Syncrude

2021 Pit Lake Monitoring and Research Report (Base Mine Lake Demonstration Summary: 2012-2020)

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

Submitted to:

Alberta Energy Regulator

Submitted by:

Syncrude Canada Ltd.

June 30, 2021

LIMITATIONS

This report is provided by Syncrude Canada Ltd. to the Alberta Energy Regulator.

Findings and interpretations found in this report are superseded by any future Base Mine Lake report.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.

The material in this report reflects the judgment of Syncrude Canada Ltd. in light of the information available at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. Syncrude Canada Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document. The use of these materials by the end user is done without any affiliation with or endorsement by Syncrude Canada Ltd. Reliance upon the end user's use of these materials is at the sole risk of the end user.

Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding this report, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending Syncrude Canada Ltd.'s written approval. If this document is issued in an electronic format, an original copy is on file at Syncrude Canada Ltd. and that copy is the primary reference with precedence over any electronic copy of the document, or any extracts from our documents published by others.

Table of Contents

List of Figures

List of Tables

1 Executive Summary

Syncrude Canada Ltd. (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 2016 Life of Mine Closure Plan (LMCP) includes three planned pit lakes at the Mildred Lake site (including Base Mine Lake) and one 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 water-capped tailings, since it is imperative that both oil sands process-affected water (OSPW) as well as environmental (non-OSPW) water 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 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 primary fluid tailings management challenge is often considered to be the long period of time it can take for some of the smallest solid components (fines) to settle within the fluid portion of the tailings, commonly referred to as fluid fine tailings (FFT) or simply as fluid tailings. As a result, application of fluid tailings management or treatment technologies is typically necessary in order 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 water-capped tailings in pit lakes.

Syncrude first began investigating the Water-Capped Tailings Technology (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 treated or untreated fluid tailings in-pit, followed by capping with a sufficient layer of water; as a means of physically sequestering tailings solids within the pit lakes in the closure landscape and to enable low-energy water treatment processes within the engineered pit lake facility. The water layer becomes deeper as the tailings solids consolidate and release pore water. 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.

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 tailings recycle water system where it is utilized 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. The two key desired outcomes for Base Mine Lake that are important for the validation of WCTT are the physical sequestration of the tailings fines below the water cap and water quality improvements over time.

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 FFT is settling as expected by model predictions, the mudline is declining in elevation year over year, 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 has also been improving with time in Base Mine Lake, as expected to demonstrate the viability of the WCTT.

2 Introduction

2.1 Syncrude Project

The Syncrude Canada Ltd. (Syncrude) Joint Venture currently holds and operates 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. Overviews of the Mildred Lake and Aurora North sites are provided in Figures 2-1 and 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, and produced into value-added light, sweet crude, called Syncrude Sweet Premium (SSP).

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; and
- is planned in consultation with local, directly affected stakeholders.

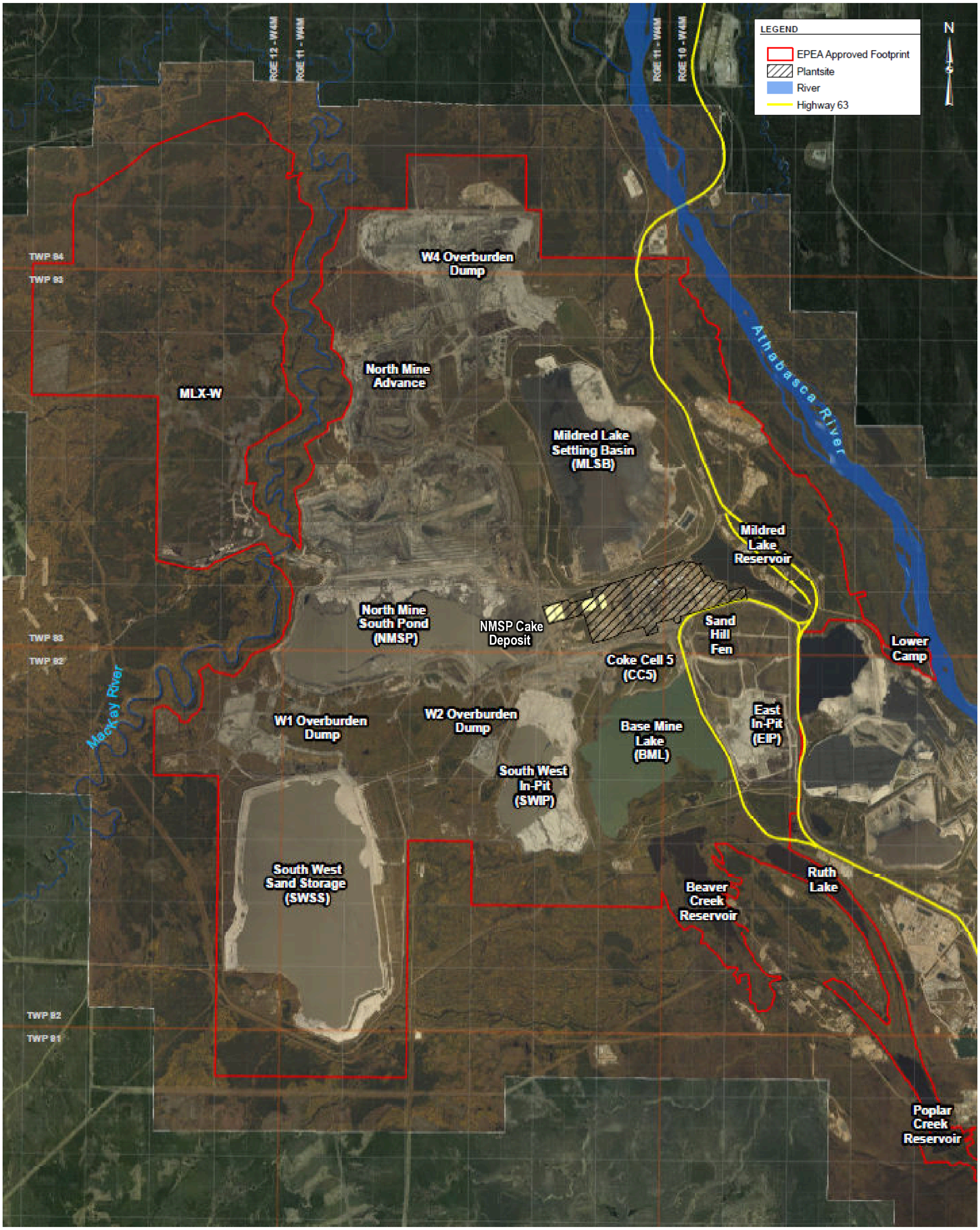


Figure 2-1: Mildred Lake Site Overview

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 Syncrude Pit Lake Monitoring and Research Report is submitted by Syncrude 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.[1]

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 water-capped tailings 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.

---

[1] As per AER File No. 4101-00000026-0202, on February 24, 2021, Syncrude received authorization from the AER to extend the submission date of the End Pit Lake Research and Development Report from February 28, 2021 to June 30, 2021.

It is Syncrude's interpretation that the annual report requirements listed under EPEA Approval condition 5.2.4 are primarily focused on pit lake designs and plans, rather than pit lake research. Many of these plans have been provided to the AER in previous EPEA and/or *Oil Sands Conservation Act* (OSCA) approval submissions or are subject to future submissions as required under Syncrude's most recent EPEA and OSCA approvals. In alignment with ongoing efforts to reduce regulatory red tape and 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;	Tailings Management Plan Life of Mine Closure 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;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(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,	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report

Condition 5.2.4 Requirement	Submission
(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;	
(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;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(f) confirmation of the assumptions and expectations for water quality release outlined in the application, including refinement, update, and validation of the predictive models;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure 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 Life of Mine Closure 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 Life of Mine Closure Plan

Condition 5.2.4 Requirement	Submission
	Pit Lake Monitoring and Research Annual Report
(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 Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(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 Pit Lake Monitoring and Research Annual Report COSIA Annual Reports
(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) optimise water residence time with particular consideration of salinity;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure 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 Pit Lake Monitoring and Research Annual Report
(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

Condition 5.2.4 Requirement	Submission
(s) identification of research or modelling limitations and uncertainties in achieving the targeted locally common boreal forest closure outcomes;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(t) plans and schedules to address research or modelling limitations and uncertainties in achieving the targeted locally common boreal forest closure outcomes;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(u) the applicability of Syncrude Canada Limited Base Mine Lake (BML) research to the other proposed water capped end pit lakes;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(v) how Syncrude will address uncertainties and risks where BML research is not applicable;	Base Mine Lake Monitoring and Research Plan Life of Mine Closure Plan Pit Lake Monitoring and Research Annual Report
(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;	5.1
(b) a summary of the results of research for the previous year;	5.2
(c) a description and presentation of trends across all timeframes;	5
(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 2020. 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 Reclamation and Closure Regulatory Framework

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 2016 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 will be submitting 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 2016 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. As required under condition 17 of Mildred Lake OSCA Approval No. 8573Q and condition 13 of Aurora North OSCA Approval No. 10781N, Syncrude will be submitting updated TMPs to the AER in 2023. 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.

3.2 Syncrude Fluid Tailings Management Technologies

The primary fluid tailings management challenge is often considered to be the long period of time it can take for some of the smallest solid components (fines) to settle within the fluid portion of the tailings, commonly referred to as fluid fine tailings (FFT) or simply as fluid tailings. As a result, application of fluid tailings management or treatment technologies is typically necessary in order to meet reclamation and mine closure objectives. 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 in use and under commercial development at Syncrude, including:

- Water-Capped Tailings (Base Mine Lake demonstration);
- Composite Tailings;
- Centrifuge Cake;
- Overburden/FFT Co-mixing; and
- Flocculated Tailings.

In addition, Syncrude is also assessing further opportunities for co-deposition of different tailings materials. Tailings co-deposition is a depositional strategy which involves the intentional placement 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 treated product(s) has the potential to improve deposit performance through enhanced dewatering and consolidation by combining tailings materials with complementary properties.

Figure 3-1 provides an overview of Syncrude's current and proposed fluid tailings management technologies, including WCTT.

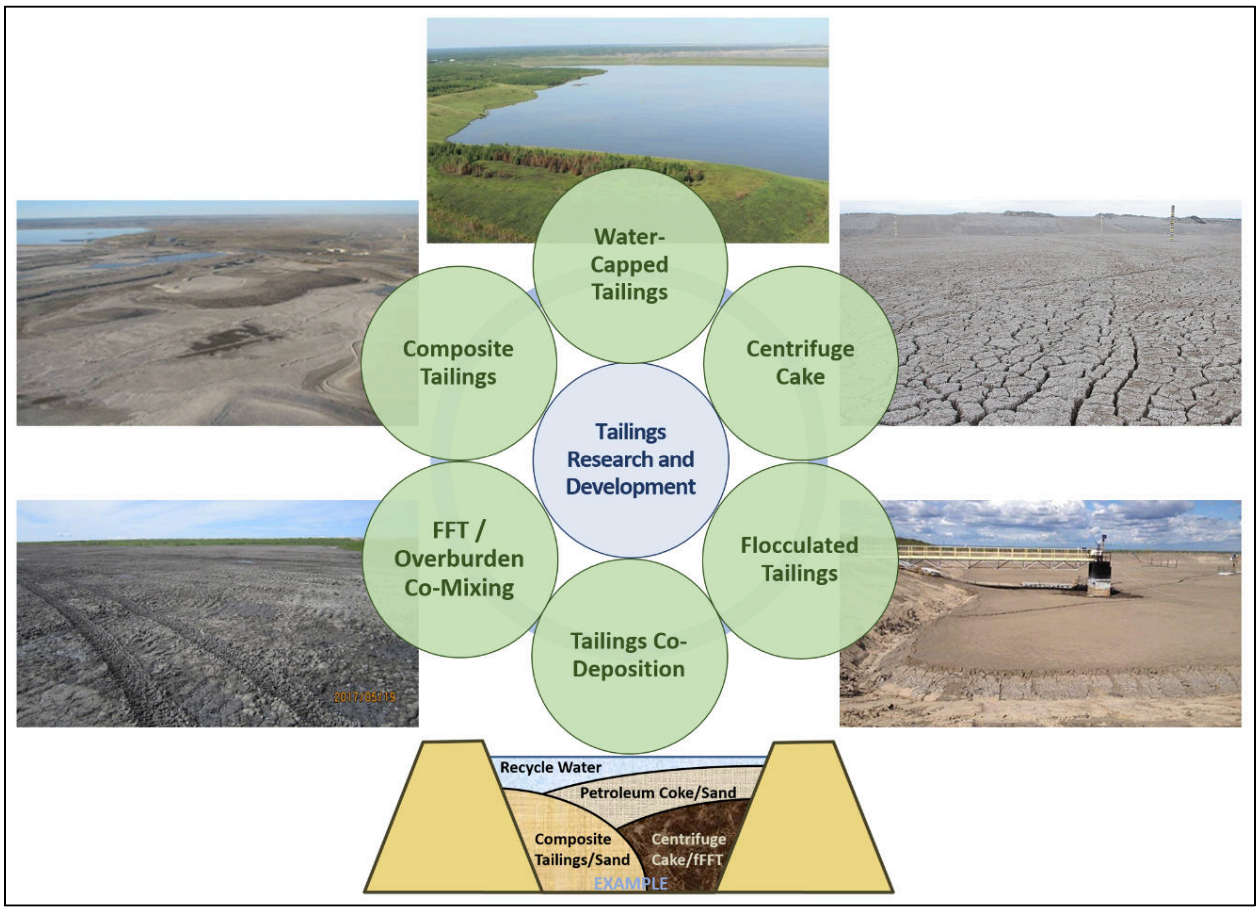


Figure 3-1: Overview of Syncrude Fluid Tailings Treatment Technologies

3.3 Water-Capped Tailings Technology Development

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. An oil sands pit lake is an area where overburden and oil sand has been removed through surface mining and is then filled with fluids prior to mine closure. Pit lakes contain water (from the process of oil sands extraction or from the environment, or both) and may or may not contain treated or untreated fluid tailings (e.g., FFT, centrifuge cake, flocculated tailings), and/or other solids (e.g., coarse tailings sand, mine overburden).

Water-Capped Tailings Technology (WCTT) involves the placement of a water layer of sufficient depth over treated or untreated fluid tailings as a means of physically sequestering the tailings solids within the pit lakes in the closure landscape and to enable low-energy water treatment processes within the engineered pit lake facility. 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 FFT settlement and increasing water cap depth over time is provided in Figure 3-2. Figure 3-3 provides a schematic of the WCTT concept.

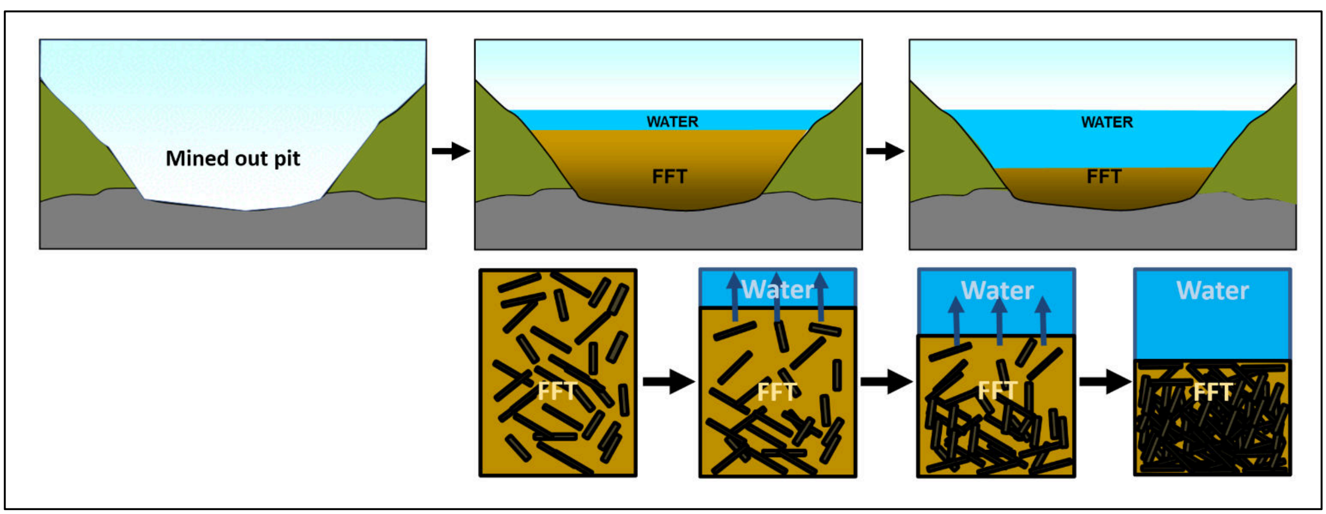


Figure 3-2: Simplified Depiction of Water-Capped Tailings Settlement over Time (not to scale)

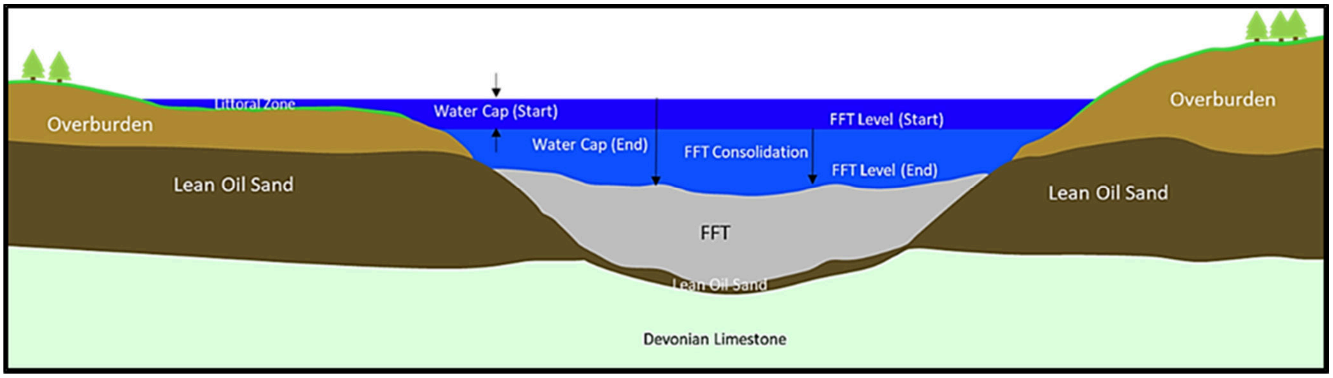


Figure 3-3: Water-Capped Tailings Technology Schematic (not to scale)

Syncrude first began investigating the 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 2,000 m^3 to 140,000 m^3 total volume. Some ponds were filled with roughly 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 were able 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 and chronic toxicity declined over time. These small ponds did not reflect normal boreal lake mixing dynamics that are important drivers of lake performance at full scale; and
- For the Base Mine Lake configuration, including the lake size and orientation, the water cap must be at least five metres deep to prevent fines from the lake bottom from being re-suspended by wind-generated waves (Lawrence, 1991).

The learnings from the decades of laboratory and field pilot research, monitoring and modelling were used to develop the Base Mine Lake demonstration at Syncrude's Mildred Lake plant site, which was commissioned on December 31, 2012.

Figure 3-4 provides an overview of the WCTT research and development progression at Syncrude.

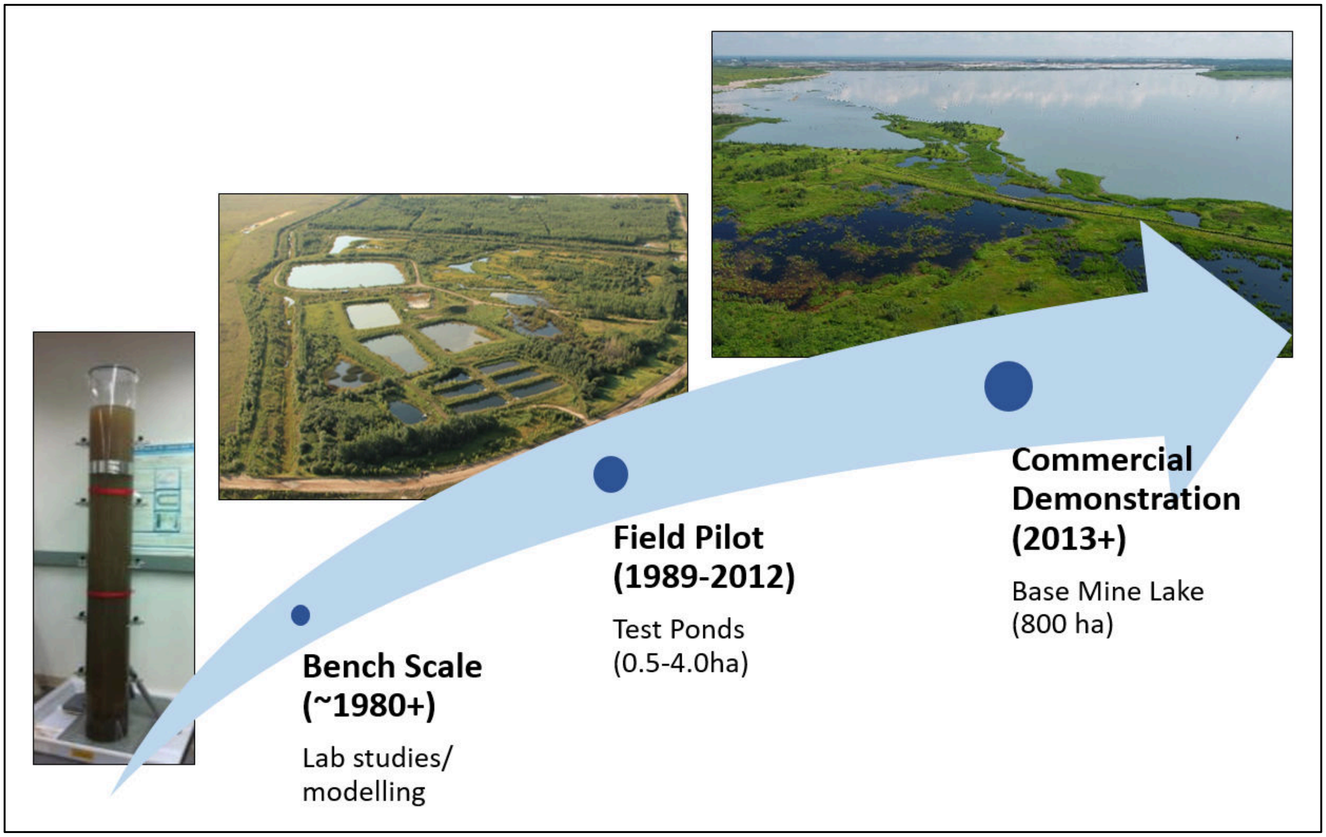


Figure 3-4: Progression of Water-Capped Tailings Research and Development

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 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 water-capped tailings technology 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, being 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.

Figure 3-5 provides an overview of the conceptual progression of a tailings facility that transitions into a pit lake and eventually receives reclamation certification. The specific components and lengths of each phase will be unique for every pit lake. Figure 3-6 illustrates 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 2016 LMCP.

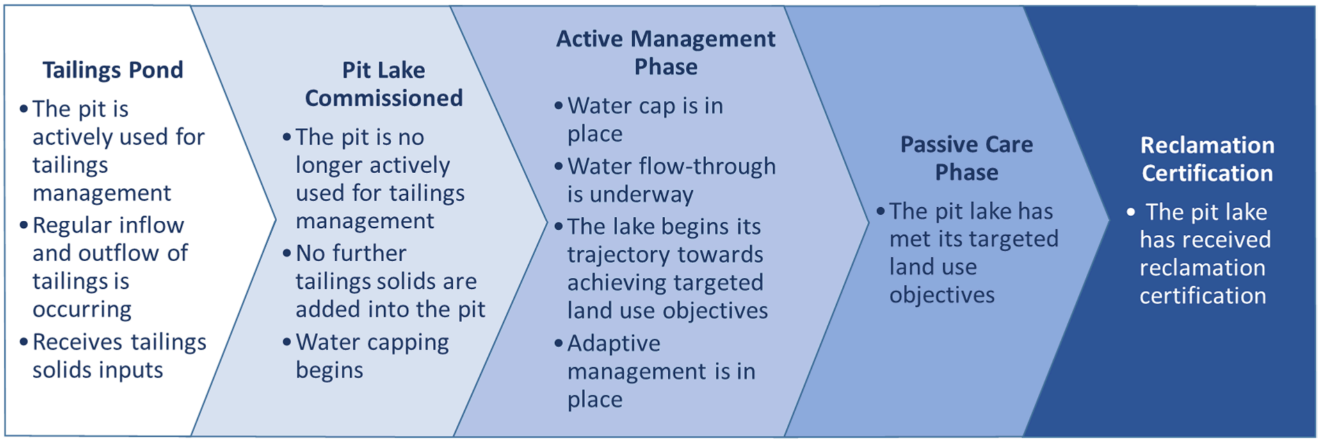


Figure 3-5: Conceptual Tailings Pond Progression into a Pit Lake

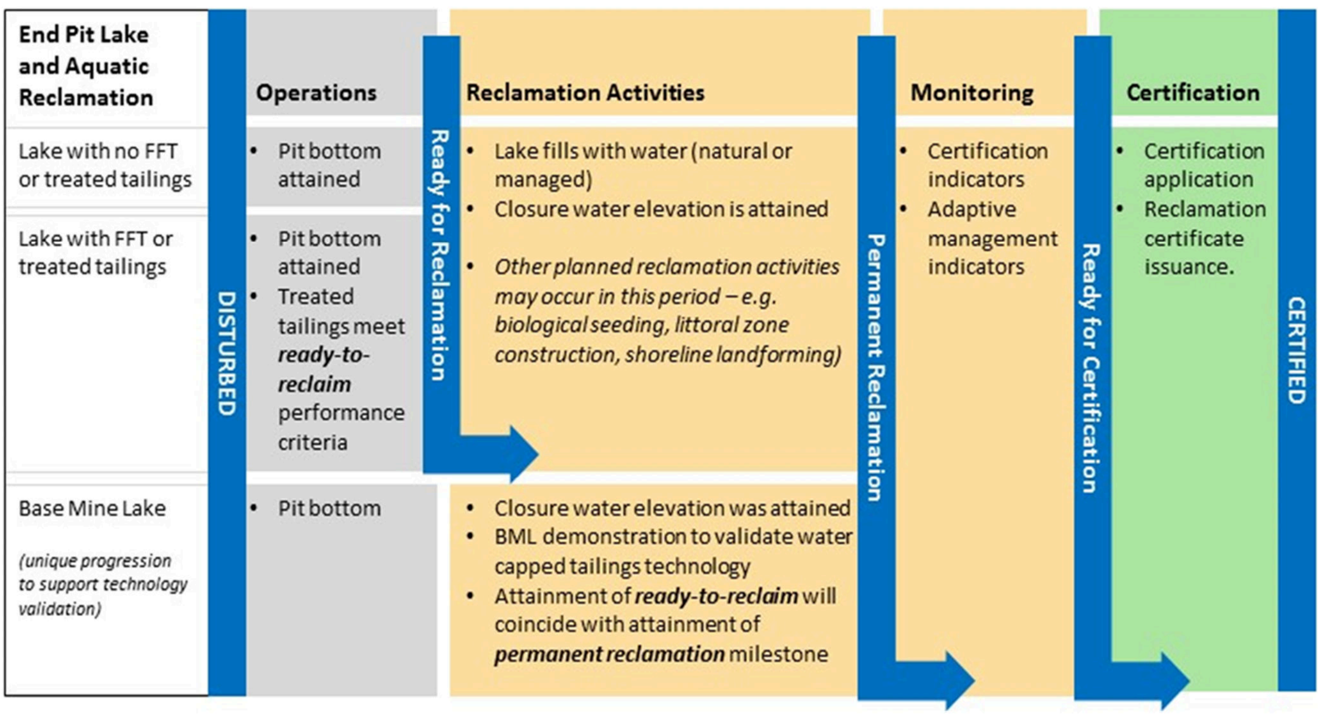


Figure 3-6: Conceptual Diagram of Progressive Certification Stages and Milestones for Pit Lake and Aquatic Reclamation (Syncrude 2016)

3.6 Syncrude's Planned Pit Lakes

Syncrude's 2016 LMCP includes three pit lakes at the Mildred Lake site and one at the Aurora North site:

- Base Mine Lake,
- North Mine Lake,
- MLX-West Pit Lake, and
- Aurora North Pit 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 oil sands process-affected water (OSPW) as well as environmental (non-OSPW) water 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, as per the 2016 LMCP.

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.	• MLX-West Pit Lake

Landform design and water modelling are key components of Syncrude's mine closure planning process. Information on the current closure design and its considerations is available in the 2016 LMCP. Syncrude has initiated work on updating the LMCP for submission to the AER on January 31, 2023, which will include updates to the surrounding landscape. To ensure the sustainability of its future pit lakes, Syncrude is developing an updated hydrologic model that will incorporate the changes to the surrounding closure landscape that are being developed for the 2023 LMCP. HydroGeoSphere will be used to provide the necessary detail for the simulations and predictions for the performance of the closure landscape under a wide range of late-21st-century climate scenarios. HydroGeoSphere was chosen as it is a fully integrated surface and groundwater model that will provide the necessary detail for the simulations and predictions of the performance. The purpose of the hydrologic model is to provide Syncrude with a planning tool for analyzing closure watershed design scenarios; based on inputs and variables known today, together with information from the latest mine, tailings and reclamation plans. The model will be a dynamic tool that will be updated as new information is acquired and/or conceptual closure changes are made.

Figure 3-7 and Figure 3-8 show the locations of each of the pit lakes and the planned drainage paths at closure for the Mildred Lake and Aurora North sites, respectively, as provided in the 2016 LMCP.

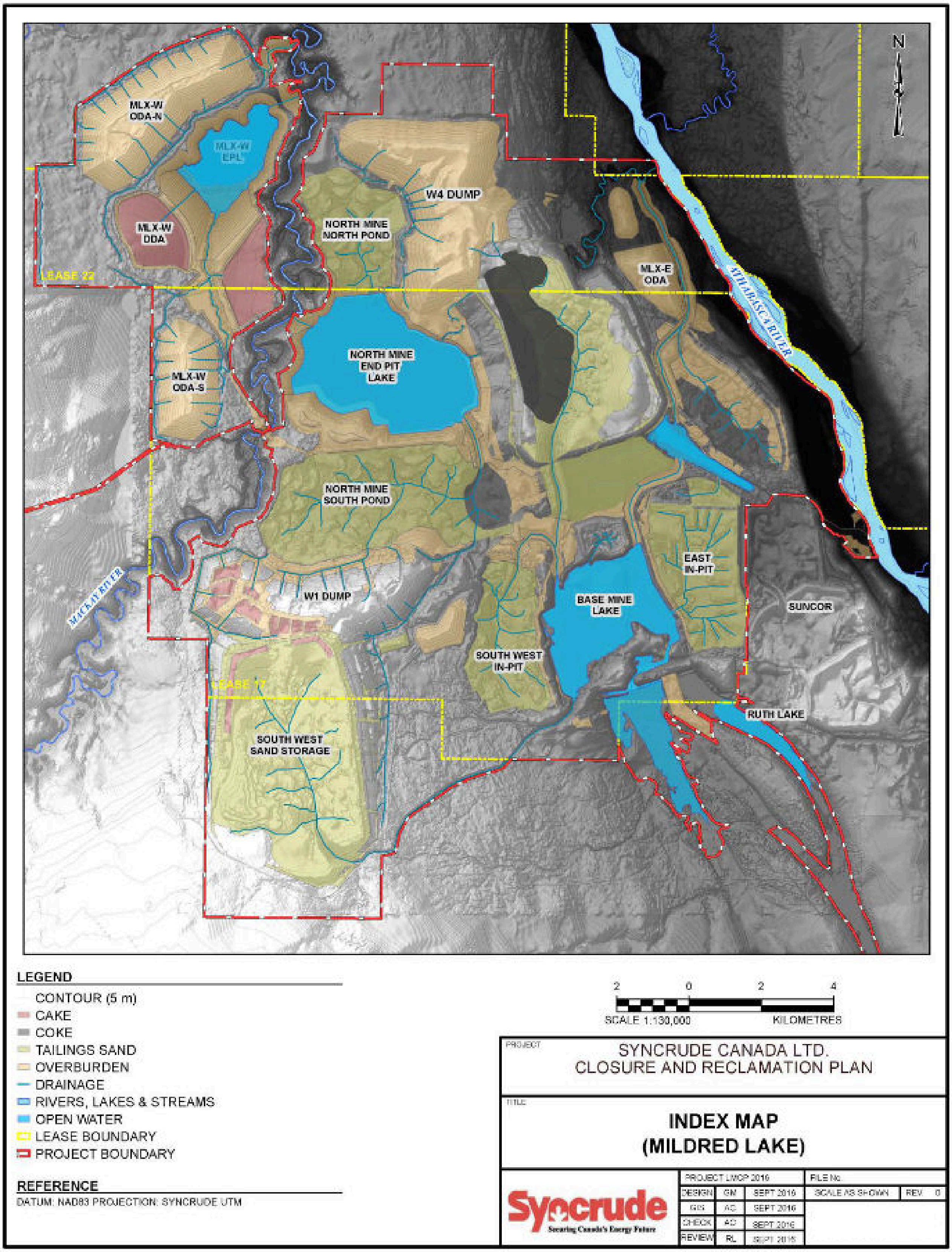


Figure 3-7: Mildred Lake Site Closure Overview (Syncrude 2016)

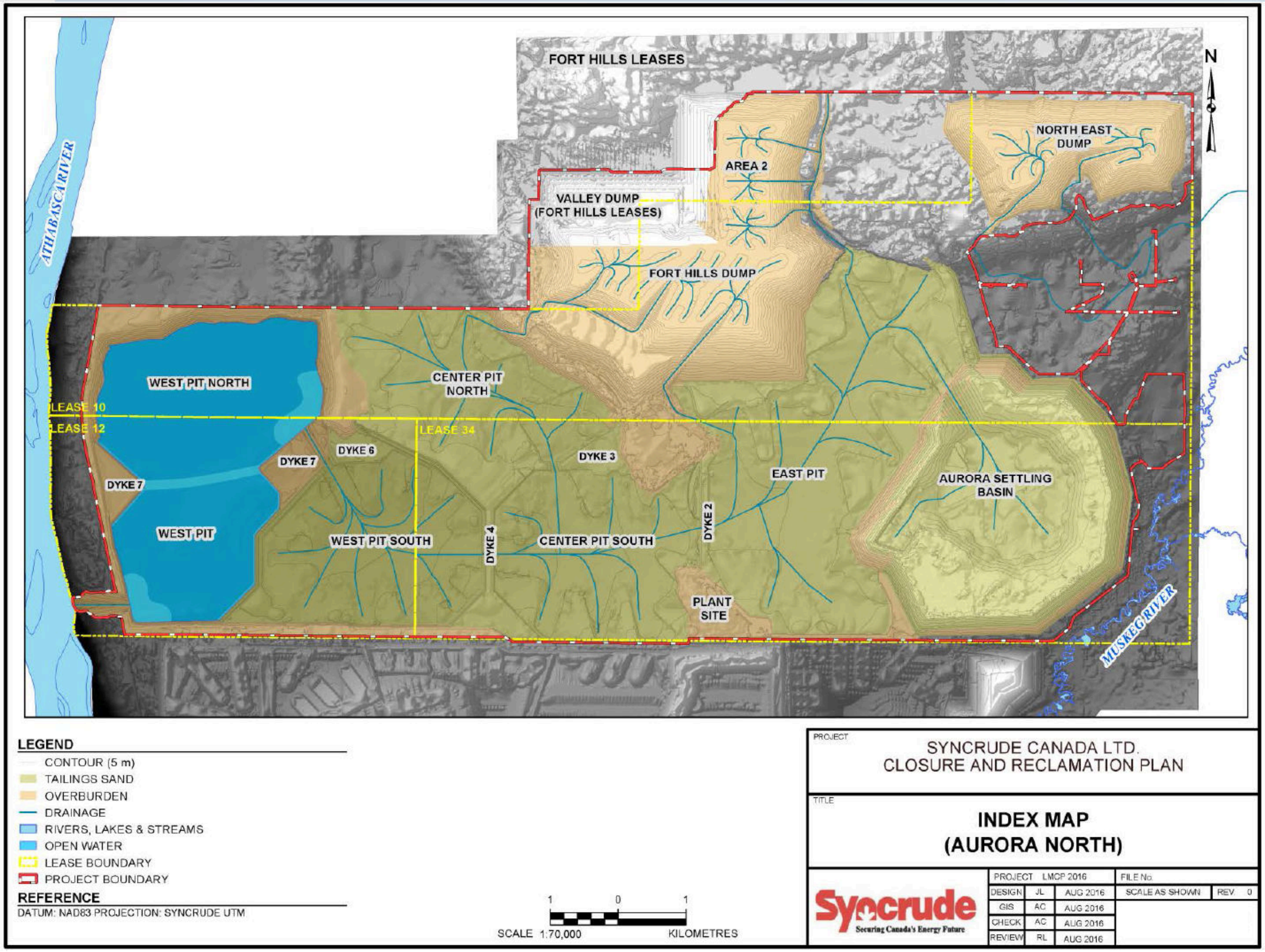


Figure 3-8: Aurora North Site Closure Overview (Syncrude 2016)

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 Lake Miwasin Demonstration 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 Lake Miwasin Demonstration

Suncor Energy Inc. (Suncor)'s Lake Miwasin is a field 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 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 downstream wetlands. Construction and reclamation was completed in 2018 and an extensive research and monitoring program is underway to support the demonstration. Details 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).[2]

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 by modelling aquatic ecosystems in a carefully controlled research environment. 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. The first set of experiments tested the densified tailings performance to support development of Suncor's PASS technology. Details can be found in the research and development reports shared by COSIA.[3]

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 with fluid fine tailings (silt, clay, process-affected water and residual bitumen) that

[2] Suncor Energy Inc. [Suncor] 2021. Pit Lake Research and Development Report. Submitted to the AER on April 28, 2021. 38 pp.

[3] 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

sits below a cap of oil sands process-affected water and fresh water. The two key desired outcomes for Base Mine Lake that are important for the validation of WCTT are the physical sequestration of the tailings fines below the water cap and water quality improvements over time. 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 3-9.

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 tailings recycle water system where it is utilized 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 FFT 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 summary report submissions and annual update meetings. The last summary report (2019 Base Mine Lake Monitoring and Research Summary Report: Results from 2013-2018) was submitted to the AER on June 27, 2019, in accordance with former EPEA Approval 26-02 (as amended).

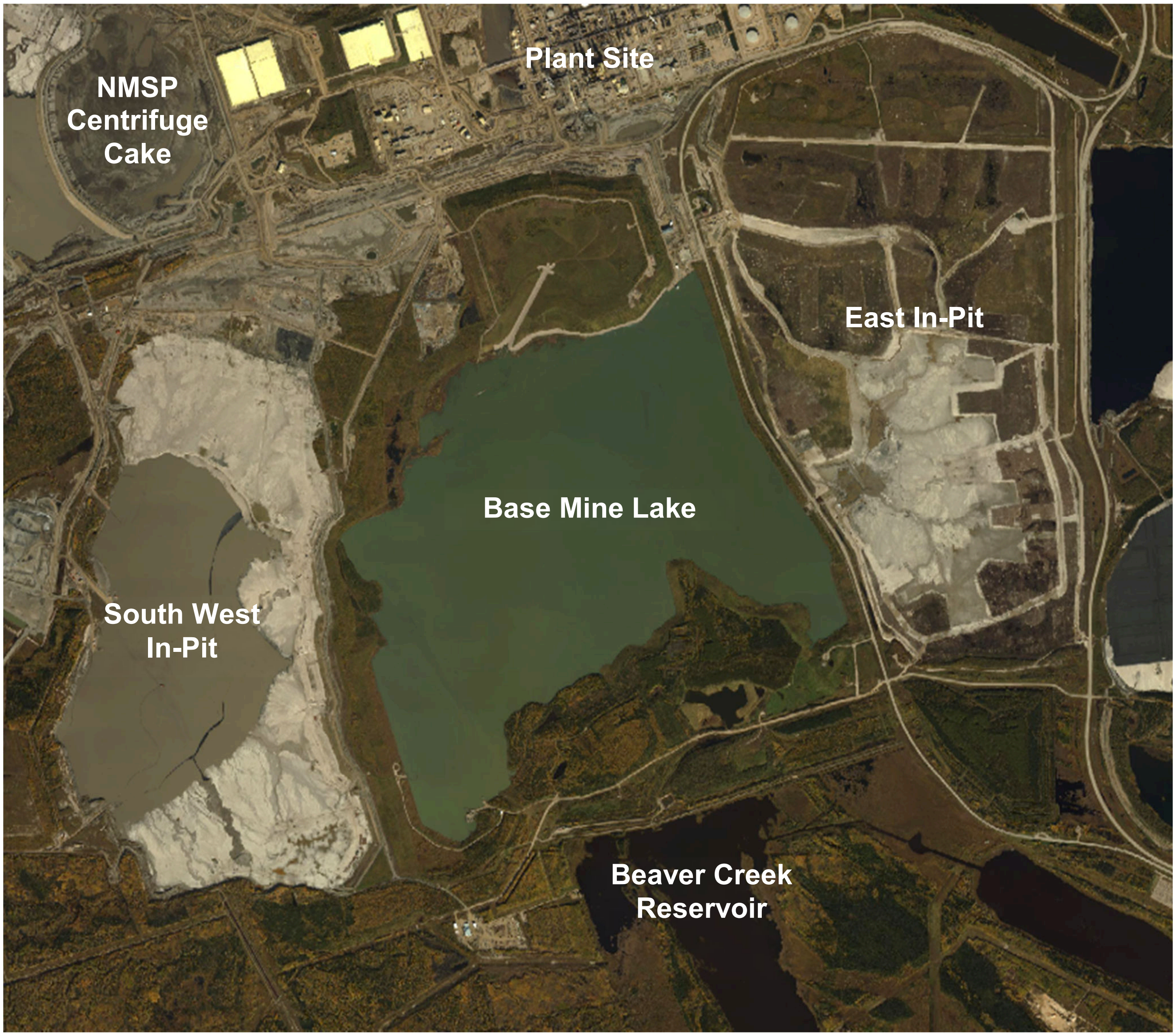


Figure 3-9: Aerial Overview of Base Mine Lake

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 making adjustments in response to new information.

Monitoring of pit lakes throughout their progression from active deposition to final 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 future plans are optimized appropriately. Based upon the analysis of monitoring results, adaptive management strategies may be identified to improve performance. These type of activities not only address current issues, but can also advance research and inform future 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.

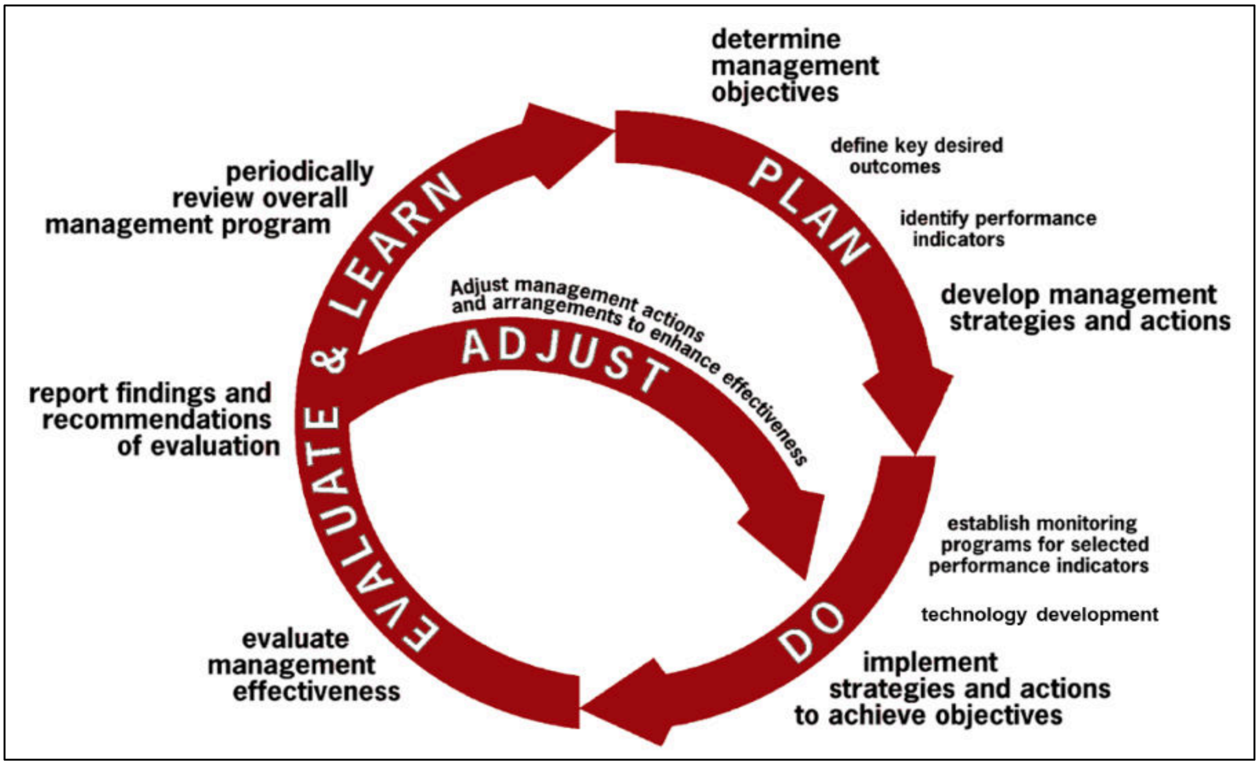


Figure 4-1: The Adaptive Management Cycle (after Jones 2005)

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; and
- 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

In order 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 to Validate Water-Capped Tailings Technology

Validation of Water-Capped Tailings Technology requires demonstration that the fines are physically sequestered beneath the water cap and that the lake water quality is improving with time. As such, Syncrude has identified the following Base Mine Lake performance indicators for validation of the WCTT[4]:

- 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);

[4] The performance indicators identified for the Base Mine Lake demonstration will be considered in the assessment of applicable Ready to Reclaim (RTR) criteria for Water-Capped Tailings Technology, required to be submitted to the AER by January 31, 2023, in accordance with condition 23 of Mildred Lake *Oil Sands Conservation Act* Approval No. 8573Q.

- 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 the validation of WCTT as a viable tailings management and reclamation option. In the early stages, the Base Mine Lake monitoring program is demonstrating that the fluid fine tailing 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
FFT Settlement	Water Balance Assessment	Aquatic Biology Assessment
FFT Geochemistry Assessment	Surface Water Quality Assessment	Surface Water Toxicity
Physical Limnology Assessment	Groundwater Assessment	Sediment Toxicity
Meteorological Monitoring	Chemical Mass Balance	
FFT Physical Assessment		

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 ultimate 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 FFT 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 5.3.

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
Characterization of controls on mass loading to an oil sands pit lake	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	University of Saskatchewan	Lee Barbour / Matt Lindsay
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 FFT-water interface to the Base Mine Lake water surface	University of Toronto / McMaster University	Lesley Warren / Greg Slater

Research Component	Primary Objective	University	Researchers (PIs)
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 FFT 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	Barry Bara

4.3.3 Adaptive Management: Adjust

The adaptive management framework allows for adjustment 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 where the tailings was discharged. As detected by the Base Mine Lake monitoring program, some residual bitumen is also present as an oily sheen on the water surface, some of which has accumulated along the shoreline.

During the winter of 2017/2018, efforts were undertaken to trial the removal of residual bitumen from the shoreline. An extensive sampling program indicated that the bitumen was sitting on the surface of the shoreline soils and was not imbedded throughout the soil. In January 2018, 300 metres of shoreline was the focus of bitumen removal activities. Equipment was used to strip the hydrocarbon from the surface of the soil without damaging the reclamation soils below. Both the timing of the removal (frozen conditions) and selection of smaller equipment minimized the effects on surrounding reclaimed shoreline and slopes.

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 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 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 clam-shell environmental dredge (targeted for deployment in 2021). Bitumen dredging activities were paused during the 2020 open water season due to COVID-19 restrictions; however, significant efforts have been 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. A summary of this research program can be found in section 5.2.7.

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.

5 Summary of Key Performance Results from the Base Mine Lake Monitoring and Research Program

The two key desired outcomes for Base Mine Lake that are important for the validation of the Water-Capped Tailings Technology (WCTT) are the physical sequestration of the fine tailings solids below the water cap and water quality improvements over time. Demonstrating the physical isolation of fines beneath the water cap of Base Mine Lake is considered a key performance outcome related to the validation of the WCTT. Results so far indicate that the FFT is settling as expected by model predictions, the mudline is declining in elevation year over year, 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 has been improving with time in Base Mine Lake, as expected to demonstrate the viability of the WCTT. The lake water is not acutely toxic and except for F2 hydrocarbons, all measured parameters are below the Alberta Surface Water Quality Short-term Guidelines for the Protection of Aquatic Life (GoA 2018).

Due to the COVID-19 pandemic and resulting health and safety protocols, including workforce restrictions, travel restrictions, and university laboratory and office restrictions, several components of the Base Mine Lake monitoring and research programs were reduced in scope or placed on hold during 2020. In general, the intent of the Base Mine Lake monitoring program approved in 2013 was met as planned in 2020. In cases where monitoring or research activities were not executed in 2020, the 2019 results are summarized in the following sections.

5.1 Key Results from the Base Mine Lake Monitoring Program

The following is a summary of key findings from a variety of components of the Base Mine Lake monitoring program, including FFT settlement, ground and surface water quality, water balance, physical limnological processes, and aquatic biology and toxicity.

5.1.1 FFT Settlement (2019)

A full-lake surface sonar survey of Base Mine Lake is typically conducted annually in October. Due to reliance on a third party contractor, Syncrude was unable to complete a sonar survey in 2020; therefore, the results summarized are from 2019. These annual assessments of the FFT surface are used to track FFT dewatering, and are also used to determine water cap depth and volume to estimate water balance.

Since the inauguration of Base Mine Lake, FFT settlement has been monitored. From 2012 through 2015, the top of FFT was determined by single-beam sonar, with mudline elevation determined via the reflection of a series of single acoustic pulses off the FFT surface as the sonar boat moved across the lake. From 2012 to 2015, the procedures and transect spacing of the sonar boat were improved and refined, thereby improving the quality of the single-beam sonar data. Regardless, the single-beam data collection required interpolation of data between the individual boat tracks. The biggest change in sonar technology occurred in 2016 when the single-beam sonar was replaced with multi-beam (or swath bathymetry) sonar equipment. The multi-beam sonar provides a spatially continuous 3D bathymetric measurement of the Base Mine Lake top-of-FFT surface. This results in a continuous point cloud of bathymetric data, higher spatial resolution of the FFT surface, and minimizes errors associated with interpolation between transects.

Table 5-1: FFT Settlement Assessment Key Findings (2019)

Summary of the FFT Settlement Assessment Key Findings
• *Converting from single beam sonar to multi beam swath bathymetry has resulted in a more accurate assessment and determination of the top of FFT surface.*
• *The top of FFT surface elevation is not flat. There is considerable variability in the surface across the lake that generally corresponds to the original pit topography. Bathymetric variation is increased from early years of monitoring. This feature is consistent with differential settlement as a result of variability in the initial FFT thickness across the lake.*
• *The largest FFT settlement has occurred in the northeastern portion of Base Mine Lake.*
• *FFT is settling as predicted by numerical modelling, up to 6.7 m between October 2012 and September 2019.*
• *The volume of FFT determined through sonar mudline assessment in Base Mine Lake decreased from 172.91 Mm^3 in October 2018 to 172.55 Mm^3 in September 2019 due to settlement.*
• *The FFT surface changes observed in the 2019 FFT program are consistent with trends observed in the historic Base Mine Lake programs since 2012.*
• *The top-of-FFT surface continues to settle annually and the overall water depth in Base Mine Lake increases at a corresponding rate, taking into account lake surface elevation changes.*

As depicted in Figure 5-1, the FFT surface is variable (not flat) across Base Mine Lake. The FFT surface in September 2019 generally varied by over 6 m, from elevation 295.2 m in the northeast portion of Base Mine Lake to approximately 301.6 m off the south shore. Based upon the sonar survey isopachs shown on Figure 5-2, the FFT elevation decreased between 0 m and approximately 6.7 m between October 2012 and September 2019. Minimal elevation decrease is seen around the perimeter (shoreline) of Base Mine Lake, where the underlying FFT thickness is generally lower and the pit surface is generally higher. The greatest decrease in the FFT surface elevation occurred in the northeastern section of Base Mine Lake. Overall FFT settlement between 2012 and 2019 is also not constant but varies across the lake, which is attributed to self-weight consolidation driving differential settlement of the variable initial thicknesses of FFT across the bottom of the lake. Consolidation/dewatering of FFT is expected to occur more rapidly in early years following infilling, and generally slows with time. A summary of the numerical model predictions, and updates to the model based on the initial Base Mine Lake conditions was shared in 2019 (Syncrude 2019). A cross-section through the lake showing October 2012 mudline and 2019 mudline with the pit hard bottom is shown in Figure 5-3.

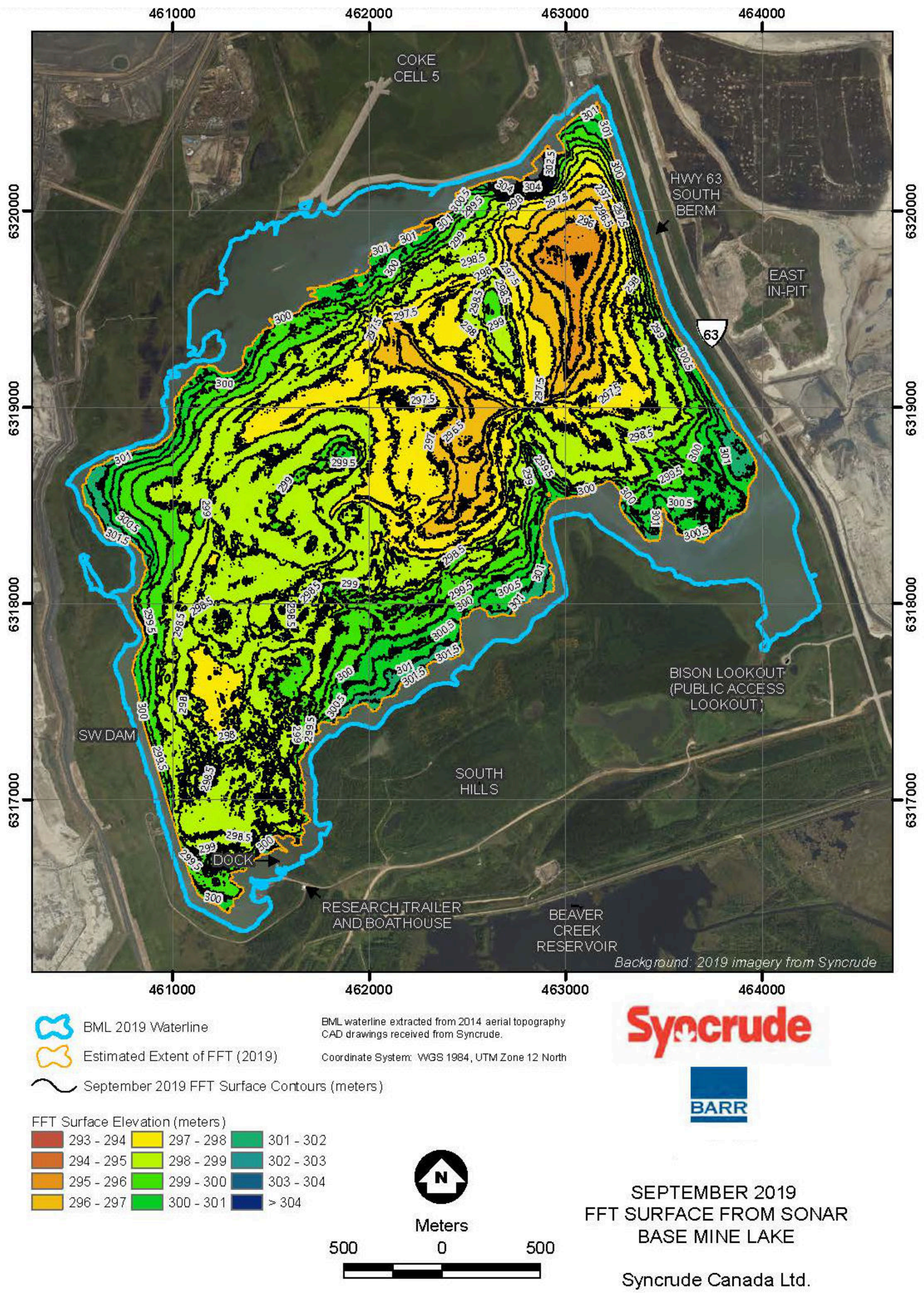


Figure 5-1: Base Mine Lake FFT Surface from Sonar (September 2019)

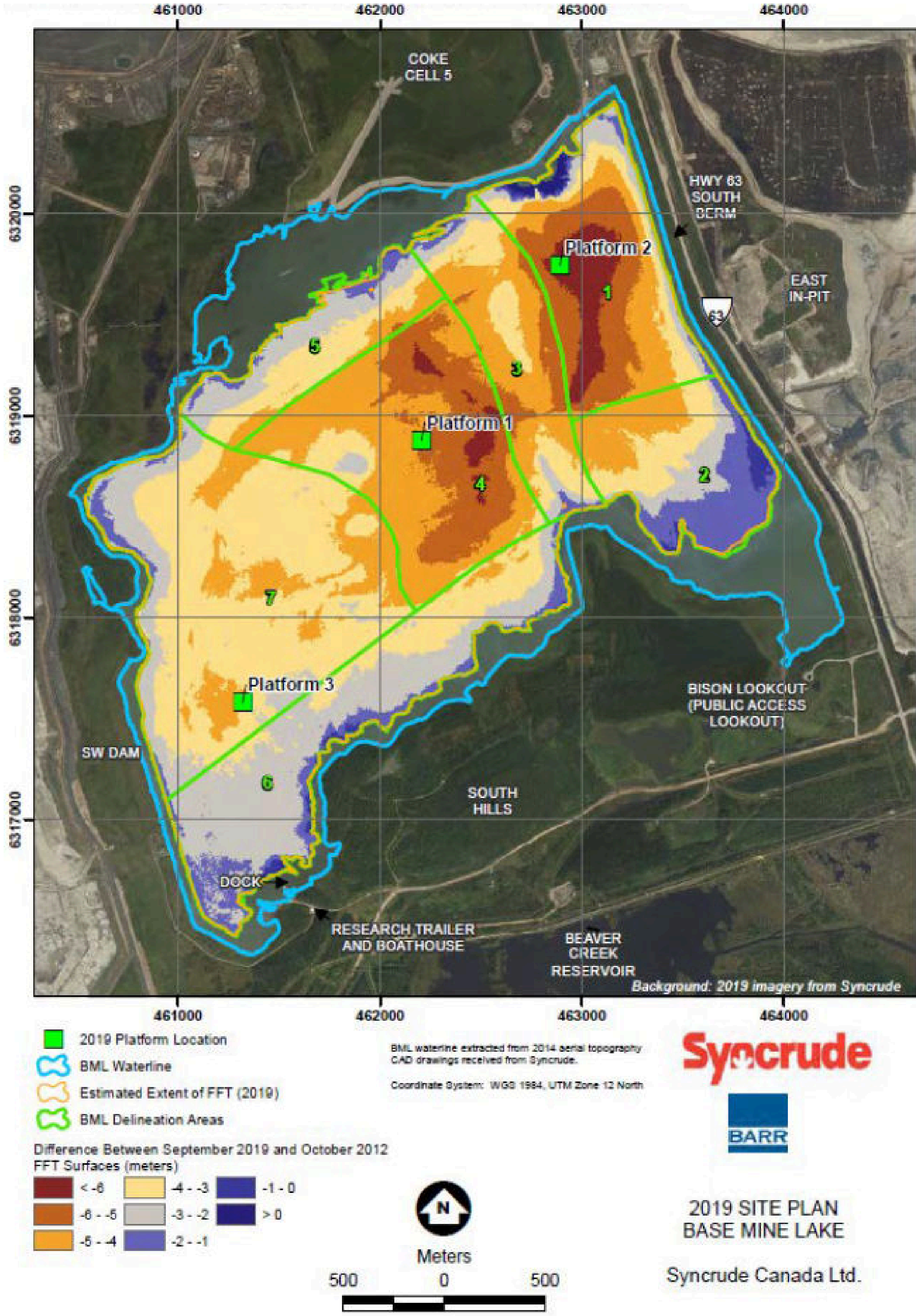


Figure 5-2: Base Mine Lake FFT Surface Change (October 2012 to September 2019)

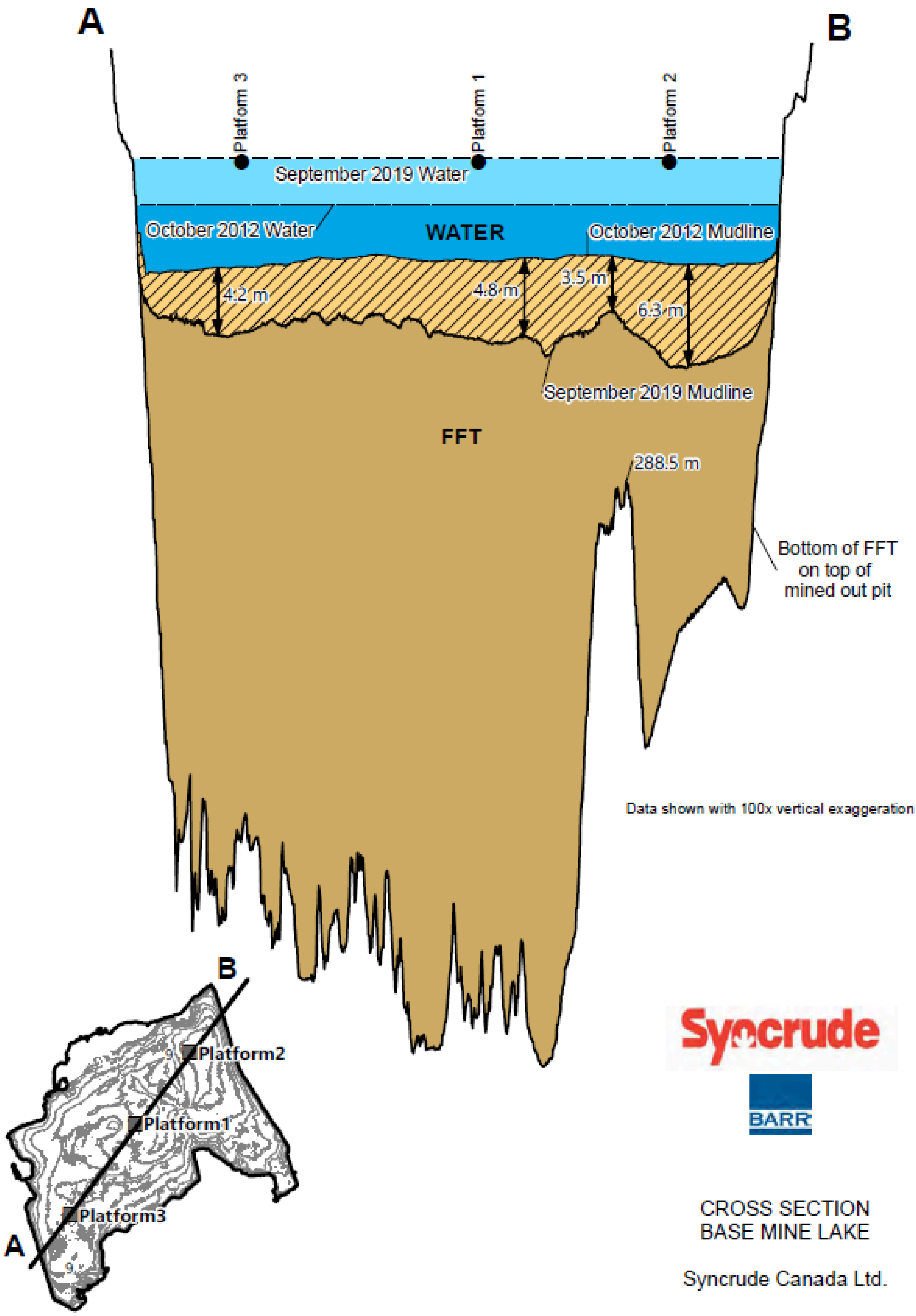


Figure 5-3: Cross-section of Base Mine Lake Showing Mudline Changes (2012-2019)

5.1.2 Groundwater

For 2020, the groundwater component of the Base Mine Lake program included complete annual monitoring and sampling activities (as described below) in July at groundwater wells located within 11 well nests around Base Mine Lake; and, a second event in September during which groundwater level data was collected only (i.e., no sampling was done during the second event). There are 27 monitoring wells in the network which are classified as shallow, intermediate or deep based on the elevation and hydrostratigraphic formation intercepted by the screened intervals. Shallow wells are generally laterally adjacent to (and may interact with) the Base Mine Lake water cap, whereas intermediate wells are generally adjacent to FFT, and deep wells extend below the bottom of the infilled pit. Seven of the wells typically cannot be sampled due to gas concerns, obstructions, bitumen presence, or damage. Continuous groundwater elevations are being recorded at seven deep well locations with dataloggers.

The July 2020 groundwater monitoring event consisted of verifying the status of 27 Base Mine Lake monitoring wells that have been historically included as part of the Base Mine Lake monitoring program, as well as conducting groundwater level measurements and collecting groundwater samples from active wells. Groundwater wells are classified as active for a monitoring event if sufficient water is available to sample and the headspace testing results are within the safe range. There were 19 wells classified as active and sampled in July. The number of active wells did not change during the September 2020 groundwater level data collection, at which time well status was also checked.

Monitoring and sampling activities at the active wells included:

- Observation of well condition and status;
- Measurement of 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 physico-chemical variables, nutrients, dissolved metals, organics and hydrocarbons.

Specific details of the 2020 program and results can be found in Appendix 1.

Table 5-2: Base Mine Lake Groundwater Assessment Key Findings

Summary of the Base Mine Lake Groundwater Assessment Key Findings
• *Overall, groundwater level and quality results for 2020 appear to be following consistent trends with, or fall within previously measured ranges of the historical data collected between 2013 and 2019.*
• *Base Mine Lake area groundwater levels are relatively low compared to the immediate surrounding areas (i.e., Base Mine Lake area currently acts as a zone of groundwater convergence).*
• *Groundwater levels on the east side of Base Mine Lake where Basal Water Sands are present appear to be recovering relatively quickly.*
• *Based on the site-wide direction of groundwater flow in a northeasterly direction, once groundwater levels have fully equilibrated around Base Mine Lake, it may be expected that groundwater inflows to Base Mine Lake will occur from the south and west and that groundwater losses from Base Mine Lake 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 minimal).*
• *From piper diagram analysis, groundwater from wells in the shallow and intermediate zones is generally characterized as a sodium-bicarbonate/sulfate-mix type water and the deep wells groundwater (e.g., from the Basal Water Sands and Devonian Limestone) as sodium-chloride type water. These results are consistent with prior years and suggest that shallow/intermediate and deep groundwater comprise distinct flow paths.*
• *Among the monitoring wells, there were 60 statistically significant trends detected among 16 water quality variables (particularly for major ions), from an overall 380 trend analyses conducted. This suggests that geochemical change may be occurring in about 16% of instances while 84% of results suggest relatively stable groundwater quality.* o *Calcium, magnesium, and calculated hardness (which is dependent on calcium and magnesium concentration) comprise 26 of the 60 identified trends.* o *Increasing trends in concentrations have been noted for alkalinity, ammonia, bicarbonate, chloride, F2 petroleum hydrocarbons, naphthenic acids, iron, nickel, dissolved organic carbon, sodium and sulfate. Naphthenic acid remains a variable of interest as concentrations are generally higher in Base Mine Lake surface water than in groundwater, and in 2020, there was one statistically significant increasing trend in naphthenic acids observed in the shallow zone.*

5.1.3 Surface Water Quality

The surface water quality component of the 2020 Base Mine Lake monitoring program consisted of both frozen (winter) and open water sampling events. The number of stations, number of depth strata, and frequency of sampling were all reduced for the 2020 open water monitoring program, in consideration of COVID-19 mitigation measures. Some of the surface water quality differences observed in the 2020 results may be related to the reduced sampling effort compared to previous years.

The 2020 winter field program included sampling at the three platforms and two deep stations; littoral stations were not included in the winter monitoring scope. Winter sampling occurred biweekly between February 10 and March 13. All three platform stations (Platforms 1, 2, and 3) were accessible for the duration of the 2020 winter field program. Routes to deep stations D04 and D26 were established later in the program, during the weeks of February 24 and March 9, respectively. Snow and ice were sampled in conjunction with the winter water quality program. Snow sampling took place on two occasions: once during the week of February 10 and again on the week of March 9. Due to cold weather and exposure restrictions, snow samples were collected from Platform 3 only during the first sampling event, while all platforms and deep stations were accessible and sampled during the second snow sampling event. The ice sampling program took place once, during the week of February 24. Snow and ice samples were analyzed for select chemical variables, while water quality samples were analyzed for a comprehensive suite of analytes.

The 2020 open water monitoring scope was reduced to include only the three platform stations; sampling was conducted bi-weekly from June 1 to October 21. The Base Mine Lake pump-out and Beaver Creek Reservoir pump-in stations were sampled only while pumps were operational, with bi-weekly visits occurring from September 10 through October 21. The two deep and five littoral stations were not sampled during the 2020 open water program, and sampling at the three platform stations was reduced to a single depth per sampling event. The reduced sampling frequency and elimination of multiple depth strata resulted in fewer open water observations relative to previous years (Table 5-3). In-situ profile data were collected using a YSI multi-meter probe and water clarity was measured using a Secchi disk; however, light penetration profiles using the Li-Cor light sensor were not collected during the 2020 open water sampling season.

Water toxicity sampling was also reduced in 2020, with fewer sampling events than other years. Water toxicity samples were collected in July and September at all three platform stations. Each sample consisted of a composite of multiple grabs from two depths within the field-estimated euphotic zone (twice the Secchi depth), collected with a 4 L horizontal Van Dorn sampler.

Table 5-3: Total Number of Analytical Water Quality Samples Collected from Base Mine Lake and Beaver Creek Reservoir (2013 to 2020)

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

Table 5-4: Base Mine Lake Surface Water Quality Assessment Key Findings

Summary of the Base Mine Lake Surface Water Quality Assessment Key Findings	
In-situ and Conventional Physico-Chemical Variables:	
Summary of 2020 Observations	• *Base Mine Lake is a 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 freshwater.* • *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.*
Spatial Trends	• *Seasonal suboxic conditions in deep waters, during periods of stratification.* • *Higher turbidity in the bottom stratum of Base Mine Lake.*

Summary of the Base Mine Lake Surface Water Quality Assessment Key Findings	
Guideline Exceedances (long-term)	• *Dissolved oxygen concentrations less than minimum guideline requirements in the hypolimnion during winter and summer stratification.* • *Chloride and sulphide concentrations remained greater than long-term guideline for protection of aquatic life (GoA 2018). [NOTE: Sulphide guideline was equal to or less than the analytical DL from 2013 to 2018; however, the calculated proportion of exceedances includes measurable results only (i.e., values greater than DL).]*
Nutrients:	
Summary of 2020 Observations	• *Primary nutrients (i.e., nitrogen- and phosphorus-containing compounds) are available in Base Mine Lake in sufficient concentrations to support primary production.* • *Variation in nutrient concentrations observed among seasons and depth strata within Base Mine Lake, related to expected biogeochemical processes.*
Temporal Trends	• *Seasonal variations of ammonia, nitrate, and phosphorus observed, although inconsistent with one another:* o *Total ammonia concentrations were highest during spring and lowest during winter.* o *Nitrate concentrations were highest during winter and lowest during fall.* • *Lower nutrient concentrations relative to previous monitoring years; however, this may be an artefact of fewer bottom depth samples taken in 2020, which historically have higher concentrations.*
Guideline Exceedances (long-term)	• *Ammonia concentrations greater than guidelines, however, the frequency of exceedances has decreased since 2013.*
Metals:	
Summary of 2020 Observations	• *Concentrations of 9 metals, including total and dissolved bismuth, cadmium, silver and tin, dissolved beryllium, chromium, thallium, and total zinc, often fell near or below analytical detection limits.* • *Variation in concentration among seasons with concentrations generally higher in summer.*

Summary of the Base Mine Lake Surface Water Quality Assessment Key Findings	
Temporal Trends	• *Concentrations of most metals have decreased in Base Mine Lake since 2013 with relatively higher reduction rates for dissolved bismuth, total cobalt, and total and dissolved antimony.* • *Total boron and total nickel concentrations have remained stable over the monitoring years.*
Guideline Exceedances (long-term)	• *Boron concentrations consistently greater than guidelines.* • *Sporadic observations of concentrations greater than guidelines for several metals, including dissolved iron, total arsenic, total cadmium, total chromium, total cobalt, total copper, and total zinc.* • *Total number of sample exceedances similar to previous years; however, caution should be taken to use this metric for interpretation of 2020 results due to adjustments of the sampling program (i.e., higher proportion of winter samples collected compared to open water and a higher proportion of surface samples collected than at depth).*
Organics:	
Summary of 2020 Observations	○ *Some petroleum-associated compounds continued to be measurable in Base Mine Lake, including naphthenic acids, alkylated PAHs, total phenolics, and F2 and F3 hydrocarbons.* • *Most volatile organics (e.g., benzene, toluene, ethylbenzene, and xylene) near or below analytical detection limits.*
Temporal Trends	• *In 2020, the highest concentrations of PAHs, F2, and F3 hydrocarbons were in winter; total phenolics were in fall; and naphthenic acids were in the spring and summer.* • *Slightly lower naphthenic acid concentrations were observed in 2020, relative to 2016 to 2019.* *Note: Total phenolics, hydrocarbons, volatile organics, and PAHs were not sampled in spring 2020.*
Guideline exceedances	• *Total phenolics and F2 hydrocarbons consistently greater than guidelines.* • *Pyrene concentrations occasionally greater than guideline.*

An extensive suite of water quality variables (ranging from 111 to 185 analytes, depending on sampling frequency) were measured from six variable groups; including, conventional physico-chemical variables, ions, nutrients, metals, organics, and polycyclic aromatic hydrocarbons (PAHs). All parameters are generally below short-term guidelines for the protection of aquatic life (PAL), except for F2 petroleum hydrocarbons. The F2 hydrocarbon fraction has an interim short-term guideline derived from soil guidelines and may not be especially relevant to Base Mine Lake surface water quality. It is expected that the F2 fraction may change in response to hydrocarbon mitigation activities.

The 2020 analytical results for the discrete water quality samples from Base Mine Lake were screened against surface water quality guidelines for the protection of aquatic life (GoA 2018). The most conservative value was used for variables with multiple guidelines (e.g., for variables with GoA and CCME guidelines, or acute and chronic guidelines). Site-specific guidelines (e.g., hardness-dependent) were calculated for each sample, as applicable.

The following water quality variables had concentrations frequently (i.e., more than 50% of observations) greater than GoA chronic guidelines in Base Mine Lake in 2020: chloride (100%), sulphide (81%)[5], total boron (83%), F2 petroleum hydrocarbons (98%), and total chromium (70%). Observations greater than chronic guidelines were less frequently observed for 10 other variables, which included both metals and organic compounds. The frequency of observations greater than guidelines has decreased since 2013, particularly for the following variables: ammonia, nitrite, total mercury, anthracene, and pyrene.

Metals that most frequently exceeded guidelines each year were total boron (from 86% of samples in 2016 to 100% of samples in 2013, 2014, and 2018, to 95% in 2019, 83% 2020), followed by total chromium (15% of samples in 2017 to 100% of samples in 2015) and dissolved aluminum (3% of samples in 2018 to 39% of samples in 2017). Boron is a chemical that is generally elevated in OSPW. Dissolved aluminum spiked in the lake after alum was added to manage mineral turbidity. Since the alum dosage, aluminum concentrations have declined; this will continue to be monitored to understand the effect of the alum dosage on many aspects of lake performance.

The parameters that are currently exceeding long-term guidelines are expected to improve with time. As the lake continues to develop, fresh/environmental water import dilutes the water cap, and the contribution of chemistry from FFT pore-water advection as a result of settlement declines. As the tailings continue to consolidate and dewater, there is less advective contribution of FFT pore-water to the water cap. The FFT pore-water is the source of elevated chemical concentrations in the water cap and as consolidation begins to slow over time, so too does the influence of pore-water on the water cap. Syncrude will continue to monitor water quality and FFT settlement, and will use this information in combination with the water balance to determine mass balance in the water cap and assess how this will change over time. This information will then inform adaptive management of the lake; specifically, decisions about water import and export (flow-through).

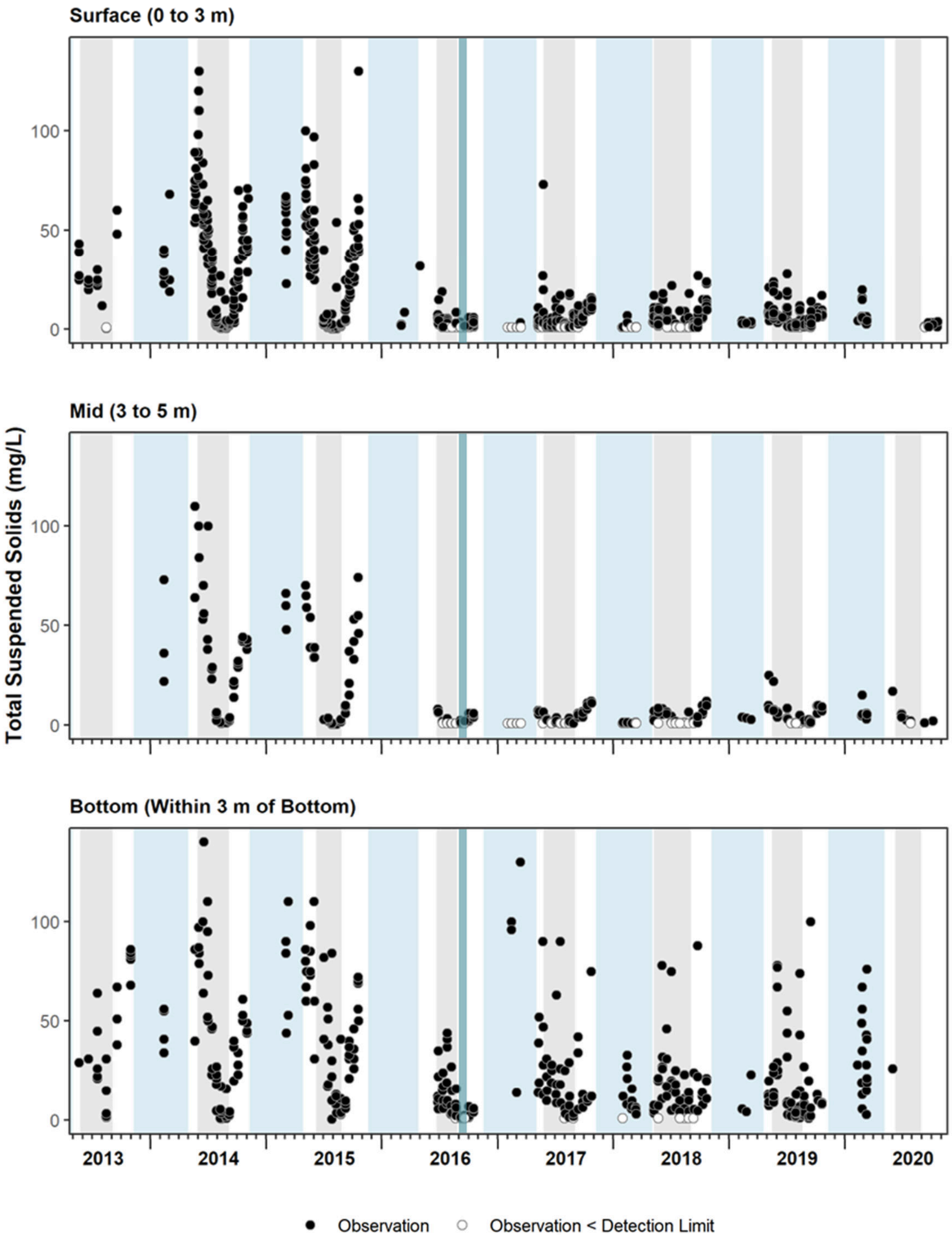
[5] Sulphide guideline was equal to or less than the analytical DL from 2013 to 2018; however, the calculated proportion of exceedances includes measurable results only (i.e., values greater than DL).

5.1.3.1 Temporal Trends in Total Suspended Solids in the Water Cap

Total Suspended Solids (TSS) concentrations in Base Mine Lake remained relatively high from 2013 through 2015 (prior to alum treatment), before decreasing and becoming more stable from 2016 through 2020 (Figure 5-4). Seasonal variations in TSS concentrations are apparent in Base Mine Lake. TSS has also shown vertical variations over the monitoring years, with less stable and higher concentrations near the bottom of the lake. It is important to note that there is no evidence of an increase in TSS since commissioning, which indicates that the fines are physically isolated beneath the water cap. The more consistent TSS measurements in recent years may be due to a more distinct FFT-water interface (mudline), allowing for better delineation of the interface in advance of near-bottom water sampling. This aligns with the empirical evidence that the FFT is settling and strengthening as expected over time.

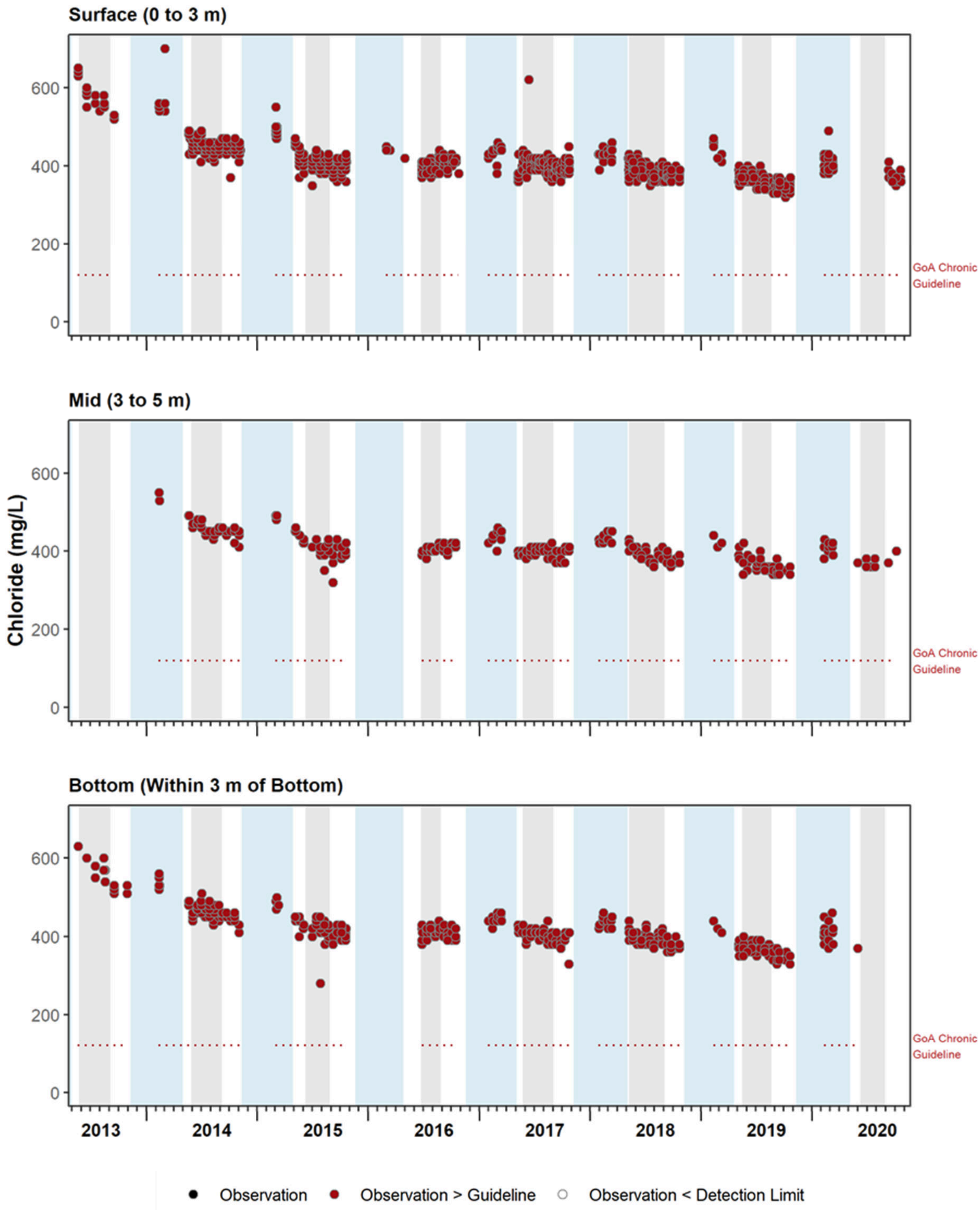
5.1.3.2 Improvement in Chloride Concentration since Commissioning

Chloride has remained the dominant anion in Base Mine Lake since monitoring was initiated in 2013, and is useful as a conservative tracer for tracking water quality improvements. Chloride concentrations are below the GoA short-term surface water quality guideline (640 mg/L), but have remained greater than the GoA long-term surface water quality guideline for the protection of aquatic life (120 mg/L) since the lake was commissioned. Consistent with previous years, there were no clear vertical concentration gradients of chlorides in Base Mine Lake in 2020. A modest improvement in chloride concentration has been observed in Base Mine Lake since initial commissioning (Figure 5-5).



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.
Green interval shows the period of the alum treatment.
Guideline for TSS is based on background condition, and therefore not presented.

Figure 5-4: Temporal Trends of Total Suspended Solids in Base Mine Lake (2013 to 2020)



Ice-covered (blue) and stratified (grey) periods shown as filled areas on each panel.
Mean weekly guideline values shown as dotted red line.

Figure 5-5: Temporal Trends of Chloride in Base Mine Lake (2013 to 2020)

5.1.4 Water Balance

Estimating the water balance of Base Mine Lake has important implications for the chemical, energy and constituent mass balance of the lake, and provides information about the sustainability of pit lakes in the closure landscape. The water balance has been completed for Base Mine Lake from November 2013 through December 2020, with a daily time step in terms of both total volumes and millimetres (mm) of water in/out. In 2020, COVID-19 restrictions limited the ability to obtain high quality measurements and gas fluxes; however, the 2020 water balance estimates will be refined when site access restrictions are lifted and data are downloaded from the in-situ dataloggers. For analysis purposes, only 'water years' (Nov-Oct) have been presented as yearly totals in mm of water in Table 5-6, and represented graphically as Mm^3 in Figure 5-6.

Table 5-5: Base Mine Lake Water Balance Assessment Key Findings

Summary of the Base Mine Lake Water Balance Assessment Key Findings
• *Water volume expressed from the FFT was estimated in 2020 using the long-term data, instead of sonar mudline measurement.*
• *Water pumped in from Beaver Creek Reservoir was minimal in 2020 and was the least annual addition of freshwater since commissioning.*
• *Outflow from Base Mine Lake was similar to 2019, and almost 4x the volume added through inflow.*
• *2020 was a very wet year, with a remarkable 538 mm of rain compared with 254 mm in 2015.*
• *Snow additions were estimated from total precipitation at the Mildred Lake Climate Station.*
• *Evaporation from Base Mine Lake was low in 2020, largely due to cold, humid and dark conditions compared to other years.*

Table 5-6: Yearly Water Balance Totals (in mm) for Base Mine Lake (2014-2020)

	OUTPUTS			INPUTS			
Year (Total)	Evaporation	Pump OUT	Dredge OUT	Pump IN	Rain	Snow	Runoff
2014	350.6	954.5		852.0	308.9	55.0	29.2
2015	350.9	952.6		780.2	254.4	50.0	21.0
2016	515.8	375.9		402.1	368.6	50.0	0.2
2017	469.8	181.2		368.4	286.1	40.0	2.0
2018	525.4	155.6		366.1	398.1	100.0	0.1
2019	535.6	461.1	43.5	811.4	314.3	70.0	0.1
2020	380.9	450.1		117.1	537.8	80	0

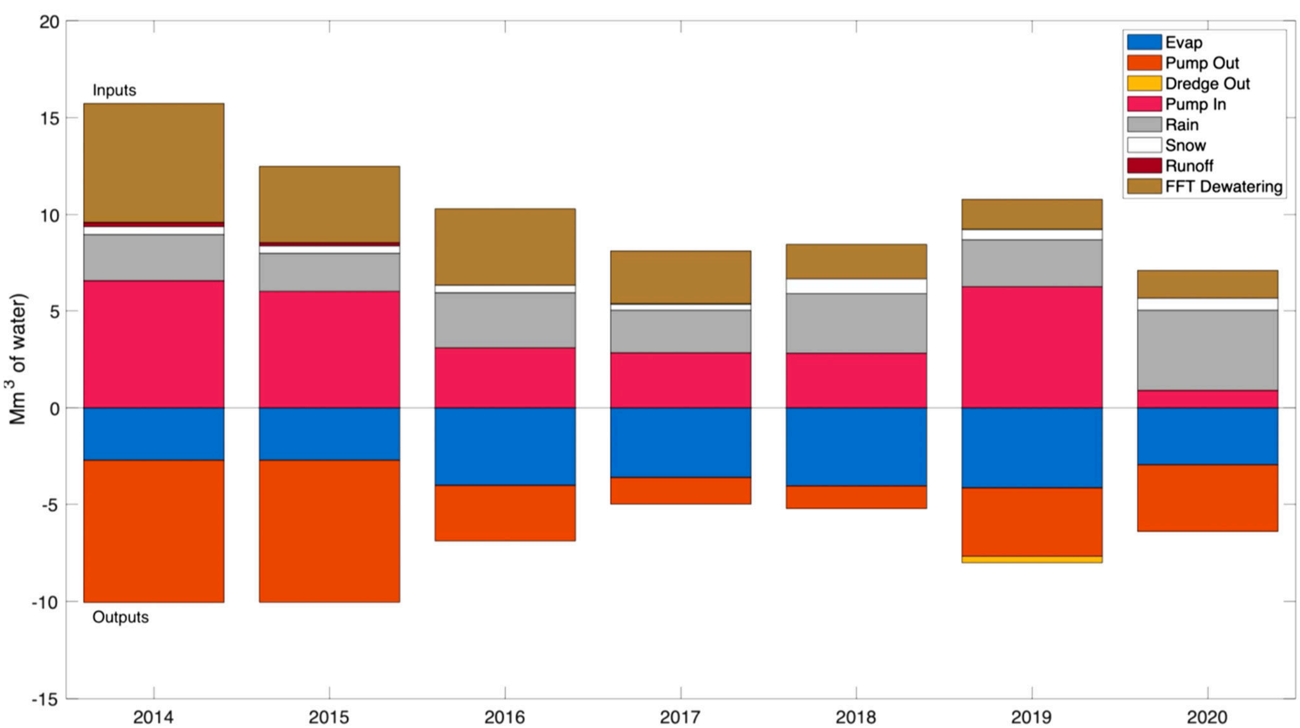


Figure 5-6: Annual Water Balance Values in Mm3 for Base Mine Lake (2014-2020)

The daily cumulative water balance for 2020 is shown in Figure 5-7. The pump outflow was very high and slightly greater than evaporation. Rainfall and snowfall accounted for over 600 mm of water inputs. Runoff was not estimated in 2020.

There continues to be decent closure in the water balance, which is quantified as the measured change in storage from surveyed water levels versus the modelled change in storage from the cumulative water balance. This validates the accuracy of the calculations. While there are always offsets due to snow and ice in winter, it is critical to check open water and end of season values.

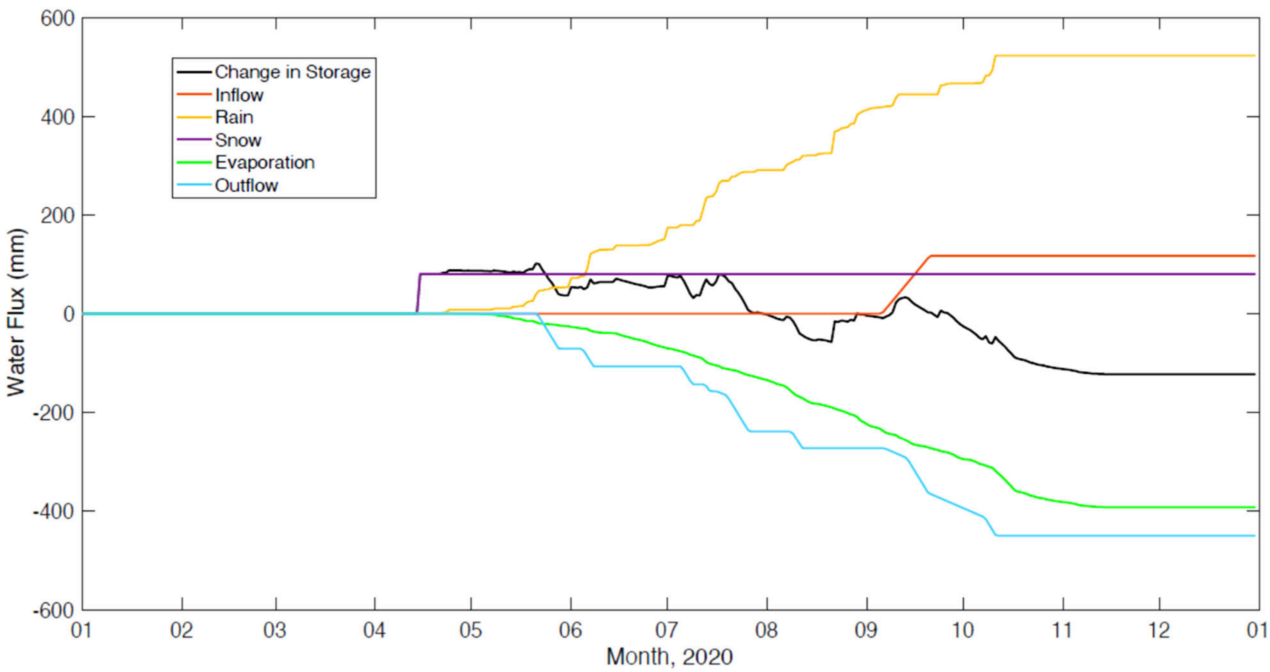


Figure 5-7: Cumulative Daily Water Balance (2020)

5.1.5 Physical Limnology

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.

Base Mine Lake has consistently exhibited conventional lake physical processes since commissioning. During the winter, the lake forms ice annually. Once 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 and wind. This results in the lake mixing again, or fall turnover. Key lake events since commissioning are indicated in Table 5-7.

Table 5-7: Summary of Ice-on, Ice-off, Stratification (Whole Lake) and Turbidity Extremes (Platform 3, 2.5 m depth)*

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

* Note that alum dosing occurred during September of 2016.
[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).

Table 5-8: Base Mine Lake Physical Limnology Assessment Key Findings

Summary of the Base Mine Lake Physical Limnology Assessment Key Findings
Physical limnological processes that were similar to all previous years:
• *Similar to previous years, in 2020 Base Mine Lake 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.* o *The winter turbidity minimum, approximately 30 NTU is similar to the minimum observed in previous winters since alum dosing in 2016.*

Summary of the Base Mine Lake Physical Limnology Assessment Key Findings
• *Increasing turbidity throughout the depth in late spring and early summer (May and June).*
• *In the summer, weekly wind events (when wind speed exceeds approximately 5 m/s) in the summer that causes oscillations of the thermocline (internal seiches) and fluctuations in turbidity within and below the thermocline.*
• *Complete vertical mixing during fall turnover results in uniform temperature, and turbidity throughout all of the water column.*
• *Turbidity profiles indicate the presence of a region at the base of the water column up to approximately 0.5 to 4 m thick with very high turbidity that is intermediate in temperature between the temperature of the FFT and the water above (this layer is warmer than the water above in the winter). This intermediate region is not uniform horizontally; it is not always observed in profile data and is typically the thickest at the deepest station.*
Physical limnological processes that were different from previous years or newly observed:
• *Spring turnover started later (May 6) than in previous years (April 20 to May 5) and was more complete than in most other years.*

5.1.5.1 2020 Trends in Turbidity

Turbidity has exhibited seasonal fluctuations tied to the physical limnological events in the lake (e.g., mixing and thermal stratification). In 2020, maximum turbidity occurred at the end of fall turnover, coincident with the initial formation of ice (November 11). Turbidity drops following ice-on, and stopped declining at the beginning of January. Similar to the winter of 2019, the minimum winter turbidity was 30 NTU. At the end of spring turnover (June 9) the turbidity of Base Mine Lake throughout most of the water column was 50 NTU. From in-lake moored sensors, turbidity at 2.5 m peaked on approximately day 161 (June 9), and, except for brief increases associated with large wind events, and proceeded to decline, reaching a low value of approximately 8 NTU at the end of July (approximately day 210, July 28). At 7.5 m, turbidity increased sporadically until day 185 (July 3). After July 3, turbidity at 7.5 m decreased and became similar to that at 2.5 m. After the onset of fall turnover (day 243, August 30) the turbidity at all of the available locations was nearly identical (8 NTU). This pattern in the turbidity during the spring and summer is similar to the patterns observed in previous years. A summary of trends in turbidity since 2013 is shown in Figure 5-8.

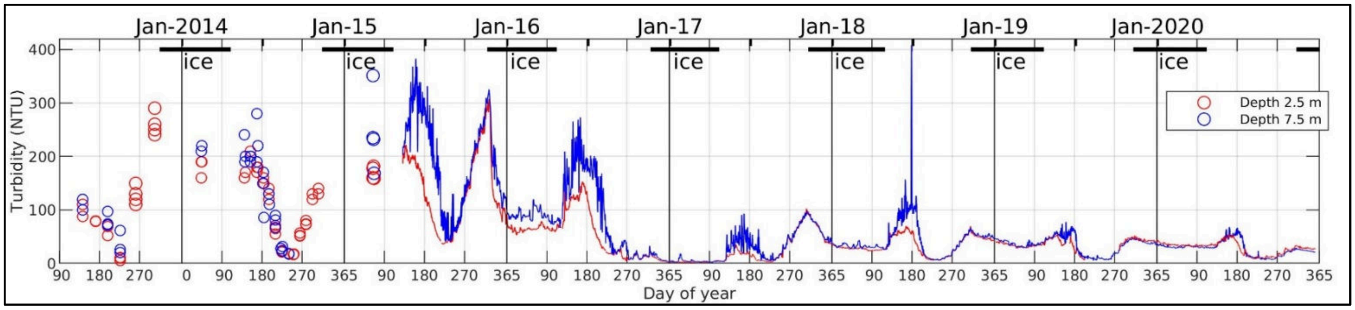


Figure 5-8: Turbidity Measured in Base Mine Lake from May 2013 to December 2020

5.1.6 Aquatic Biology (2019)

Due to reliance on third party contractors and site access restrictions due to COVID-19, aquatic biology samples were not collected in 2020 and the following section is a summary of work and results from the 2019 program. The 2019 aquatic biology program included six components: periphyton, phytoplankton, zooplankton, benthic invertebrates, sediment quality, and sediment and water toxicity. The following monitoring was conducted for each component:

- Periphyton colonization and growth were monitored over 7, 14, 21, and 28-day test periods at the three platform stations from the end of July through August. Two replicates were collected at each platform;
- Phytoplankton samples were collected three times during winter at Platform 3 (February and March), and monthly during open water (May to October) from the three platforms and Beaver Creek Reservoir pump-in station. Three replicates were collected at each station;
- Zooplankton samples were collected monthly from May to October at the three platforms and Beaver Creek Reservoir pump-in station. Three replicates were collected at each station;
- Benthic invertebrate samples were collected in September from six littoral stations, equally distributed between the NW and SE quadrants of Base Mine Lake. Five replicates were collected at each station;
- Sediment quality samples were collected in September from the six benthic invertebrate littoral stations. Five replicates were collected at each station; and
- Acute and chronic toxicity tests were performed on water and sediments from Base Mine Lake using a range of test organisms. Water toxicity samples were collected in May, July, and September at all three platform stations, while sediment toxicity samples were collected in September from the six benthic invertebrate littoral stations.

Table 5-9: Base Mine Lake Aquatic Biology Monitoring Program Key Findings (2019)

Summary of the Base Mine Lake Aquatic Biology Monitoring Program Key Findings	
Periphyton:	
Summary of 2019 Observations	• *Moderate-low colonization of substrates by periphyton.* • *Colonizing periphyton moderately diverse; diatoms dominant in abundance and biomass.*
Temporal Trends	• *Both abundance and biomass have exhibited high annual variability.* • *Same taxonomic groups have dominated in abundance and biomass, but dominance of individual taxa has varied among years.* • *Diversity of colonizing periphyton communities has generally increased from year-to-year.*
Spatial Trends	• *No consistent spatial patterns in periphyton colonization.*
Phytoplankton:	
Summary of 2019 Observations	• *Viable phytoplankton community in Base Mine Lake.* • *Phytoplankton abundance peaked in August.* • *Phytoplankton biomass peaked in September.* • *Moderately diverse community; cyanobacteria dominant in abundance and euglenoids dominant in biomass.*
Temporal Trends	• *Abundance and biomass exhibited high monthly and annual variability with lower values in recent years.* • *Dominance of taxonomic groups has varied over monitoring years, with euglenoids and cryptomonads the most dominant in recent years.* • *Diversity has generally increased year to year.*
Spatial Trends	• *No consistent spatial patterns in phytoplankton abundance or diversity within Base Mine Lake.*
Zooplankton:	
Summary of 2019 Observations	• *Zooplankton abundance peaked in August.*

Summary of the Base Mine Lake Aquatic Biology Monitoring Program Key Findings	
	• *Zooplankton biomass peaked in July.* • *Moderately diverse community; more balanced community in fall with cladocerans and rotifers present.*
Temporal Trends	• *Both abundance and biomass have exhibited high monthly and annual variability with 2019 recording slightly higher total abundance than 2018.* • *Consistent monthly/seasonal community patterns among monitoring years.* • *Diversity has generally increased over monitoring years.*
Spatial Trends	• *Zooplankton communities varied among the three platforms without any distinct pattern.*
Benthic Invertebrates:	
Summary of 2019 Observations	• *Higher biomass and abundance in NW quadrant.* • *Midge larvae alone accounted for >88% of the abundance in both quadrants (this is less dominance in abundance than 2018), while a more diverse community of gastropods resulted in the higher biomass in the NW quadrant.*
Temporal Trends	• *Highly variable abundance and biomass among monitoring years; 2018 numbers lower than 2017.* • *Same taxonomic group dominant in all monitoring years (Diptera: Chironomidae).* • *Similar diversity recorded in all monitoring years.*
Spatial Trends	• *Highly variable communities observed among sampling stations and between the NW and SE quadrants, with higher biomass and abundance in NW quadrant.*
Sediment Quality:	
Summary of 2019 Observations	• *Physical and chemical compositions of sediments varied between NW quadrant and SE quadrant.* • *Several sediment variables exceeded the interim sediment quality guidelines (GoA 2018), with the NW quadrant exhibiting higher frequencies than the SE quadrant.*

Summary of the Base Mine Lake Aquatic Biology Monitoring Program Key Findings	
Temporal Trends	• *Similar physical properties of sediments observed in all monitoring years.* • *Sediment chemistry has varied among monitoring years.*
Spatial Trends	• *Sediment composition and chemistry in NW quadrant better for development of benthic invertebrate communities than SE quadrant.*
Water Toxicity:	
Summary of 2019 and 2020 Observations	• *No acute toxicity effects observed on test organisms (2019 and 2020).* • *Chronic toxicity effects observed on bacteria, algae, macrophytes, and zooplankton. No chronic effects observed on fish survival or growth, or on zooplankton survival (2020 only).*
Temporal Trends	• *Variable chronic toxicity effects among seasons.* • *No acute toxicity of Base Mine Lake water observed since 2014.*
Spatial Trends	• *Variable toxicity effects among stations/Base Mine Lake platforms.*
Sediment Toxicity:	
Summary of 2019 Observations	• *Sediment toxicity tests conducted on freshwater midge larvae and amphipods showed effects on the survival and growth of both organisms.* • *Midge larvae growth tests for Base Mine Lake sediments observed higher biomass increase in comparison to control sediments.*
Temporal Trends	• *Highly variable toxicity effects among years.* • *All toxicity effects on test organisms observed in 2019 less than historical maximums, except amphipod survival at one location in NW quadrant.*
Spatial Trends	• *Highly variable toxicity effects among stations as well as between the NW and SE quadrants.*

5.2 Key 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. 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, 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.

5.2.1 Physical Limnology of Base Mine Lake and the Potential for Meromixis (Lawrence, Tedford, Pieters: University of British Columbia)

The objective of this program is to understand the circulation of Base Mine Lake and its potential for meromixis. Some results from 2020 are described herein.

Near bottom images, acoustic ebullition data, sub bottom echograms, CT-scans of bubbles and bitumen trapped in the ice, satellite and drone imagery of the ice and multiple years of bathymetry, have dramatically improved our understanding of the dynamics at the water-FFT interface. Before the collection of this data, particularly the bottom images, the water-FFT interface was incorrectly assumed to be a relatively uniform, somewhat diffuse transition between the water and the FFT. Research is leading toward a complete qualitative, and in some cases quantitative, description of these bottom features.

Recovered oxygen data was less than in previous years due to restrictions resulting from the COVID-19 pandemic. As in previous years, oxygen concentrations declined throughout the winter and increased in the summer. The 2020 data may be augmented when instruments are recovered in 2021.

Salinity profiles collected during the winters of 2017, 2018, 2019 and 2020 have evidence of FFT sourced salts. Although FFT sourced salt is expected due to dewatering of the FFT, these were the first profiles that have clear evidence of a bottom source. This new evidence may be the result of increased depth decreasing the impact of salt exclusion from the ice on the near bottom salinity. During the winter the dominant source of salinity variation is the exclusion of salt from the ice, and therefore ice melt results in a sudden and relatively large decrease in salinity. During summer, fresh/environmental water inflows are the dominant source of salinity variation.

The energy balance is not completed yet, but data indicate that heat from the FFT at the mudline is warming the lower portion of the water cap during the ice-on period. Conversely, the water cap is warming the upper portion of the FFT during the ice-free period.

5.2.2 Characterization of Controls on Mass Loading to an Oil Sands 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 Base Mine Lake. Recent findings offer insight on processes controlling mass-loading across this interface.

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.

Most of this work is complete and published in scientific journals and theses. The remaining efforts are focused on refining methane solubility models, and developing methane gas samplers to deploy in the FFT to understand how different factors (e.g., temperature, pressure) may influence potential for methane exsolution and ebullition. Due to COVID-19 restrictions, samplers were not deployed in 2020 and plans are underway to deploy in 2021.

5.2.3 Field Investigation of Base Mine Lake Water Cap Oxygen Concentrations, Consumption Rates and Key BOD/COD Constituents Affecting Oxic Zone Development (Warren, Slater: University of Toronto, McMaster)

This research program focuses on field investigation of the Base Mine Lake 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 Base Mine Lake water cap oxygen concentrations, oxygen consumption rates, and identify the biogeochemical processes linked to its consumption from the FFT-water interface to the Base Mine Lake water surface. The outcomes will identify the key OCC and processes affecting oxygen status throughout the Base Mine Lake water cap, as well as any early developmental stage trends in water cap dissolved oxygen dynamics.

In 2020, two winter sampling campaigns (February and March) were carried out prior to the COVID-19 lockdown which closed university research facilities for roughly 6 months and prevented summer sampling campaigns, as well as significantly delayed analytical and experimental research on campus. Research focused on experimental assessment of sulfate reduction (and possible associated sulfur oxidation) in FFT-Base Mine Lake water cap microcosms; ongoing development of analytical methods and analyses for sulfur oxidation intermediates (SOI) in the Base Mine Lake water cap; molecular microbiological assessment of microbial communities and their functional capacities from Base Mine Lake water cap and surface FFT communities at University of Toronto; and ongoing analyses of methane, naphthenic acids and hydrocarbons at McMaster University.

While both field and laboratory based research activities were necessarily highly curtailed in 2020, results are emerging that provide new insights into the sulfur cycle occurring in Base Mine Lake, as well as the microorganisms likely important to this oxygen impacting cycle. Experimental microcosms examined sulfate reduction and the possibility of coupled sulfur re-oxidation for P1 and P3 using FFT and water samples collected by Syncrude and shipped to the University of Toronto in September 2020. These are important steps to establishing the overall potential impact of sulfur cycling on Base Mine Lake oxygen concentrations.

Preliminary experimental microcosm results assessing sulfate reduction and the possibility of associated sulfur oxidation using FFT and water samples from Platforms 1 and 3 revealed active sulfate reduction as well as subsequent sulfur oxidation. For all microcosm experiments, sulfur compounds indicative of re-oxidation of sulfide were present by the end of the experiments; and both sulfate reducing bacteria (SRB) and sulfur oxidizing bacteria (SOB) were present. Further experiments will begin to identify the processes, constrain rates of both sulfate reduction as well as possible sulfur oxidation under oxic and anoxic conditions (i.e., using nitrate) to contribute to understanding of the possible risks of sulfur cycling within the Base Mine Lake water cap for oxygen concentrations. Ongoing metagenomics analyses of the functional capabilities of Base Mine Lake water cap communities highlight widespread (depth, season, year) capabilities for sulfur oxidation across the 2015-2019 time series of Base Mine Lake water cap characterization to date, as well as increasing gene abundance for both sulfur oxidation and sulfate reduction in lower waters post the alum addition in 2016; suggesting greater activity of these metabolisms with the alum reset to microbial biogeochemical cycling within the water cap. Future field campaigns and experimental work will continue to delineate sulfur cycling within Base Mine Lake and determine the associated impacts for Base Mine Lake oxygen concentrations.

Analysis of dissolved methane from two winter sampling campaigns found trends similar to 2018 with evidence of oxidation at the FFT-water interface and between sampling events, and contrasted the low methane concentrations observed in February 2019. Despite reduced capacity for laboratory analysis, development of comprehensive gas chromatography methods to characterize molecular fingerprints of naphthenic acids and petroleum hydrocarbons continued. Higher resolution analysis of near surface FFT (1-2 m) indicated that compound distributions were more complicated than initial results indicated. Development of methods to assess presence and trends in low molecular weight organics in the FFT in order to assess residual naphtha presence is ongoing. Further analysis and data interpretation of water cap naphthenic acid profiles supported a generally stable fingerprint, though some variations were observed that may enable identification of localized inputs. This work will provide a foundation for further assessment of the distribution and microbial cycling of organic carbon within the Base Mine Lake system.

5.2.4 Microbial Communities and Methane Oxidation Processes in Base Mine Lake (Dunfield: University of Calgary)

This research project has three main objectives: (1) to monitor the development of the microbial community (bacteria and microbial eukaryotes) in Base Mine Lake 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 Base Mine Lake; the lake may be transitioning from a primarily organotrophic system based on hydrocarbon degradation to a primarily phototrophic system based on algal primary productivity which may change parameters such as oxygen status and nutrient cycling; and, (3) to understand the roles of some abundant microbial groups (methanotrophic bacteria and phototrophic algae) in bioremediation of organic pollutants.

Due to COVID-19 restrictions, few new samples were able to be collected in 2020 and efforts were focused on completing analysis of data from 2015-2019. Key learnings so far include:

- Although Base Mine Lake microbial 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].
- Diversity of several groups of microbes in Base Mine Lake is increasing slightly over time.
- Total algal cell densities have increased over time. The total diversity of phototrophic algal species has also increased. Three major groups *(Cryptomonas, Choricystis, and Synechococcus)* cycle seasonally, a pattern typical of many natural lakes.
- Methanotrophic bacteria show regular seasonal patterns, becoming abundant in winter and spring and less abundant in summer. Methanotroph populations in surface sediment are 3-4 orders of magnitude greater than in the water column, which supports other evidence that this is the main site of methane oxidation, especially during summer stratification

5.2.5 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: (1) determining factors that control evaporation from Base Mine Lake; (2) understanding long-term water balance for Base Mine Lake; and, (3) 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. Due to COVID-19 restrictions, there was no CO_2 or CH_4 data reported in 2020; however, this data may still be saved on dataloggers and plans are underway to retrieve any available information in 2021.

5.2.6 Characterization of Organic Compounds and Naphthenic Acids in Base Mine Lake: Implications for Methane Production, Transport, Oxygen Consumption and Naphthenic Acid Persistence (Slater: McMaster)

This project was commissioned in 2020 and will focus on characterizing the organic compounds, including naphthenic acids, present in the Base Mine Lake system (FFT and water cap) to help understand three key aspects of Base Mine Lake performance: (1) methane production and release; (2) sources of naphthenic acids and petroleum hydrocarbons to the Base Mine Lake water cap; and (3) the role of ebullition in transporting FFT constituents into the water cap. These three aspects contribute to an understanding of oxygen concentrations and naphthenic acids in Base Mine Lake.

Information will be provided in future submissions as data becomes available.

5.2.7 Base Mine Lake Process Dynamics (Bara: Syncrude)

This research is focused on understanding the mechanisms and mitigation of bitumen liberation from mats on the FFT surface. A significant effort has been underway to delineate and understand the extent of bitumen mats on the FFT surface. Residual naphtha in these mats are consumed by methanogenic microbes, producing methane gas. The gas bubbles can be coated in bitumen 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.

Observations from the Base Mine Lake research and monitoring program have indicated that ice cores from Base Mine Lake can show both gas bubbles and bitumen (Figure 5-9) 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. Pilot work in 2019 indicated images of the cores produced using a CT scanner would allow quantification of gas voids and bitumen (see Figure 5-10 for an example image). A method for reliable analysis of the Oil-Water-Solids content of the cores was also developed.

The most ambitious ice core program ever executed on Base Mine Lake was undertaken in 2021 (see Table 5-3). To support safe work on the ice, over 6.5 km of ice route was formed and maintained, more than 850 holes were augered, and more than 270 ice cores were analyzed. These cores were collected on a grid based sampling system across the entire lake, and a smaller grid over the bitumen mat locations. The cores collected in 2020 are currently being analyzed and an update on results will be provided in future submissions.

Figure 5-9: Two Ice Cores from Base Mine Lake (2020)[6]

[6] Each photo taken with black background to show bubbles, and white background to emphasize bitumen. The core on the left two images was collected from an area of the lake with significant bubbling and bitumen. The core on the right two images was collected from an area of the lake with fewer bubbles and significantly less bitumen.

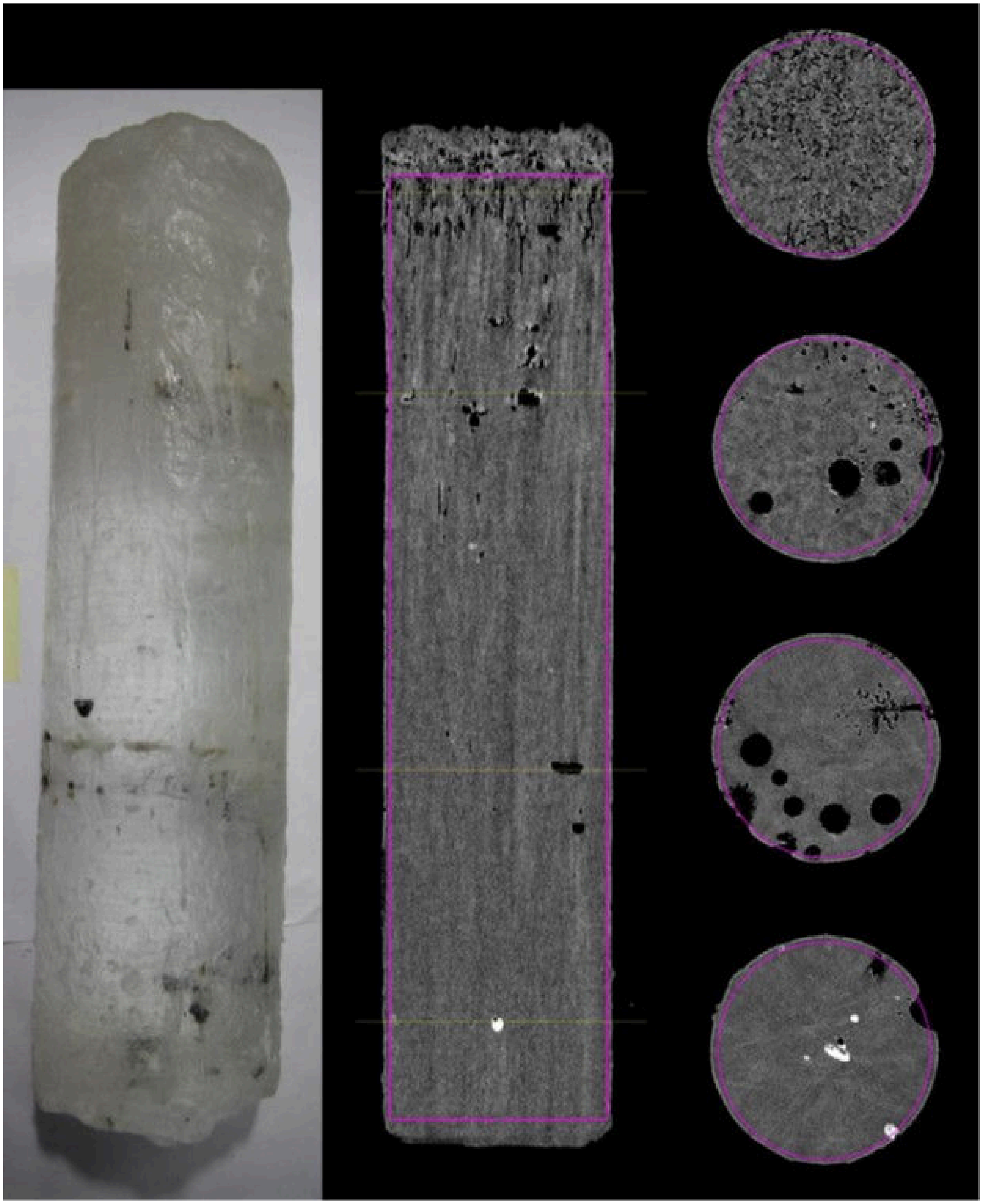


Figure 5-10: Example Ice Core and the Imagery Produced from CT Scanning (including Cross-sections)[7]

[7] The black voids on the CT scan are gas bubbles and the white areas are bitumen.

5.3 Bibliography of Peer Reviewed Publications Produced by Base Mine Lake Research Programs

Albakistani E. 2018. Methane Cycling and Methanotrophic Bacteria in Base Mine Lake, a Model End-Pit Lake in the Alberta Oilsands. PhD Thesis. Calgary, AB: University of Calgary. https://prism.ucalgary.ca/handle/1880/107699

Aguilar M, Richardson E, Tan B, Walker G, Dunfield PF, Bass D, Nesbø C, Foght JM, 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. DOI: 10.1111/jeu.12320

Arriaga D. 2018. The Interplay of Physical and Biogeochemical Processes in Determining Water Cap Oxygen Concentrations within Base Mine Lake, the First Oil Sands Pit Lake. PhD Thesis. Hamilton, ON: McMaster University.

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

Bowman DT. 2017. Chemical Fingerprinting of Naphthenic Acids by Comprehensive Two Dimensional Gas Chromatography Mass Spectrometry at Reclamation Sites in the Alberta Oil Sands. PhD Thesis. Hamilton, ON: McMaster University. http://hdl.handle.net/11375/21963

Bowman DT, Jobst KJ, Ortiz X, Reiner EJ, Warren LA, McCarry BE, Slater GF. 2018. Improved coverage of naphthenic acid fraction compounds by comprehensive two-dimensional gas chromatography coupled with high resolution mass spectrometry. *J. Chromatography A.* 1536:88-95. DOI: 10.1016/j.chroma.2017.07.017

Bowman DT, McCarry BE, Warren LA, Slater GF. 2017a. Profiling of individual naphthenic acids at a composite tailings reclamation fen by comprehensive two-dimensional gas chromatography mass spectrometry. *Environmental Science & Technology* 649: 1522-1531 DOI: 10.1016/j.scitotenv.2018.08.317

Bowman DT, Jobst KJ, Ortiz X, Reiner EJ, Warren LA, McCarry BE, Slater GF. 2017b. Improved coverage of naphthenic acid fraction compounds by comprehensive two-dimensional gas chromatography coupled to a high resolution mass spectrometer. *Journal of Chromatography A* 1536: 88-95. DOI: 10.1016/j.chroma.2017.07.017

Brandon JT. Turbidity Mitigation in an Oil Sands End Pit Lake through pH Reduction and Fresh Water Addition. MSc Thesis. Edmonton, AB: University of Alberta. DOI: 10.7939/R3ST7F72D

Chen, L-X., R. Meheust, A. Crits-Christoph, K.D. McMahon, T.C. Nelson, G.F. Slater, L.A. Warren and J.F. Banfield. 2020. Large freshwater phages with the potential to augment aerobic methane oxidation. Nature Microbiology https://doi.org/10.1038/s41564-020-0779-9

Clark MG, Drewitt GB, Carey SK. 2021. Energy and carbon flux from an oil sands pit lake. *Science of the Total Environment*. 752:1141966. DOI: 10/1016/j.scitotenv.2020.141966

Dereviakin, M. 2020. Monitoring Spatial Distribution of Solvent Extractable Petroleum Hydrocarbons in Pit Lake Fluid Fine Tailings SGES McMaster University

Dompierre KA. 2016. Controls on mass and thermal loading to an oil sands end pit lake from underlying fluid fine tailings. PhD Thesis. Saskatoon, SK: University of Saskatchewan. 157 pp. https://harvest.usask.ca/handle/10388/7772

Dompierre KA, Barbour SL. 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. DOI: 10.1016/j.jconhyd.2016.03.006

Dompierre KA, Lindsay MBJ, Cruz-Hernández P, Halferdahl GM. 2016. Initial geochemical characteristics of fluid fine tailings in an oil sands end pit lake. *Science of the Total Environment* 556:196-206. DOI: 10.1016/j.scitotenv.2016.03.002

Dompierre KA, Barbour SL. 2017. Thermal properties of oil sands fluid fine tailings: Laboratory and in-situ testing methods. *Canadian Geotechnical Journal* 54(3): 428-440. DOI: 10.1139/cgj-2016-0235

Dompierre KA, Barbour SL, North RL, Carey SK, Lindsay MBJ. 2017. Chemical mass transport between fluid fine tailings and the overlying water cover of an oil sands end pit lake. *Water Resources Research* 53: 4725-4740. DOI: 10.1002/2016WR020112

Goad C. 2017. Methane biogeochemical cycling over seasonal and annual scales in an oil sands tailings end pit lake. MSc Thesis. Hamilton, ON: McMaster University. http://hdl.handle.net/11375/21956

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

Hurley DL. 2017. Wind waves and Internal Waves in Base Mine Lake. MSc Thesis. Vancouver, BC: University of British Columbia. 91 pp. DOI: 10.14288/1.0351993

Lawrence GA, Tedford EW, Pieters R. 2016. Suspended solids in an end pit lake: potential mixing mechanisms. *Can. J. Civ. Eng.* 43:211-217 DOI: 10.1139/cjce-2015-0381

Mori, JF, Chen L, Jessen GL, Slater GF, Rudderham S, McBeth J, Lindsay MBJ, Banfield JF and Warren LA. 2019. Putative mixotrophic nitrifying-denitrifying gammaproteobacterial implicated in nitrogen cycling within the ammonia/oxygen transition zone of an oil sands pit lake. *Frontiers in Microbiology* https://doi.org/10.3389/fmicb.2019.02435

Morris PK. 2018. Depth Dependent Roles of Methane, Ammonia and Hydrogen Sulfide in the Oxygen Consumption of Base Mine Lake, the pilot Athabasca Oil Sands Pit Lake. MSc Thesis. Hamilton, ON: McMaster University. 97 pp. http://hdl.handle.net/11375/23040

Poon HY. 2019. An Examination on the Effect of Diluent on Microbial Dynamics in Oil Sands Tailings and the Mechanistic Insight on Carbon Dioxide-mediated Turbidity Reduction in Oil Sands Surface Water. PhD Thesis. Edmonton, AB: University of Alberta. 207 pp. DOI: 10.7939/r3-fek4-7t49

Poon HY, Brandon JT, Yu X, Ulrich A. 2018. Turbidity mitigation in an oil sands pit lake through pH reduction and fresh water addition. *Journal of Environmental Engineerin*g 144. DOI: 10.1061/(ASCE)EE.1943-7870.0001472

Rawluck S. 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. https://haskayne.ucalgary.ca/files/haskayne/2017-Capstone-Abstracts.pdf

Richardson, E. 2020. The cell biology and ecology of heterotrophic eukaryotes in a tailings reclamation site in Northern Alberta. University of Alberta. https://era.library.ualberta.ca/items/8904ed02-2119-4ee4-adf0-330149c5af8a

Risacher FF. 2017. Biogeochemical development of the first oil sands pilot end pit lake. MSc Thesis. Hamilton, ON: McMaster University. http://hdl.handle.net/11375/22274

Risacher FF, Morris PK, Arriaga D, Goad C, Colenbrander Nelson T, Slater GF, Warren LA. 2018. The interplay of methane and ammonia as key oxygen consuming constituents in early stage development of Base Mine Lake, the first demonstration Oil Sands pit lake. *Applied Geochemistry* 93: 49-59. DOI: 10.1016/j.apgeochem.2018.03.013

Rochman FF. 2016 Aerobic hydrocarbon-degrading microbial communities in oilsands tailings ponds. PhD Thesis. Calgary, AB: University of Calgary. DOI: 10.11575/PRISM/24733

Rochman FF, Sheremet A, Tamas I, Saidi-Mehrabad A, Kim JJ, Dong X, Sensen CW, Gieg LM, Dunfield PF. 2017. Benzene and naphthalene degrading bacterial communities in an oil sands tailings pond. *Frontiers in Microbiology* 8: article 1845. DOI: 10.3389/fmicb.2017.01845.

Rochman FF, Kim JJ, Rijpstra WIC, Sinninghe Damsté JS, Schumann P, Verbeke TJ, 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

Rudderham SB. 2019. Geomicrobiology and geochemistry of fluid fine tailings in an oil sands end pit lake. MSc Thesis. Saskatoon, SK: University of Saskatchewan. 98 pp. https://harvest.usask.ca/handle/10388/11975

Saidi-Mehrabad A, Kits DK, Kim JJ, Tamas I, Schumann P, Khadka R, Rijpstra WIC, Sinninghe Damsté JS, Dunfield PF. 2020. *Methylicorpusculum oleiharenae* sp. nov., an aerobic methanotroph isolated from an oil sands tailings pond in Canada. *International Journal of Systematic and Evolutionary Microbiology* 7:908-921 DOI: 10.1038/ismej.2012.163

Samadi N. 2019. Partitioning of contaminants between fluid fine tailings and cap water under end-pit lake scenario: Biological, chemical and mineralogical processes. MSc Thesis. Edmonton, AB: University of Alberta. 152pp. DOI: 10.7939/r3-8730-4k32

Tedford EW, Halferdahl GM, Pieters R, Lawrence GA. 2018. Temporal variations in turbidity in an oil sands pit lake. *Environmental Fluid Mechanics*. 19:457-473. DOI: 10.1007/s10652-018-9632-6

Yu X. 2019. Improving Cap Water Quality in An Oil Sands End Pit Lake with Microbial Applications. PhD Thesis. Edmonton, AB: University of Alberta. DOI: 10.7939/r3-g0s1-by42

Yu X, Lee K, Ma B, Asiedu E, Ulrich A. 2018. Indigenous microorganisms residing in oil sands tailings biodegrade residual bitumen. *Chemosphere*. 209: 551-559. DOI: 10.1016/j.chemosphere.2018.06.126

Yu X, Lee K, Ulrich A. 2018. Model naphthenic acids removal by microalgae and Base Mine Lake cap water microbial inoculum. *Chemosphere* 234: 796-805. DOI: 10.1016/j.chemosphere.2019.06.110

Xhao K, Tedford EW, Zare M, and Lawrence GA. 2021. Impact of atmospheric pressure variations on methane ebullition and lake turbidity during ice-cover. *Limnology and Oceanography Letters.*

6 References

Alberta Energy Regulator. 2017. Directive 085: Fluid Tailings Management for Oil Sands Mining Projects. Available: https://www.aer.ca/documents/directives/Directive085.pdf

Alberta Energy Regulator. 2018. Specified Enhancement Direction 003: Direction for Conservation and Reclamation Submissions Under an *Environmental Protection and Enhancement Act* Approval for Mineable Oil Sands. Available: https://www.aer.ca/documents/manuals/Direction_003.pdf

Alberta Energy Regulator. 2020. *Environmental Protection and Enhancement Act* Approval No. 26-03-00. Effective on June 18, 2020.

Allen, C. R., J. J. Fontaine, K. L. Pope, and A. S. Garmestani. 2011. Adaptive management for a turbulent future. *Journal of Environmental Management* 92:1339-1345.

Canadian Council of Ministers of the Environment. 2014a. Sediment Quality Guidelines for the Protection of Aquatic Life. Retrieved on November 1, 2016 from http://st-ts.ccme.ca/en/index.html?chems=all&chapters=3&pdf=1

Canadian Council of Ministers of the Environment. 2014b. Tissue Residue Quality Guidelines for the Protection of Wildlife Consumer of Aquatic Biota. Retrieved on November 1, 2016 from http://st-ts.ccme.ca/en/index.html?chems=all&chapters=1&pdf=1

Canadian Council of Ministers of the Environment. 2014c. Water Quality Guidelines for the Protection of Aquatic Life. Retrieved on November 1, 2016 from http://st-ts.ccme.ca/en/index.html?chems=all&chapters=1&pdf=1

Energy Resources Conservation Board. 1994. ERCB Decision D 94-5, Syncrude Continued Improvement and Development Project.

Government of Alberta. 1995. *Environmental Protection and Enhancement Act* Approval No. 26-01-00. Effective on December 21, 1995.

Government of Alberta. 2012. *Environmental Protection and Enhancement Act* Approval No. 26-02-05. Effective on November 26, 2012.

Government of Alberta. 2015. Lower Athabasca Region - Tailings Management Framework for the Mineable Athabasca Oil Sands. Available: https://open.alberta.ca/dataset/962bc8f4-3924-46ce-baf8-d6b7a26467ae/resource/7c49eb63-751b-49fd-b746-87d5edee3131/download/2015-larp-tailingsmgtathabascaoilsands.pdf.

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

Government of Canada. Environment Canada Biological Test Methods and Guidance Documents. Available: https://www.canada.ca/en/environment-climate-change/services/wildlife-research-landscape-science/biological-test-method-publications.html

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: https://cosia.ca/sites/default/files/attachments/2018%20Mesocosm%20Research%20Report.pdf

International Organization for Standardization. 2016. Environmental management systems-general guidelines on implementation ISO 14004:2016. 59pp. Available: https://www.iso.org/standard/60856.html

Jones, G. 2005. Is the management plan achieving its objectives? Case study 21.1 pp 555-557 In Worboys, G, De Lacy, T. and Lockwood, M. (eds), Protected Area Management. Principles and Practices. Second Edition. Oxford University Press.

Jones, G. 2009. The Adaptive Management System for the Tasmanian Wilderness World Heritage Area - Linking Management Planning with Effectiveness Evaluation. In: Allan C., Stankey G.H. (eds) Adaptive Environmental Management. Springer, Dordrecht.

Lawrence, GA., Ward, PRB, and MacKinnon MD. 1991. Wind-wave induced suspension of mine tailings in disposal ponds-a case study. Can. J. Civ. Eng. 18: 1047-1053. Available: https://cdnsciencepub.com/doi/pdf/10.1139/l91-127

Stankey, G.H., Clark, R. N., and Bormann, B. T. 2005. Adaptive Management of Natural Resources: Theory, Concepts, and Management Institutions. United States Department of Agriculture, Forest Service. General Technical Report PNW-GTR-654.

Suncor Energy Inc. 2021. Pit Lake Research and Development Report. Submitted to the AER on April 28, 2021.

Syncrude Canada Ltd. 1996. Base Mine Lake Research and Monitoring Plan. Submitted to AEP on June 26, 1996.

Syncrude Canada Ltd. 2013. Base Mine Lake Monitoring Plan (Updated). Submitted to AESRD on April 9, 2013.

Syncrude Canada Ltd. 2013. Base Mine Lake Research Plan. Submitted to AESRD on November 8, 2013.

Syncrude Canada Ltd. 2016. Life of Mine Closure Plan. Submitted to the AER on December 21, 2016.

Syncrude Canada Ltd. 2019. Base Mine Lake Monitoring and Research Summary Report: Results from 2013-2018. Submitted to the AER on June 27, 2019.

Syncrude Canada Ltd. 2020. Pit Lake Regional Research Initiatives. Submitted to the AER on April 15, 2020.

Syncrude Canada Ltd. 2020. Base Mine Lake Monitoring and Research Plan. Submitted to the AER on November 13, 2020.

Walters, C. J. 1986. *Adaptive Management of Renewable Resources.* Macmillan, New York.

Walters, C. J. 2007. Is Adaptive Management Helping to Solve Fisheries Problems? *Ambio* 36: 304-307.

Appendix 1: Base Mine Lake 2020 Groundwater Report (prepared by Hatfield Consultants LLP, June 2021)