2023 Pit Lake Monitoring and Research Report
(Base Mine Lake Demonstration Summary: 2012-2022)

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

Submitted to:

Alberta Energy Regulator

Submitted by:

Suncor Energy (Syncrude) Operating Inc. (SESOI)

September 29, 2023

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Findings and interpretations found in this report are superseded by any future Base Mine Lake report. This report represents the data and interpretations from data collected from Base Mine Lake 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 2023 Life of Mine Closure Plan (LMCP) includes three planned pit lakes at the Mildred Lake site (including Base Mine Lake) and two at 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 management challenge is the long period of time it can take for some of the smallest solid components (fines) to settle within the fluid tailings[3]. As a result, application of fluid tailings 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 fluid tailings, including the Water-Capped Tailings Technology (WCTT).

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 fluid tailings. The technology involves the placement of fluid tailings in-pit, followed by capping with a sufficient layer of water to enable low-energy water treatment processes within the engineered pit lake facility. 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 to the lake, the water quality improves over time.

In 1994, Syncrude received endorsement from the Energy Resources Conservation Board (ERCB) for the proposed WCTT concept, as well as specific approval to develop Base Mine Lake 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 Base Mine Lake demonstration.

[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.

For tailings ponds that transition into pit lakes, the lake is typically commissioned once tailings solids infilling is complete, and the facility is no longer utilized for active tailings management. For the Base Mine Lake demonstration, placement of fluid tailings 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 Base Mine Lake 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 Base Mine Lake from Beaver Creek Reservoir and as required, water is pumped out of Base Mine Lake 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 Base Mine Lake, and outflow is established to the receiving environment.

Syncrude submitted its first Base Mine Lake Research and Monitoring Plan to AEP in 1996. An updated Base Mine Lake Monitoring Plan and an updated Base Mine Lake Research Plan were further submitted to the former Alberta Environment and Sustainable Resource Development (AESRD) in 2012 and 2013, respectively. Syncrude submitted its latest Base Mine Lake Monitoring and Research Plan to the 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 Base Mine Lake 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 Base Mine Lake 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 Base Mine 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 monitoring and research program is to support the demonstration of the WCTT and to provide a body of scientific evidence which demonstrates that Base Mine Lake is on a trajectory to become integrated into the reclaimed landscape.

Demonstrating the physical isolation of tailings fines beneath the water cap of Base Mine Lake 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 Base Mine Lake, as expected. The 2023 Tailings Management Plan submission includes ready to reclaim criteria for the fine tailings in Base Mine Lake as the tailings have undergone self-weight consolidation and remain sequestered under the water cap.

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

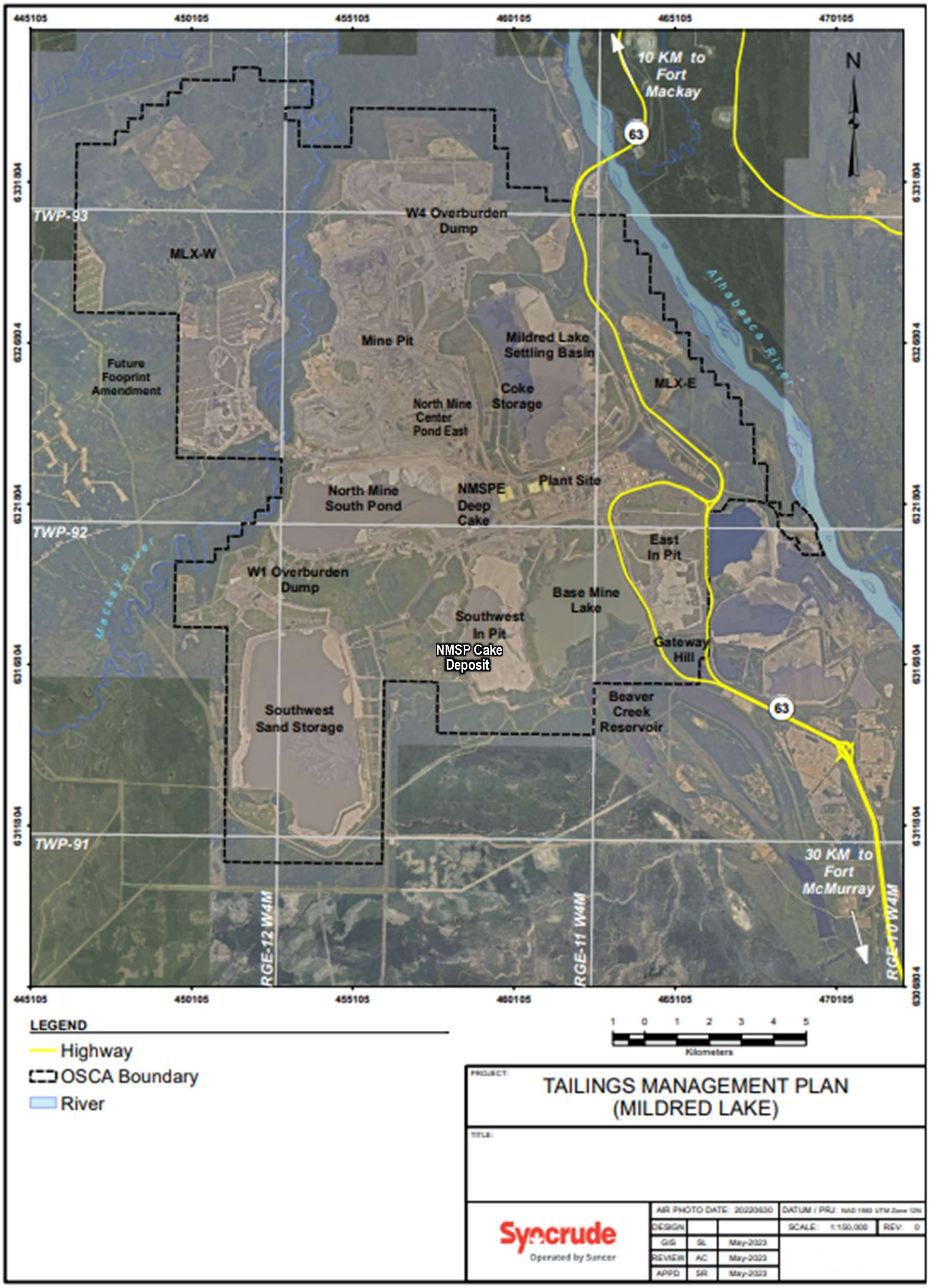


Figure 2-1: Mildred Lake Site Overview

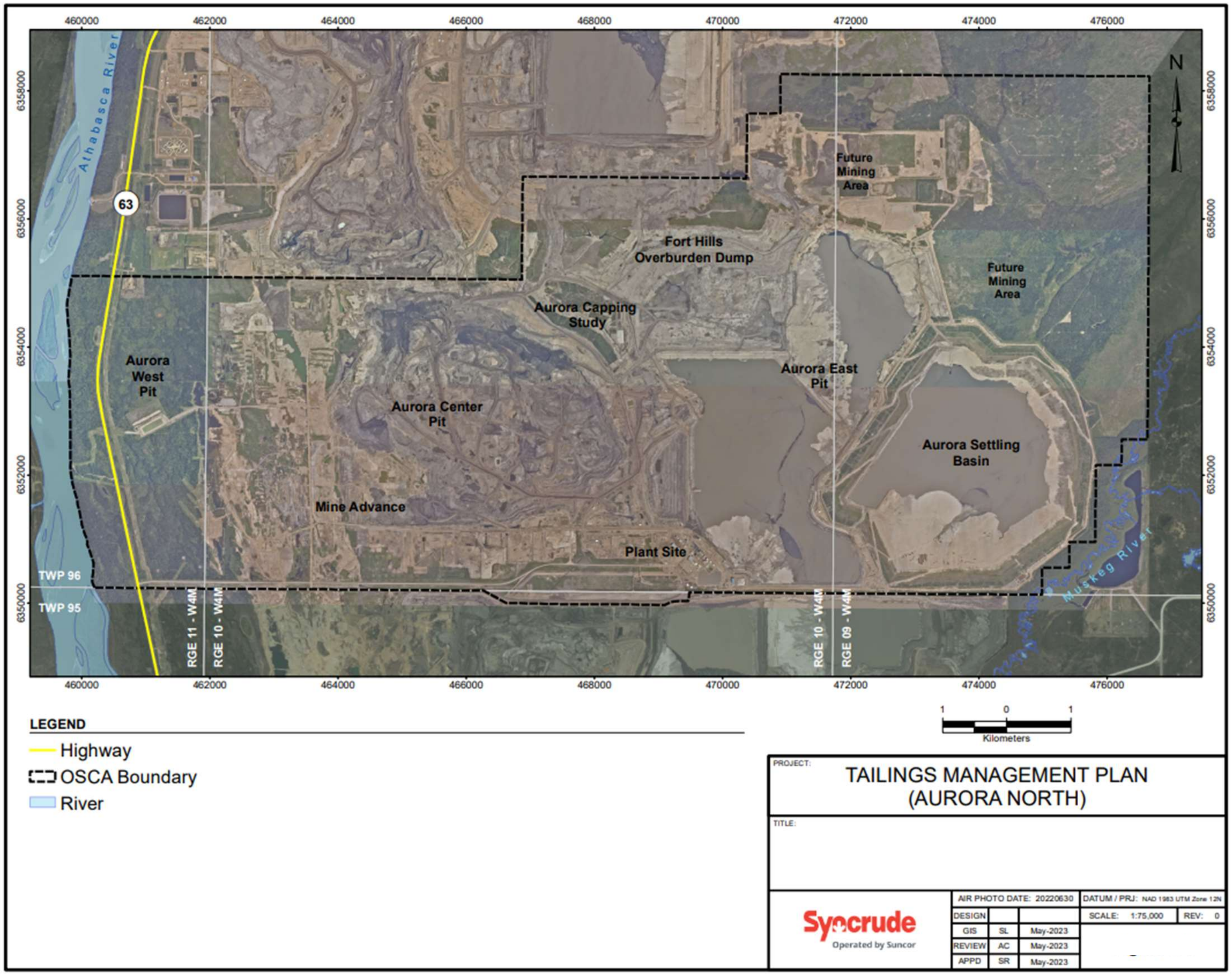


Figure 2-2: Aurora North Site Overview

2.2 Regulatory Context

Syncrude received *Environmental Protection and Enhancement Act* (EPEA) Approval 26-03-00 ("the EPEA Approval") from the Alberta Energy Regulator (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.

Base Mine Lake 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 Base Mine Lake demonstration. In accordance with EPEA Approval conditions 7.5.5 and 7.5.7, Syncrude submitted an updated Base Mine Lake 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 environmental performance in Canada's oil sands through collaborative action and innovation. Along with Syncrude's Base Mine Lake 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*

[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.

(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 Base Mine Lake 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;	Life of Mine Closure Plan Mine Reclamation Plan Base Mine Lake Monitoring and Research Plan
(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;	Life of Mine Closure Plan Base Mine Lake Monitoring and Research Plan
(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 Pit Lake Monitoring and Research Annual 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;	Life of Mine Closure Plan
(f) confirmation of the assumptions and expectations for water quality release outlined in the application, including refinement, update, and validation of the predictive models;	Life of Mine Closure Plan Base Mine Lake Monitoring and Research Plan Pit Lake Monitoring and Research Annual Report
(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;	Life of Mine Closure Plan
(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

Condition 5.2.4 Requirement	Submission
(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 (iv) optimize water residence time with particular consideration of salinity;	Life of Mine Closure Plan Base Mine Lake Monitoring and Research Plan
(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;	Life of Mine Closure Plan 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;	Life of Mine Closure Plan 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;	Life of Mine Closure Plan Base Mine Lake Monitoring and Research Plan
(v) how Syncrude will address uncertainties and risks where BML research is not applicable;	Life of Mine Closure Plan 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.	N/A

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;	7
(b) a summary of the results of research for the previous year;	8
(c) a description and presentation of trends across all timeframes;	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.	N/A

The following Pit Lake Monitoring and Research Report summarizes the key findings from the Base Mine Lake monitoring and research program for 2022. 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'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 fluid tailings volumes. The primary objective of the TMF is to reduce fluid tailings accumulation on the landscape by ensuring that fluid tailings 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 fluid tailings 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, fluid tailings 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.

- <u>Life of Mine Closure Plan</u>

  A Life of Mine Closure Plan (LMCP) is a project-level plan required under EPEA (SED-003) for mineable oil sands projects. Syncrude submitted an updated LMCP to the AER in 2023 for the Mildred Lake and Aurora North sites. 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 fluid tailings 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. 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 fluid tailings throughout the life of the Mildred Lake and Aurora North projects. The 2023 TMP submission includes ready to reclaim criteria for the sequestered tailings in BML. 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.

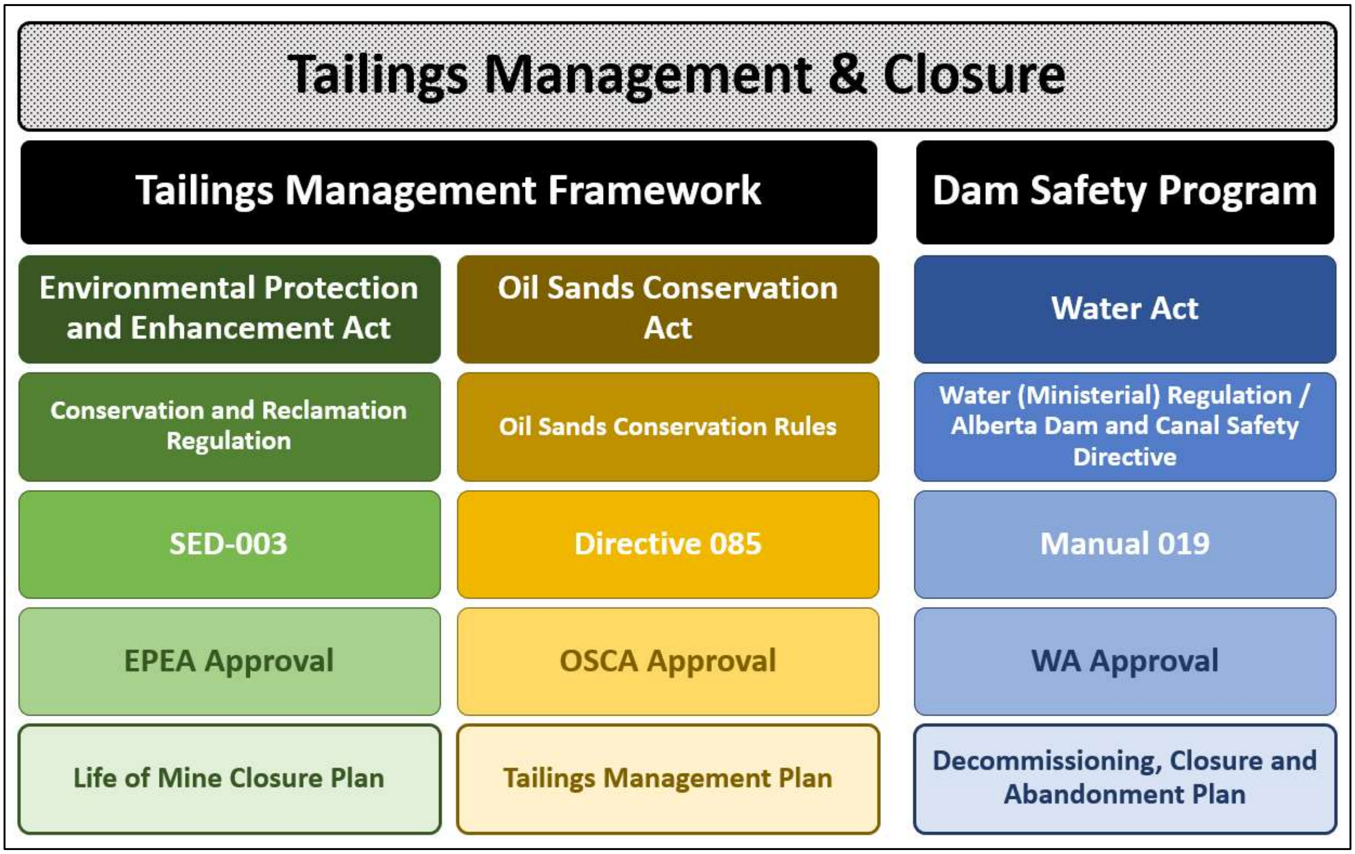


Figure 3-1: Tailings Management and Closure Regulatory Overview

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 (Base Mine Lake demonstration)
- Composite Tailings
- Centrifuge Cake
- Flocculated Tailings, and
- Fluid Tailings/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 fluid tailings management technologies, including the co-deposition placement.

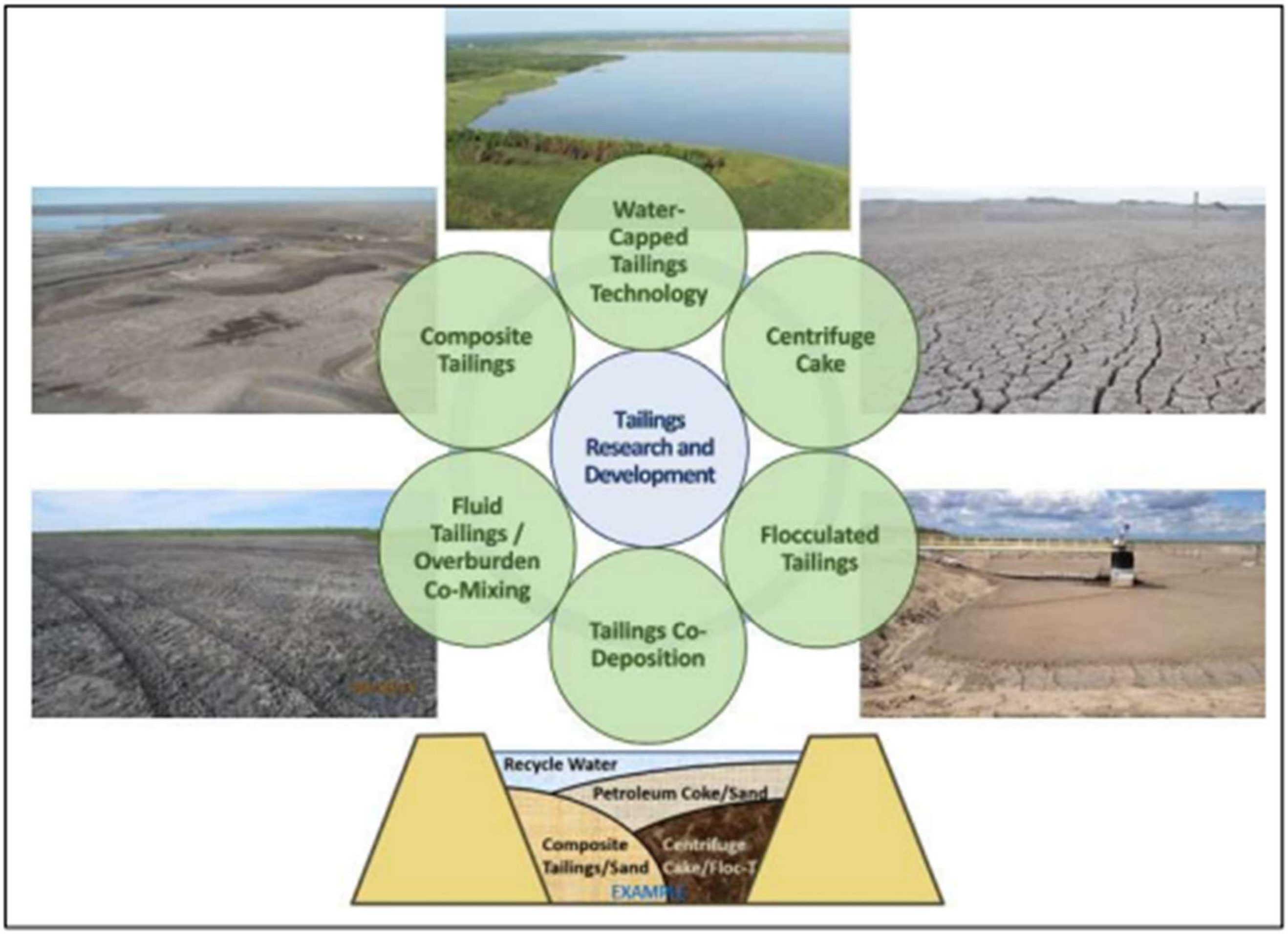


Figure 3-2: Overview of Syncrude Fluid Tailings Implemented Management Technologies

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 an effective planning and incorporation of research results. Pit lakes have been part of oil sands mine closure plans since the first mine was opened in 1967 and are the most researched component 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 to date 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).

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 lake water quality improves over time.

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

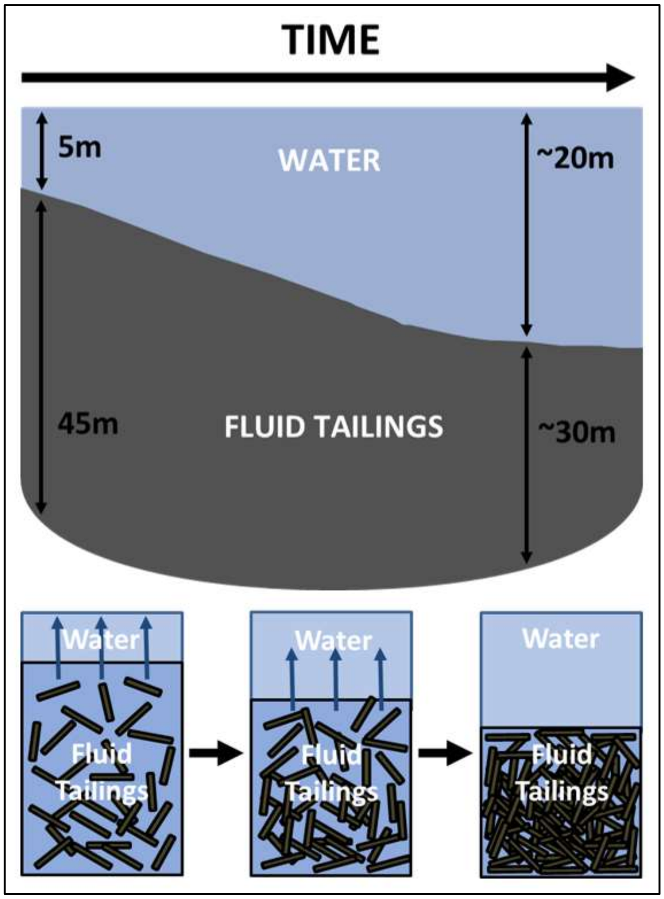


Figure 3-3: Simplified Depiction of Water-Capped Tailings Settlement over Time (not to scale)

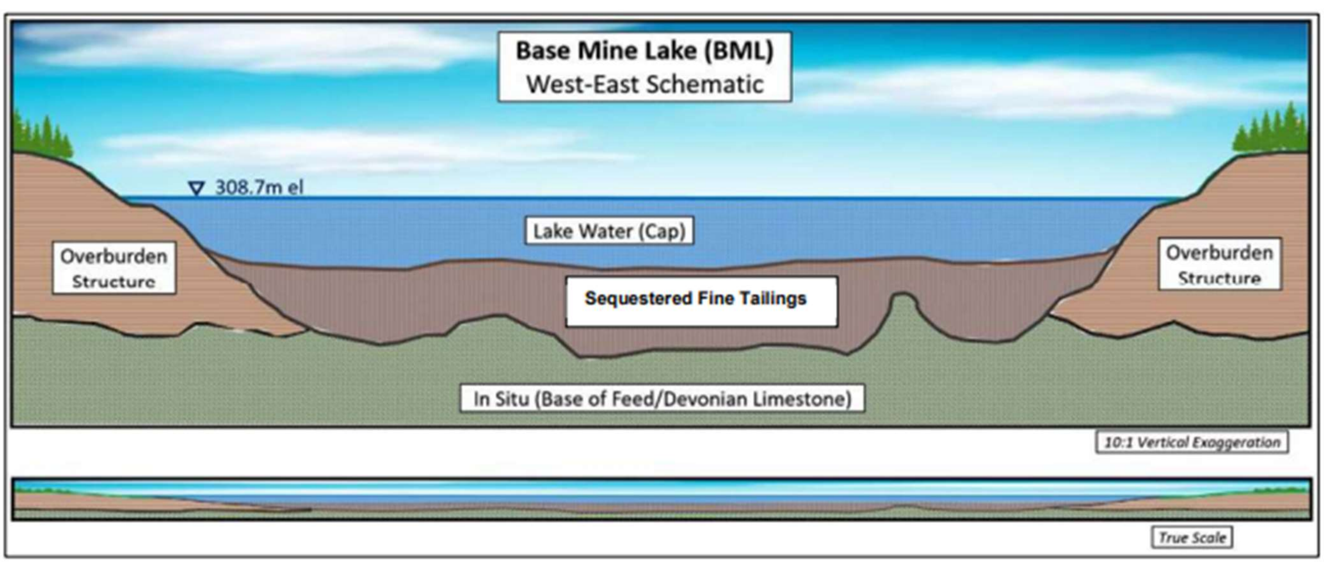


Figure 3-4: Water-Capped Tailings Technology Schematic (not to scale)

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 fluid tailings. 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 m3 to 140 thousand m3 total volume. Some ponds were filled with approximately three metres of fluid tailings 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:

- Naturally occurring bacteria can be relied upon to break down many compounds, such as ammonia, sulfate and dissolved organics;

- The relatively small-scale test ponds demonstrated that acute water toxicity dissipated quickly (weeks to months), and chronic toxicity declined over time. These small ponds did not exhibit conventional boreal lake mixing dynamics (dimixis) that are important drivers of lake performance at full-scale; and

- For the Base Mine Lake 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 Base Mine Lake demonstration, which was commissioned on December 31, 2012.

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

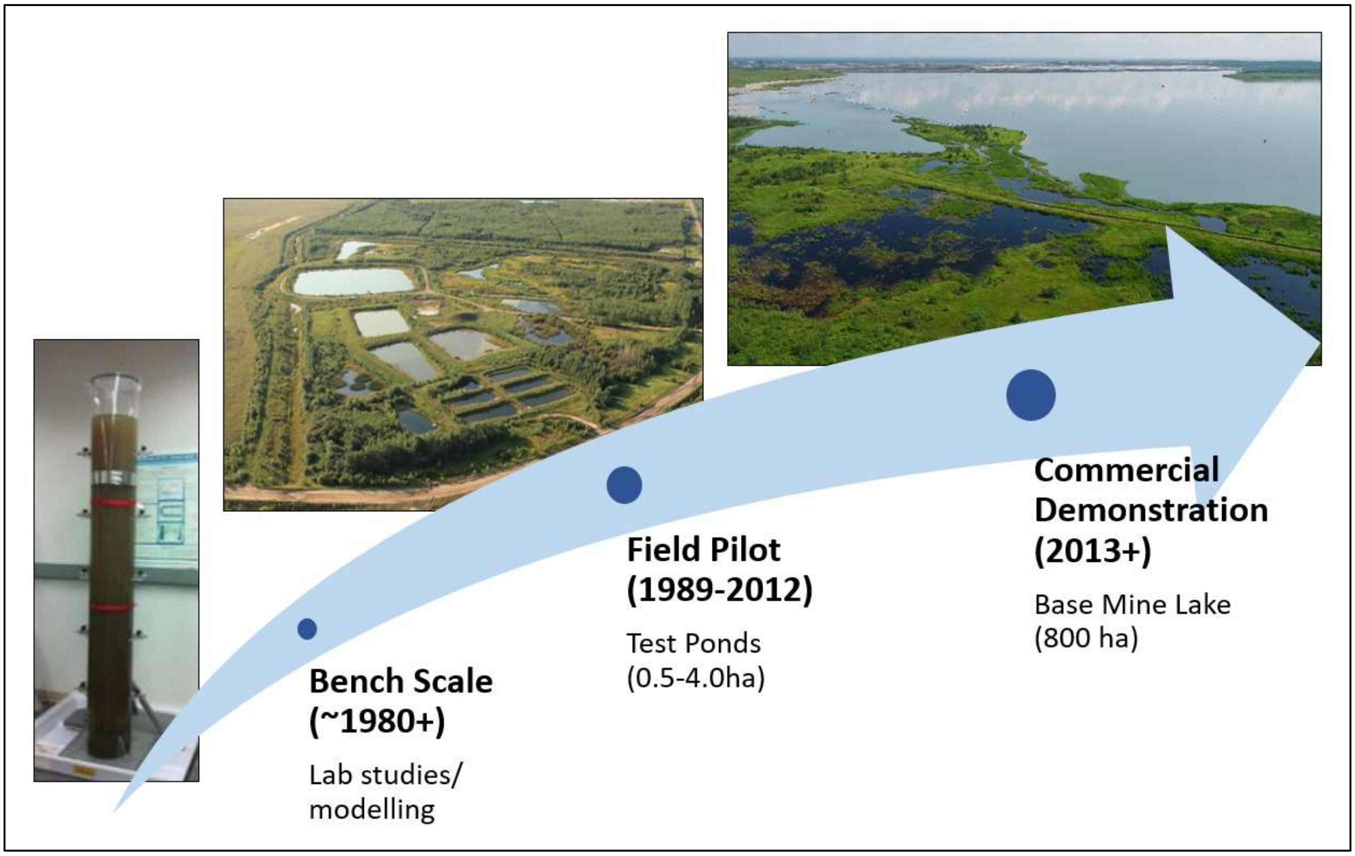


Figure 3-5: Progression of Water-Capped Tailings Research and Development

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 Energy Resource Conservation Board (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 fluid tailings 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 (FFT) 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 FFT with a 5 m water cap. This test became known as the Base Mine Lake (BML) 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 *Environmental Protection and Enhancement Act* (EPEA), in March 1995, Syncrude submitted Application No. 002-26 to the former Alberta Environmental Protection (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 Base Mine Lake 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 Pond 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 fluid tailings, the first milestone is typically meeting Ready-to-Reclaim (RTR) criteria. Directive 085 defines RTR as the "state achieved when fluid tailings 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 fluid tailings deposits. Once a fluid tailings 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 fluid tailings 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 ponds 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.

Figures 3-6 and 3-7 illustrate the relationship between reclamation stages, as well as progressive reclamation and certification milestones for pit lakes and aquatic reclamation, as provided by Syncrude in the LMCP.

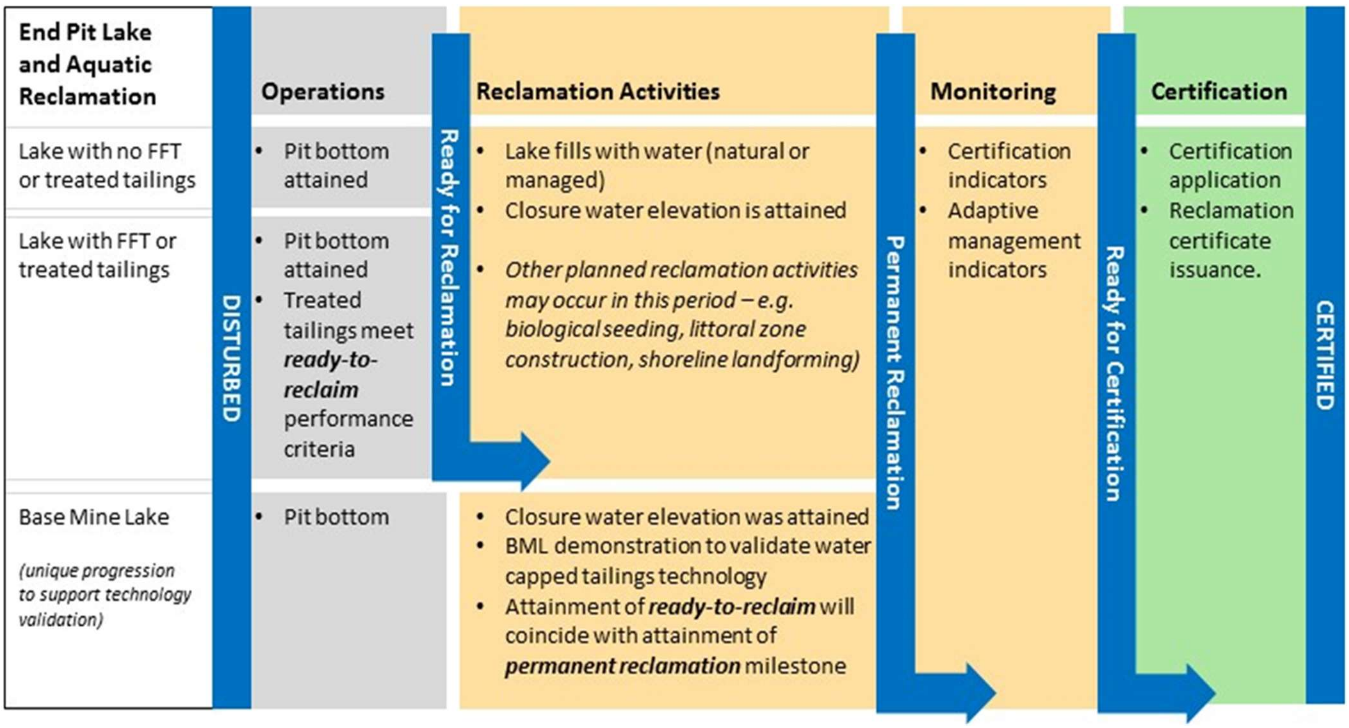


Figure 3-6: Conceptual Diagram of Progressive Certification Stages and Milestones for Pit Lake and Aquatic Reclamation (Syncrude 2016)

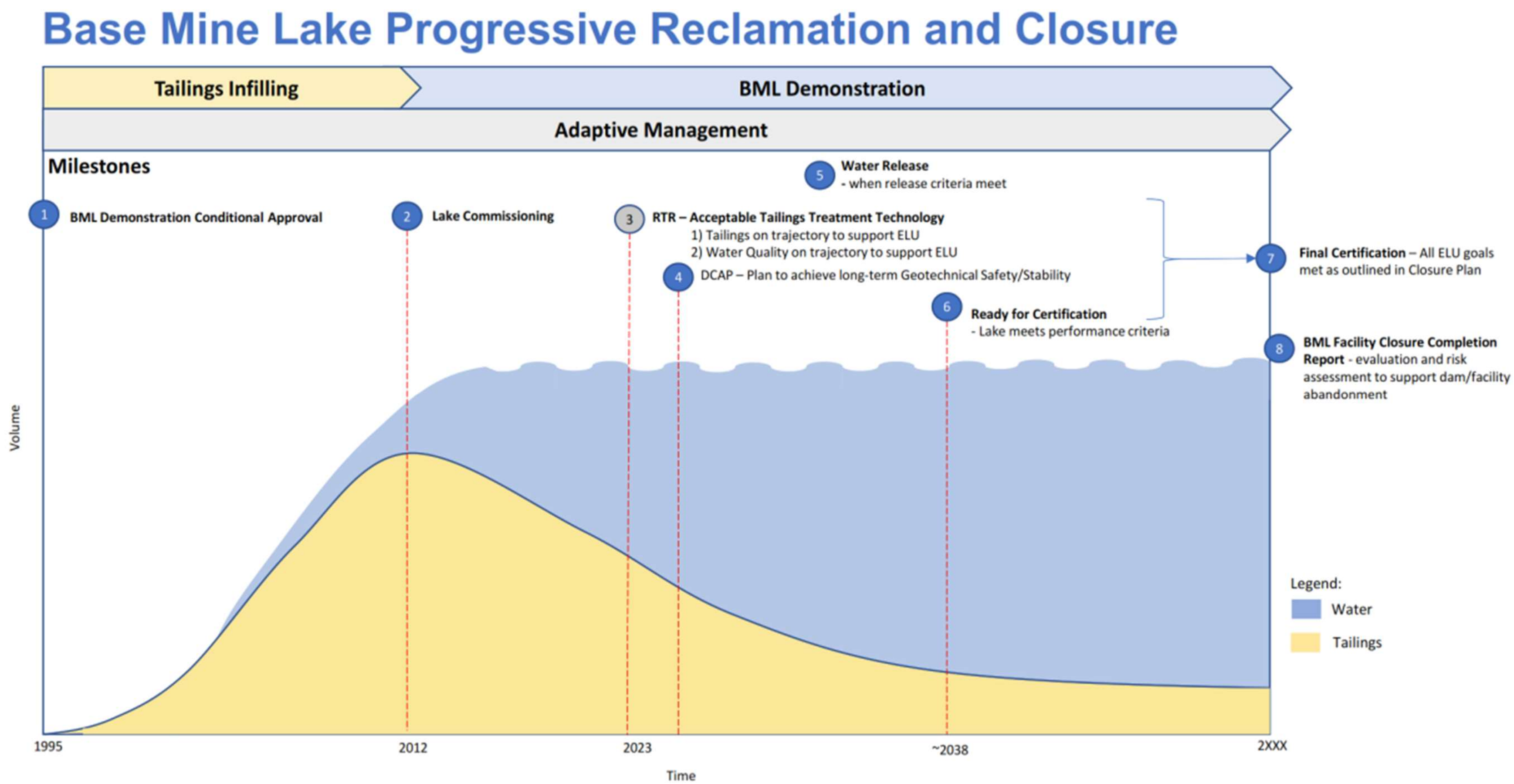


Figure 3-7: Base Mine Lake Progressive Reclamation and Closure

3.6 Syncrude's Planned Pit Lakes

Syncrude's 2023 LMCP includes 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 Base Mine Lake integrated monitoring and research program will be helpful in ensuring that these future standards can be met. 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 Pit 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.	• West Mine Lake

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 the 2023 LMCP submission.

Figure 3-8 and Figure 3-9 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, as provided in the 2023 LMCP.

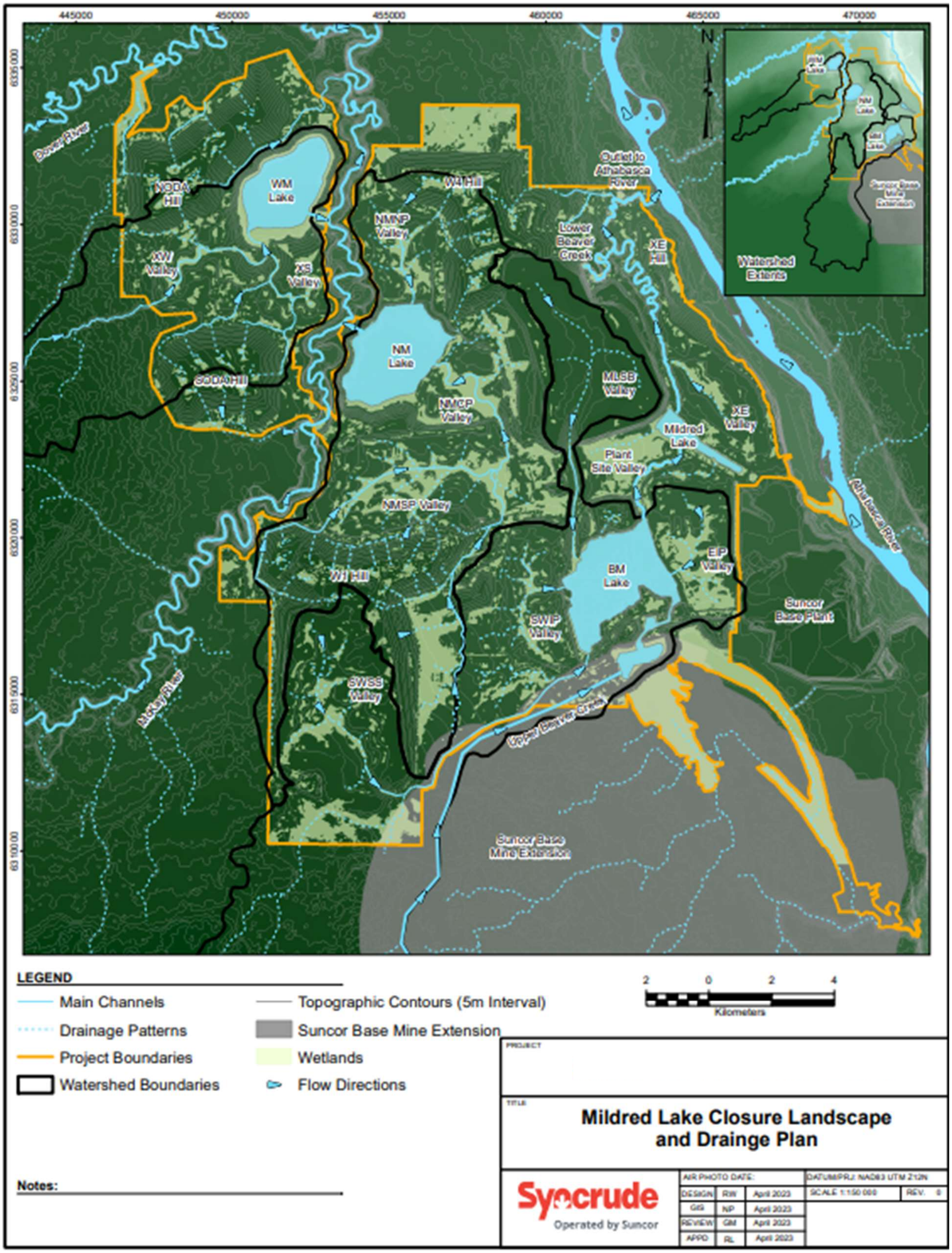


Figure 3-8: Mildred Lake Site Closure Overview (Syncrude 2023)

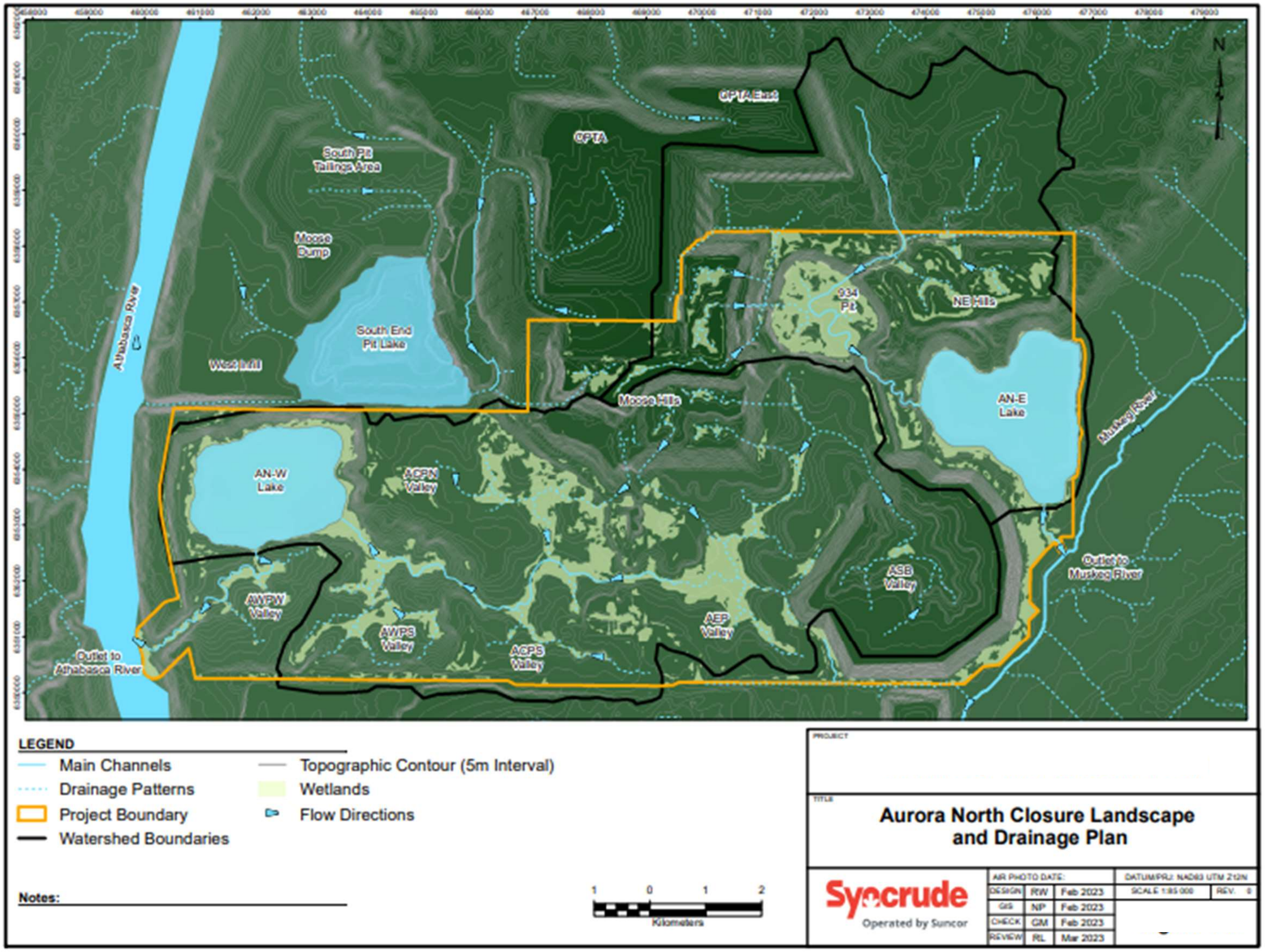


Figure 3-9: Aurora North Site Closure Overview (Syncrude 2023)

3.7 Regional Pit Lake Research Initiatives

Syncrude participates in regional pit lake research initiatives through its membership with COSIA. In addition to Base Mine Lake, 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. Additional details can be found in the COSIA annual reports posted online at www.cosia.ca.

3.7.1 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 fluid tailings, 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 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-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]

3.8 Base Mine Lake Demonstration Overview

Base Mine Lake 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

[5] Suncor Energy Inc. [Suncor] 2021. Pit Lake Research and Development Report. Submitted to the AER on April 28, 2021. Fort Hills Energy L.P. 2022. Pit Lake Research and Development Report. Submitted to the AER on April 29, 2022.

[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

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 Base Mine Lake into the closure landscape and obtain reclamation certification.

Placement of fluid tailings 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 Base Mine Lake 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). Base Mine Lake has a fluid surface area of roughly 800 hectares and a total volume of roughly 240 Mm^3 (fluid tailings + water). An aerial overview of Base Mine Lake within the Mildred Lake site is shown in Figure 3-10.

Infrastructure has been installed to pump fresh water into Base Mine Lake from Beaver Creek Reservoir and as required, water is pumped out of Base Mine Lake 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 Base Mine Lake, and outflow is established to the receiving environment (i.e., Athabasca River). Design features incorporated into Base Mine Lake 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 Base Mine Lake 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 Base Mine Lake is on a trajectory to become integrated into the reclaimed landscape.

Results from the Base Mine Lake monitoring and research program have been shared with the AER through biennial/annual summary report submissions and annual update meetings. The last summary report (2022 Pit Lake Monitoring and Research Report) was submitted to the AER on June 30, 2022, in accordance with Syncrude's EPEA Approval.

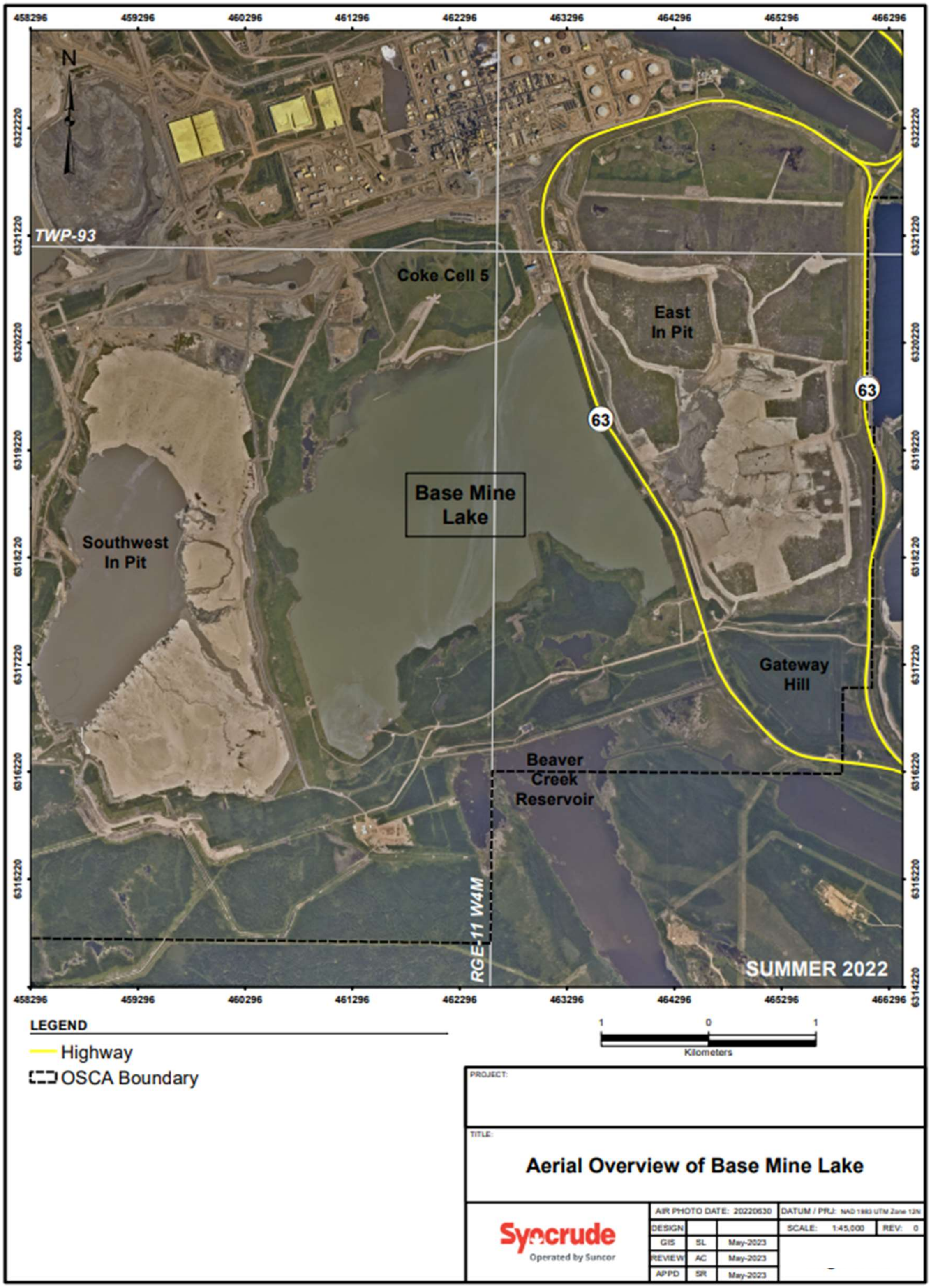


Figure 3-10: Aerial Overview of Base Mine Lake

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 Base Mine Lake demonstration. The Base Mine Lake 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 Base Mine Lake demonstration, combined with learnings from regional pit lake research initiatives, are being used to inform Syncrude's future pit lake designs and plans.

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.

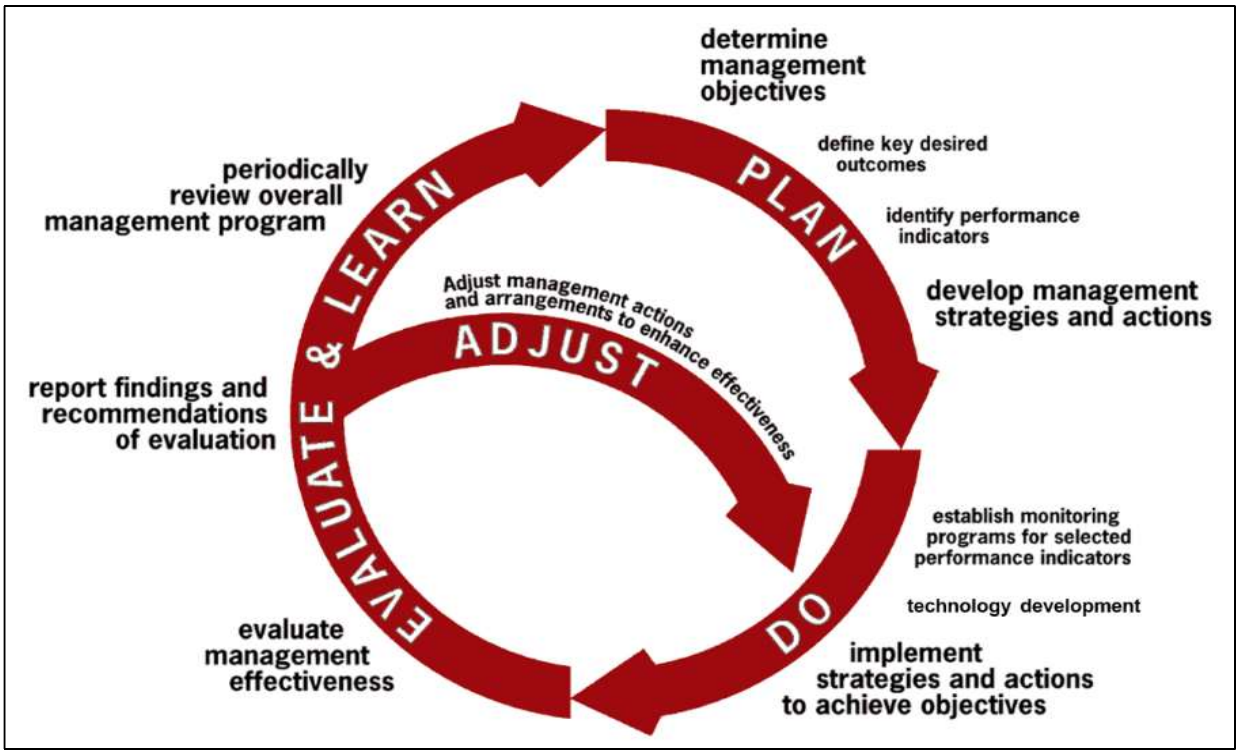


Figure 4-1: The Adaptive Management Cycle (after Jones 2005)

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 Base Mine Lake in the following sections.

4.3 Adaptive Management Approach for Base Mine Lake

The adaptive management approach for Base Mine Lake 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 Base Mine Lake are described herein.

4.3.1 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.

4.3.1.1 Key Desired Outcomes

In general, pit lakes will support ecological functions and lake specific wildlife habitat. The specific end land use goal for Base Mine Lake is that the lake will support lake ecological functions, including sustainable small-bodied fish populations (Syncrude 2016). Base Mine Lake 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).

4.3.1.2 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 Base Mine Lake, each with unique performance indicators. 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. Base Mine Lake is expected to change over time and performance expectations for each milestone are necessarily different.

4.3.1.2.1 Shorter-Term Performance Indicators

Syncrude has identified the following Base Mine Lake performance indicators for validation of the WCTT:

- 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 fluid tailings 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).

4.3.1.2.2 Longer-Term: Performance Indicators to Support Reclamation Certification

Certification of Base Mine Lake 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 Base Mine Lake 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).

4.3.2 Adaptive Management: Do, Evaluate and Learn

A key purpose of the Base Mine Lake 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 Base Mine Lake is on a trajectory to become integrated into the reclaimed landscape. The outcomes from the Base Mine Lake 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 Base Mine Lake, 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 Base Mine Lake 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 Base Mine Lake monitoring and research program supports the adaptive management of the lake's performance towards attainment of the key desired outcomes.

At the time of writing, the Base Mine Lake demonstration is supported as a Joint Industry Project (JIP) under COSIA. As such, the Base Mine Lake 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.

4.3.2.1 Base Mine Lake Monitoring Program

The specific objective of the Base Mine Lake monitoring program is to provide information to support WCTT as a viable tailings management and reclamation option. In the early stages, the Base Mine Lake 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 Base Mine Lake. 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 Monitoring Program Components

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

4.3.2.2 Base Mine Lake Research Program

The Base Mine Lake 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 Base Mine Lake 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 Base Mine Lake towards a functional component of the closure landscape. The current research programs were focused on key parameters influencing early Base Mine Lake 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 fluid tailings 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 oxygen dynamics in the lake. These programs focus on understanding the oxygen balance and process of oxygen consumption (e.g., methanotrophy) and oxygen production (photosynthesis). The research programs associated principal investigators (PIs) and participating universities are summarized in Table 4-2. A list of peer reviewed publications and theses from the research programs is provided in Section 8.9.

Table 4-2: Current Base Mine Lake Research Programs

Research Component	Primary Objective	University	Researchers (PIs)
Physical limnology of Base Mine Lake and the potential for meromixis	To understand the circulation of Base Mine Lake and its potential for meromixis	University of British Columbia	Greg Lawrence / Ted Tedford / Roger Pieters
Field investigation of Base Mine Lake water cap oxygen concentrations, consumption rates and key BOD/COD constituents affecting oxic zone development.	To establish temporal and spatial variability in in-situ Base Mine Lake water cap oxygen concentrations, oxygen consumption rates and identify the biogeochemical processes linked to its consumption from the tailings-water interface to the Base Mine Lake water surface	University of Toronto / McMaster University	Lesley Warren / Greg Slater
Microbial communities and methane oxidation processes in Base Mine Lake	(i) To study Biological Oxygen Demand (BOD) in the lake, (ii) to examine a potential role of methanotrophs in the degradation of naphthenic acids (NAs), and (iii) to examine the microbial community in Base Mine Lake, how the community changes over time with changes in lake chemistry, and the potential use of community analyses as an indicator of reclamation	University of Calgary	Peter Dunfield
Understanding Air-Water Exchanges and the long-term hydrological viability of Base Mine Lake	To measure and improve the understanding of the physical mechanisms controlling CH_4 and CO_2 fluxes across the air-water interface, to determine the factors that control evaporation from Base Mine Lake and to understand the long-term water balance of Base Mine Lake	McMaster University / Carleton University	Sean Carey / Elyn Humphreys
Characterization of Organic Compounds and Naphthenic Acids in Base Mine Lake: Implications for methane production, transport, oxygen consumption, and NA persistence	To understand methane production and release, the sources of naphthenic acids and petroleum hydrocarbons to the Base Mine Lake water cap, and the role of ebullition in transporting fluid tailings constituents into the water cap	McMaster University	Greg Slater
Base Mine Lake Process Dynamics	To understand bitumen liberation to water surface, and develop monitoring and mitigation tools for bitumen	Syncrude	Adedeji Oluwaseun

4.3.3 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 Base Mine Lake performance: application of alum to manage mineral turbidity, and hydrocarbon mitigation.

4.3.3.1 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 lake. 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 Base Mine Lake monitoring and research program for several reasons. First, mineral turbidity in the lake is a result of suspended fine mineral particles; and, 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 alum dosage was effective at reducing turbidity. 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.

4.3.3.2 Hydrocarbon Mitigation

Residual bitumen makes up a relatively small component of the fluid tailings. When FFT was placed in the mined-out pit, some of this residual bitumen separated from the FFT, resulting in bitumen mats forming on the surface of the FFT; primarily focused in areas of the pit of tailings discharge (Figure 4-3 and Figure 4-4). As detected by the Base Mine Lake monitoring program, some residual bitumen is also present as a hydrocarbon sheen on the water surface, some of which has accumulated along the shoreline. 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. Observations and empirical data from both the research and monitoring program has led to the development of a conceptual model (Figure 4-2) which is being tested empirically through several research and monitoring programs. Some results have validated that the bitumen mats were formed as a result of aeration of the tailings at deposition points.

To determine the extent and location of bitumen mats on the surface of the FFT, sonar acoustic imagery, ponar grab sampling of the mudline, and visual observations of bitumen on the water surface and at the FFT surface were used together to determine the location and extent of bitumen mats. Sampling efforts identified bitumen mats on the surface of the FFT in areas of the lake where the FFT was poured, and evidence indicates these mats are not very thick (i.e., centimetres in thickness). These areas are important sources of bitumen to the water column, and it was determined that removal of these mats could lead to a significant improvement in the long-term performance of Base Mine Lake.

In 2018 and 2019, a horizontal auger dredge was deployed in Base Mine Lake to target removal of bitumen mats on the FFT surface. This preliminary dredging effort has provided valuable information to design and develop a more efficient dredging effort using a mechanical clam-shell environmental dredge piloted in 2021. Bitumen dredging activities were paused during the 2020 open water season due to COVID-19 restrictions; however, significant efforts were invested in the development of an ice core analysis program to detect gas and bitumen liberation, which will be used as a tool for monitoring changes after bitumen removal.

Ice cores are a record of bitumen and gas in the lake during the ice-on season. Because there are no internal mixing dynamics of the water column during the ice-on period, the gas and hydrocarbon trapped in the ice core represents gas and bitumen liberation from the FFT directly below the ice core location. Results from the ice core program in 2021 indicated that there are areas of the lake where there is gas and bitumen liberated, and these are located above areas where bitumen mats have been previously detected. There are also other areas of the lake where there is gas but no bitumen liberation (Figure 4-5). This supports the hypothesis that the dominant source of hydrocarbon to the water column is from the bitumen mats.

In 2021, the bitumen mat remediation campaign focused on the bitumen mats in the southwest corner of BML, identified in 2019 using ponar sampling (Figure 4-3). The clamshell dredge targeted bitumen mats on the FFT surface (Figure 4-4E), and each clamshell grab contains bitumen and some water and FFT. The clamshell is emptied into a hopper barge until full. The barge is then transferred to shore where an on-shore excavator moves the material into a truck for disposal (Figure 4-6). The mechanical process of lifting bitumen to the surface and loading barges resulted in an increase in bitumen sheen on the water surface in the area near the dredge. Booming the area and active skimming of the surface sheen was performed during the operation. Photos taken from the edge of dredged bitumen mats suggest the method is working effectively (Figure 4-7).

The Base Mine Lake monitoring and research program will help to determine the effects that bitumen mat removal have on the lake performance in both the short- and the long-term. Preliminary results quantifying gas and bitumen content in ice cores collected in 2022 (post-dredged areas) compared to 2021 (pre-dredged areas) indicate bitumen mat dredging using the environmental clamshell dredge reduces flux of hydrocarbon through the water column (Figure 4-8). A summary of key learnings is presented in section 8.8.

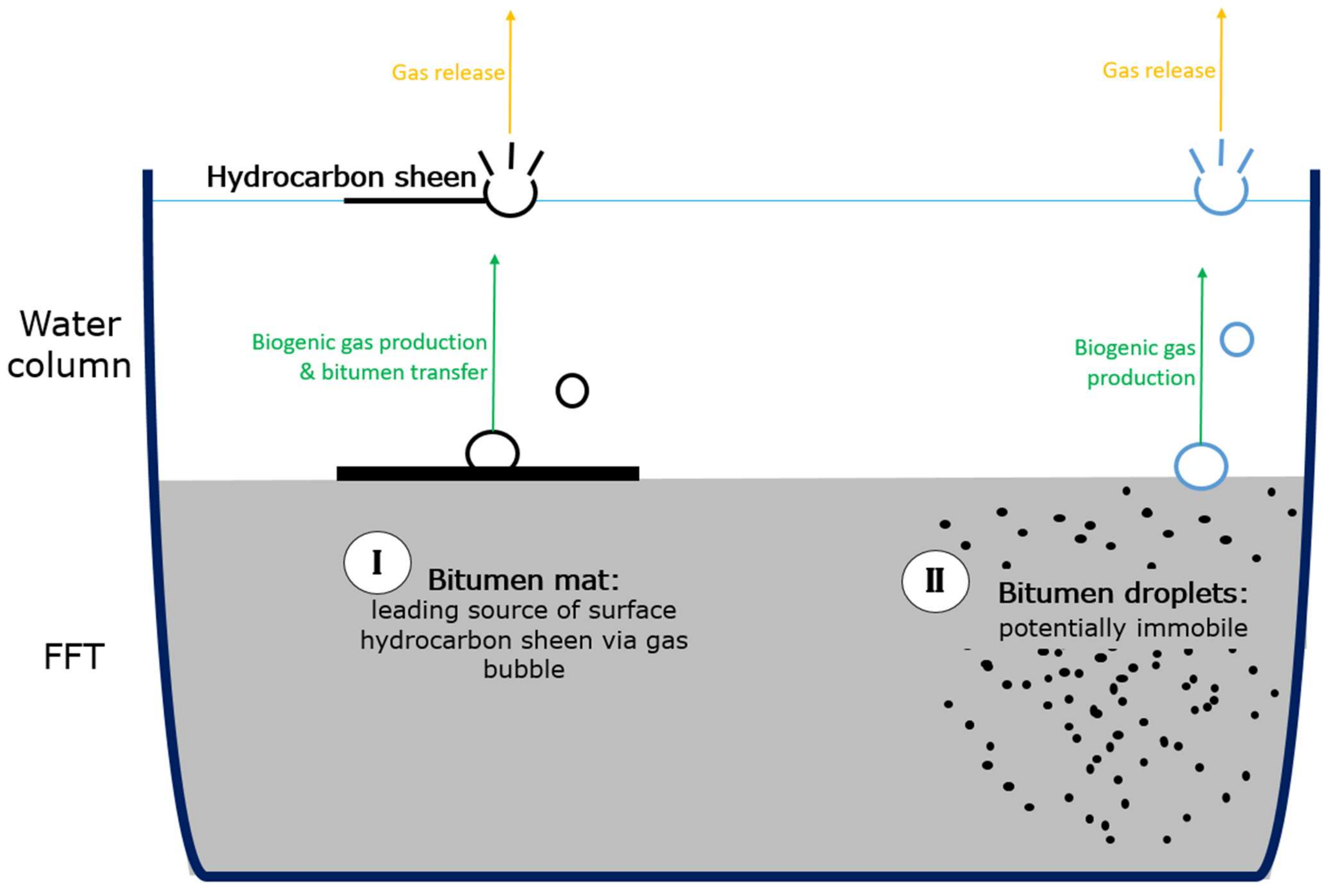


Figure 4-2: Conceptual model of bitumen dynamics in BML

Figure 4-3: Location of bitumen mats identified in 2019 using ponar sampling

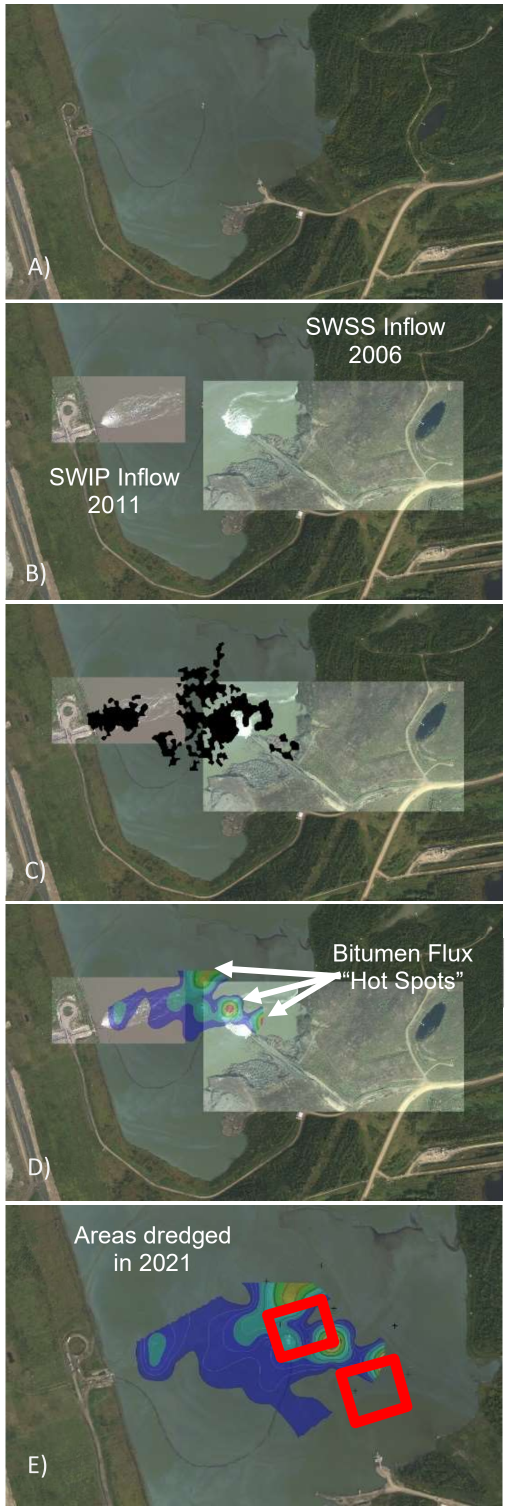


Figure 4-4: Demonstration of bitumen mat and flux hotspots in relation to tailings pour locations: A) BML SW corner, B) image of pouring locations, C) bitumen mat locations detected with ponar sampling, D) bitumen flux hotspots detected through ice core analysis, E) focus of dredging activities in 2021

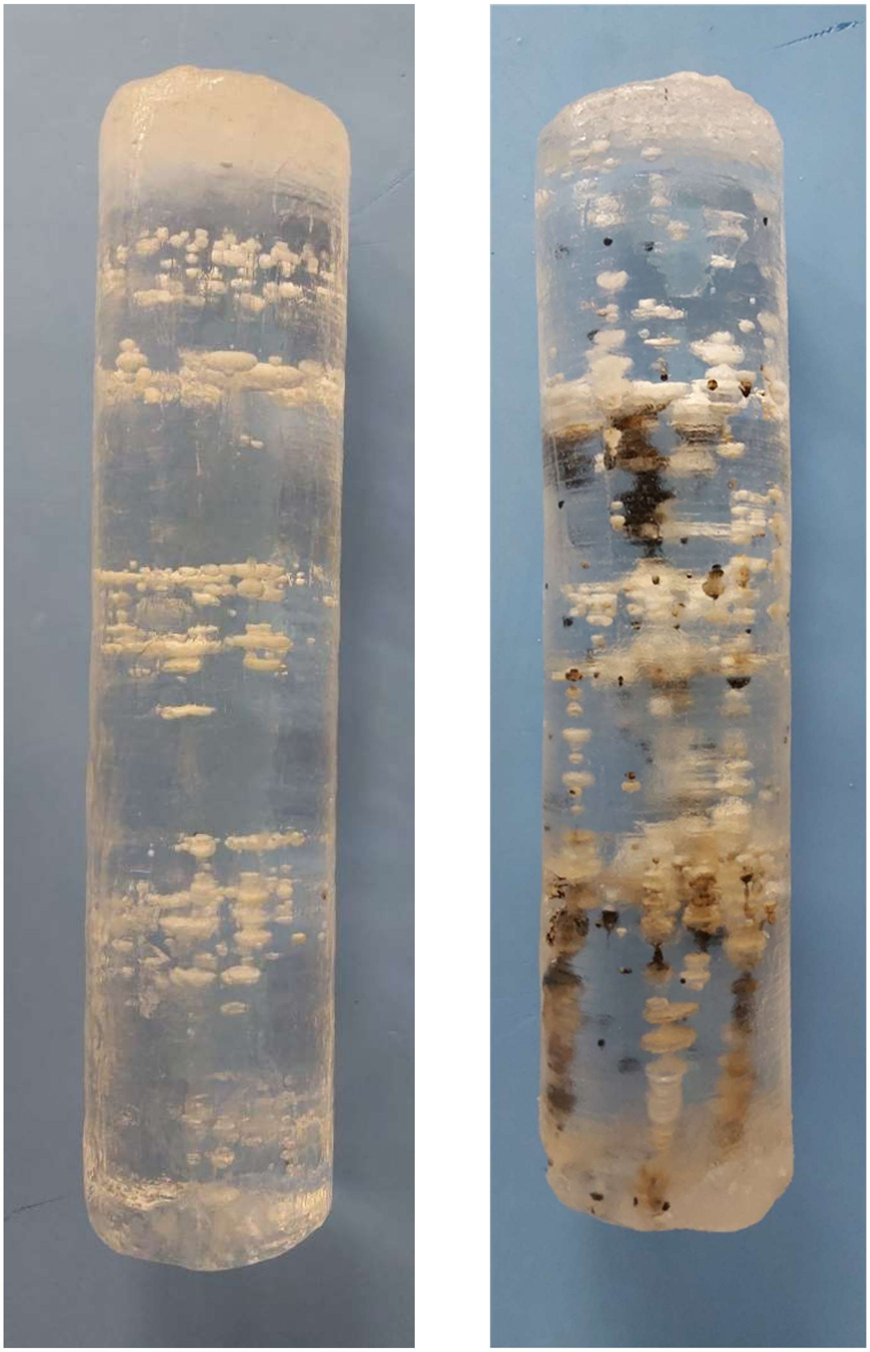


Figure 4-5: Ice core samples from two different areas in BML with gas and no visible bitumen on left and bitumen and gas on right

Figure 4-6: 2021 Clamshell dredge operation method A) material handler on dredge collects bitumen and FFT and water from mudline of BML, B) material handler deposits contents of clamshell into hopper barges until full, C) hopper barges are pushed to shore using tugboats, and D) on-shore excavator moves material from hopper barge into wiggle wagons for disposal

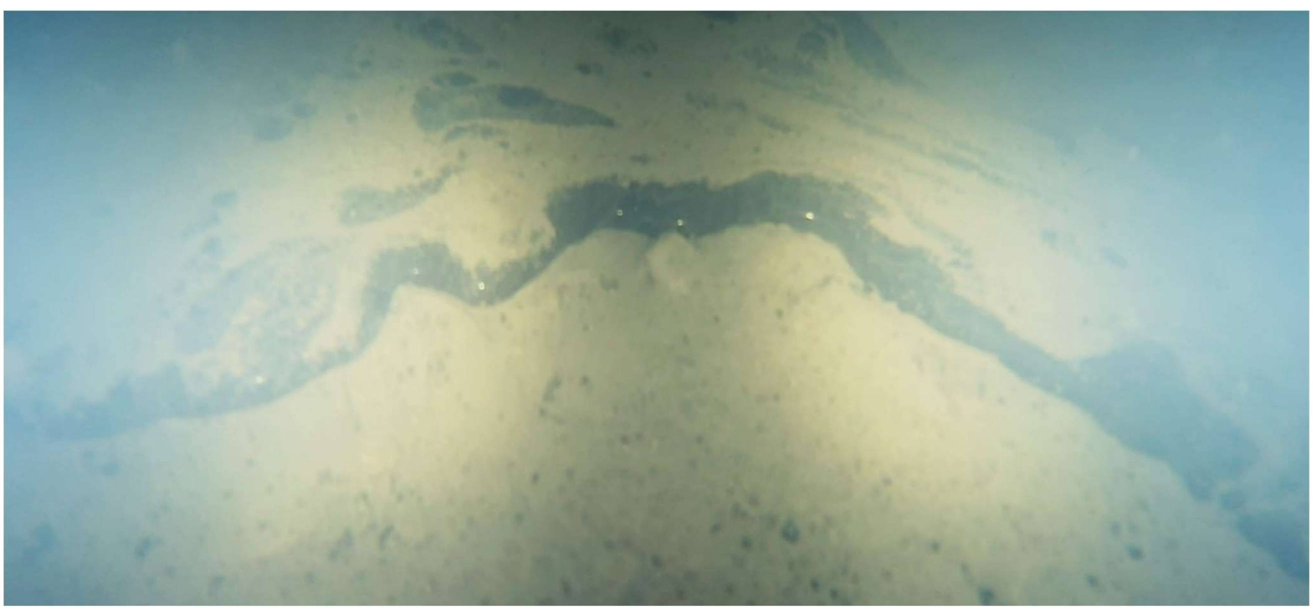


Figure 4-7: Visible edge of bitumen mat on FFT surface after dredge has cut through; note the clean edge and clear water column

Figure 4-8: Ice cores taken from same location before dredging (2021, on left) and after dredging (2022, on right) demonstrating reduction in bitumen flux post-dredging

5 Summary of Key Performance Results for BML: Shorter-term performance indicators

The following sections describe results associated with shorter-term performance indicators.

5.1 The lake should have all solids in place and be filled to design elevation with a water cap sufficient to prevent wind-wave driven resuspension of fines

For the Base Mine Lake demonstration, placement of fluid tailings 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 was commissioned as Base Mine Lake 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 design water elevation of 308.7 masl.

The depth of water required to prevent wind-wave driven resuspension of sediments (e.g., FFT) 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, 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 m and has been consistently deeper than 9 m since May 2015 (Lawrence *et al.* 2016). There has been no evidence of wind-wave driven resuspension of sediment since BML was commissioned (see section 7.3). It is also expected that densification resulting from FFT consolidation and increasing water cap depth with time will further reduce or eliminate the likelihood of wind-wave driven resuspension of FFT (Dunmola *et al*. under review).

5.2 The fluid tailings should be settling as it dewaters with time

Since commissioning BML, and as expected from modelling (Dunmola *et al.* 2023), the FFT has been settling as indicated by decreasing mudline over time (Figure 5-1), releasing pore water into the water cap. The rate of FFT settlement is gradually decreasing over time, from ~ 1.1 m in 2012 – 2013 to 0.24 m in 2018 – 2019 (Dunmola *et al.* 2023 Contours of cumulative FFT settlement between October 2012 and October 2021 highlight the spatial variability of observed settlement (Figure 5-2). The total settlement ranges from 0.3 to 7.3 m, with the largest settlement recorded in the northeastern portion of the lake. The least settlement was observed near the BML shoreline where the initial FFT thickness was the smallest. The total volume of FFT in BML has decreased from 196.0 Mm^3 in 2012 to 169.08 Mm^3 in 2021, a volumetric deformation of 13.7 %.

Numerical modelling of FFT consolidation was completed in 2007 and was updated in 2019. The 2019 numerical predictions generally agree with the field data. 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. Settlement predictions for the updated model compared to field measurements are shown in Figure 5-3. Also, the FFT settlement is complemented by profile increases in solids content, indicating FFT dewatering and densification with time (Figure 5-4). The transition in geotechnical properties at the mudline is also getting distinct over time. Features in the FFT surface (e.g., cracks, pock marks) are further evidence that the mudline distinct and the FFT is densified (Figure 5-5). These are multiple lines of evidence that the fines are physically isolated below the water cap.

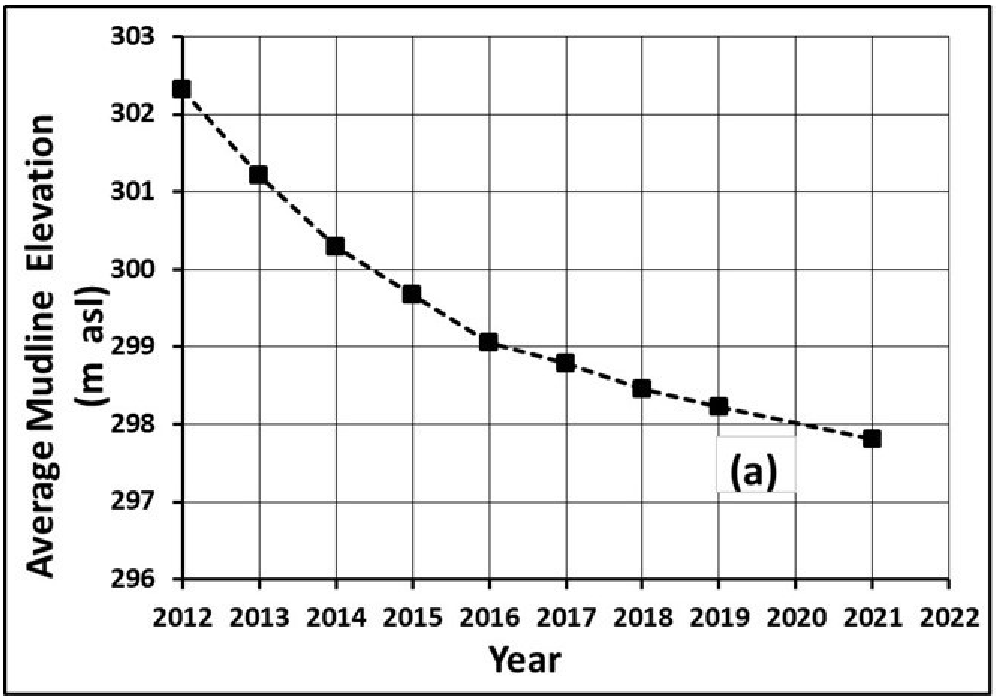


Figure 5-1: Field measurement of average FFT mudline elevation in BML from 2012-2019 (Dunmola *et al.* 2023).

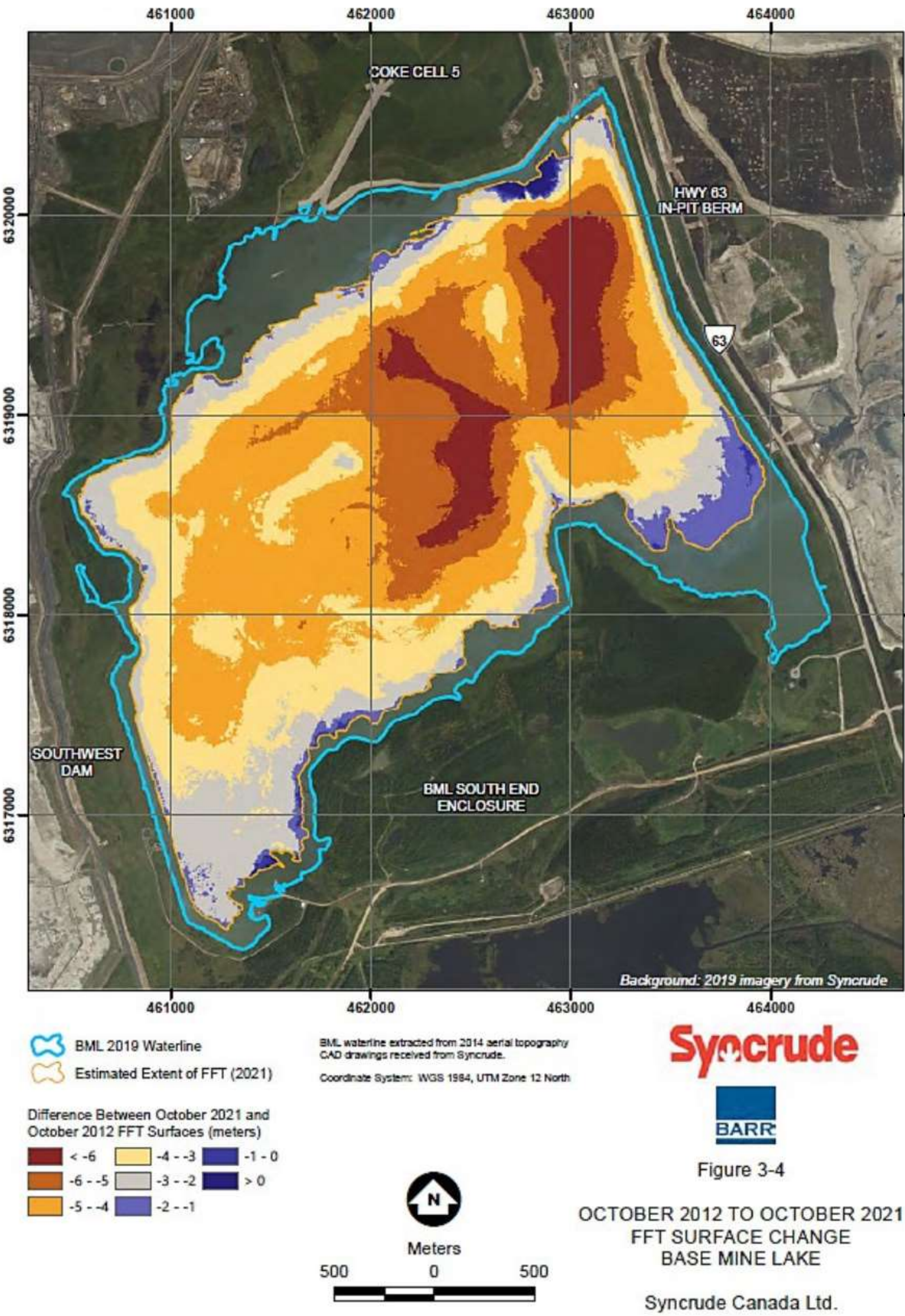


Figure 5-2: October 2012 to October 2021 FFT surface elevation change in Base Mine

Lake.

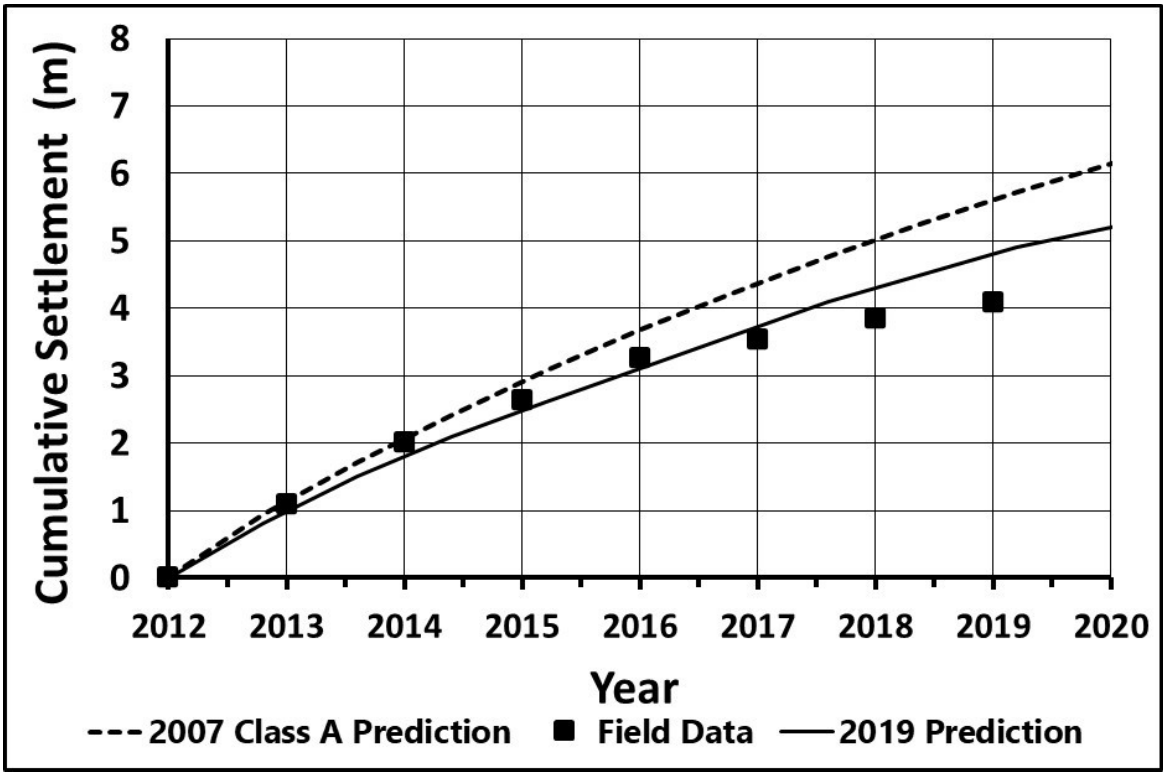


Figure 5-3: Field measurement of cumulative FFT settlement shown with numerical predictions in 2007 and 2019 (Dunmola *et al.* 2023).

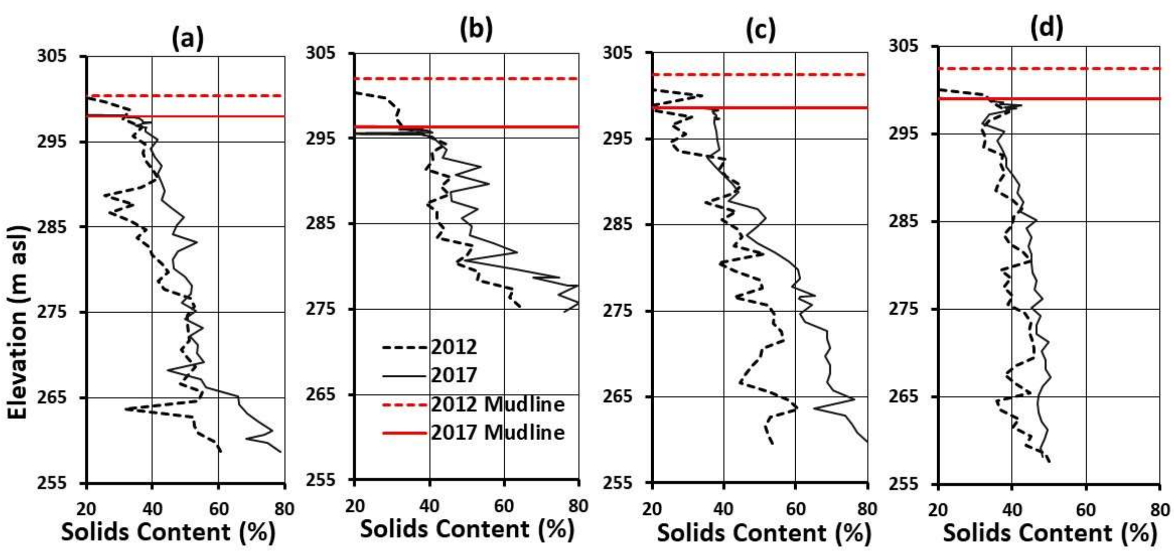


Figure 5-4: Profiles of solids content in 2012 and 2017 at sampling locations: (a) D11; (b) Platform; (c) D08; and (d) D38. Also shown are the respective mudlines.

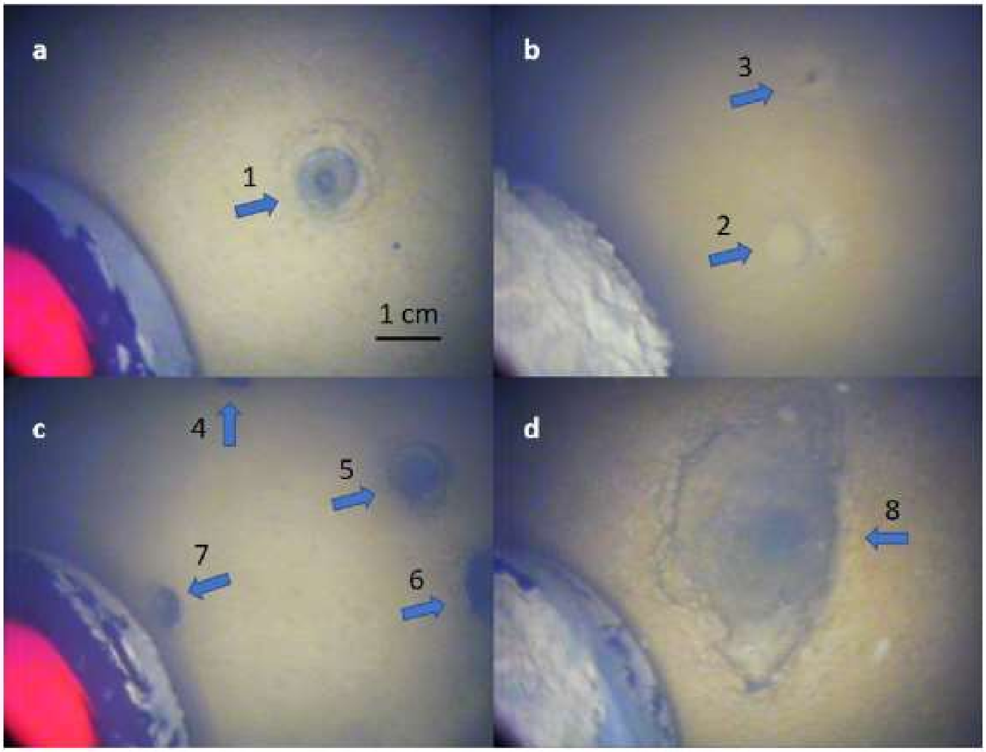


Fig. 4. Photographs taken from a camera suspended approximately 5 cm above the water-mud interface on 03 October 2019. (**a**) An active pockmark (#1) with a narrow conduit within. (**b**) Two pockmarks (#2–3) located close to each other. Pockmark 2 is backfilled with sediment, indicating bubbles did 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 5-5: Photographs taken from a camera suspended approximately 5 cm above the water-mud interface on 03 October 2019 (after Zhao *et al.* 2021).

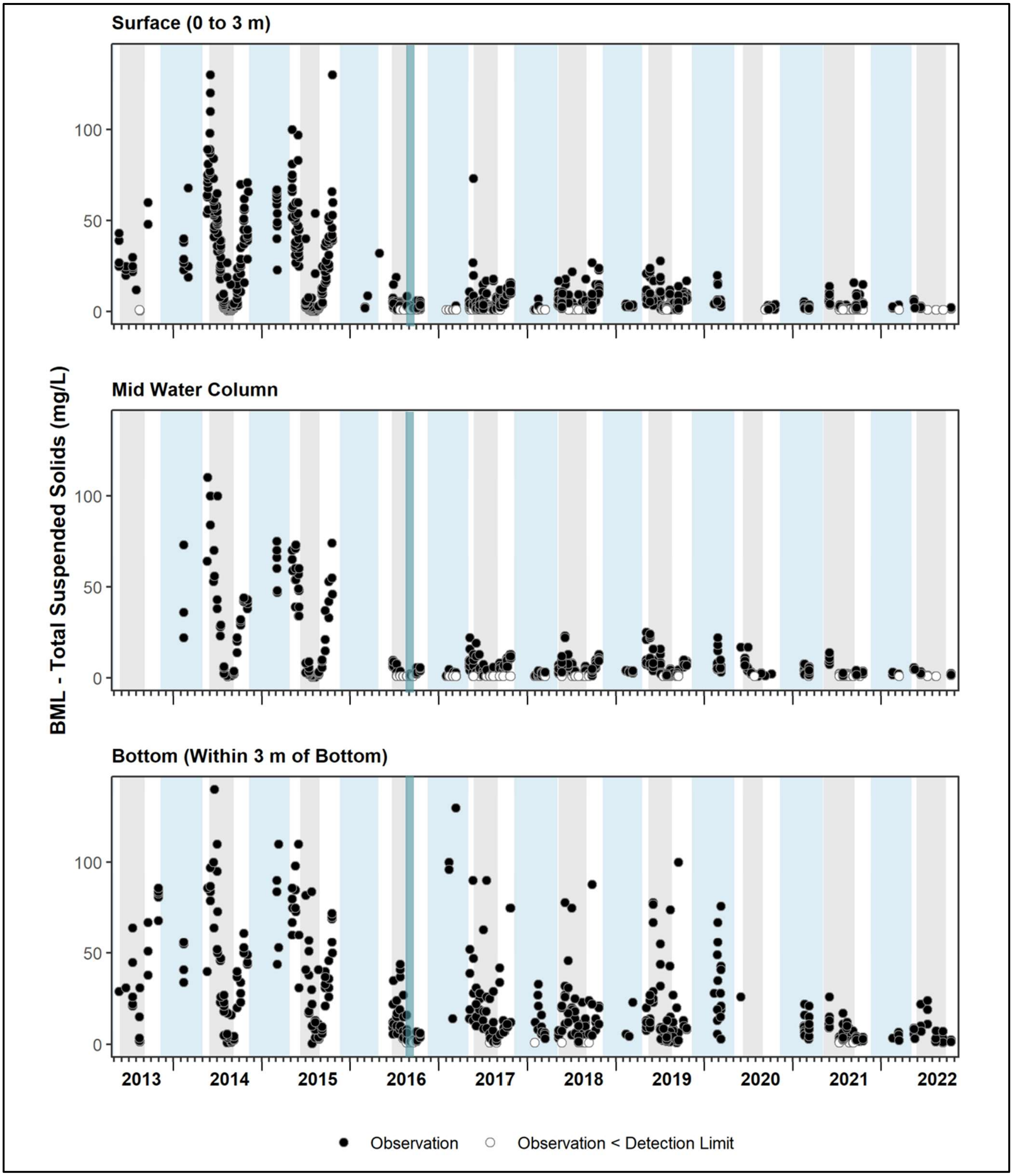
5.3 Total Suspended Solids (TSS) should show improvements over time or be in the range of natural variability

TSS concentrations in BML 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 5-6). 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 5-6). 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.

High TSS concentrations are limited to <0.5m above tailings water interface for all sampling locations (Figure 5-6 and Figure 5-7). These elevated TSS values may be associated with sampling artefacts (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.

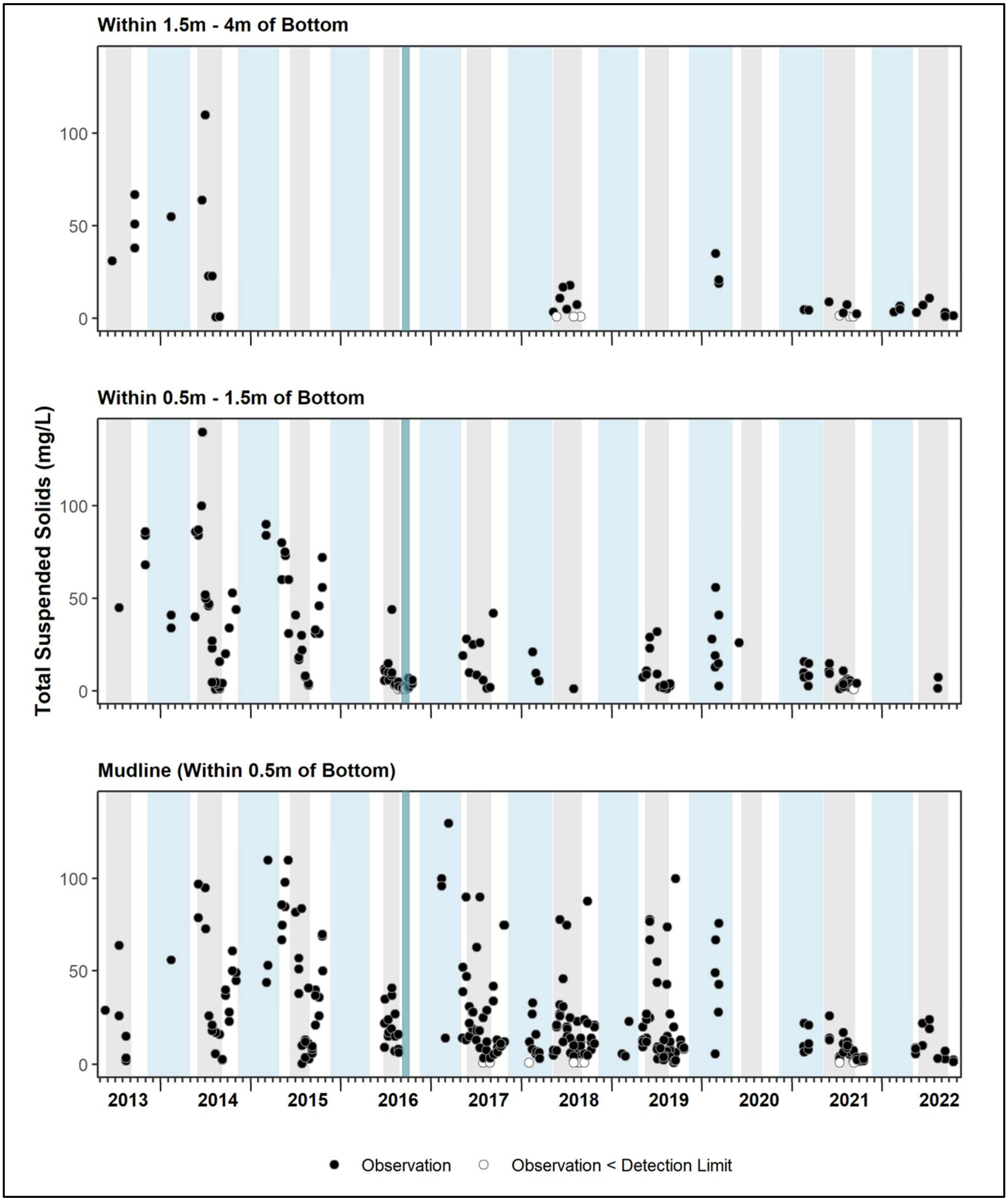
Seasonal variations in TSS concentrations were less apparent in BML in 2022 than prior to 2016, with median concentrations highest in spring (5.7 mg/L), followed by winter, fall, and summer (2.1 mg/L, 1.7 mg/L, and 1.5 mg/L, respectively). These results match the historical trends: the highest TSS concentrations have been observed in spring. Median TSS concentrations in summer, fall, and winter 2022 were lower than the historical post-alum treatment (2017 through 2021) medians (2.9, 6.4, and 3.9 mg/L, respectively)

In 2022, TSS concentrations in Beaver Creek Reservoir (BCR) had a median concentration of 6.7 mg/L during the summer, which was lower than the BCR historical median (7.0 mg/L) but still within the historical range.



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.

Figure 5-6: Total Suspended Solids (TSS) in BML water cap in mg/L from 2013-2022.



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.

Figure 5-7: TSS in BML Water Cap in mg/L From 2013 to 2022 Within 4m of the FT Water Interface (Scale Adjusted to Show Mudline Trend).

5.4 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)

The water will meet 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) prior to release to a receiving water body.

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.

6 Summary of Key Performance Results for BML: Progress towards longer-term performance indicators

As described previously, the longer-term objective for Base Mine Lake 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 Base Mine Lake 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).

The 2022 analytical results for the discrete water quality samples collected from BML 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. Table 6-1 summarizes the proportion of each analyte that exceeded guideline values in each monitoring year; however, 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 2022, a lower percentage of samples exceeded the GoA chronic water quality guideline relative to the historical record, with chloride, sulphide, total ammonia, total boron, and F2 hydrocarbons exceeding guidelines consistently every year.

Generic risk-based water quality guidelines have not yet been developed in Alberta or Canada for naphthenic acids quantified either as individual compounds or total concentrations of multiple NA. Thus, NA are not included in Table 6-1.

Table 6-1: Proportion (as %) of surface water quality samples from Base Mine Lake that exceeded GoA chronic guidelines for surface water quality, 2013 to 2022.

Group/Variables	Year[a]									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Conventional Physico-Chemical Variables, Ions, and Nutrients										
Total Alkalinity (as $CaCO_3$)	0	0	0	0	0	0	0	0	0	0
Chloride	100	100	100	100	98	100	100	100	100	100
Sulphate	25	0	0	0	0	0	0	0	0	0
Sulphide[b]	71	55	66	68	57	69	66	81	87	64
Nitrate (as N)	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
Total Ammonia (as N)	84	88	68	48	61	55	58	10[c]	51	34
Dissolved and Total Metals										
Dissolved Aluminum	21	5.6	1.0	33	39	1.0	4.3	22	15	14
Dissolved Iron	2.3	0.4	2.0	0	0.3	0	6.2	7.8	1.0	0
Total Arsenic	0	1.6	0.8	0.5	1.4	0.6	0	2.5	0	1.5
Total Boron	100	100	95	86	96	100	95	83	67	93
Total Cadmium	0	0.4	0.4	0	0.6	0.6	0	2.5	0	1.5
Dissolved and Total Metals (Cont'd)										
Total Chromium	25	61	100	42	14	45	49	70	18	22
Total Cobalt	23	90	62	35	15	41	10	6.2	0.3	4.6
Total Copper	0	1.6	0	0	0.9	0.9	0	3.7	0	3.2
Total Lead	0	2.0	0.4	0	1.7	1.2	0	0	0	1.5
Total Mercury	7.5	3.6	0.7	1.0	1.3	0	0.9	0	0	0
Total Methyl Mercury	-	3.8	0	0	1.3	6.7	0	0	0	0
Total Molybdenum	9.1	0	0	0	0	0	0	0	0	0
Total Nickel	0	0	0	0	0.3	0	0	0	0	0
Total Selenium	51	1.2	0	0	0.3	0.3	0	0	0	1.7
Total Silver	0	0	0	0	0.3	0.3	0	0	0	1.5
Total Thallium	0	0	0	0	0	0.3	0	0	0	1.5
Total Uranium	0	0	0	0	0	0.3	0	0	0	1.5
Total Zinc	0	2.4	0.4	0	0.6	0.9	0	9.0	0.5	6.5
Organics										
Total Phenolics	100	71	52	50	15	79	46	35	11	0
Benzene	-	0.6	0	0	0	0	0	0	0	0
Ethylbenzene	-	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
F2 (C10-C16)	-	100	99	100	100	97	99	98	100	100
Toluene	-	1.7	0	0	0.6	0	0	0	0	0
Total Xylenes	-	0.6	0	0	0	0	0	0	0	0
PAHs										
Acenaphthene	0	0	0	0	0	0	0	0	0	0
Acridine	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
Benzo(a)anthracene	0	4.2	1.4	1.0	1.3	0	0	0	0	0
Benzo(a)pyrene	0	3.5	1.4	1.0	0.6	0	0	0	0	0
Fluoranthene	0	4.2	0.7	0	0.6	0	0	0	0	0
Fluorene	0	0	0	0	0	0	0	0	0	0
Naphthalene	0	0	0	0	0	0	0	0	0	0
Phenanthrene	0	3.5	0	0	0.6	0	0	0	0	0
Pyrene	54	61	67	15	23	17	10	14	3.6	6.2
Quinoline	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.

7 Summary of Key Performance Results from the Base Mine Lake Monitoring Program

To date, the results from the monitoring and research program indicate that the fine tailings are 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. The lake exhibits conventional boreal dimixis. These and other typical lake physical dynamics are important drivers of both the chemical and biological response in the lake. The water balance is dominated by tailings pore water flux and fresh water import from Beaver Creek Reservoir. Bitumen sheen may have an effect on water evaporation from the lake surface. Surface water quality is also improving with time in Base Mine Lake, as expected to demonstrate the viability of the WCTT. Using standard whole-water toxicity test protocols, the lake water is not acutely toxic and exhibits residual chronic toxicity.

The water cap should not be acutely toxic

Toxicity tests measure the biological response of test organisms exposed to a water or sediment sample for a controlled time period. Organisms are exposed to BML 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).

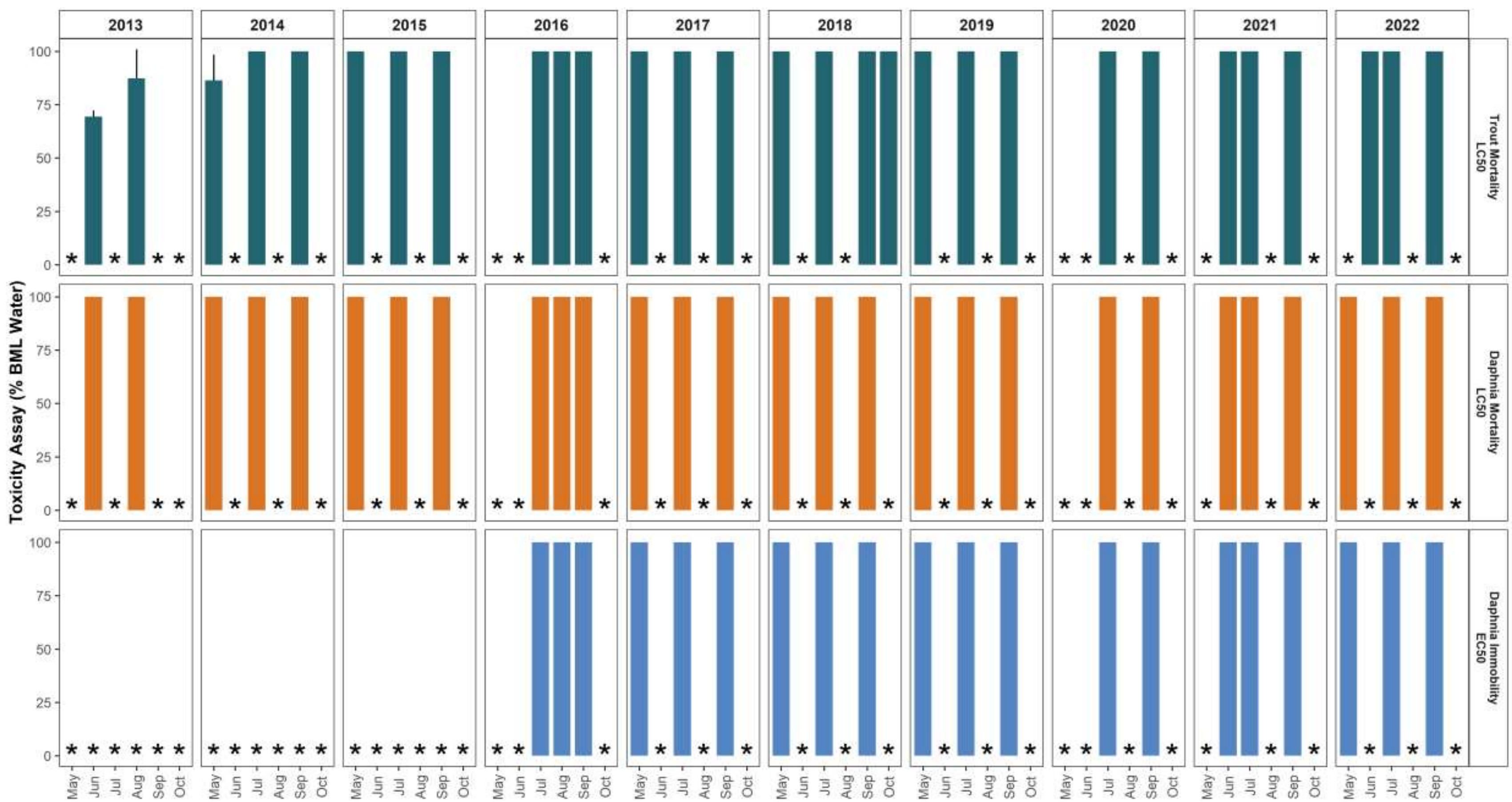
Water toxicity samples are collected during the open water season. Each sample consists of a composite of multiple grabs from two discrete depths in the field-estimated euphotic zone (twice the Secchi depth), collected with a 4L horizontal Van Dorn sampler. The grab samples were composited in clean laboratory-supplied 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 2022, with all LC50 values >100% v/v BML water (Figure 7-1). Historically, rainbow trout exposure to BML 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 water has shown no survival effect since monitoring began in 2013, with all LC50 values >100% v/v BML (Figure 7-1). 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 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 values shown are toxicity assay results from a lake-wide composite sample

Figure 7-1: Rainbow trout and Daphnia magna acute toxicity results for BML whole water 2013-2022, showing absence of acute toxicity since early 2014.

7.1 Physical Components of the Base Mine Lake Monitoring Program

The physical components of the Base Mine Lake monitoring program primarily relate to understanding trends in fluid tailings 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 fluid tailings mudline provides an understanding of the fluid tailings consolidation behaviour, and pore water volume and chemistry flux from the fluid tailings 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.

7.1.1 Fluid Tailings Settlement

Table 7-1 below provides a summary of the key findings from the FFT settlement assessment.

Table 7-1: FFT Settlement Assessment Key Findings

FFT Settlement Assessment Key Findings
• The top of the FFT surface is not flat. There is considerable variability in the mudline surface across the lake that generally corresponds to the original pit topography.
• FFT is settling, up to approximately 7.6 m between October 2012 and September 2022.
• The volume of FFT in BML has decreased from 169.08 Mm^3 in October 2012 to 167.71 Mm^3 in September 2022
• The volume of FFT is BML has decreased from 195.97 Mm^3 in October 2012 to 167.71 Mm^3 in 2022, a cumulative settlement of 28.26 Mm^3 (a volumetric decrease of 14.4%)
• The FFT surface changes observed in the 2022 FFT program are consistent with historic changes since 2022.
• The rates and magnitude of the FFT settlement are consistent with the expected self-weight consolidation as modelled by finite-strain consolidation theory (Carrier et al. 2019, and Dunmola et al. 2023).

A complete sonar survey of BML was conducted in September 2022. 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. FFT surface contour maps were completed for each fall sonar survey. FFT surface contour maps for 2012 and 2022 are shown in Figure 7-2. A map of cumulative settlement since commissioning is presented in Figure 5-2.

The FFT 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 FFT settlement in BML from 2012-2022, including differential settlements, variation in pit-bottom topography, and varying initial thicknesses of FFT creates variation in the mudline elevation.

The FFT surface is not flat across BML. As shown on Figure 7-2, the FFT surface in September 2022 generally varies spatially by over 6.7 m, from elevation 294.5 m in the northeast portion of BML to approximately 301.2 m off the south shore. Based upon the sonar survey isopachs, the FFT settled between 0 m and approximately 7.6 m between October 2012 and September 2022. Minimal settlement is observed around the perimeter (shoreline) of BML, where underlying FFT thickness is generally lower, and the pit surface is generally higher.

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

Cumulative FFT settlement across the lake between 2012 and 2022 is not constant but varies across the lake generally based upon the underlying thickness of FFT. To illustrate this, a scatterplot of the original 2012 FFT thickness versus the cumulative FFT settlement from 2012 through 2022 is provided in Figure 7-3. 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 FFT thickness throughout the lake. There is quite a bit of scatter in the data for several factors, in addition to original FFT thickness, which may include variations in the physical characteristics of the FFT. Overall settlement of the FFT continues and the maximum settlement is approximately 7.6m.

A cross-section through the three permanent platforms (P1, P2, and P3) in BML showing both the 2012 and 2022 water elevations and the 2012 and 2022 FFT surfaces, demonstrates that overall settlement is in part related to FFT thickness, as discussed above (Figure 7-4).

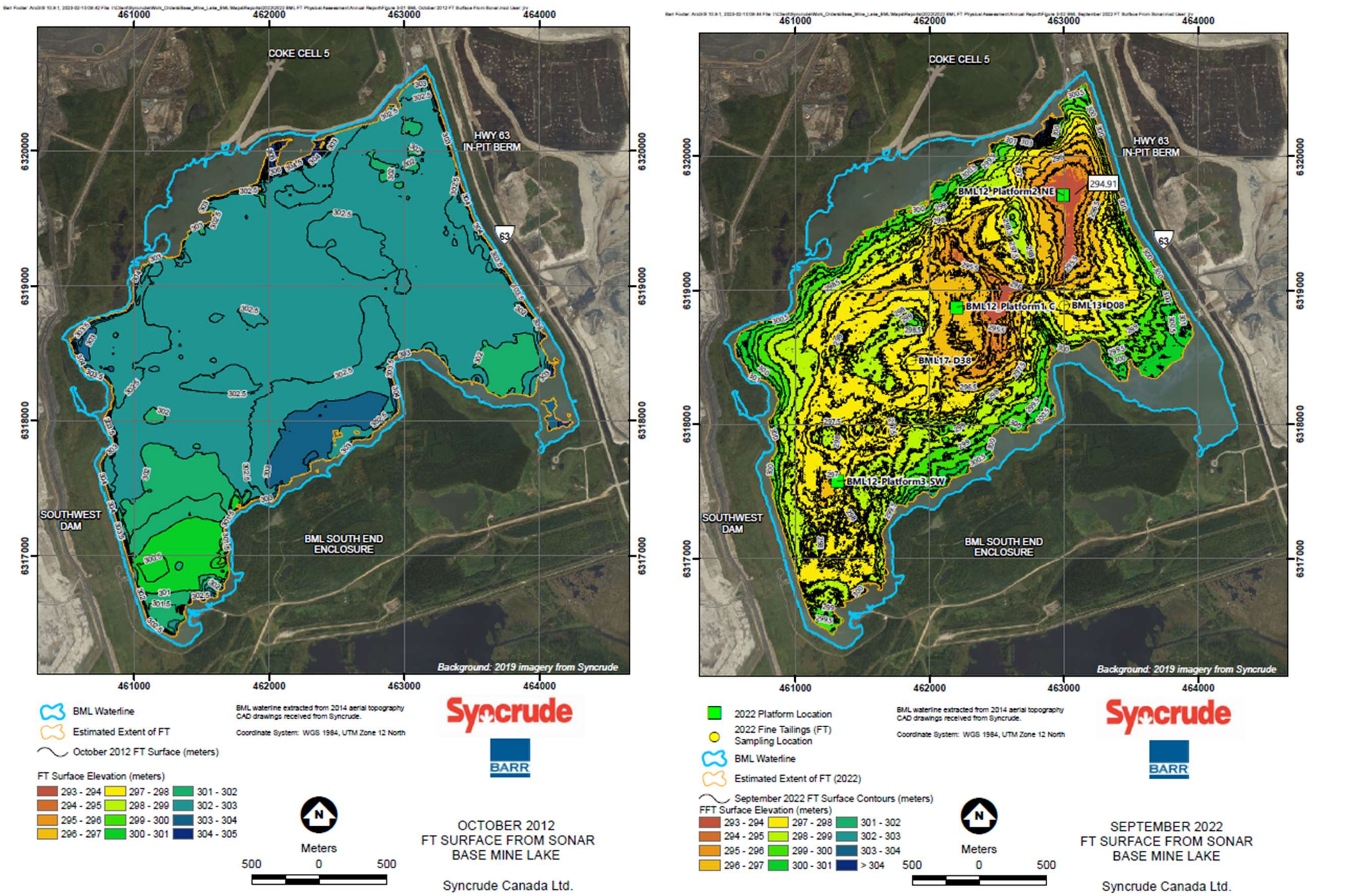


Figure 7-2: Surface contour maps of FFT mudline from October 2012 (at left) and September 2022 (at right) showing variation in mudline bathymetry.

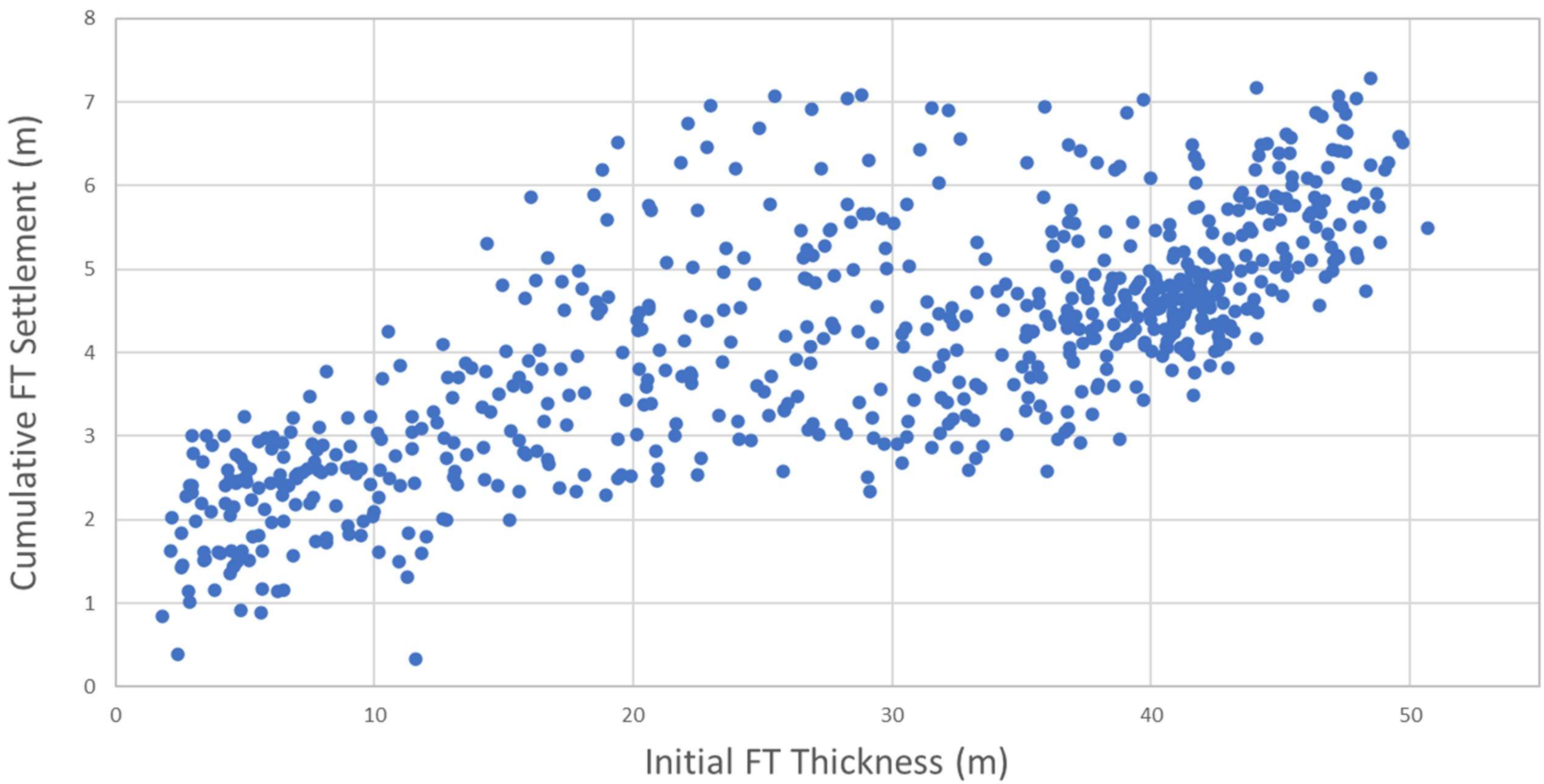


Figure 7-3: Scatterplot of cumulative FFT settlement in meters (2012-2022) versus Initial (2012) FFT thickness.

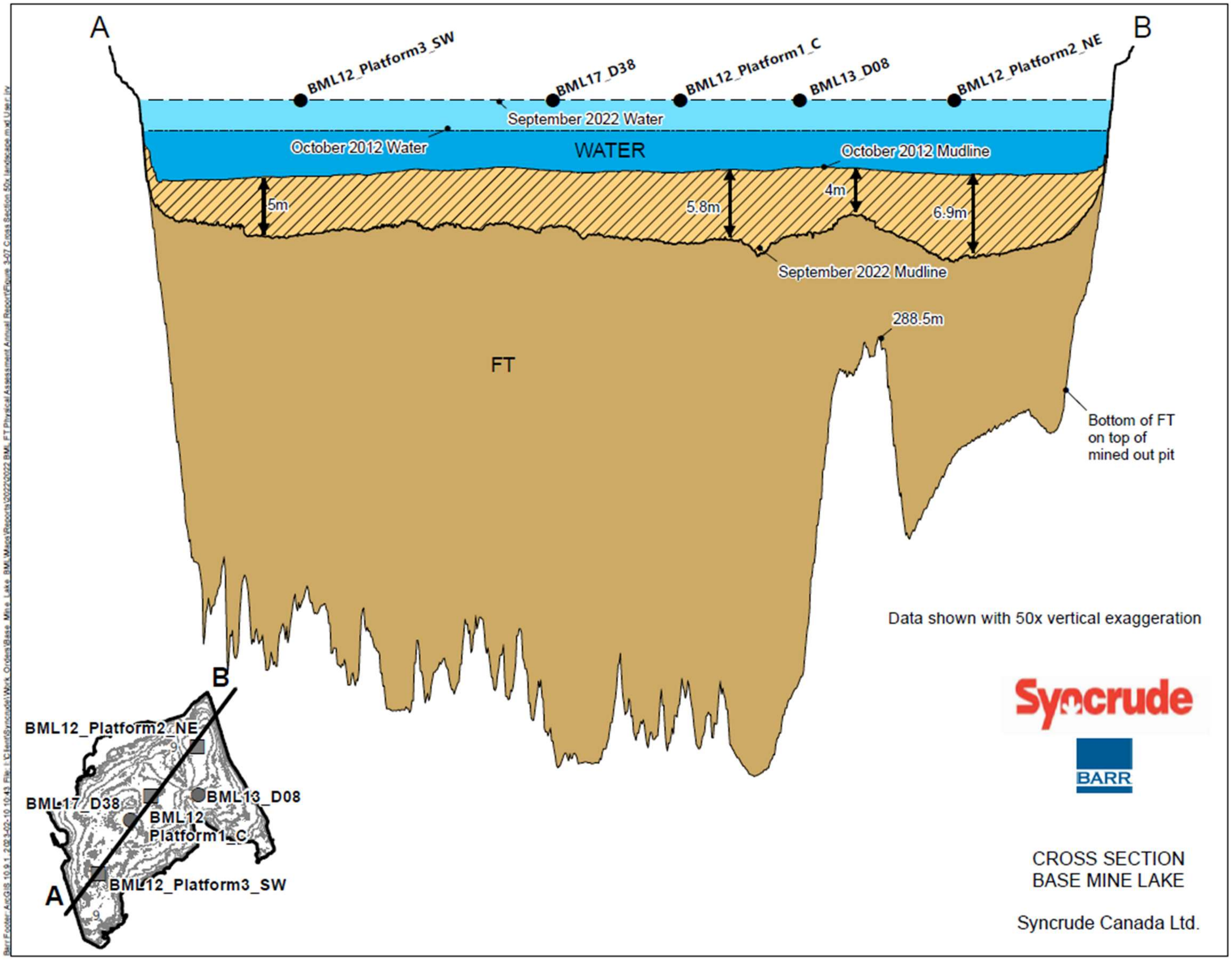


Figure 7-4: Cross-section of BML showing mudline elevation changes since 2012.

7.1.2 Fluid Tailings Physical Assessment

In October of 2021, at the same time as the sonar survey, a physical assessment of the FT was undertaken. The assessment consisted of FT profile sampling and laboratory analysis, and *in situ* geotechnical testing.

Profiles of the FT solids content indicate that the solids content has increased over time and that pore-water continues to be expressed; however, the rate of solids content increase was greater between 2013 and 2017 than 2017 and 2021.

In addition to solids content and FOFW profiles, undrained shear strength throughout the FT was also collected in 2012, 2018, and 2021. Testing completed at Platform 2 and D08 is shown on Figure 7-5 and **Error! Reference source not found.**7-6, respectively. Both figures also include solids content profiles and the gamma count trace from BGCPTu. It can be seen in the figures that there is a marked increase in the shear strength of the FT between 2012 and 2021.

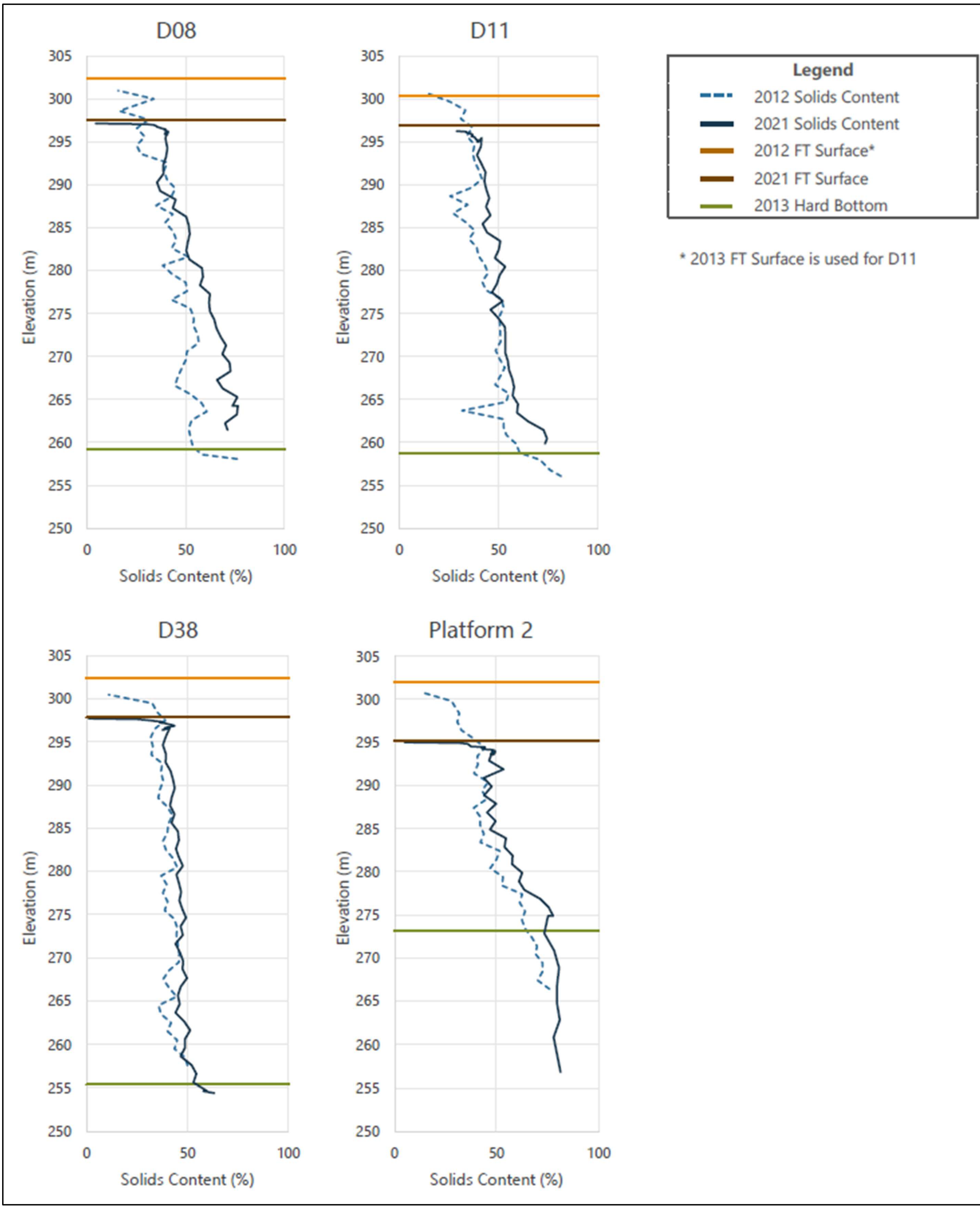


Figure 7-5: Profiles of Solids Content (by wt. %) in 2012 and 2021

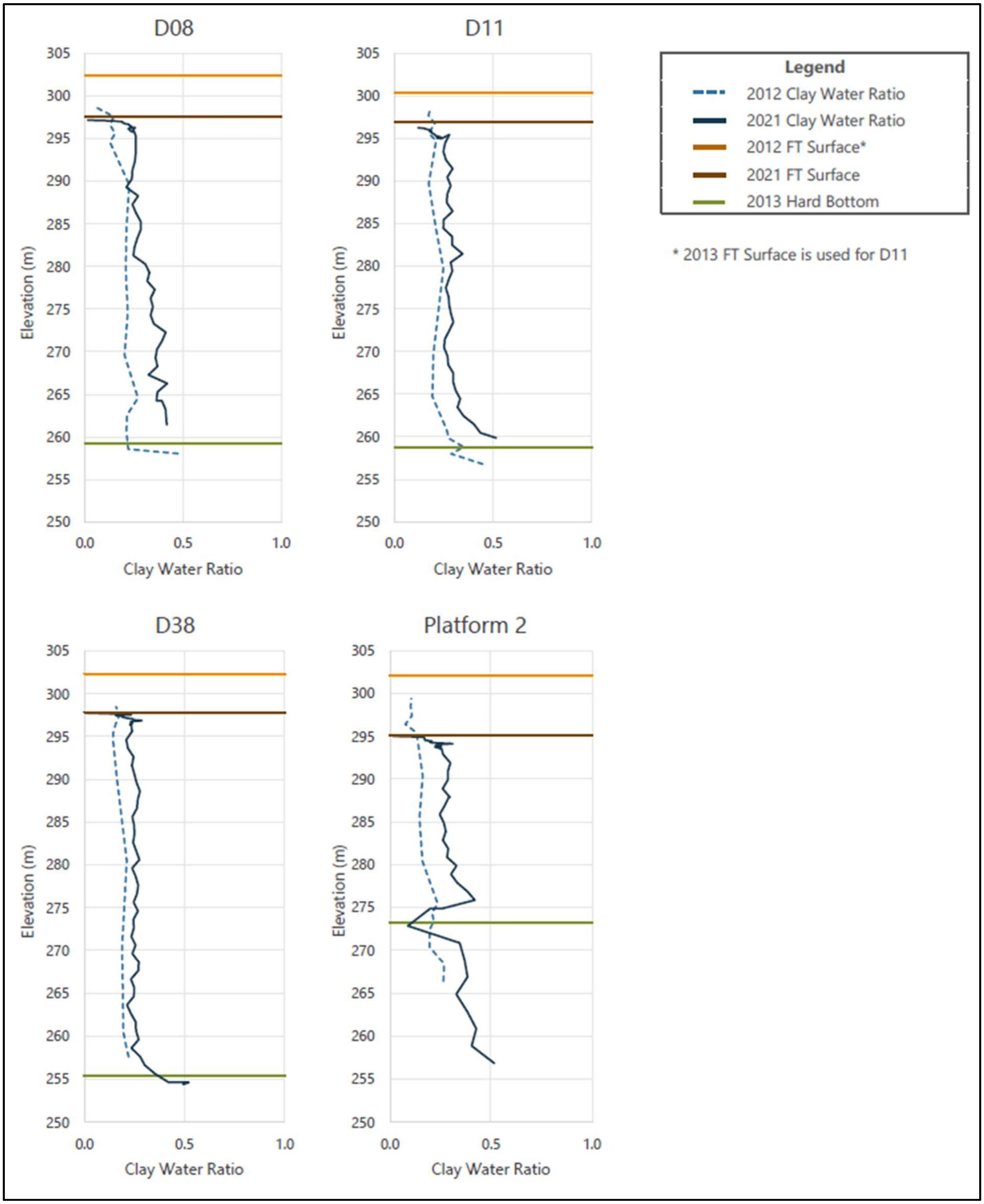


Figure 7-6: Profiles of Clay to Water Ratio (CWR) in 2012 and 2021

7.1.3 Physical Limnology Assessment

Table 7-2 below highlights the key findings from the physical limnology assessment.

Table 7-2: Physical Limnology Assessment Key Findings

Physical Limnology Assessment Key Findings
Physical Limnological processes that were similar in 2022 to 2014-2021
• Similar to previous years, BML 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 45% saturation.
• Turbidity increased throughout the water column in late spring (May).
• 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 that cause large oscillations of the thermocline (internal seiches) and large fluctuations in turbidity and oxygen within and below the thermocline (when wind > 4 m/s).
• Complete vertical mixing during fall turnover results in uniform temperature, salinity, turbidity throughout. The exception is the bottom of the profile where the nose of the instrument is likely descending 1 to 10 centimeters into the FFT
Physical Limnological processes that were varied from previous years or newly observed
• The onset of turnover (September) was much later than previously recorded and resulted in a longer summer stratified period (122 days) than any previous years.
• The turbidity in 2021 and 2022 was generally less than the turbidity in previous years.
• The turbidity instruments moored below 7.5m at P2 show unexpected high values and large variations throughout the whole winter. The source of this turbidity remains unknown
• 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 FFT 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 region has become almost too thin to observe

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 has consistently exhibited conventional boreal lake physical processes since commissioning. Annually, during the winter, the lake forms ice. When the ice melts in the spring, temperature driven density changes in the lake results in the lake mixing, or spring turnover. During the summer, the lake is thermally stratified. In the fall, thermal stratification diminishes as a result of cooling temperatures and wind. This results in the lake mixing again or fall turnover. Key lake events since commissioning are indicated in the Table 7-3 below. Figure 7-7 shows turbidity data measured at platform 3 over the years.

Table 7-3: Summary of ice-on, ice-off, stratification (whole lake) and turbidity extremes from moored sensors at Platform 3 (P3) at 2.5 m depth

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

[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.

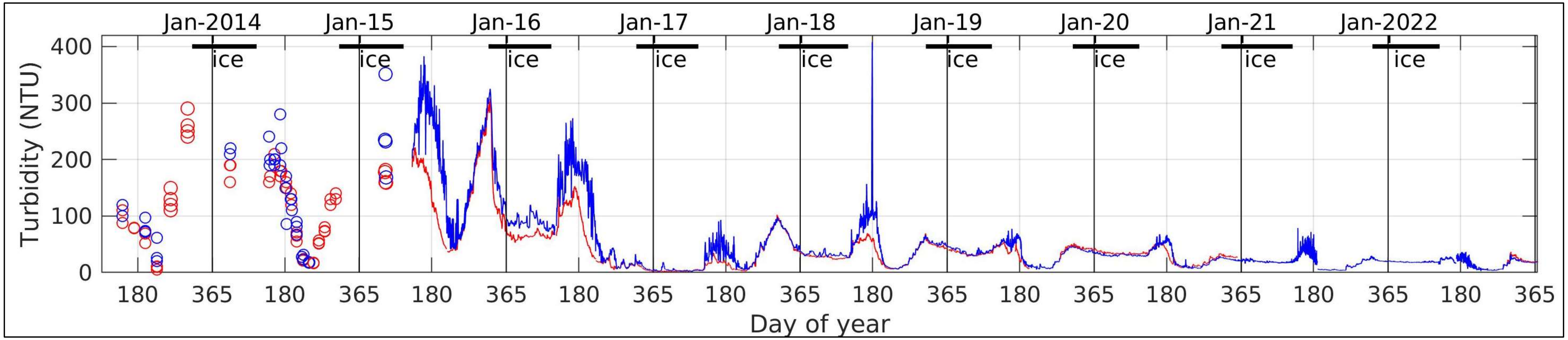


Figure 7-7: Turbidity measured at Platform 3 at a depth of 2.5m and 7.5m from March 2013 to December 2022. Due to platform instability during 2022 data from platform 2 is plotted.

7.1.3.1 Ice and Winter Reverse Thermal Stratification in 2022 (Nov. 21, 2021 – May 7, 2022)

Air and water temperature, turbidity, specific conductivity, and dissolved oxygen concentration (as a percentage of the saturation concentration) from Base Mine Lake before, during and after the period of ice-cover in 2021-2022 is presented in Figure 7-8. Once ice cover occurred (day -47, November 21, 2021), notable changes were observed in the water column: the water temperature continued to decrease in the top 7m but increased below 7m (Figure 7-8b); the conductivity increased due to salt exclusion from the ice (day –40 to day 90, November 28, 2021 to March 31, 2022, Figure 7-8d) (); the oxygen concentration declined from approximately 75% to 45% (Figure 7-8e). Ice-off occurred on day 127, May 7, 2022.

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 7-8b). 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; the near bottom water gained heat from the bottom FFT/sediment and the near surface water lost heat through the ice to the cold atmosphere.

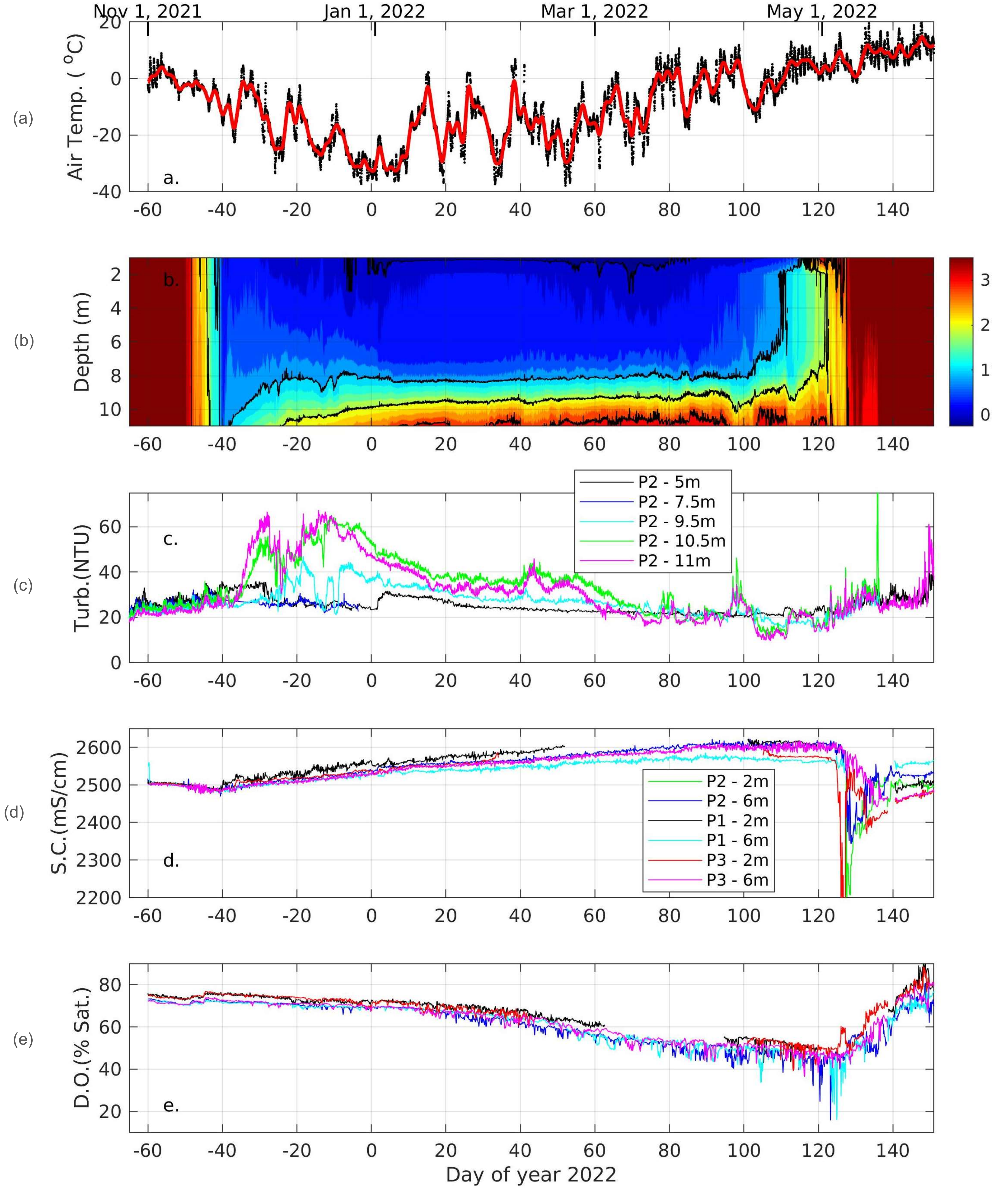


Figure 7-8: Measurements during winter 2021-2022. (a) Air temperature at P1. (b) Water temperature profiles measured at P2, the black contours are at 1, 2 and 3C. (c) Turbidity measured at P2 and P3. (d) Specific conductivity (mS/cm) measured at various locations indicated. (e) Oxygen concentration expressed as a percentage of the saturated concentration i.e., adjusted for water temperature.

7.1.3.2 Under-Ice Turbidity

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

1. At 5m, 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 7.5m was similar to 2021.

3. The peak in turbidity below 7.5m (9.5m, 10.5m and 11m) occurred approximately four to five weeks after ice-on. This is similar to measurements made below 7.5m during previous winters.

4. The minimum turbidity under ice occurred at the deepest sensors (below 7.5m) in the spring before ice-off (see day 110, Figure 7-8 c). The source of this slightly clearer water is unknown.

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

Due to ice access restrictions, profiles during the winter of 2022 were collected at only one station which was close to D04. The vertical profile of temperature was consistent with those observed in natural lakes under ice: water temperature increased with depth (reverse thermal stratification). Similar to previous winters, the profile exhibited a homogeneous water-layer that was approximately 4m thick at the top (Figure 7-9 a. and b.). Below this homogeneous layer, temperature increased toward the bottom. The salinity and turbidity profile collected at this location was similar to, but slightly more homogeneous than, profiles collected during the winter of 2021.

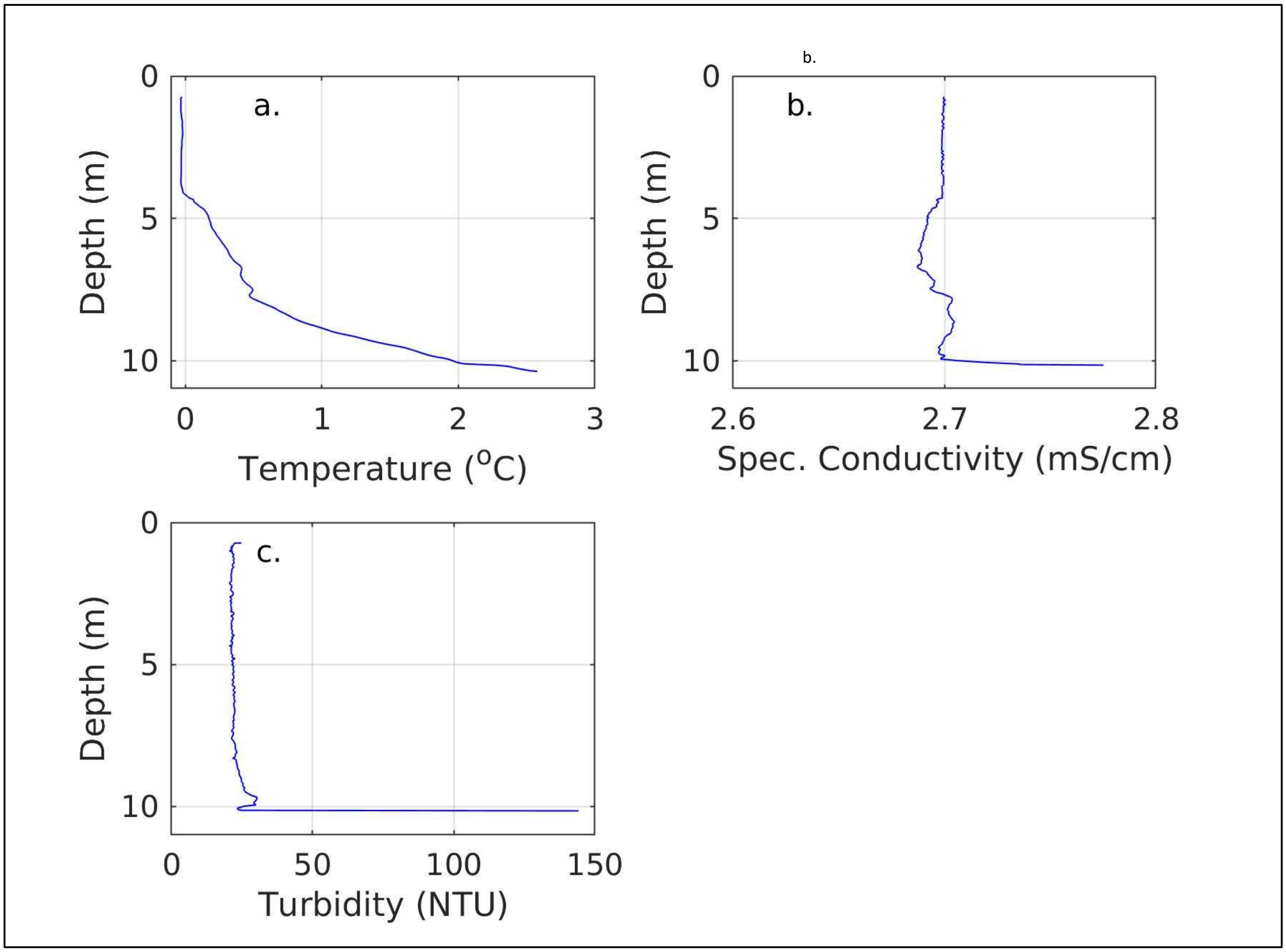


Figure 7-9: Winter (March 3) 2022 Seabird profiles of (a.) temperature, (b.) specific conductivity and (c.) turbidity.

7.1.4 2022 Spring Turnover (May 7 – May 29, 2022)

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. If a lake is as saline as BML, 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. A wind event at the end of May resulted in complete turnover in 2022 - temperature, turbidity and oxygen were all homogenized (Figure 7-10 b., c., d., and e.). This mixing lasted only a few days with all of these parameters diverging after the winds calmed on May 28 (day 148).

7.1.5 2022 Summer Stratified Period (May 29 – Sept. 27, 2022)

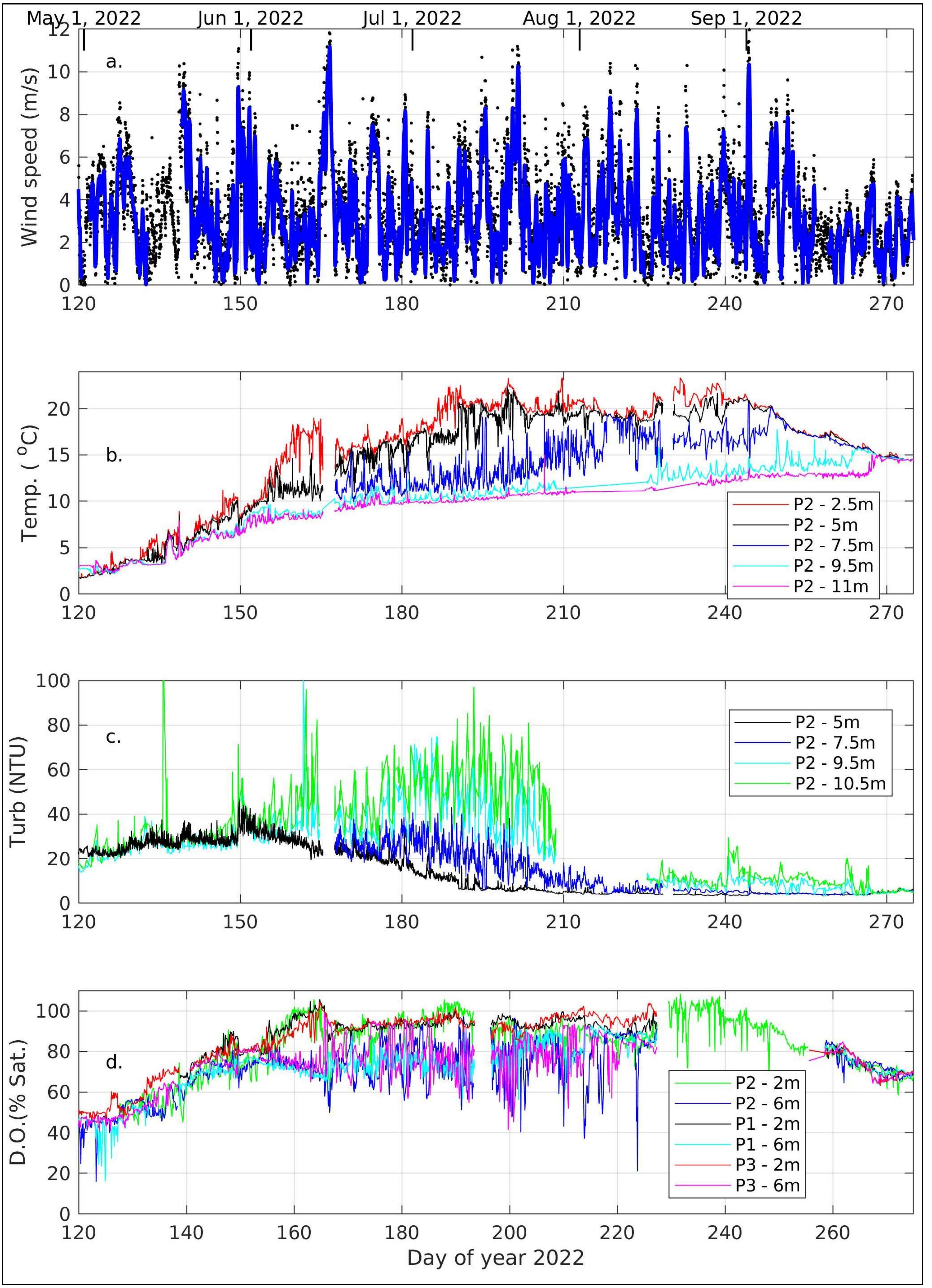
Like previous summers, Base Mine Lake exhibited summer thermal stratification that is typical of temperate and northern lakes. In this section, the evolution and structure of temperature, turbidity and dissolved oxygen are described.

7.1.5.1 Wind Forcing and Thermal Evolution During the Summer Period

In Figure 7-10, 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 7-10. 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 149 (May 29) and ended on approximately day 270 (September 27). The epilimnion (the upper water layer above approximately 3m depth as shown by the red line in Figure 7-10 b. and c.) warmed from the beginning of this period until approximately day 190 (July 9). From day 190 until day 250 (Sept. 7) the epilimnion remained near 20 °C while the deeper water gradually warmed. From day 250 until turnover on day 270 (September 27) the epilimnion gradually cooled.

7.1.5.2 Turbidity in BML During the Summer Period

Turbidity increased at all depths until the onset of the summer stratified period (day 149, May 29). After this date the shallower measurements (see 5m Fig. 7-8 c) showed turbidity decreasing reaching a minimum of 3 to 5 NTU on approximately day 210 (July 29) and remained at this low level until day 270 (Sept. 27). The deeper turbidity (9.5m and 10.5m) increased until approximately day 190 (July 9) and then decreased until turnover. These changes are similar to those observed in previous years.



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 7-10: (a.) Wind speed at P1 (b.) Water temperature in BML at P2. (c.) Turbidity measured at P2(d.) Dissolved oxygen concentration in percent of saturation concentration

7.1.5.3 Examination of Summer Profiles

Vertical and horizontal variability of temperature, specific conductivity, and turbidity collected on day 229 (August 16th) is shown in Figure 7-11. The thermal stratification during this period is typical of BML or any other temperate lake on a mid-summer day. There are three layers within the water column as indicated in Figure 7-11a.; 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 2022 were generally similar to previous years. The exceptional specific conductivity profile observed in August of 2021 (slightly higher conductivity in the epilimnion compared to the hypolimnion) did not reoccur.

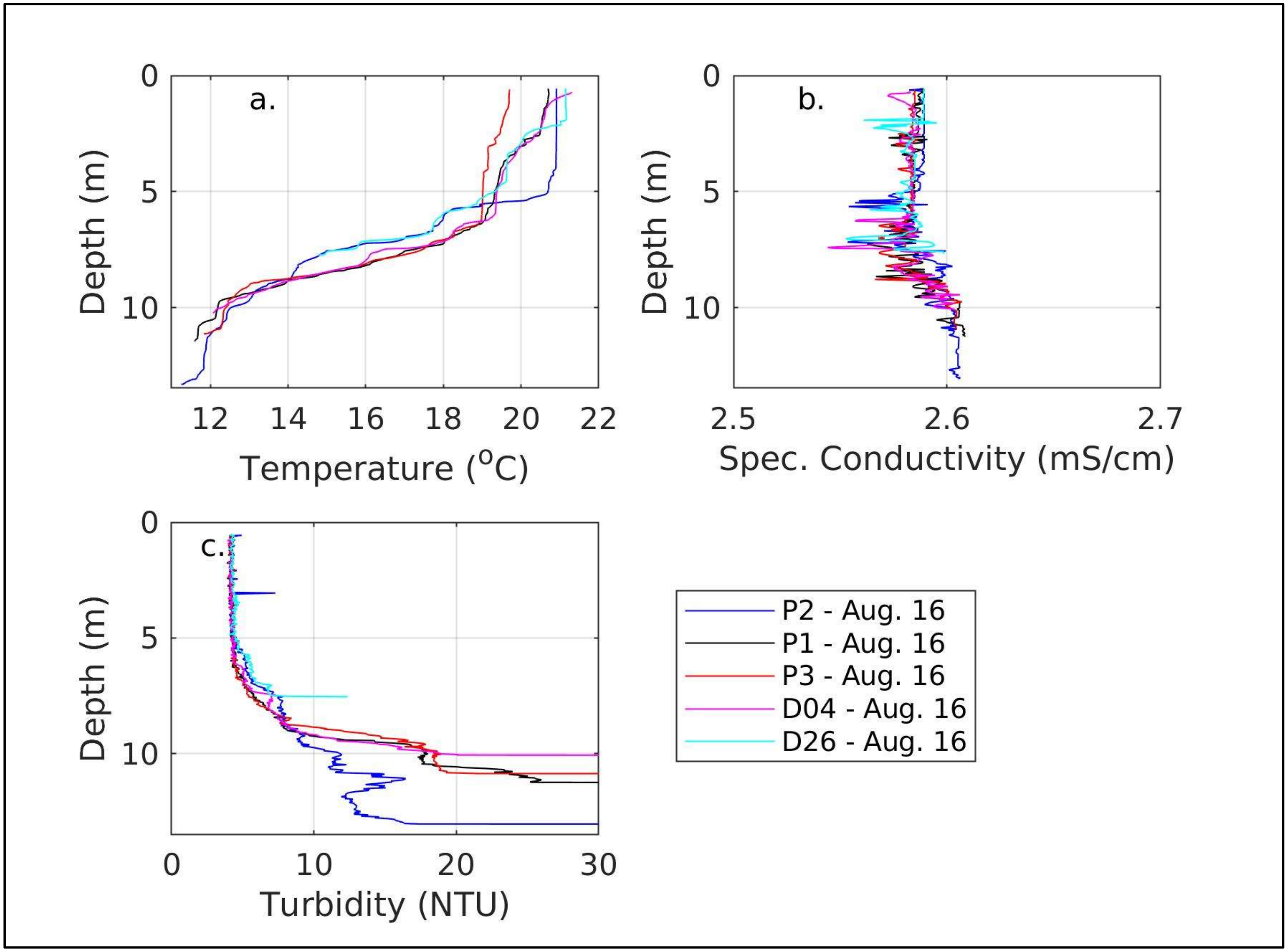


Figure 7-11: Seabird profiles of (a.) temperature, (b.) specific conductivity and (c.) turbidity on 16 August 2022 at stations indicated in the legend

7.1.6 2022 Fall Turnover (Sept. 27 – Nov. 10, 2022)

7.1.6.1 Temperature and Turbidity Evolution

Relatively mild temperatures and calm winds in September resulted in the latest fall turnover (approximately day 257, September 27) since the commissioning of Base Mine Lake. Profiles of temperature, specific conductivity and turbidity collected on day 291 (October 18th, 2022) – three weeks after turnover - are plotted in Figure 7-12. In general, all three parameters are quite vertically uniform at all five stations with evidence of the instrument entering either an intermediate region or the FFT near the bottom. The turbidity at ice-on (Day 314, Nov 10, 2022) was lower than any previous year (data not shown).

7.1.6.2 Fall Profiles

In Figure 7-12 a, b, and c the profiles of temperature, specific conductivity and turbidity collected on day 291 (October 18) are plotted. In general, all three parameters are quite uniform from top to bottom at all five stations with evidence of the instrument entering either an intermediate region or the FFT.

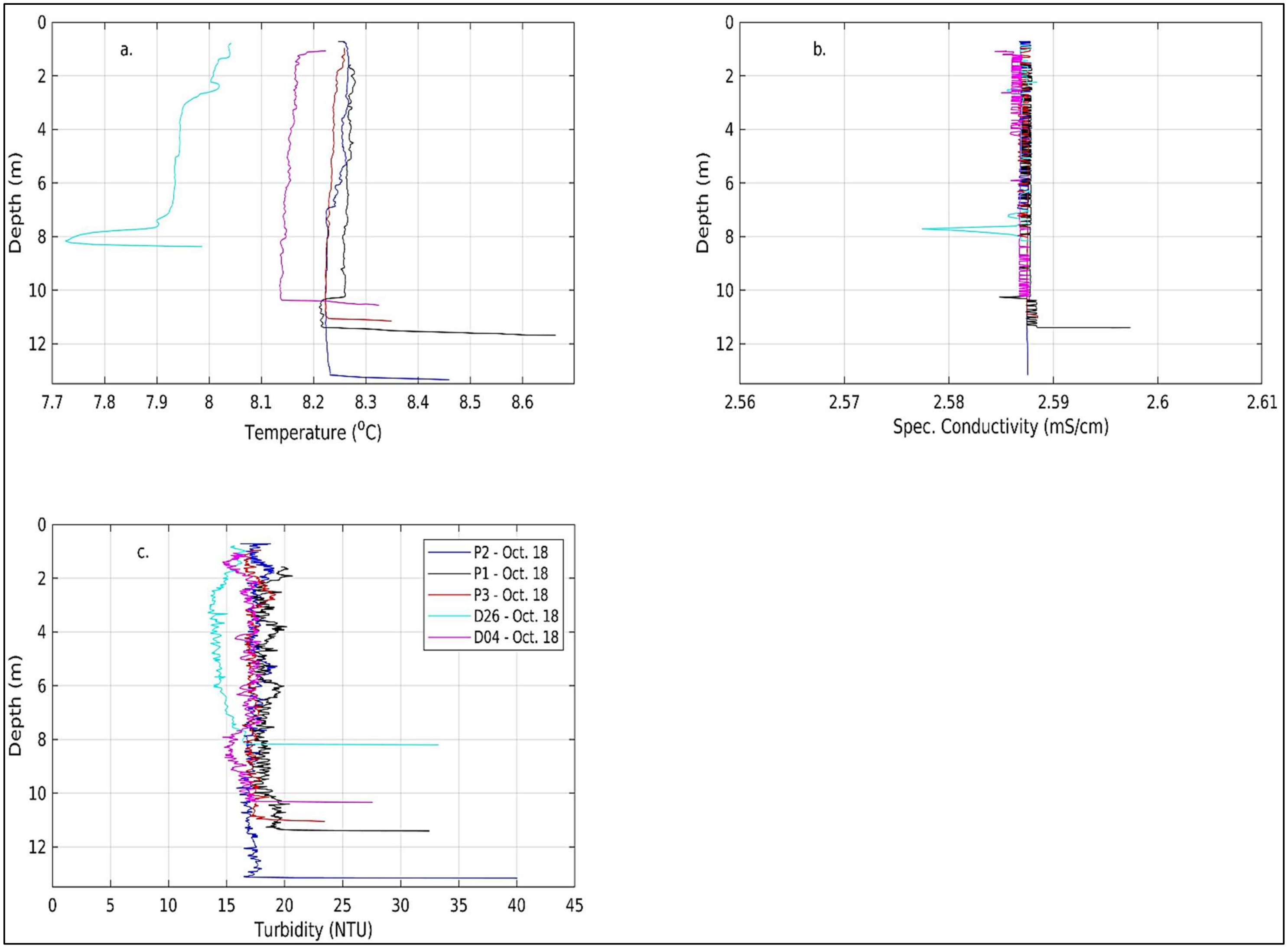


Figure 7-12: Fall 2022 Seabird profiles at the 5 locations indicated in the legend of (a) temperature, (b) specific conductivity and (c) turbidity.

7.2 Chemical Components of the Base Mine Lake Monitoring Program

The chemical components of the Base Mine Lake 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.

7.2.1 Water Balance Assessment

Table 7-4 below summarizes the key findings from the water balance assessment.

Table 7-4: 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 lake, and pore water release to the water cap.
• There is an influence of hydrocarbon sheen on suppressing evaporation.
• 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. Rules of thumb were imposed based on historical data to help provide a number.
• Methane and carbon dioxide fluxes have declined from the initial years post-commissioning.

Estimating the water balance of BML 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 for Base Mine Lake was revised in 2021. There are several changes to previous estimates that have arisen from data quality analysis and evaluation of longer-term estimates now that eight years of measurements have occurred. The water balance is complete from January 1, 2014, to December 31, 2022, on a daily basis in terms of both volumes of water and mm of water (depth per unit area). New approaches have been made to better estimate runoff contributions from the terrestrial areas.

7.2.1.1 Air Temperature

Since commissioning, air temperatures at BML have fluctuated by approximately 4 degrees in the open water season on an annual basis with the exception being an anomalously cool September 2018 (Figure 7-13). Open water air temperatures were above the 30-year Fort McMurray climate normal (1981-2010) whereas winter temperatures were above/below normal during ice-on periods.

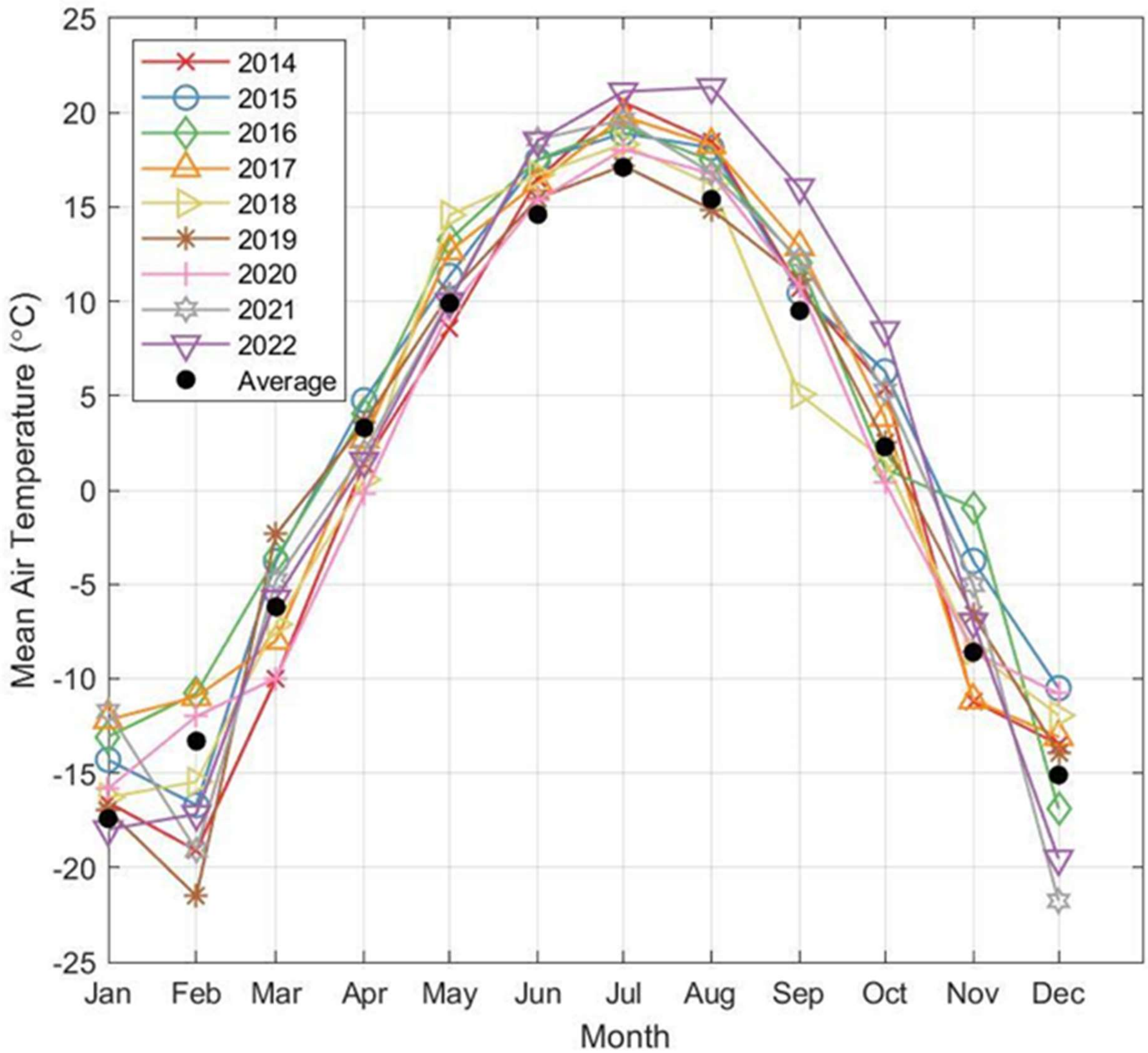


Figure 7-13: Air temperature from 2014-2022. Black circles are the 30-year climate normal for Fort McMurray.

7.2.1.2 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 7-14). The climate normal for Fort McMurray A is ~420 mm, suggesting that there are approximately equal years above/below average. As discussed further, this variance is largely a result of rainfall as opposed to snow.

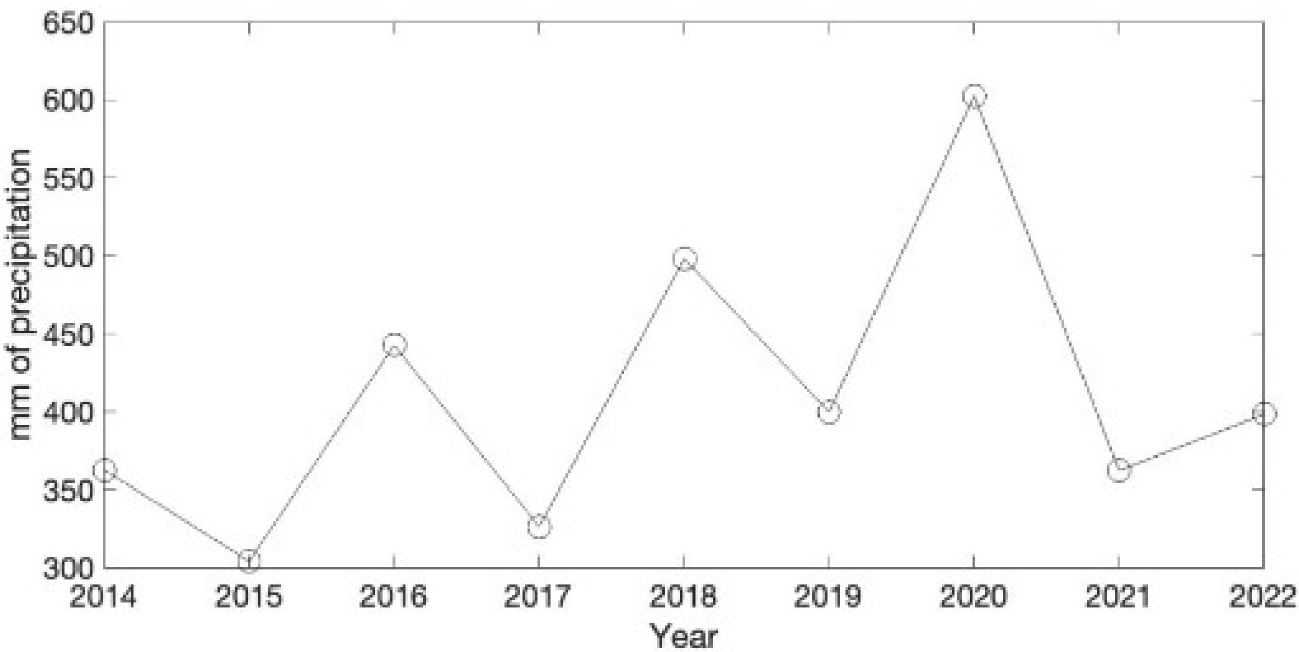


Figure 7-14: Total precipitation from 2014 to 2022.

7.2.1.3 Snow

The input of snow to BML is handled in a rudimentary manner. Each year snow surveys at BML 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 was the only year with a snowpack approaching normal. Note that SWE is taken as the maximum measured via surveys and continuous measurements. Figure 7-15 shows the cumulative melt added to the BML on the day of ice-off.

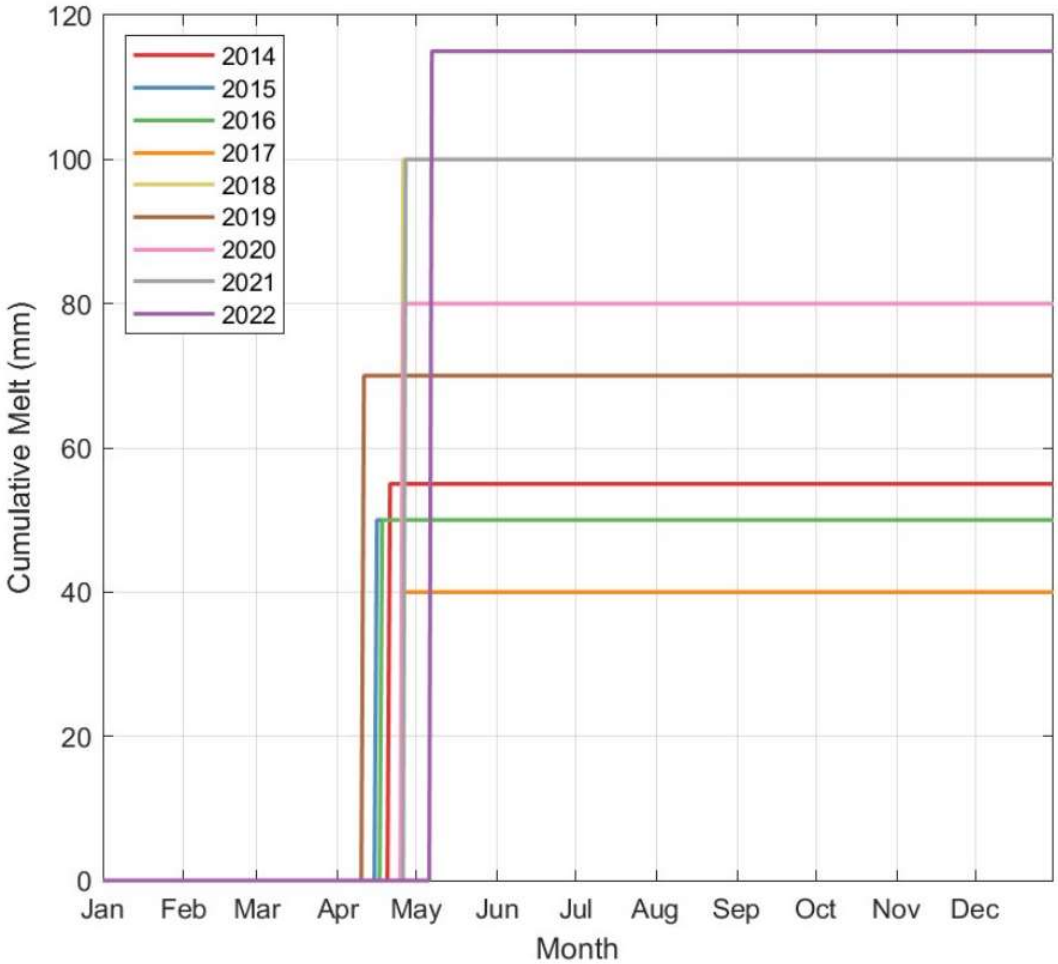


Figure 7-15: Cumulative melt added to the BML on the day of ice-off.

7.2.1.4 Rain

Rainfall is obtained by comparing daily totals from five gauges adjacent to BML 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 7-16) indicates that approximately half the years are below and half above the 30-year climate normal. Cumulative rainfall in the 9 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.

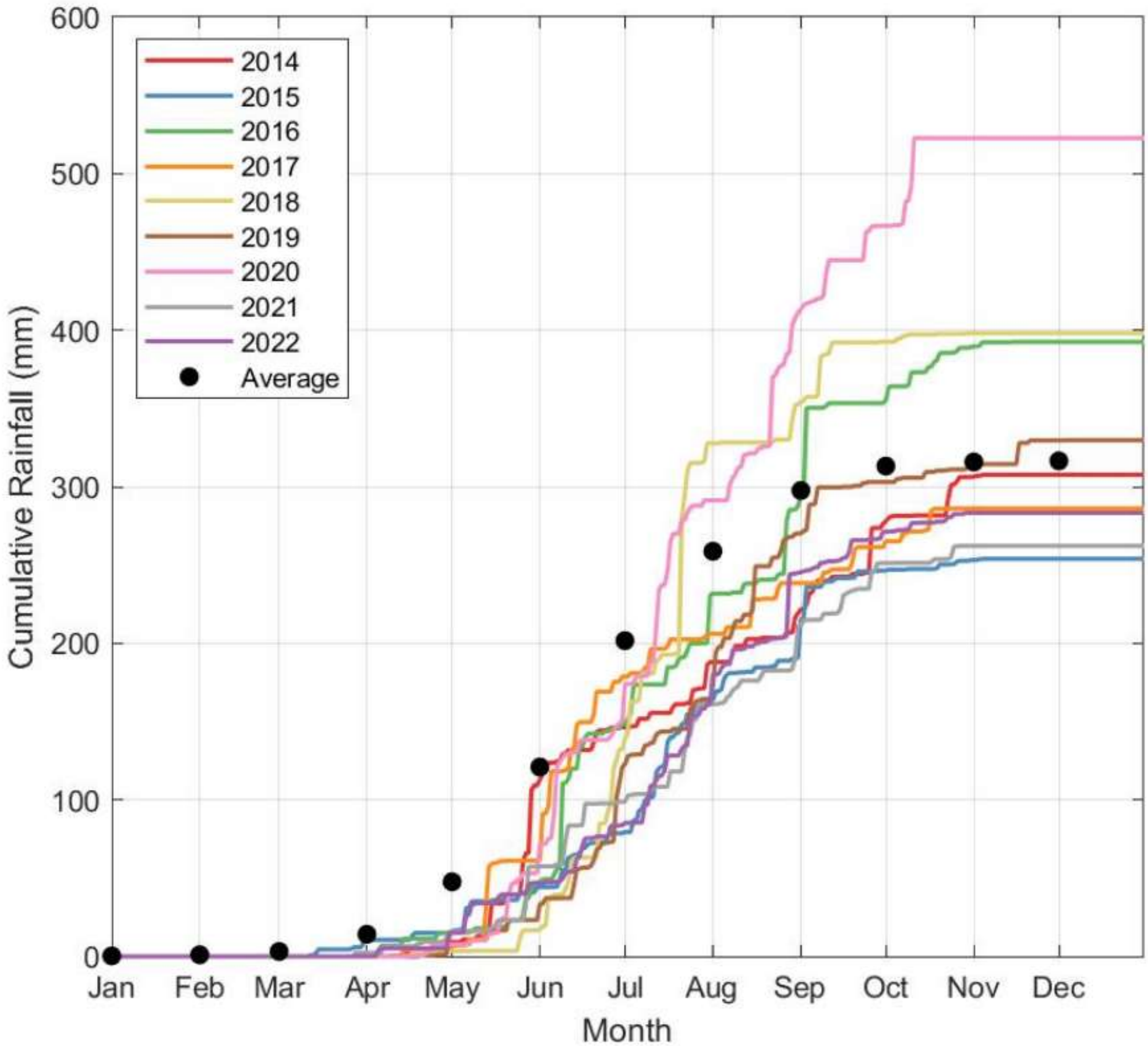


Figure 7-16: Cumulative daily rainfall. Open circles are the Fort McMurray cumulative monthly rainfall normal.

7.2.1.5 Runoff

In previous years, runoff was calculated from the Golden Pond weir on South Bison Hill and scaled to the terrestrial area contributing into BML. However, after 2015 the weir reported almost no water entering BML. This low value was attributed to the very high storage capacity of reclamation soils and near-zero values were entered into the annual balance. However, after 8 years, it has become clear that there was ‘extra’ water in the lake that could not be accounted for. There were many potential sources of errors, yet poor runoff estimation or groundwater fluxes were considered the two likeliest sources as all other fluxes were directly measured (with varying degrees of confidence). Firstly, over-winter changes in pressure in the lake during periods of minimal snowfall was examined. There is little evidence for increasing or decreasing pressure associated with gains/loss from groundwater, which would occur in winter, therefore net gains/losses in groundwater were assumed negligible (Figure 7-17).

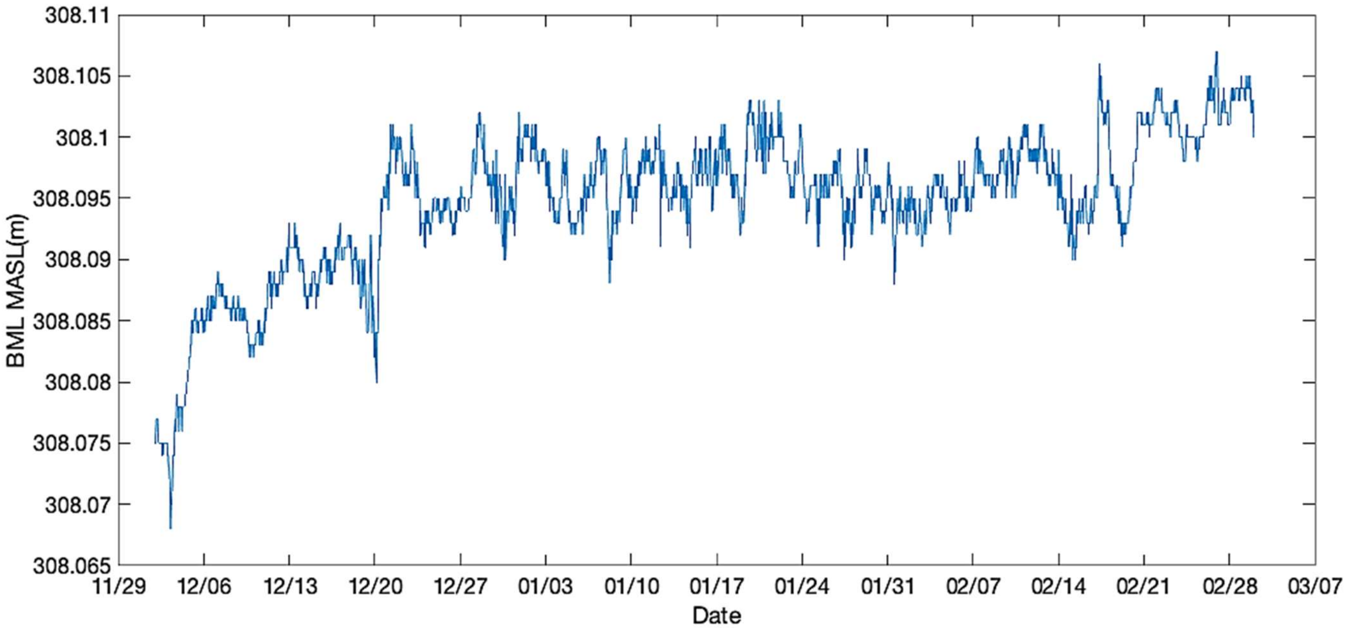


Figure 7-17: Over-winter water pressure in 2017 showing minimal changes during a largely snow-free January.

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 9 years. Figure 7-18 shows the annual estimated runoff, and while total fluxes were small, they ranged from 17 to 52 mm.

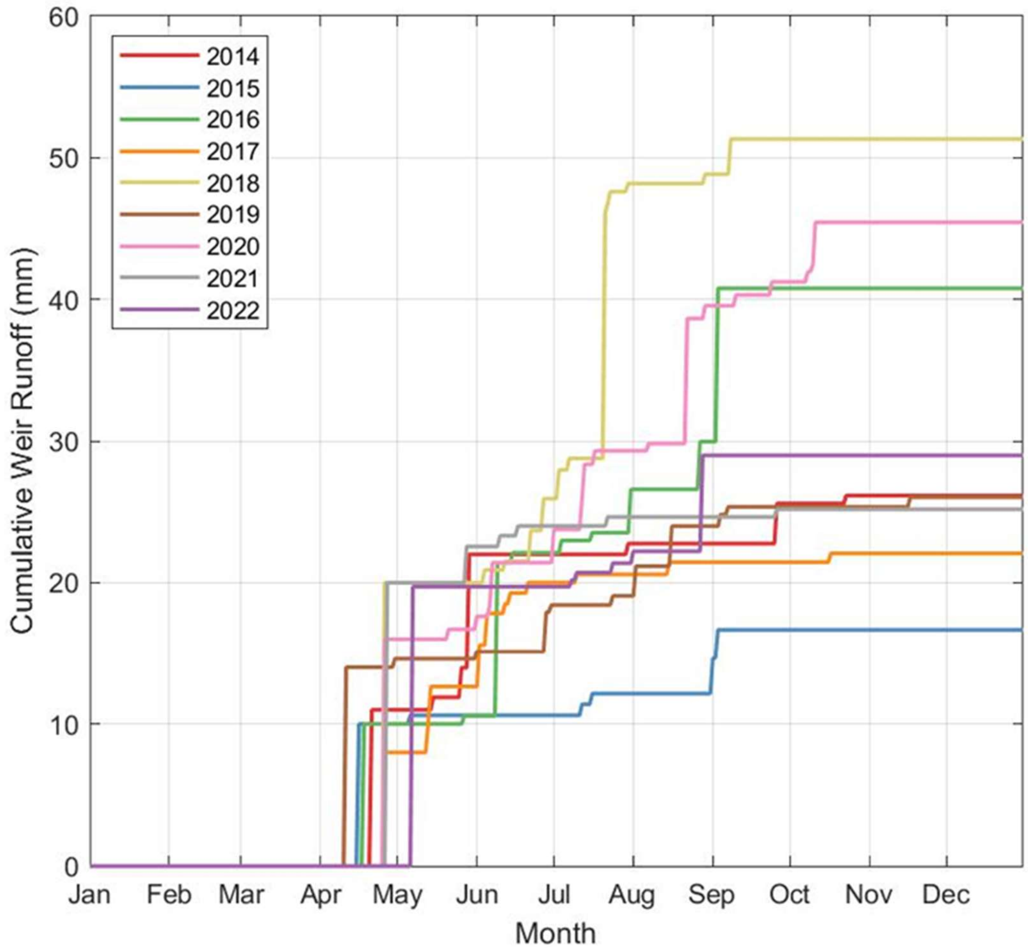


Figure 7-18: Cumulative calculated daily runoff fraction and weir runoff.

7.2.1.6 Pumping

When there is inflow or outflow, volumes of both the additions (Figure 7-19) and removals (Figure 7-20) of water from BML from pump operation are determined daily. In the early years of commissioning, there were very large inputs/outputs from BML 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 and very little (~23 mm) was removed. In 2022, 172 mm was pumped in, and 176 mm pumped out.

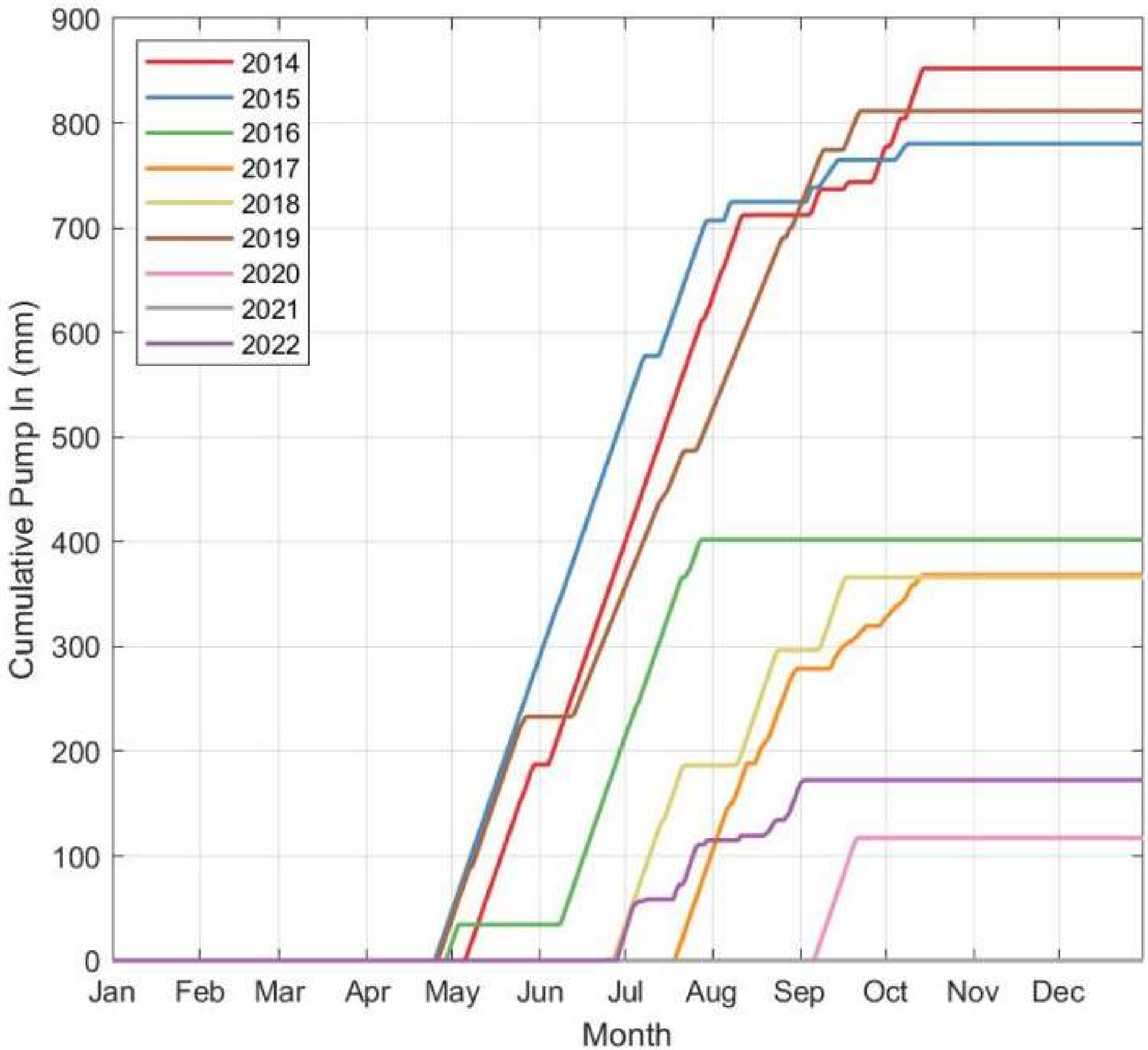


Figure 7-19: Total pump volume in from Beaver Creek Reservoir.

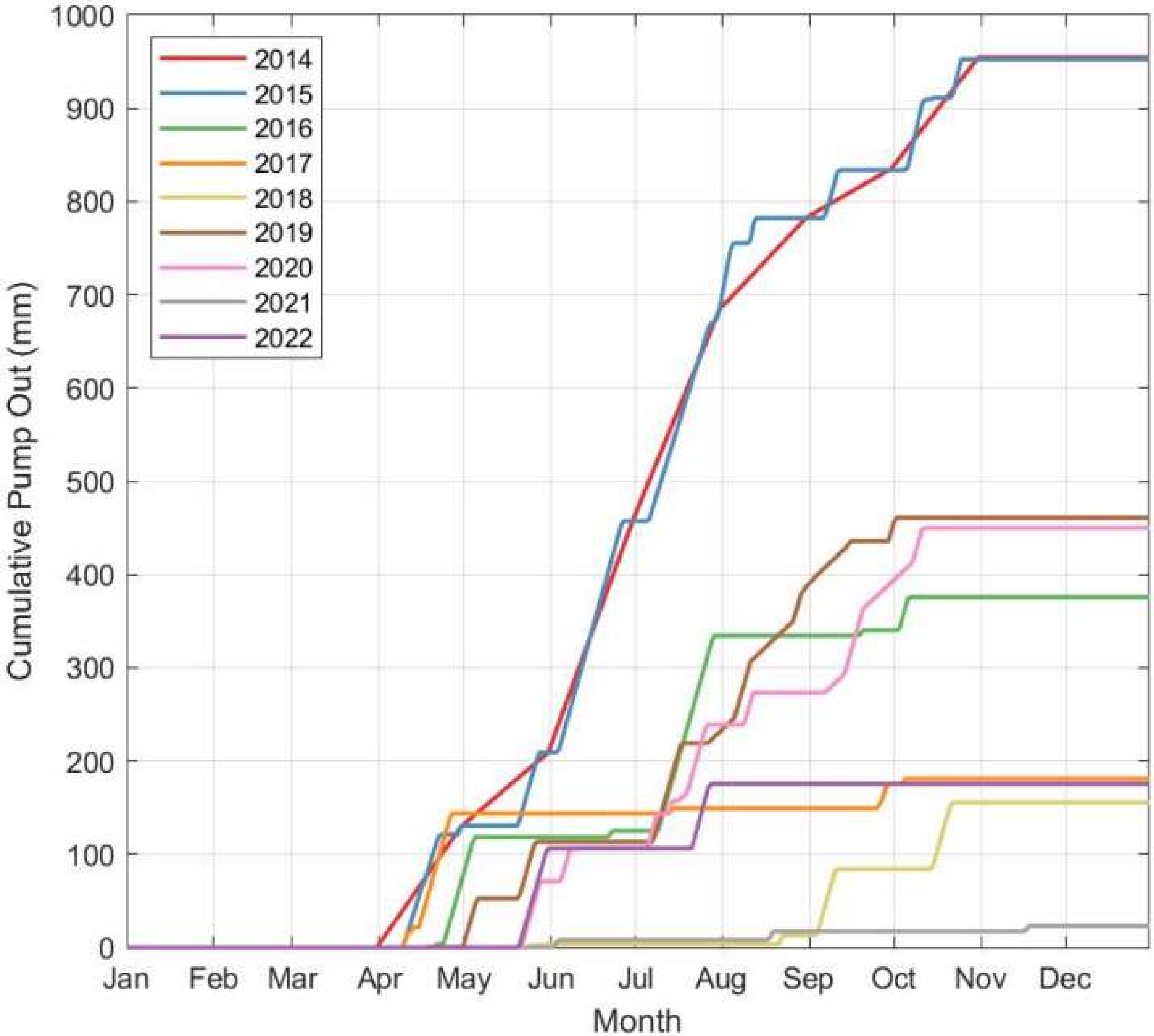


Figure 7-20: Total pumped removal of water from BML.

7.2.1.7 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 data. This is also compared with the publicly available air-sea toolbox to in-fill evaporation rates and compare actual rates with those of large open water bodies (Figure 7-21).

Evaporation from BML appears similar to other water bodies on site. Evaporation values were particularly low in 2014 and have gradually increased and range between 450 and 500 mm per year.

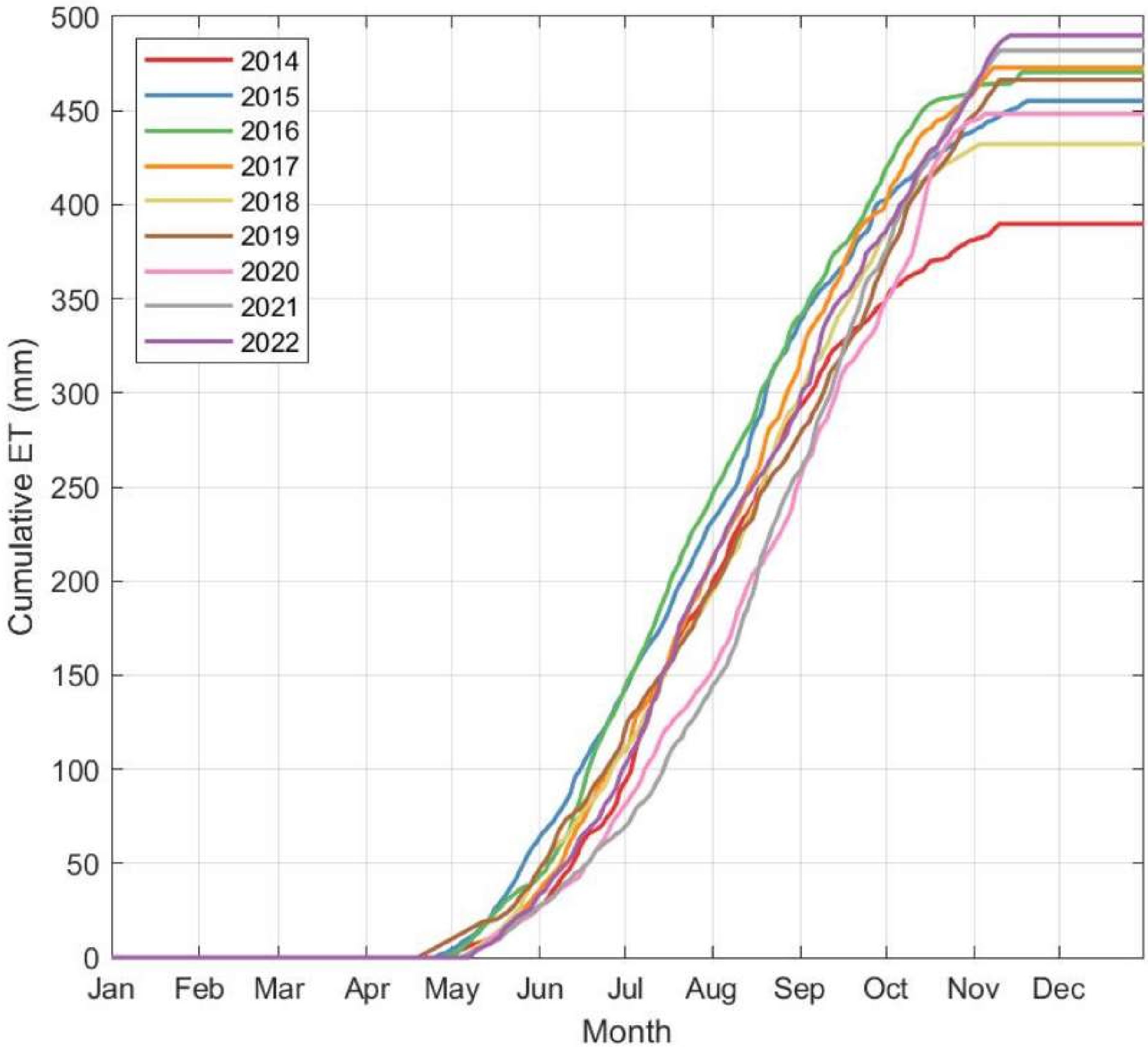


Figure 7-21: Cumulative evaporation from Base Mine Lake measured at Platform 1.

7.2.1.8 Multi-year Water Balances

Cumulative monthly totals in terms of mm and Mm^3 of water are presented in Figures 7-22 and 7-23; annual totals are presented in Tables 7-5 and 7-6. The volumetric totals include the water expressed from the FFT as determined by the annual FFT mudline elevation surveys.

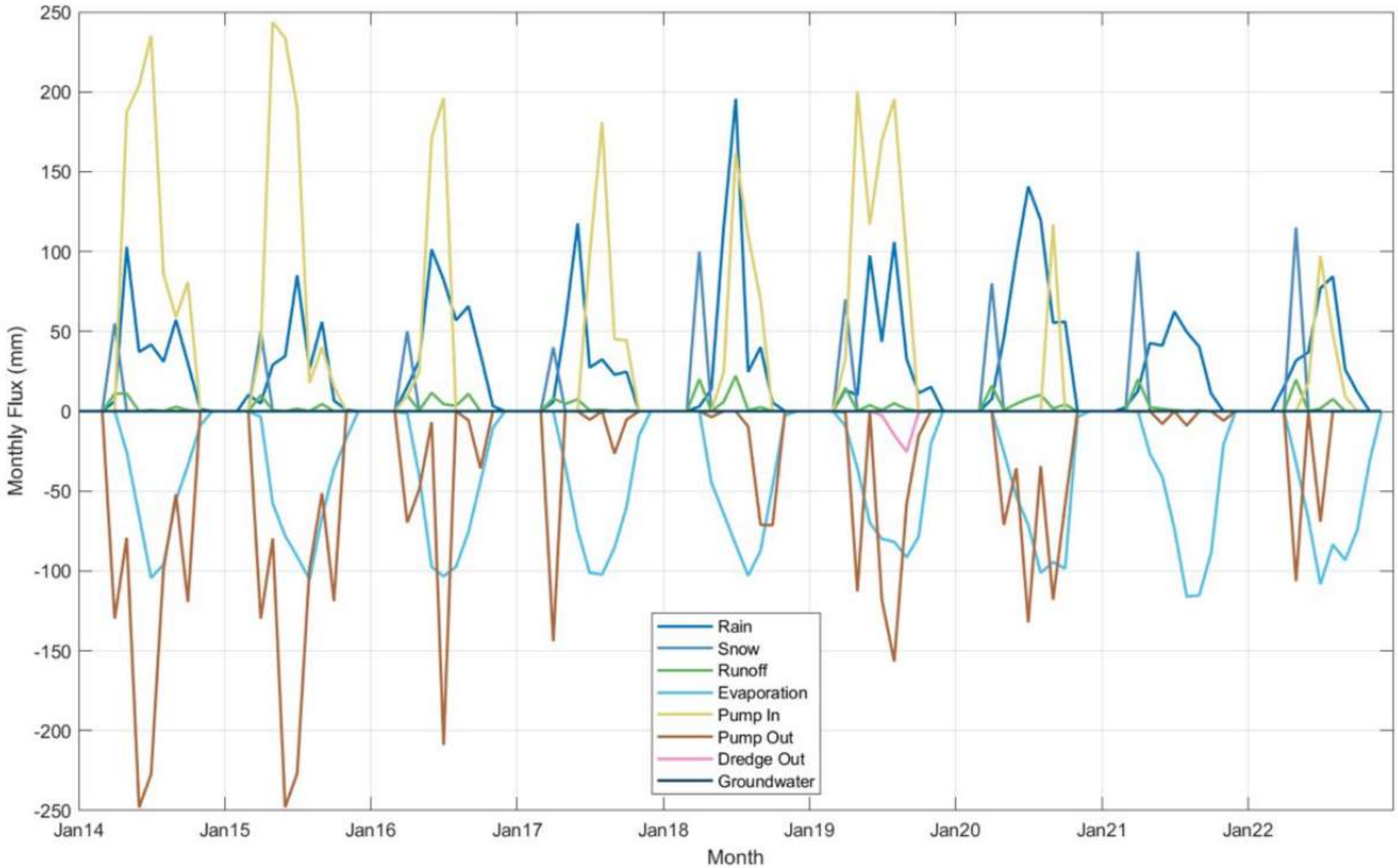


Figure 7-22: Monthly BML water balance in mm.

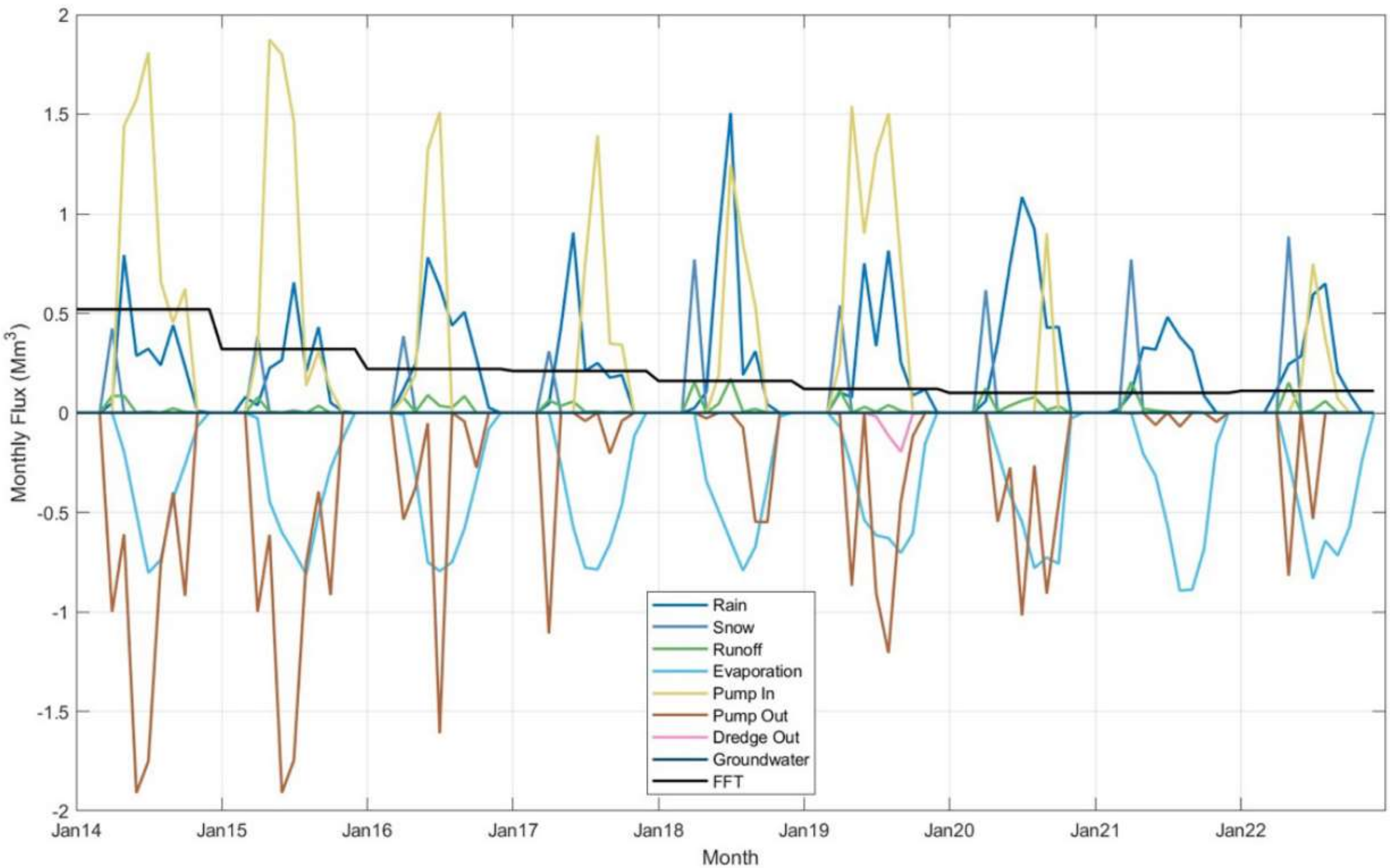


Figure 7-23: Monthly BML water balance in Mm³.

Table 7-5: Annual BML water balance (in mm)

Year	Ran	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

Table 7-6: Annual BML water balance (in Mm^3)

Year	Rain	SWE	Runoff	Evap	Pump In	Pump _Out	Dredge _ Out	FFT 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

7.2.2 Methane and Carbon Dioxide fluxes

CO_2 and CH_4 fluxes from BML continue to be measured. There has been considerable challenge in obtaining high quality CH_4 data for 2020 and 2021. In 2020, the COVID-19 pandemic limited access for data collection, and also in 2021 the platform became unmoored and the solar panels that power the CH_4 analyzer faced north. There was insufficient power to report comprehensive CH_4 for 2021 analysis is underway on the data for when the panels were oriented south. CO_2 and CH_4 figures with data to date are presented in Figures 7-24 and 7-25. The uptick in CH_4 in 2021 should be disregarded as 2022 values of CH_4 are more in line with previous years. On an annual basis there appears to be a slight increase in CO_2 flux from BML over the past six years.

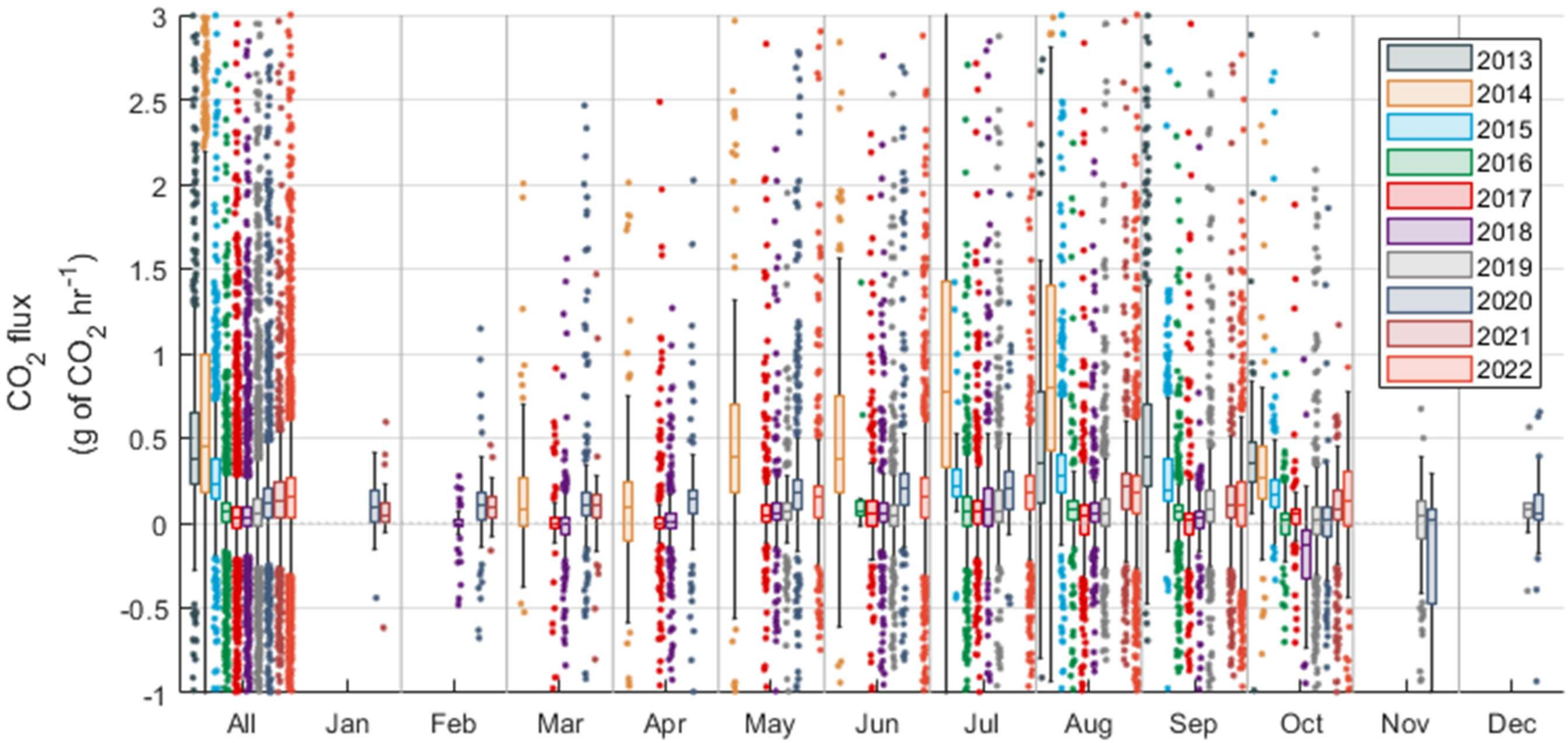


Figure 7-24: Annual and monthly binned CO_2 fluxes from BML.

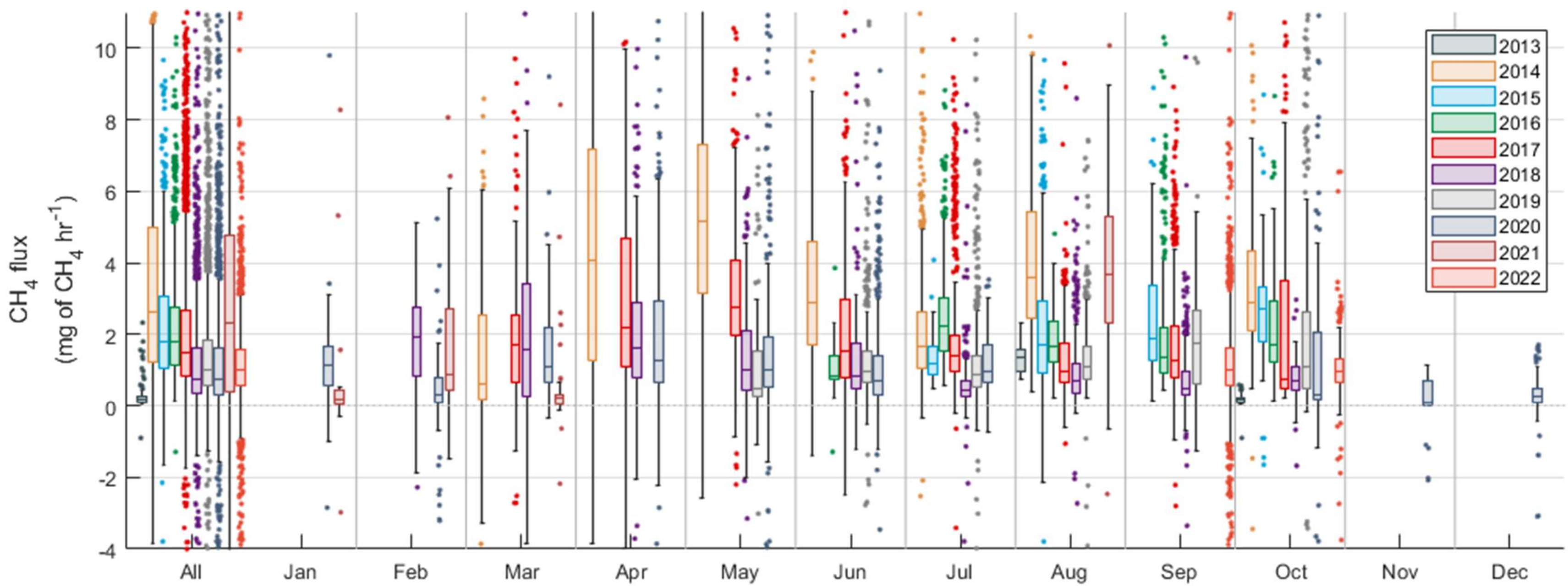


Figure 7-25: Annual and monthly binned CH_4 fluxes from BML.

7.2.3 Surface Water Quality Assessment

Table 7-7 below summarizes the key findings from the BML surface water quality assessment.

Table 7-7: BML Surface Water Quality Assessment Key Findings

BML Surface Water Quality Assessment Key Findings	
In-situ and Conventional Physico-Chemical Variables	
Summary of Observations	• Dimictic lake with typical patterns of mixing in spring and fall and stratification in winter and summer. • Elevated concentrations of monovalent anions (chloride) 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. • Decreased concentrations of major anions, cations, and TDS since 2013. • Decreased concentrations of suspended solids, and evidence for further decrease and increased stability since 2016 alum treatment. Concentrations of TSS are also decreasing at bottom depths.
Spatial Trends	• Seasonal suboxic conditions in deep waters, during periods of stratification. • Higher turbidity in the BML water cap near the FFT surface.
Guideline Exceedances (long-term)	• Dissolved oxygen concentrations less than minimum guideline requirements in the hypolimnion during winter, through summer stratification and into the fall. • 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 in sufficient concentrations to support primary production. • Variation in nutrient concentrations observed among seasons and depth strata within BML, related to expected biogeochemical processes.
Temporal Trends	• Seasonal variations of ammonia, nitrate, and phosphorus observed. • Lower nutrient concentrations in 2022 were lower relative to the previous monitoring years.
Spatial Trends	• Depth-related variation in nutrient concentrations: • BML bottom layer potential source of ammonia. • Total phosphorus concentrations greater within the surface and bottom depth strata.
Guideline Exceedances (long-term)	• Ammonia and nitrite concentrations greater than guidelines, however, the frequency of exceedances has decreased since 2013.

BML Surface Water Quality Assessment Key Findings	
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 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 were greater in the bottom depth strata.
Guideline Exceedances (long-term)	• Boron concentrations consistently greater than long-term guidelines. • Sporadic observations of concentrations greater than long-term guidelines for several metals, including dissolved aluminum, and iron, and total zinc. • 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: ○ Naphthenic acids, alkylated and parent PAHs, and F2 and F3 hydrocarbons. • Most volatile organics (e.g., benzene, xylene, toluene) were near or below analytical detection limits.
Temporal Trends	• Highest concentrations of PAH were in summer, F2 and F3 hydrocarbons were in fall, and NA were in winter 2021. • Improvements to the extraction method for naphthenic acids in 2015 has resulted in higher concentrations being reported in recent years. • Negligible variation in naphthenic acid concentrations over the last three years (2016 to 2018).
Spatial Trends	• Limited depth-related variation, with PAH concentrations marginally higher in bottom water samples.
Guideline Exceedances (long-term)	• Total phenolics and F2 hydrocarbons consistently greater than guidelines. [NOTE: F2 hydrocarbons have only a short-term guideline.] • No anthracene exceedances in 2022 and very few pyrene exceedances (6.2% of water samples).

The surface water quality component of the 2022 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 FFT mudline). During open water, the following depth determination protocols were established for analytical sampling according to station type:

- BML 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 FFT 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 FFT mudline).
- BML 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 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 BML water quality is presented in Table 7-8 to Table 7-15 below. Some other key results from the surface water quality program are presented in the following sections.

Table 7-8: Summary and General Surface Water Chemistry Results from Base Mine Lake (BML): 2021 and 2022

	2021[a]	2022[b]
Depth from Surface (m)	**0.3**	**0.3**
General		
pH (units)	8.51	8.62
Conductivity (uS/cm)	2455	2475
Temperature (°C)	12.3	7.3
Dissolved Solids (mg/L)**	1700	1400
Total Solids Content (g/100g)	-	-
Alkalinity (Total as $CaCO_3$) ($mg.L^{-1}$)	620	620
Chemical Oxygen Demand ($mg.L^{-1}$)	149	144
Biological Oxygen demand ($mg.L^{-1}$)	2	2
Redox Potential (mV)		
Phenols ($ug.L^{-1}$)**	3.1	1.5
Tannin & Lignins ($mg.L^{-1}$)**	-	-
Cyanide ($ug.L^{-1}$)**	-	-
MBAS ($mg.L^{-1}$)**	-	-
Sulphides ($ug.L^{-1}$)	13	1.8
Hydrogen Sulphide ($ug.L^{-1}$)	13	2
Methyl Hg (ng/L)	-	-
Mercury (Hg) (ug/L)	0.00074	0.00064
Arsenic (As) (ug/L)	2.4	2.1
Selenium (Se) (ug/L)	0.224	0.176
Boron (B) (mg/L)	1.39	1.86
Total Pet. Hydrocarbon (TPH) ($mg.L^{-1}$)	-	2
Bitumen Content (% by wt.)	-	-
Naphtha Content (% by wt.)	-	-
Total PAH's (mg/L)	0.0015	0.0015
Alkylated PAH's as % of Total PAH's	-	-
Dis. Inorganic Carbon (DIC) ($mgC.L^{-1}$)**	-	-
Dis. Organic Carbon (DOC) ($mg.L^{-1}$)**	33	-
Naphthenic Acids ($mg.L^{-1}$)	23	27
Na/Cl Ratio (meq/meq)	-	-
Major Ion Ratio (∑Cat/∑An meq/meq)	-	-
Hardness (as mg/L $CaCO_3$)**	130	110
Acute Toxicity		
Rainbow Trout LC_{50} (% by vol)	>100	>100
Rainbow Trout (% survival at 96 hrs.)	>100	>100
Daphnia Magna LC_{50} (% by vol)	>100	>100
Daphnia Magna EC_{50} (immobility)	>100	>100
Microtox IC_{50} (% by vol)	>91	>91
Microtox IC_{20} (% by vol)	-	>91
Nutrients		
o-Phosphate ($ug.L^{-1}$)	2.5	3.1
Total Phosphorous ($ugP.L^{-1}$)	13	8.5
Ammonia ($mgN.L^{-1}$)	0.19	0.22
Nitrite ($ugN.L^{-1}$)	17	6.7
Nitrate ($ugN.L^{-1}$)	170	120
Nitrate + Nitrite ($ugN.L^{-1}$)	180	120
Total Nitrogen ($mgN.L^{-1}$)	1.3	1.2
Silicon ($mg.L^{-1}$)	3.1	2.4
Major Ions ($mg. L^{-1}$)		
i) Cations ($mg. L^{-1}$)		
Sodium (Na^+)	550	534
Potassium (K^+)	8.7	7.15
Magnesium (Mg^{+2})	14	10.8
Calcium (Ca^{+2})	28	24.8
Total Cations (meq/L)	**26.7**	**25.5**
ii) Anions ($mg. L^{-1}$)		
Fluoride (F^-)	1.6	1.6
Chloride (Cl^-)	350	360
Bromide (Br^-)	-	-
Sulphate ($SO_4^=$)	170	150
Carbonate ($CO_3^=$)	35	16
Bicarbonate (HCO_3^-)	690	720
Total Anions (meq/L)	**25.9**	**25.6**

a) Sample collected June 1, 2021. Coordinates (UTM): 6318910N, 462240E. Depth of FFT interface: 11.7 m
b) Sample collected May 17, 2022. Coordinates (UTM): 6319790N, 462837E. Depth of FFT interface: 11.3 m

Table 7-9: Dissolved Elemental Concentrations in Base Mine Lake (BML) Surface Water: 2021 and 2022

		2021[a]	2022[b]
Depth from Surface (m)	***DL***	**0.3**	**0.3**
Conductivity (uS/cm)		2455	2475
Dissolved Major Elements (mg.L^{-1})			
Sodium (Na)	***2.5***	550	534
Potassium (K)	***0.3***	8.7	7.15
Magnesium (Mg)	***0.2***	14	10.8
Calcium (Ca)	***0.3***	28	24.8
Silicon (Si)	***0.1***	3.52	2.42
Boron (B)	***0.02***	1.42	1.86
Strontium (Sr)	***0.0001***	0.591	0.591
Sulphur (S)	***6***	52	42
Dissolved Trace Elements (ug.L^{-1})			
Aluminum (Al)	***1***	4.2	49.2
Antimony (Sb)	***0.04***	0.227	0.208
Arsenic (As)	***0.04***	2.48	1.99
Barium (Ba)	***0.04***	236	198
Beryllium (Be)	***0.02***	0.034	0.01
Boron (B)	***20***	1420	1630
Cadmium (Cd)	***0.01***	0.01	0.005
Chromium (Cr)	***0.2***	0.6	0.19
Cobalt (Co)	***0.01***	0.539	0.42
Copper (Cu)	***0.1***	0.4	0.388
Iron (Fe)	***2***	249	52.8
Lead (Pb)	***0.01***	0.285	0.0527
Lithium (Li)	***1***	118	115
Manganese (Mn)	***0.1***	18.5	3.95
Mercury (Hg)	-	-	-
Molybdenum (Mo)	***0.1***	16.8	16.8
Nickel (Ni)	***0.04***	4.54	4.07
Phosphorus (P)	-	-	-
Rubidium (Rb)	-	-	-
Selenium (Se)	***0.08***	0.25	0.258
Silicon (Si)	***100***	3520	2410
Silver (Ag)	***0.01***	0.01	0.0061
Strontium (Sr)	***0.1***	591	479
Thallium (Tl)	***0.004***	0.005	0.0023
Thorium (Th)	-	-	-
Tin (Sn)	***0.4***	0.4	0.22
Titanium (Ti)	***1***	11.8	1
Tungsten (W)	-	-	-
Uranium (U)	***0.004***	2.2	2.0
Vanadium (V)	***0.4***	2.69	1.95
Yttrium (Y)	-	-	-
Zinc (Zn)	***0.2***	1.59	8.39
Zirconium (Zr)	***0.2***	4.9	1.26

a) Sample collected June 1, 2021. Coordinates (UTM): 6318910N, 462240E. Depth of FFT interface: 11.7 m

b) Sample collected May 17, 2022. Coordinates (UTM): 6319790N, 462837E. Depth of FFT interface: 11.3 m

Table 7-10: PAH Concentrations in Base Mine Lake (BML) Surface Water: 2021 and 2022

PAH Concentrations				
	Mol wt		**2021[a]**	**2022[b]**
Depth from Surface (m)		***DL (ug/L)***	**0.3**	**0.3**
Polycyclic Aromatic Hydrocarbons				
Total Parent PAH's			*0.16*	*0.14*
Total Alkylated PAH's			*1.36*	*1.00*
Alkylated PAH's as % of Total PAH's			*90*	*87*
PAH Compounds (µg/L)				
Quinoline	129	***0.005***	0.0083	0.0077
Naphthalene	128	***0.005***	0.0087	0.0053
2-Methylnaphthalene	142	***0.005***	0.0050	0.0050
C1-Naphthalene	142	***0.005***	0.0096	0.0080
C2-Naphthalene	156	***0.005***	0.0410	0.0380
C3-Naphthalene	170	***0.005***	0.1100	0.1000
C4-Naphthalene	184	***0.005***	0.1400	0.1500
Acenaphthylene	152	***0.005***	0.0050	0.0050
Acenaphthene	154	***0.005***	0.0092	0.0056
Fluorene	166	***0.005***	0.0050	0.0050
C1-fluorene	180	***0.005***	0.0370	0.0210
C2-fluorene	194	***0.005***	0.0490	0.0630
C3-fluorene	208	***0.005***	0.1200	0.1000
Biphenyl	154	***0.005***	0.0050	0.0050
C1-biphenyl	168	***0.005***	0.0050	0.0050
C2-biphenyl	182	***0.005***	0.0050	0.0050
Phenanthrene	178	***0.005***	0.0050	0.0050
C1-phenanthrene/anthracene	192	***0.005***	0.0290	0.0260
C2-phenanthrene/anthracene	206	***0.005***	0.0720	0.0530
C3-phenanthrene/anthracene	220	***0.005***	0.1200	0.0470
C4-phenanthrene/anthracene	234	***0.005***	0.0460	0.0240
Anthracene	178	***0.005***	0.0050	0.0050
Acridine	*179*	***0.005***	0.0050	0.0050
Dibenzothiophene	184	***0.005***	0.0050	0.0050
C1-dibenzothiophene	198	***0.005***	0.0170	0.0260
C2-dibenzothiophene	212	***0.005***	0.1800	0.0740
C3-dibenzothiophene	226	***0.005***	0.1000	0.0560
C4-dibenzothiophene	240	***0.005***	0.0270	0.0130
Fluoranthene	202	***0.005***	0.0050	0.0050
Pyrene	202	***0.005***	0.0094	0.0099
C1-fluoranthene/pyrene	216	***0.005***	0.0270	0.0210
C2-fluoranthene/pyrene	230	***0.005***	0.0360	0.0330
C3-fluoranthene/pyrene	244	***0.005***	0.0980	0.0660
C4-fluoranthene/pyrene	258	***0.005***	0.0290	0.0280
Benzo(a)anthracene	228	***0.005***	0.0050	0.0050
Chrysene	228	***0.005***	0.0050	0.0050
C1-benzo(a)anthracene/chrysene	242	***0.005***	0.0110	0.0072
C2-benzo(a)anthracene/chrysene	256	***0.005***	0.0370	0.0120
C3-benzo(a)anthracene/chrysene	270	***0.005***	0.0091	0.0050
C4-benzo(a)anthracene/chrysene	284	***0.005***	0.0050	0.0050
Benzo[e]pyrene	252	***0.005***	0.0050	0.0050
Benzo(b&j)fluoranthene	252	***0.005***	0.0050	0.0050
Benzo(k)fluoranthene	252	***0.005***	0.0050	0.0050
C1-benzo(bjk)fluoranthene/benzo(a)pyrene	266	***0.005***	0.0050	0.0050
C2-benzo(bjk)fluoranthene/benzo(a)pyrene	280	***0.005***	0.0050	0.0050
Benzo(c)phenanthrene	252	***0.005***	0.0050	0.0050
Benzo(a)pyrene	252	***0.005***	0.0050	0.0050
Benzo[a]pyrene (equival.)	252	***0.010***	0.0100	0.0100
Dibenz(a,h)anthracene	278	***0.005***	0.0050	0.0050
Perylene	252	***0.005***	0.0050	0.0050
Benzo(g,h,i)perylene	276	***0.005***	0.0050	0.0050
Indeno(1,2,3-cd)pyrene	276	***0.005***	0.0050	0.0050
Dibenzo(a,e)pyrene	302	***0.005***	-	-
Dibenzo(a,h)pyrene	302	***0.005***	-	-
Dibenzo(a,i)pyrene	302	***0.005***	-	-
Dibenzo(a,l)pyrene	302	***0.005***	-	-

a) Sample collected June 1, 2021. Coordinates (UTM): 6318910N, 462240E. Depth of FFT interface: 11.7 m
b) Sample collected May 17, 2022. Coordinates (UTM): 6319790N, 462837E. Depth of FFT interface: 11.3 m

Table 7-11: BTEX and Hydrocarbon Fraction Concentrations in Base Mine Lake (BML) Surface Water: 2021 and 2022

		2021[a]	2022[b]
Depth from Surface (m)	***DL (ug/L)***	**0.3**	**0.3**
BTEX Compounds			
Benzene	***0.4***	0.4	0.4
Ethylbenzene	***0.4***	0.4	0.4
Toluene	***0.4***	0.4	0.4
o-Xylene	***0.4***	0.4	0.4
m & p-Xylene	***0.8***	0.8	0.8
Xylenes (Total)	***0.89***	0.89	0.89
Hydrocarbon Fractions			
F1 (C6-C10)	***100***	100	100
F2 (C10-C16)	***100***	610	500
F3 (C16-C34)	***100***	3000	1600
F4 (C34-C50)	***200***	200	200
F4G-SG (Heavy Hydrocarbons-Grav.)		-	-

a) Sample collected June 1, 2021. Coordinates (UTM): 6318910N, 462240E. Depth of FFT interface: 11.7 m
b) Sample collected May 17, 2022. Coordinates (UTM): 6319790N, 462837E. Depth of FFT interface: 11.3 m

Table 7-12: Bioassays Results from Base Mine Lake (BML) Surface Water: 2021 and 2022

Sample Description				
Base Mine Lake			**2021[a]**	**2022[b]**
Northing (UTM)	m		6319000	6319790
Easting (UTM)	m		462875	462837
Sample Date			01-Jun-21	17-May-22
pH			8.5	8.6
Conductivity	uS/cm		2455	2475
Naphthenic Acids (NAs)	mg/L		23	27
NH_4^+	mgN/L		0.2	0.22
BIOASSAY RESULTS (Vol %)				
Rainbow Trout Bioassay[1]	Acute Toxicity: mortality (96 hrs) (Vol %)	LC_{50}	>100	>100
		LC_{25}	-	-
	Acute Toxicity: mortality	% Survival (neat at 96hr)	>100	>100
Daphnia Magna Bioassay[2]	Acute Toxicity: mortality (48 hrs) (Vol %)	LC_{50}	>100	>100
		LC_{25}	-	-
	Acute Toxicity: immobility (Vol %)	EC_{50}	>100	>100
		EC_{25}	-	-
	Acute Toxicity: mortality	% Survival (neat at 48hr)	100	100
Bacterial (Microtox) Bioassay[3]	Acute Toxicity: Light Inhibition (Vol %)	IC_{50} (15 mins)	>91	>91
		IC_{20} (15 mins)	-	>91

a) Sample collected June 1, 2021. Coordinates (UTM): 6318910N, 462240E. Depth of FFT interface: 11.7 m
b) Sample collected May 17, 2022. Coordinates (UTM): 6319790N, 462837E. Depth of FFT interface: 11.3 m
1) RT Bioassay: Trout 96-h Static Acute Test (WTR-ME-041): Species- *Oncorhynchus mykiss (Ref. Method for Determining Acute Lethality of Effluents to Rainbow Trout, 1990. Environment Canada, EPS 1/RM/13. including May 1996 and December 2000 amendments.)*
2) ZP Bioassay: Daphnia 48-h Static Acute Test (WTR-ME-015) Species: Daphnia magna (Ref. *Biological Test method: Reference Method for Determining Acute Lethality of Effluents to Daphnia magna, 2000. Environ. Can., EPS 1/RM/14. Second Edition*)
3) Bacterial Bioassay: Luminescent Bacterium Vibrio fischeri 15 min. Inhibition of Light Output Static Test (SOIL-ME-001) Species: Vibrio fischeri (Ref. Toxicity Test Using Luminescent Bacteria (Vibrio fischeri), 1992. Environment Canada, EPS 1/RM/24.

Table 7-13: Locations, analyses, and frequency of snow, ice, and water quality sampling at Base Mine Lake, winter 2022

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 (S)[3]	BML12_PLATFORM 1_C[5]	-	-	-	-	-	-	-	-	-	-
Ice (◊)[3]	BML12_PLATFORM 2_NE[5]	-	-	-	-	-	-	-	-	-	-
Snow (T)[3]	BML12_PLATFORM 3_SW	S	ST◊	ST◊	ST◊	ST	ST◊	ST◊	ST	ST	S
	BML13_D04[4]	S	ST◊	ST◊	ST◊	ST	ST◊	ST◊	ST	ST	S
	BML15_D26[5]	-	-	-	-	-	-	-	-	-	-

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

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

[3] Surface water, ice, and snow samples collected during the weeks of February 17 and March 15.

[4] Deep station D04 sampled only during March field visit.

[5] Platform stations 1 and 2 and deep station D26 were not accessible during winter 2022.

-= not sampled

Table 7-14: Locations, analyses, and frequency of surface water sampling at Base Mine Lake, open-water 2022

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	S	S	S	S	S	S	S	S	-	S
	BML12_PLATFORM 2_NE	S	S	S	S	S	S	S	S	-	S
	BML12_PLATFORM 3_SW	S	S	S	S	S	S	S	S	-	S
	BML13_D04[3]	-	-	-	-	-	-	-	-	-	-
	BML15_D26[3]	-	-	-	-	-	-	-	-	-	-
Lake Pump-out[4]	BML_PUMP_OUT	S	S	S	S	S	S	S	-	S	-
Reservoir Pump-in[5]	BCR_PUMP_IN	S	-	S	S	S	S	S	-	-	-

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

[2] Photosynthetically active radiation (PAR) depth profile was measured using a Li-Cor unit during the open-water season.

[3] Deep stations D04 and D26 were not visited during the 2022 open-water season.

[4] Samples collected in September and October 2022.

[5] In situ measurements collected July-October 2022. Analytical samples collected July, September, and October 2022.

💧 = water sample collection

- = not sampled

Table 7-15: Total number of analytical water quality samples collected from Base Mine Lake and Beaver Creek Reservoir, 2013 to 2022

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

7.2.3.1 Trends in conductivity profiles through time

Lake-wide specific conductivity has decreased progressively in BML (Figure 7-26); median specific conductivity at the BML 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 2022. Consistent with results from previous years, specific conductivity also was seasonally variable in 2022, with a median value of 2,664 µS/cm at platform stations in winter relative to around 2,500 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.

7.2.3.2 Sodium

Sodium has remained the dominant cation in BML since monitoring began in 2013, although concentrations have declined slightly in recent years (Figure 7-27). The seasonal median concentrations of sodium in 2022 ranged from 530 mg/L in fall to 591 mg/L in winter, which were slightly lower than the historical seasonal medians (550 to 610 mg/L). Sodium has remained evenly distributed throughout the water column since 2014.

7.2.3.3 Chloride

Chloride has remained the dominant anion in BML since monitoring was initiated in 2013, with absolute concentrations showing a decreasing trend over time. Median chloride concentrations in 2022 were similar in all seasons, ranging from 360 to 390 mg/L, while falling below the historical seasonal median range of 390 mg/L in fall to 430 mg/L in winter (Figure 7-28). 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 2021.

7.2.3.4 Sulphate

Sulphate continued to be the second-most abundant anion in BML in 2022, exhibiting only minor variation among seasons and across depth strata (Figure 7-29). Seasonal median sulphate concentrations in 2022 ranged from 150 to 170 mg/L, which were slightly lower than the seasonal medians from previous years (ranged from 180 to 190 mg/L). Sulphate concentrations were below the long-term surface water quality guideline for the protection of aquatic life in 2022 (Figure 7-29).

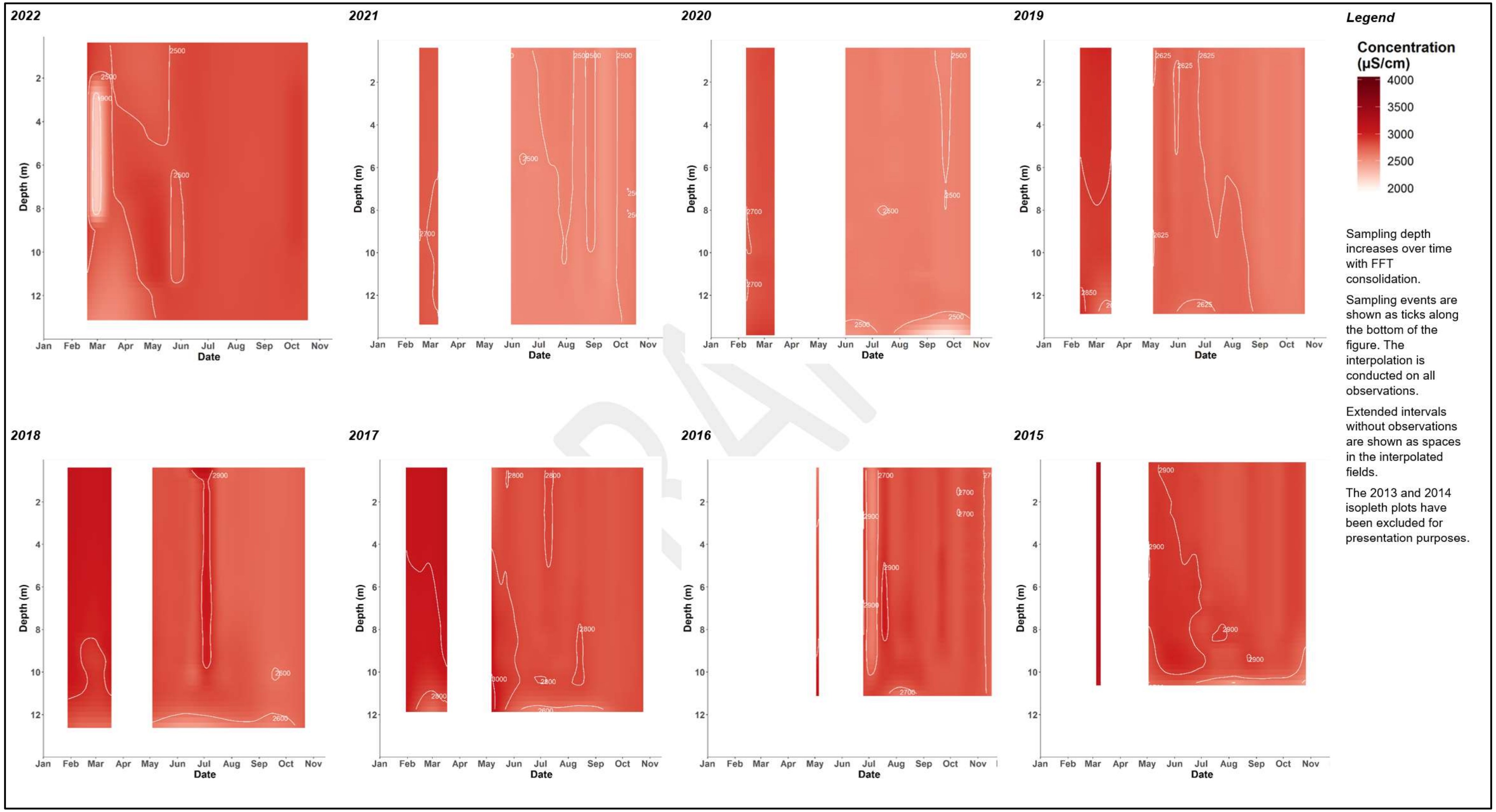


Figure 7-26: In situ specific conductivity (µS/cm) profiles measured at Base Mine Lake platform and deep stations, 2015 to 2022.

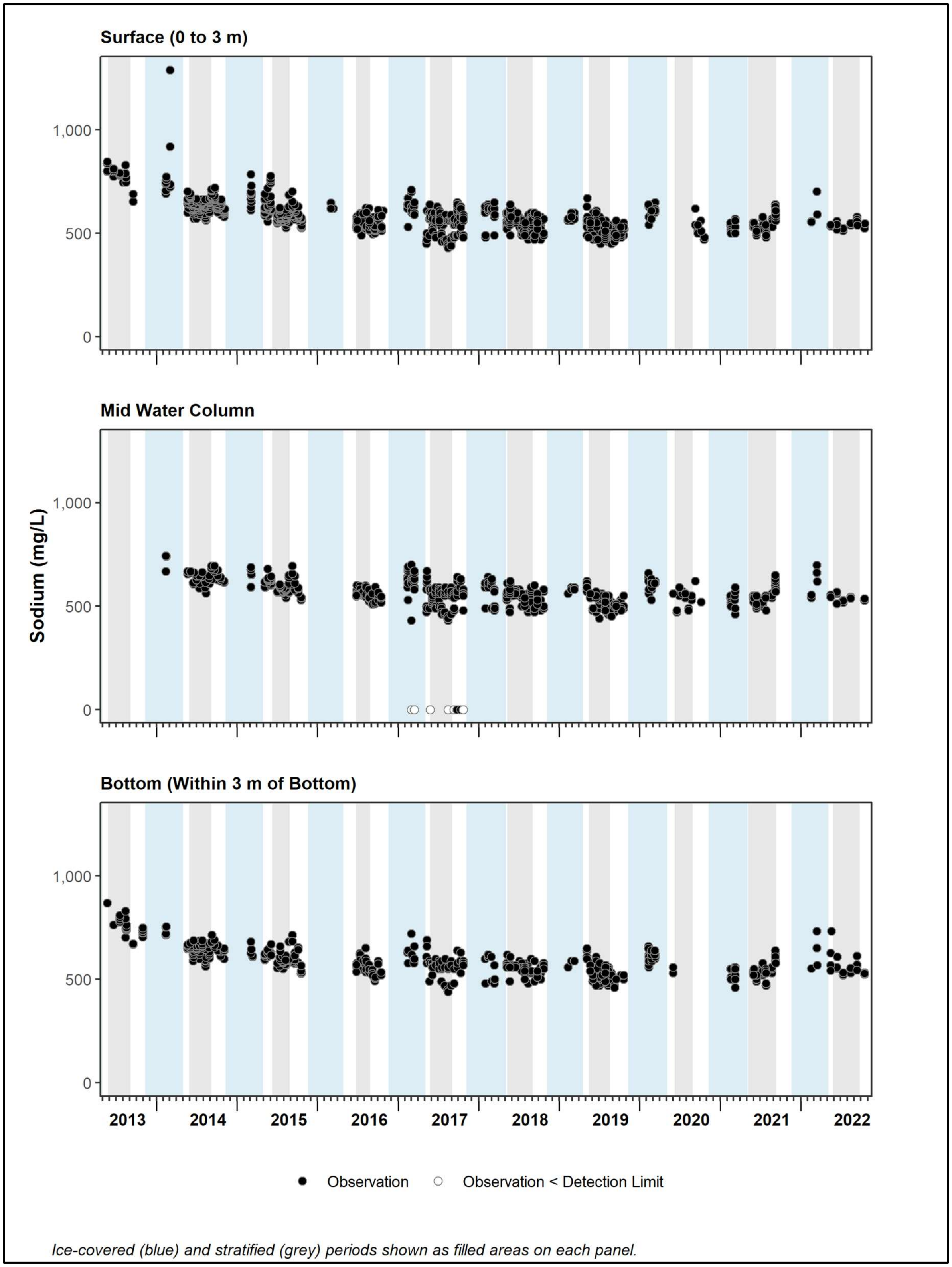


Figure 7-27: Sodium in Base Mine Lake, 2013 to 2022.

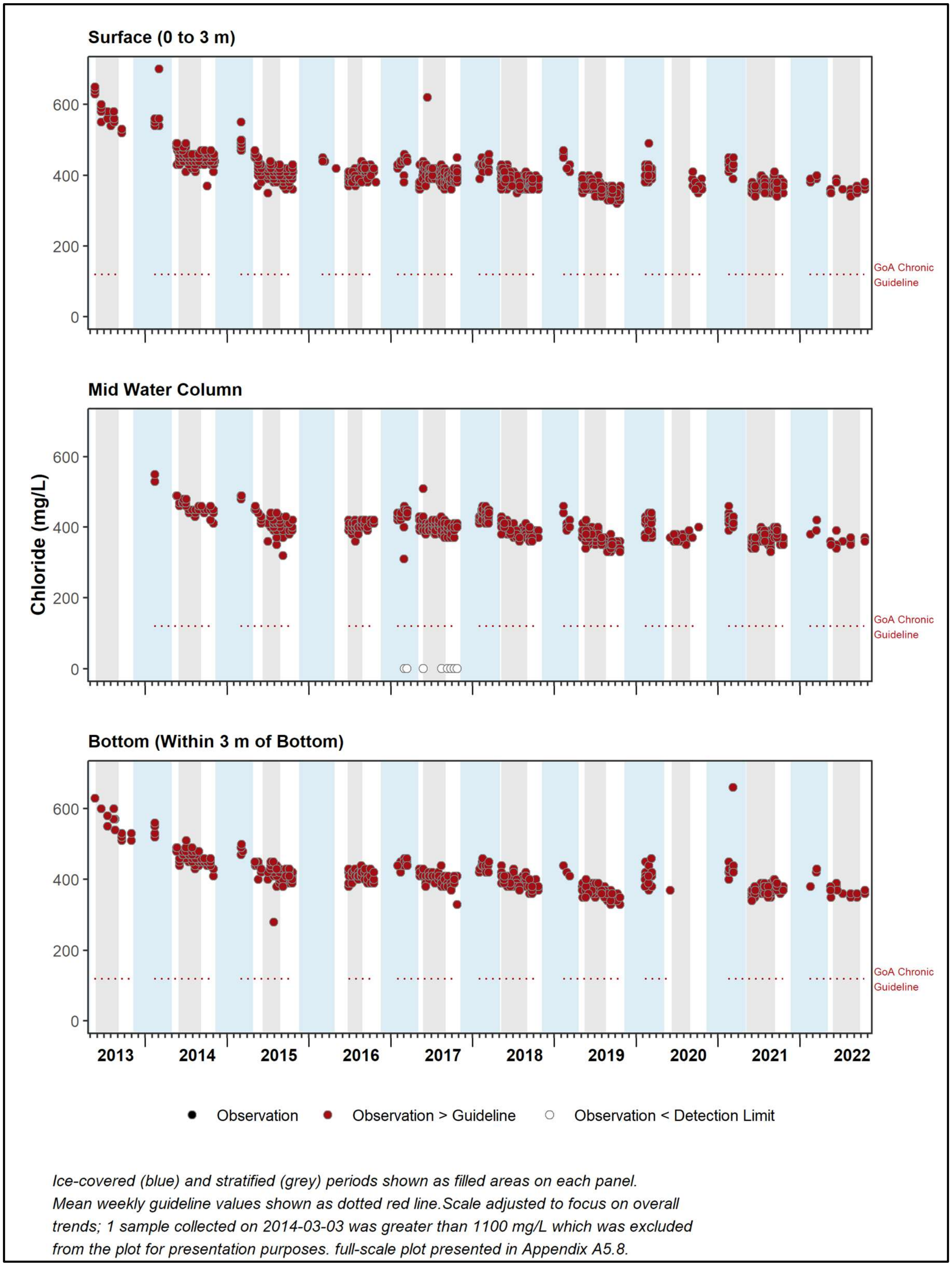
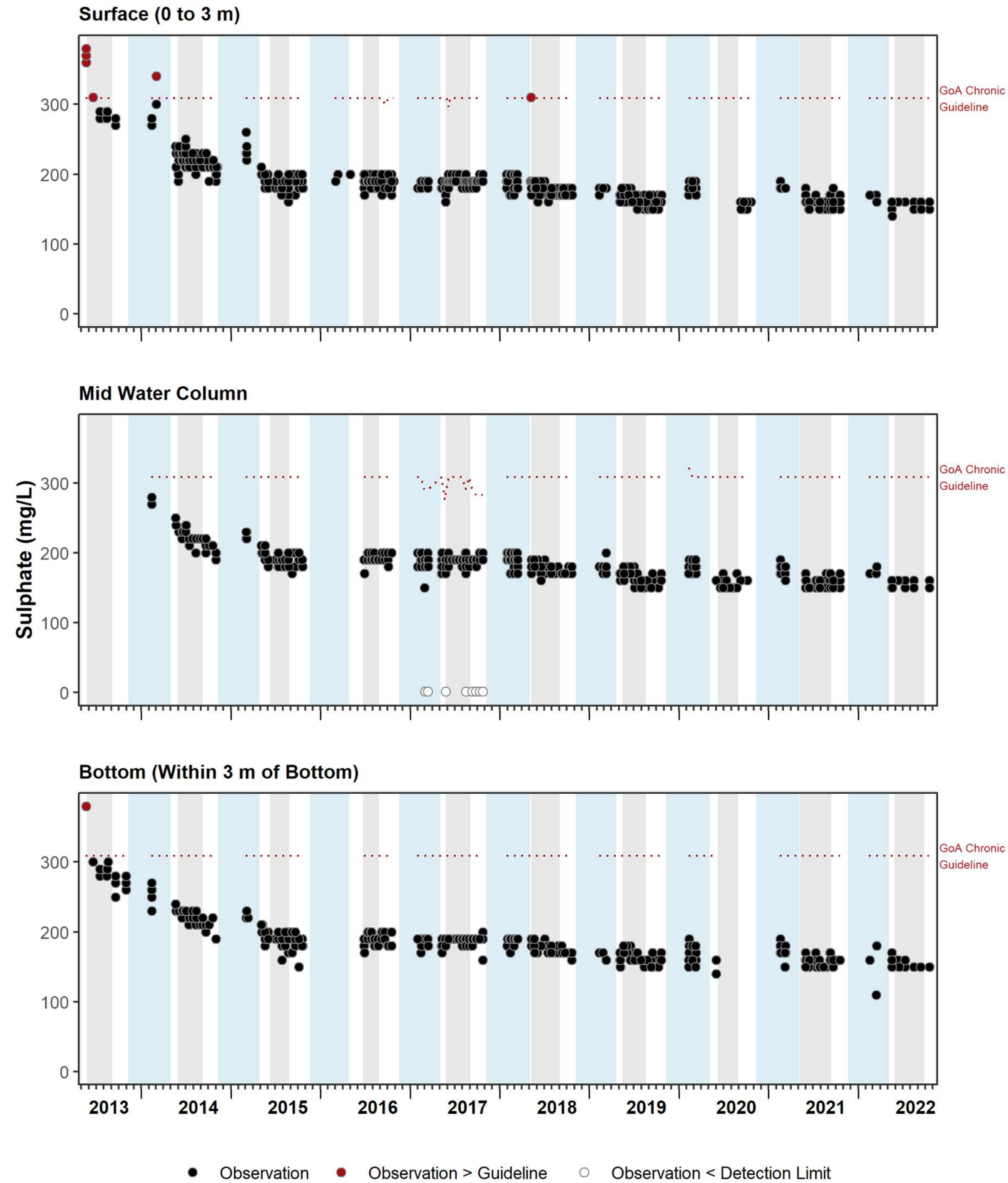


Figure 7-28: Chloride in Base Mine Lake, 2013 to 2022.



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel. Mean weekly sulphate guideline values shown as dotted red line and are hardness dependent. Scale adjusted to focus on overall trends; 3 samples collected between 2013-08-18 and 2014-03-03 were greater than 400 mg/L which were excluded from the plot for presentation purposes. full-scale plot presented in Appendix A5.9.

Figure 7-29: Sulphate in Base Mine Lake, 2013 to 2022.

7.2.3.5 BML Ionic Composition

The major ion composition of BML water has been relatively stable since 2013 (Figure 7-30). The composition of cations is strongly dominated by monovalent cations, especially sodium, which comprised approximately 92% 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 58:29:13, respectively. Cation and anion ratios in BML have shifted gradually over the years, while remaining comparable to OSPW originating from the WIP; the ionic signatures of OSPW and BML have been, and continue to be, substantially different than BCR.

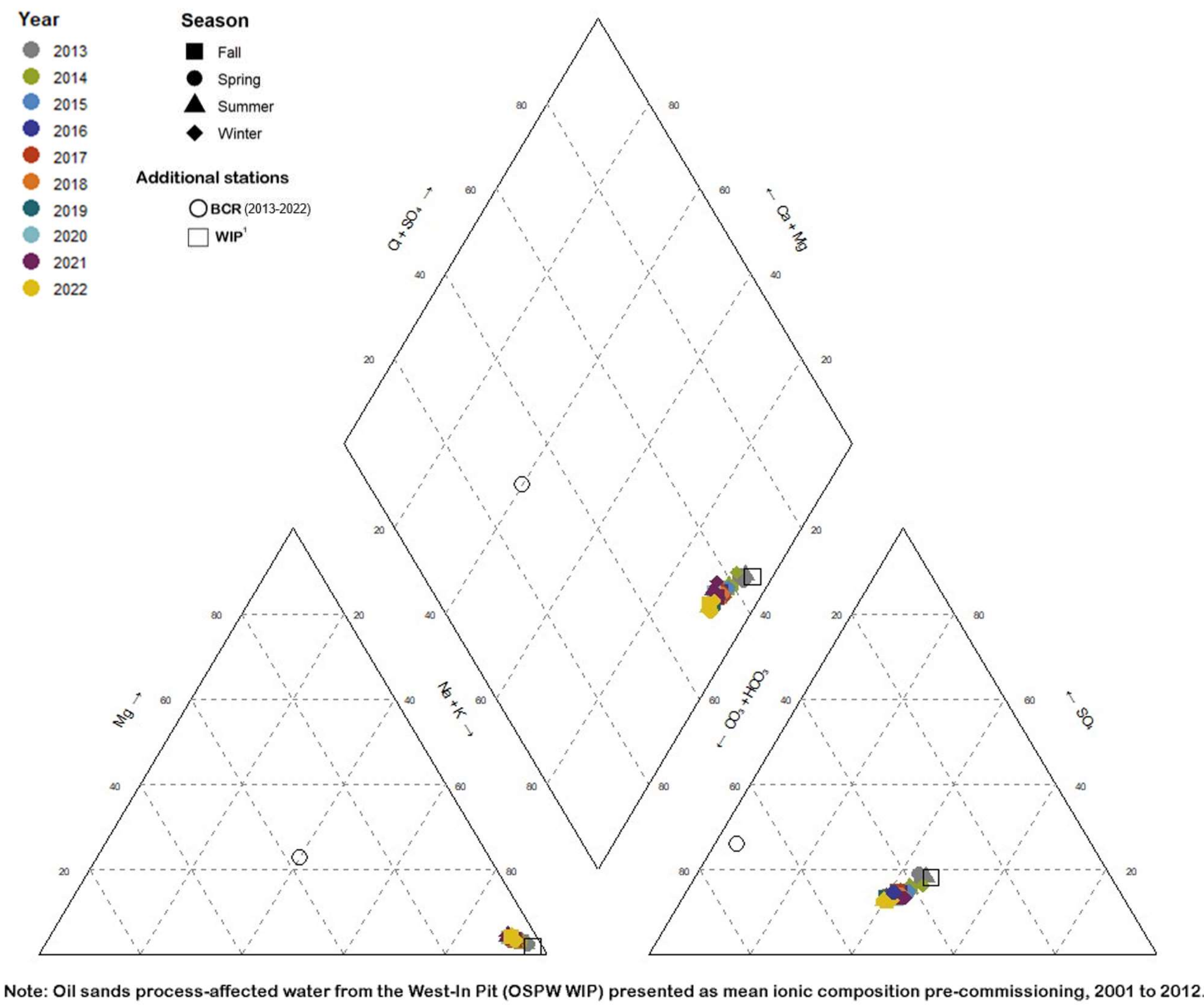


Figure 7-30: Piper plots of major ion composition in Base Mine Lake, 2013 to 2022.

7.2.3.6 Metals

Total and dissolved forms of 29 metals, total ultra-low-level mercury, and methylmercury were analyzed in support of the 2022 program. Temporal trends among individual metals vary, but focusing on those with detectable concentrations in >50% of the collected samples (Table 7-16 and 7-17), 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 7-33), selenium (Figure 7-34), 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 2022, including arsenic (Figure 7-31), boron (**Error! Reference source not found.**7-32), cadmium, and chromium. For arsenic and boron, there has been and approximate 40% decrease in concentration over the ten-year time span, while the average annual chromium concentration in BML water has decreased approximately eight-fold.

- A longer-term trend, from 2013 though 2022, 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 2022.

Metal concentrations were relatively homogenous through the water column in 2022, except for total manganese, which was present in higher concentrations in the bottom 3 m of the lake. Most metals also exhibited some seasonal variability, with median concentration generally highest during winter in 2022; this result was consistent with the historically higher medians observed during winter and spring.

Table 7-16: Proportion (as %) of surface water quality total metals form Base Mine Lake that were above detection limit, 2013 to 2022.

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

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

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

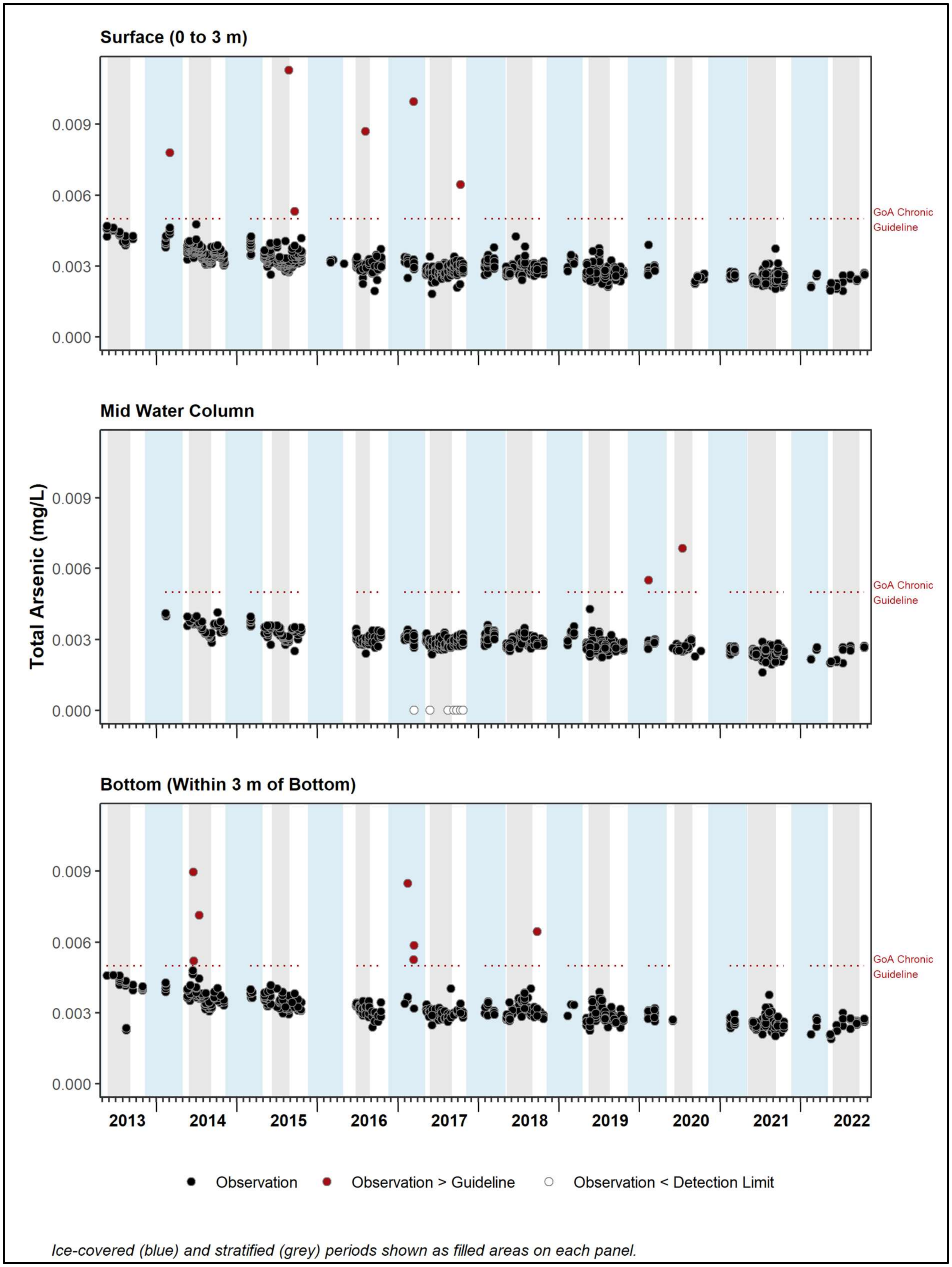


Figure 7-31: Total arsenic in Base Mine Lake, 2013 to 2022.

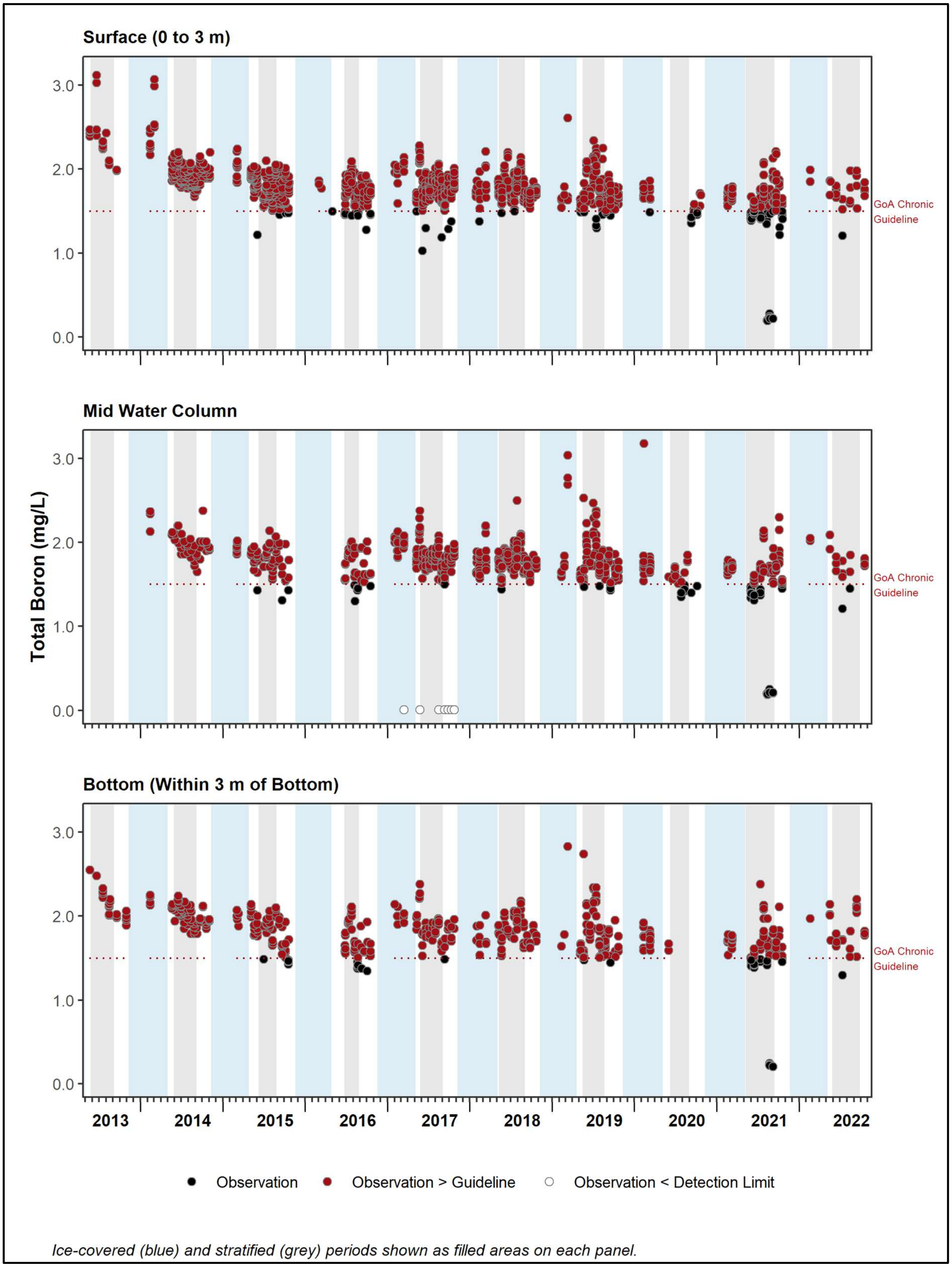


Figure 7-32: Total boron in Base Mine Lake, 2013 to 2022.

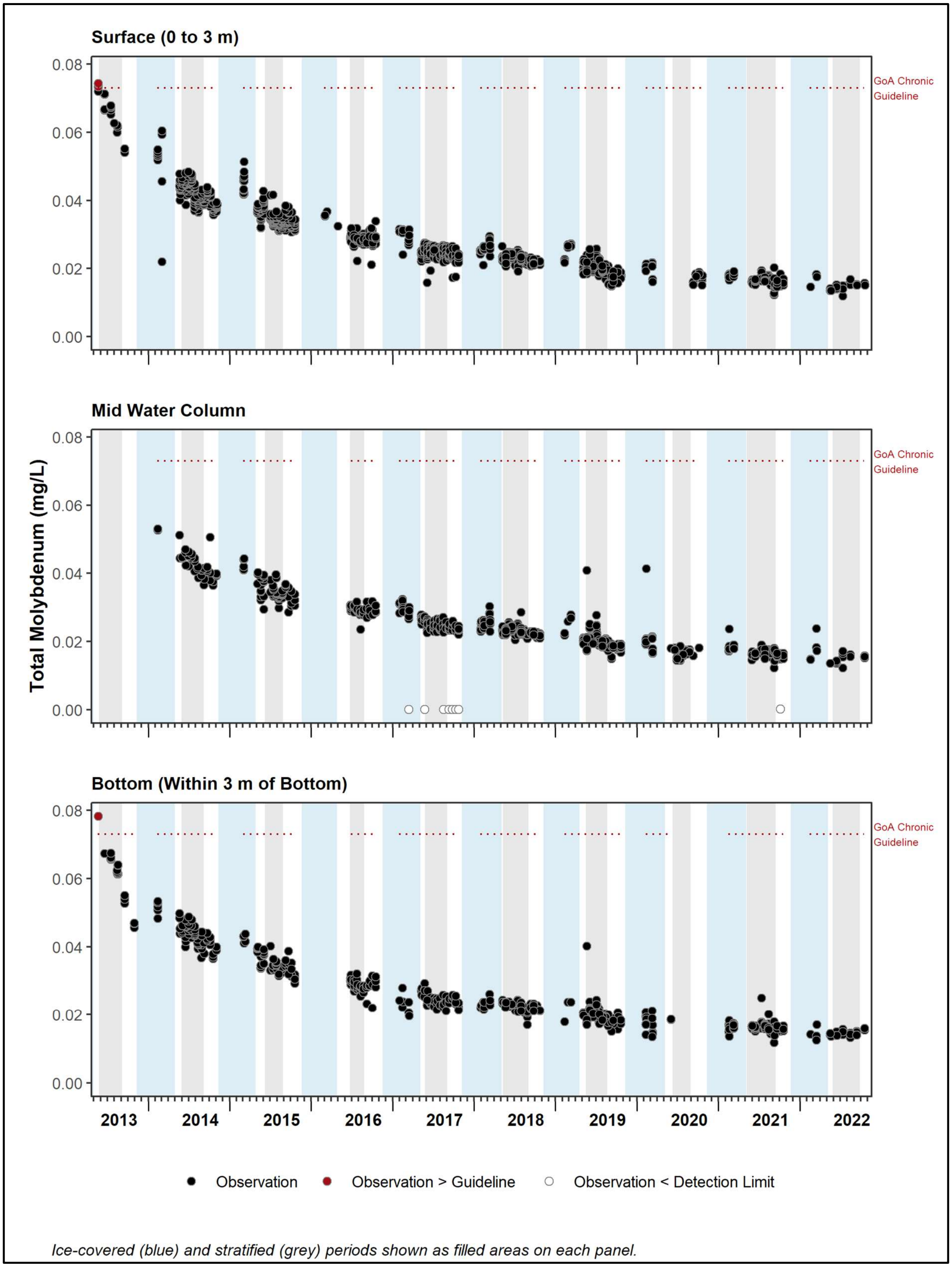
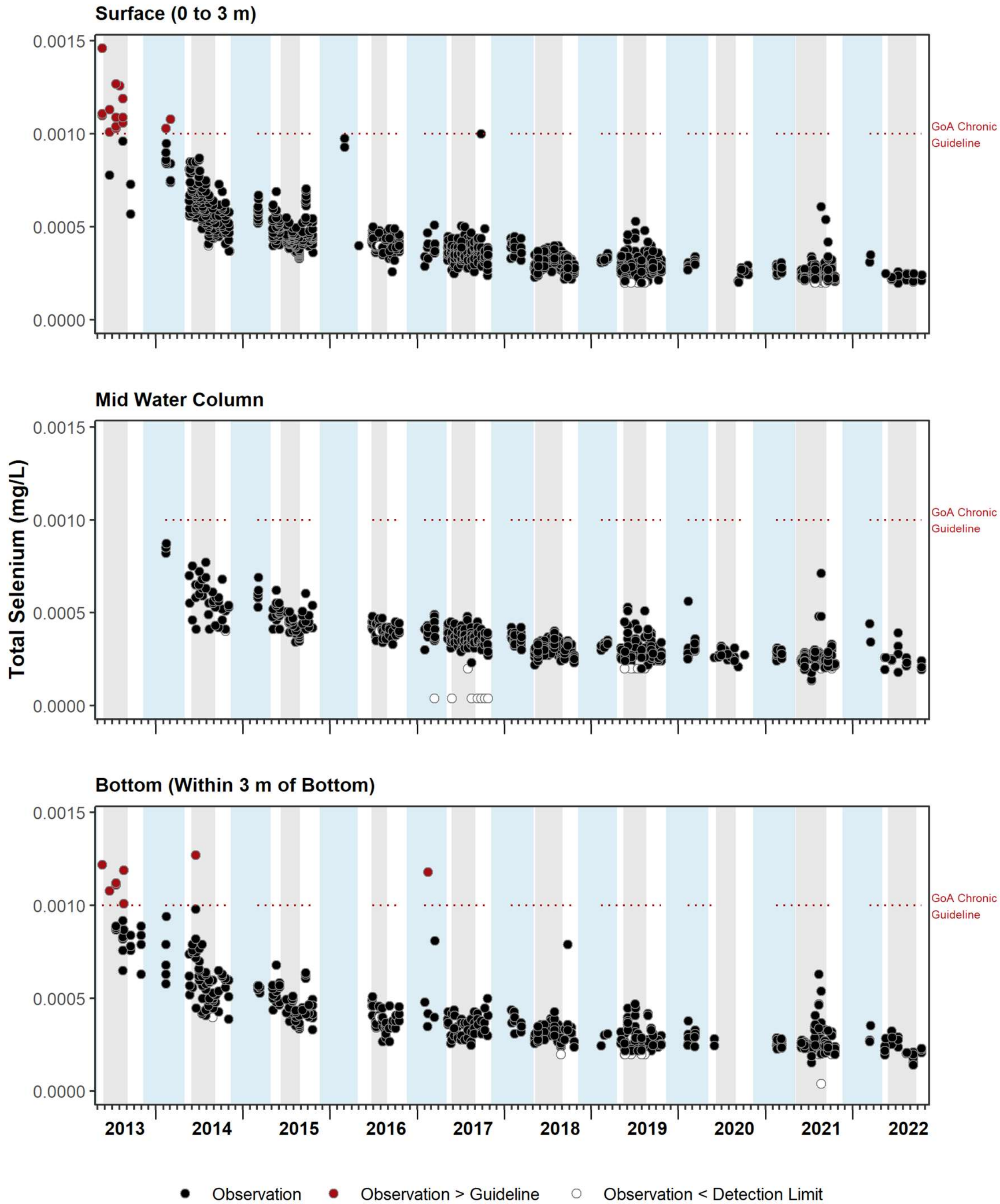


Figure 7-33: Total molybdenum in Base Mine Lake, 2013 to 2022.



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.
Scale adjusted to focus on overall trends; full-scale plot presented in Appendix A5.49.2
samples from 2018-07-30 to 2022-03-15 (0.0468 mg/L to 0.0667 mg/L) were excluded from the plot

Figure 7-34: Total selenium in Base Mine Lake, 2013 to 2022.

7.2.3.7 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 7-35) are an artifact of the laboratory adjustment to the correct Syncrude 1995 method.

The NA median concentrations have remained relatively stable since 2013 (Figure 7-35). 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. More routinely detected PAHs in BML water in 2022 include pyrene and quinoline, which were present in measurable quantities. Total PAH concentrations in BML have shown within-year variation, as well as variation at different depths of the water column (Figure 7-36). Historically, seasonal median concentrations of total PAH were highest in spring (median concentration 3.5 µg/L). Lowest median concentrations of total PAH were recorded in winter (0.89 µg/L). Median PAH concentrations in winter, summer, and fall were lower than the corresponding historical medians, but within the range of historically observed concentrations. For spring, median PAH concentration in 2022 was slightly lower than the historical minimum.

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 2021. Pyrene was one of the most frequently

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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.

detected parent PAH species in 2022 (detected in 76% of samples analyzed. Exceedance frequencies of was 6.2%, which is higher than 2021 (3.6%), but less than the historical frequency of exceedances.

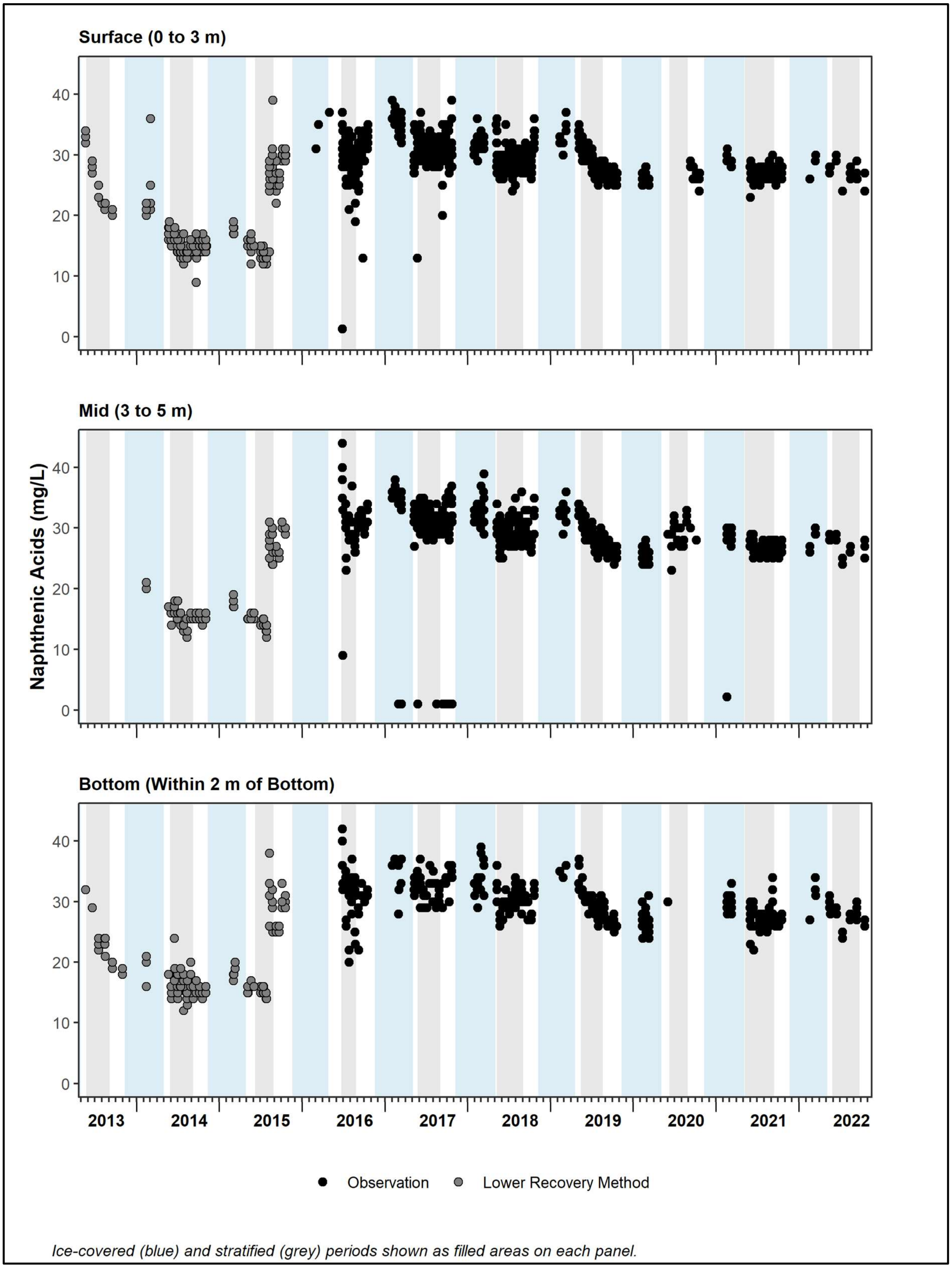
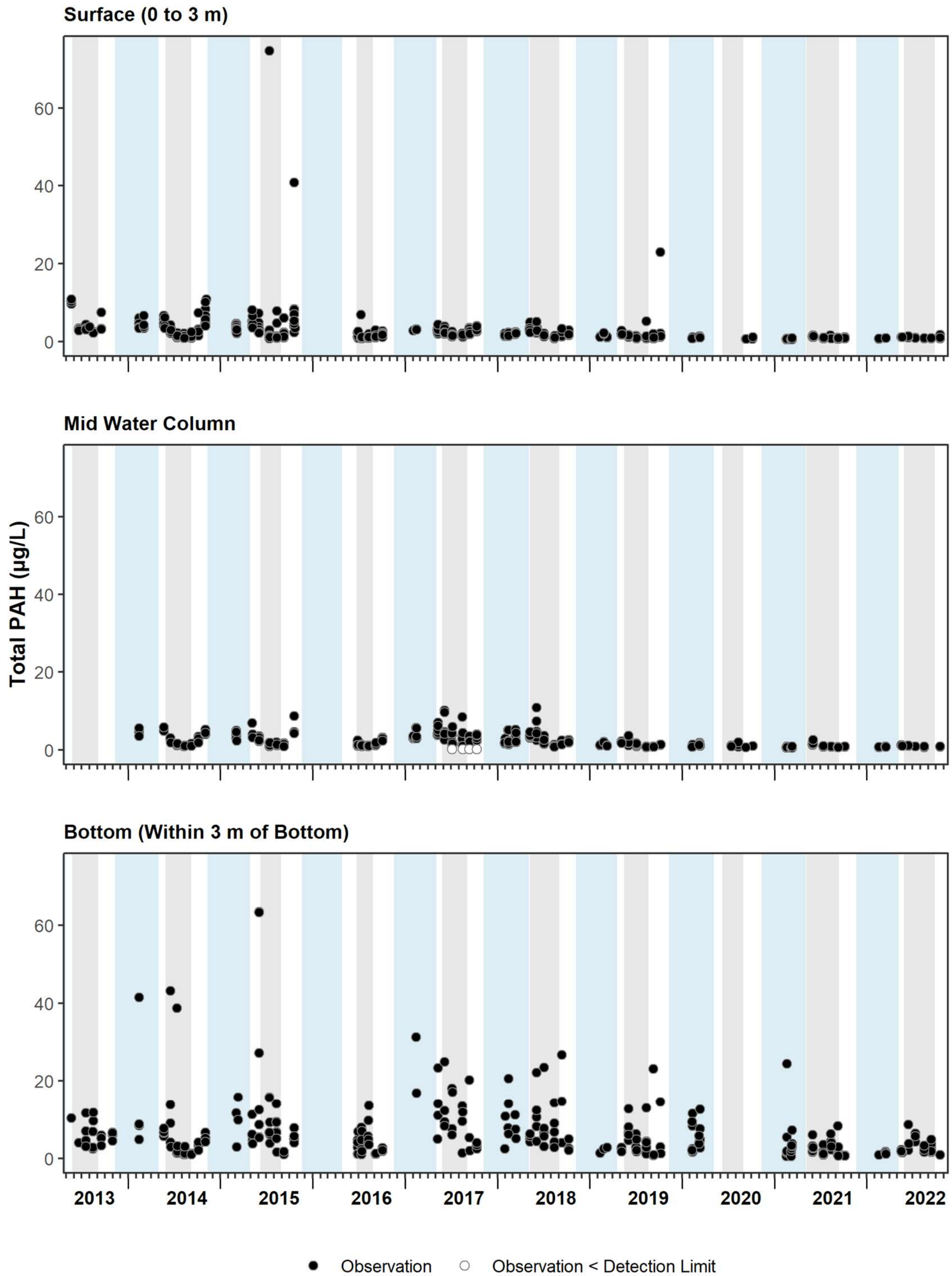


Figure 7-35: Naphthenic acids in Base Mine Lake, 2013 to 2022.



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.
Scale adjusted to focus on overall trends; full-scale plot presented in Appendix A5.161.

Figure 7-36: Total polycyclic aromatic hydrocarbons in Base Mine Lake, 2013 to 2022.

7.2.4 Groundwater Quality Assessment

Table 7-18 below summarizes the key findings from the BML groundwater assessment.

Table 7-18: BML Groundwater Assessment Key Findings

BML Groundwater Assessment Key Findings
• Overall, groundwater level and quality results for 2022 appear to be following consistent trends with or fall within previously measured ranges of the historical data collected between 2013 and 2021.
• 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 lake level of about 308.5 masl and currently recorded BML 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 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 will occur from the south and west and that groundwater losses from BML 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 FFT (i.e., are likely small).
• The key indicator variables evaluated do not suggest any significant adverse changes since BML 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. There were no notable changes in the ionic composition of the groundwater from prior years.
o Among the monitoring wells, there were 76 statistically significant trends detected among 20 water quality variables (particularly for major ions). o Major ions (bicarbonate, calcium, chloride, magnesium, sodium, and sulphate) comprise 29 of the 76 identified trends. o There was a net increase of 11 significant increasing trends and a net decrease of 2 significant decreasing trends compared to the 2021 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 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 18% of instances (i.e., the significant trends) while 82% of the 410 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. 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. There are now 41 monitoring wells in the BML network which are classified as shallow, intermediate, or deep (Figure 7-37). 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 7-19. Continuous groundwater elevations are being recorded at seven deep well locations with dataloggers. Well status is discussed below.

For 2022, the spring (June 2022) and fall (November 2022) 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 this event. 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.

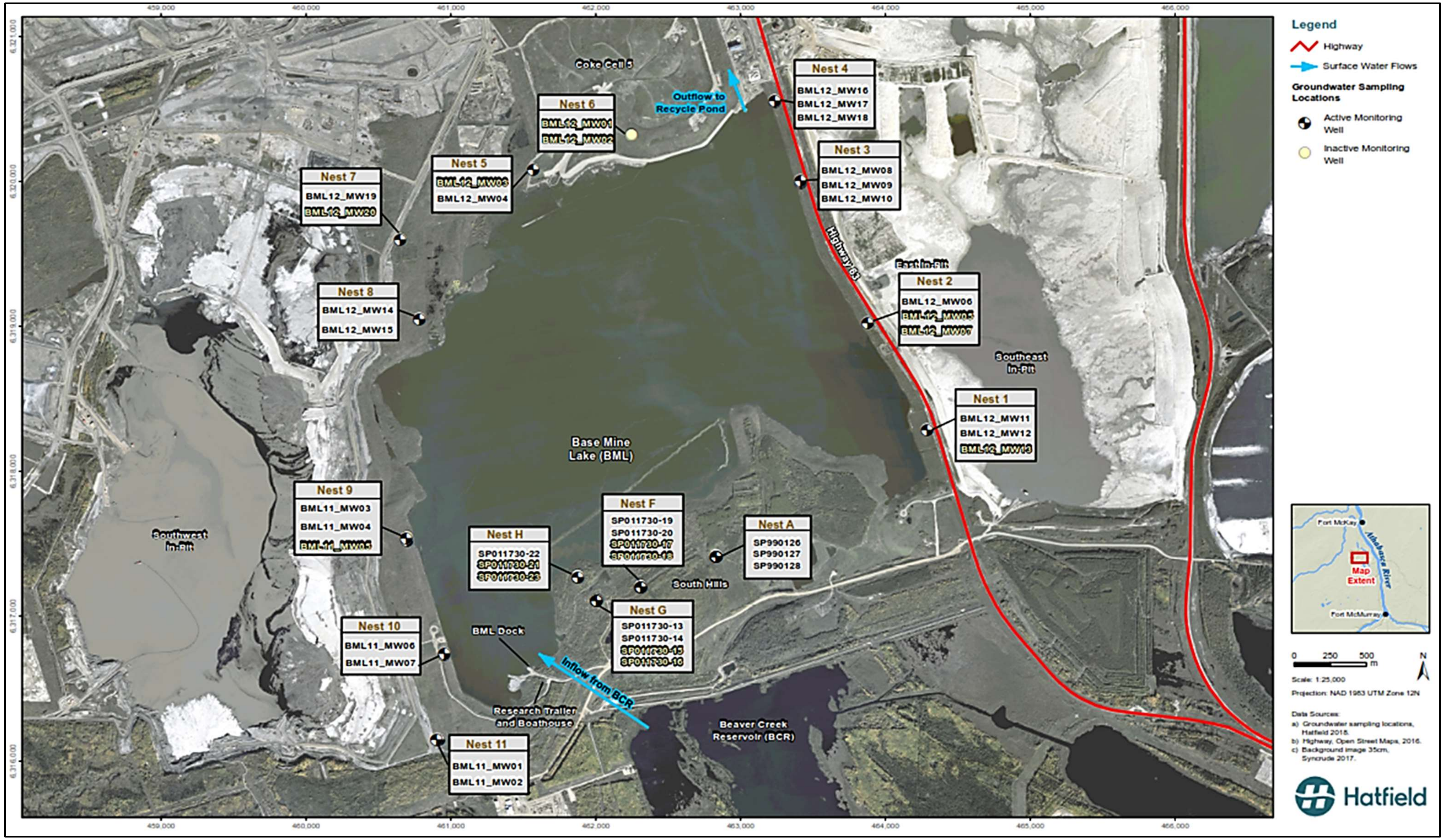


Figure 7-37: Groundwater sampling locations for the 2022 Base Mine Lake Monitoring Program.

Table 7-19: Groundwater sampling locations for the 2022 Base Mine Lake 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 as Figure 7-38 and Figure 7-39, respectively. 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, bicarbonate and chloride in Group 2 wells, and chloride in Group 3 wells. There is some variation in the characterization with Group 2 wells BML11_MW01 (in-situ Kcw), BML11_MW02 (in-situ Kcb), BML12_MW14 (Dev. Lm.), and BML12_MW19 (Dev. Lm.) exhibiting a water chemistry closer to that of Group 3 wells and the Group 2 wells in engineered fill exhibiting a water chemistry that is between Group 1 and 3 results. This suggests that major ion composition is influenced by depositional environment. The ionic characterization did not materially change between spring and fall and are consistent with historical results. Group 1 monitoring well SP11730_13 (Nest G) and Group 2 monitoring well BML12_MW17 (Nest 4) also appear to be characterized by a major ion chemistry that is distinct from that of other Group 1 and 2 wells.

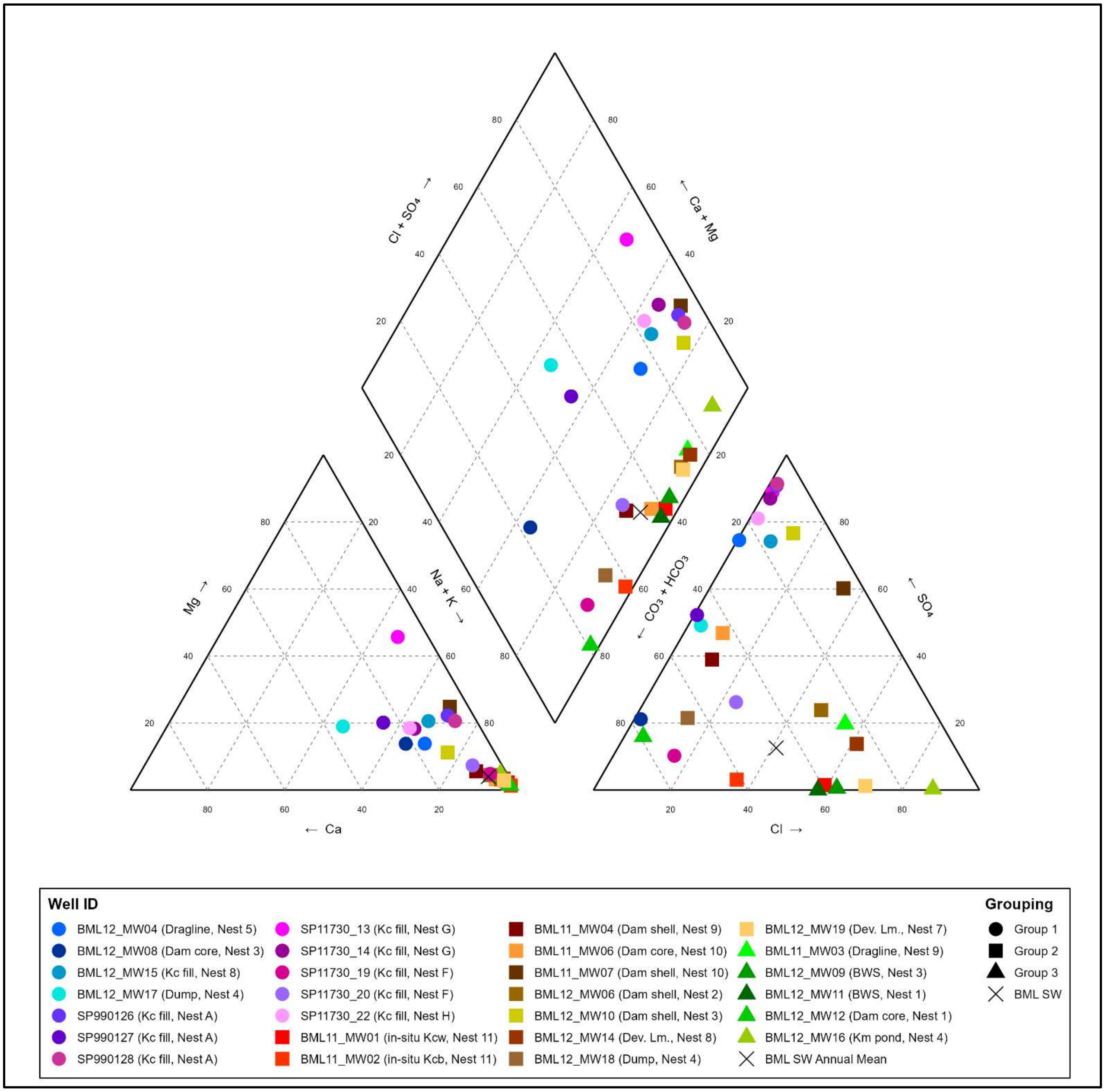


Figure 7-38: Piper plot of ionic composition in BML groundwater zones (Spring 2022).

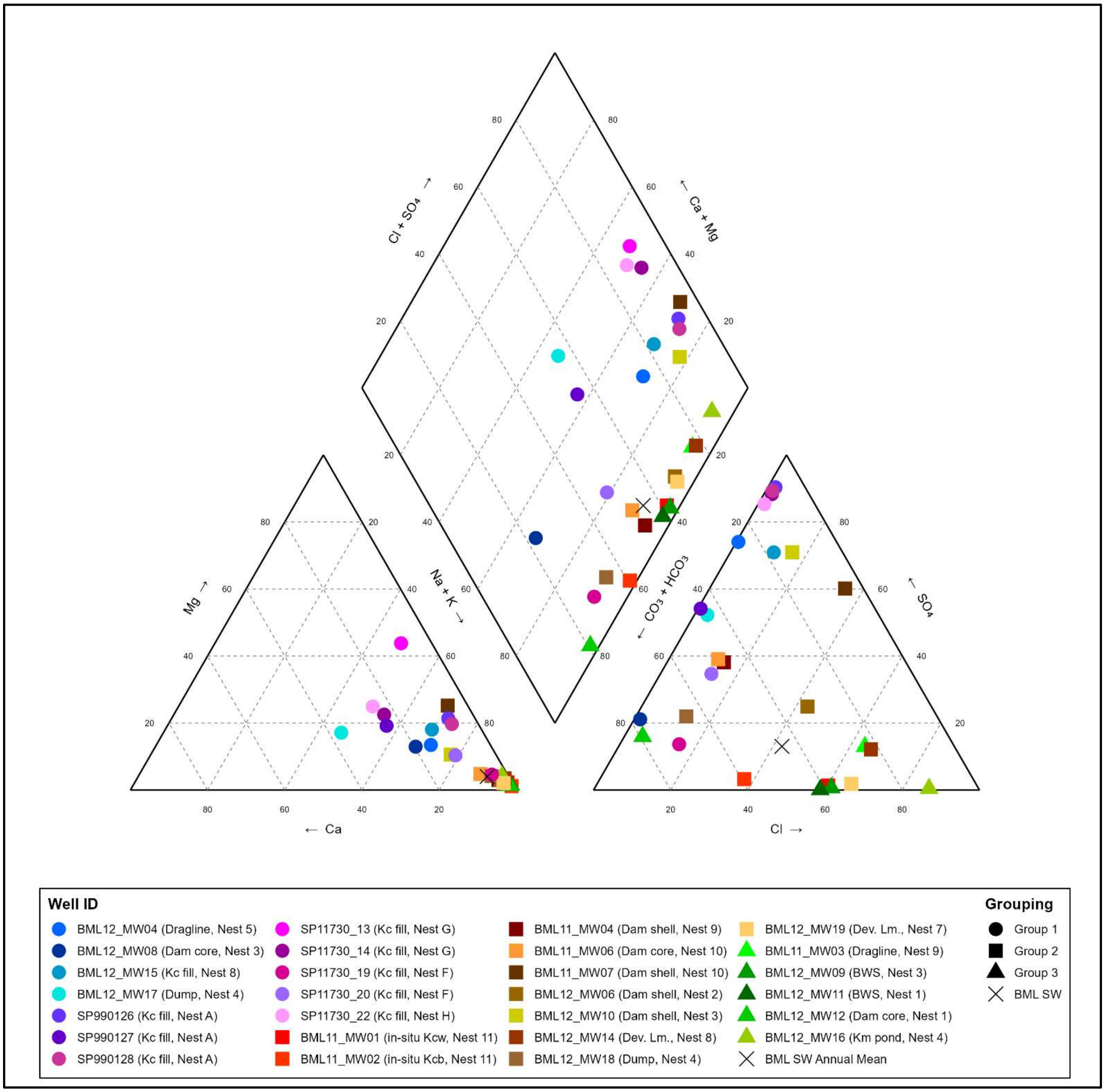


Figure 7-39: Piper plot of ionic composition in BML groundwater zones (Fall 2022).

7.3 Biological Components of the Base Mine Lake Monitoring Program

The biological aspects of the Base Mine Lake monitoring program document the important components of the lake's food chain. Monitoring the changes in acute toxicity further validates the shorter-term milestone of water quality improvements with time. Chronic toxicity trends provide an understanding of the longer-term lake trajectory to support end land use expectations.

7.3.1 Phytoplankton abundance, biomass, and diversity

During the winter (February to March) of 2022, poor ice quality restricted access onto the lake and phytoplankton samples could only be collected from BML12_Platform 3_SW. Three replicates were collected in both February and March. Winter sampling was conducted immediately below the ice surface where phytoplankton communities would be present during snow- and ice-covered periods. During the open-water season (May to October), a single replicate phytoplankton sample was collected monthly at each of the three BML platforms and the BCR pump-in station. Samples were collected from two discrete depths within the euphotic zone, which is defined as the extent of the water column that is exposed to sufficient sunlight for photosynthesis to occur. The euphotic zone was estimated in the field as twice the Secchi depth. Conventional microscopic taxonomic analysis and biovolume calculations were completed.

Phytoplankton densities in BML and BCR have been highly variable across months (seasonally) and years since monitoring commenced in 2013 (Figure 7-40). Phytoplankton communities in BML have generally followed seasonal trends typical of temperate lakes, with low abundance of winter phytoplankton, high abundance in the spring followed by a gradual decrease in abundance during the summer because of senescence and zooplankton grazing, and an increase in the fall in response to nutrient upwelling from fall turnover (Sommer et al. 1986).

In 2022, winter abundance of phytoplankton was high (30,000 to 61,000 cells/L) compared to wintertime observations in previous years (8,300 to 46,000 cells/L) except in 2014 when high abundances of euglenids and filamentous cyanobacteria were observed (1.3 to 1.6 million cells/L) (Figure 7-40). Phytoplankton abundance from May through July was low (35,000 to 83,000 cells/L) compared with the same season in previous years, until chlorophytes and cyanobacteria increased 20 to 40-fold in August and September (1.3 to 1.6 million cells/L), before decreasing but remaining seasonally high in October (516,000 cells/L) (**Error! Reference source not found.**40).

Nine major taxonomic groups of phytoplankton have been identified in BML since monitoring began: Bacillariophyceae (diatoms), Chlorophyceae (green algae), Chrysophyceae (golden algae), Cryptophyceae (cryptophytes), Cyanophyceae (cyanobacteria, blue-green algae), Dinophyceae (dinoflagellates), Euglenophyceae (euglenids), Rhodophyceae (red algae), and Xanthophyceae (yellow-green algae) (Figure 7-40). Both the abundance and dominance of individual taxonomic groups has shifted since phytoplankton monitoring began in 2013. Phytoplankton communities between 2013 and 2015 had very high abundances (> 15 million organisms/L) and were dominated by colonial cyanobacteria and euglenids. From 2016 to 2020 phytoplankton abundance remained under 500,000 cell/L and were dominated by diatoms and green algae, with a more even community composition. In 2021 and 2022 phytoplankton community composition and dominance was similar to previous years; however, peak abundance ranged from 1.3 to 64 million cells/L due to cyanobacteria and chlorophyte blooms in June and August 2021 and July and August 2022.

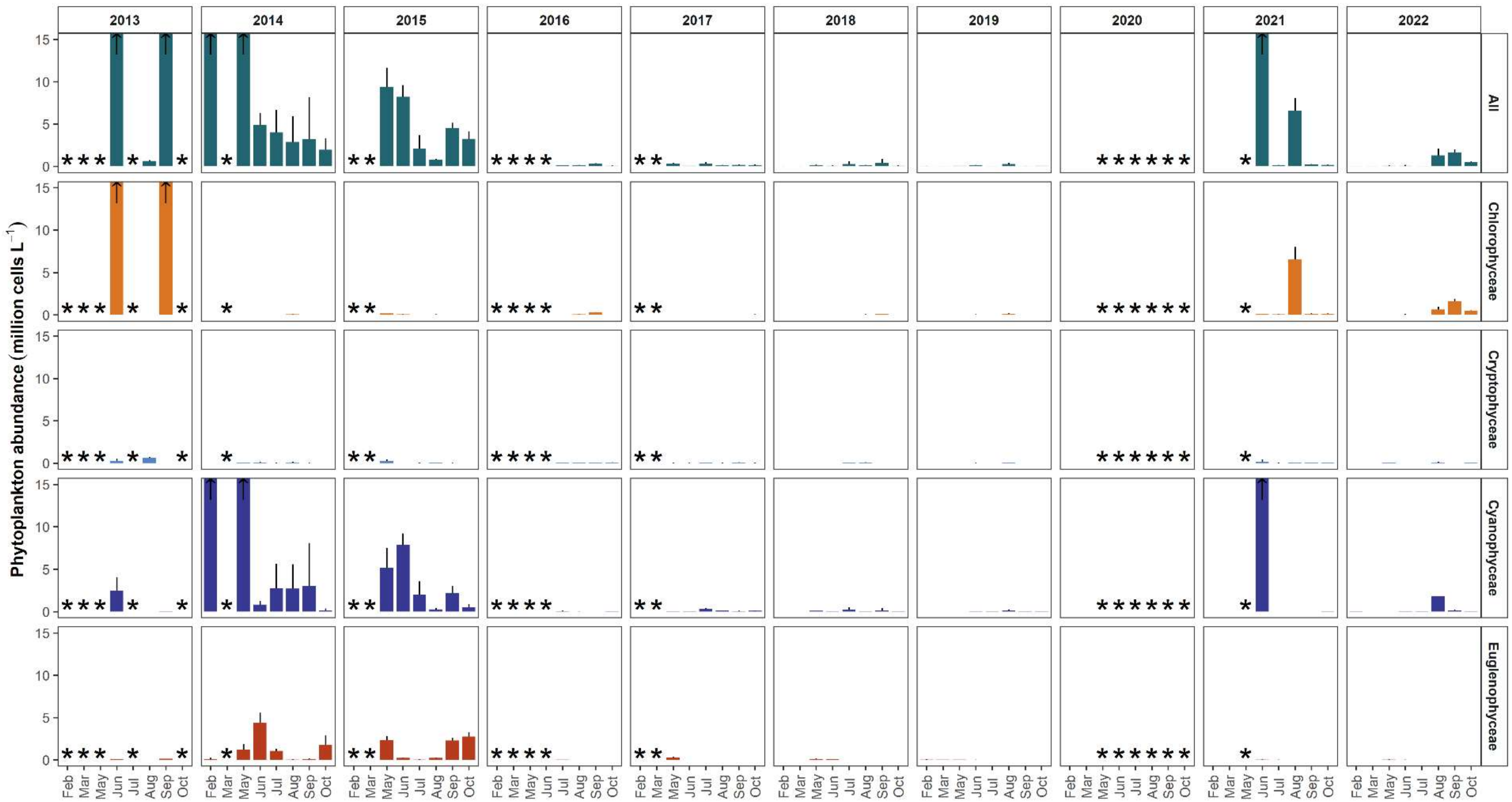
Prior to 2016, the BML phytoplankton community was generally dominated by cyanobacteria and chlorophytes. Since then, cyanobacteria have become much less abundant in BML, except during blooms in June 2021 and August 2022 (**Error! Reference source not found.**7-40). Chlorophytes were among the most dominant algae throughout 2022. During the winter, euglenids and chlorophytes were the most abundant groups in BML, while during the open-water season, cyanobacteria and chlorophytes were the most abundant groups. Euglenids and cryptophytes were both present in BML throughout the sampling season, albeit at comparatively low abundances (**Error! Reference source not found.**7-40). Above-average temperatures late in the open-water season (Hatfield 2023c) likely resulted in peaks in phytoplankton abundance in August and September (1.3 million cells/L and 1.6 million cells/L, respectively), consisting primarily of cyanobacteria in August and chlorophytes in September (Figure 7-40). The most abundant individual taxa in 2022 included the chlorophytes *Elaktothrix* and *Tetrachlorella*, and the cyanobacteria *Gomphosphaeriea*.

Phytoplankton biomass in 2022 followed similar seasonal trends as historic data; however, monthly biomass in 2022 tended to be lower than what has been observed historically. In 2022, phytoplankton biomass beaked in May (501 mg/m^3), and similar to abundance, was lowest in July (19 mg/m^3). The timing of peak monthly biomass in both BCR and BML is highly variable from year to year; however, similar seasonal trends are evident in both waterbodies. Phytoplankton biomass in BML has tended to remain below 1,000 mg/m^3 with two notable exceptions in July and August 2018, when biomass was recorded as 5,323 mg/m^3 and 32,823 mg/m^3 respectively. Biomass in BCR has been greater than 1,000 mg/m^3 in all but four sampling months. The highest biomass in BCR was similarly recorded in July and August of 2018 when it peaked at 11 million mg/m^3.

Phytoplankton biomass in BML has been consistently dominated by euglenids and cryptophytes since May 2014, while chlorophytes dominated biomass in 2013 (Figure 7-41). In 2022, peak biomass in May corresponded to peak euglenid biomass, whereas in August it corresponded with peak cryptophyte and chlorophyte biomass. The cryptophyte *Cryptomonas* and the euglenid *Lepocinclis* were the taxa that contributed the most to phytoplankton biomass in 2022.

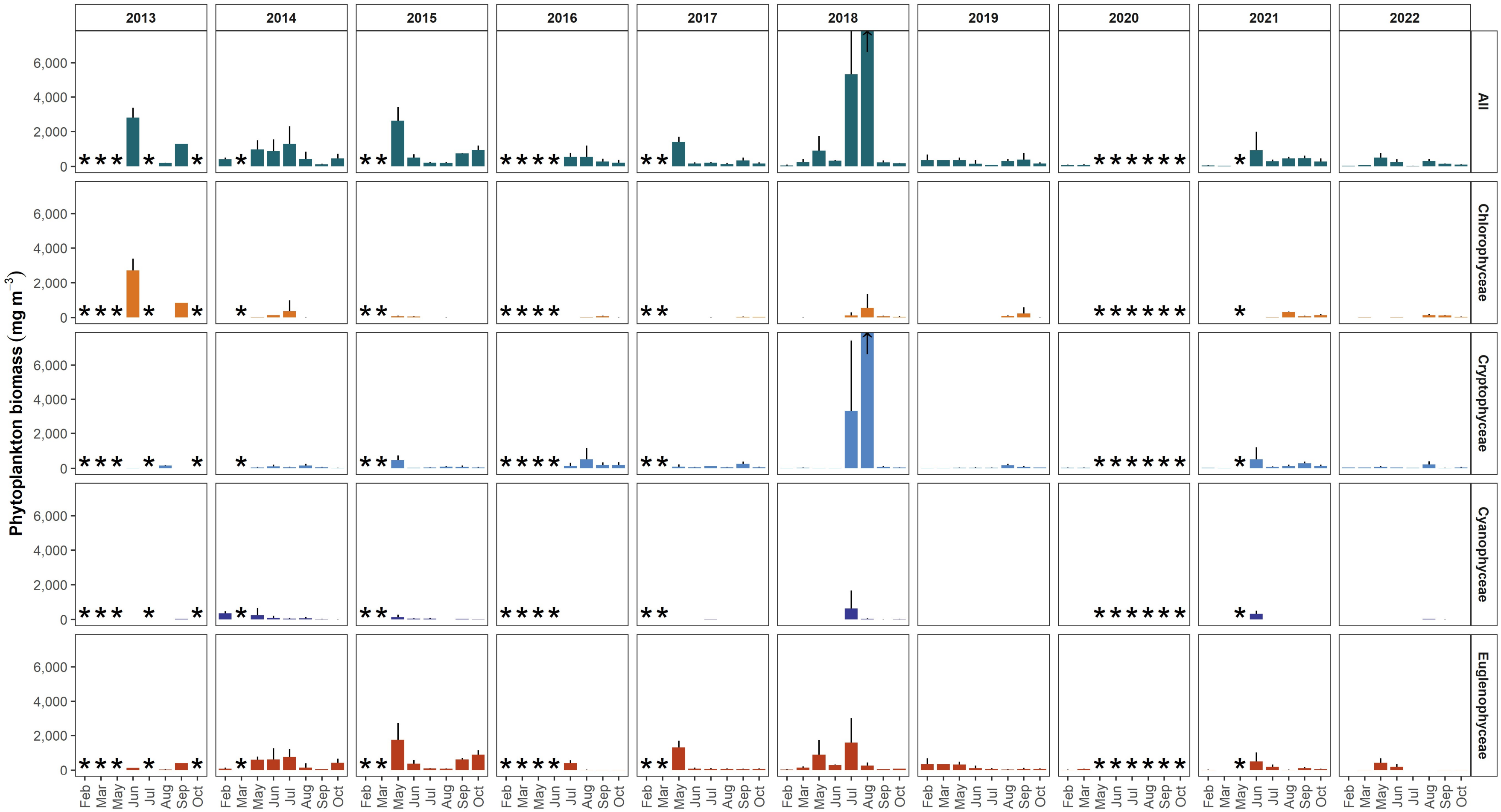
There has been no correlation between chlorophyll *a* concentrations and biovolume estimates of biomass during any year except 2017. In 2022, peak biovolume-based estimates of biomass were observed in May whereas peak chlorophyll *a* was observed in August and September (Figure 7-41;). Additionally, chlorophyll *a* in BML has decreased steadily through time whereas the same trend has not been observed in biovolume estimates of biomass. In BCR, chlorophyll *a* concentrations were measured in July, September, and October. The highest concentration of chlorophyll *a* corresponded with the greatest biomass in September (Figure 7-41; Figure 7-42); conversely, chlorophyll *a* concentration was higher in July than October, but biovolume estimates of biomass in October were higher than July.

Phytoplankton community richness in 2022 was similar to that of 2021, with mean monthly richness ranging from three taxa in July when minimum abundance and biomass were recorded, to a maximum of 10 taxa in September. Evenness and Simpson's diversity have both increased in BML since 2013, indicating a shift from a community dominated by a few highly abundant taxa to a more diverse species assemblage (Figure 7-43). In 2022, Simpson's diversity and evenness ranged from 0.23 to 0.70 and 0.15 to 0.77, respectively. The minima for Simpson's diversity and evenness occurred in October and September, respectively, due to a community heavily dominated by chlorophytes in the late-summer and early-autumn.



Mean phytoplankton abundance (total and dominant taxonomic groups) pooled across BML stations, with error bars shown as standard deviations. High abundance of chlorophytes in June (33 million cells per L) and September 2013 (16 million cell per L),and cyanobacteria in February 2014 (33 million cells per L), May 2014 (47 million cells per L), and June 2021 (76 million cells per L) are flagged with arrows.
Months without phytoplankton abundance samples are marked with asterisks.

Figure 7-40: Monthly phytoplankton abundance in Base Mine Lake, 2013 to 2022.



Mean phytoplankton biomass (total and dominant taxonomic groups) pooled across BML stations, with error bars shown as standard deviations. High total and cryptophyte biomass in August 2018 (33,000 and 32,000 mg/m^3 respectively) are marked with arrows. Months without phytoplankton biomass samples are marked with asterisks.

Figure 7-41: Monthly phytoplankton biomass in Base Mine Lake, 2013 to 2022.

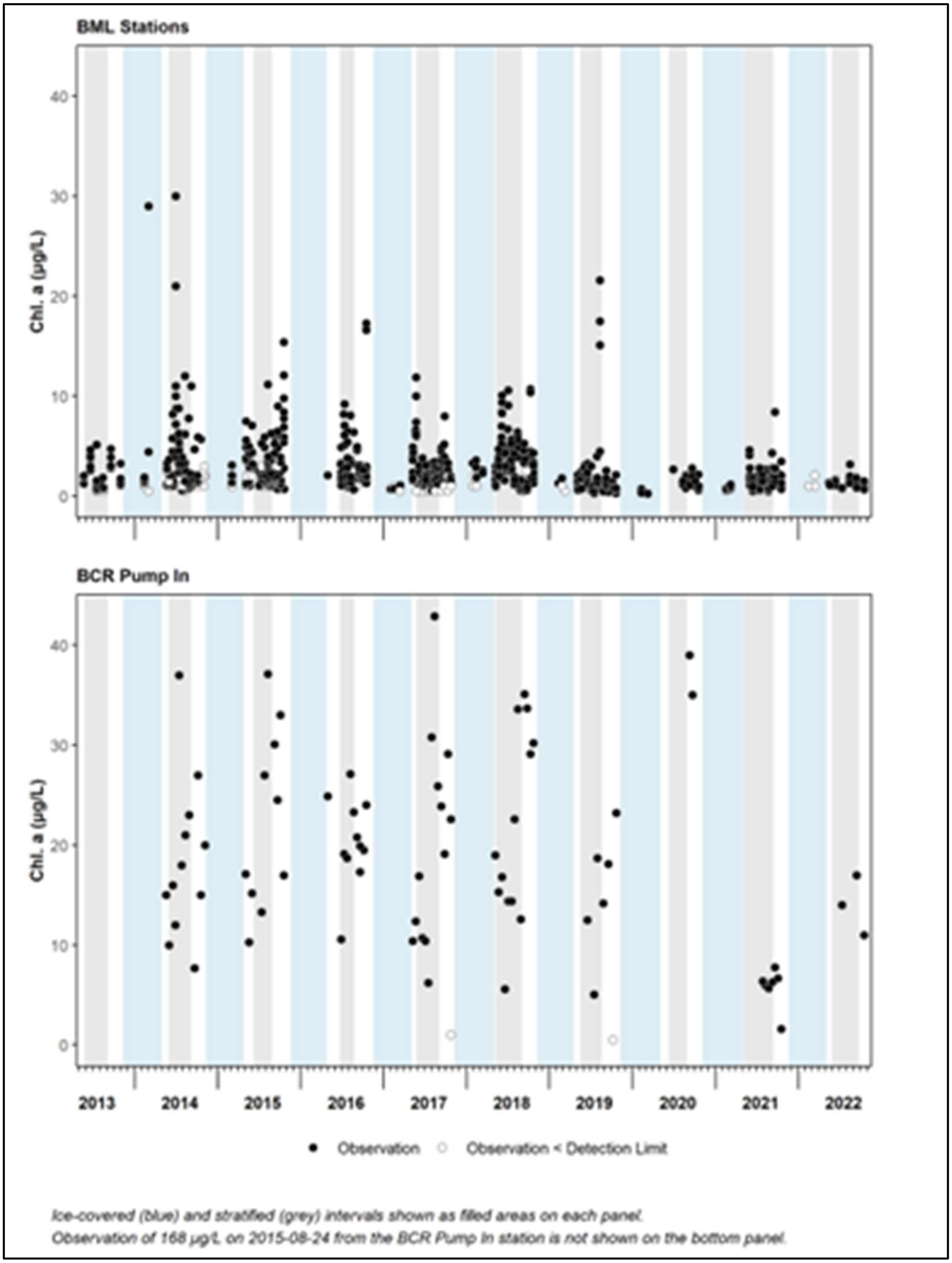
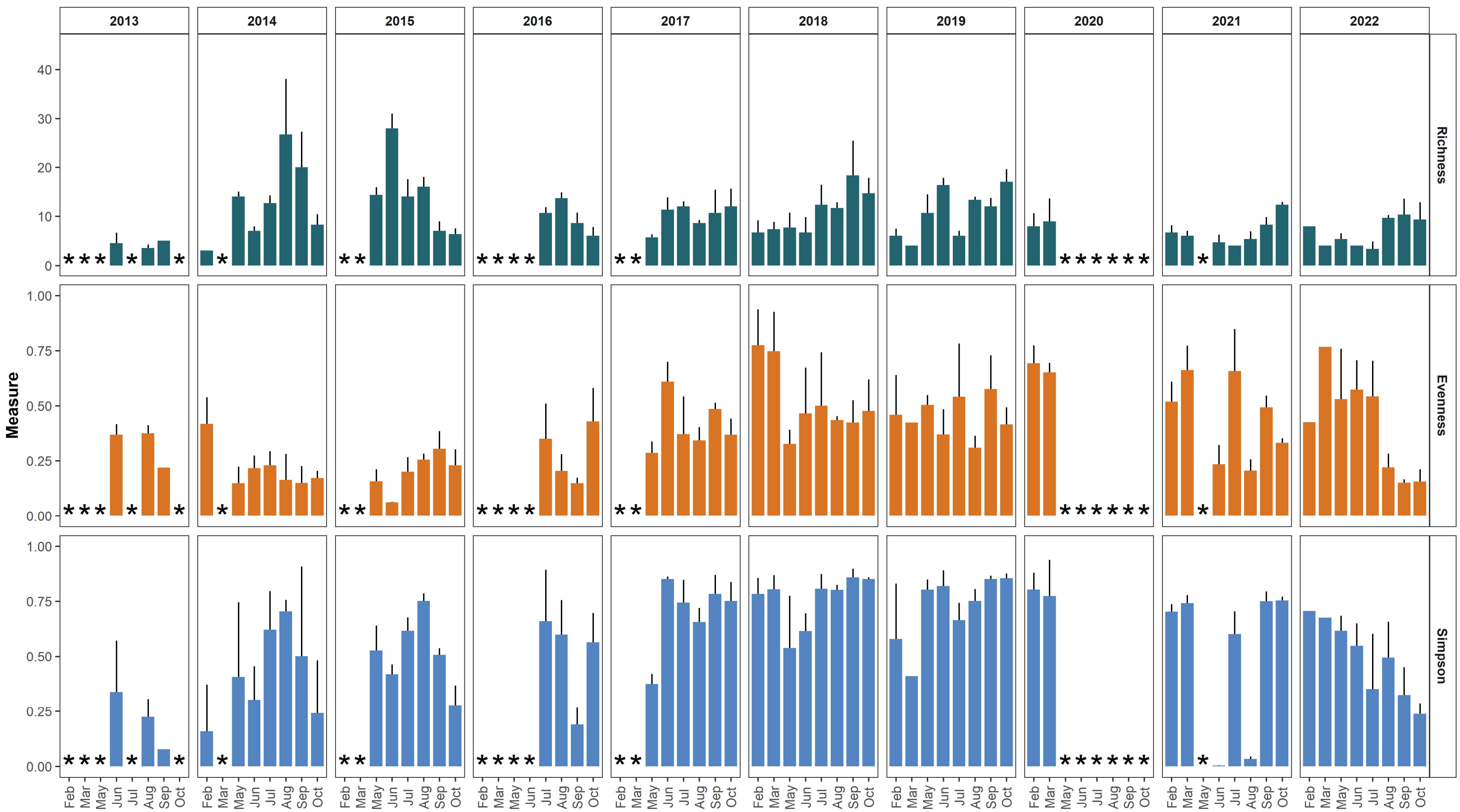


Figure 7-42: Chlorophyll a concentration in Base Mine Lake (upper panel) and Beaver Creek Reservoir (lower panel), 2013-2022



Mean phytoplankton diversity metrics pooled across BML, with standard deviations shown as error bars. Months without phytoplankton samples are marked with asterisks.

Figure 7-43: Monthly phytoplankton richness, evenness, and Simpson's diversity index in BML 2013-2022

7.3.2 Zooplankton abundance, biomass, and diversity

Zooplankton samples were collected each month from May to October 2022. Conventional microscopic taxonomic identifications and dry weight biomass using published length-width conversions were completed. Results are presented in Figure 7-44 a-c.

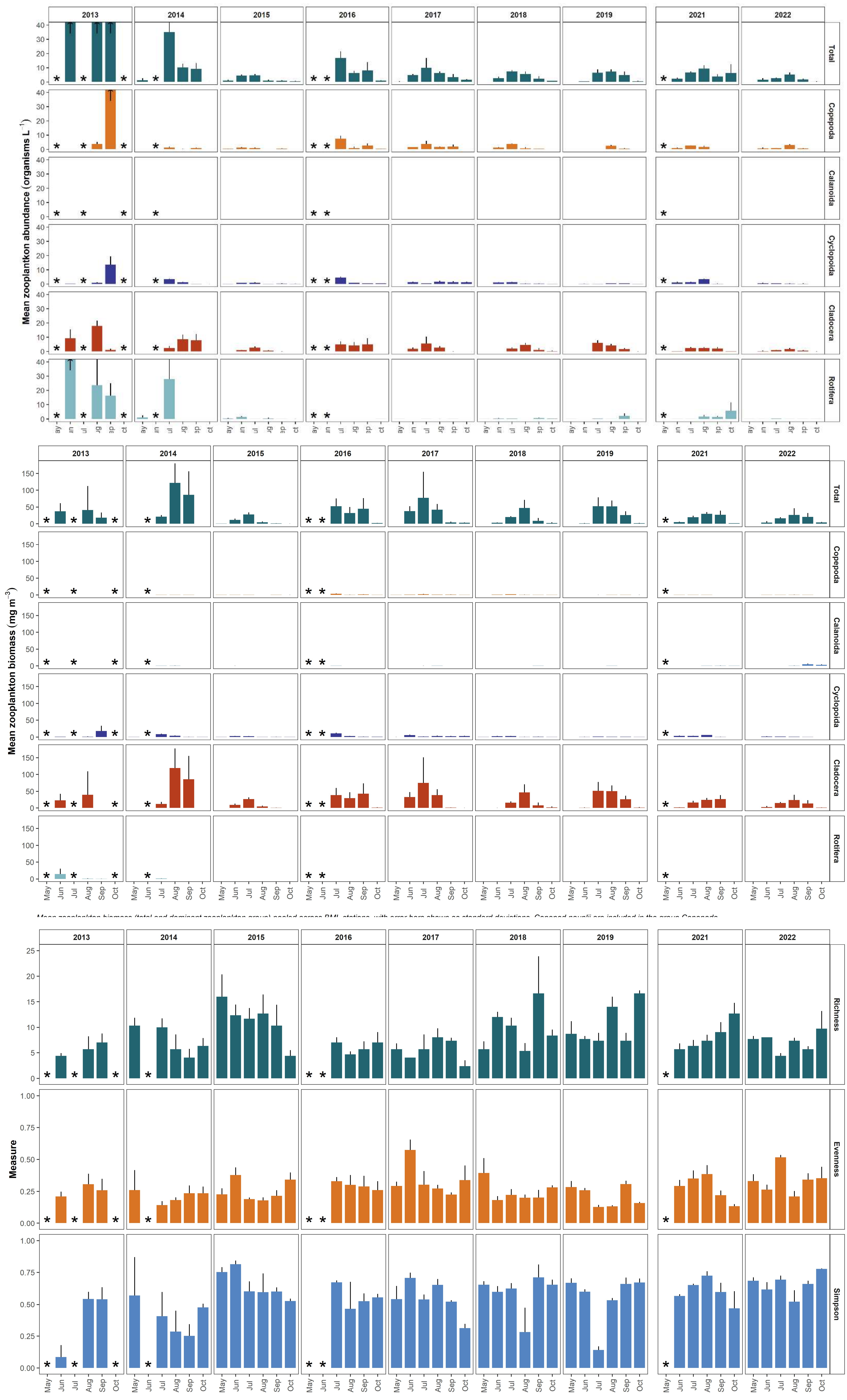
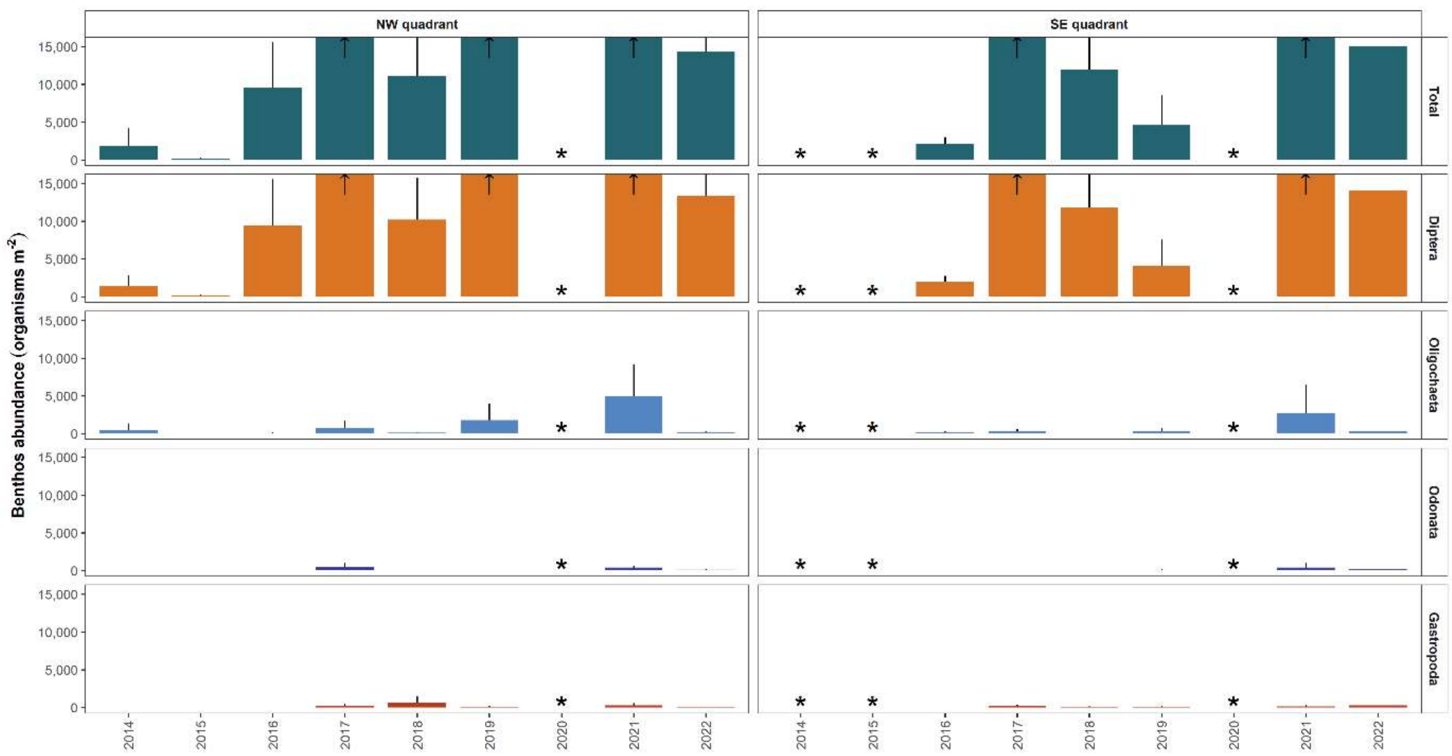


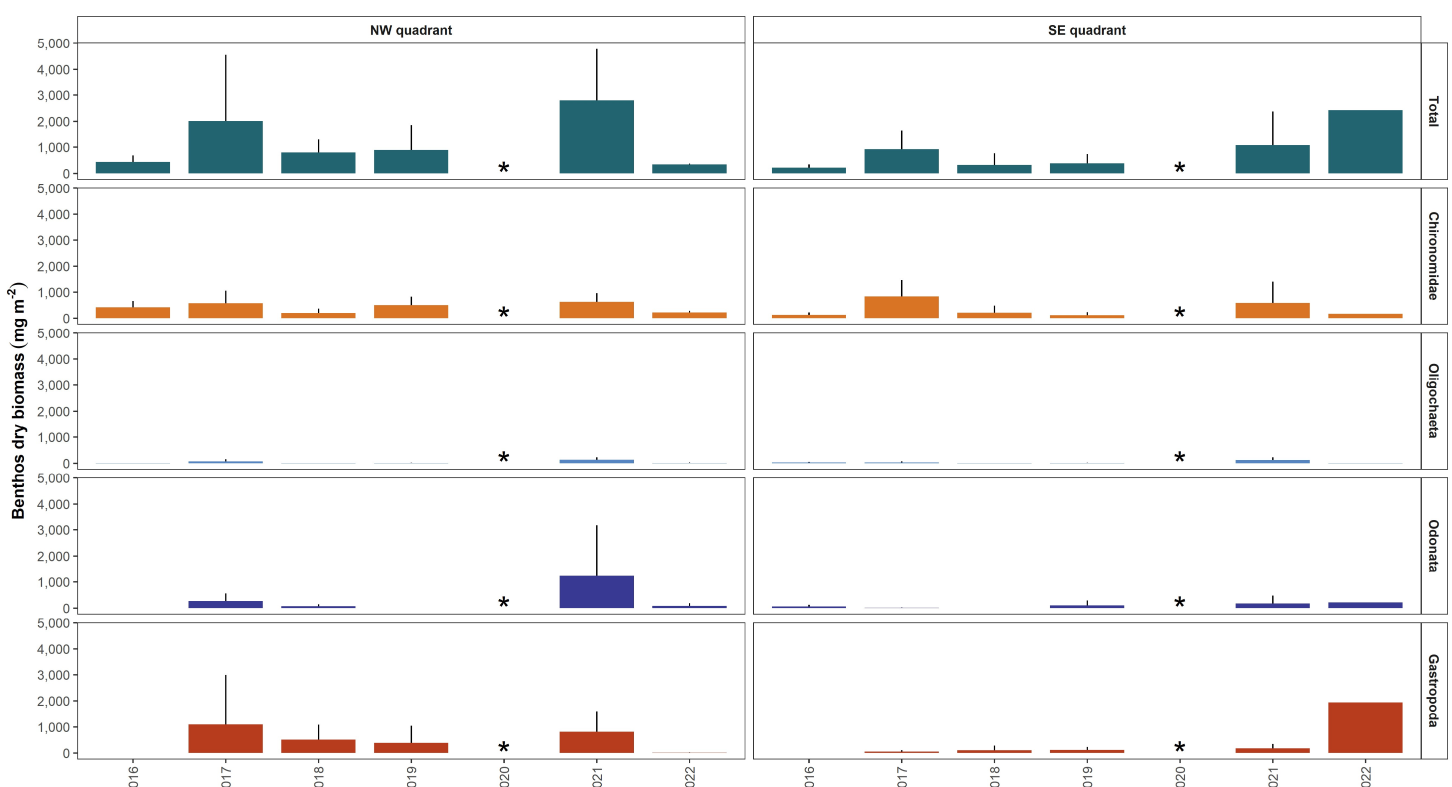
Figure 7-44: Monthly zooplankton (a)abundance, (b)biomass, and (c) diversity metrics in Base Mine Lake, 2013 to 2022.

7.3.3 Benthic macroinvertebrate diversity and biomass

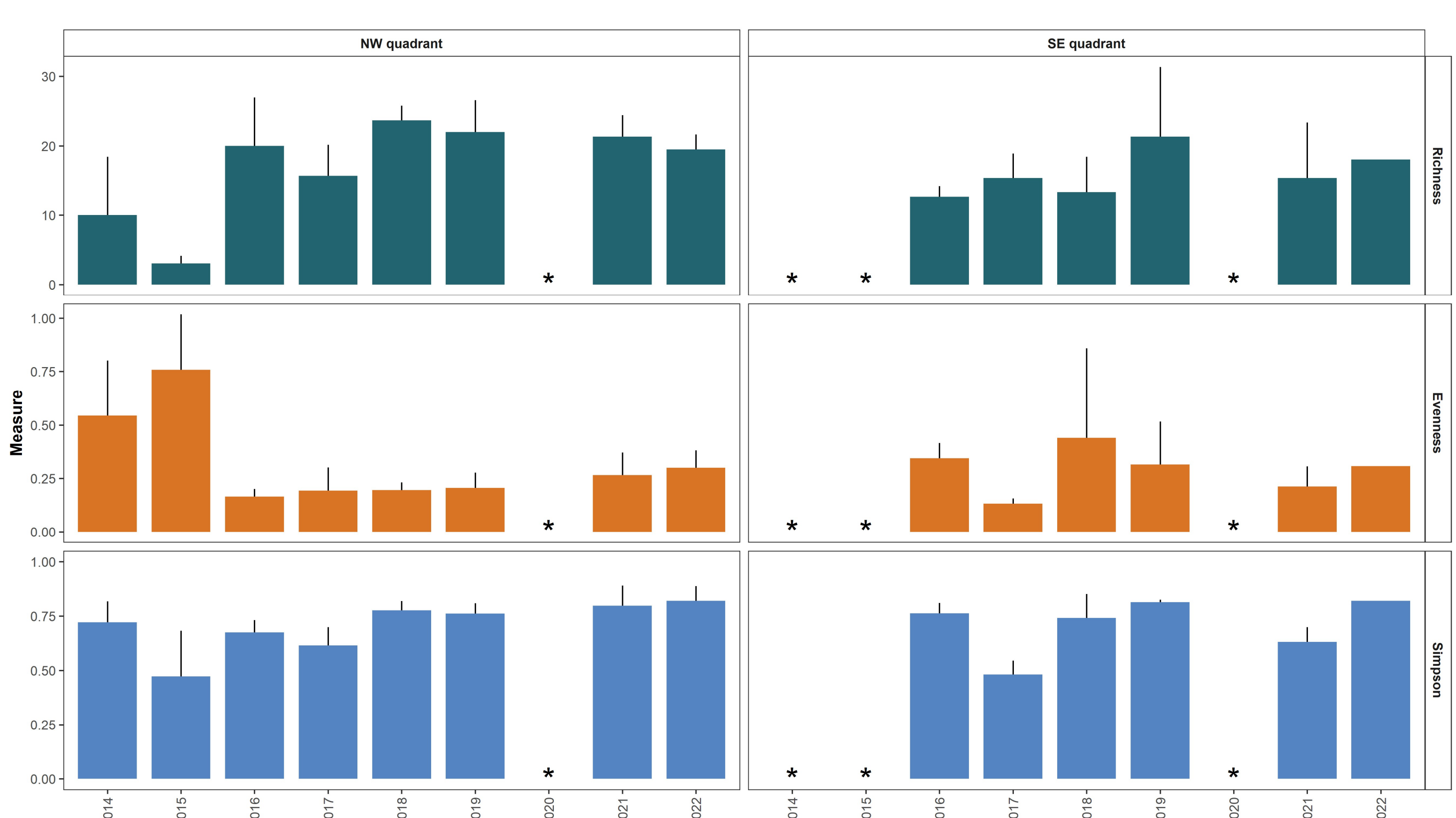
Benthic invertebrates were sampled between September 6 and 12, 2022, using petite ponar grabs in littoral areas (0.36-0.77 m depth of water). Benthic invertebrate samples were sorted and identified following standard Canadian Aquatic Biomonitoring Network (CABIN) protocols. Total dry biomass by taxonomic group was determined by drying and weighing specimens. Results are presented in Figure 7-45.



Mean benthic invertebrate abundance (organisms per m^2) with standard deviation shown as error bars. Stations were pooled by quadrant and displayed by dominant benthic group and total abundance. Four and six stations were sampled in the NW quadrant in 2014 and 2015, respectively. From 2016 to 2021, three stations were sampled in each of the NW and SE quadrants. In 2022, 2 stations were sampled in the NW quadrant and 1 station was sampled in the SE quadrant. High abundance of dipterans are flagged with arrows for the NW quadrant [2017 (32,000 per m^2), 2019 (20,000 per m^2), and 2021 (32,000 per m^2)] and the SE quadrant [2017 (38,000 per m^2) and 2021 (19,000 per m^2)]. No samples were collected from the SE quadrant in 2014 or 2015, or from either quadrant in 2020 (marked with asterisks).



Mean benthic invertebrate dry biomass with standard deviations shown as error bars. Stations were pooled by quadrant and are displayed by dominant benthic group and total biomass. Three stations were sampled in each quadrant from 2016 to 2021. In 2022, two stations were sampled in the NW quadrant and one station was sampled in the SE quadrant. No samples were collected in 2020 (marked with astericks).



Mean benthic invertebrate community diversity metrics pooled by quadrant, with error bars shown as standard deviations. Years without samples are marked with asterisks. No samples were collected in 2020.

Figure 7-45: Benthic invertebrate taxonomic richness, evenness, and Simpson's diversity index in Base Mine Lake, 2014 to 2022.

7.3.4 Surface water toxicity bioassay

Water toxicity samples were collected in May, July, and September 2022, at all three platform stations to create a composite sample for the lake. 70 L of water was collected for testing. Samples were shipped immediately, unpreserved, to Nautilus Environmental (Nautilus) in Calgary, Alberta.
Acute and chronic water toxicity tests were performed by Nautilus using the following methods:

- Acute toxicity tests:
  - 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).
- Chronic toxicity 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 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 bacteria, algae, aquatic vascular plants (i.e., macrophytes), benthic invertebrates, zooplankton, or fish. Survival endpoints report the proportion of test organisms that survive over a fixed duration at particular dilutions of the water being tested. Measurement endpoints (e.g., LC50) are estimates of the concentration of exposure medium (i.e., BML water) that results in a lethal or sub-lethal effect on test organisms (in this example, 50%), with increasing concentrations representative of decreasing effects. Acute toxicity (decreased survival) was observed for *D.magna* and juvenile *O.* mykiss in 2013 and 2014, respectively, but not since then. Chronic toxicity responses to BML water have decreased since monitoring began in 2013, 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, whereas acute toxicity has not been observed consistently in BML. No clear seasonal trends in chronic toxicity have been evident since the onset of monitoring. In 2022, toxicity of BML water was similar or better than what has been documented previously.

7.3.4.1 Acute Toxicity

The 96-hour static acute test on *O. mykiss* did not show any effect on survival resulting from exposure to BML water in 2022, with all LC50 values >100% v/v BML water (Figure 7-46). Exposure to BML water resulted in mortality in 2013 and May 2014, with LC50 values ranging from 69% to 87% v/v; no survival effect has been observed in any subsequent rainbow trout test. From the onset of testing, BML water has not affected the survival or motility of *D. magna* in the 48-hour acute test (Figure 7-46).

7.3.4.2 Chronic Toxicity

7.3.4.2.1 Survival Tests

In 2022, there was no effect of BML water on the 7-day survival of *C. dubia* with all LC50 values >100% v/v BML (Table 7-20; Figure 7-47). There has been no indication of chronic toxicity to *C. dubia* since 2018. Prior to 2018, mean LC50 values ranged from 75% to 92% v/v BML water. Similarly, there was no effect in 2022 on the 7-day survival of *P. promelas* with all LC50 values >100% v/v BML water. Previously, chronic toxicity was observed once in July 2013, with an LC50 of 69% v/v BML water.

7.3.4.2.2 Growth Inhibition Tests

BML has had limited effects on the 7-day growth of *P. promelas* with no observed toxicity since July 2018 (Figure 7-47). Since July 2014, there have only been three months where the IC25 was <100%; July 2013 (55% v/v BML), May 2014 (88% v/v BML), and July 2018 (80% v/v BML). In 2022, there was no effect of BML water on the 7-day growth of fathead minnow.

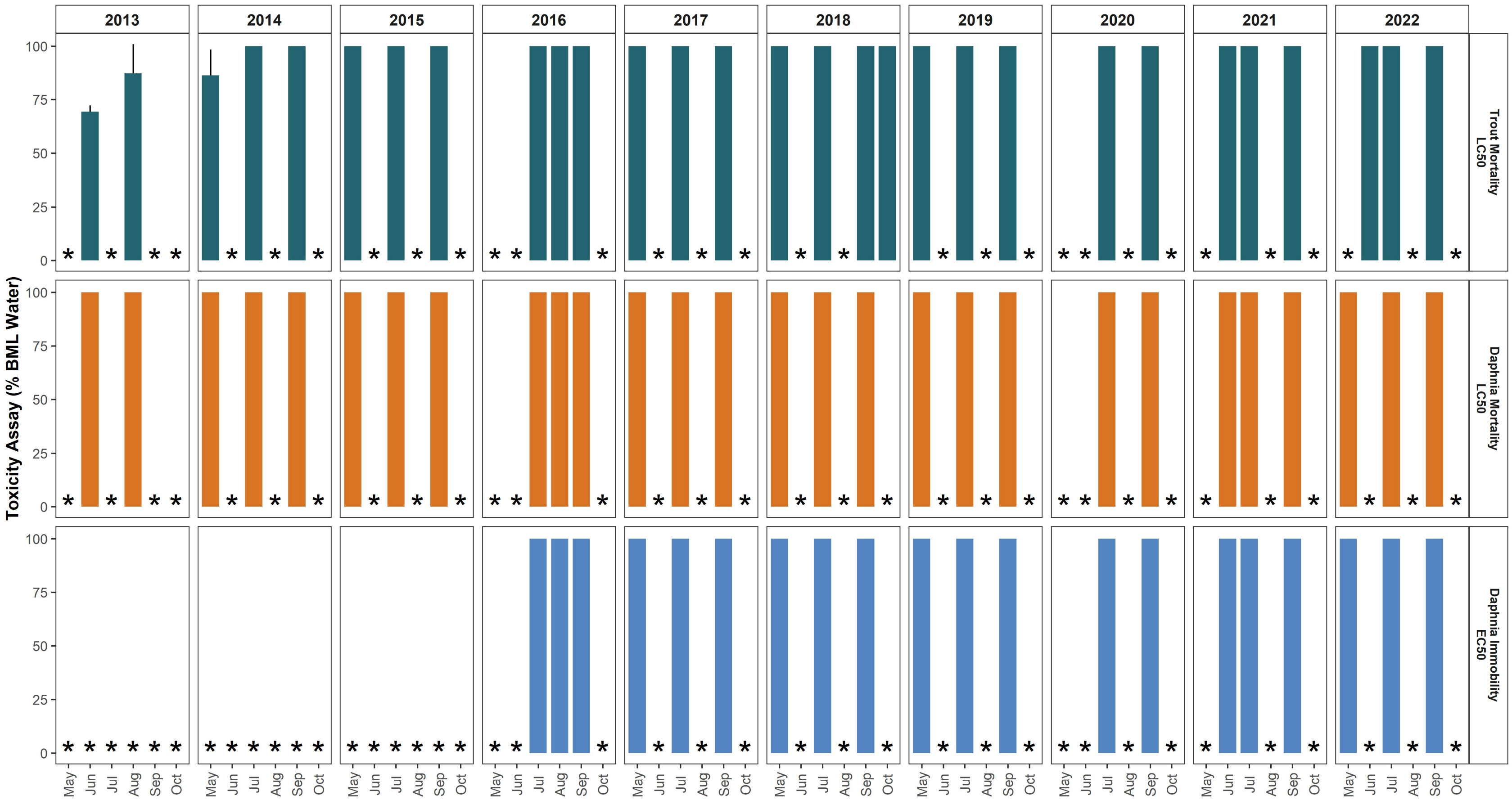
Chronic effects of BML water on *R. subcapitata* have generally been minimal, with results exceeding 75% v/v since September 2016, except in June 2021 (50% v/v BML water) (Figure 7-47). There has been at least one sampling event during every monitoring year (except 2016) with no effect of BML water on the growth of *R. subcapitata* (>91% v/v BML). In 2022, there was no effect of BML water for any of the sampling events (Figure 7-47**Error! Reference source not found.**).

The 7-day *L. minor* growth tests have been the most sensitive to BML water with a reduction in both dry weight and frond numbers historically (Figure 7-47). In 2022, there was no effect of BML water on dry biomass in May and September; however, the IC25 in August was 19% v/v BML. There was no effect of BML water on frond number in May 2022 (IC25 >96% v/v); however, the IC25 in August and

September was 10% v/v and 30% v/v respectively. The 7-day *L. minor* growth tests have exhibited high temporal and spatial variability since 2014. The endpoints observed in the 2022 biomass and frond number tests are within the historical ranges observed (Figure 7-47).

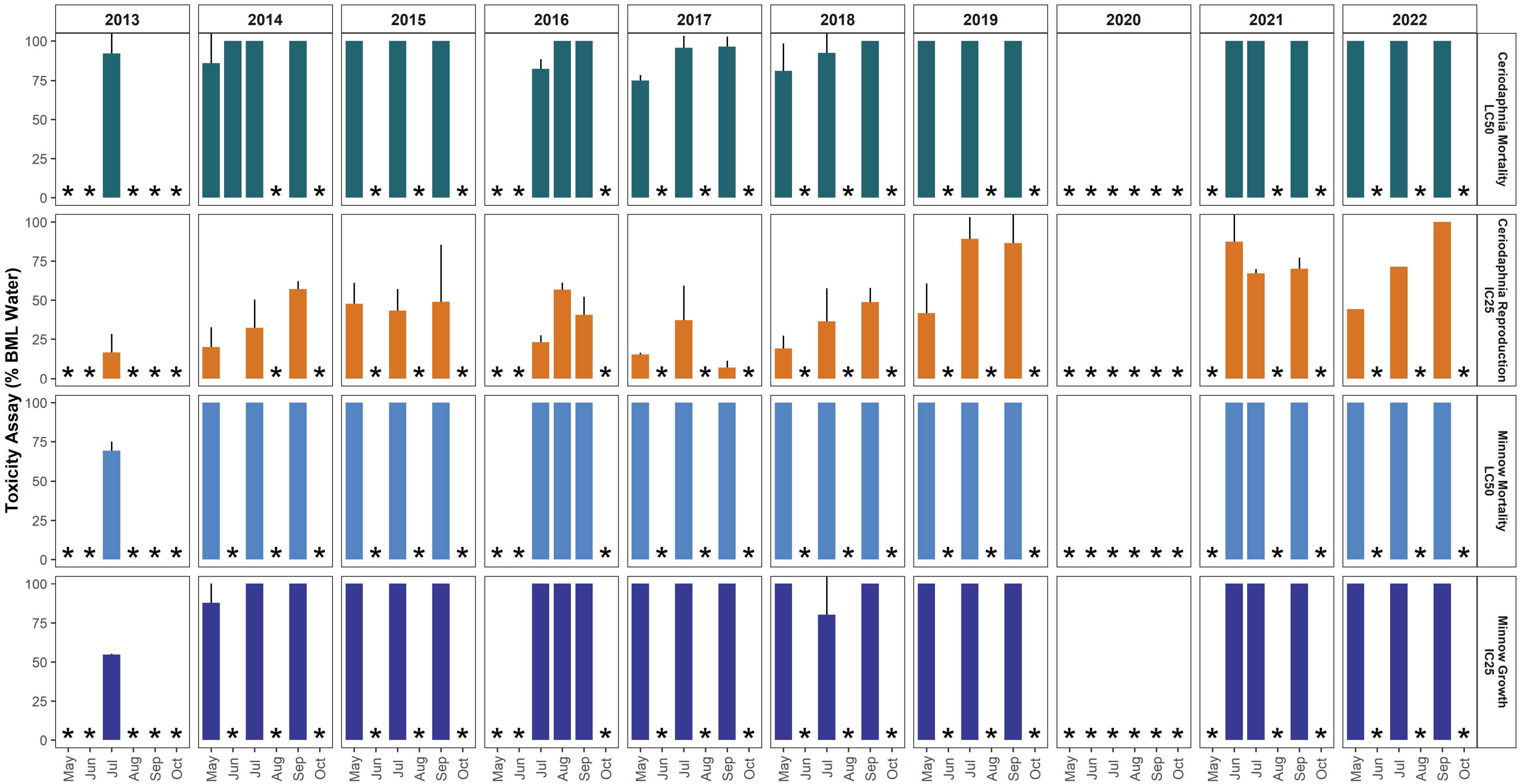
7.3.4.2.3 Reproduction Test

The 7-day reproduction tests on *C. dubia* provided evidence of sub-lethal toxicity in two of the three 2022 tests. *C. dubia* showed the greatest IC25 response to the composite sample collected in May (44% v/v BML), but no toxic response in September (>100% v/v BML) (Figure 7-48). The effects of BML water on *C. dubia* reproduction have generally decreased (i.e., become less toxic) from 2013 to 2022. Results of the *C. dubia* IC25 response were similar in 2022 (44% to >100% v/v BML), 2021 (67.3 to 87.3% v/v BML), and 2019 (42 to 89% v/v BML) (Figure 7-48). The effects of BML water on *C. dubia* reproduction have generally decreased from 2013 to 2021. The *C. dubia* IC25 response was similar in 2021 (67.3 to 87.3% v/v BML) and 2019 (42 to 89% v/v BML).



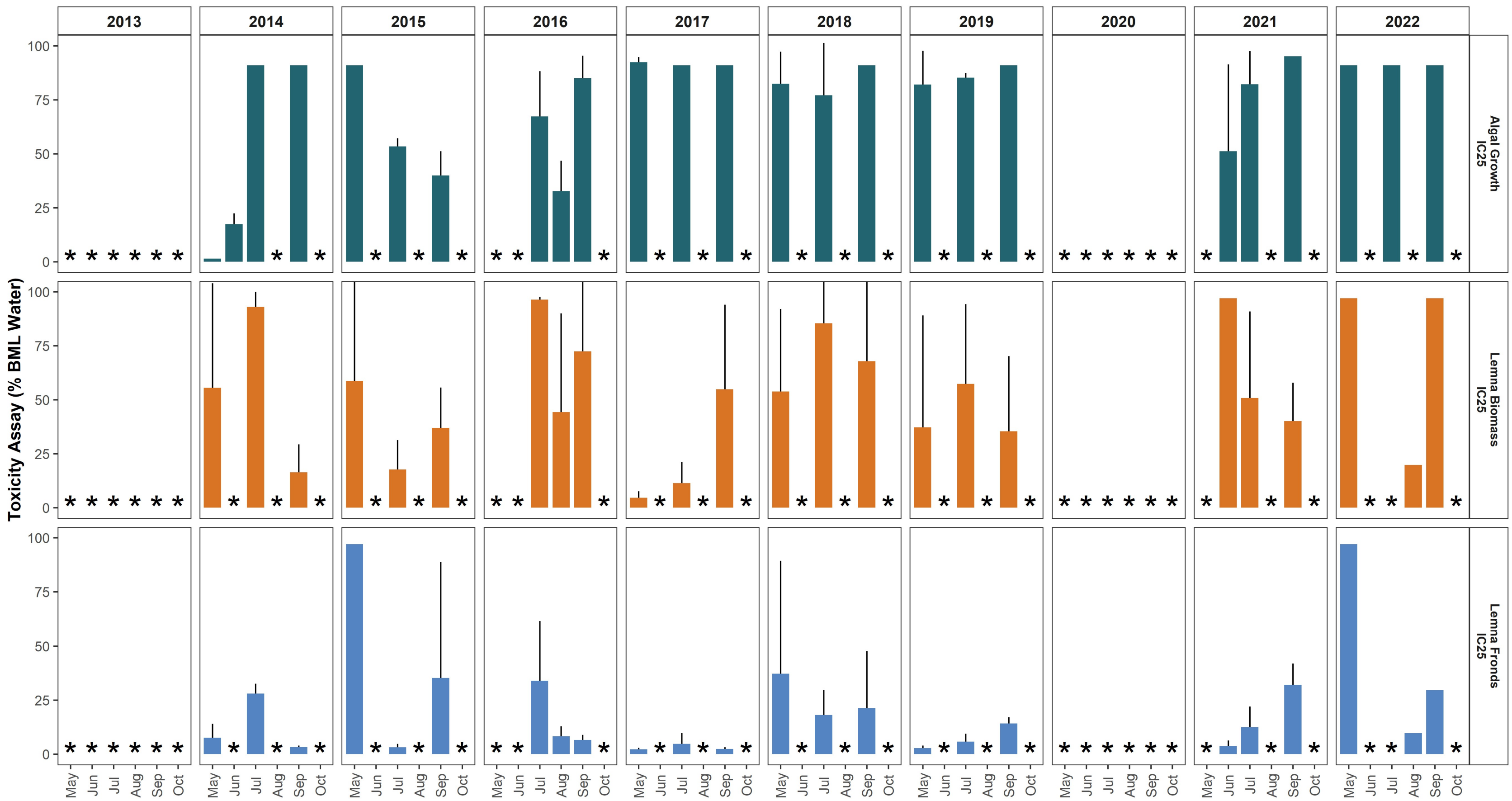
Shown are pooled averages of toxicity assay results across BML platform stations, with standard deviations shown as error bars where applicable. LC50 is the concentration of BML water, diluted by non-toxic medium, estimated to cause 50% mortality in exposed test organisms. EC50 is the concentration of 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 values shown are toxicity assay results from a lake-wide composite sample

Figure 7-46: Acute toxicity responses of invertebrates and fish exposed to Base Mine Lake waters, 2013 to 2022.



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 values shown are toxicity assay results from a lake-wide composite sample

Figure 7-47: Chronic toxicity responses of invertebrates and fish exposed to Base Mine Lake waters, 2013 to 2022.

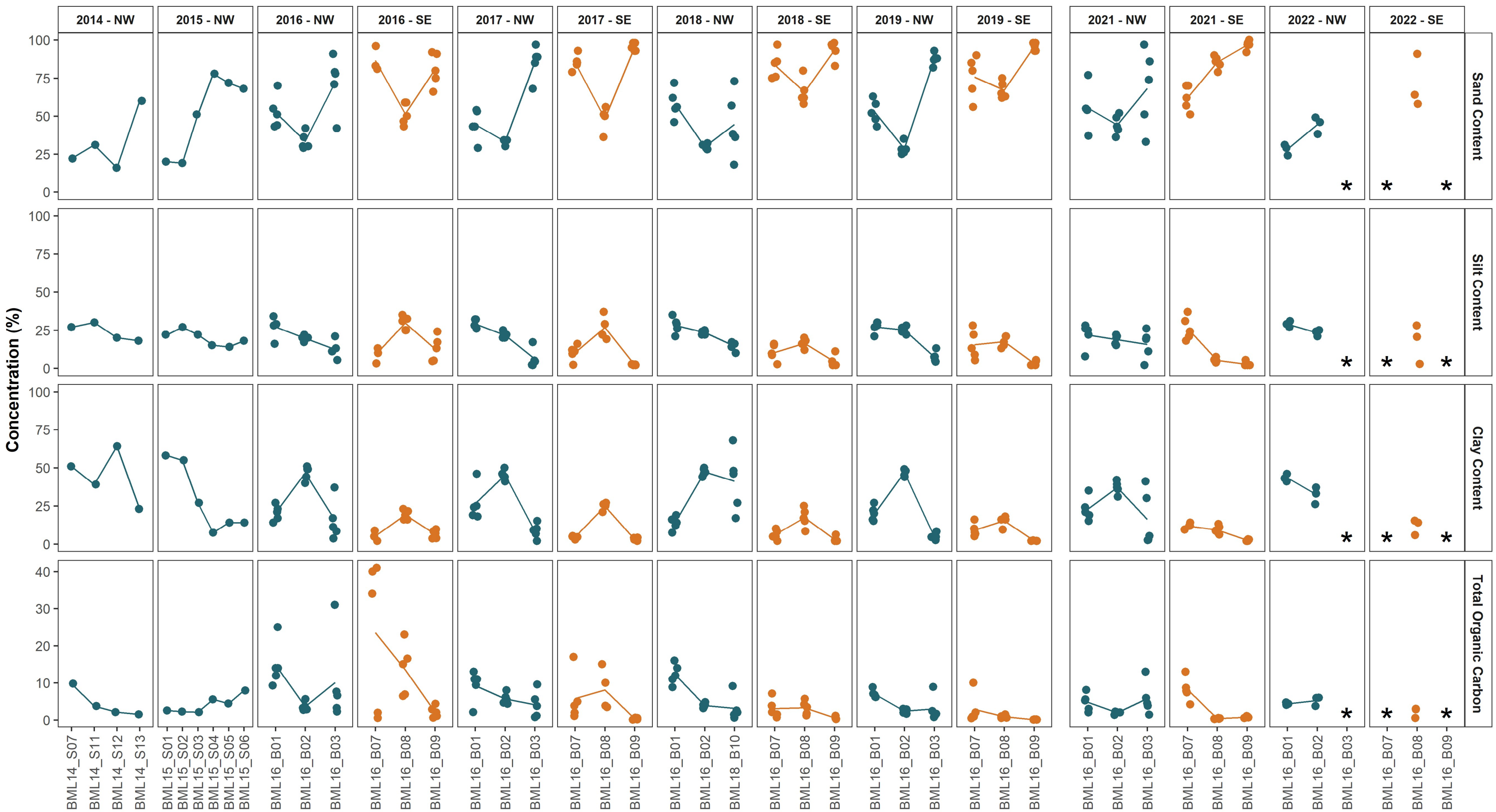


Shown are pooled averages of toxicity assay results across BML platform stations, with standard deviations shown as error bars where applicable.The IC endpoints are the concentrations of BML water, diluted by non-toxic medium, estimated to impair the physiology and growth of exposed test organisms. Months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

Figure 7-48: Chronic toxicity responses of primary producers exposed to Base Mine Lake waters, 2013 to 2022.

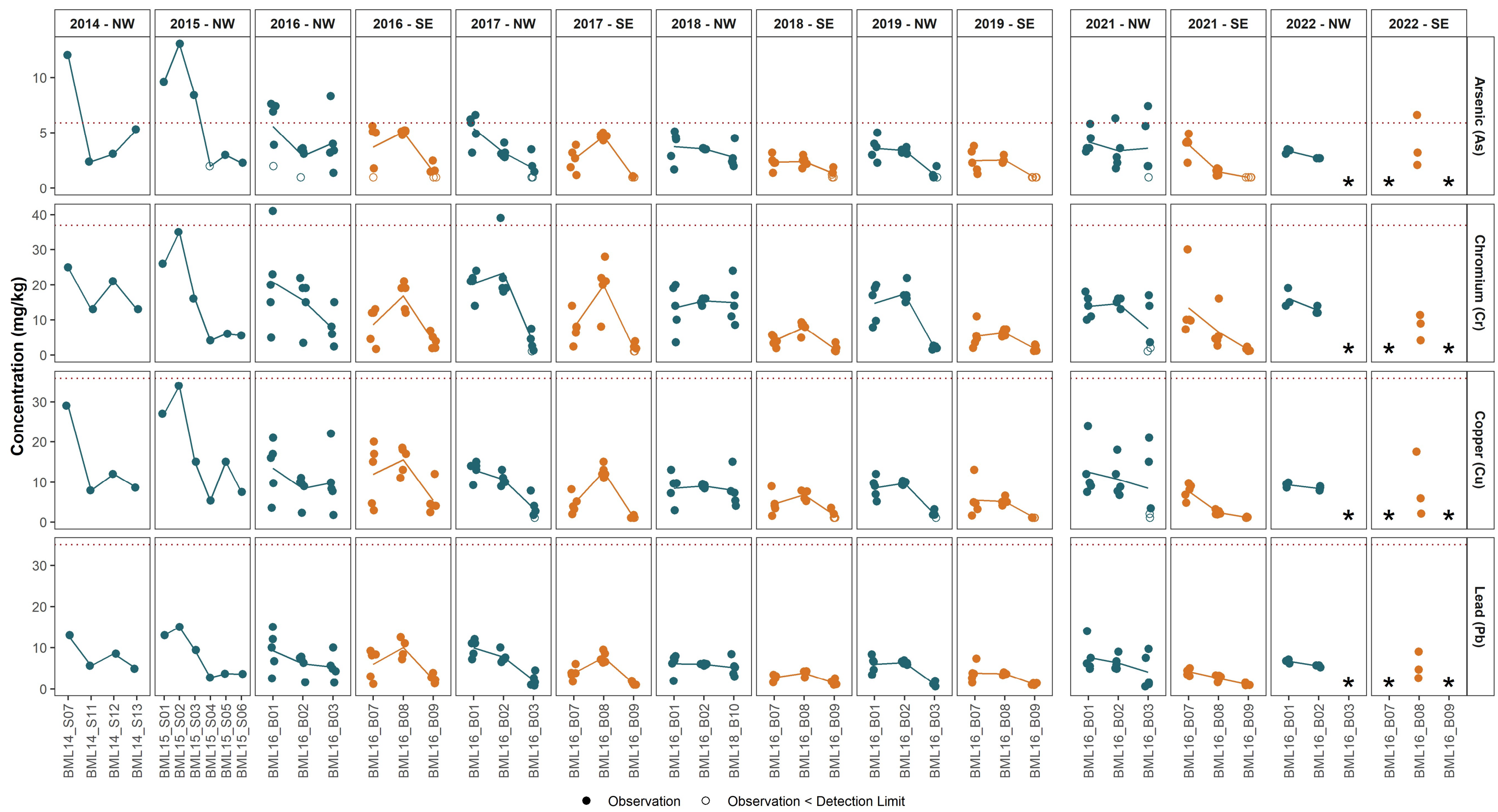
7.3.5 Littoral zone sediment chemistry

Sediment quality samples were collected between September 6 and 12, 2022, in conjunction with the benthic invertebrate program. Three replicate samples were collected at each of the six littoral stations, using a petite ponar with an effective sampling area of 0.023 m^2. Littoral zone sediment is not FFT, but conventional reclamation soils. There are some areas of the littoral where hydrocarbon sheen from the water surface has accumulated on top of the surface soils as a result of lake elevation fluctuations. Sediment testing findings are summarized in Figure 7-49 to Figures 7-51.

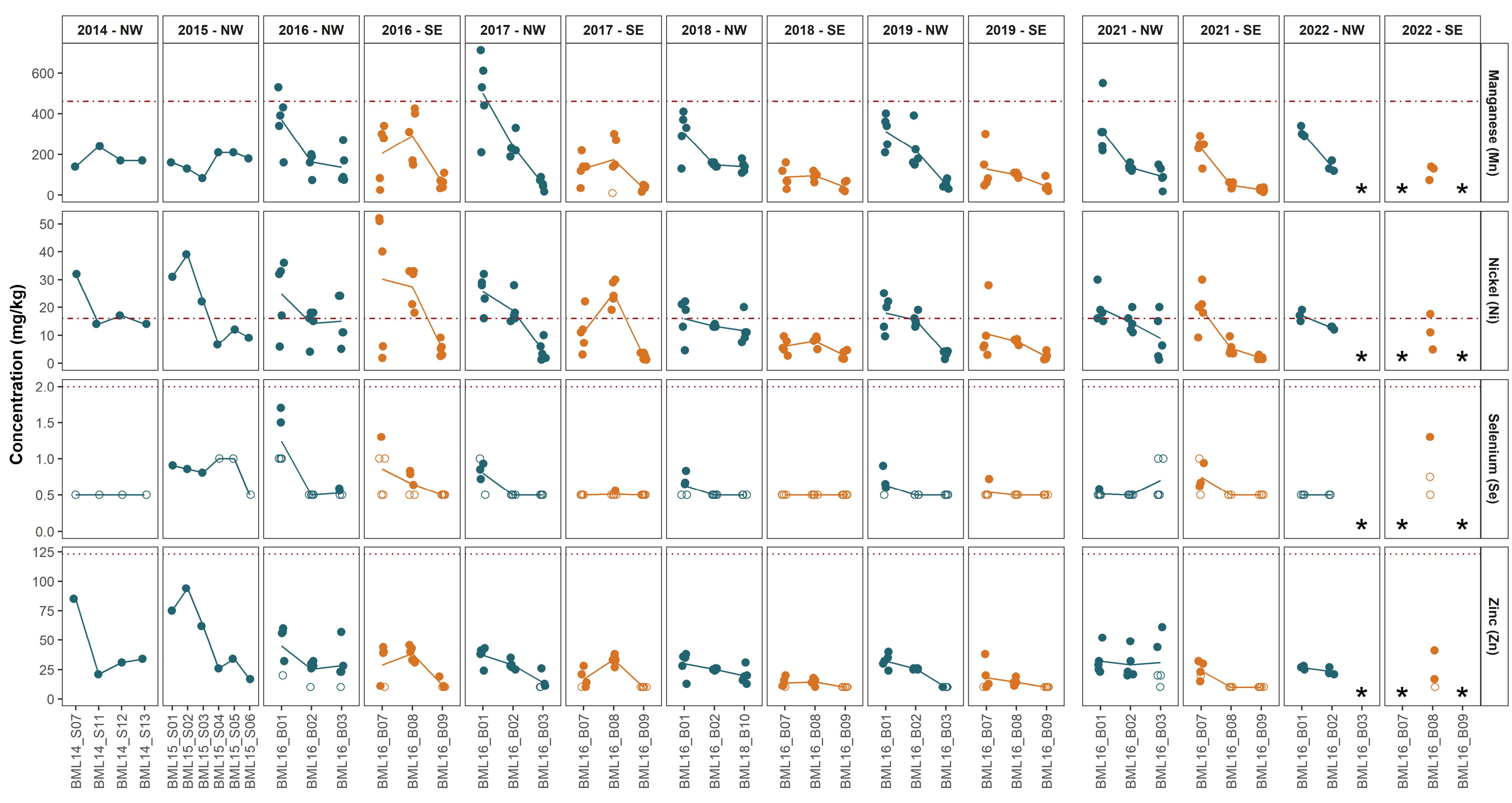


Sediment quality measurements at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). Mean sediment concentration for each station is shown as a solid-coloured line. No samples were collected in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks.

Figure 7-49: Physical composition/properties of sediment collected from the NW and SE quadrants of Base Mine Lake, 2014 to 2022.

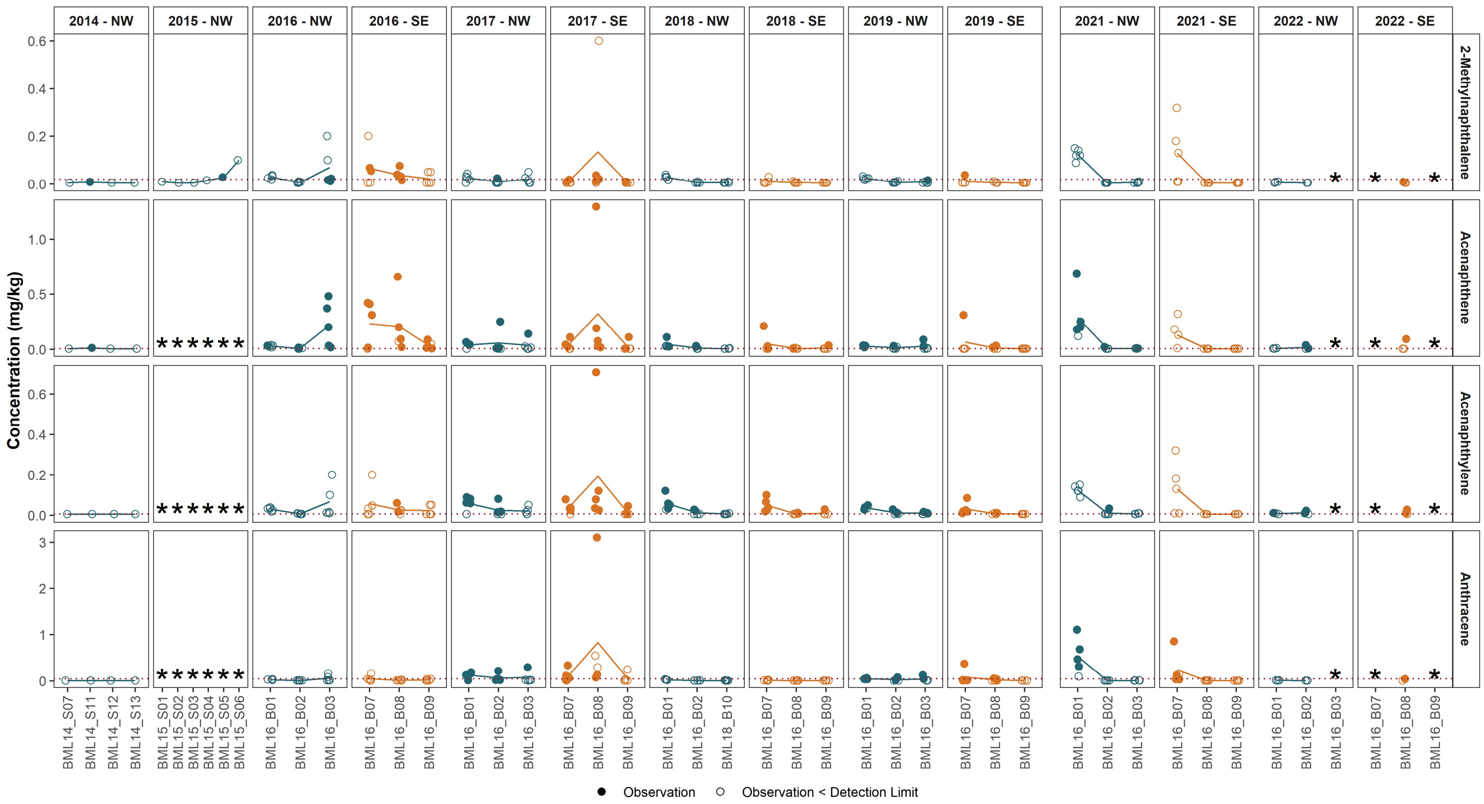


Concentration of select sediment quality analytes at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). Mean sediment concentration for each station shown as the solid-coloured line. No samples were collected in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks. Interim Sediment Quality Guidelines (ISQG) shown as dotted lines.

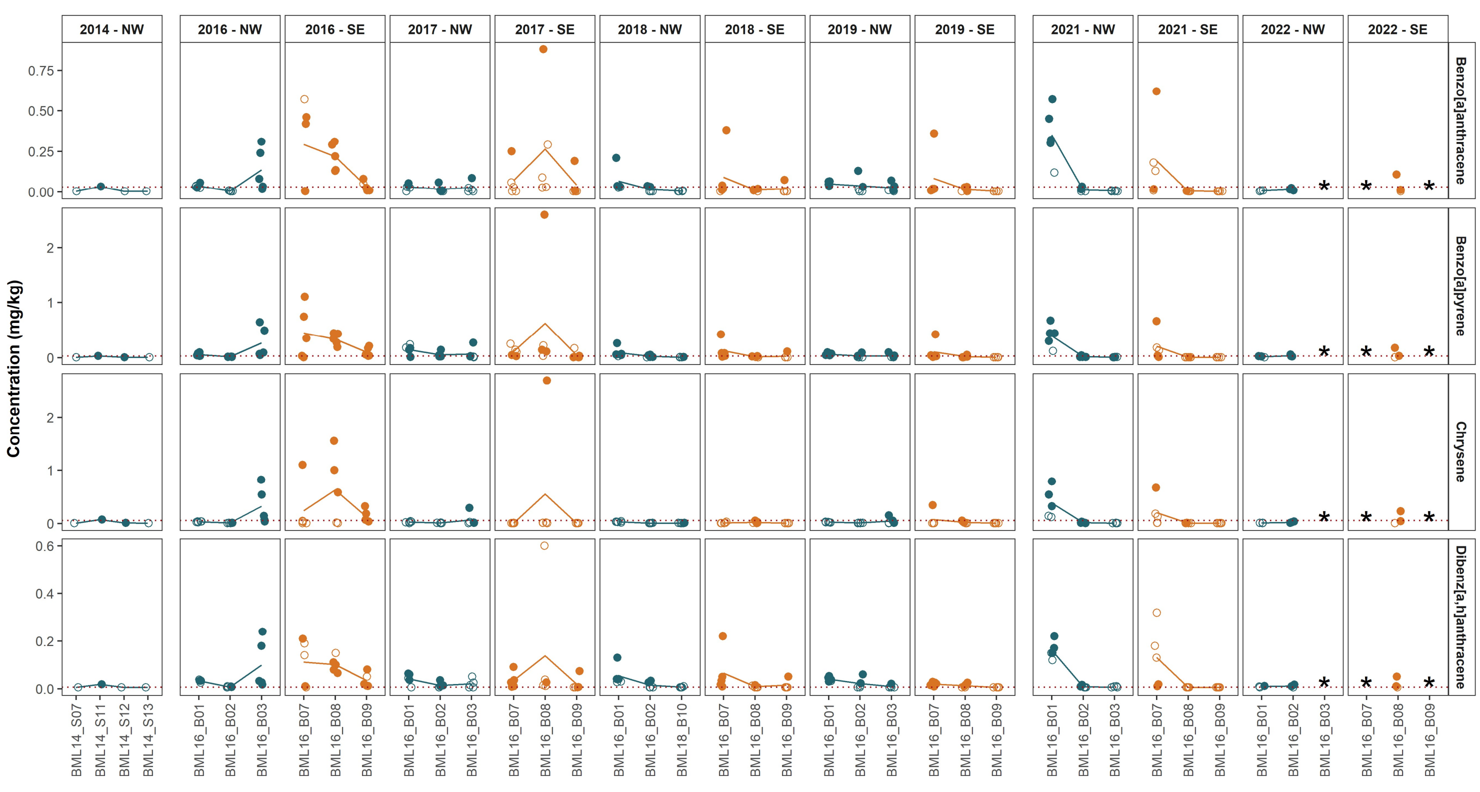


Concentration of select sediment quality analytes at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). Mean sediment concentration for each station shown as the solid-coloured line. No samples were collected in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks. Interim Sediment Quality Guidelines (ISQG) shown as dotted lines and Lowest Effect Level (LEL) shown as dot-dash lines.

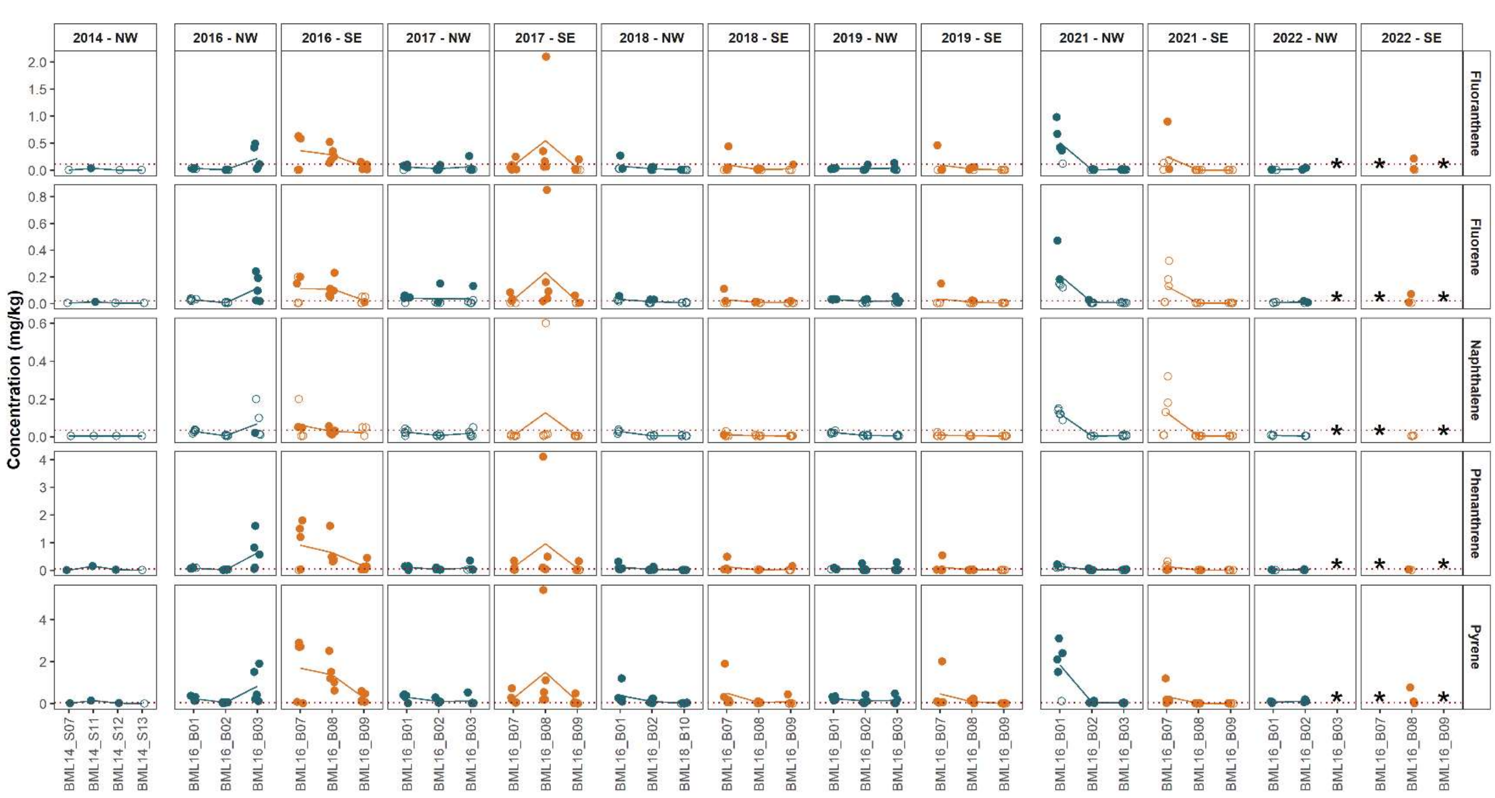
Figure 7-50: Select metal concentrations in sediment collected from the NW and SE quadrants of Base Mine Lake, 2014 to 2021.



Concentration of select PAH analytes at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). Only 2-methylnaphthalene was measured in 2015 and no samples were collected in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks. Mean sediment concentration for each sampling event shown as the solid-coloured line, Interim Sediment Quality Guidelines (ISQG) shown as dotted lines



Concentration of select PAH analytes at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). No samples were collected in 2015 or in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks. Mean sediment concentration for each sampling event shown as the solid-coloured line, Interim Sediment Quality Guidelines (ISQG) shown as dotted lines



Concentration of select PAH analytes at each station with individual replicates displayed as circles (open if less than detection limit and closed if greater than the detection limit). No samples were collected in 2015 or in 2020. In 2022, only two stations in the NW quadrant and one station in the SE quadrant were sampled. Stations not sampled are marked with asterisks. Mean sediment concentration for each sampling event shown as the solid-coloured line, Interim Sediment Quality Guidelines (ISQG) shown as dotted lines

Figure 7-51: Select PAH concentrations in sediment collected from the NW and SE quadrants of Base Mine Lake, 2014 to 2021.

Table 7-20: Exceedances of sediment quality guidelines (as % of samples) in the NW and SE quadrants of Base Mine Lake, 2014 to 2022

Variable	NW Quadrant																							
	2014			2015			2016			2017			2018			2019			2021			2022		
	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	-
Chromium (Cr)	0	0	-	0	0	-	7	0	-	7	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	-
Lead (Pb)	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
Mercury (Hg)	0	0	-	0	0	-	0	0	-	7	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Nickel (Ni)	-	-	50	-	-	50	-	-	53	-	-	47	-	-	27	-	-	27	-	-	33	-	-	33
Selenium (Se)	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	-
Parent PAHs																								
2-Methylnaphthalene	0	0	-	33	0	-	47	0	-	40	0	-	27	0	-	27	0	-	33	0	-	0	0	-
Acenaphthene	25	0	-	ns	ns	-	87	20	-	67	13	-	53	7	-	73	0	-	60	33	-	67	0	-
Acenaphthylene	0	0	-	ns	ns	-	80	7	-	67	0	-	53	0	-	73	0	-	53	13	-	67	0	-
Anthracene	0	0	-	ns	ns	-	13	0	-	40	7	-	0	0	-	20	0	-	33	27	-	0	0	-
Benzo[a]anthracene	25	0	-	ns	ns	-	47	0	-	27	0	-	27	0	-	53	0	-	40	13	-	0	0	-
Benzo[a]pyrene	25	0	-	ns	ns	-	53	0	-	53	0	-	40	0	-	53	0	-	40	0	-	17	0	-
Chrysene	25	0	-	ns	ns	-	27	0	-	7	0	-	0	0	-	7	0	-	33	0	-	0	0	-
Dibenz[a,h]anthracene	25	0	-	ns	ns	-	87	13	-	67	0	-	53	0	-	67	0	-	60	27	-	67	0	-
Fluoranthene	0	0	-	ns	ns	-	13	0	-	7	0	-	7	0	-	7	0	-	33	0	-	0	0	-
Fluorene	0	0	-	ns	ns	-	53	13	-	47	7	-	40	0	-	53	0	-	40	20	-	0	0	-
Naphthalene	0	0	-	ns	ns	-	20	0	-	13	0	-	7	0	-	0	0	-	33	0	-	0	0	-
Phenanthrene	25	0	-	ns	ns	-	67	20	-	40	0	-	33	0	-	33	0	-	40	0	-	0	0	-
Pyrene	25	0	-	ns	ns	-	80	13	-	53	0	-	47	7	-	67	0	-	47	27	-	83	0	-

7.3.6 Littoral zone sediment toxicity

Sediment toxicity samples were collected in September 2022, in conjunction with the sediment quality sampling program. Sediment toxicity samples were collected from three of the six sediment/benthic invertebrate sampling stations. Five replicate samples were collected at each sediment toxicity station, using a petit ponar with an effective sampling area of 0.023 m^2. There are some areas of the littoral where bitumen sheen from the water surface has accumulated on top of the surface soils as a result of lake elevation fluctuations.

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)* and chironomids *(Chironomus dilutus)* exposed to lake sediment with the responses of test organisms exposed to laboratory-supplied control sediment.

Sediment toxicity is used to determine whether the substrate of BML may be acutely or chronically toxic to benthic invertebrates, and to provide information on the lake's ability to support colonization by benthic organisms. Figure 7-52 and Figure 7-53 summarize toxicity responses of test organisms exposed to sediment samples collected from the NW and SE quadrants each fall from 2015 to 2022. Sampling effort varied across years; a single station from the NW quadrant was tested in 2014 and 2015; however, data from 2014 are not presented because a laboratory issue resulted in lack of reliable data. In 2016, a single station from each quadrant was sampled. From 2017 to 2021, three stations in the NW quadrant (BML16_B01, BML16_B02, and BML16_B03) and three stations in the SE quadrant (BML16_B07, BML16_B08, and BML16_B09) were tested annually except in 2020 when no sediment toxicity samples were collected. In 2018, station BML16_B03 was not sampled; instead, sampling was approximately 1 km south of the B03 location and designated as BML18_B10. Sediment toxicity sampling at BML16_B03 resumed in 2019. In 2022, the sampling scope was reduced from three stations each in the NW and SE quadrant to three stations across the whole lake so that three of the six established stations are sampled every other year. In 2022, two stations in the NW quadrant (BML16_B01 and BML16_B02) and one in the SE quadrant (BML16_B08) were sampled.

The 2022 results are compared with those from 2015 through 2021. Toxicity responses of *C. dilutus* and *H. azteca* are presented as the difference between the response in BML and control groups (i.e., BML – Control) to facilitate comparisons among years.

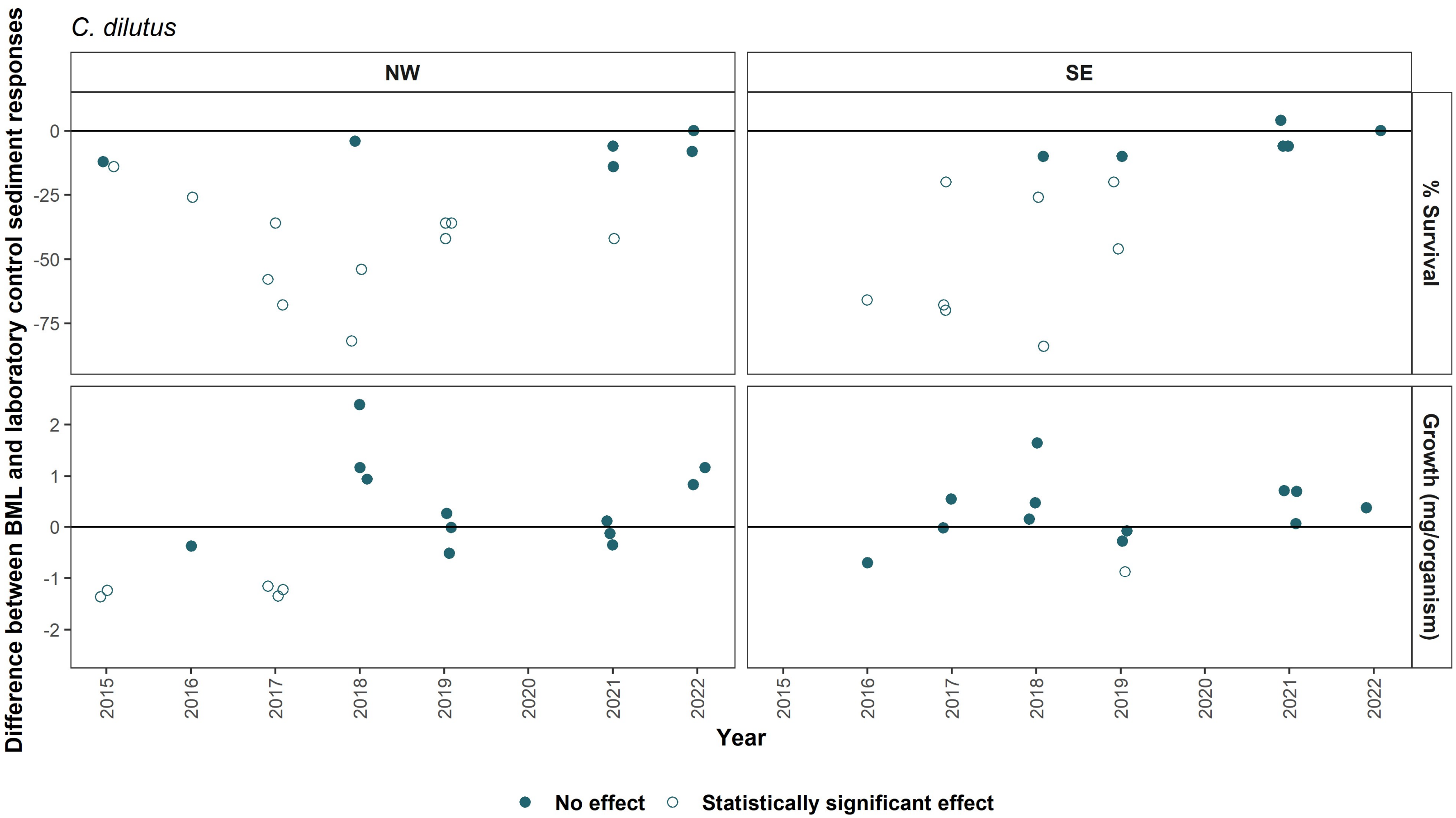
7.3.6.1 Acute Toxicity

There was no statistically significant effect of BML sediment on the survival of *C. dilutus* in either quadrant in 2022 (i.e., there was no significant difference between survival rates in the BML and control sediments). The 10-day survival test resulted in 92% to 100% survival in the NW quadrant and 100% survival in the SE quadrant (Figure 7-52).

Sediment from the NW quadrant had a statistically significant effect on the 14-day *H. azteca* survival test with a mean survival of 88% and 76% for stations BML16_B01 and BML16_B02, respectively, compared to the control sediment (100% survival) (Figure 7-53**Error! Reference source not found.**). There was no statistically significant effect on *H. azteca* survival in the SE quadrant (92%). Historically, there has been high spatial variability (within and between quadrants) in survival responses for both test organisms; however, acute toxicity effects from BML sediment appear to be decreasing over time.

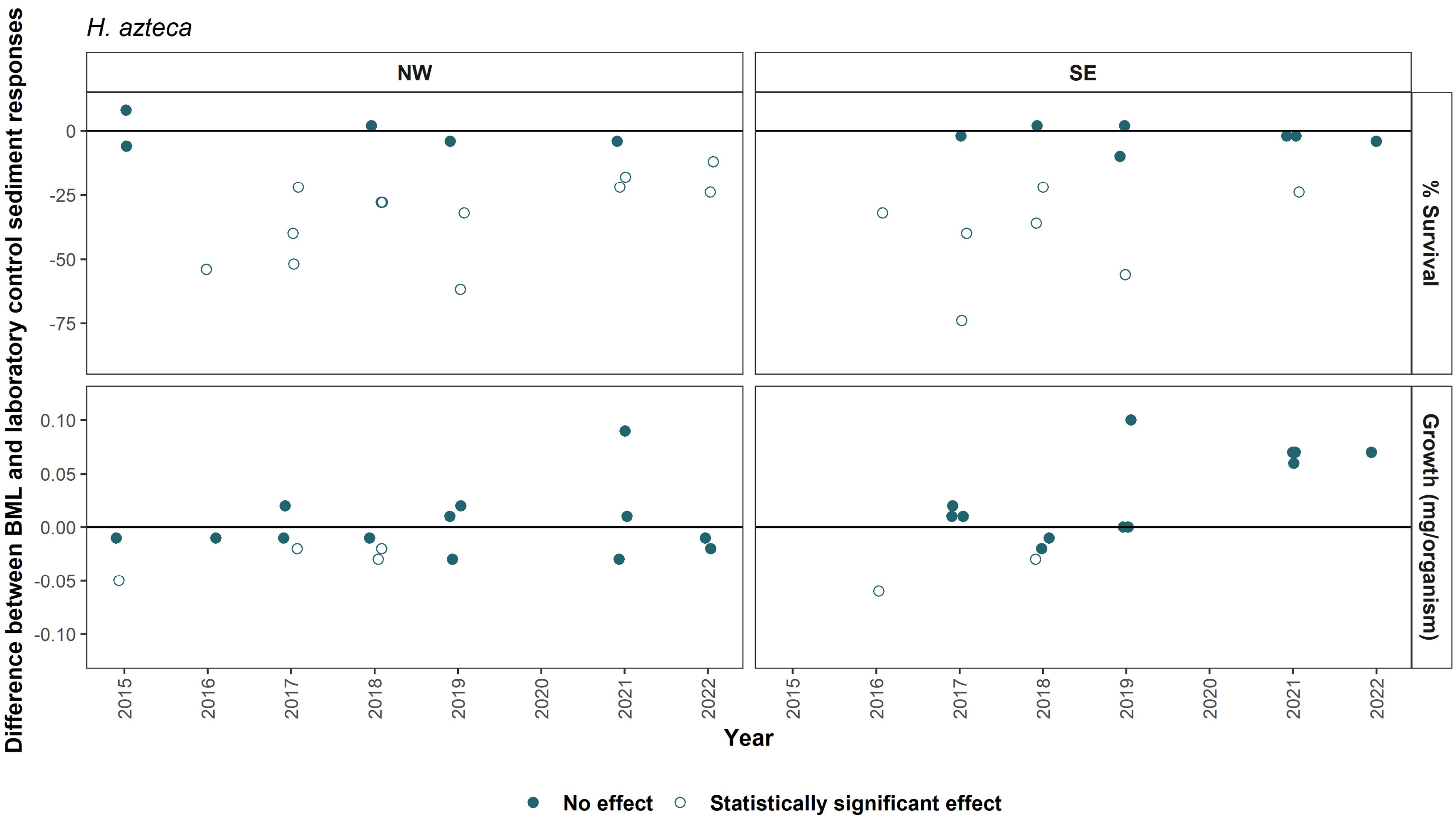
7.3.6.2 Chronic Toxicity

Exposure to sediment from the NW and SE quadrants did not reduce the growth of *C. dilutus* or *H. azteca* in 2022 (Figure 7-52 and Figure 7-53) Sediment from both quadrants stimulated the growth of *C. dilutus* compared to the control, with the effect more pronounced in the NW quadrant. Individuals in the SE quadrant exhibited a body mass of 2.17 mg/organism on average, compared to the control group average of 1.80 mg/individual. Individuals in the NW quadrant were on average between 2.62 mg/organism and 2.96 mg/organism.



Difference in % survival (upper panels) and growth (mg/organism; lower panels) of C. dilutus in BML sediment compared to control sediment across years in the NW (left panels) and SE (right panels) quadrants. Circles are the difference between the mean response of each BML station compared to the mean response of the control. Positive values indicate increased survival or growth from BML sediments while negative values represent a decrease in these endpoints. Open circles show a statistically significant adverse effect and closed circles show no statistically adverse effect of BML based on a one-tailed alternative hypothesis with a significance of α = 0.05. No stations were sampled in the SE quadrant in 2015 and no samples were collected in 2020.

Figure 7-52: Toxicity responses of freshwater midge exposed to sediment from NW and SE quadrants of Base Mine Lake, 2015 to 2022.



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. Circles are the difference between the mean response of each BML station compared to the mean response of the control. Positive values indicate increased survival or growth from BML sediments while negative values represent a decrease in these endpoints. Open circles show a statistically significant adverse effect and closed circles show no statistically adverse effect of BML based on a one-tailed alternative hypothesis with a significance of α = 0.05. No stations were sampled in the SE quadrant in 2015 and no samples were collected in 2020.

Figure 7-53: Toxicity responses of amphipods exposed to sediment from NW and SE quadrants of Base Mine Lake, 2015 to 2022.

8 Summary of Key Performance Results from the Base Mine Lake Research Program

The Base Mine Lake 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 Base Mine Lake that are responsible for the trends observed in the monitoring program. The various components comprising the Base Mine Lake monitoring and research programs are closely linked.

As mentioned previously, the current focus of the research program is to support the demonstration of the Water-Capped Tailings Technology (WCTT). The program also provides supporting information about key processes fundamental to the progression of Base Mine Lake towards becoming a functional component of the reclaimed closure landscape. The current research programs are focused on key parameters influencing early Base Mine Lake 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 Base Mine Lake 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 Base Mine Lake 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.

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

The objective of this program is to understand the circulation of BML 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. The movement of platform 3 is damaging turbidity instruments and resulting in lost data, especially in the bottom half of the water column. Ebullition (bubbling) is modulated by pressure throughout the year. A bubble trap was successfully built and deployed, and this work will expand in 2023. We are moving toward 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. Below the epilimnion, particularly below the depth of the deepest sensors (6m), it is more difficult to know how dissolved oxygen is changing. During upwelling events near anoxic water rises to the 6m deep sensors indicating that the bottom water may be getting less oxic. As the FFT settles and the water cap deepens, the stability of the lake is expected to increase and the hypolimnetic dissolved oxygen near the FFT interface may decrease.

Profiles collected during the winters beginning in 2017 have evidence of FFT 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 FFT has resulted in an increase in the volume of the water cap and the total mass of salt in the water cap. 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. 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-FFT interface. This work includes using and developing numerical models. Other research groups associated with Base Mine Lake (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. Future modelling will investigate the impact heat and salt flux on turbidity.

8.2 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 Base Mine Lake 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 FFT-water interface in BML. 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 FFT 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 FFT-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 FFT. 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.

8.3 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 FFT 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.

8.4 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 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 FFT-water interface to the BML water surface. The outcomes will identify the key OCC and processes affecting oxygen status throughout the BML 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. The program has provided evidence of sulfur cycling (both reduction and oxidation) occurring in BML 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 resulting in differential impacts on linked oxygen consumption rates (OCR).

In 2022, work remained focused on assessing the rates and important controls of sulfur oxidizing and reducing processes; the sulfur reducing and sulfur oxidizing microbial communities (SRB and SOB, respectively) involved; and identifying the possible controls, outcomes, and rates (see Jessen *et al*., 2022 and Yan *et al*., 2022 for details) and impacts of these sulfur cycling processes on Base Mine Lake (BML) oxygen concentrations.

In addition, laboratory-based experiments using field collected BML samples throughout the year and field experiments were conducted at site in May, June, July, and August. These experiments were designed to assess:

1. rates of sulfate reduction (SRR) with respect to season and carbon source, as well as the effects of aqueous iron on SRR, sulfide precipitation, and iron-sulfide mineral formation
2. rates of oxygen consumption (OCR) to identify the potential of anoxia expansion from lower to higher hypolimnion due to oxygen consuming activities in late summer BML water cap.
3. the presence of microbial anaerobic methane oxidation using sulfate, and the influence of this process on sulfide and methane concentrations, both major OCCs in BML

Analysis and interpretation of results is ongoing.

8.5 Microbial communities and methane oxidation processes in Base Mine Lake (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 over time, and compare it to adjacent natural habitats (e.g., Beaver Creek Reservoir, BCR) and active tailings ponds (e.g., Mildred Lake Settling Basin, MLSB).

2) To understand the role of algae in the carbon cycle of BML. 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.

DNA sequencing of 2021 samples is still ongoing and will be completed in, 2022, followed by analysis and interpretation. Results from this program are similar to previous years, but the data are more comprehensive. Although BML communities are highly variable in time, they are unique compared to communities in a tailings pond (MLSB) and communities in a more natural water body (BCR). Statistical analysis has identified some species (bacterial and eukaryotic) that are similarly abundant between BML and BCR, and others that are similarly abundant in BML vs MLSB. Certain "indicator" species that are typical of BCR but not MLSB appear to be increasing in BML over time, particularly some diatoms. Species diversity of eukaryotes, methanotrophic bacteria, and algae in BML are increasing slightly over time. Total algal cell counts are increasing over time since 2016. Major algal species cycle in repeatable seasonal patterns, a pattern typical of many natural boreal lakes. Methanotrophic bacteria show regular seasonal and spatial patterns, becoming abundant in winter and spring and less abundant in summer. Methanotroph populations in surface sediment are 2 to 4 orders of magnitude greater than in the water column, supporting other evidence that this is the main site of methane oxidation, especially during summer stratification. Methane oxidation in the water column is most important in fall and winter.

8.6 Understanding Air-Water Exchanges and the long-term hydrological viability of Base Mine Lake (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, 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 9.2.1)

8.7 Characterization of organic compounds and naphthenic acids in Base Mine Lake: 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 Base Mine Lake (BML). 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.

Analysis of methane concentrations in isojars samples in fall 2021 observed concentrations consistent with the previous range observed by Matt Lindsay's group and reported in Francis *et al.* (2022). During 2022 we initiated microcosm studies of methane production within FFT using fluid sampler profiles of the upper FFT (4 to 6 samples from 0.5 to circa 4 m depth) to assess methane production. Methane production was occurring compared to irradiated controls, with varying production rates that were not systematically related to depth. Production rates (at 20 C) ranged between 2.2 micromolar/L/day to 38.6 micromole/L/day. These values are being used to develop a model of total methane production potential in the upper FFT. Concurrently, phospholipid biomarkers and their isotopic compositions are being analysed to assess the role of methane as a carbon source for the FFT microbial community.

Concurrently, characterization of the low molecular weight hydrocarbons (LMWHC) present in corresponding FFT samples was undertaken. LMWHC are thought to potentially be related to residual naphtha from the extraction process. We identified that headspace analysis above FFT samples allowed LMWHC to be characterized without interference from the large unresolved complex mixture present associated with the residual bitumen. Our work tentatively identified 95 LMWHC present within the FFT. Comparison of FFT LMWHC profiles with those of a sample of naphtha and with raw bitumen ore noted that compounds considered more biodegradable that are present in naphtha (i.e., toluene, alkanes) were not present in the FFT, indicating their removal by biodegradation. However, the timing of this degradation cannot be ascertained using this data. Modelling of the potential distribution of these LMWHC between bitumen, water and headspace indicated that the vast majority of LMWHC would be present in bitumen at equilibrium. Work planned for 2023 will utilize Syncrude's research lab approaches to achieve greater identification and quantification of LMWHC in FFT and more precise, direct assessment of the distribution of these compounds between residual bitumen, FFT porewater and any gas phases.

High resolution Mass Spectrometry was undertaken of BML water column, FFT porewater and Beaver Creek reservoir to assess trends in naphthenic acids and biogeochemical cycling of petroleum hydrocarbons. Results indicate evidence of anaerobic microbial production of more oxygenated naphthenic acids within the FFT. Greater levels of oxygenation in the water column samples indicated further aerobic biodegradation. Presence of singly oxygenated aromatic compounds in shallow water samples indicated occurrence of photolytic breakdown of PH in the upper water column.

8.8 Base Mine Lake Process Dynamics (Barry Bara/Oluwaseun Adedeji, Syncrude)

This research is focused on understanding the mechanisms and mitigation of bitumen liberation from mats on the FFT surface and to track effectiveness of bitumen mitigation activities. A significant effort has been underway to delineate and understand the extent of bitumen mats on the FFT surface. Residual naphtha in these mats is consumed by methanogenic microbes, producing methane gas. The gas bubbles can be coated in bitumen (Figure 8-1), and when released, carry bitumen to the water surface resulting in a hydrocarbon sheen. This sheen can drift into the shoreline where it coats plants and sediments. See section 4.3.3.2 for details of the bitumen dynamics conceptual model.

Observations from the Base Mine Lake research and monitoring program have indicated that ice cores from BML can show both gas bubbles and bitumen (see section 4.3.3.2) 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. This program was developed using a CT scanning method for the ice cores which allows quantification of gas voids and bitumen (see Figure 4-5 for images of ice cores). 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 effects of bitumen mat dredging activities on gas and bitumen liberation to the water column.

Figure 8-2 shows contour plots of the gas and bitumen content per unit area generated from the 2020 ice core data. Similarly, Figure 8-3 shows contour plots of the gas and bitumen content per unit area generated from the 2021 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 Base Mine Lake, and areas with elevated gas volume measured in regions of low bitumen content.

Figure 8-4 shows the 2021 bitumen content contour map compared to the bitumen mat location map that was presented in **Error! Reference source not found.**4.3.3.2. 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 Base Mine Lake.

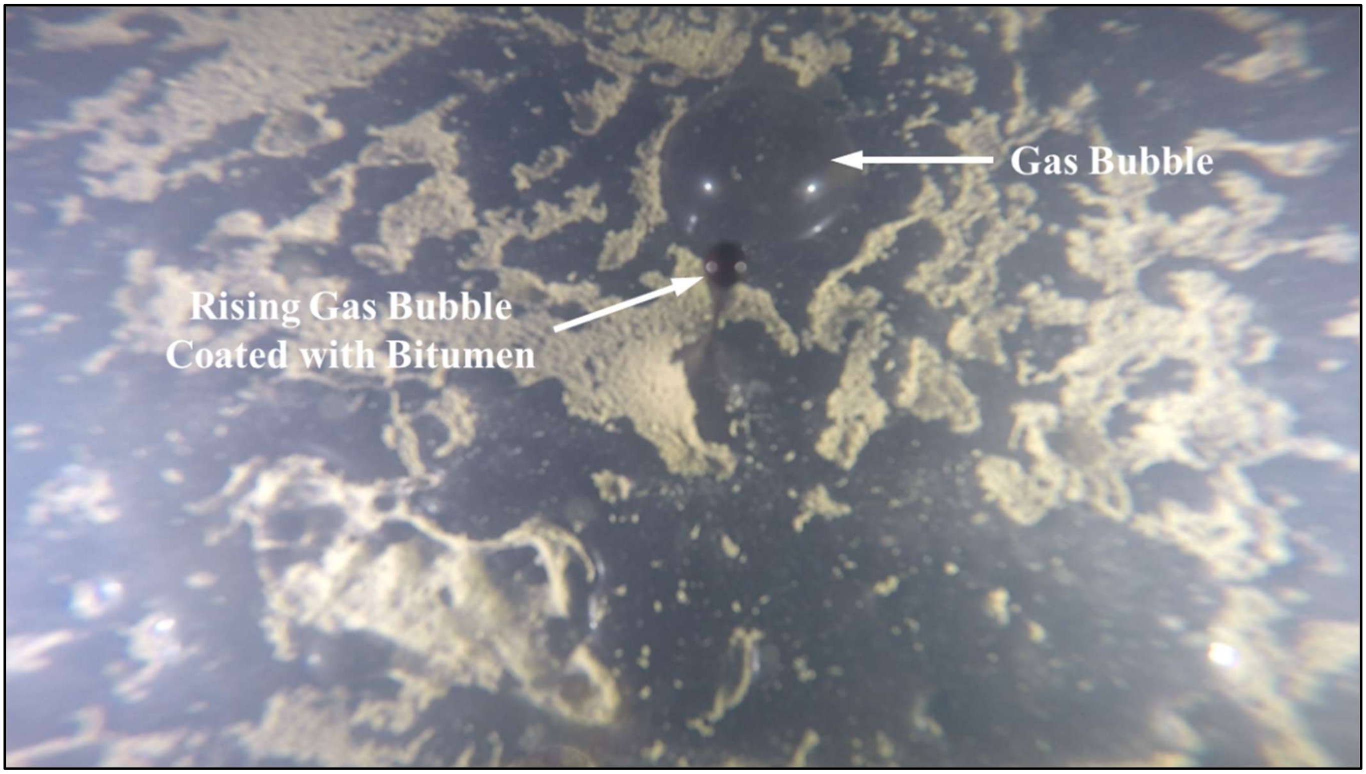


Figure 8-1: Image of the surface of a bitumen mat showing a gas bubble coated with bitumen being released from the mat along with a gas bubble sitting on the surface of the mat. Note the settled fine solids on top of the mat.

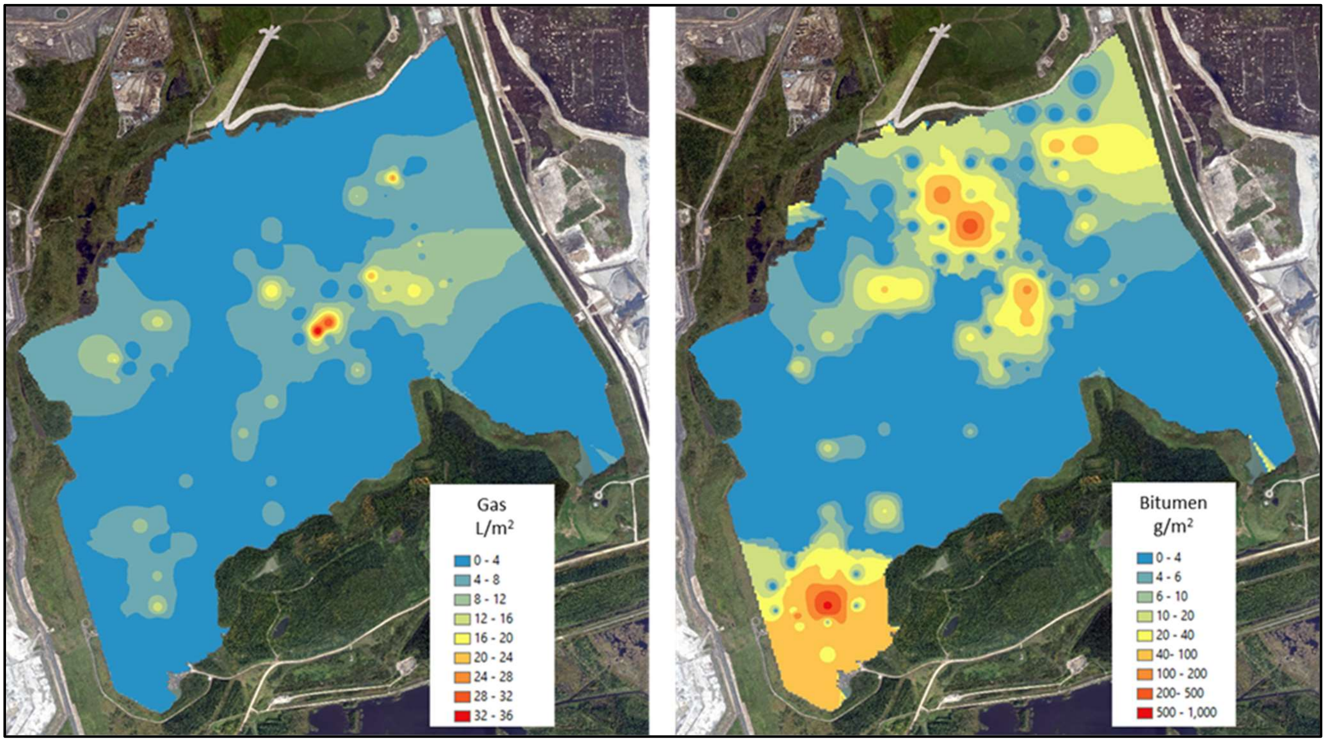


Figure 8-2. Contour maps of gas volume and bitumen mass per unit area contained in the ice cap generated from the 2020 ice core program field data

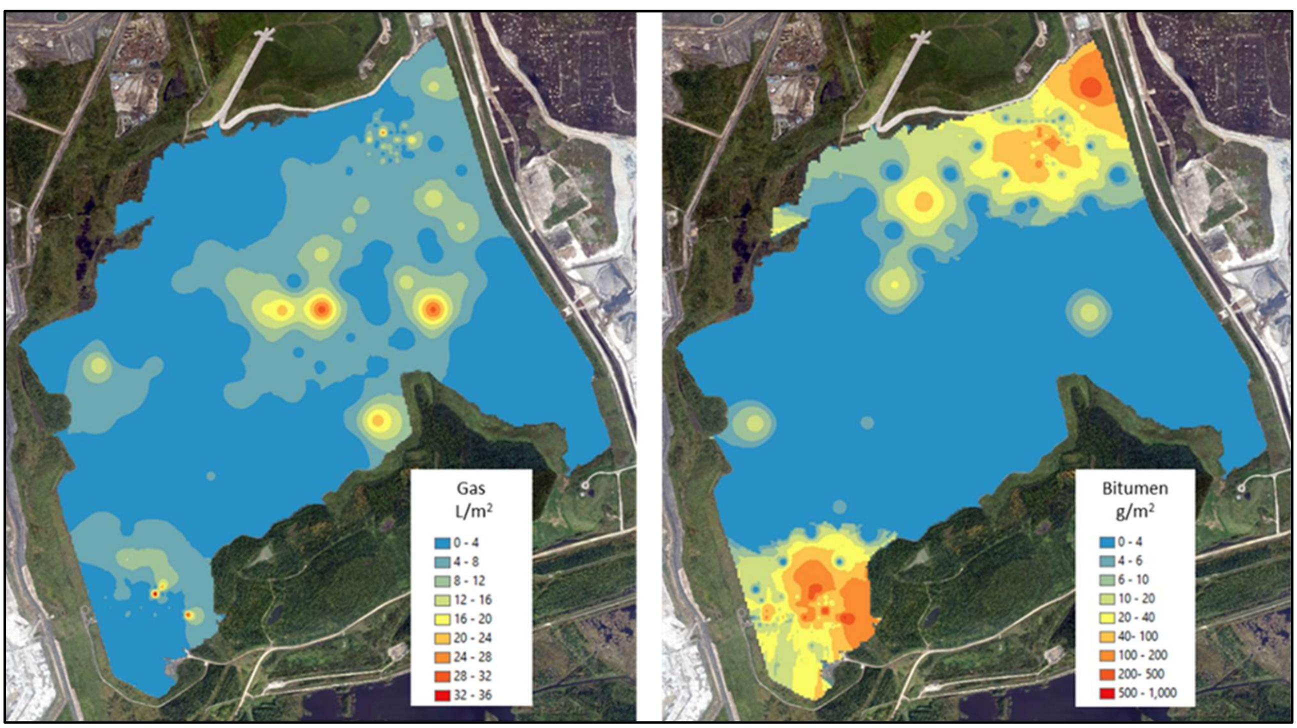


Figure 8-3. Contour maps of gas volume and bitumen mass per unit area contained in the ice cap generated from the 2021 ice core program field data

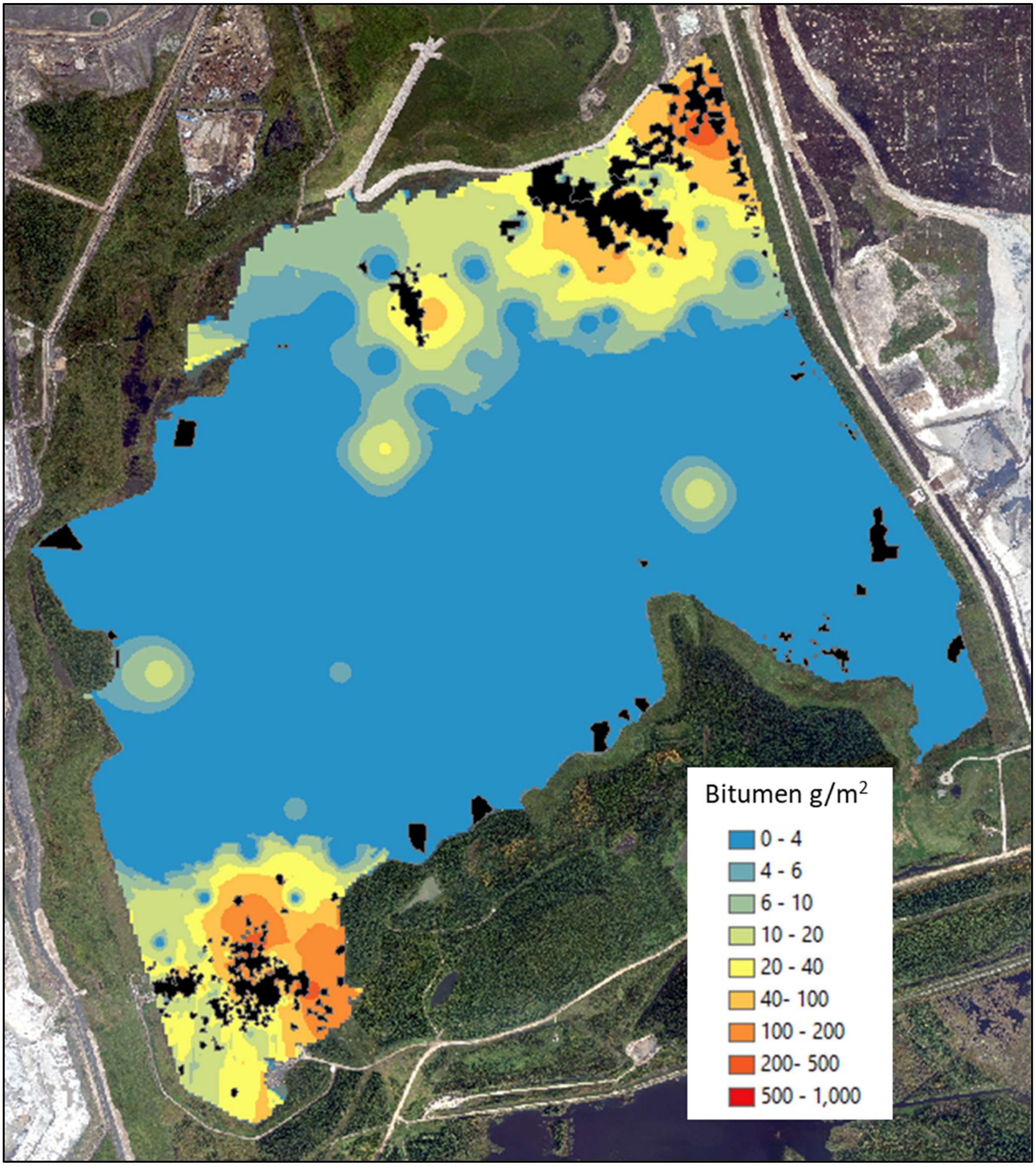


Figure 8-4: Contour plot of bitumen mass per unit area contained in the ice cap generated from the 2021 ice core program field data compared to bitumen mats determined from ponar grab sampling

Figure 8-5 **Error! Reference source not found.**(a, b) and Figure 8-6 (a, b) show surface plots of bitumen and gas volumes measured in ice cores in Base Mine Lake 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 FFT are not transporting significant hydrocarbon to the surface of Base Mine Lake. This validates the adaptative management approach to focus on bitumen mat mitigation for Base Mine Lake.

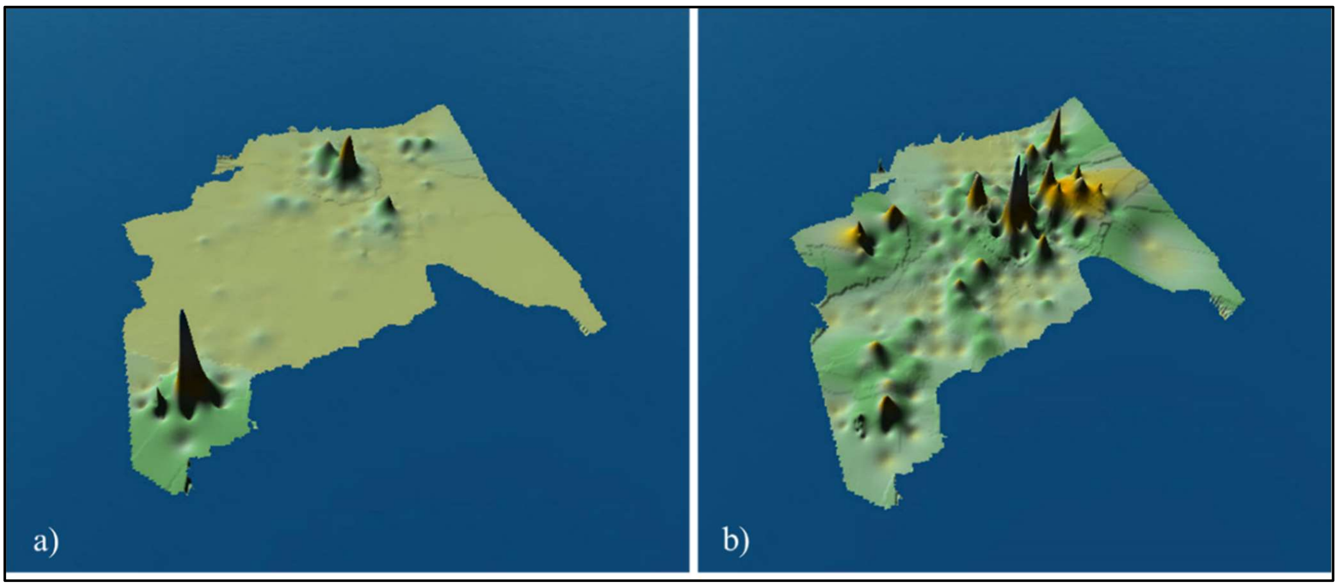


Figure 8-5: a) surface plot of the bitumen content from ice core analysis for 2020, b) surface plot of the gas content measured in ice cores in 2020

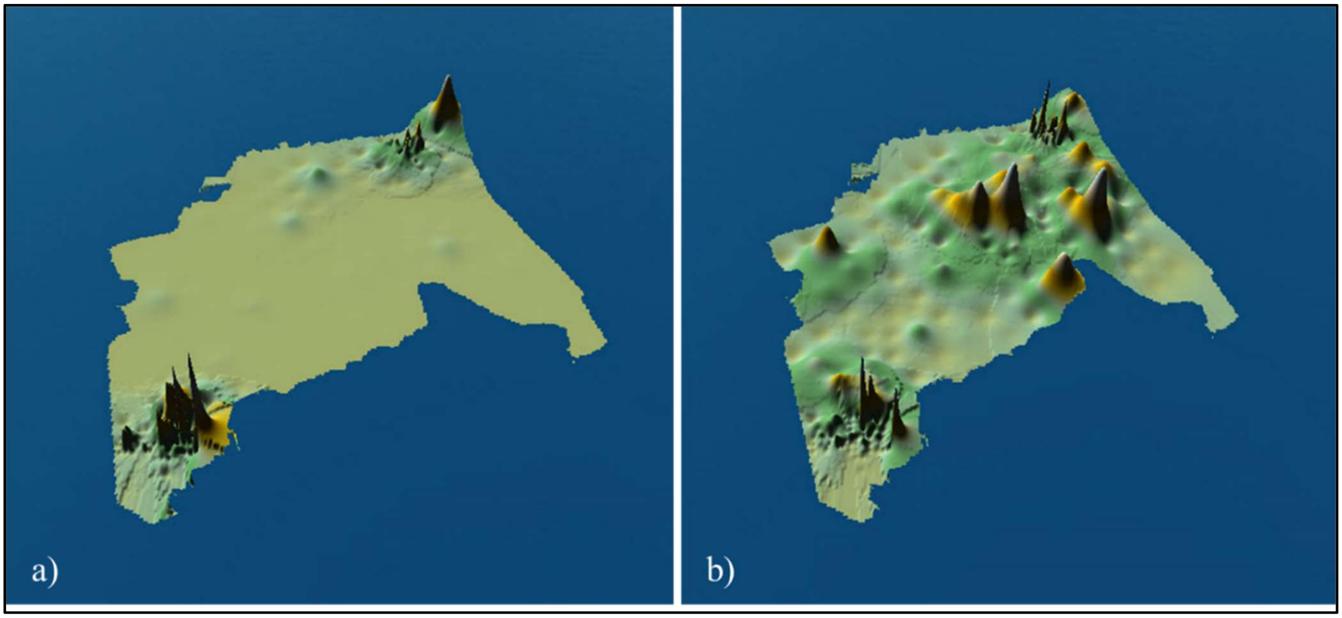


Figure 8-6: a) surface plot of the bitumen content measures in ice cores in 2021, b) surface plot of the gas content measured in ice cores collected in 2021.

8.9 List of Peer Reviewed Publications Produced by BML Research Programs

Research Project: University
Physical limnology of BML and the potential for meromixis: University of British Columbia
Publications: Hurley, D., Lawrence, G., and Tedford, E. (2020). Effects of Hydrocarbons on Wind Waves in a Mine Pit Lake. Mine Water and the Environment. 39. 10.1007/s10230-020-00686-7. Lawrence, G. A., Tedford E. W, and Pieters, R. 2016. Suspended solids in an end pit lake: potential mixing mechanisms. Can. J. Civ. Eng. 43:211-217 Olsthoorn, J., Tedford, E. W., & Lawrence, G. A. (2022). Salt-Fingering in Seasonally Ice-Covered Lakes. *Geophysical Research Letters*, *49*(17), e2022GL097935 Tedford, E. W., Halferdahl, G., Pieters, R., and G. A. Lawrence. 2018. Temporal variations in turbidity in an oil sands pit lake. Environmental Fluid Mechanics. https://doi.org/10.1007/s10652-018-9632-6 Zhao, K., Tedford, E., and Lawrence, G. (2022). Ebullition Regulated by Pressure Variations in a Boreal Pit Lake. Frontiers in Earth Science. 10. 0.3389/feart.2022.850652.

Zhao, K., Tedford, E.W., Zare, M., Frigaard, I.A., and Lawrence, Greg. (2021). Bubbles rising through a layer of Carbopol capped with water. Journal of Non-Newtonian Fluid Mechanics. 300. 104700. 10.1016/j.jnnfm.2021.104700.

Theses:

Chang, Sarah. 2020. Heat budget for an oil sands pit lake. M.Sc. Thesis, University of British Columbia. http://hdl.handle.net/2429/75704

Hurley, David Lee. 2017. Wind waves and Internal Waves in Base Mine Lake. M.Sc. Thesis, University of British Columbia. 91 pp. http://hdl.handle.net/2429/62524

Zhao, Kai. 2023. Ebullition from lake sediments. Ph.D. Thesis, University of British Columbia. 116 pp. https://dx.doi.org/10.14288/1.0424309

Characterization of controls on mass loading to an oil sands end pit lake: University of Saskatchewan

Publications:

Dompierre, K. A, and S. L. Barbour. 2016. Characterization of physical mass transport through oil sands fluid fine tailings in and end pit lake: a multi-tracer study. Journal of Contaminant Hydrology 189:12-26.

Dompierre, K. A., Lindsay, M. B. J., Cruz-Hernández, P., and Halferdahl, G. M. 2016. Initial geochemical characteristics of fluid fine tailings in an oil sands end pit lake. Sci Tot Env 556:196-206.

Dompierre, K., Barbour, S.L. (2017). "Thermal properties of oil sands fluid fine tailings: Laboratory and in-situ testing methods", Canadian Geotechnical Journal, 2017, 54(3): 428-440.

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Francis, D., Barbour, S.L., and Lindsay, M. (2021). Ebullition enhances chemical mass transport across the tailings-water interface of oil sands pit lakes. Journal of Contaminant Hydrology. 245. 103938. 10.1016/j.jconhyd.2021.103938.

Theses:

Dompierre, Kathryn. 2016. Controls on mass and thermal loading to an oil sands end pit lake from underlying fluid fine tailings. Ph.D. Thesis, University of Saskatchewan, Saskatoon, Canada, 157 pp.

Francis, Daniel, J. 2020. Examining controls on chemical mass transport across the tailings-water interface of an oil sands end pit lake. M. Sc. Thesis, University of Saskatchewan, Saskatoon, Canada, 177 pp. https://harvest.usask.ca/handle/10388/12776

Rudderham, S.B., 2019. Geomicrobiology and geochemistry of fluid fine tailings in an oil sands end pit lake. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Canada, 98 pp.

Microbial communities and methane oxidation processes in Base Mine Lake: University of Calgary

Publications:

Aguilar M, Richardson E, Tan B, Walker G, Dunfield PF, Bass D, Nesbø C, Foght J, Dacks JB (2016) Next-generation sequencing assessment of eukaryotic diversity in oil sands tailings ponds sediments and surface water. J. Eukaryotic Microbiol. 63:732-743.

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Rochman FF, Kim JJ, Rijpstra WIC, Sinninghe Damsté JS, Schumann P, Verbeke TJ, and Dunfield PF (2018) *Oleiharenicola alkalitolerans gen. nov., sp. nov*., a new member of the phylum *Verrucomicrobia* isolated from an oilsands tailings pond. International Journal of Systematic and Evolutionary Microbiology 68:1078-1084. doi: 10.1099/ijsem.0.002624

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Saidi-Mehrabad A, Kits DK, Kim JJ, Tamas I, Schumann P, Khadka R, Rijpstra WIC, Sinninghe Damsté JS, Dunfield. PF. (2018) *Methylicorpusculum oleiharenae* sp. nov., an aerobic methanotroph isolated from an oil sands tailings pond in Canada. International Journal of Systematic and Evolutionary Microbiology (in revision)

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Albakistani, Emad (2018) Methane Cycling and Methanotrophic Bacteria in Base Mine Lake, a Model End-Pit Lake in the Alberta Oilsands.

Haupt, Evan. (2016). Methanotrophic Bacteria and Biogeochemical Cycling in an Oil Sands End Pit Lake. MSc Thesis. University of Calgary. http://dx.doi.org/10.11575/PRISM/26893

Rawluk, Samuel (2017). The effect of chemical treatment on oil sand end-pit-lake microbial communities: an Investigation for a proxy of reclamation status. MSc in Sustainable Energy Development Capstone Project.

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

Publications:

Arriaga D, Nelson TC, Risacher FF, Morris PK, Goad C, Slater GF, Warren LA. 2019. The co-importance of physical mixing and biogeochemical consumption in controlling water cap oxygen levels in Base Mine Lake. *Appl Geochem* 111:104442.

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Risacher, F.F. 2017. MSc. Early-stage water cap oxygen consumption trends within the first commercial scale oil sands pit lake, Base Mine Lake. McMaster University. 77 pp. http://hdl.handle.net/11375/22274

Understanding Air-Water Exchanges and the long-term hydrological sustainability of Base Mine Lake: McMaster University, Carleton University

Publications:

Clark MG, Drewitt GB, Carey SK. 2021. Energy and carbon fluxes from an oil sands pit lake. *Sci Total Environ* 752:141966.

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)

Publications:

Poon, H. Y., Brandon, J.T., Yu, X., and A. Ulrich. 2018. Turbidity mitigation in an oil sands pit lake through pH reduction and fresh water addition. Journal of Environmental Engineering. 144(12): 04018127-1 – 04018127-7.

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