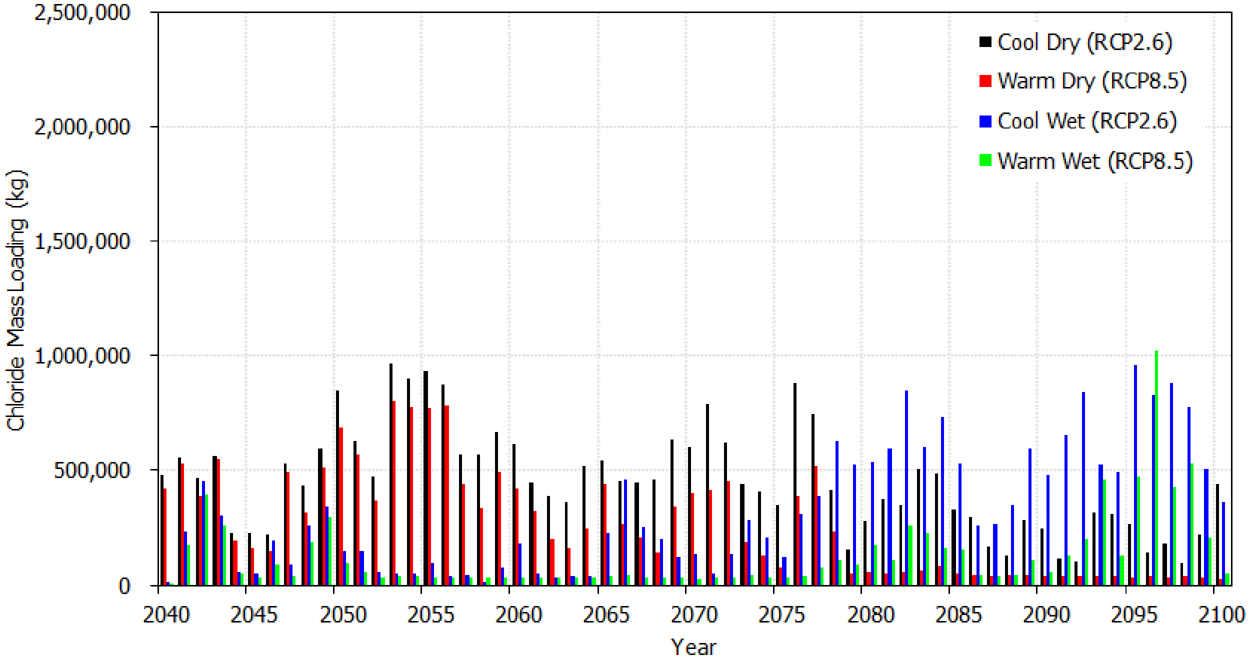


Figure 56 – Annual Chloride Mass Loading from MSLB Valley

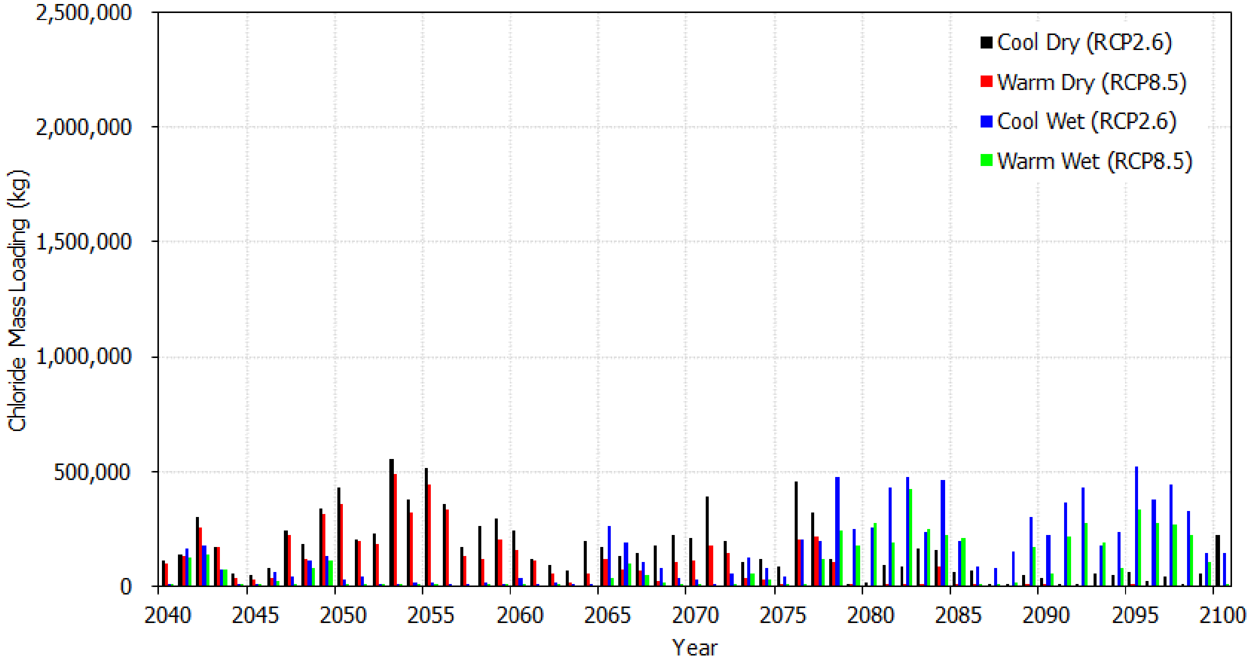


Figure 57 – Annual Chloride Mass Loading from MLX-E Valley

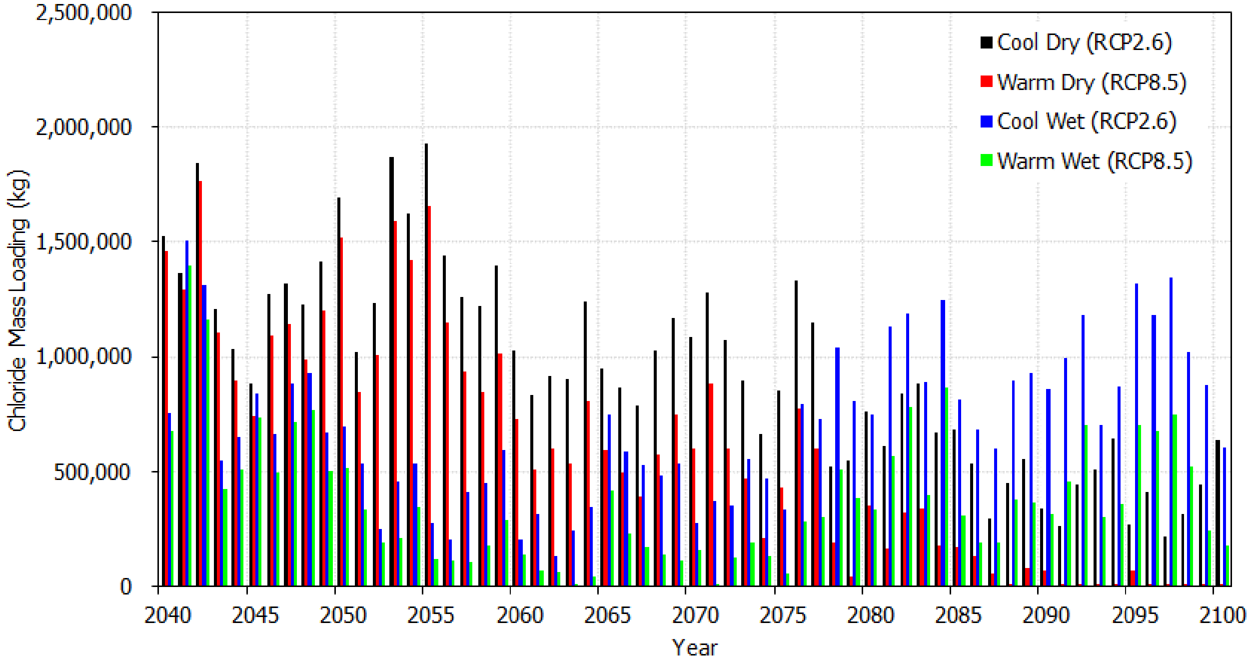


Figure 58 – Annual Chloride Mass Loading from NMSP Valley

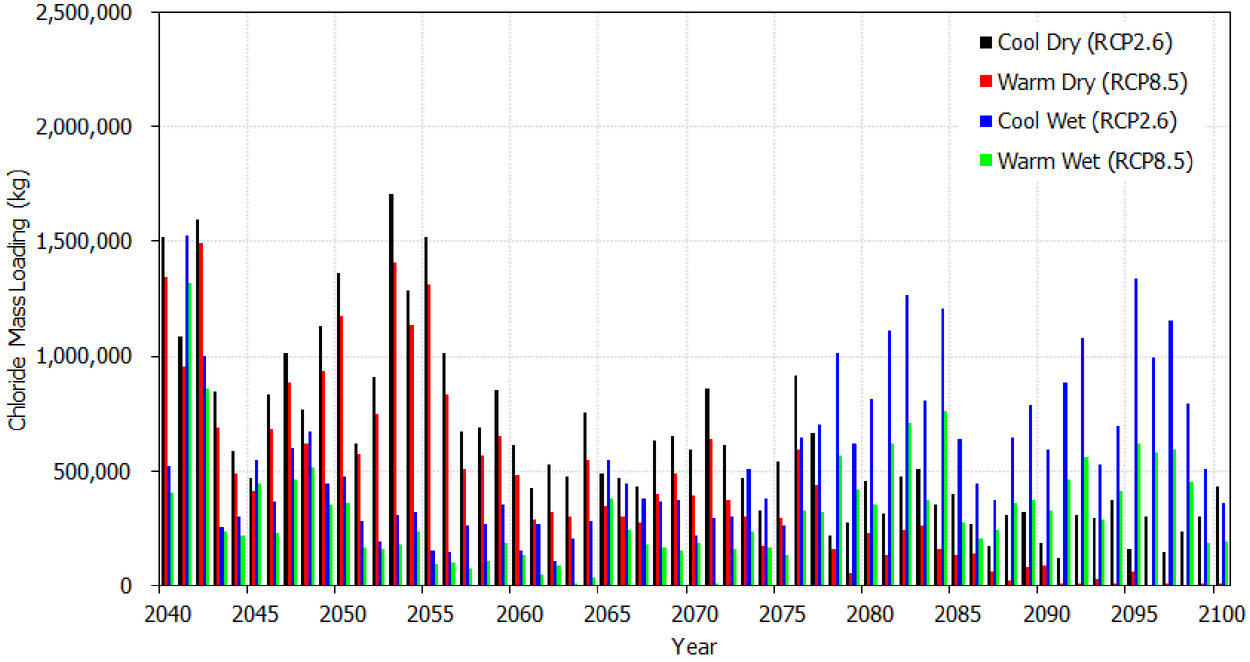


Figure 59 – Annual Chloride Mass Loading from NMCP-E Valley

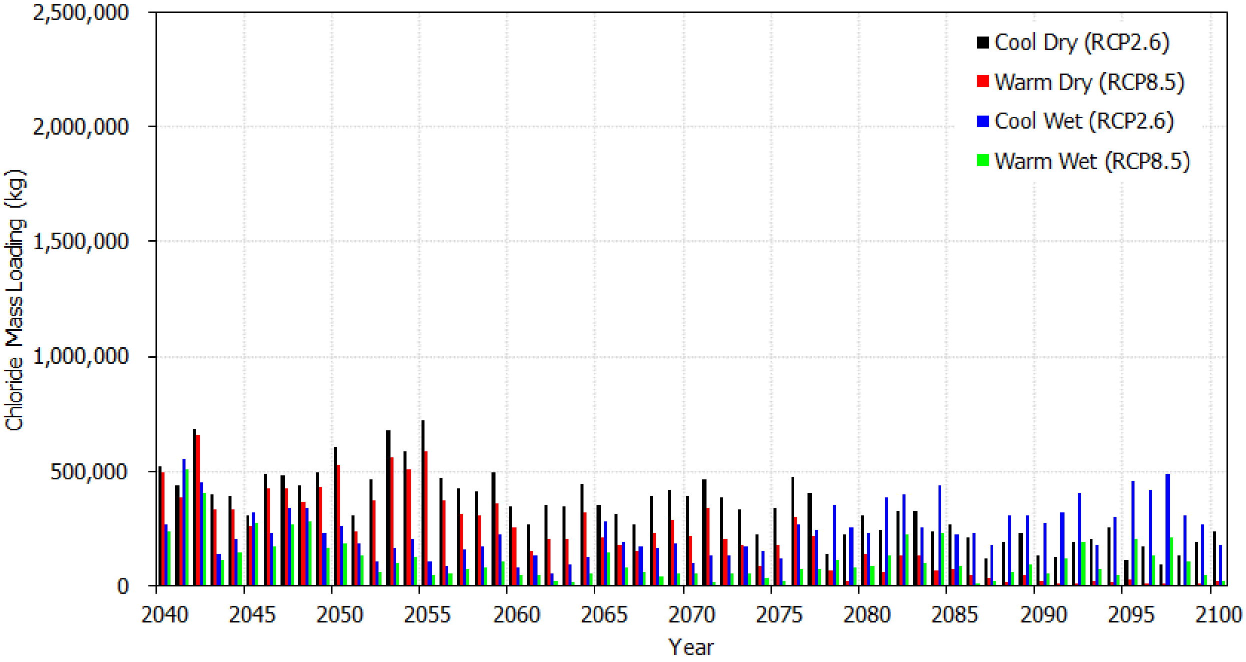


Figure 60 – Annual Chloride Mass Loading from NMNP Valley

CHLORIDE CONCENTRATION AND LOADING – BM LAKE

Tailings within BM Lake were placed in 2013 and partial consolidation of FT has occurred. The initial concentration of BM Lake is based on monitoring data (Syncrude 2021). Future consolidation release water from FT within BM Lake and mass loads from EIP and SWIP were included, as well as inflow from Beaver Creek. The chloride concentration plot (Figure 61) shows dilution over the initial 20 to 40 years followed by evapoconcentration in response to dry climate cycles. The chloride mass loading (Figure 62 and Table 32) shows a general downward trend in mass load released from BM Lake with increased load in response to wet climate cycles.

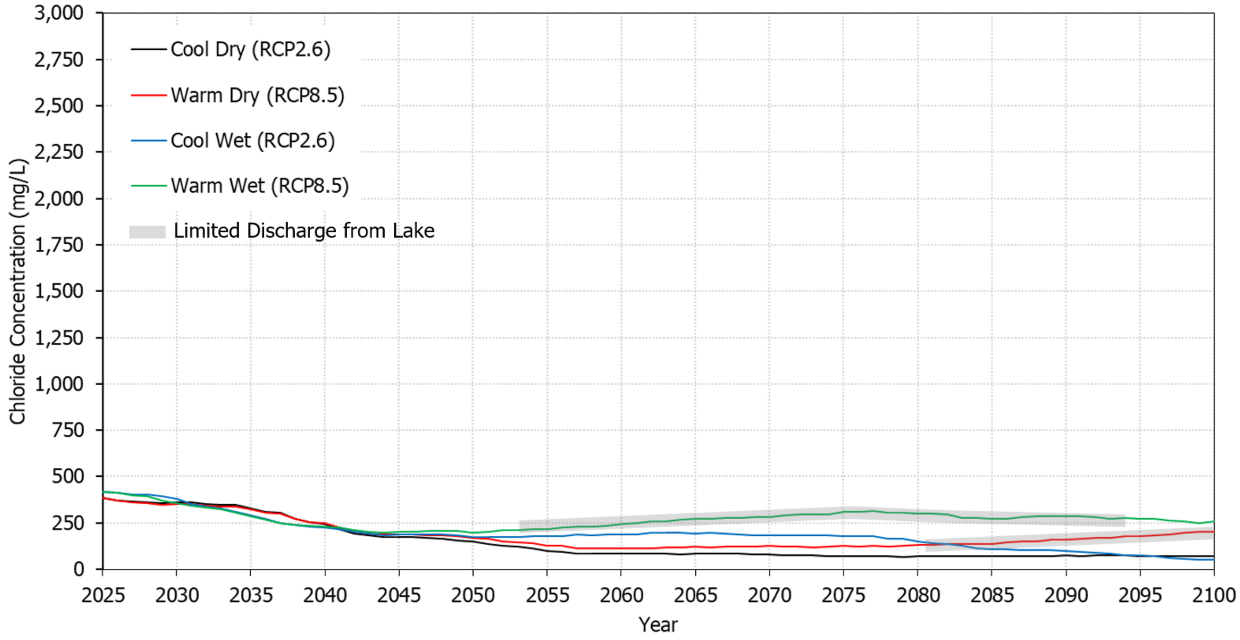


Figure 61 – Chloride Concentration in BM Lake

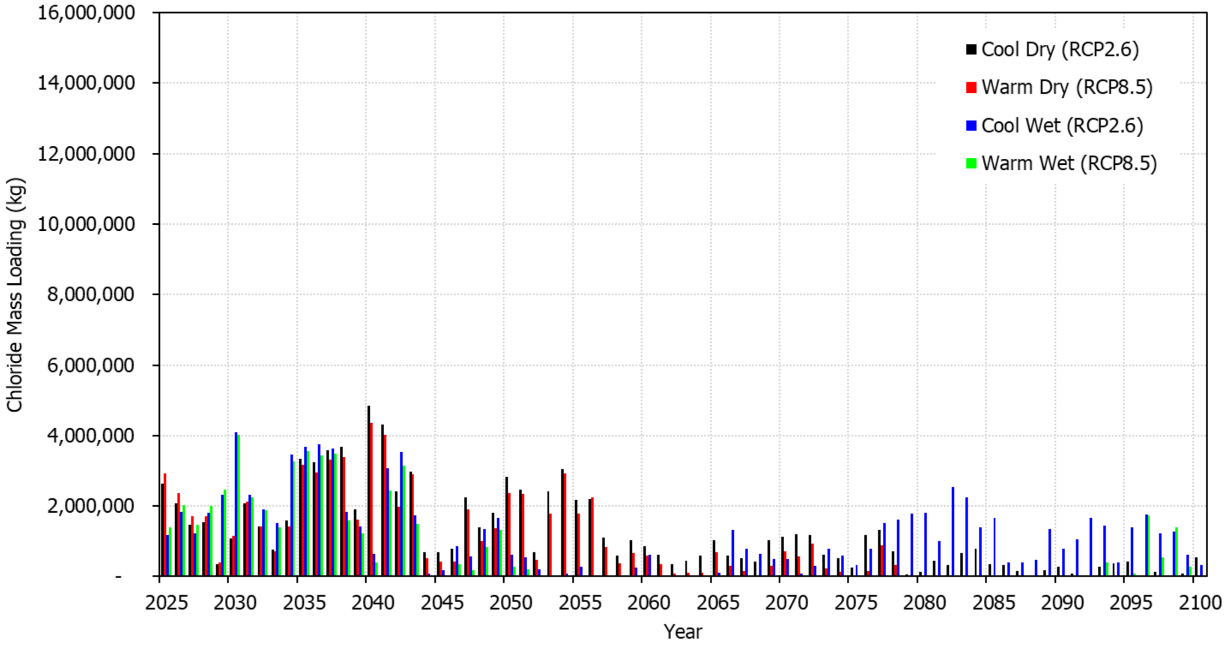


Figure 62 – Annual Chloride Mass Load from BM Lake

Table 32 – Chloride Mass Loading from BM Lake

Scenario	Chloride Loading ($\times 10^6$ kg)			
	Minimum Annual	Mean Annual	Maximum Annual	Total from 2025 to 2100
Cool Dry RCP2.6	0.01	1.2	4.8	95
Warm Dry RCP8.5	-	0.9	4.4	75
Cool Wet RCP2.6	-	1.2	4.1	89
Warm Wet RCP8.5	-	0.7	4.0	51

CHLORIDE CONCENTRATION – NM LAKE

The chloride concentration plot (Figure 63) shows dilution and evapoconcentration of chloride concentrations in response to wet and dry climate cycles. The chloride mass loading from NM Lake (Figure 64 and Table 33) is closely tied to wet climate cycles when discharge occurs from the lake.

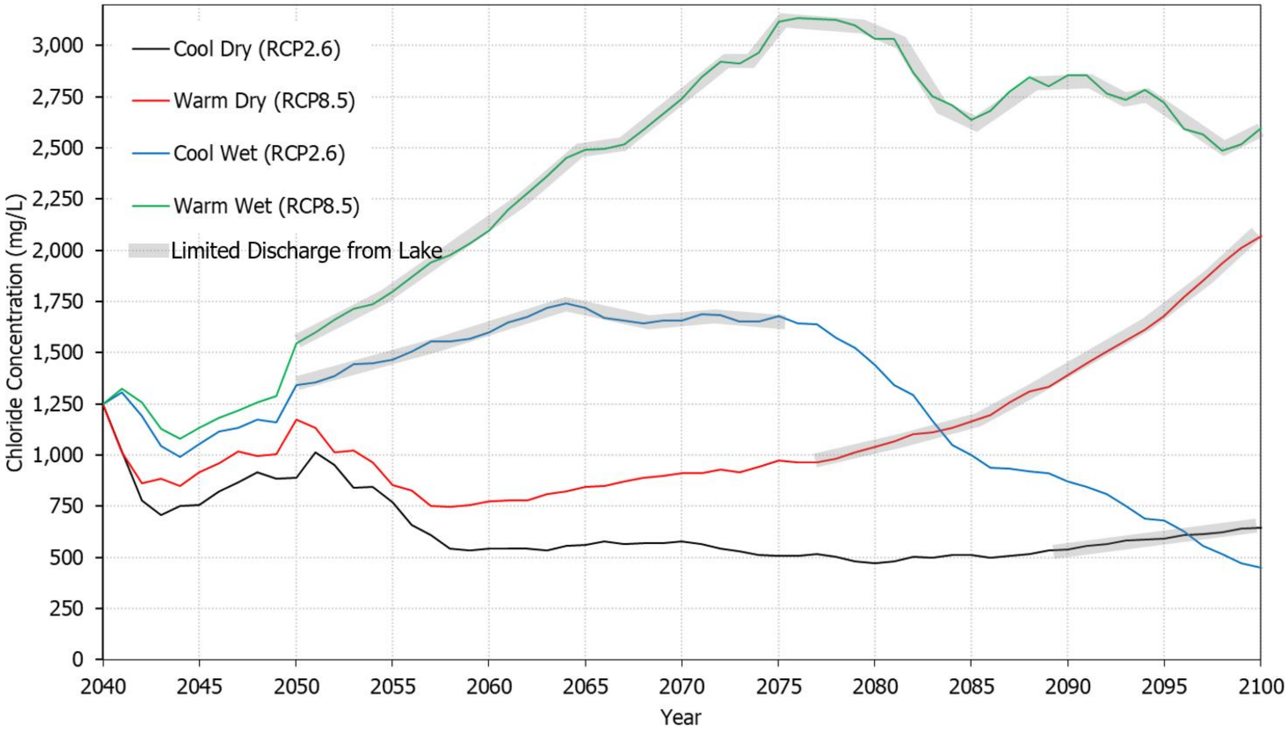


Figure 63 – Chloride Concentration in NM Lake

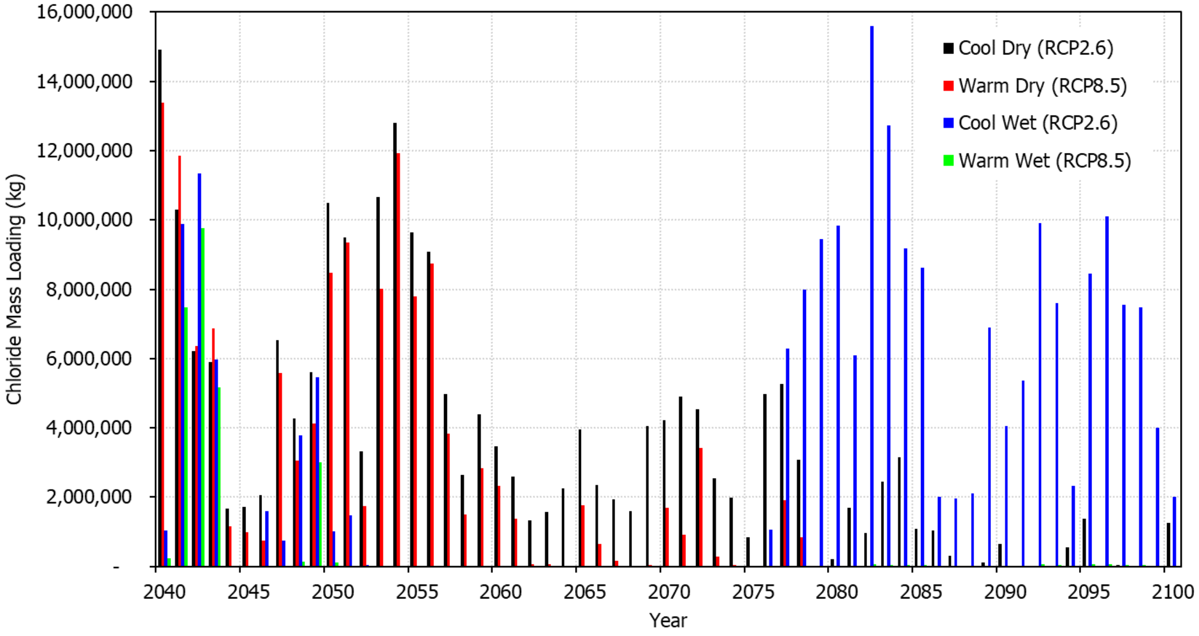


Figure 64 – Annual Chloride Mass Load from NM Lake

Table 33 – Chloride Mass Loading from NM Lake

Scenario	Chloride Loading (x10^6 kg)			
	Minimum Annual	Mean Annual	Maximum Annual	Total from 2040 to 2100
Cool Dry RCP2.6	-	3.4	14.9	209
Warm Dry RCP8.5	-	2.2	13.4	134
Cool Wet RCP2.6	-	3.5	15.6	211
Warm Wet RCP8.5	-	2.7	9.8	0.06

5.3.2 MLX-W WATER QUALITY RESULTS

Water quality was tracked at the outlet of XW Valley and XS Valley for the four climate change scenarios. The landforms contribute chloride mass to WM Lake. The model results are used to track the movement of solutes from landform into WM Lake overtime and assess mixing within the lake. This information can inform management plans to commission the lakes and ultimately release the runoff into the McKay River.

CHLORIDE CONCENTRATION – MLX-W

Figure 65 and Figure 66 show the outflow rate vs. chloride concentration relationships at the outlets of XW Valley and XS Valley. Outflow rate vs. concentration plots help understand the dynamics of the potential mass loading under various climatic cycles. The plots show that for the valleys, higher flows are associated with lower concentrations due to dilution of porewater with fresh surface water. The concentration and flow dynamics demonstrate an inherent mechanism within the landforms that limits discharge of solute mass from the site during low flow periods.

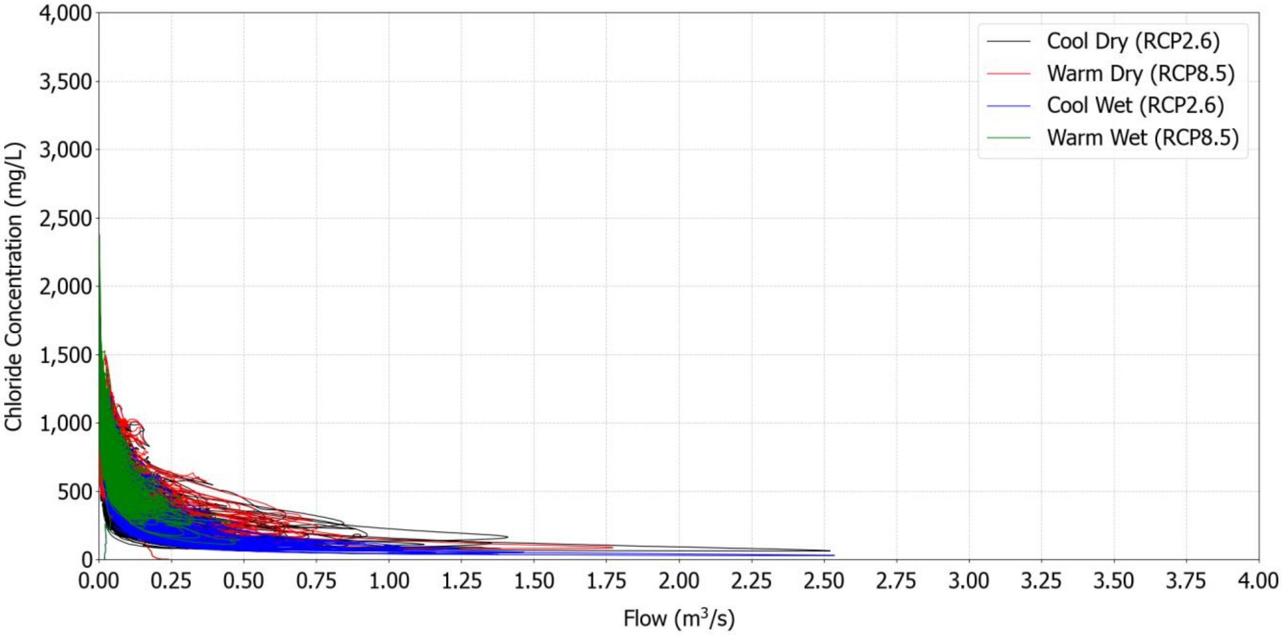


Figure 65 – Concentration vs. Flow Discharged from XW Valley (C_0 = 1,250 mg/L)

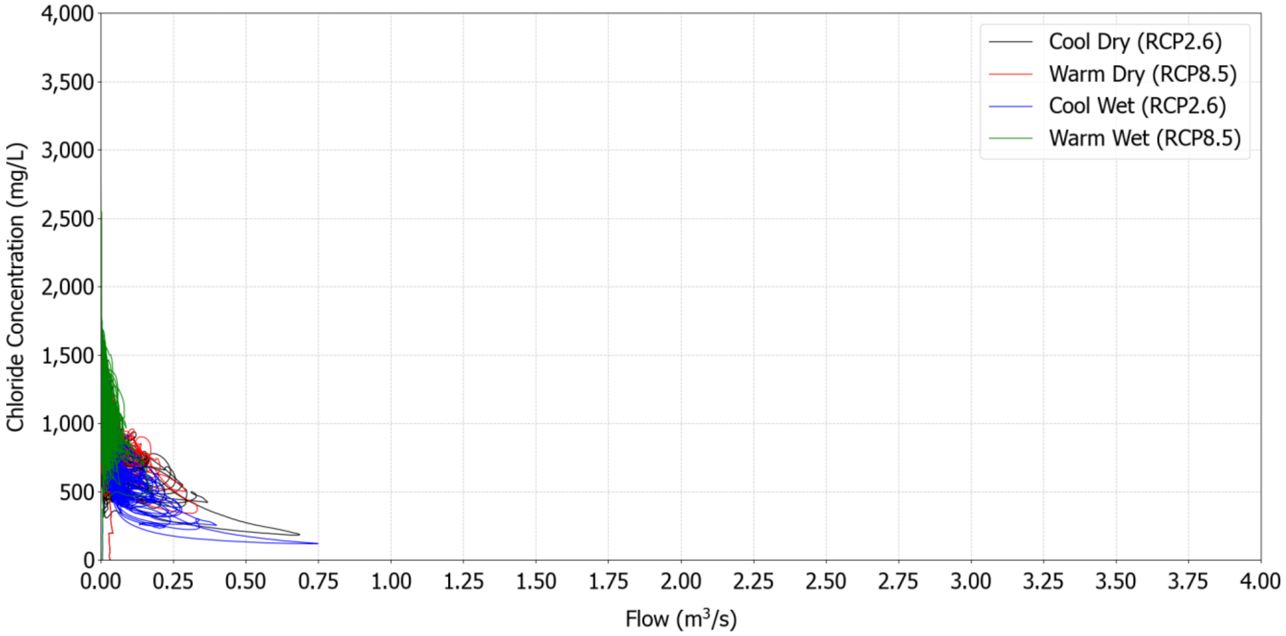


Figure 66 – Concentration vs. Flow Discharged from XS Valley (C_0 = 1,250 mg/L)

CHLORIDE MASS LOADING – MLX-W LANDFORMS

Mass loading is the product of runoff volume and chloride concentration and is useful to understand the relative magnitude of chloride contributions from various landforms, mixing in pit lakes, management of water during the transition to closure, and the potential effects of eventual release of runoff from the reclaimed site to downstream watercourses. Modelled annual chloride mass loading at each tailings landform outlet are shown in Figure 67 and Figure 68. Cumulative mass loads over the simulation are shown in Table 35. For context the initial chloride mass is provided in Table 34.

Table 34 – Initial Chloride Mass in Landforms

Landform	Material	Initial Chloride Mass at Year 2040 (x10^6 kg)
XW Valley	Coke Cap	50
	FT	88
XS Valley	Coke Cap	36
	FT	56
WM Lake	OSPW	158 (full at 100% OSPW)
	FT	34

Table 35 – Chloride Mass Loading from Landforms between 2040 and 2100

Landform	Mass Load from FT Consolidation (x10^6 kg)	Modelled (HGS) Chloride Mass Loading at Outlet from 2040 to 2100 (x10^6 kg)			
		Cool Dry (RCP2.6)	Warm Dry (RCP8.5)	Cool Wet (RCP2.6)	Warm Wet (RCP8.5)
XW Valley	19	55	48	49	40
XS Valley	15	31	24	24	20
WM Lake	9	mass load is considered in initial conditions			

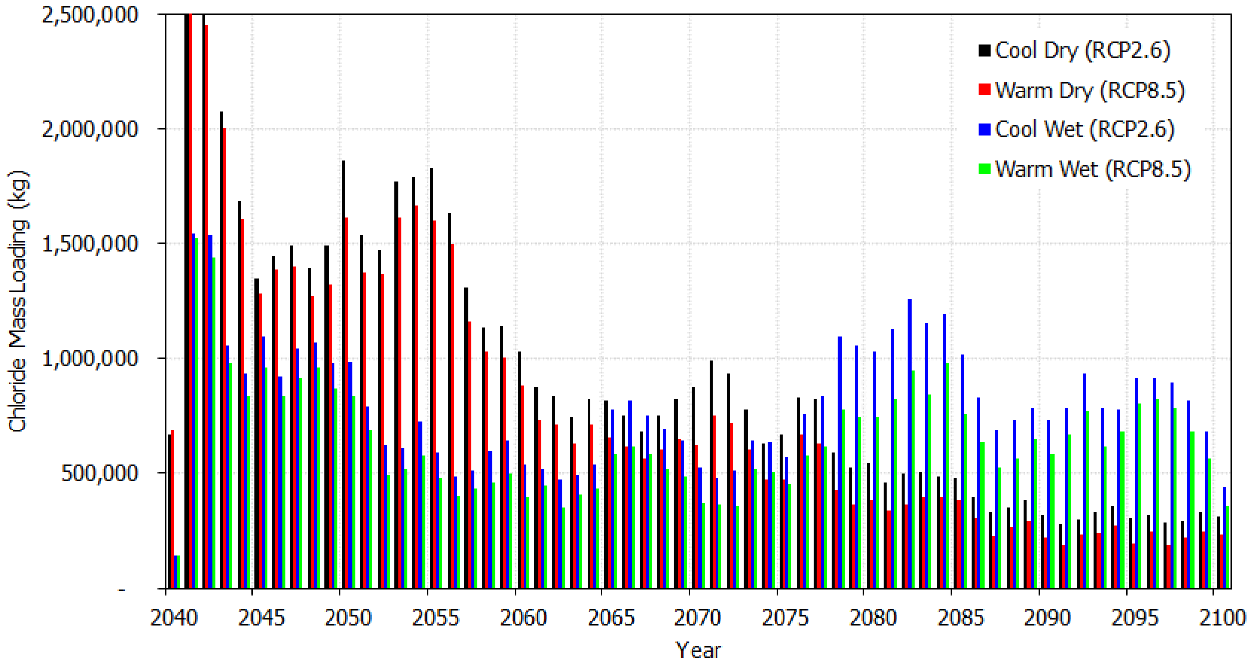


Figure 67 – Annual Chloride Mass Loading from XW Valley

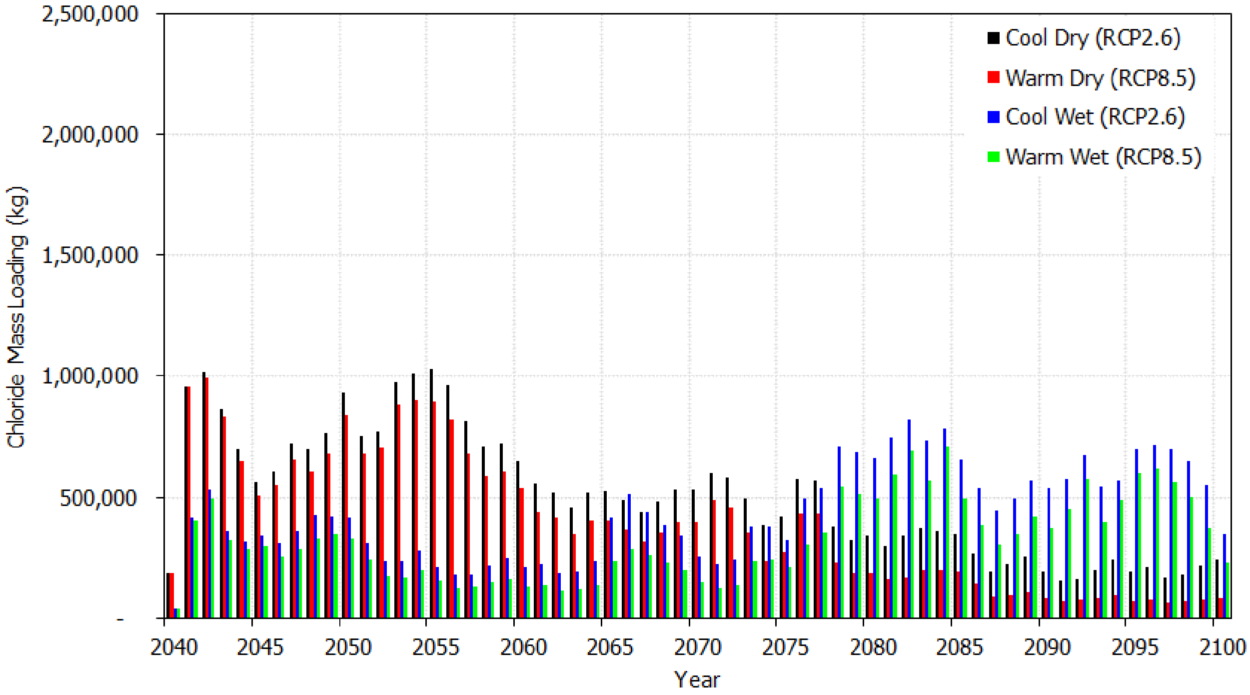


Figure 68 – Annual Chloride Mass Loading from XS Valley

The model results suggest the majority of the chloride mass that mobilizes from the landform is from the transmissive coke cap, while the FT layer which has a low hydraulic conductivity is not a significant source of chloride. To understand the extent of porewater displacement within the landforms during the simulation periods, the initial mass in the coke capping of the XW and XS valleys (Table 34) can be compared to the mass loads mobilized during the simulation period (Table 35). The OSPW within the pore space of the coke cap in the XW Valley is almost entirely displaced. The coke cap in the XS Valley is about half to three-quarters displaced, depending on the climate conditions. The FT are likely to contribute relatively a minor amount of OSPW in the future. Extended simulations could help inform the magnitude of this contribution.

CHLORIDE CONCENTRATION – WM LAKE

The above mass loading and water balance results were used to develop chloride balances for WM Lake to estimate annual lake concentrations (Figure 69). During dry cycles, especially when the lake level drops below the sill, chloride mass accumulates within the lake resulting in increased concentrations. The plots suggest that elevated chloride concentrations will persist beyond year 2100 and are highly dependant on climate. Given the movement of mass from the landforms, as illustrated in Table 34 and Table 35, it is likely that chloride concentrations in the lake will gradually decline beyond year 2100 during positive water balance periods. The chloride mass loading from WM Lake (Figure 70 Table 36) is closely tied to wet climate cycles when discharge occurs from the lake.

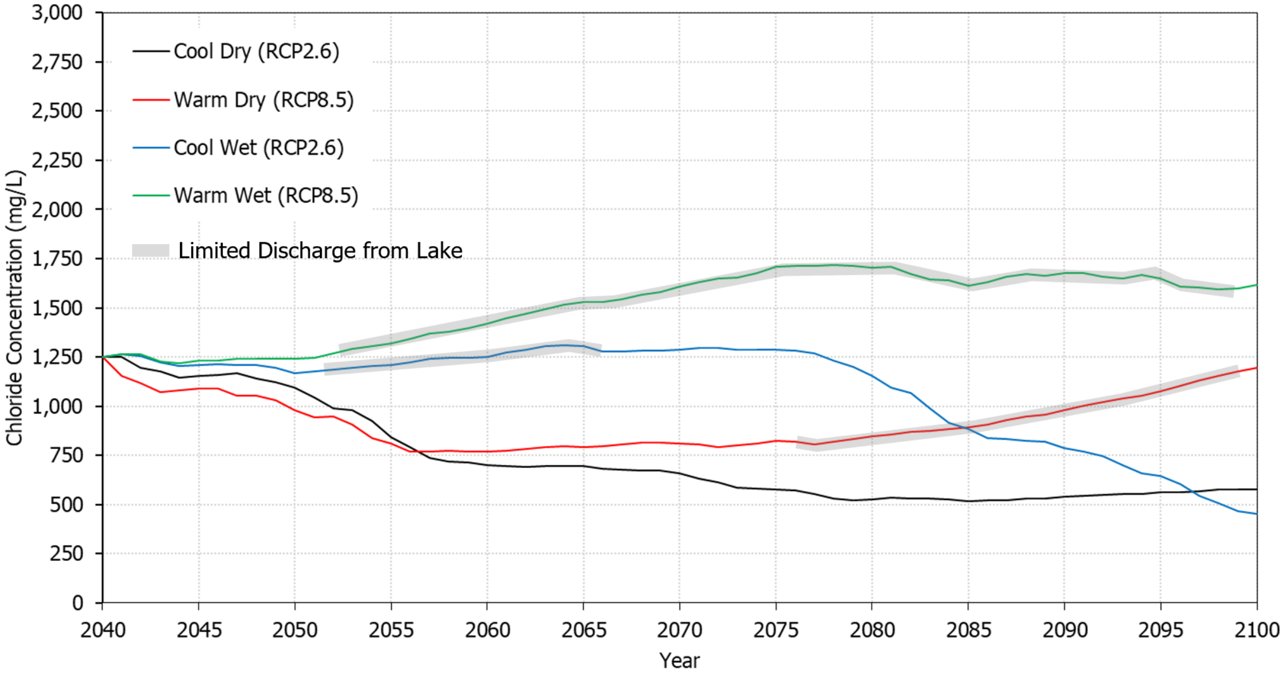


Figure 69 – Annual Chloride Concentration in WM Lake

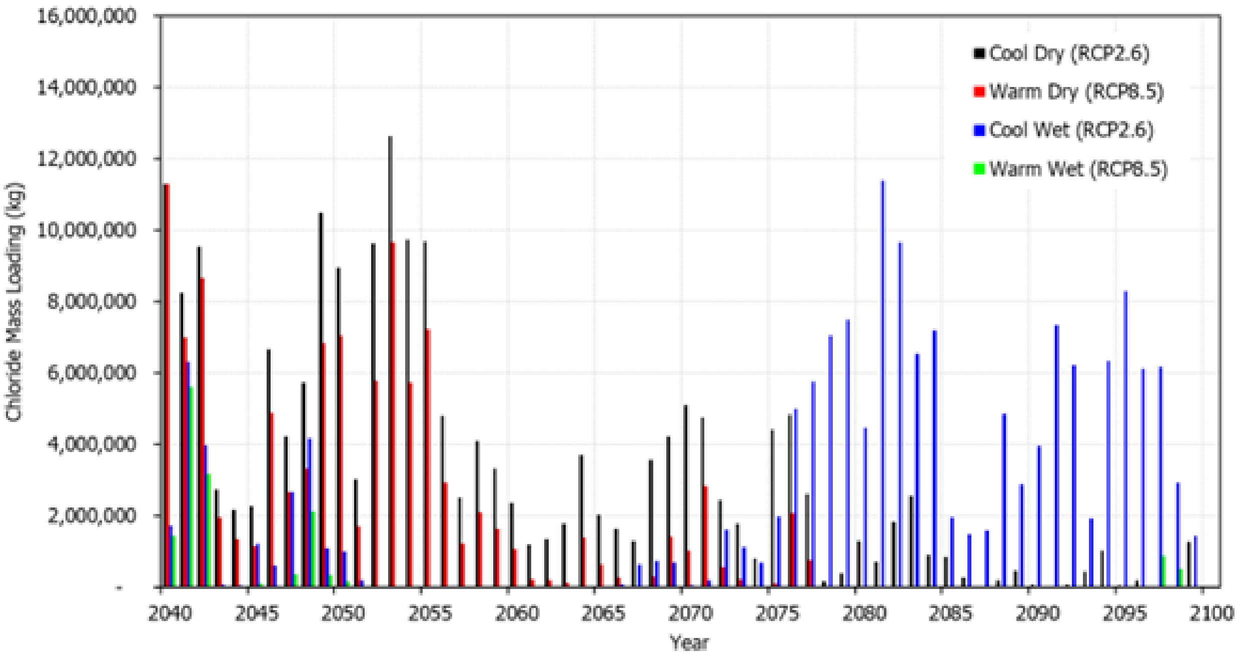


Figure 70 – Annual Chloride Mass Loading from WM Lake

Table 36 – Chloride Mass Loading from WM Lake

Scenario	**Chloride Loading (x10⁶ kg)**			
	Minimum Annual	**Mean Annual**	**Maximum Annual**	**Total from 2040 to 2100**
Cool Dry RCP2.6	-	3.2	12.6	194.6
Warm Dry RCP8.5	-	1.8	11.3	107.5
Cool Wet RCP2.6	-	2.7	11.4	159.0
Warm Wet RCP8.5	-	0.2	5.6	14.9

5.3.3 AURORA NORTH WATER QUALITY RESULTS

Water quality was tracked at the outlet of each tailings landform for the four climate change scenarios. The landforms contribute chloride mass to AN-W Lake. The model results are used to track the movement of solutes from landform into AN-W Lake overtime and assess mixing within the lake. This information can inform management plans to reclaim the site and commission the pit lakes with the objective of ultimately releasing runoff into the surrounding watercourses. Note that water quality is not reported for the landforms within AN-E Lake as Syncrude tailings are not present. Water quality and loading from AN-E Lake are included due to the planned initial placement of OSPW placed in AN-E Lake.

CHLORIDE CONCENTRATION – AURORA NORTH

Figure 71 through Figure 75 show the outflow rate vs. chloride concentration relationships at the outlets of tailings landforms. The initial porewater chloride concentration is shown in the title of each figure. Chloride concentrations above initial levels are a result of evapoconcentration, whereas those below initial conditions suggest dilution due to precipitation and or runoff from upstream watersheds. The model results suggest that the chloride concentrations in the outflow dilute during wet conditions and concentrate during dry conditions. Outflow rate vs. concentration plots help understand the dynamics of the potential mass loading under various climatic cycles. The plots show that for the valleys, higher flows are associated with lower concentrations due to dilution of porewater with fresh surface water. The concentration and flow dynamics demonstrate an inherent mechanism within the landforms that limits discharge of solute mass from the site during low flow periods.

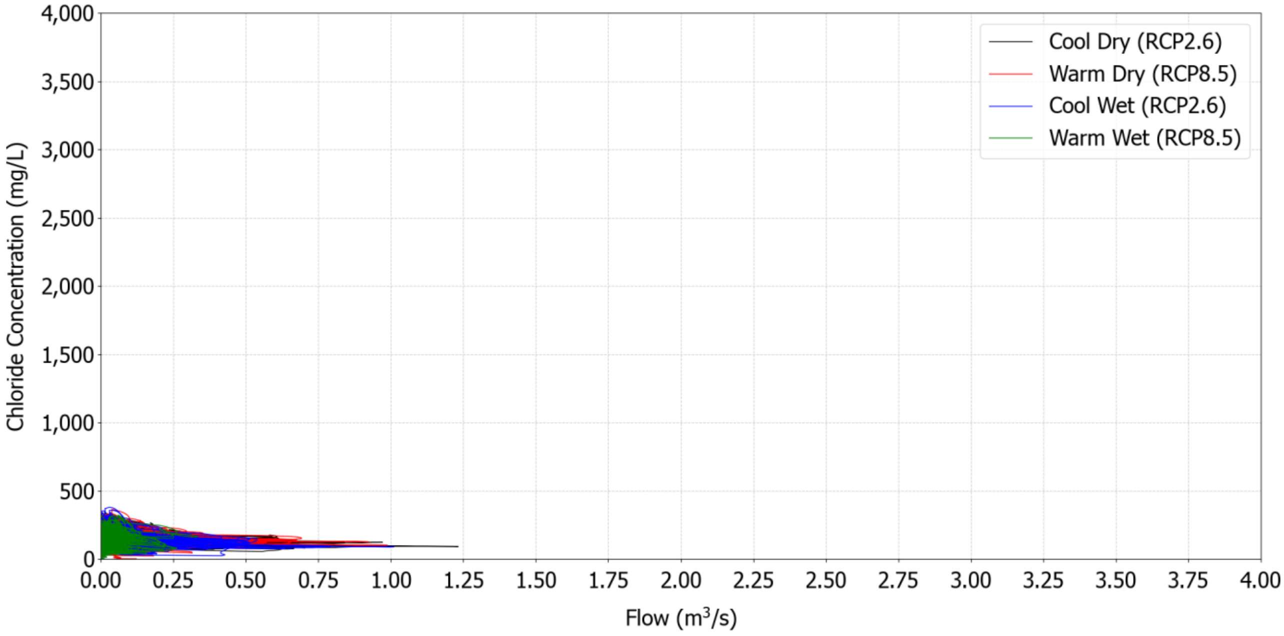


Figure 71 – Chloride Concentration vs. Flow Discharged from AEP Valley (C_0 = 466 mg/L)

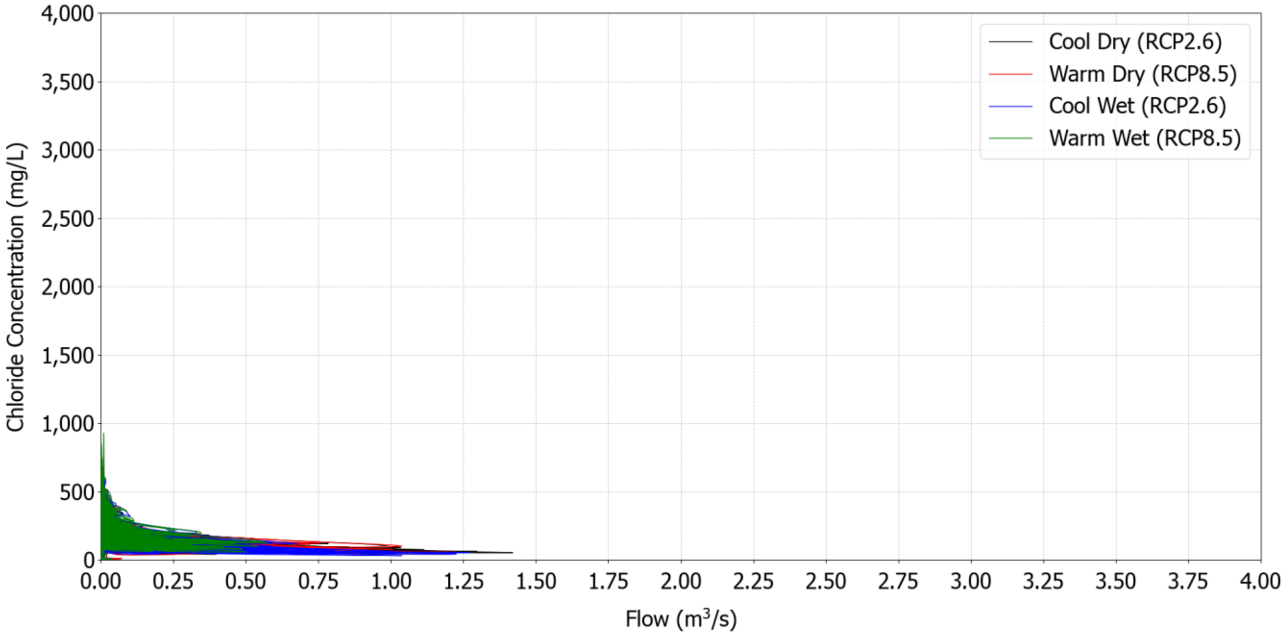


Figure 72 – Chloride Concentration vs. Flow Discharged from ACPN Valley (C_0 = 665 mg/L)

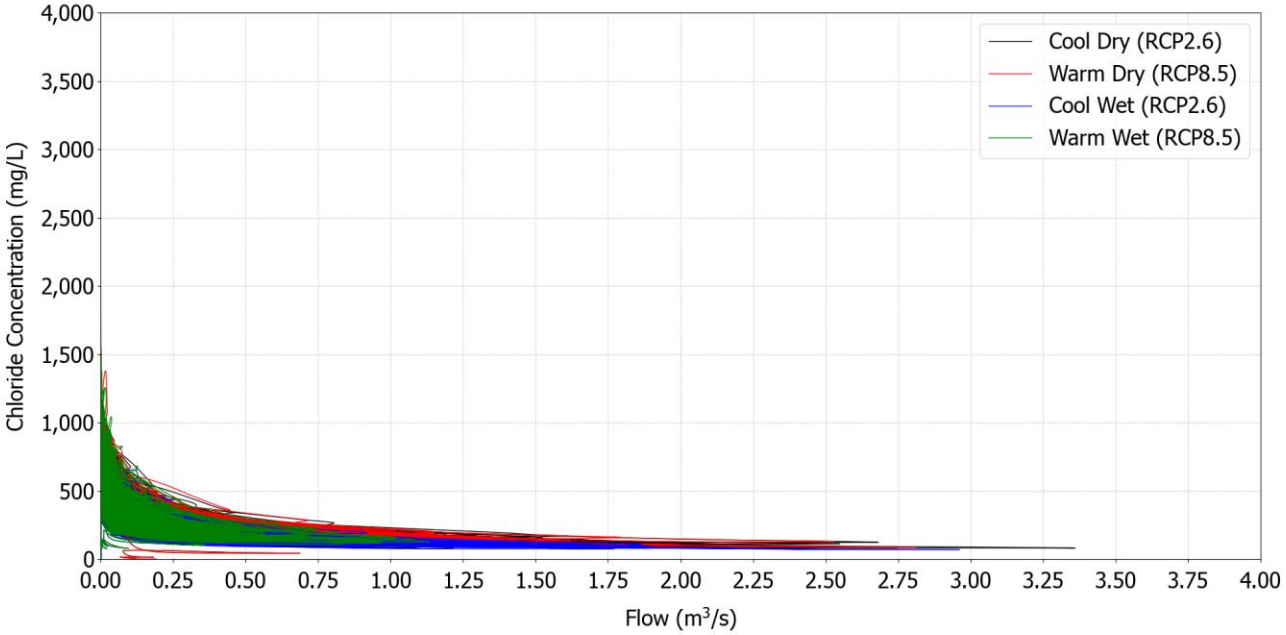


Figure 73 – Chloride Concentration vs. Flow Discharged from ACPS Valley (C_0 = 871 mg/L)

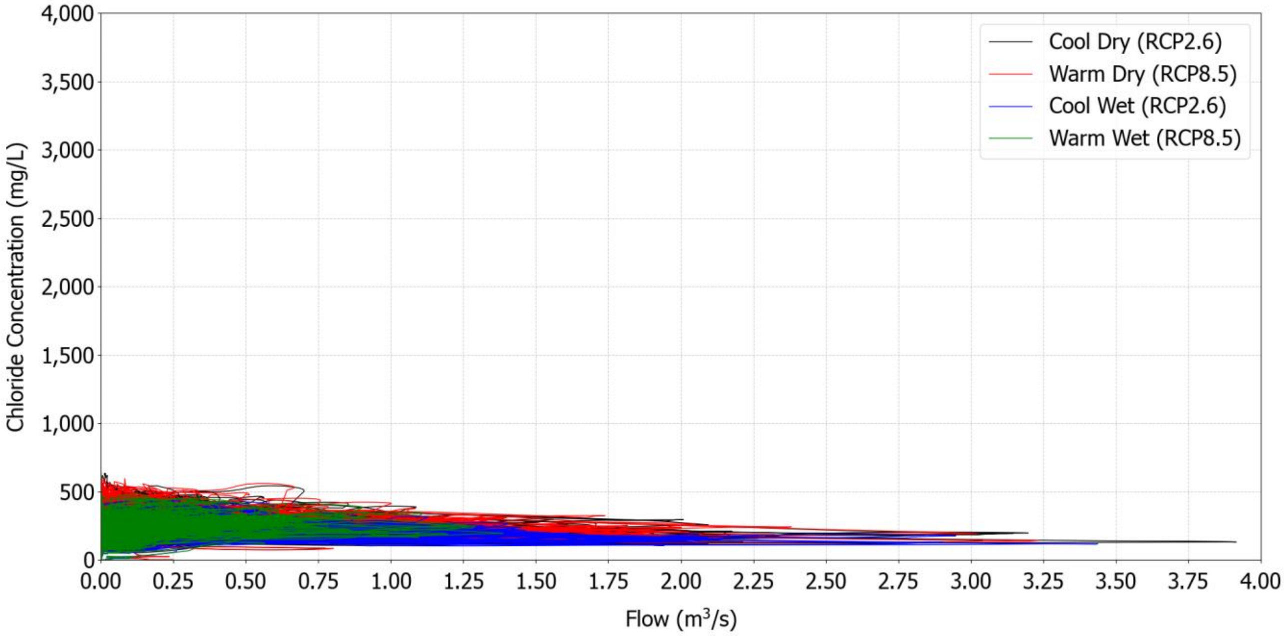


Figure 74 – Chloride Concentration vs. Flow Discharged from AWPS Valley (C_0 = 984 mg/L)

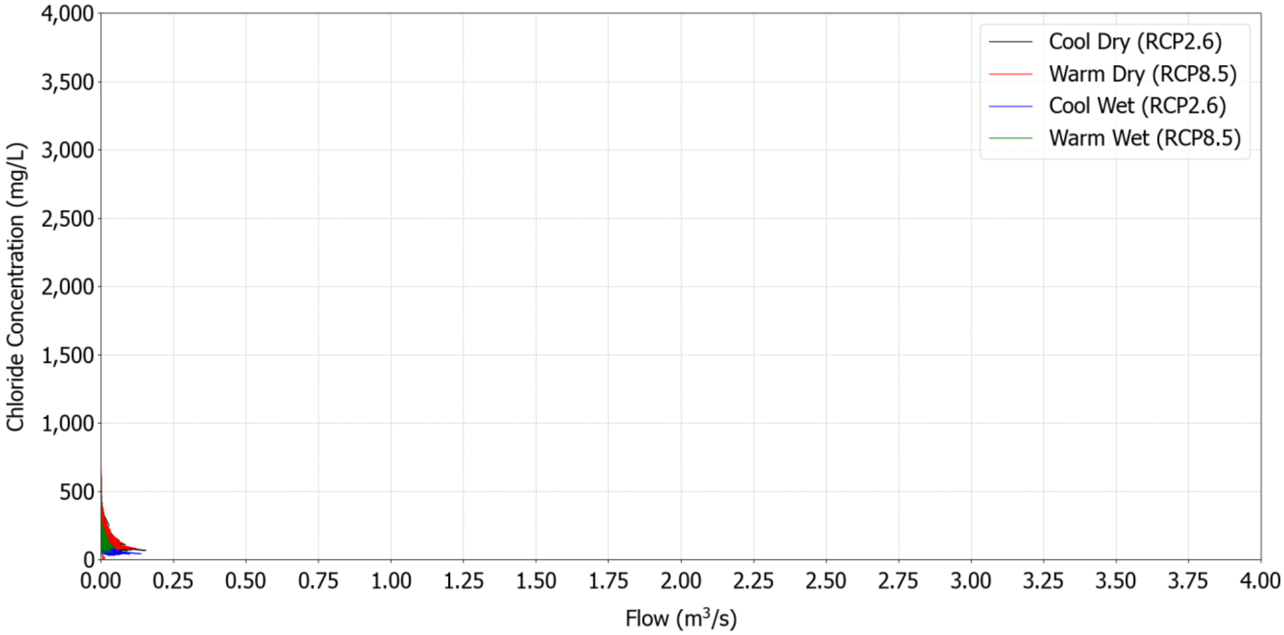


Figure 75 – Chloride Concentration vs. Flow Discharged from SE Corner Valley (C_0 = 466 mg/L)

CHLORIDE MASS LOADING – AURORA NORTH

Mass loading is the product of runoff volume and chloride concentration and is useful to understand the relative magnitude of chloride contributions from various landforms, management of water during the transition to closure, and the potential effects of eventual release of runoff from the reclaimed site to downstream watercourses. The initial chloride mass assumed in the HGS model by landform is provided in Table 37. Cumulative mass loads released from each landform over the HGS simulation are shown in Table 38. The mass loads from FT consolidation are also included in the table but were not included in the HGS model. Comparison of the initial mass and the mass mobilized suggests that the majority of the OSPW will remain within the pore space of the landforms over the simulation periods.

Table 37 – Initial Chloride Mass in Landforms Assumed in HGS Model- AN

Landform	Material	Initial Chloride Mass at Year 2035 (x10^6 kg)
ASB Valley	Tailings	110
AEP Valley	Tailings Sand	56
	CT	110
ACPN Valley	Tailings Sand	26
	CT	69
ACPS Valley	Tailings Sand	50
	CT	64
AWPS Valley	Tailings Sand	57
	CT	54
AWPW Valley	Tailings Sand	44
	CT	47
AN-W Lake	OSPW Cap	94 (Full Lake at 100% OSPW)
	FT	45
AN-E Lake	OSPW	177 (Full Lake at 100% OSPW)

Table 38 – Cumulative Chloride Mass Loading from Landforms between 2035 and 2100 - AN

Landform	Mass Load from FT Consolidation (x10⁶ kg)	Modelled (HGS) Chloride Mass Loading at Outlet from 2035 to 2100 (x10⁶ kg)			
		Cool Dry (RCP2.6)	Warm Dry (RCP8.5)	Cool Wet (RCP2.6)	Warm Wet (RCP8.5)
AEP Valley	NA	13	9	6	2
ACPN Valley	NA	7	5	5	3
ACPS Valley	NA	21	15	13	7
AWPS Valley	NA	19	15	8	3
AWPW Valley	NA	14	9	8	5
SE Corner	NA	1	0.8	0.3	0.1
AN-W Lake	71	mass load from consolidation is considered in initial conditions			
AN-E Lake	NA				

Modelled annual chloride mass loading of each tailings landform outlet are shown in Figure 76 through Figure 81. Mass loading generally appears to trend downward; however, the loading is primarily influenced by climate conditions (wet and dry cycles). Variation in the magnitude of mass loads released from a given landform is a function of landform scale, topography, stratigraphy, and initial OSPW within the pore space.

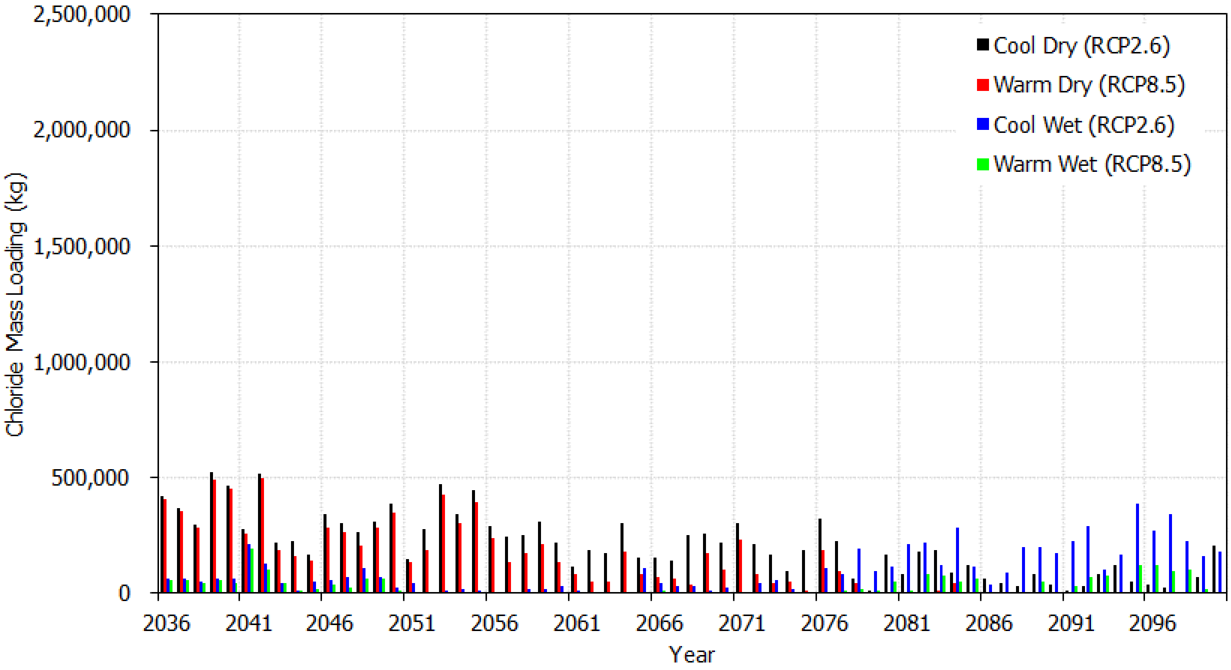


Figure 76 – Annual Chloride Mass Loading AEP Valley

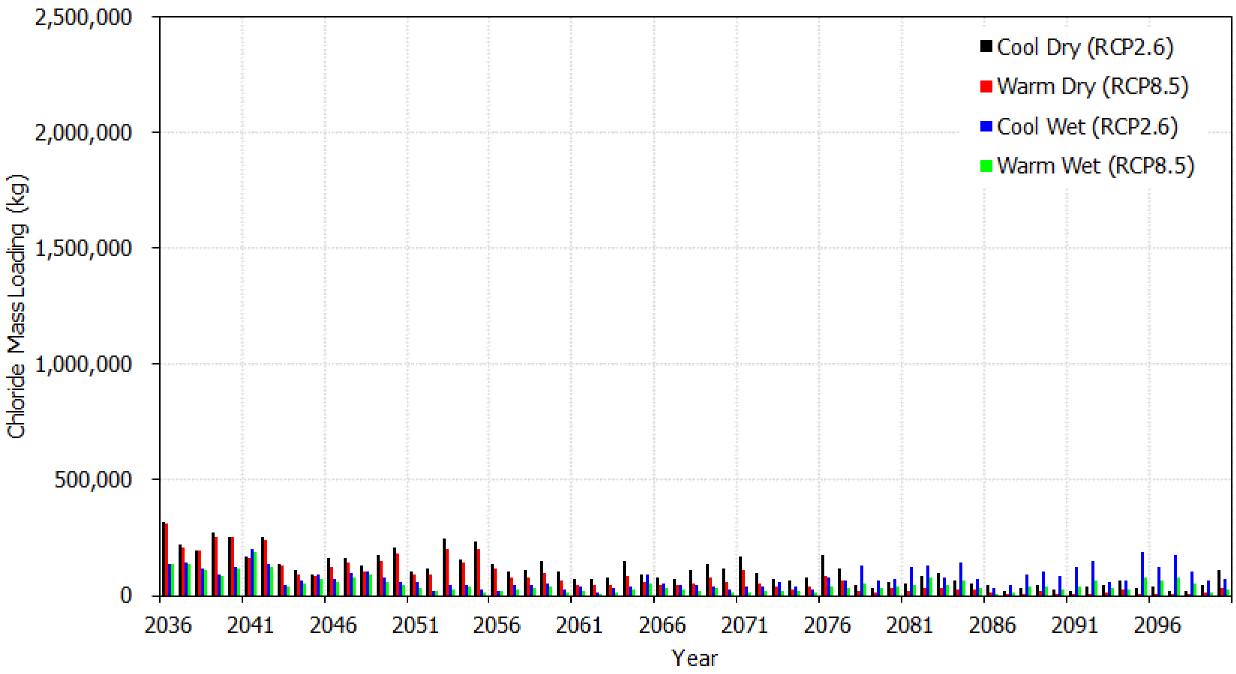


Figure 77 – Annual Chloride Mass Loading ACPN Valley

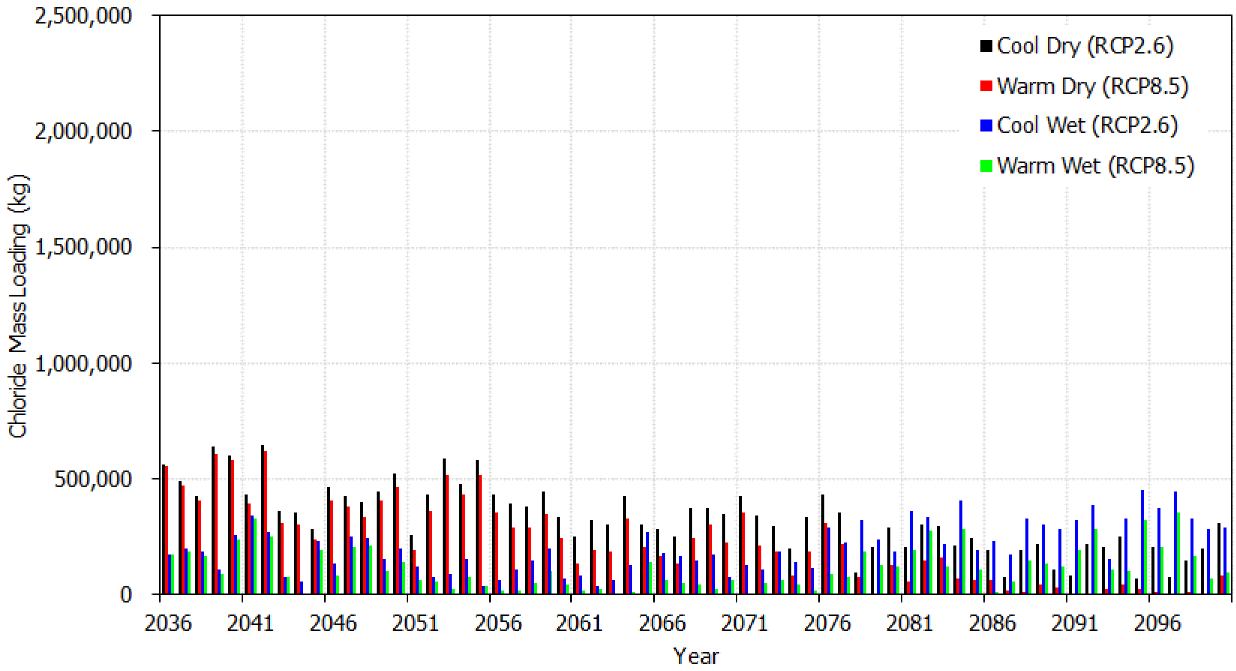


Figure 78 – Annual Chloride Mass Loading ACPS Valley

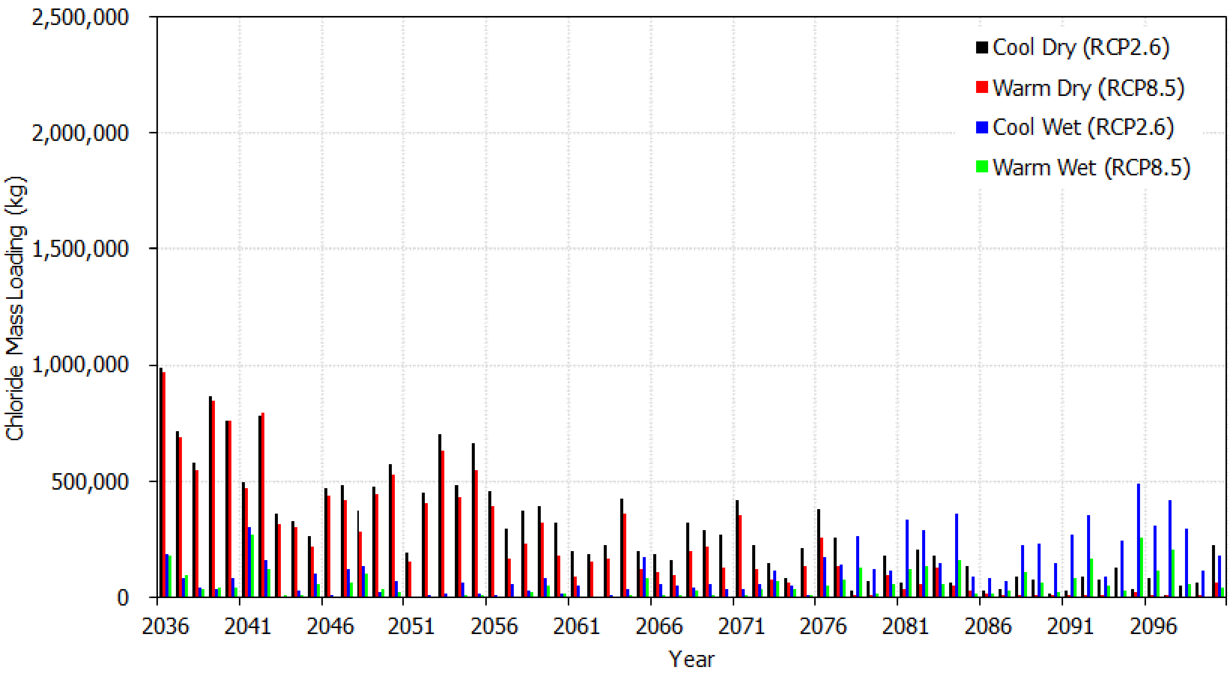


Figure 79 – Annual Chloride Mass Loading AWPS Valley

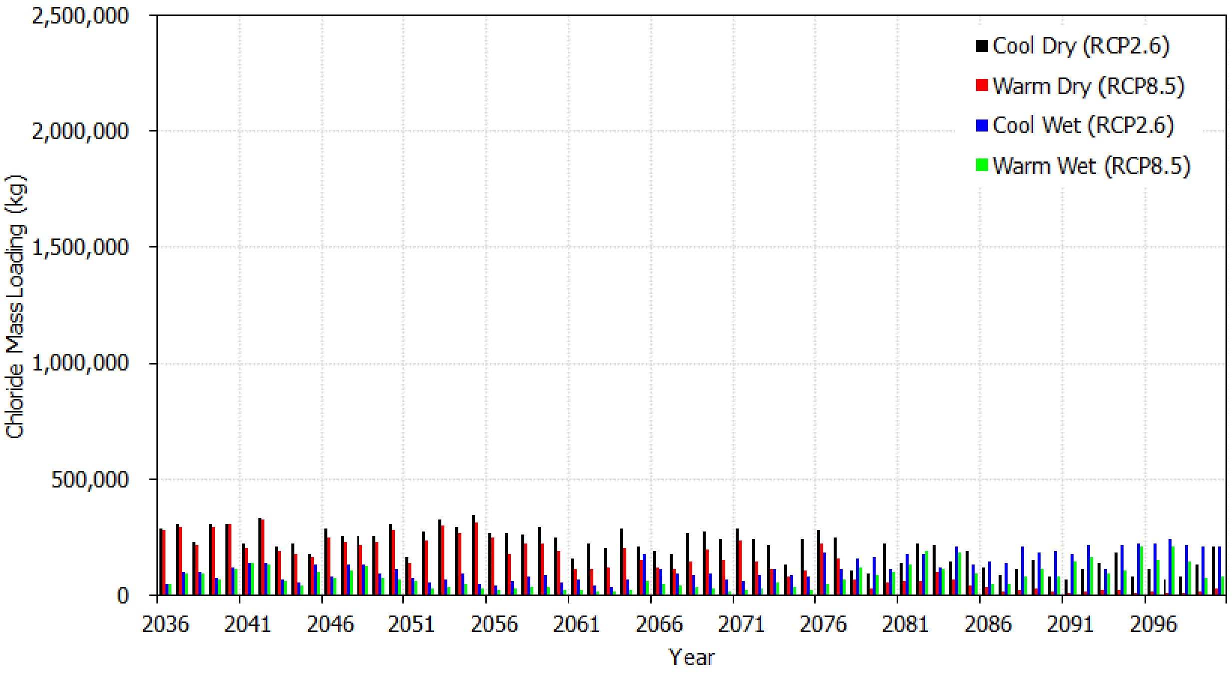


Figure 80 – Annual Chloride Mass Loading AWPW Valley

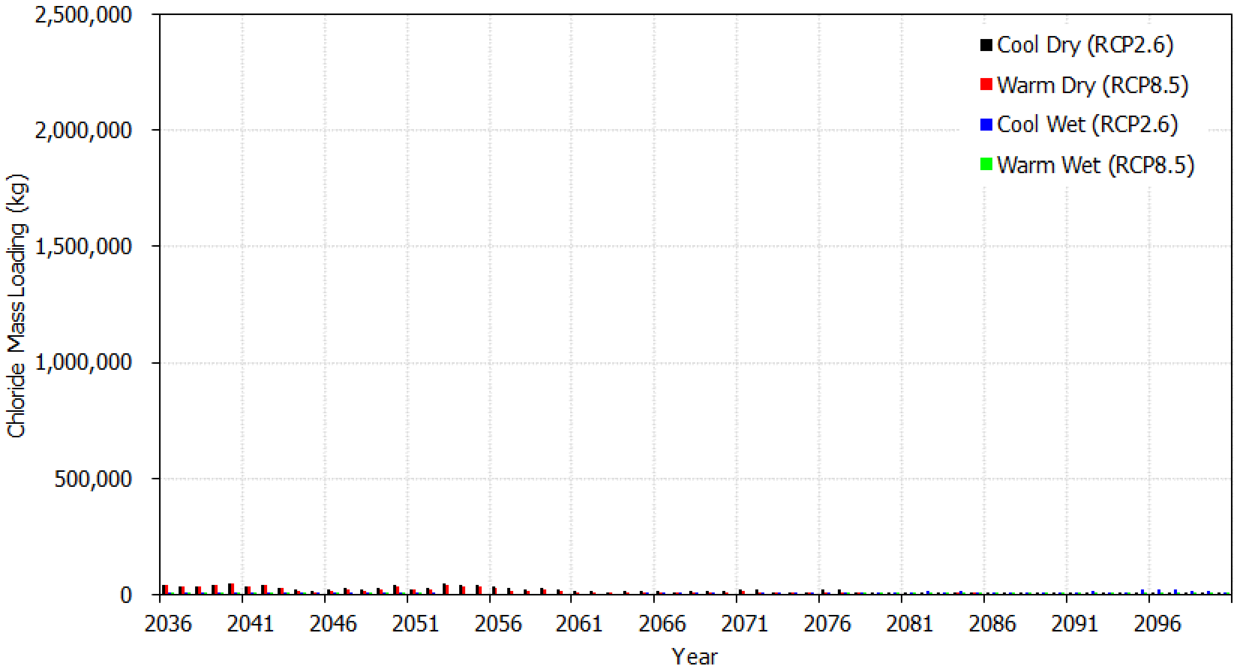


Figure 81 – Annual Chloride Mass Loading SE Corner

CHLORIDE CONCENTRATION – AN-E LAKE

It was assumed that AN-E Lake would be filled with 50% OSPW by year 2058. The chloride concentration (Figure 82) suggests gradual dilution of the chloride in the lake given steady through flow (no lake level drop) and lack of ongoing chloride source (no tailings deposition planned in the AN-E Lake or the watershed of AN-E Lake). The chloride mass loading from AN-E Lake (Figure 83 and Table 39) is closely tied to wet climate cycles when discharge occurs from the lake.

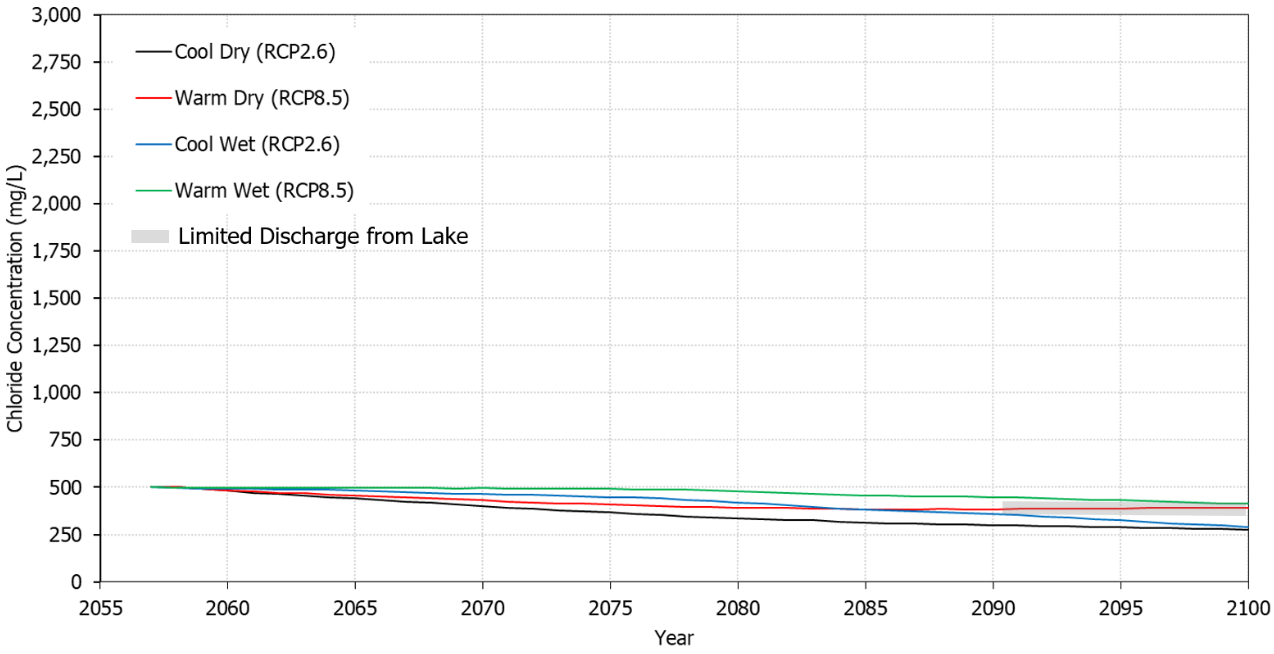


Figure 82 – Annual Chloride Concentration in AN-E Lake

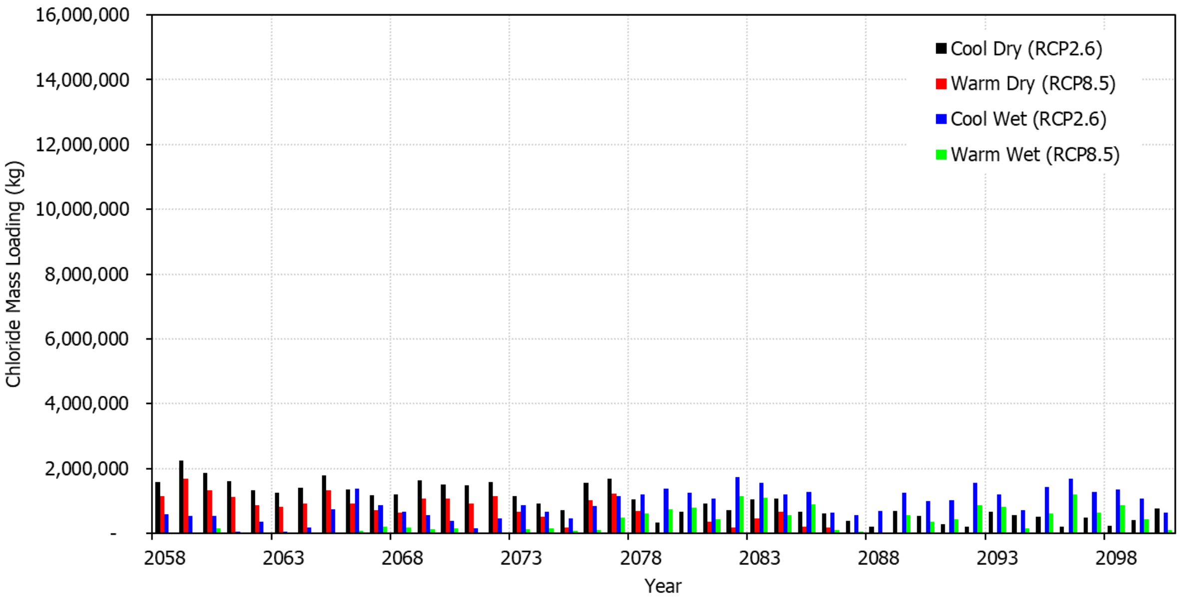


Figure 83 – Annual Chloride Mass Loading from AN-E Lake

Table 39 – Chloride Mass Loading from AN-E Lake

Scenario	Chloride Loading (x10^6 kg)			
	Minimum Annual	Mean Annual	Maximum Annual	Total from 2058 to 2100
Cool Dry RCP2.6	0.2	1.0	2.2	42.1
Warm Dry RCP8.5	-	0.5	1.7	22.0
Cool Wet RCP2.6	0.05	0.9	1.7	38.2
Warm Wet RCP8.5	-	0.4	1.2	15.3

CHLORIDE CONCENTRATION – AN-W LAKE

The above mass loading and water balance results were used to develop chloride balances for AN-W Lake to estimate annual lake concentrations (Figure 84). During dry cycles, especially when the lake level drops below the sill, chloride mass accumulates within the lake resulting in increased concentrations. The plots suggest that elevated chloride concentrations will persist beyond year 2100 and are highly dependant on climate. The chloride mass loading from WM Lake (Figure 85 and Table 40) is closely tied to wet climate cycles when discharge occurs from the lake.

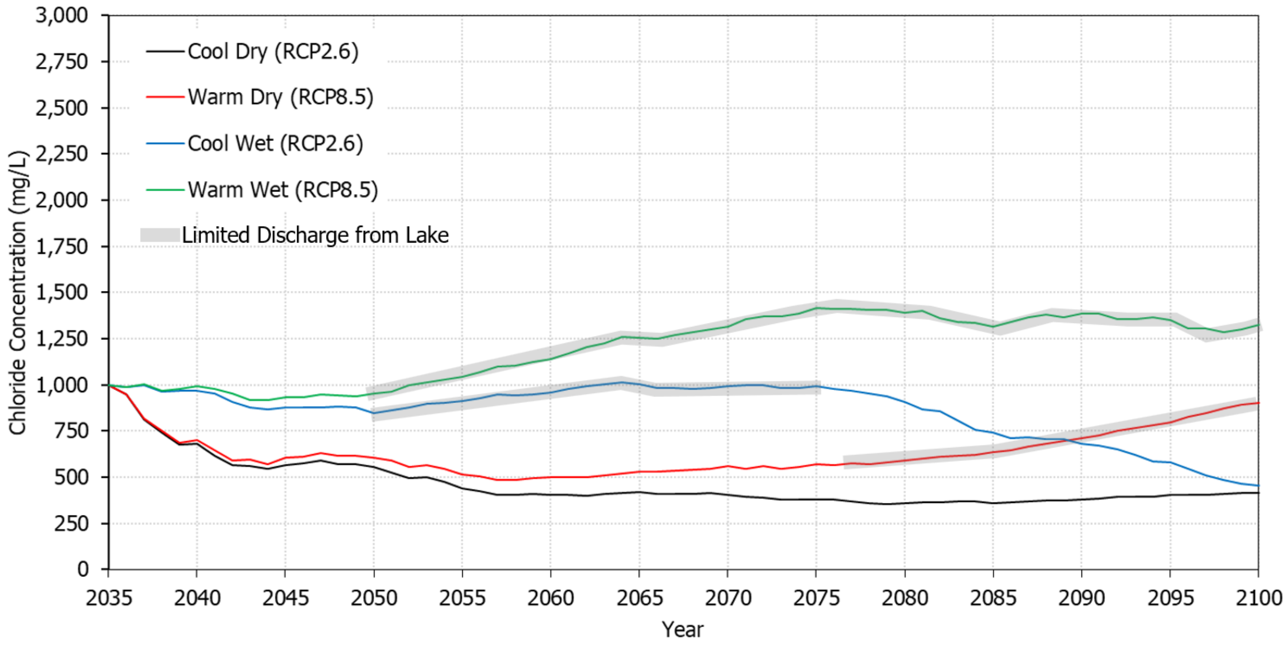


Figure 84 – Annual Chloride Concentration in AN-W Lake

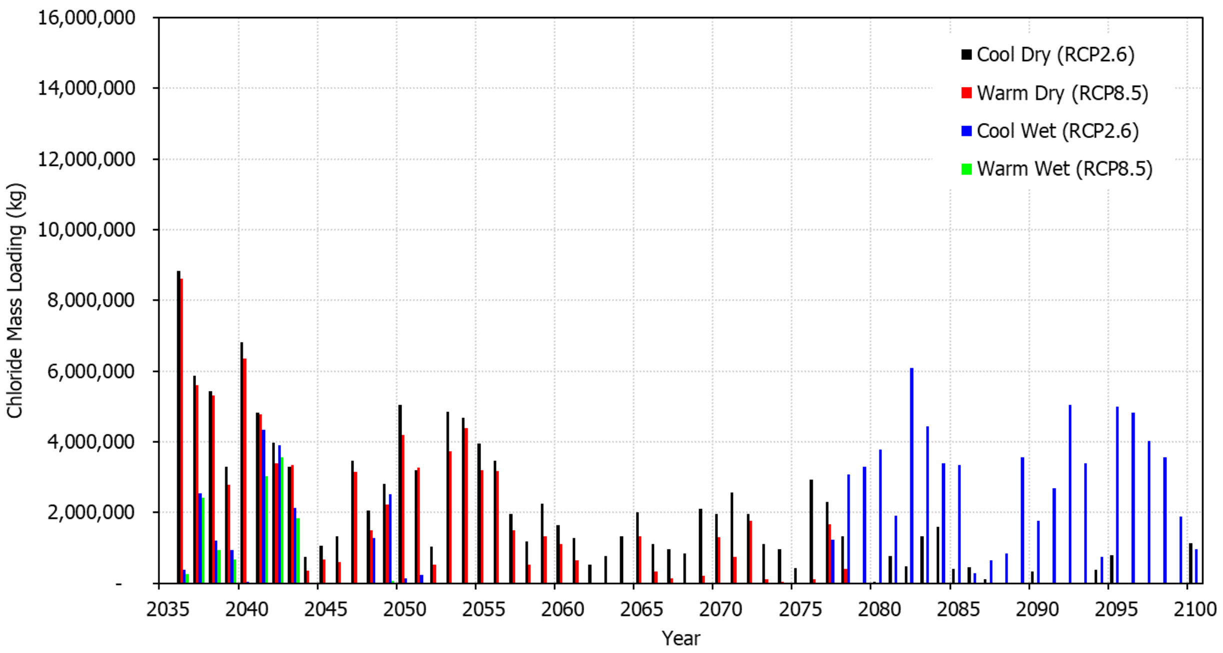


Figure 85 – Annual Chloride Mass Load From AN-W Lake

Table 40 – Chloride Mass Loading from AN-W Lake

Scenario	Chloride Loading (x10^6 kg)			
	Minimum Annual	Mean Annual	Maximum Annual	Total from 2035 to 2100
Cool Dry RCP2.6	-	1.9	8.8	122
Warm Dry RCP8.5	-	1.3	8.6	84
Cool Wet RCP2.6	-	1.4	6.1	89
Warm Wet RCP8.5	-	0.2	3.6	13

5.3.4 PRELIMIMINARY REVIEW OF RELEASE TO SURROUNDING RIVERS

The proposed closure drainage plan involves releasing runoff from pit lakes to the surrounding watercourses. The Athabasca River would receive runoff from BM and AN-W Lake, AWPW Valley, the toe of MLSB, and XE Valley. The McKay River would receive runoff from WM and NM lake. The Muskeg River would receive runoff from AN-E Lake. An approximate calculation was completed to compare relative assimilative capacity of the surrounding rivers and estimate the change in chloride mass loading and concentrations with a range of potential discharges from Syncrude's sites.

Historical flow, chloride concentration, and annual chloride mass load for the Athabasca River, McKay River, and Muskeg River are summarized in Table 41 and are based on data approximated from Alberta Environment (2008), Amec (2014), Environment Canada (2023), Fiera (2013), and Newton (2022). The difference in flow rate between the rivers is due to the differences in watershed area as illustrated in Figure 6.

The range of estimated annual mass loads of chloride released from the Syncrude sites is included in Table 41 for comparison with the historic chloride mass load in each river. The comparison suggests:

- the estimated chloride mass released from Syncrude sites into the Athabasca River is an order of magnitude less than the historical mass load of the river; and
- the estimated chloride mass released from Syncrude sites into the McKay River and Muskeg River is an order of magnitude greater than the historical mass load for the respective rivers.

An approximate mixing calculation was developed to estimate the chloride concentration in each river downstream of the proposed runoff release from the sites. The estimate used historic river flow rates and the combination of chloride mass loads in the river and the estimated load released from Syncrude sites. Adjustment factors were used to roughly account for limited lateral mixing across the river channels based on the channel width. It was assumed that mixing occurs in one-tenth of the Athabasca River width, one-half of the McKay River width, and fully across the Muskeg River. The annual mass loading rates from the sites were also adjusted to account for seasonality (i.e., the majority of runoff is expected to occur over the spring and summer months). The summer concentration was estimated by using twice the annual mass loading rate from the sites, while the winter concentrations were estimated using one-fifth of the annual loading rate. Table 41 provides a range of mixed chloride concentrations in each river downstream of the sites. The mixed concentrations are all below the Government of Alberta (2018) short-term chloride guideline (640 mg/L) and below the long-term chloride guideline (120 mg/L), except for in the McKay River under the scenarios with the highest estimated loads. For McKay River and WM / NM Lakes, most mass loading from pit lakes is expected to occur during wet periods, when McKay River flows are higher. During the lowest McKay River flows, the water level in pit lakes would likely be below sill (i.e., no outflow or loading).

Table 41 – Summary of Preliminary Assessment of Runoff Released to Receiving Watercourses

Parameter	Athabasca River	McKay River	Muskeg River
historical flow rate - summer (m^3/s)	1,200	25	4
historical flow rate - winter (m^3/s)	200	2	0.3
historical annual chloride mass Load ($x10^6$ kg)	175	1.5	0.2
range of estimated annual mass load of chloride released from Syncrude sites ($x10^6$ kg)	3 to 15	5 to 30	1 to 2
historical chloride concentration - summer (mg/L)	5	2	2
range of fully mixed in-river chloride concentration with mass load from Syncrude sites - summer (mg/L)[1]	6.6 to 13.4	32 to 139	10 to 18
historical chloride concentration - winter (mg/L)	25	25	10
range of fully mixed in-river chloride concentration with mass load from Syncrude sites - winter (mg/L)[1]	26 to 30	41 to 174	31 to 52

Note: [1] Fully mixed refers to mixing within one-tenth of the Athabasca River width, one-half of the McKay River width, and fully across the Muskeg River. Higher concentrations would be expected within a localized mixing zone.

It is important to note that this analysis is coarse and meant to provide an order of magnitude estimate to inform further assessment and planning of water management working toward release of runoff from the sites. It should also be noted that mass loads from other reclaimed mines are not considered. A more detailed analysis is required to better understand details of seasonal mass loading rates coupled with receiving stream flows. Similarly, refined analyses would be required to properly capture mixing zone dynamics and extents (e.g., river and site runoff flow rates, channel geometry, lateral dispersion in river).

6. CONCLUSIONS

6.1 WATER BALANCE

The simulated AET and runoff for landforms for historical climate conditions are like regional reference values. Climate change scenarios result in an increase in AET and a corresponding reduction in runoff. The results suggest that little to no runoff is anticipated from overburden dumps (hills) under all conditions. The water balance of the closure valleys is characterized by relatively higher AET and higher runoff yields. It is anticipated that closure valleys adjacent to overburden dumps have higher runoff depths due to interflow from the dumps.

The pit lake water balance results suggest that the pit lakes will perform as locally common lakes. For historical climate scenarios the water levels of all lakes are maintained near the sill elevation. For the climate change scenarios, lake levels drop below the sill for all pit lakes. The lake levels increase during wet cycles. The reduction in water level is more pronounced for pit lakes with smaller watershed area to lake area ratios. It is important to recognize that the RCP2.6 and RCP8.5 represent the lower and upper bounds of climate change projections.

6.2 GROUNDWATER

The elevation of water table closely follows the topography of the ground surface, indicating flow from topographic highs to topographic lows. Groundwater was estimated to be near surface throughout topographic lows and along closure valleys and at the base of the hills. Wetlands are expected to form at these locations. The extent of wetlands fluctuates in response to wet and dry conditions. Groundwater flow into and out of pit lakes is not a significant component of the water balance other than for AN-E Lake, which receives groundwater inflow approximately equal to 50% of the direct precipitation over the lake.

6.3 WATER QUALITY

6.3.1 LANDFORMS

Analysis of coupled surface runoff and chloride concentrations at the outlet of the valleys suggests higher flows are associated with lower concentrations due to dilution of porewater with fresh surface water. Lower flows result in higher concentrations. The concentration and flow dynamic demonstrates an inherent mechanism within the landforms that limits discharge of solute mass from the site during low flow periods.

Annual mass loading from landforms were tracked. The results suggest loading generally trends downward; however, the loading is primarily influenced by climatic conditions (wet and dry cycles). Variation in the magnitude of mass loads released from a given landform is a function of landform scale, topography, stratigraphy, and initial OSPW within the pore space.

Comparison of the initial mass and the mass mobilized over the simulations suggests the majority of the OSPW will remain within the pore space of the tailings within landforms; however, mass is readily mobilized from coke cap portions of landforms.

6.3.2 PIT LAKE CONCENTRATION

Generally, dilution of OSPW occurs during wet cycles; however mass loads from upstream landforms and FT keep concentrations elevated in the lakes. During dry cycles, especially when the lake level drops below the sill, chloride mass accumulates within the lake resulting in increased concentrations. The model results suggest that elevated chloride concentrations will persist beyond year 2100 and are highly dependant on climate. Consolidation release water from FT within in the pit lakes has potential to contribute significant mass loads to pit lakes in the years following placement.

6.3.3 PRELIMINARY REVIEW OF CHLORIDE MASS LOADING TO RECEIVING RIVERS

An approximate calculation was completed to compare relative assimilative capacity of the surrounding rivers and estimate the change in chloride mass loading and concentrations with a range of potential discharges from Syncrude's sites. Comparison of estimated chloride mass released from Syncrude sites into the Athabasca River is an order of magnitude less than the historical mass load of the river. The estimated chloride mass released from Syncrude sites into the McKay River and Muskeg River is an order of magnitude greater than the historical mass load for the respective rivers.

An approximate mixing calculation was developed to estimate the chloride concentration in each river downstream of the proposed runoff release from the sites. The mixed concentrations are all below the Government of Alberta (2018) short-term chloride guideline (640 mg/L) and below the long-term chloride guideline (120 mg/L), except for in the McKay River under the scenarios with the highest estimated loads. For McKay River and WM / NM Lakes, most mass loading from pit lakes is expected to occur during wet periods, when McKay River flows are higher. During the lowest McKay River flows, the water level in pit lakes would likely be below sill (i.e., no outflow or loading). It is important to note that this analysis is coarse analysis and meant to provide an order of magnitude estimate to inform further assessment and planning of water management working toward closure of the sites.

7. LIMITATIONS

7.1 CLIMATE

Climate conditions (i.e., wet, and dry cycles) dominate the water balance and solute migration from reclaimed landforms. Future climate conditions are not known. The climate scenarios simulated in this study used upper and lower bounds of assumed future emissions, as defined by RCP2.6 (stringent GHG mitigation) and RCP8.5 (very high GHG emission). Climate mitigation policies and future commitments will likely reduce the rate of GHG emissions to a level that potentially will be between the RCP2.6 and RCP8.5 scenarios considered in this study.

It is acknowledged that climate change will also lead to regional changes in vegetation (e.g., Schneider 2013). However, such changes were not considered in the model, and vegetation characteristics were assumed to be based on vegetation as currently planned (i.e., similar to existing regional vegetation). Generally, if vegetation is impacted by water availability, it is speculated that AET will decrease and further water conservation would occur (i.e., drier conditions will lead to a shift in vegetation communities (for both reclaimed and natural) that take up less water). Therefore, assuming AET properties for the current vegetation communities is a conservative assumption when assessing the impacts of climate change on the water budget of a reclaimed landform (i.e., drought conditions).

Modelling results suggest that a large reduction in water availability would occur under RCP8.5 conditions. Under these conditions it is anticipated that the water levels in many pit lakes and natural regional lakes would fall below the sill (van der Kamp et al. 2008).

7.2 MODEL RESOLUTION

The scale of sitewide models requires simplification of ground topography and subsurface discretization given computational limitations. Detailed modelling of EIP (ARKK 2021a) suggests inclusion of a highly refined model surface (2 m grid spacing) of existing reclaimed areas can influence the water balance. Generally, the constructed meso-topography, micro-topography, ponding areas are expected to result in increased infiltration and wetter soils that provide increased surface runoff during times of surplus (i.e., summer rain events and snowmelt). Availability of detailed measured data for tailings deposit stratigraphy, detailed information on land cover/vegetation types, and inability to discretize stratigraphy in coarse sitewide models is potentially a significant gap in estimating runoff and solute migration from landforms. Landform scale models are required to close gaps related to discretization and computational limitations, and better understand sitewide model performance.

7.3 TRANSISTION FROM OPERATION TO CLOSURE

Effectively capturing the transition of landforms from operation to closure is challenging as described throughout this report. Reconciling the complex timing of progressive reclamation across the sites requires integration of closure plans with operational plans. The modelling approach in this study sets the groundwork for future assessments. Achieving closure objectives will require multiple iterations of closure and operational plans fed by additional closure experience, evolution of technology, and development of acceptable water release criteria by the regulators.

7.4 MEASURED DATA

A traditional model calibration and validation was not possible for this study. Much of the reclaimed landscape does not exist. Instead, model results were "validated" based on regional and site-specific historical runoff and evapotranspiration values as discussed throughout the report. Ongoing monitoring and refinement of models will be important to better understand water balance and solute transport of the closure landscape.

7.5 FROZEN GROUND

Frozen ground conditions were not included in the model. ARKK (2021a) modelling of EIP landform using HGS included wet and dry climate cycle simulations with and without ground freezing and thawing. Including frozen ground in the model resulted in little to no change in annual runoff and a 10 to 20% reduction of the chloride mass released from EIP. Although the annual runoff depths are similar, the runoff distribution throughout the year is different with and without frozen ground. This could be important for water availability for vegetation within the landform, chloride concentrations within the landform, and water and mass loads discharged to downstream areas (i.e., pit lakes).

Further work is required to better understand the effects of frozen ground at sitewide scales and when accounting for various landform types. It is likely that annual runoff would increase when accounting for frozen ground. The modelling in this study is therefore conservative in terms of lake levels and chloride concentrations within the sites.

7.6 RUNOFF FROM RECLAIMED OVERBURDEN DUMPS

The modelling for this study likely underestimates runoff from reclaimed overburden dumps based on comparison with observed runoff at South Bison Hills (Huang et al. 2018). The underestimation could potentially be a result of not simulating ground freezing and thawing and the resolution of the model grid.

7.7 WATER QUALITY AND MASS LOADING FROM LANDFORMS

This study is not intended to provide a comprehensive evaluation of water quality evolution under reclaimed conditions. However, this study provides groundwork for future monitoring and modelling (to occur over the next 10 years) to predict the evolution of comprehensive water quality over closure timeframes.

Only chloride is modelled and was assigned within the pore space of tailings landforms (valleys) and pit lakes (both in FFT and water caps) of Syncrude mines. Other areas were assigned a chloride concentration of 0 mg/L. Chloride is a conservative solute in surface water and groundwater (i.e., does not degrade) and is indicative of worst-case solute migration and mass-loading under given surface water and groundwater flow fields. It will be important to consider other solutes of interest (e.g., hydrocarbons, metals, naphthenic acids) to evaluate water quality and mass loading as reclamation progresses.

The modelling suggests water quality and mass loading throughout the sites will be heavily dependant on water movement. Sensitivities to water movement are discussed above. The following considerations are also relevant to better understand water quality and mass loading at the sites and timing of release of water from the sites.

- Initial concentration of OSPW within the tailings landforms.
- Management of water during the transition from operation to closure.
- Management and prediction of consolidation of FT in pit lakes and landforms and the rate and concentration of porewater that is expressed from FT.
- Migration and degradation of hydrocarbon and naphthenic acids though various mechanisms.
- Mass loading from saline sodic overburden.
- Assimilative capacity and ecological sensitivity of receiving streams.
- Development of water release criteria by the regulators.

It is important to note that monitoring data from BM Lake (Syncrude 2021) indicates that surface water quality has been improving with time. The lake water is not acutely toxic. All parameters measured are below Government of Alberta (2018) short term (acute) guidelines for the Protection of Aquatic Life, except for the F2 hydrocarbon fraction in the water. A large proportion of the lake chemical parameters are already below long-term (chronic) Surface Water Protection of Aquatic Life guidelines, which are important for closure outcomes. It is important to note that some of these parameters are naturally elevated in the region Full details on the performance of BM Lake is available at Syncrude (2021).

8. CLOSURE

We trust that this report meets your requirements. Please contact the undersigned should you have any questions regarding the content of this document. The report was completed with contributions by Ali Kiyani, M.Sc., P.Eng. (Water Resource Engineer), Young-Jin Park, Ph.D. (Senior Groundwater Scientist), Nick Perdaems, M.Sc., E.I.T. (Civil Engineer), and Indu Ghuge (Data Scientist).

Respectfully,

Ranjeet Nagare, Ph.D., P.Eng.
Principal Hydrogeological Engineer

Rob Wirtz, P.Eng.
Principal Water Resource Engineer

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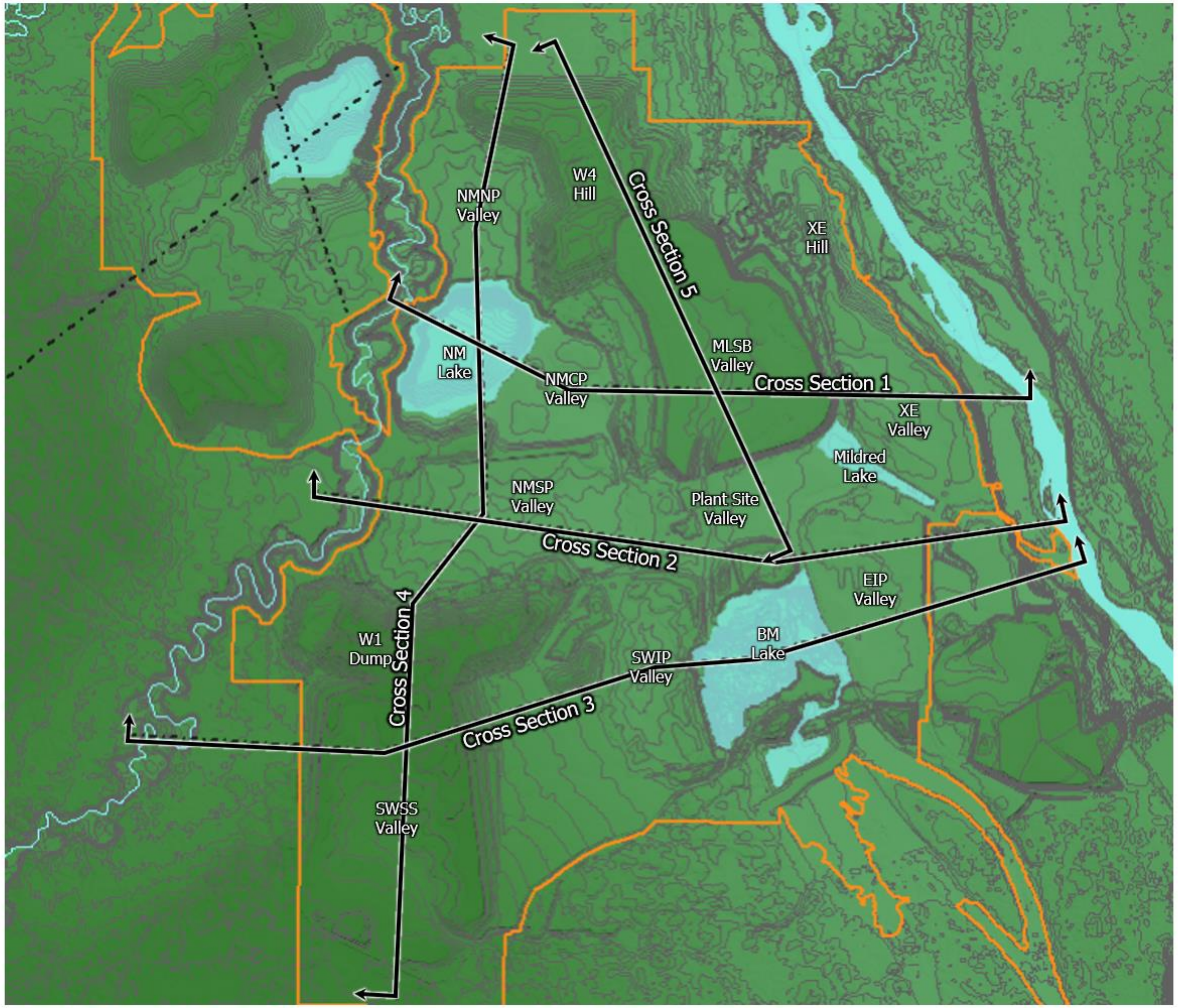
APPENDIX 1 MILDRED LAKE CROSS SECTIONS

Mildred Lake Cross Section Location Summary



Mildred Lake Cross Section 1
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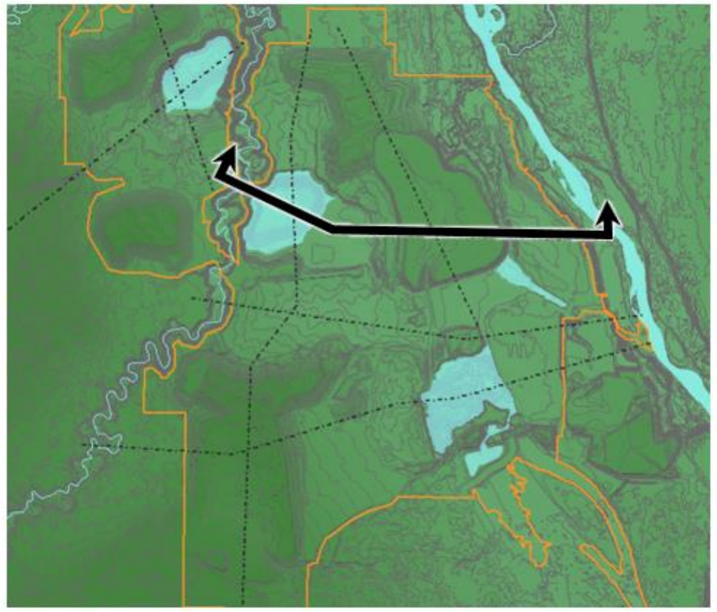
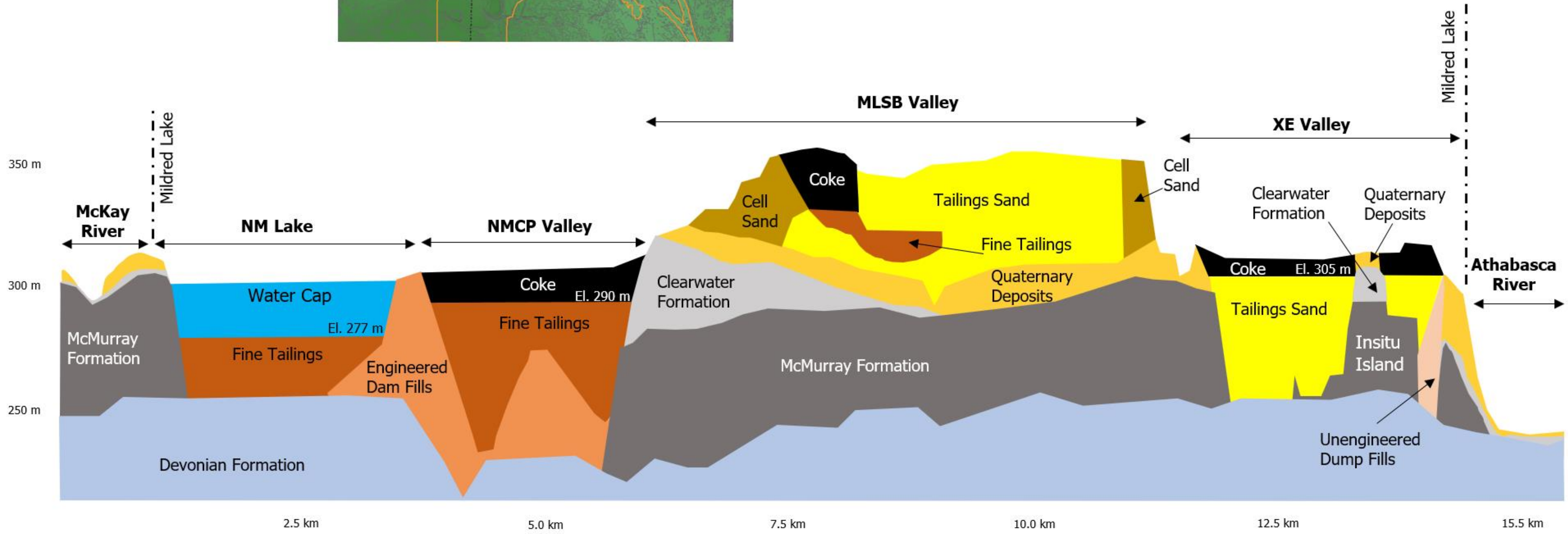


WEST

EAST



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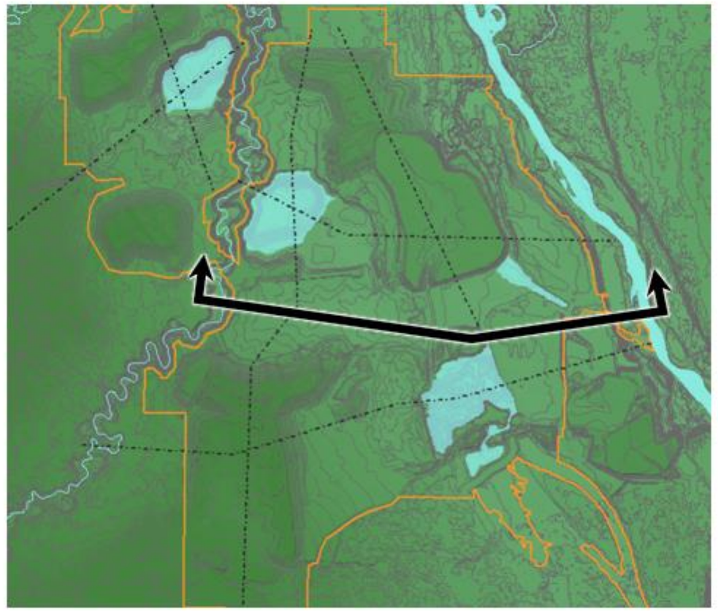

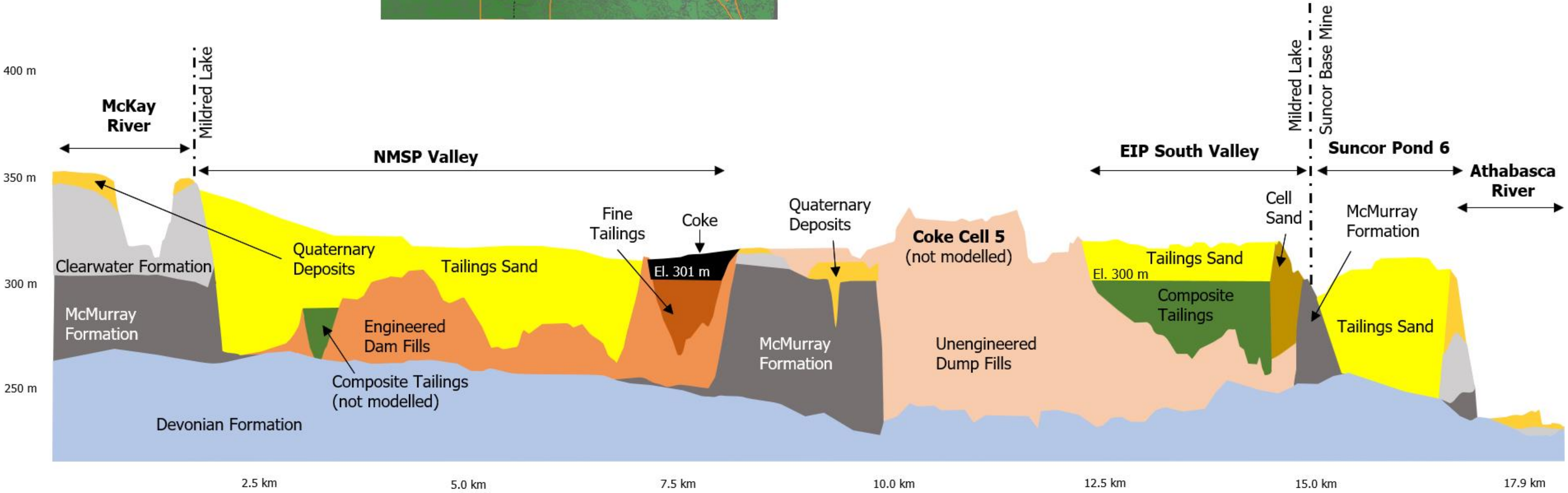

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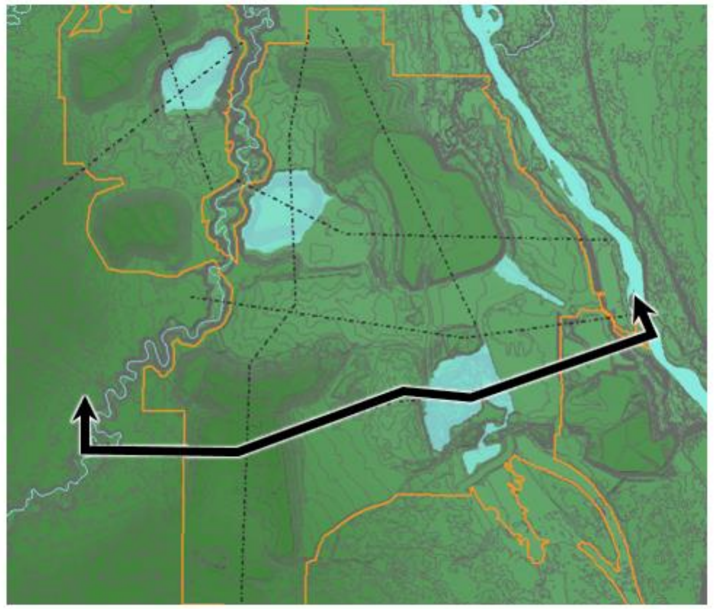

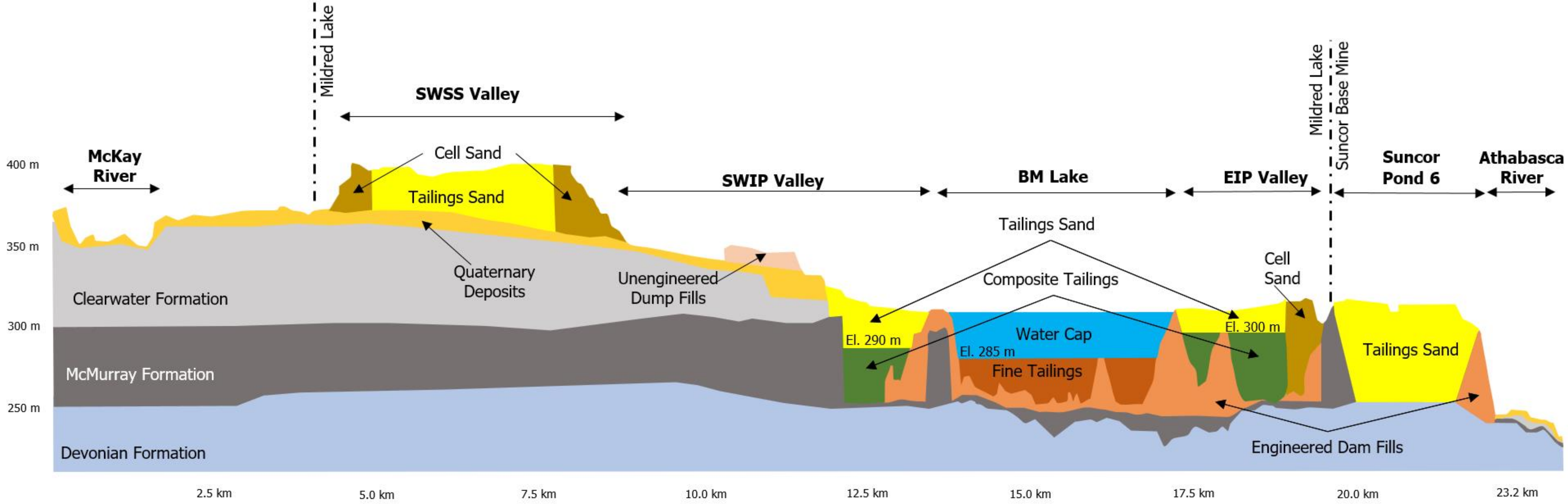

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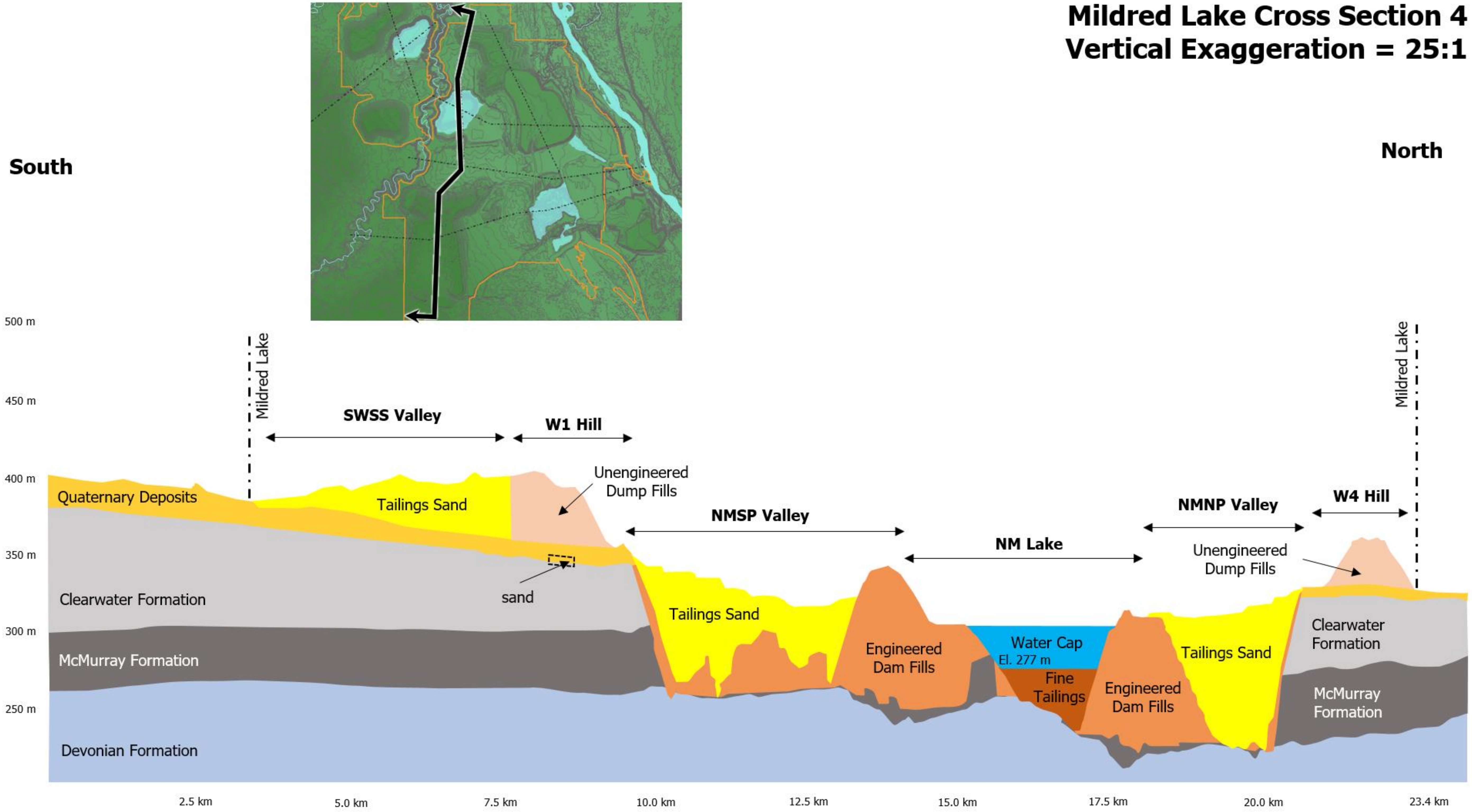

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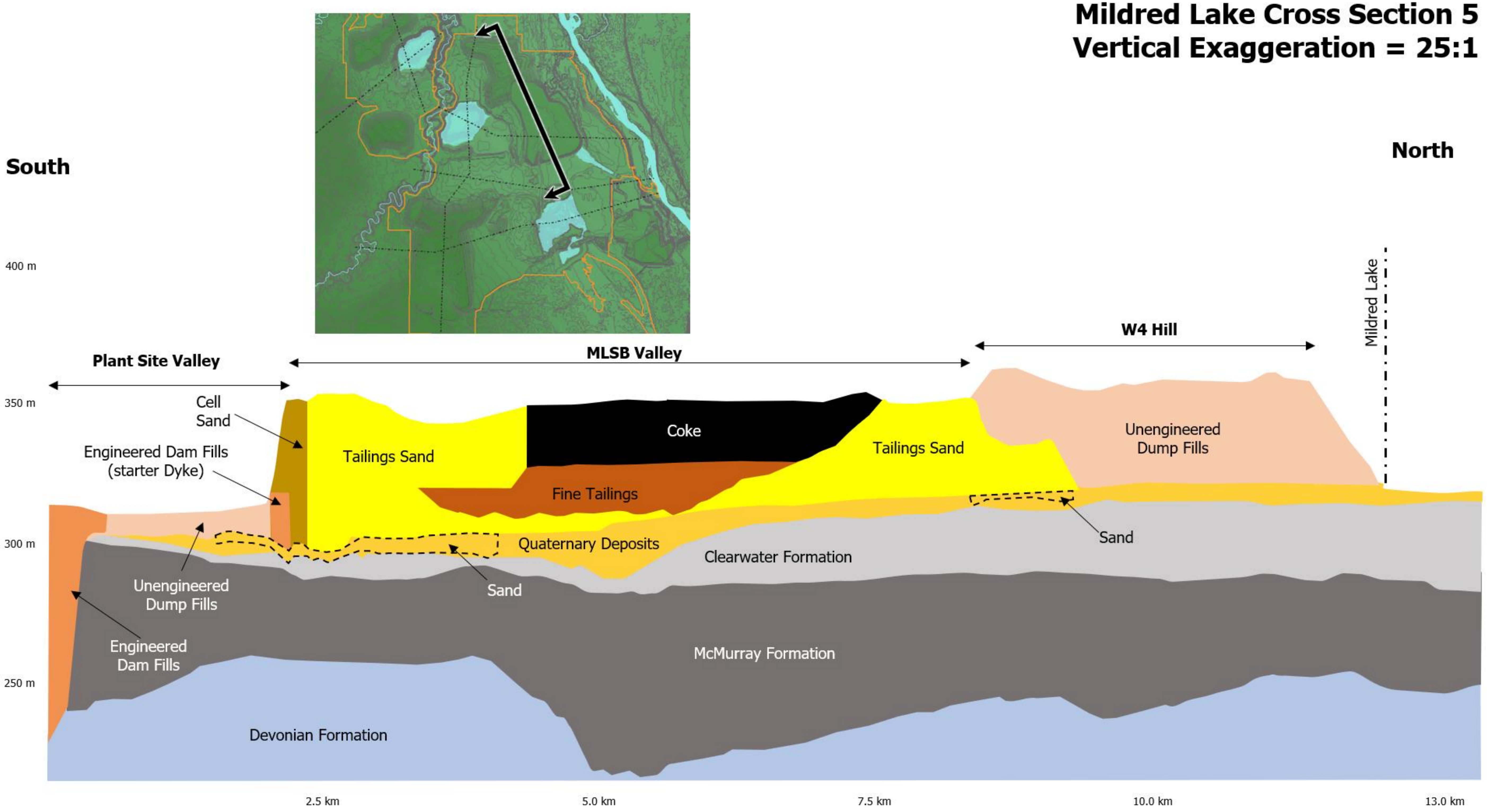
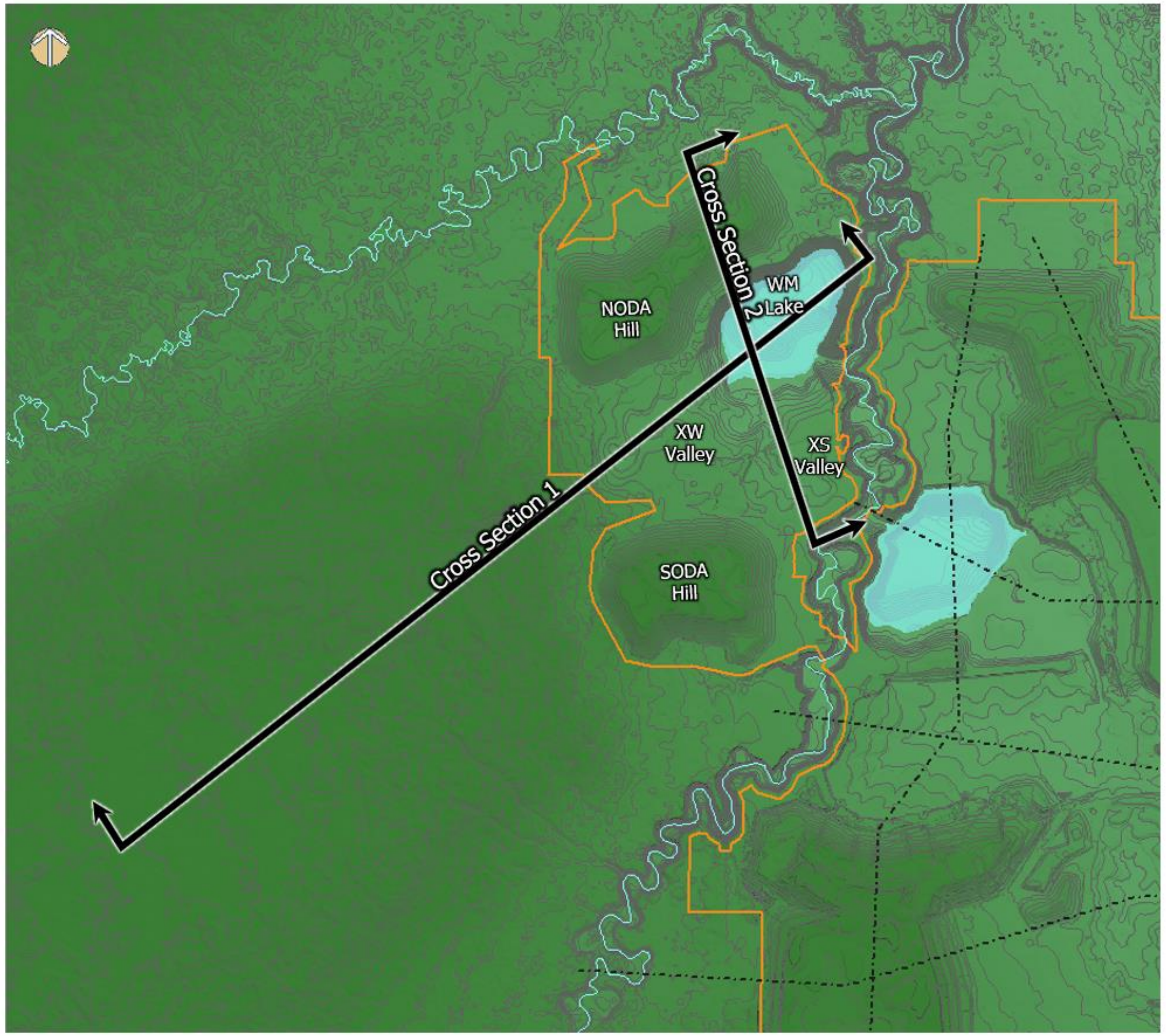
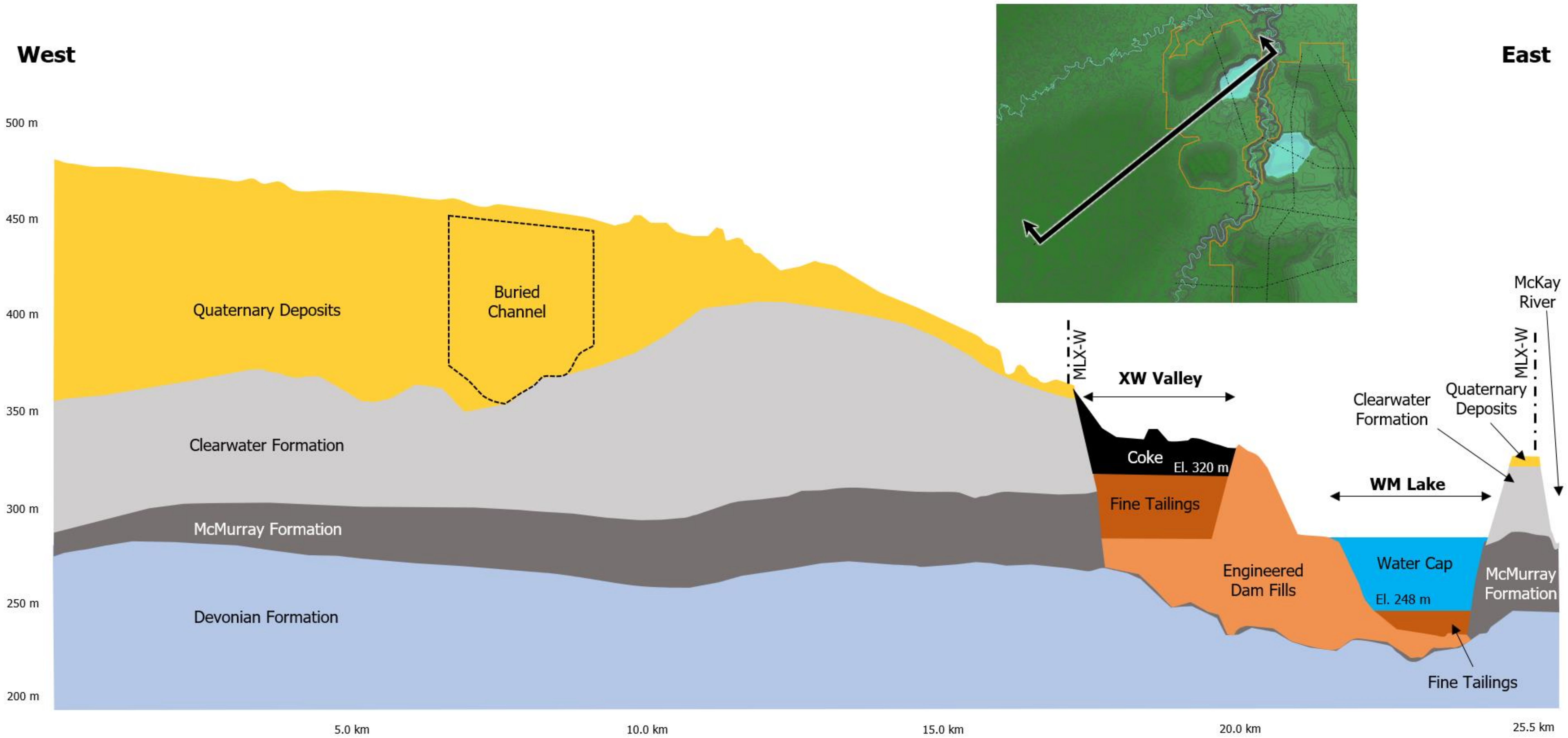


APPENDIX 2 MLX-W CROSS SECTIONS

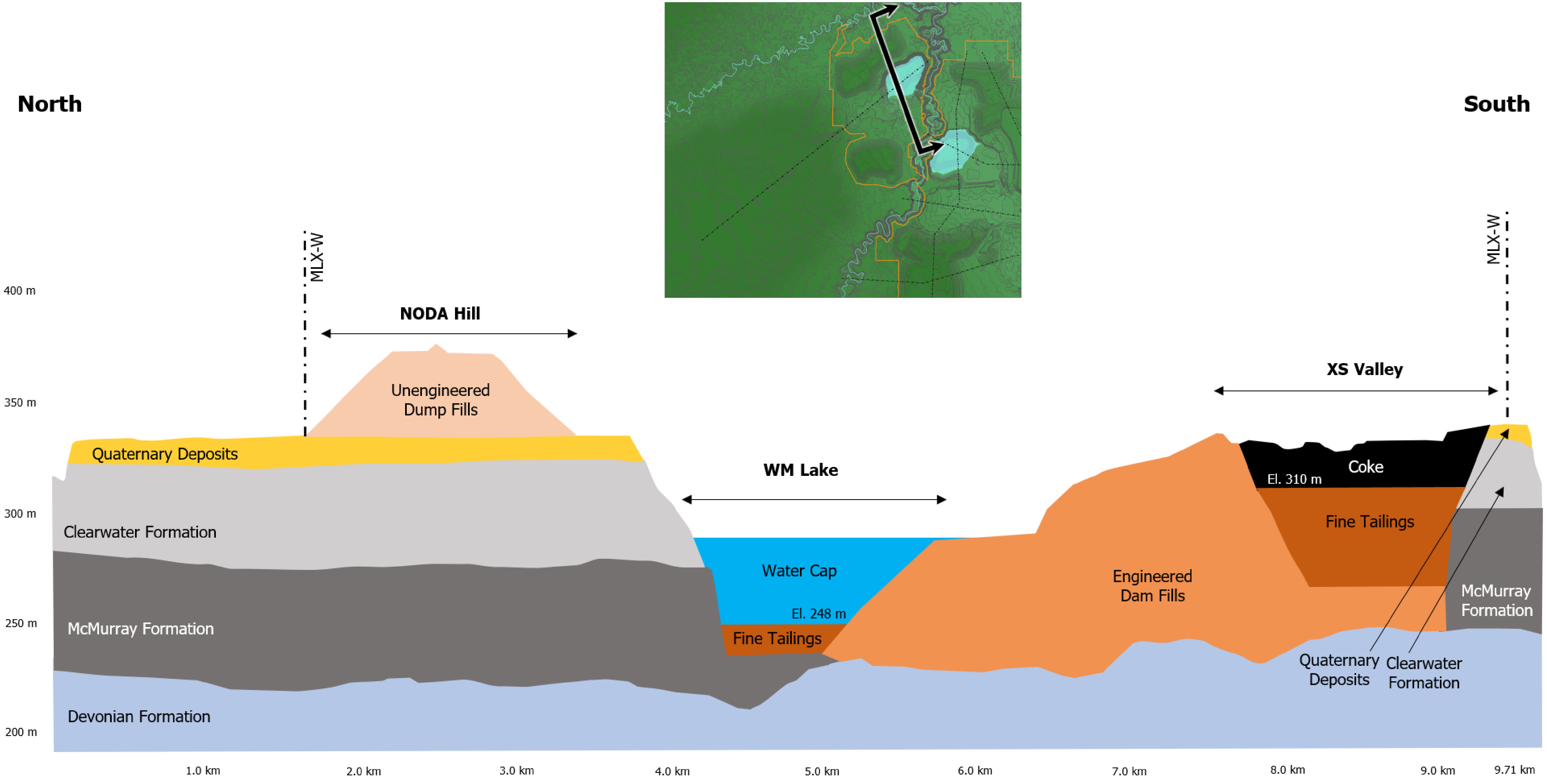
MLX-W Cross Section Location Summary



MLX-W Cross Section 1
Vertical Exaggeration = 33:1

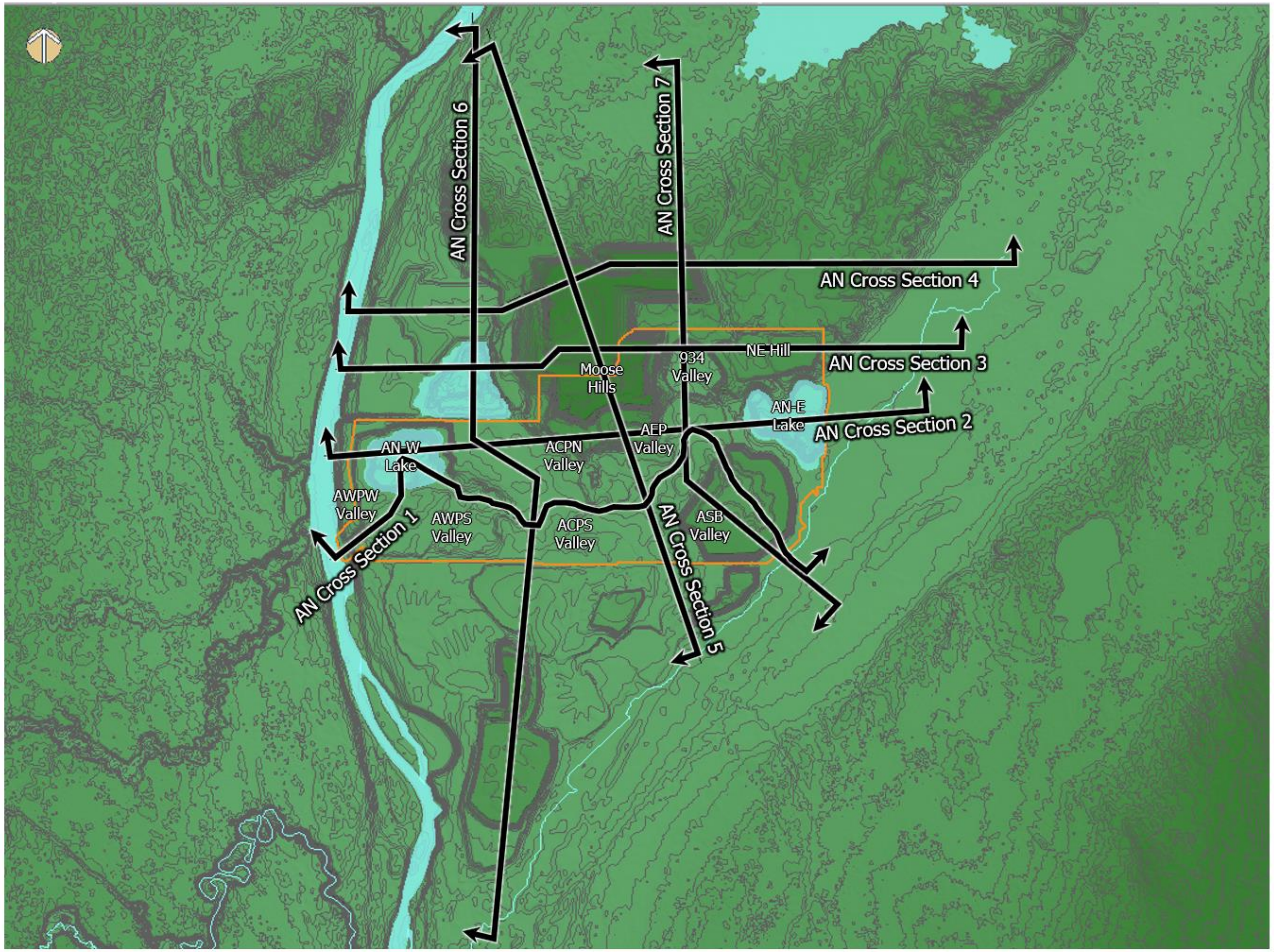


MLX-W Cross Section 2
Vertical Exaggeration = 15:1



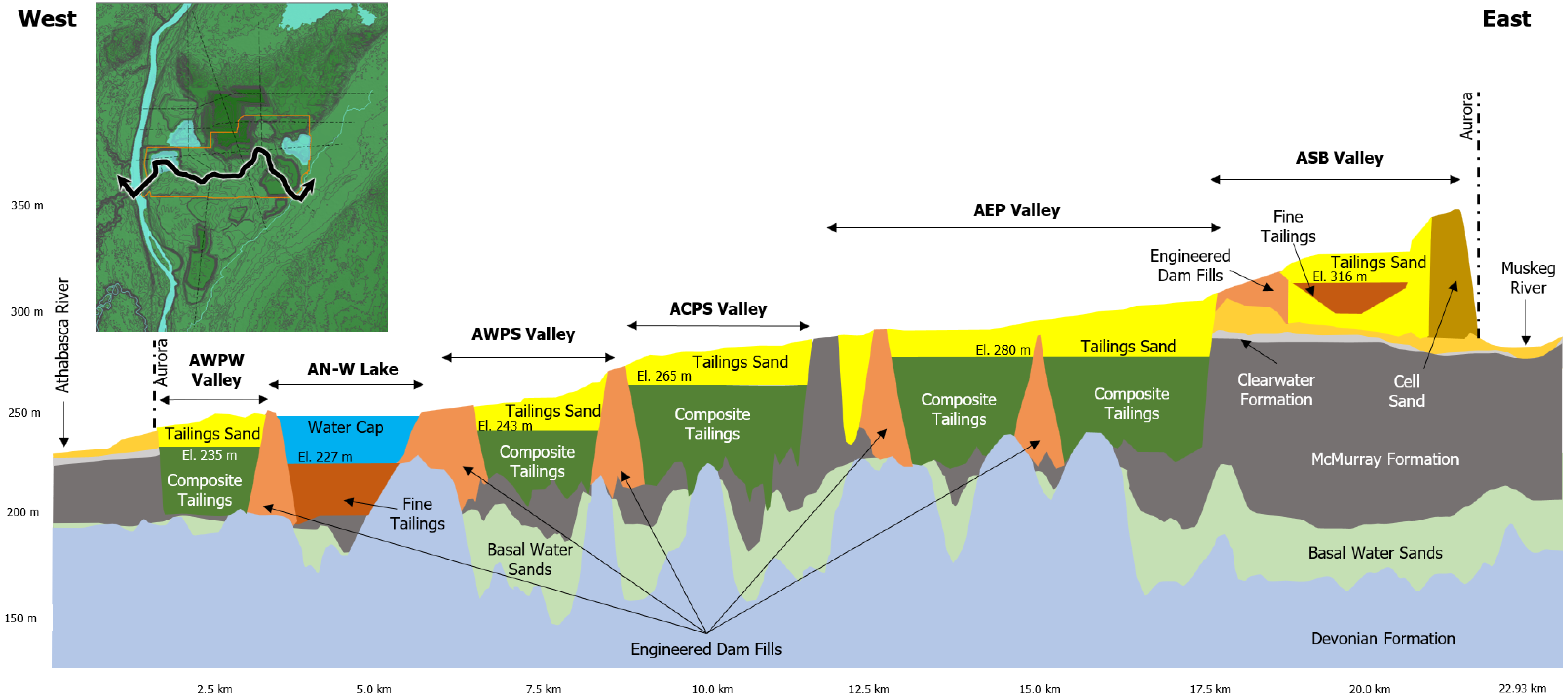
APPENDIX 3 AURORA NORTH CROSS SECTIONS

AN Cross Section Location Summary



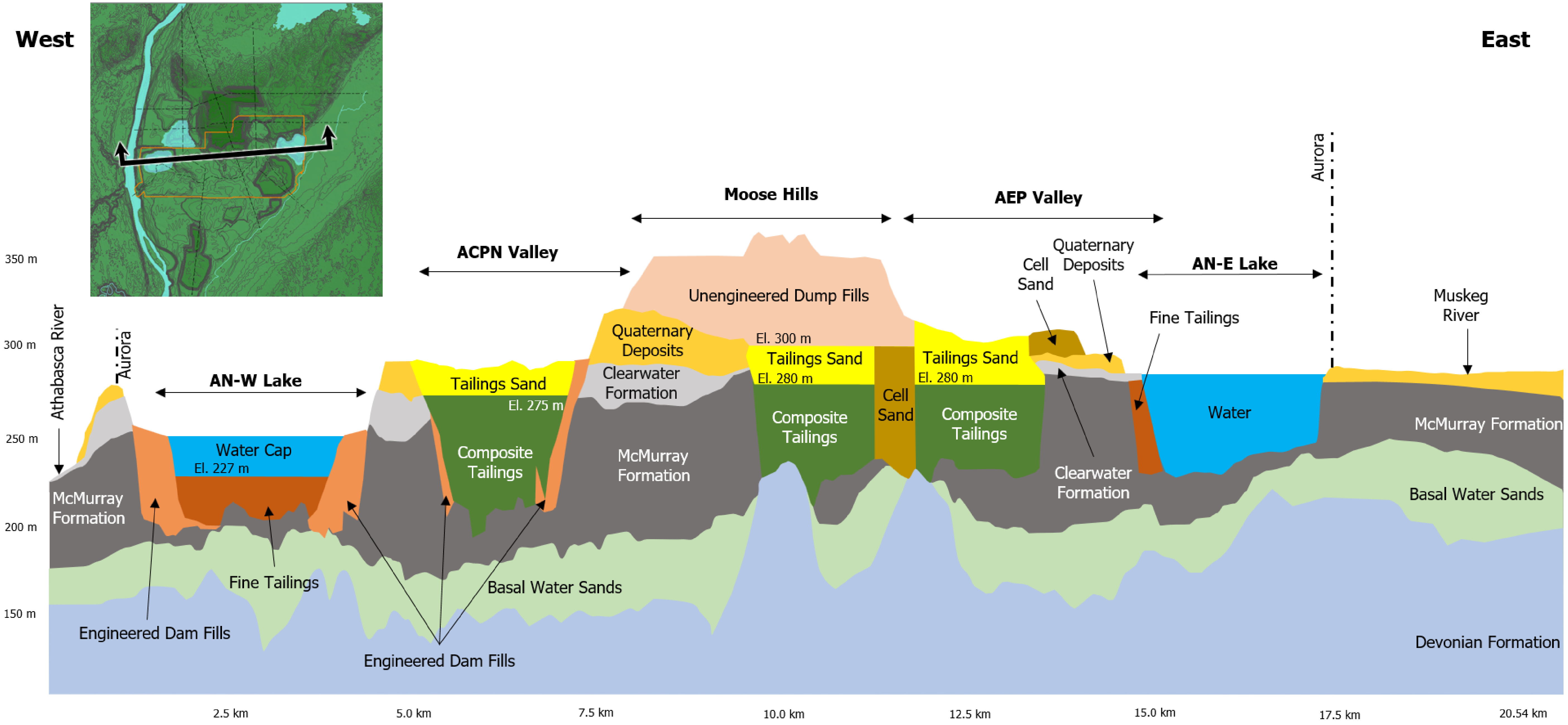
The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.

AN Cross Section 1
Vertical Exaggeration = 30:1



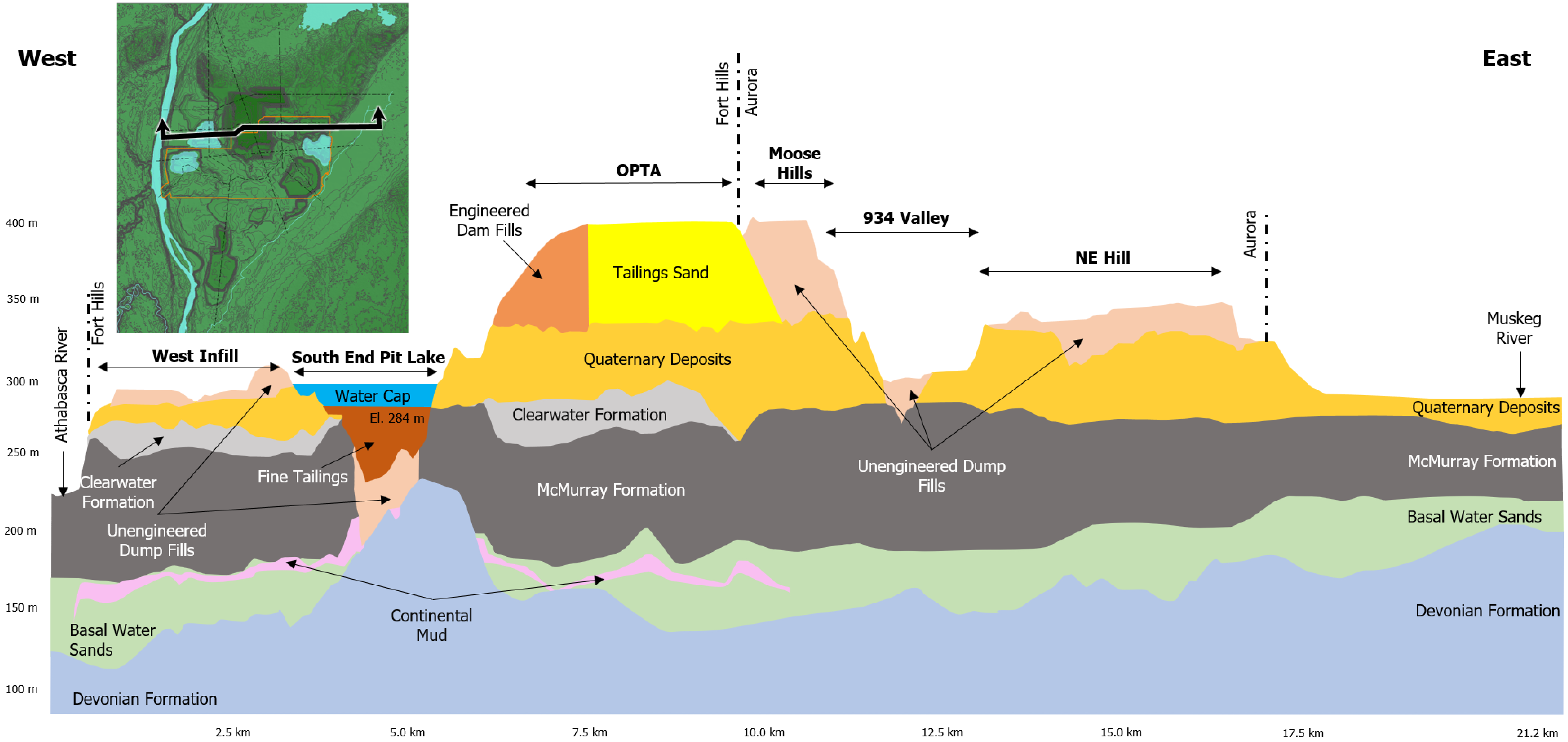
The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.

AN Cross Section 2
Vertical Exaggeration = 25:1



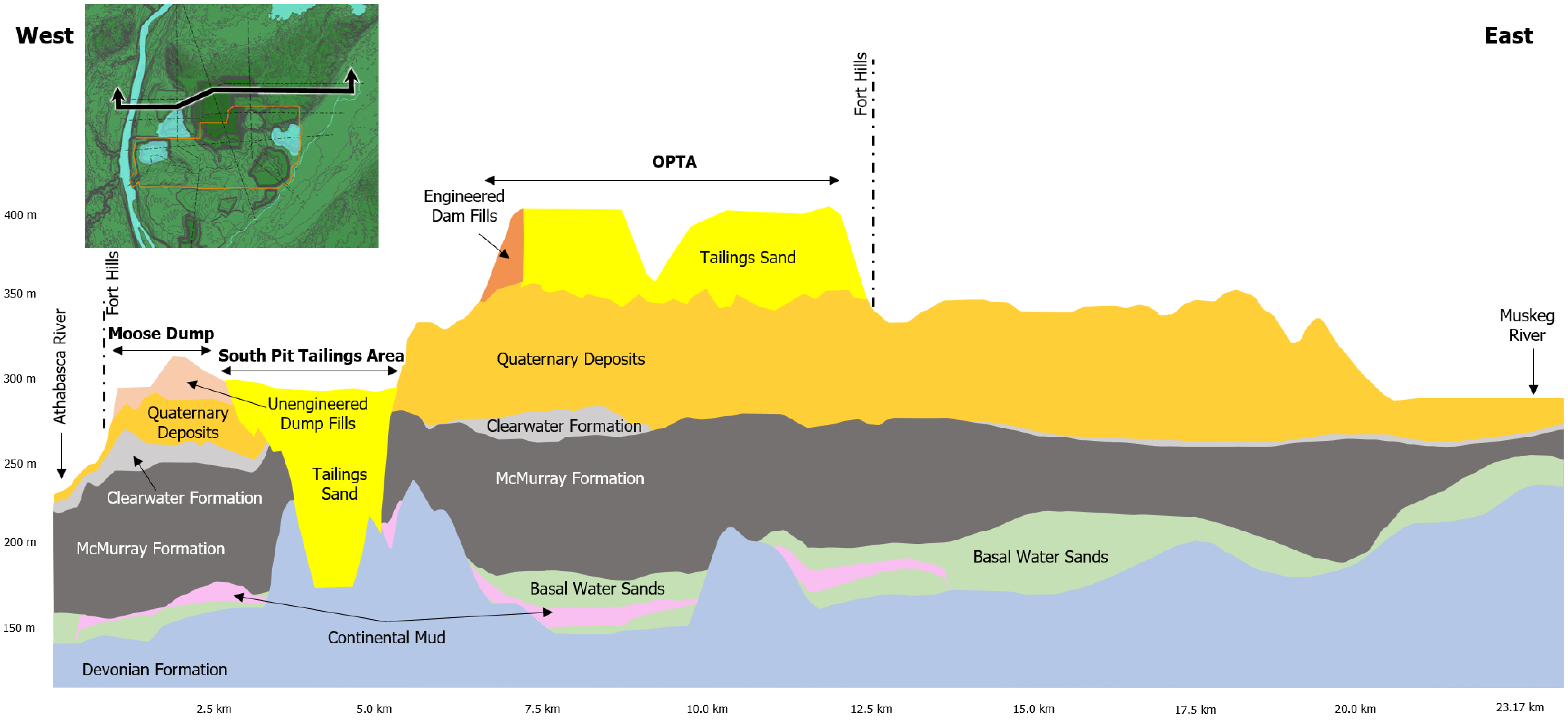
The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.

AN Cross Section 3
Vertical Exaggeration = 23:1



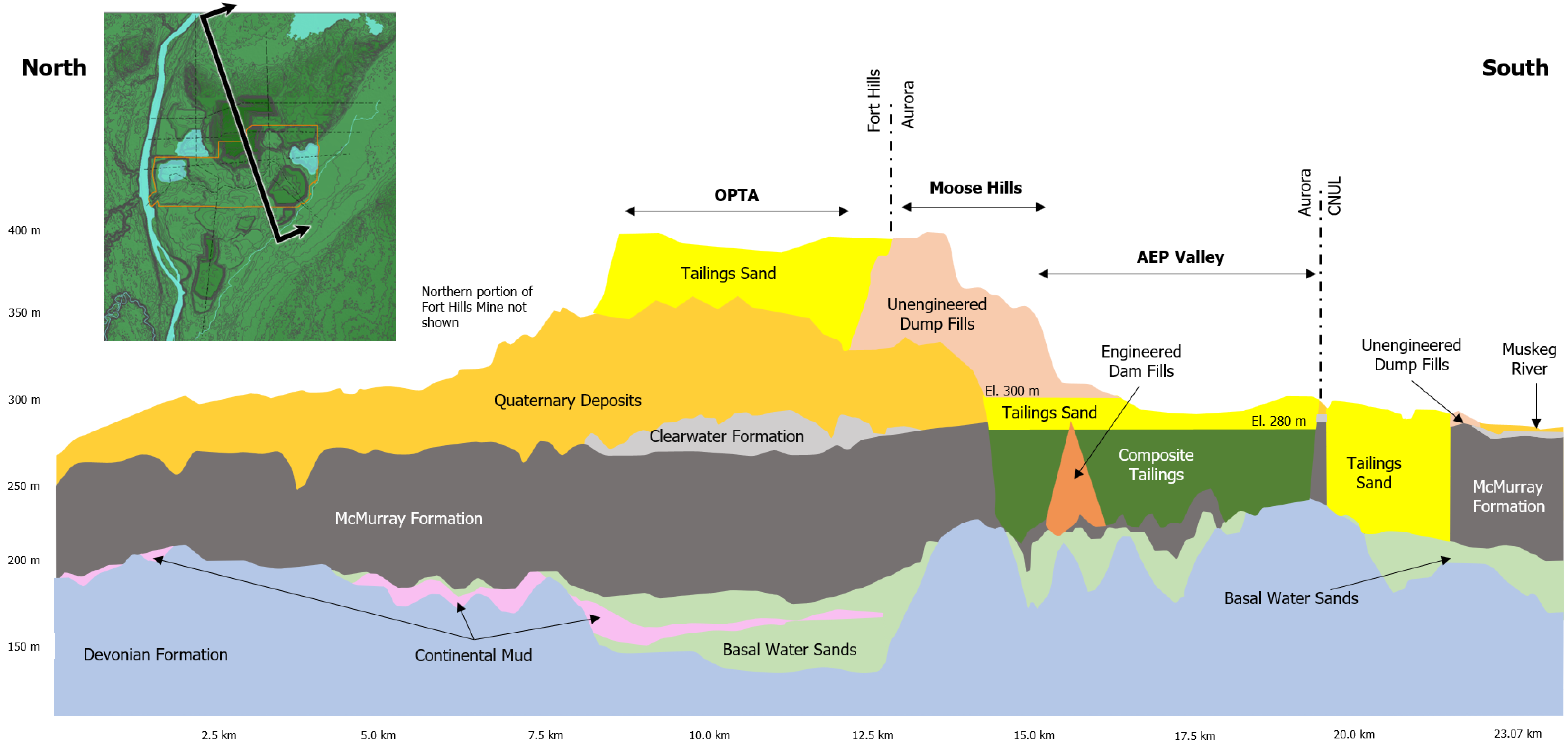
The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.

AN Cross Section 4
Vertical Exaggeration = 25:1



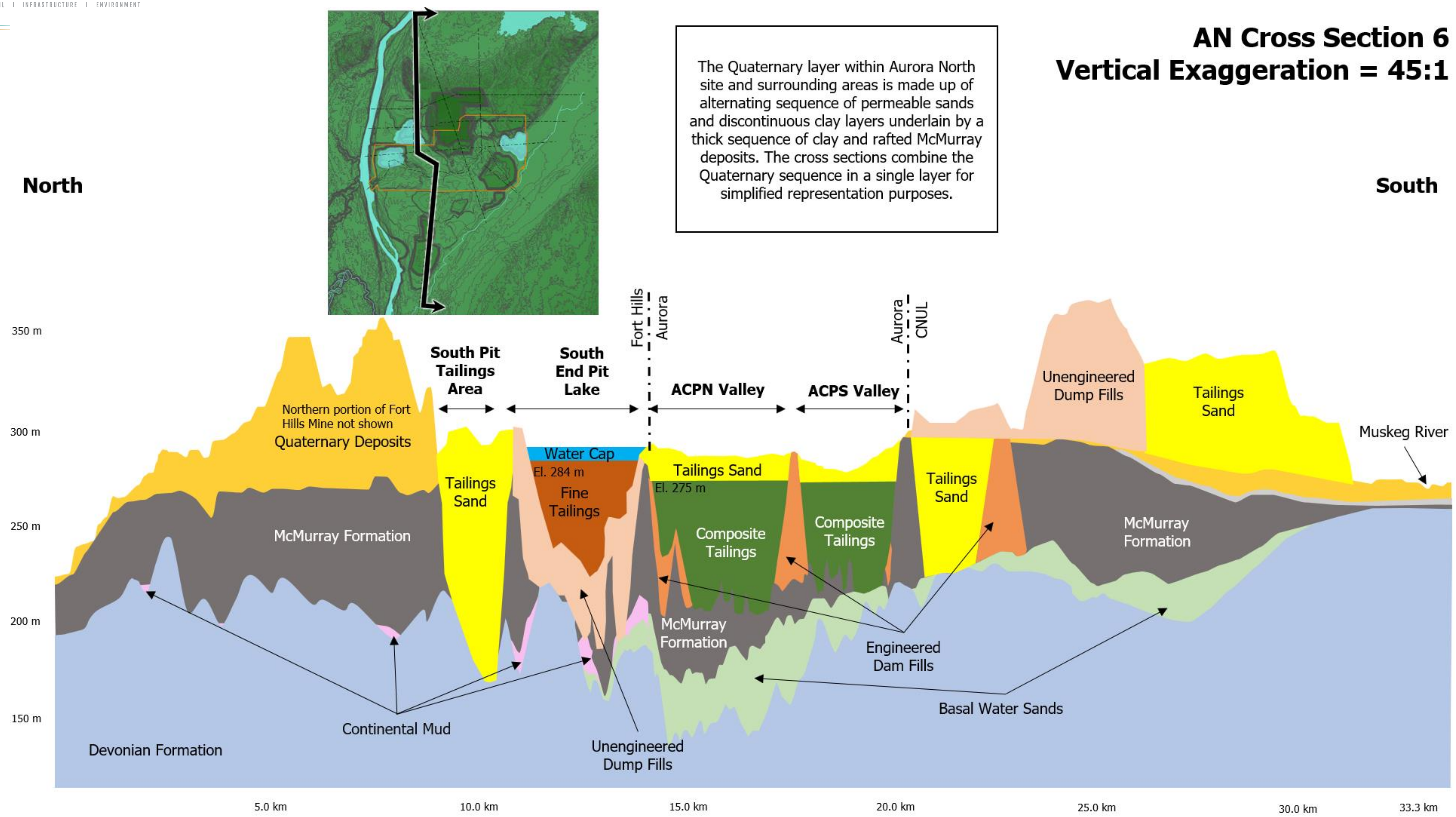
The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.

AN Cross Section 5
Vertical Exaggeration = 25:1



AN Cross Section 6
Vertical Exaggeration = 45:1

The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.



AN Cross Section 7
Vertical Exaggeration = 25:1

The Quaternary layer within Aurora North site and surrounding areas is made up of alternating sequence of permeable sands and discontinuous clay layers underlain by a thick sequence of clay and rafted McMurray deposits. The cross sections combine the Quaternary sequence in a single layer for simplified representation purposes.