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Teck

May 1, 2018

Ms. Kierney Leach
Technical Regulatory Specialist
Mackenzie Valley Land and Water Board
7th Floor – 4910 50th Avenue
PO Box 2130
Yellowknife, NT X1A 2P6

email: kleach@mvlwb.com

Dear Ms. Leach,

Re: MV2017L2-007 Submission of Reclamation Research Plan

Pursuant of Part H item 3 of Water Licence MV2017L2-007, please find attached the *Reclamation Research Plan*. This plan outlines the type of research required to update the Closure and Reclamation Plan that is required under Part H item 1 of the Licence by December 31, 2020.

Hope this submission meets the current requirements. If you have any further questions or concerns, please feel free to contact myself at (250) 427-8422.

Kind Regards,

MUnger

Digitally signed by Michelle Unger
DN: cn=Michelle Unger, o=Teck, ou, email=michelle.unger@teck.com, c=CA
Date: 2018.05.01 13:50:26 -06'00'

Michelle Unger, B.Sc.
Manager, Environmental Compliance
Teck Metals Ltd

Enc:
Pine Point Mine Reclamation Research Plan (RRP), Tailings Impoundment Area (TIA) prepared by Barr Engineering, May 1, 2018

Pine Point Mine Reclamation Research Plan (RRP)

Tailings Impoundment Area (TIA)

Prepared for
Teck Metals Ltd.

May 1, 2018

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Pine Point Mine Reclamation Research Plan (RRP)

May 1, 2018

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Certifications

I certify that this report was prepared by me, or under my direct supervision, and that I am licenced to practice in the fields of civil and environmental engineering with the Northwest Territories and Nunavut Association of Professional Engineers and Geoscientists (NAPEG).

ORIGINAL SIGNED

______________________________	May 1 2018
Dale Kolstad P.Eng. #: L3901	Date

Barr Engineering and Environmental Science Canada, Ltd. holds Permit to Practice #P1055.

Abbreviations

ARD	Acid Rock Drainage
BAT	best available technology
CCME	Canadian Council of Ministers of the Environment
CDA	Canadian Dam Association
CO	Closure Option
CSM	conceptual site model
DSR	Dam Safety Review
ET	evapotranspiration
MAC	Mining Association of Canada
ML	Metals Leaching
MVLWB	Mackenzie Valley Land and Water Board
OMS	Operations, Maintenance, and Surveillance
Pb	Lead
RRP	Reclamation Research Plan
SNP	Surveillance Network Program
TIA	Tailings Impoundment Area
Zn	Zinc

1.0 Introduction

1.1 Purpose

Teck Metals Ltd. (herein referred to as "Teck") has been requested by the Mackenzie Valley Land and Water Board (MVLWB) to submit a Reclamation Research Plan (RRP) by May 1, 2018 as per Water Licence MV2017L2-007. The purpose of this RRP is to resolve uncertainties and address questions and potential environmental risks associated with the closure and reclamation approach for the Tailings Impoundment Area (TIA) of the former Pine Point Mine. Barr Engineering and Environmental Science Canada, Ltd. (Barr) has been retained by Teck to assist in the development of this RRP.

The results from reclamation research will aid in selection of a final closure option for the TIA and support the development of an updated Closure and Reclamation Plan for the TIA (formerly called the "Restoration and Abandonment Plan - TIA", last updated in 2006) by December 31, 2020. The updated Closure and Reclamation Plan will align with the MVWLB and Aboriginal Affairs and Northern Development Canada's November 2013 Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites in the Northwest Territories (herein referred to as the "MVWLB Guidelines"), and Teck's Responsible Mine Closure & Reclamation objectives and dedication to sustainable mining practices.

1.2 Objectives

In accordance with the MVWLB Guidelines, the overarching closure goal for former mine sites is to "return the site and affected areas to viable, and wherever practicable, self-sustaining ecosystems that are compatible with a healthy environment and with human activities". To meet this closure goal, companies must demonstrate that a site is physically stable, chemically stable, does not require long-term active care, and has potential for future use. This closure goal is consistent with Teck's approach to responsible mine closure that focuses on returning the land to a stable state for post-mining land uses and healthy ecosystems. The closure goal may be modified through engagement with stakeholders during reclamation research, and the closure and reclamation plan update process.

The water quality of the TIA pond remains an ongoing challenge due to continued acid-rock drainage (ARD)/ metals leaching (ML) issues associated with the tailings, which currently require on-going active chemical treatment to meet the Water Licence discharge requirements. As such, this RRP aims to identify and address remaining uncertainties in meeting the closure goal and Teck's objectives following the current reclamation and closure plan, and to aid in development of an updated plan. The persistence of the ARD/ML issue is the primary driver for reclamation research at the TIA. The specific objectives of this RRP are to:

- Review the current closure plan, including completed reclamation efforts and remaining items, toward meeting Teck's responsible mine closure and reclamation approach and MVWLB guidance for closure of tailings containment areas.
- Evaluate MVWLB recommended Closure Options for tailings ARD/ML impacted areas and categorize these options as feasible, potentially feasible, or not feasible for the TIA based on the currently available information and understanding of the site.

- Identify reclamation research and/or engineering study required to address outstanding uncertainties/questions surrounding the potentially feasible Closure Options.
- Provide a phased approach for the reclamation research and/or engineering study to guide the work efficiently toward development of the preferred Closure Option in preparation for submission or the updated Closure and Reclamation Plan to the MVWLB by December 31, 2020.

1.3 Plan Organization

The plan is organized as follows:

- Section 1 provides the plan introduction, including the purpose and objectives for this RRP and outlines the organization of the plan.
- Section 2 provides the background on the TIA and results of reclamation efforts toward closure following the current reclamation and closure plan for the site.
- Section 3 provides the closure goal and principles for the TIA following Teck's responsible mine closure and reclamation approach and MVWLB guidelines.
- Section 4 provides the initial closure objectives for the TIA following MVWLB guidelines. A summary of the current condition and pending actions under the current closure plan toward meeting those objectives is provided. Remaining uncertainties are identified and provide the directional needs for research described in Section 6.
- Section 5 provides the initial closure options for the TIA to address remaining ARD/ML issues following MVWLB guidelines. A summary of the current condition and feasibility of the approaches is provided. Some closure options are removed from consideration due to likely infeasibility, while others are retained for further consideration. Remaining uncertainties are identified for potentially feasible options and provide the directional needs for research described in Section 6.
- Section 6 provides the reclamation research components, following the reclamation research plan template provided within the MVWLB guidelines.

In general, Sections 1 through 5 are intended to provide the substantive components of a current interim closure and reclamation plan, which the guidance presumes is in place prior to a RRP development. These sections serve the purpose of providing basis for the remaining uncertainties to be addressed and closure options that will be pursued.

2.0 Site Background and CSM

This section provides a summary of the current closure plans/activities at the TIA, the site setting/regional conditions, pertinent aspects of the TIA, and the conceptual site model developed for the TIA. This background information and CSM form the current basis of understanding for the site and formation of the research plan.

2.1 Closure Summary

The Pine Point mine was operated by Cominco (a predecessor of Teck) as a large open-pit lead (Pb) and zinc (Zn) mine from 1964 to 1988. When the Pine Point Mine closed in 1988, the original Closure and Reclamation Plan (titled "Restoration and Abandonment Plan", approved June 1987) was implemented. Updates to the plan were issued in 1990 and again in 1991 as reclamation work neared completion. In accordance with the plan, surfaces leases and mining claims were surrendered back to the Crown during the mid to late 1990s, with the exception of one surface land lease (#85B/16-9-9), which encompasses the TIA. Restoration work at the TIA has focused on the three primary elements listed below. In 2006 the reclamation plan (titled "Update to Restoration and Abandonment Plan, Tailings Impoundment Area") was updated to focus on the latter two elements. The TIA is considered to be in the Closure-Active Care phase of mine life and operates under a Type B Water Licence (licence (MV2017L2-0007). Key elements of this plan include:

- **Surface stability** – which was established through placement of a nominal 150 mm thick layer of coarse sand and gravel cover over the tailings. This eliminated the dusting issue that was previously present with exposed tailings. The current cover encompasses approximately 86% of the surface area; all but the ponded area against the north dyke. Revegetation of the tailings to provide surface stability was attempted, but deemed infeasible.
- **Effluent quality** – the principal problem is the concentration of zinc in the surface water (pond), which was originally believed to be the result of the release of residual dissolved material created in the acid leach circuit that would be flushed out from snow and rainfall over a few years. However, column testing indicated it would be several more years (ten years or more) before water quality may improve to acceptable levels. Thus, Teck implemented a water treatment program consisting of caustic soda addition (initial approach – abandoned due to physical risks) and lime dosing (current approach) with metals precipitation within the polishing pond prior to discharge. Acid generation potential was acknowledged, but neutralizing by carbonate materials removes the risk of low pH effluent. However, metals leaching and dissolution continues to date, resulting in zinc concentrations (~1.5 mg/L) in the pond at approximately three times the Water Licence Limit of 0.5 mg/L.
- **Long-term stability of the dykes and decant structures** – is planned following resolution of the effluent quality issue. The plan is to reduce slope erosion by recontouring the dykes to a maximum slope of 3.0H to 1.0V. To achieve this, the crests will be cut down to a minimum of 0.5 meters from the tailings surface. At this time, there will no longer be a pond within the impoundment area, and thus, the operational conditions of 1.0 m minimum freeboard will not be applicable. Reducing the slope gradient of the recontoured dykes will also enhance revegetation

of the slopes that will further increase the long-term stability. A permanent spillway designed to handle flood events would be installed. Design of the final dyke and decant system has not been completed to date. Teck monitors and maintains the stability of the dykes through implementation of its Operations, Maintenance, and Surveillance (OMS) manual.

2.2 Project Setting/Environment

A brief summary of the project setting/environment is provided in Table 1. The site location is shown on Figure 1.

Table 1 Project Setting/Environment Summary

Item	Description
Location	Southern Northwest Territories, approximately 75 km east of Hay River, 50 km SW of Fort Resolution, and 13 km south of the southern shoreline of Great Slave Lake. Lies within the Mackenzie Mining Division and the Traditional Territory of the Deninu K'ue and K'atl'Odeeche First Nations and is part of the Akaitcho Treaty 8 land.
Terrain	Low gradient; sloping gently towards Great Slave Lake from ~ el. 230 m at the mine to 160 m at the lake shore.
Groundwater	Regional groundwater flow is to the north towards the Lake. Groundwater conditions in the Pine Point area have been well studied since at least the 1970s during regional dewatering related to the open pit and underground mine workings in the area. The relatively thick (50-60 meter) glacial till, localized permafrost, and shale layers in the upper bedrock act to form and effective confining layer above the underlying limestone and dolomite. Karstic features such as sinkholes, solution channels, and cavities are widespread, as are artesian groundwater conditions. Perched water is common, held up by varied clays and cemented sands locally known as "hardpan". Small localized lakes are abundant to the north in the region of groundwater from the TIA, and natural discharges of brine and sulphurous water are common in the region. The natural groundwater level and quality immediately below the TIA is unknown, but the natural groundwater level locally varies in depth between a few feet to about 60 feet below ground surface.
Surface Water	Regional surface water flow is to the north towards the Lake.
Geology	Regional geology consists of Ordovician to Devonian sediments overlaying Archean crystalline rocks and Proterozoic sediments. The area around Pine Point contains numerous Pb-Zn orebodies within karst and solution-induced Middle Givetian carbonate deposits known as Mississippi Valley Type (MVT) deposits. Surficial material is composed of a layer of glacial till, gravel, sand, and clay.
Seismicity	Seismic hazard in the region of Pine Point mine is ranked as low.
Vegetation	Regional vegetation is typical of the Taiga Plains Ecozone (Great Slave Lake Plain), composed predominately of wetlands and bog-fen vegetation such as dwarf black spruce, Labrador tea, ericaceous shrubs, and mosses. Jack pine and willows were also observed in the region of the site.
Wildlife	Wildlife includes moose, black bear, and deer are rarely observed in the region. The site is south of caribou migration routes and northwest of wood buffalo habitats.

Item	Description
Climate	Climatic conditions include sub-arctic winter conditions from October to late April and warm and relatively dry summers with long daylight hours. Mean monthly temperatures below 0°C are consistently observed from October to April. Snowfalls are consistently expected over this period, smaller amounts in May, June, and September. Pine Point is located in an area with net positive evapotranspiration. The average total annual lake evaporation is estimated to be 524 mm, based on surrounding regional weather stations. Evaporation occurs from May to September, with the majority of evaporation occurring in June and July (accounts for approximately 50% of the evaporation).
Permafrost	Pine Point falls within the discontinuous sporadic permafrost zone (less than 50% coverage of permafrost).

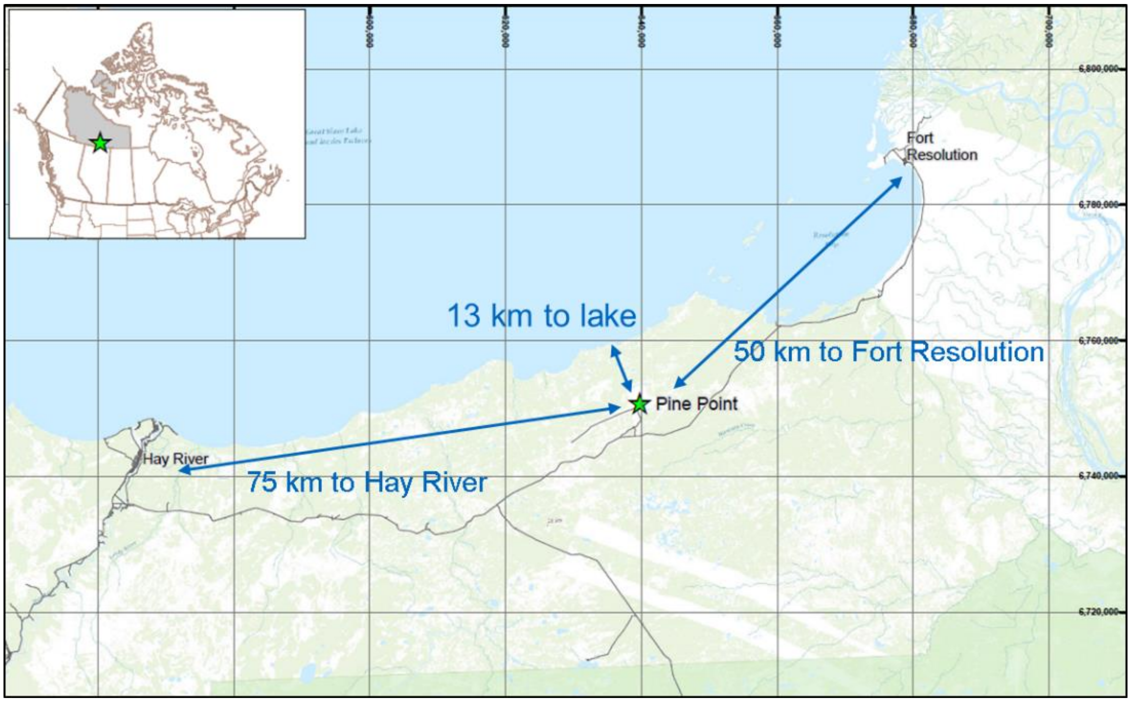

Figure 1 Site Location

2.3 Site Conditions

A brief summary of the TIA site conditions is provided in Table 2. See Figure 2 for a general layout of the TIA.

Table 2 Site Conditions Summary

Item	Description
Surface Area	Covers an area of approximately 2.5 by 2.8 km (~700 hectares).
Stratigraphy	Site stratigraphy is relatively uniform and the impoundment is underlain by natural soils found in three distinct layers: Organic Silt & Peat ~ 0.1 – 0.2 m thick, Natural Mineral Soil ~ 0.3 – 1.5 m thick (maximum thickness of 3.4 m) that are compact to dense gravelly sand to silty clay, and Till that is dense silty sand.
Tailings - Physical Properties	Contains approximately 54 million tonnes of Pb-Zn tailings composed of sorted, and bedded, fine to medium sand from the south (former trestle) to silt with lesser amounts of clay-sized particles to the north (pond). Tailings are ~ 14 m thick at the former trestle to ~ 5.3 m thick at the north dyke.
Tailings - Mineralogy	Tailings consist primarily of gangue minerals, mainly dolomite with lesser amounts of calcite. These minerals are accompanied by low-percentage to trace quantities of sulphide containing minerals including pyrite, marcasite, sphalerite, and galena, as well as muscovite and quartz. Tailings are acid generating (ARD), but are neutralized by the gangue minerals. Precipitates, including sulphate-based gypsum and thernardite, and hexahydrites appear at the tailings surface in spring and summer, respectively. Zinc may be present in biachnite, carbonate (such as smithsonite), and possibly minrecordite precipitates.
Cover	A 150 mm sand and gravel cover was installed over 1,250 acres (86%) of the tailings surface in 1991. The only area that remains uncovered is the soft tailings area adjacent to the downstream dyke. Limited revegetation (volunteer) of the cover has occurred to date.
Water Balance	The annual water balance for the TIA from 1993 to 2017 provides the following: annual equivalent precipitation is 542 mm, which includes reduction in snowfall values of 31% by sublimation and snow redistribution. Total losses, including evaporation, evapotranspiration, and infiltration is 514 mm. Net water released (treated discharge) is 28 mm, or about 5% of the equivalent precipitation.
Local Groundwater	Radial flows from the tailings high point on the southern end outward. In spring, the vertical gradients are directed downward. Water levels in the tailings rise as meltwater and summer/fall rains infiltrated and recharged tailings pore water. In summer and into fall, the vertical gradients decrease or the gradient becomes horizontal indicating pore water discharge to the pond.
Ponding	The main pond covers the north end of the TIA and its extent varies depending on water elevation. The pond water originates from surface water runoff including precipitation and snowmelt; water levels within the tailings typically drop during the spring and then increase in the summer and fall as the meltwater and summer rains infiltrate the tailings.
Water Management	Pond water with elevated concentrations of metals (primarily zinc, and to a lesser extent lead and copper) is treated in the polishing pond with hydrated lime to remove the metals by chemical precipitation for 3 to 6 weeks starting in July on an annual basis. The treated water (Zinc ~ 0.2 mg/L) discharges into a muskeg/wetland area via a spillway. The mineral sludge is dredged periodically and placed within the TIA footprint. The persistence of zinc at a current concentration of approximately 1.5 mg/L in the pond, is approximately three times greater than the Water Licence limit of 0.5 mg/L.

Item	Description
Water Quality Monitoring	Water quality monitoring is performed under a Surveillance Network Program (SNP), which includes sampling of surface water in the TIA, TIA water discharges, and at selected locations in the receiving aquatic environment. In general zinc concentration falls from 0.2 mg/L to below the Canadian Council of Ministers of the Environment (CCME) freshwater limit of 0.03 mg/L at lakeshore.
Perimeter Dyke	The perimeter dyke that contains the tailings and pond water extends fully along the north and west side – classified as "significant" consequence structures under the Canadian Dam Association Dam Safety Guidelines – of the disposal area and partially along the higher south and east sides – classified as "low" consequence structures under as per the Dam Safety Guidelines; due to the gently sloping terrain, only a partial dyke system is required along the south and east sides. The total length of the perimeter dykes is approximately 8.5 km with a maximum height of 15m at the northwest corner of the impoundment. The available information indicates the north and west dykes were developed with a clay zone on the pond side to act as a low permeability zone, and a downstream shell was built with sand and gravel to maintain a low phreatic surface through the dykes. Dyke raises for the north and west dykes were constructed using downstream construction methods and included a downstream gravel toe zone which was overlain at the top of the dyke section by a 1 to 2 m thick layer of local silt or silty clay. A very limited clay zone was developed on the pond side of the south dyke, with the bulk of the dyke developed with sand and gravel. The south dyke was not designed or built to retain water, only tailings. The east dyke was not developed with a clay upstream or pond side low permeable zone.
Dyke Setting	The TIA dykes are founded on glacial deposits. The site geology indicates the TIA dykes are underlain by very stiff silty clay with isolated pockets of gravel. Along parts of the dyke alignment, local pockets of peat were encountered, and were not removed in the initial construction phase, but were removed during subsequent dyke crest raises.
Dyke Monitoring	General inspections of the TIA area occur each spring after the freshet (April to May), summer (June to August), and prior to spring freeze-up in the fall (September to October). Dam Safety Inspections are performed annually and following any extreme weather or seismic events. Dam Safety Review (DSR) are performed every 10 years, the last was completed in 2014. Minor erosion and seepage issues continue to be identified and repaired.
Permafrost	The tailings did not remain frozen during the 1996 year-long investigation. Site-specific data on the presence or extent of permafrost within the TIA or under the dykes are not available.

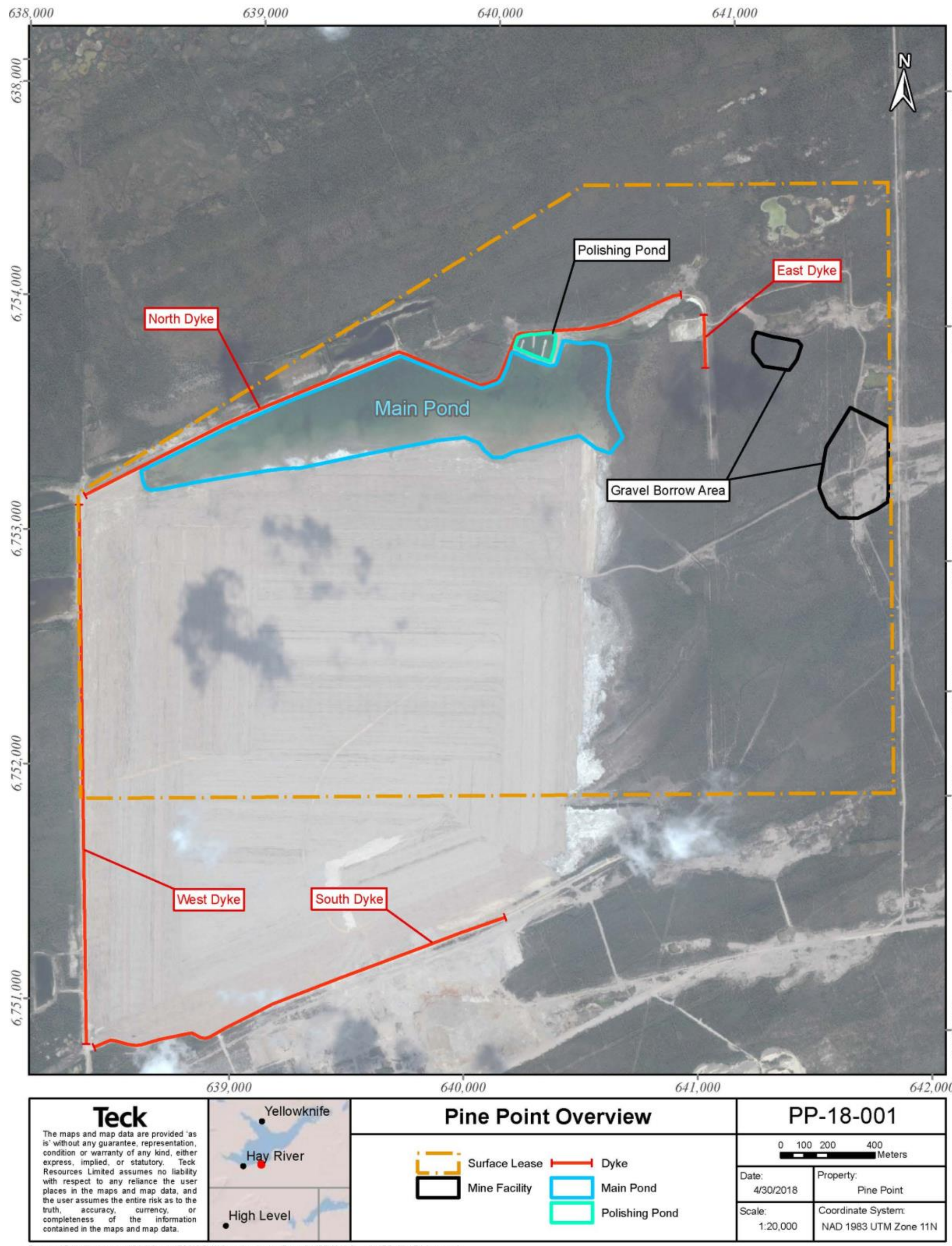

Figure 2 Tailings Impoundment Area (TIA)

2.4 Conceptual Site Model (CSM)

An initial conceptual site model (CSM) has been developed based on the currently available information – as summarized above – to representatively illustrate the sources, fate and transport; inclusive of physical, chemical and biological processes, and exposure pathways and receptors for metals contamination in the solid and water phases at the TIA. The CSM is dynamic and iteratively evolved as more information becomes available. Development and refinement of the CSM aids in identifying remaining uncertainties with regard to site understanding/characterization and is supportive in the selection of an appropriate closure option.

Figure 3 shown below is a modified geologic cross section cut through the TIA with water fluxes shown. This reflects the current understanding of the physical setting and properties of the tailings, the climatic conditions, and the water balance. The site has potential evapotranspiration (ET) in excess of precipitation (rain and snow melt) on an annual basis. However, surface run-off and seepage of metals impacted water to the pond occurs seasonally. This ponded water is actively treated with lime to remove the metals prior to discharge, as the ponded water contains approximately 1.5 mg/L zinc. The remaining challenge with metals leaching (ML) is illustrated in Figure 4. The dominant source of zinc to the surface water appears to be within leachable surface precipitates (carbonates, hydroxides, and sulfates) that can be dissolved through contact with precipitation and transported to the pond in run-off. The secondary, and more attenuated sources of zinc appear to be within the tailings porewater, which derive from: a) zinc within leachable precipitates near the surface (same carbonates, hydroxides, and sulfates as above) dissolves into infiltrating water (downward percolation), which becomes the tailings porewater and is then delivered to the pond by seepage, and b) zinc within "primary" sulfides in the tailings which get oxidized, releasing zinc that is then mobilized by downward percolation into the tailings porewater, and is then delivered to the pond by seepage.

Based on the current CSM and with changes to site conditions, it is uncertain as to when the metals concentrations will fall below the applicable limits. The initial understanding of acid rock drainage (ARD) and metals fate and transport relies on development of models for both the site water budget and geochemical processes. Consequently, ARD/ML issues at the TIA are anticipated to pose the greatest challenge to satisfying closure objectives for the site.

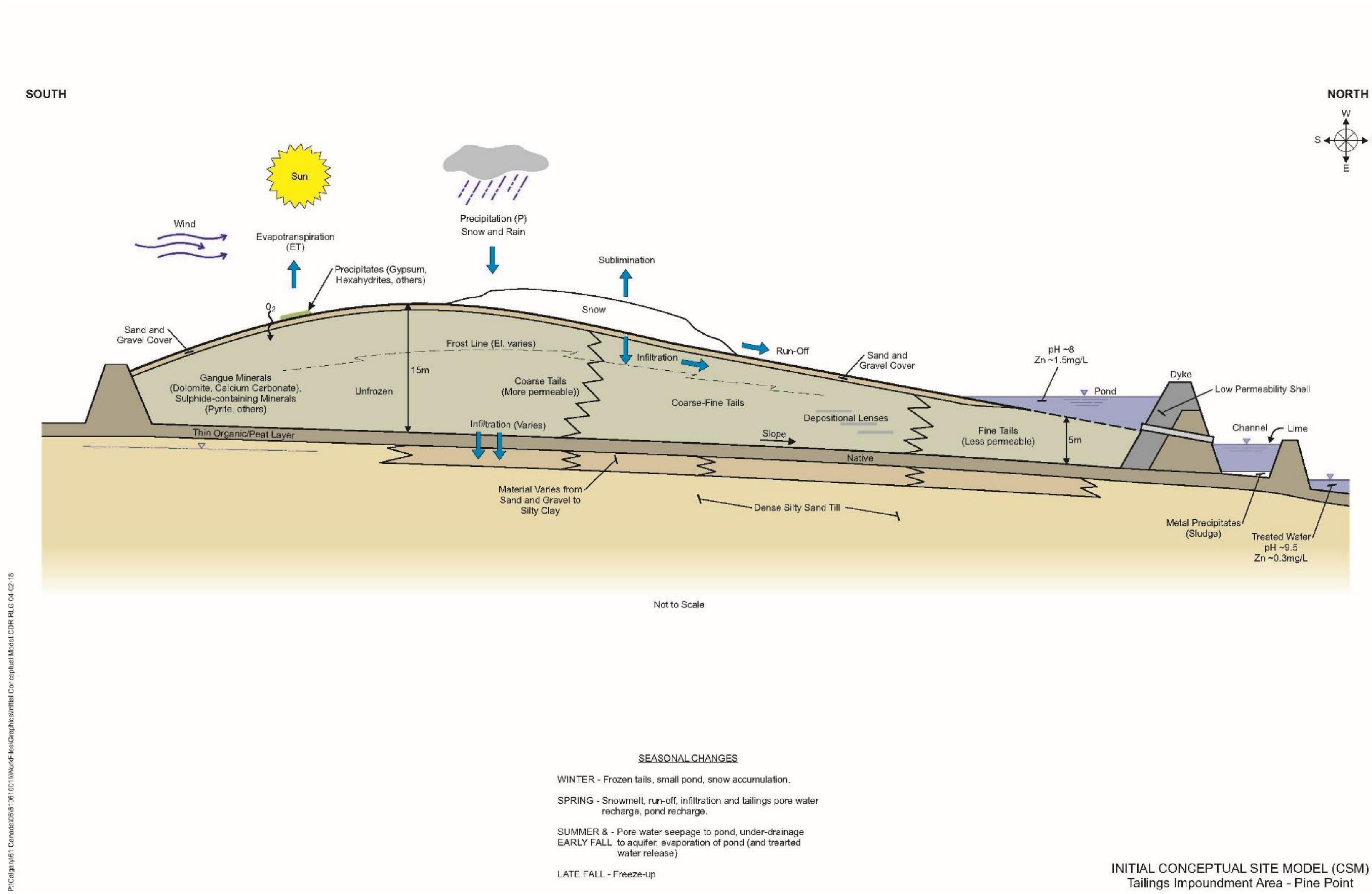

Figure 3 Initial Conceptual Site Model (CSM) Illustration – modified geologic cross-section through TIA

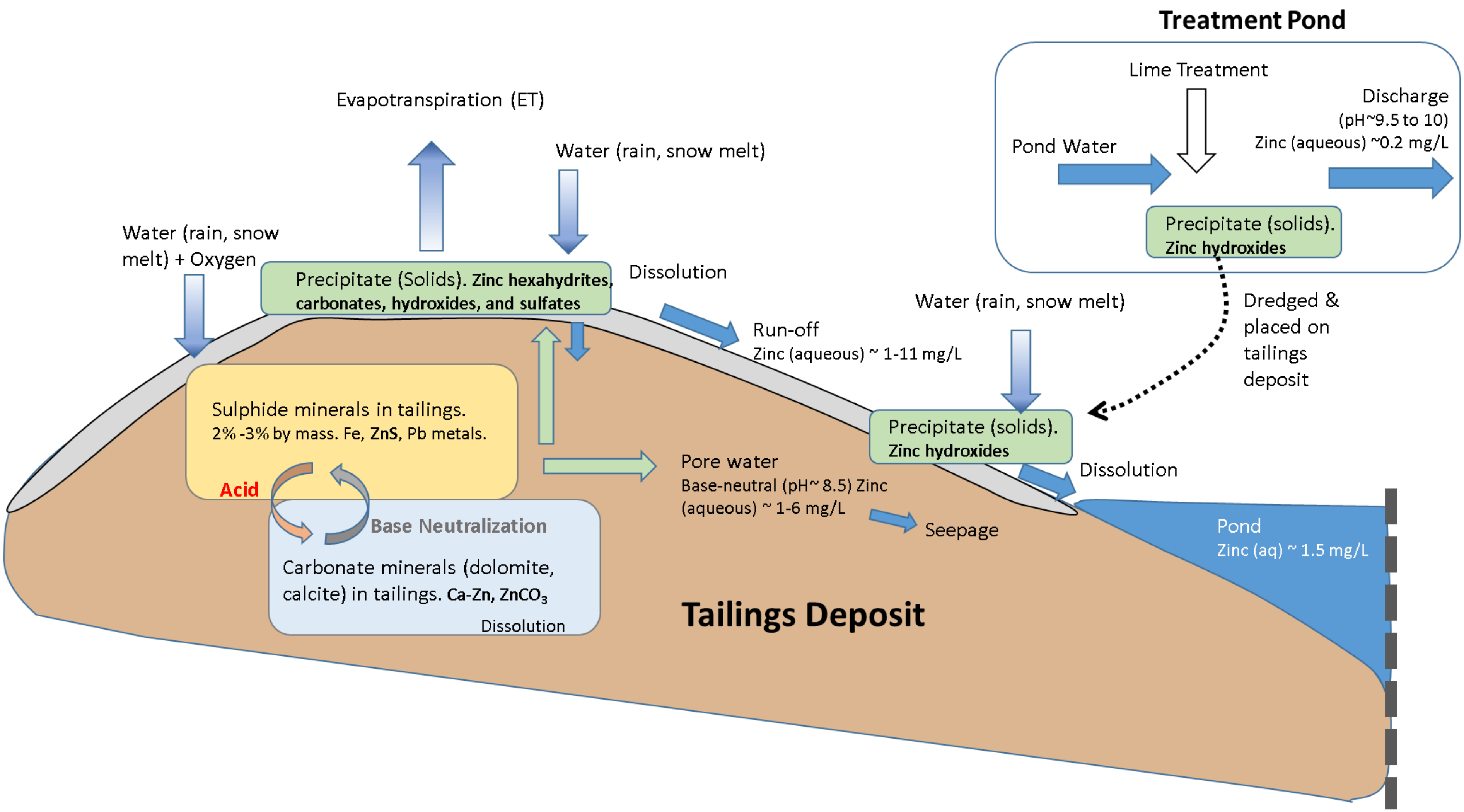

Figure 4 CSM Illustration – interpretation of geochemical reactions involving zinc metals at the TIA

3.0 Closure Goal & Principles

The closure goal at the TIA is to return it to viable and self- sustaining ecosystem, as practicable, that is compatible with a healthy environment and with human activities. This goal is consistent with Teck's approach to responsible mine closure that focuses on returning the land to a stable state for post-mining land uses and healthy ecosystems. The closure goal may be modified through engagement with stakeholders during reclamation research, and the closure and reclamation plan update process.

Successful closure and reclamation of the TIA at Pine Point Mine involves meeting the guidance contained within Teck's Sustainability Strategy objectives, incorporating input from First Nations and Communities of Interest (COI), fulfilling the requirements of Teck's current Type B Water Licence (MV2017L2-0007), meeting the commitments made to international associations, and developing a Closure and Reclamation Plan that complies with MVLWB Guidelines (2013).

3.1 Teck's Sustainability Strategies & Guiding Principles

Teck's Sustainability Strategy was developed to help integrate sustainability into their business by considering social and environmental objectives alongside financial objectives in planning and operations. Principles within the Sustainability Strategy will be applied to the Pine Point TIA to the extent practicable, considering the TIA has been inactive for 30 years. Teck's closure and reclamation approach includes the following key provisions:

- Public safety
- Water quality protection
- Healthy ecosystems; including conserving and enhancing biodiversity
- Returning mined areas to productive uses; including alternative uses for the land as suggested by Indigenous Peoples and local communities

Teck will also consider applicable components of the sustainable mining frameworks upon which they participate in to shape the closure and reclamation approach. Teck is a member of the Mining Association of Canada (MAC). Teck's Canadian operations participate in MAC's Towards Sustainable Mining (TSM) framework (MAC 2015), with management of mine closure being an integral part of the MAC members' commitments made under the TSM Guiding Principles. Teck is also a member of the International Council for Mining and Metals (ICMM), which requires its members to implement the ICMM Sustainable Development Framework. This framework commits members to integrating a set of principles into corporate policies and all aspects of mine activities, including closure.

3.2 MVLWB Closure Principles

In accordance with the MVLWB, closure objectives are guided by four core closure principles applicable to mine sites. The four core closure principles are provided below and will be considered when developing closure objectives and reviewing potential closure options.

1. **Physical Stability** – Any project component that remains after closure should be constructed or modified at closure to be physically stable, ensuring it does not erode, subside, or move from its intended location under natural extreme events or disruptive forces to which it may be subjected. Closure and reclamation will not be successful in the long term (e.g., 1000 years) unless all physical structures are designed such that they do not pose a hazard to humans, wildlife, aquatic life, or environmental health & safety.
2. **Chemical Stability** – Any project component (including associated wastes) that remains after closure should be chemically stable; chemical constituents released from the project components should not endanger human, wildlife, or environmental health and safety, should not result in the inability to achieve the water quality objectives, and should not adversely affect soil or air quality in the long term.
3. **No Long-Term Active Care Requirements** – The proponent must make all practical efforts to ensure that any project component that remains after closure does not require long-term active care and maintenance. Thus, any post-closure monitoring can only continue for a defined period of time. Physical and chemical stability will help ensure achievement of this principle.
4. **Future Use (including Aesthetics and values**) – The site should be compatible with the surrounding lands and water bodies upon completion of the closure activities.

Of the four core closure principles, chemical stability and the no long-term active care requirement currently require additional measures to attain the objectives and are the focus of this research plan due to the persistence of metals leaching from the TIA. The current physical stability of the TIA embankment structures and tailings pile is well controlled under Teck's OMS program but modifications may be needed to provide no long-term active care. Future land use is highly dependent on the closure objective selected and will require further consideration and stakeholder engagement.

4.0 Closure of Tailings Containment Areas

Closure objectives are statements that clearly describe what the selected closure activities aim to achieve. Well-developed closure objectives should be measurable, achievable, and appropriate to the mine component area requiring reclamation, which is the TIA in this case. The MVWLB Guidelines – Section 3.3.4 – provide example closure objectives for tailings containment areas. These closure objectives are likely applicable to the Pine Point TIA and are listed below in Table 3, along with commentary regarding the current condition of the TIA in relation to the objectives, outstanding items that remain to fulfill the current closure plan, and remaining uncertainties related to the objectives that will drive the research needs contained within this plan. The remaining uncertainties are categorized in relation to site understanding (CSM) and for closure options (CO) development. A brief description of the site conditions and the feasibility of meeting the objectives follow the table, with the initial feasibility determination shaded and italicized. The questions generated from review of each objective are also listed and are linked with the figures in Section 5 by an identification tag. The objectives are not mutually exclusive, and thus, any improvements made to address one objective are likely to have positive impacts on the other objectives.

The content is focused on the technical aspects of closure and reclamation approach at this time. It is recognized that consultation and stakeholder engagement are needed to further develop the social, cultural, and other non-technical aspects that may require research or study prior to the closure plan update. For example, the future land use and blending of the pile into the surrounding area are two items of likely discussion and modification pending stakeholder input.

Table 3 Closure Objectives for Tailings Containment Areas

Closure Objective	Current Condition	Outstanding Items for Completion of Current Closure Plan	Remaining Uncertainties - Site Understanding and for Closure Options
Dust levels are safe for people, vegetation, aquatic life, and wildlife.	• Dust levels have been addressed with the existing coarse sand and gravel cover. • The dustfall monitoring program was previously completed (ceased in 1991).	• The cover will be completed over the tailings in the currently ponded portion of the TIA following the addressing of water quality concerns.	• None unless cover system is modified which may result in dust levels higher than those currently present at the site.
Remnant embankments and surfaces of tailings containment areas are physically and geotechnically stable in the long-term.	• Ongoing Operation, Monitoring, and Surveillance is being performed in accordance with the OMS Manual (Golder, 2018) • The current dykes: 1) are stable and meet current CDA stability requirements; 2) are annually inspected per Water Licence MV2017L2-0007; and 3) have a Dam Safety Review (DSR) every 10-years, per CDA guidelines. There are minor slope erosion issues and seepage issues on the North and West dykes that are monitored. (Golder, 2017; SRK, 2014 & 2015) • The two concrete spillway structures were upgraded in 2012 and likely meet CDA guidelines, but their design basis was not included in the provided documents. • Based on the regular monitoring of dykes and regular treatment of release of water from the facility, the TIA is considered to be in the Closure-Active Care phase of mine life.	• The proposed flattening of the downstream dyke slopes to about 3H:1V (from 2H:1V) will improve stability. • The two concrete spillways will likely be removed and replaced with a robust outlet system that will be more stable and not require operation.	• Changes to the dyke that may be needed to provide a long-term stable embankment under passive care and minimize risk of catastrophic and/or chronic release of tailings into the surrounding environment. • Possible classification reduction or delisting to non-dam landform (no ponding).
Piles blend with local topography and vegetation, where appropriate.	• Currently the TIA slopes and drains in the same general direction as surrounding topography. • TIA is an elevated feature in the local landscape. • Vegetation studies conducted between 1976 and 1987, including direct revegetation of the Pb-Zn tailings, indicated that revegetation was infeasible for several reasons. • Currently the coarse sand and gravel cover is not purposefully vegetated. • Vegetative growth on the dyke structures is removed if the trunks/stems exceed specific diameters due potential impacts to dyke integrity.	• Flattening of the dykes will provide additional blending (soften tie-in) with local topography compared to current condition.	• Further integration of the dyke and surface/cover into the surrounding area/closure landscape. • Implications of volunteer (naturally emergent) vegetation growth in long term. • Metals accumulation in volunteer vegetation and potential impact for future land use such as wildlife grazing. • Benefits of purposeful revegetation of cover.

Closure Objective	Current Condition	Outstanding Items for Completion of Current Closure Plan	Remaining Uncertainties - Site Understanding and for Closure Options
Effluent discharge impacts on downstream ecosystems are minimal and align with designated future uses.	• Operational practices for water treatment are detailed in the Water Treatment Manual (Teck 2017) and Water Treatment Management Plan for Upset Conditions (SRK 2018). • Water is actively chemically treated with hydrated lime and flows through the settling pond. The resulting zinc concentration in the discharged water is below licence limits (0.5 mg/L). • Additional sample locations (part of SNP network) along the flowpath (muskeg/wetlands areas) and at the surface water receptor (Great Slave Lake) are also monitored for impacts and adherence with CCME water quality criteria. • Samples collected along the SNP indicate some natural attenuation/reduction in zinc concentrations.	• Water quality improvement and completion of active water treatment	• The rate of metal leaching is not well understood, and thus, the duration of leaching resulting in zinc concentration in surface water (pond) above the Water Licence limit of 0.5 mg/L is uncertain. • The seasonal change in zinc concentration in the pond (currently) and the potential for large contaminant mass flux slugs (i.e., with freshet). • The sensitivity of water quality and discharge impacts as the result of climate change. • Long-term ability for existing muskeg/wetlands and natural processes to reduce zinc concentrations to acceptable concentrations in route to lake. • The presence of prevailing reducing conditions in groundwater & surface water. • Whether discharge of pond water – in present and future condition upon completion of current closure plan – causes an unacceptable risk to the environment, or whether the remaining impacts can be naturally attenuated. • The designated future land use.
The threat that the tailings containment area becomes a source of contamination (e.g., tailings migration outside of contained area, contamination of water outside of container area) has been minimized or eliminated.	• Tailings migration potential outside TIA significantly reduced/eliminated through established perimeter dykes, cover system, and over-topping mitigation. • Ongoing Operation, Monitoring, and Surveillance being performed in accordance with OMS Manual (Golder, 2018)	• No additional items outside completion of dyke flattening, cover construction, and spillway modification.	• Potential migration of tailings addressed with long-term dyke and cover stability. • Potential for the regional groundwater to interact with the base of the pile appears unlikely, but is uncertain. • The presence of fine tailings contributes to ponding & influences metals concentrations.
The risk for the occurrence of ARD/ML has been minimized.	• ARD occurs but is neutralized by the presence of gangue minerals. Neutralized leachate does contain elevated concentrations of metals. • Previous investigation has provided valuable information for development of a conceptual site model and for feasibility screening of closure options.	• No additional items outside water quality improvement and completion of active water treatment.	• Tailings are sorted as indicated & sulphide containing material is well dispersed in the pile. • Minerals (primary and secondary) been accounted for and the mass distribution of minerals is known. • All surface water inflows have been effectively diverted from the TIA. • Site climatic conditions and water balance understood well enough to support option selection. • Feasibility of passive biological, chemical, or physical treatments • Feasibility of active biological, chemical, or physical treatments to meet closure objectives, specifically long-term passive interests. • Exploitation of evapotranspiration (ET) potential with the current cover or modified cover (e.g., store and release type). • Use of ET potential (e.g., with active spraying) in lieu of active chemical treatment, or other options, to reduce risk of occurrence or magnitude of impacts to surface water.
The risk of catastrophic and/or chronic release of tailings into the surrounding environment has been minimized.	• See discussion on remnant embankments and tailings migration above		

4.1.1 Dust Level Acceptability

A dustfall emissions program was established in 1988 to monitor and measure total solids, lead, zinc, and cadmium concentrations contained in dustfall originating from the tailings impoundment. Due to the reoccurrence of sizable dust plumes, a coarse sand and gravel cover was installed between 1990 and 1991. The cover extends over 1,250 acres, or 86%, of the tailings surface. Due to the apparent effectiveness of the cover in reducing dust migration problems and reducing zinc and lead concentrations, the dustfall monitoring program was discontinued.

The only area that remains uncovered is the soft tailings area adjacent to the downstream dyke. This is the area where water ponds against the dyke and is actively treated for release. Due to the presence of the ponded water, dust migration is an unlikely issue for this area. The current closure plan includes covering of the remainder of the tailings surface when the water quality issues are resolved.

Meeting the dust level acceptability objective appears feasible based on the current stability of the cover and the planned completion of the cover. Integration of the cover approach with the selected closure option for the ARD/ML issue is also required, and may result in some modification, but not to the detriment of air quality.

4.1.2 Embankment Structure Stability

Overall, it appears that the current embankments are stable and meet applicable guidelines (e.g., Canadian Dam Association (CDA) Dam Safety Guidelines (2013)) and Application of Dam Safety Guidelines to Mining Dams bulletins (CDA 2014) but have some minor slope erosion and seepage issues through the embankment. Ongoing efforts following the OMS Manual will continue to verify the current embankment stability and CDA compliance.

The most recent (2014) Dam Safety Review (DSR) reported that the observed condition of the TIA and its components were satisfactory, with the principal qualifications being rills on some downstream segments of the North and West Dykes and wave-induced erosion and shallow slope deformation on the upstream face of the North Dyke. In accordance with the DSR results, the OMS manual was updated and the current 2018 version included a review of stability factors, which were found to be in excess of the CDA requirements with the exception of post-earthquake criteria, which is out of date. Furthermore, an alert water level (201.6 m) and maximum operational water level (201.8 m) were developed in accordance with CDA (2013) guidelines to prevent overtopping.

The two concrete spillway structures were upgraded in 2012 and likely meet CDA guidelines, but their design basis was not included in the provided documents. The two concrete spillways are in good condition and likely also meet applicable stability guidelines. It is anticipated that the concrete spillways will be removed at closure and replaced with robust outlets that will allow runoff to be conveyed to the downstream watercourse(s). The spillways should be designed to minimize the need for continued inspection and maintenance.

Following the cessation of active water treatment and the elimination of ponded water, Teck's plan to reduce the downstream slope angle from the current 2.0H to 1.0V to 3.0H to 1.0V will further improve dyke stability. In addition, construction of these modifications will repair the slope erosion rills and sloughing (caused by runoff and wave action) and reduce the probability of future slope erosion. Reducing the slope gradient of the recontoured dykes will also enhance revegetation of the slopes. Consequently, the proposed closure approach will increase embankment stability, mitigate seepage through the embankment, repair the erosion damage and reduce the probability of future embankment slope erosion.

Should the TIA move to the Closure–Passive Care phase (as described above), in which the system is considered stable with no water treatment or management of the pond, such that water may be passively released from the system, the design criteria for the dam should be revised based on recommendations by CDA (2014) and Teck (2014).

Meeting the embankment stability objective appears feasible based on the current stability of the structure and the planned stability improvements, but further modifications may be needed following stability evaluation and establishment of the final design basis. Integration of the embankments with the selected closure option for the ARD/ML issue is also required, such as possible classification reduction or delisting to non-dam landform (no ponding).

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
What changes to the dyke are needed to provide a long-term stable environment in alignment with the selected closure option?	CO – General -1
Can the dyke be delisted to non-dam landform through integration with the selected closure option?	CO – General – 2 X
Is design significantly robust to stand up to climate fluctuations?	Other Considerations

Additional information and/or study required to assess geotechnical/structural stability of the embankments and to inform future design include the following, which will also be considered in the research plan:

- Identify potential failure modes and perform stability evaluation/modeling
- Develop spillway concept – the robust outlet system
- Explore possible classification reduction for dykes and potential delisting with integration into closure scenarios considered to address ARD/ML impacts

4.1.3 Blending with Local Topography & Vegetation

The TIA is an elevated feature within the local topography and the annual accumulation of ponded water against the North dyke requires active-care to ensure dyke stability. Should the TIA move to the Closure–Passive Care phase, in which the system is considered stable with no water treatment or management of the pond, the plan to reduce the slope gradient and re-contour the dykes will help soften the tie-in with local topography. Furthermore, it will enhance natural revegetation of the slopes.

Meeting the local topography blending objective from a landform perspective appears feasible based on the planned dyke softening approach, but further modifications may be needed to meet future land use needs. Significant landform modification is likely infeasible due to the large quantity of tailings present.

Several vegetation studies were conducted in the 1970's and 1980's to investigate the potential use of vegetation to stabilize the surface of the tailings impoundment at Pine Point. During the studies, introduced grass and legume species, introduced and native woody species, and native wetland sedge and rush species were planted on tailings of varying texture and salinity. The studies revealed that the tailings surface provided a harsh environment for the establishment of plant species. The tailings surface was deficient in certain essential plant nutrients, such as nitrogen, phosphorous, and potassium, and contained potentially toxic concentrations of salts and metals, such as zinc and lead. Climatic factors exposed the plant species to extremely low winter temperatures, high winds which resulted in tailings surface erosion, and variable precipitation which resulted in moisture stress. In addition, the forage plant specimens that survived accumulated lead and zinc in the leaves at a concentration in exceedance of maximum tolerable levels for domestic animals. The studies concluded that the use of vegetation to stabilize the surface of the TIA was not a viable option and that alternative method of stabilization (such as the installed coarse sand and gravel cover) should be considered.

The current cover is relatively devoid of significant vegetation. However, some volunteer woody species appear to be establishing themselves. Trees that pose a damage risk to the dykes, in the event of future treefall, are routinely removed.

Meeting the local topography blending objective from a vegetation perspective across the entirety of the TIA appears infeasible in the short-term due to several of the same reasons that challenged the development of vegetation on the tailings surface. Namely, nutrient deficiency, lack of suitable growth medium, and the relatively harsh environmental conditions. However, there appears to be potential for selective revegetation of a portion of the TIA depending on the closure option selected. Integration of the revegetation approach with the selected closure option for the ARD/ML issue is also required, such as to limit metals uptake in vegetation to protect wildlife.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
How will the dyke be integrated into the closure landscape?	CO – General -1
Can the surface/cover be modified to better blend with the surrounding area – through both contouring and revegetation?	CO – Capping focus – 1
Is metals accumulation occurring in emergent vegetation on the current cover?	CSM – Receptors – 2
Is metals accumulation in cover vegetation a concern for future land use (e.g., wildlife grazing) and what are the implication for any cover modifications that may be considered?	CO – capping focus – 6

4.1.4 Acceptable Effluent Discharge Impacts on Downstream Eco-Systems

Under Teck's current Type B water licence, it was ruled that potential adverse environmental effects are insignificant or mitigatable using the current technology, where ponded water is treated prior to discharge under the current Closure-Active Care phase of mine life. Water samples are collected prior to treatment, post-treatment, along the discharge channel, and at Great Slave Lake as part of the SNP to ensure compliance with established EQC for discharged water. This ensures parameter concentrations are at an acceptable level, such that downstream eco-systems are not negatively impacted.

Average water quality data collected over the last 10 years illustrates continued compliance with EQC following active lime treatment of TIA water. Prior to treatment, zinc concentrations have averaged 1.5 mg/L (station 35-1a), which is approximately three times the EQC of 0.5 mg/L. Following treatment (station 35-1b), the average zinc concentration over the past 10 years has been reduced to 0.2 mg/L, refer to Figure 5**.** A slight increase (still below 0.5 mg/L) has been observed in the last 5-7 years due to a reduction in the amount of lime used in the treatment process.

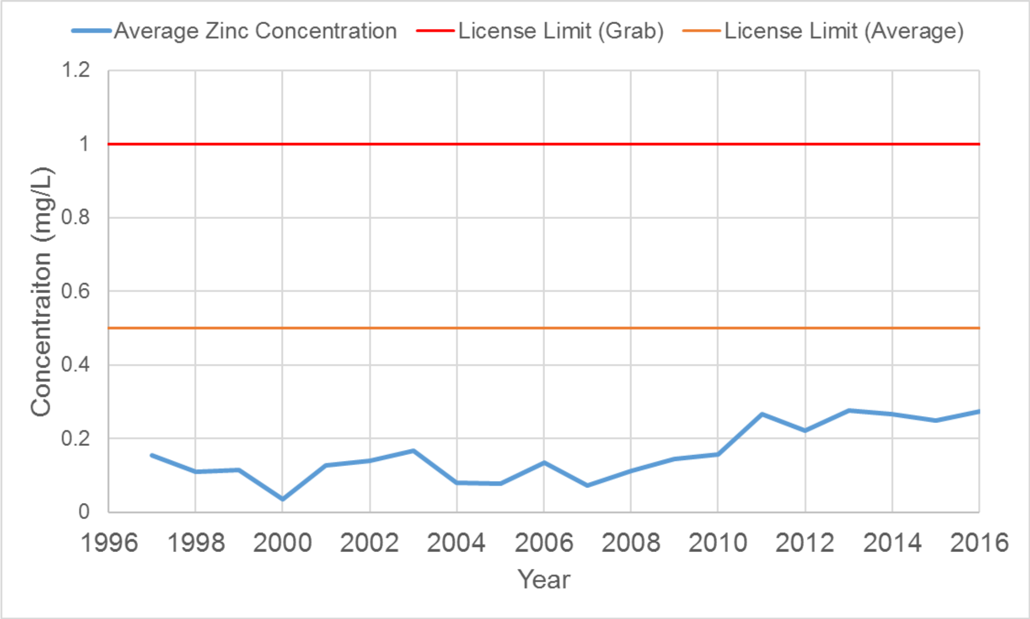

Figure 5 Past 20 years of treated water discharge monitoring data

Zinc concentrations at the two sample stations encountered next along the water flow path to Great Slave Lake (stations 35-5 and 35-4) are further reduced below 0.2 mg/L. The remaining five stations, including two stations at Great Slave Lake (stations 35-9 and 35-10) indicate zinc concentrations below 0.03 mg/L (the CCME guideline for the protection of freshwater aquatic life), with few exceptions, refer to Figure 6.

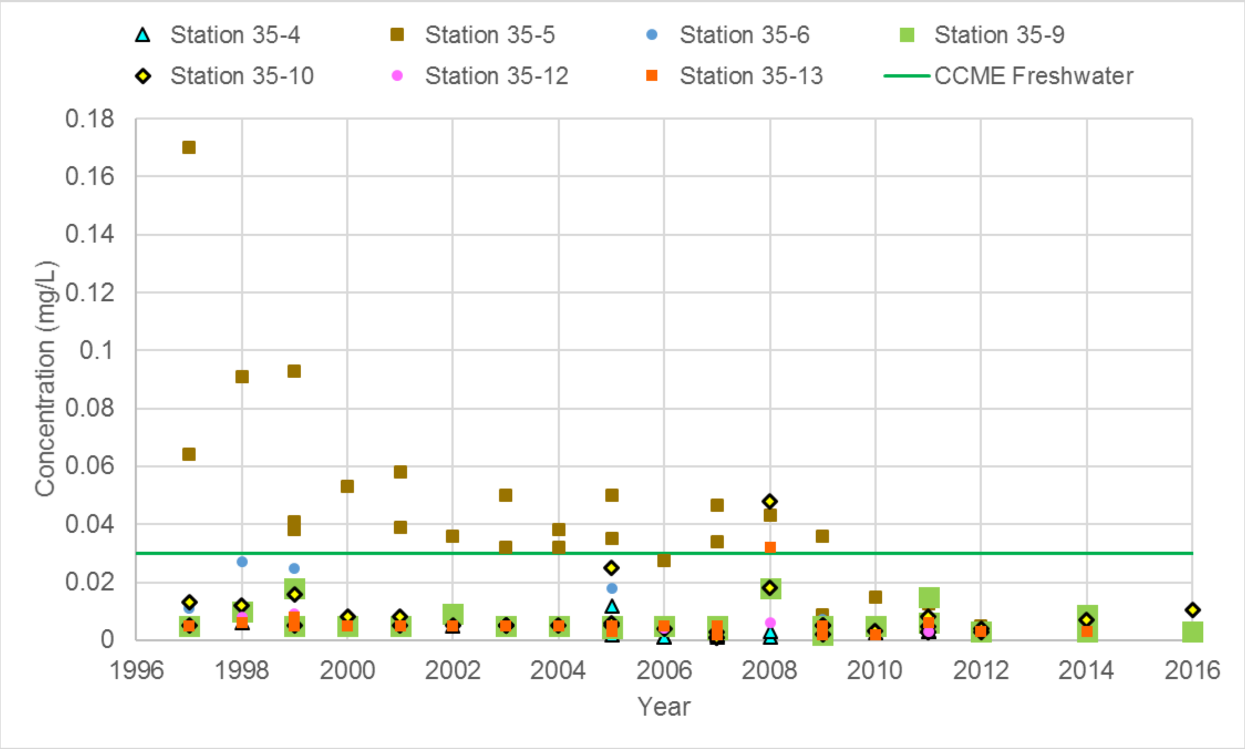

Figure 6 Past 20 years of down gradient surface water monitoring data

There are several remaining uncertainties regarding the acceptability of effluent discharge impacts on the downstream ecosystem as listed in Table 3. A better fundamental understanding of the rate of leaching at the site and future concentrations of zinc within run-off are needed to inform the closure strategy regarding the ARD/ML issue. The natural reduction in the zinc concentration in surface water between the TIA discharge and Great Slave Lake monitoring stations indicates potential to incorporate natural attenuation/passive treatment into the selected closure option and will be investigated.

Meeting the acceptable effluent discharge impacts on the downstream ecosystem objective is feasible with active chemical treatment, but may or may not be feasible utilizing other mitigation approaches.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
Is the rate of metal leaching well understood, and how long will it be until the zinc concentration falls below the Water Licence limit of 0.5 mg/L?	CSM – Fate & Transport – 3
How much can existing muskeg and natural processes reduce zinc concentrations in route to the lake?	CSM – Fate & Transport – 4
Are reducing conditions natural to the area in groundwater and surface water?	CSM – Fate & Transport – 2
Can pond water be discharged and allowed to naturally attenuate, or will it cause and unacceptable risk to the environment?	CSM – Receptors – 1 CO – Treatment focus – 1

4.1.5 Diminished Threat of Contamination from Tailings

The threat of contamination from tailings includes two primary aspects; 1) the physical migration potential of the tailings outside the TIA, and 2) the degradation of water quality outside the TIA.

Physical tailings migration potential outside the TIA is significantly reduced/eliminated through the perimeter dyke and cover system. There is current risk of fine tailings mobility from the uncovered portion of the tailings pile with a flooding and overtopping event. Thus, the need for the OMS program for the TIA. Tailings mobility should be essentially eliminated upon completion of the cover system and construction of the long-term stable dyke and spillway system.

Meeting the diminished threat of contamination from tailings – physical migration potential – objective is feasible with the dyke and cover system.

Potential degradation of surface water quality was discussed above in Section 4.1.4, and the threat of contamination posed by metal precipitates formed in the treatment channel is mitigated by dredging the material and placing it within the TIA. Potential degradation of groundwater appears unlikely, but is uncertain. The coarse sand and gravel cover does allow water infiltration into the tailings, and a locally mounded groundwater table has been observed within the TIA – providing a vertical gradient downward toward the regional groundwater table. However, the observed mounding also indicates that the materials underlying the TIA may have relatively low permeability resulting in limited contaminant flux. And the quantity of infiltration is relatively low on an annual basis, as discussed previously with regard to the water balance. Previous testing of the aquifer below the tailings impoundment yielded an average zinc concentration of 0.09 mg/L, which is anticipated to be similar to background conditions.

Meeting the diminished threat of contamination from tailings – degradation of water quality – objective is likely feasible since the threat to groundwater appears to be relatively low under current conditions and could be improved with the addressing of the ARD/ML issue.

4.1.6 Reduced Risk of ARD/ML Occurrence

The concentration of zinc in the ponded water has decreased with time, but its persistence at concentrations above the Water Licence limit poses a challenge to developing a passive care situation in the near term. The CSM in Section 2.4 illustrates the uncertainty as to when the metals concentrations will fall below the applicable limits, and there are several other remaining uncertainties regarding the risk of ARD/ML as listed in Table 3. The initial understanding of ARD and metals fate and transport relies on development of models for both the site water budget and geochemical processes. Consequently, better understanding the continuation of ARD/ML at the site and assessing closure options for remaining ARD/ML impacts that will satisfy this closure objective, is a primary focus of this research plan and is discussed in Section 5.

Meeting the reduced risk of ARD/ML objective appears to be potentially feasible through mitigation approaches as discussed in Section 5, but further research is required to substantiate the feasibility of the closure options.

4.1.7 Preventing Catastrophic and/or Chronic Release of Tailings

The prevention of catastrophic and/or chronic release of tailings into the environment is largely dependent on the physical and geotechnical stability of the existing embankments and mitigation of tailings mobility as discussed previously. The liquefaction potential of the tailings due to seismic activity will need to be considered, as will the effects of climate change on long-term stability of the TIA.

Meeting the prevention of catastrophic and/or chronic release of tailings objective appears feasible based on the current stability of the structure and the planned stability improvements, but further modifications may be needed following stability evaluation and establishment of the final design basis.

5.0 Closure Options for Remaining ARD/ML Impacts

This section provides the initial closure options for the TIA to address remaining ARD/ML issues following MVWLB guidelines, which provide several closure options for progressive and post-closure reclamation to address ARD/ML. A summary of the current condition and feasibility of the approaches is provided. Some closure options are removed from consideration due to likely infeasibility, while others are retained for further consideration. Remaining uncertainties are identified for potentially feasible options and provide the directional needs for research described in Section 6. The closure option, its approach to reducing ARD/ML impacts through either elimination or mitigation, the feasibility screening result, and potential application to the TIA is provided in Table 4. Additional description regarding each closure option is provided in the paragraphs below.

Table 4 Closure Options for Remaining ARD/ML Impacts

Closure Option	Elimination Approach	Mitigation Approach	Feasibility	Potential Application
1. Flood underground mine workings or place potentially acid generating materials completely under water or underground.	X		Not Feasible	Not Applicable. Tailings impoundment is unlined and above water table.
2. Utilize freezing conditions (ground or air) to limit the formation and discharge of leachate.	X		Not Feasible	Not Applicable. Tailings impoundment is not located in permafrost zone and climate change indicates further warming of area.
3. Place potentially acid generating rock/material within the center of the waste pile to encapsulate it by other host rock, non-reactive material, and/or permafrost.	X		Not Feasible	Not Applicable. Source material is dispersed throughout tailings pile. Some potential to consolidate or isolate precipitate minerals that will be considered in mitigation approaches.
4. Control acidic and contaminated water at the source; prevent contaminated water flows. e.g., prevent water infiltration – seal	X		Not Feasible	Not Applicable. This would be fully negating ARD by removing sources of water and oxygen to the tailings or other controls. The TIA is unlined, and installation of a plastic/non-permeable seal over the entire area – though highly effective – would be cost prohibitive due to the size.

Closure Option	Elimination Approach	Mitigation Approach	Feasibility	Potential Application
5. Prevent or reduce water infiltration into material stored above ground that could generate ARD/ML by installing cover systems or seals. e.g., reduce water infiltration - cover		X	Potentially Feasible	Potential to modify existing cover system including application of store and release approach, thickening the cover, reducing cover permeability, consolidating the tailings footprint, and targeted reduction of higher infiltration areas.
6. Mitigate consequences of ARD by the use of treatment systems, preferably for in-situ conditions. Utilize **passive/semi-passive** treatment options: Chemical, Biological, and/or Physical		X	Potentially Feasible	Constructed or natural system. Fully passive system does not require any power to operate and no maintenance within the design life period. Semi-passive system will require some maintenance, but it is typically minimal. Refer to specific examples below.
a. Chemical E.g., open limestone channels/drains, adsorption, and mineral precipitation in settling ponds and along flow paths		X	Potentially Feasible	Potential to incorporate limestone channels/drains, which would have water treatment benefits similar to current active lime treatment.
b. Biological E.g., Sulphate reduction and precipitation of metal sulphides in natural wetlands; phytoremediation		X	Potentially Feasible	Potential for sulphate reduction and precipitation of metal sulphides in natural wetlands; already occurring naturally in organic/peat layer below TIA and in muskeg downgradient of TIA. Remove ponding. Let zinc in water naturally attenuate through muskeg in route to lake. Could also construct peat treatment cells for polishing residual metals.

Closure Option	Elimination Approach	Mitigation Approach	Feasibility	Potential Application
c. Physical E.g., Particle filtration, adsorption, settling from water phase.		X	Potentially Feasible	Treatment may be combined with another approach. Indications are that current cover system is providing some physical, passive benefit, to controlling particle migration. Sedimentation pond is currently is used to settle metal precipitates generated from chemically treated water. Filtering in natural media, such as wetlands.
7. Mitigate consequences of ARD by the use of treatment systems, preferably for in-situ conditions. Utilize **active** treatment options: chemical, biological, and/or physical		X	Potentially Feasible	Constructed engineered system. Active systems require power to operate and maintenance for continued functionality. Refer to specific examples below.
• Chemical E.g., chemical treatment involving neutralization or mineral precipitation; ion exchange and adsorption		X	Potentially Feasible	Current approach being used (lime addition to form metal hydroxides). May require long-term active care.
• Biological E.g., sulphate reduction and precipitation of metal sulphides in bioreactors		X	Potentially Feasible	Sulfate-reducing bioreactors can be constructed in cells operated as part of a treatment process. Zinc would be expected to co-precipitate as a metal sulfide. Peat sorption is also an option.
• Physical E.g., membrane filtration, or evaporative drying)		X	Potentially Feasible	Exploit ET potential by spray irrigation on top of tailings pile.
8. Divert or intercept surface and groundwater from potential sources of ARD/ML.		X	Feasible	Surface water inflows to TIA appear to have been, or can be, eliminated. Indication is that natural groundwater is below base of tailings in reducing conditions.

5.1 Closure Options

The following sections provide a discussion on the closure options and basis for rendering the initial determination of feasibility provided in Table 4. This determination has been made through consideration of the currently available information and the CSM, as well as experience gained from other tailings sites with ARD/ML issues. As identified in Table 4, there is a relatively large array of closure options that could be feasible for the TIA, singularly or in combination with other options. A best available technology (BAT) review will be performed first to narrow the options to those that may be best suited for the TIA. The BAT review will focus on the treatment options (passive or active, chemical, biological, or physical). A similar review effort will be performed for cover options. There are a couple of questions that pertain to the site understanding and will factor into closure option selection, and specifically with capping options, that will be addressed with this research plan as tabulated below.

Answering the following questions through research are recommended to aid in closure option selection:

Question	Tag
Are the site climatic conditions and water balance understood well enough to support option selection?	CSM – Fate & Transport – 6 CO – Capping focus – 3
To what extent does the presence of fine tailings contribute to ponding and influence metals concentrations in surface water?	CSM – Fate & Transport – 7 CO – Capping focus – 2

5.1.1 Flooding/Submergence/Underground Disposal

Two possible closure options listed in the MVLWB Guidelines for addressing ARD/ML were combined and addressed under Item 1 in Table 4, due to similarity of the approach and rationale as to why these options are not feasible for the TIA. The two closure options are 1) Flood underground mine workings – which was extended to flood TIA in this case, and 2) Place potentially acid generating materials completely under water or underground.

The principle behind flooding or submerging an ARD/ML area is that the additional water can dilute existing metal concentrations in pore water and mitigate the formation of precipitates, which are amenable to dissolution and transport via run-off and seepage. However, the TIA is an above-ground, unlined, feature in a net ET area. As such, flooding/submerging would require importing (pumping) water into the TIA on a long-term basis, which is impractical from a closure standpoint as it would require ongoing, active care. Flooding/submergence may also results in physical and geotechnical instability of the embankment structures; under current operation alert and maximum operational water levels have been established to prevent overtopping of the dykes. Altering these water levels could potentially increase the risk of catastrophic failure and/or chronic release of tailings.

This option is deemed not feasible and no further evaluation is necessary.

5.1.2 Use Freezing Conditions to Mitigate Leachate Formation

Due to the sub-arctic climatic conditions found in many regions throughout the Northwest Territories, one recommendation from the MVLWB guidelines is to utilize freezing conditions (ground or air) to limit the formation and discharge of leachate. When tailings are frozen, the water phase is immobilized, which prevents run-off and seepage. This is observed at the TIA from October through April when the average mean temperature is below 0ºC. However, climatic conditions at the TIA do not support this approach as the TIA is located in a discontinuous sporadic permafrost zone and from May to September, the tailings thaw, and snowmelt and precipitation contribute to the ponding of water along the North dyke. While site-specific data on the presence or extent of permafrost within the TIA or under the dykes are not available, it is unlikely that the permafrost, if existent, would be insufficient to support this approach.

This option is deemed not feasible and no further evaluation is necessary.

5.1.3 Encapsulate Acid Generating Material

This option envisions encapsulating reactive mine wastes within mine wastes, host rock, and/or permafrost, which do not contain reactive materials, in an effort to prevent oxygen and water from interacting with the reactive waste materials. This option is not feasible for the TIA as reactive materials (sulphide containing minerals) are likely dispersed throughout the TIA, leaving negligible "non-reactive" material to use for encapsulation. The discontinuous sporadic permafrost zone prevents permafrost from serving as the encapsulation medium.

This option is deemed not feasible – pending verification of source contamination.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
Is it certain that the tailings are sorted as indicated and sulphide containing material is well dispersed in the pile?	CSM – Source Definition – 1

5.1.4 Install Seal System to Eliminate Contaminated Water at Source

This option attempts to fully prevent and control the formation of acid and metals leaching at the source by installing a seal system to eliminate water and oxygen infiltration into the tailings. It would also prevent and control dissolution of metal precipitates (zinc hexahydrates and zinc hydroxides). Thus, eliminating metals mobility and significantly reducing the zinc concentration in the ponded water. Preventing water and oxygen infiltration into the tailings would entail the design and installation of an engineered cover with a geomembrane or geosynthetic clay liner. Installation of a seal system is anticipated to be highly effective for the TIA considering the primary source of water in oxygen to the tailings is through surface infiltration. Seal systems have been proven effective in other applications; they are commonly used in landfill and some mining applications. However, there is risk to the long-term integrity of the seal due to continued exposure to annual freeze/thaw cycles. The approach, though likely highly effective, is cost prohibitive as the area to cover for this application is significant (~700 hectares), would likely require re-countering of the existing tailings, and require inclusion of liner protection materials, such as sand or geotextiles.

Thus, the feasibility of sealing the entirety of the TIA is deemed not feasible. However, sealing of select areas where higher infiltration occurs or more metal precipitates are more prevalent may be feasible. Additional research into the application of selective seal systems at the TIA site is required.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
• Have all minerals (primary and secondary) been accounted for and what is the distribution of the minerals by mass?	CSM – Source Definition – 2
• Is it certain that the regional groundwater does not interact with the base of the tailings pile?	CSM – Fate & Transport – 1

5.1.5 Install Cover Systems to Reduce Water Infiltration

This option limits net percolation through the tailings, without attempting to fully prevent infiltration. Reduction of water infiltration potentially reduces acid generation and the dissolution of precipitates (zinc hexahydrates and zinc hydroxides) and the resulting zinc concentration in the ponded water. This option would also act to limit oxygen diffusion into the tailings. The regional climatic regime supports this as a potentially feasible option because evapotranspiration is higher than precipitation. However, seasonal high infiltration periods (e.g., from snowmelt during the spring freshet) or high infiltration periods generated from rain events, would need to be managed through storage in the cover or through other parts of the cover design.

This option is deemed potentially feasible.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
How does the zinc concentration in the pond change seasonally? Are there currently any large mass flux slugs to the pond that would be challenging to manage? How sensitive is the pond water quality to climate change?	CSM – Fate & Transport – 4
Can the surface/cover be modified to enhance passive ET using a store and release or other approach?	CO – Capping focus - 5
Have all surface water inflows been effectively diverted from the TIA?	CO – Capping focus – 1

Additional information and/or study required to assess and develop the cover system design include the following, which will also be considered in the research plan:

- Develop the cover concept; including functionality, configuration, material volumes, re-contouring, and installation approach.
- Refine the TIA water balance with representative climatic data, while considering climate change, and accounting for cover modification scenarios.
- Verify the tailings composition below the cover and in the ponded area where fine tailings are suspected to be present.
- Refine the CSM with regard to geochemical reactions and the fate and transport of zinc, specifically the precipitate forms containing zinc that are located near the surface of the pile which interacts with stormwater.
- Determine availability and type of local borrow sources to support a cover design. Assess cover material properties with regard to cover requirements (e.g., water storage capacity for store and release type).
- Consider revegetation strategies for future uses; considering species, metals uptake, aesthetics, etc.

5.1.6 Passive Treatment Options (Chemical, Biological, Physical)

Passive treatment options may include chemical, biological, or physical mechanisms for mitigating the transport of the chemicals of concern (i.e., zinc) from the source into the environment. These mechanism occur through natural processes (attenuation) and can be enhanced through the construction of engineered treatment zones where the physical and chemical conditions needed to support passive treatment can be controlled. Significant guidance on the use of passive technologies for the treatment of mining-influenced waters is available from multiple sources including the MEND Program (MEND, 1999).

This option is deemed potentially feasible.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
Can passive chemical, biological, or physical treatment be effective at the site?	CO – Treatment focus – 2

For the initial step in this research program, each of these approaches is considered potentially feasible. Additional information and/or study required to assess and develop the cover system design include the following, which will also be considered in the research plan:

- Perform a BAT review to identify potentially viable technology candidates
- Develop the treatment concept for potentially viable passive and active systems, including size and complexity of the system, estimation of treatment potential, and constraints and limitations
- Perform an initial screening of the technologies based on effectiveness, implementability, and cost

Evaluation of specific approaches is anticipated for the second year of the research program; if the results from work completed in the first year suggest that any or all of these approaches are still considered potentially viable. A brief summary of each of these potential approaches with potential insights for conceptual model development are included in the following sections.

5.1.6.1 Chemical – Passive Treatment System

This option would include the use of a chemical process, similar to the lime addition process that is currently being used to actively treat the ponded water. The current active treatment system uses the addition of lime to raise the pH to 9.5, which facilitates rapid precipitation of zinc hydroxides. The current system has been used for decades and found to be effective.

A limestone-drain is an example of a passive treatment system that could potentially meet the same treatment objectives as the current active treatment system, without the need for active operation. Limestone drains have been successfully employed to manage mine-influenced waters at multiple sites. While limestone drains may not result in pH values as high as the current active treatment system, this may be beneficial for long-term treatment because the current active treatment system occasionally results in treated water pH values in excess of 9.5, which is the maximum agreed to value under Teck's current Type B Water Licence. Operating at a lower pH, however, may also reduce the effectiveness of zinc removal.

If additional research and updated modelling suggests that a passive limestone drain may be effective, then technology specific testing could be completed to evaluate:

- Equilibrium pH values that can be achieved in a limestone drain
- Zinc concentration that can be achieved at the equilibrium pH
- Hydraulic retention time needed to approach equilibrium
- Limestone consumption rate

- Limestone passivation potential

Consideration would also have to be given to land/lease limits to incorporate the technology. These items would be evaluated no earlier than the second year of the research plan as described further in Section 0.

5.1.6.2 Biological – Passive Treatment System

Passive biological treatment of zinc occurs when sulfate in the effluent is reduced biologically to sulfide, facilitating the precipitation of zinc sulfide. Sulfate reduction occurs naturally in flooded, reduced environments where degradable organic material is present but oxygen is absent, for example in the sediment of ponds and in wetlands and peat-bogs. At the site, it is likely that some sulfate reduction is already occurring naturally in the sediments of the existing TIA pond. Furthermore, passive biological treatment can be designed to occur by directing flow into an area such as a wetland or a subsurface reactor that is augmented with a degradable material, such as wood-chips, straw or some other organic matter, mixed with other essential nutrients (i.e., nitrogen and phosphorous).

At the site, passive biological treatment is likely occurring naturally as mine-influenced water flows through peat sediments below the TIA (observed in previous investigations) and the soils and muskeg downgradient of the TIA discharge, as indicated by zinc concentrations below the CCME Guidelines for the protection of freshwater aquatic life at downstream SNP locations. Furthermore, recommendations from "wetlands treatment" testing performed in 1988 to evaluate metals removal and the hydraulic capacity of muskeg recommended additional testing and a pilot-scale evaluation if the approach was of interest to Pine Point Operations.

One of the first steps of a biological passive treatment at the TIA would be to determine the extent to which passive biological treatment is occurring naturally. If additional research and updated modelling suggests that a biological passive treatment system may be effective, then technology specific testing could be completed to evaluate:

- Degradability of existing natural materials in wetlands and other flooded, reduced environments near the TIA
- Available sulfate and nutrients in the TIA pond water
- Potential hydraulic retention times needed to affect sulfate reduction and sulfide precipitation
- Potential temperature or other environmental factors that may limit passive biological treatment

Consideration would also have to be given to potential risk to downstream eco-systems; under the current water licence, water with concentrations above specified limits cannot be discharged. These items would be evaluated no earlier than the second year of the research plan as described further in Section 0.

5.1.6.3 Physical – Passive Treatment System

Physical mechanisms for passive treatment include filtering of solid-phase constituents in water or the adsorption of dissolved-phase chemicals onto solid surfaces. This typically occurs as water moves through wetlands, peatlands, or the subsurface (similar to biological passive treatment) and chemical constituents are naturally attenuated due to physical straining of solid particles and the interaction of dissolved constituents with potential binding sites on the solid materials.

Passive physical treatment can also be engineered through the construction of infiltration systems that would distribute water to and through materials that have the capacity to filter or adsorb solid or dissolved phase constituents. For example, peat beds have been used extensively to provide physical treatment of mine-influenced water.

One of the first steps of a passive physical treatment at the TIA would be to determine the extent to which passive physical treatment is occurring naturally. If additional research and updated modelling suggests that a passive physical treatment system may be effective, then technology specific testing could be completed to evaluate:

- Sorptive capacity of peat materials located near the TIA
- Hydraulic conductivity of peat materials near the TIA

Consideration would also have to be given to potential risk to downstream eco-systems; under the current water licence, water with concentrations above specified limits cannot be discharged. These items would be evaluated no earlier than the second year of the research plan as described further in Section 0.

5.1.7 Active Treatment Options

Active treatment options are potentially feasible for the mitigation of existing impacts as noted in Table 4. Generally, active treatment options are established, conventional technologies that would not require any additional investigation or testing. For example, chemical treatment is currently being used to treat the TIA discharge to remove zinc. While these technologies could be employed, they are not viewed as favorably as passive technologies because of their need for long-term operation and maintenance (i.e., active) requirements. Active treatment would only be employed if no other mitigation methods are found to be effective.

Similar to the passive treatment approaches, active treatment may consist of chemical, biological, or physical treatment processes that could be successfully employed to remove zinc and other constituents from the TIA drainage before it is returned to the environment, Each of these approaches is described below.

This option is deemed potentially feasible.

Answering the following questions through research are recommended to improve confidence in this feasibility determination:

Question	Tag
Can active chemical, biological, or physical treatment be effective at the site?	CO – Treatment focus – 3

5.1.7.1 Chemical – Active Treatment System

As noted, chemical treatment is currently being employed at the site to remove zinc from the TIA discharge. Using lime to raise the pH to approximately 9.5 results in the formation of insoluble zinc hydroxide, which is precipitated and removed from the water. The current system has been used for decades and is effective. No additional investigation or testing is needed to continue to the use of this treatment system and the operating requirements and costs for this operation are understood. Consideration to new/alternate technologies or process improvements during the technology review.

5.1.7.2 Biological - Active Treatment System

Active biological treatment would employ the same process as passive biological treatment. Microbial degradation of organic matter in a reduced (oxygen limited) environment will result in the conversion of sulphate to sulfide. In this environment, zinc will combine with sulfide to form an insoluble precipitate that can be removed from the water. In an active biological system, all of the components needed for biological growth – organic substrate, nutrients, etc. – are combined within a controlled reactor and the environmental conditions may also be optimized (temperature, pH) to facilitate the biological activity needed to produce the zinc sulfide. In an active system, the solids generated by this process can also be managed for disposal in a method that would not allow the zinc sulfide to be re-oxidized.

Operation of biological reactors is a conventional, well-established technology. Site specific testing would be needed to define the size and operating requirements for an active biological treatment system. However, no additional testing of this option is planned at this time because other active treatment options (chemical) are already in place and have been demonstrated to be effective.

5.1.7.3 Physical - Active Treatment System

Active physical treatment could include several different options, including:

- filtration or sorption of zinc onto a solid surface, similar to the use of sorptive media for passive treatment, or
- reducing the volume of water in the TIA by enhancing evaporation

Of these two options, increasing the rate of evaporation using active methods is a mitigation approach that may be favorable to active chemical treatment because it would not require the use of chemicals and it would not generate any solid waste products. Active operations would be needed to redistribute TIA water over a larger area surface area during the time of the year when evaporation is favorable over precipitation. Existing data suggest that the likely season for increased evaporation of TIA water could be from late July until early September. During this period, water stored in the TIA could be distributed over the surface of the existing tailings to enhance evaporation.

Additional collection of meteorological data to further develop the site conceptual model in the first year of the research study will be used to determine if this option has the potential to be more favorable than chemical treatment. Field testing in subsequent years could include operation of a pilot-scale spray irrigation system where a range of potential irrigation rates could be measured and monitored.

5.1.8 Divert or Intercept Surface & Groundwater

Diversion of surface water from flowing into the TIA appears to be effectively completed with use of the existing perimeter dyke system. There may be opportunity to improve surface water management within the TIA through either cover modification or implementation of a treatment regime as discussed previously. Any blending of the TIA with the surrounding area approaches pursued will also require that surface water management be considered.

Construction documentation (i.e., dyke foundation), previous investigation, and general reconnaissance indicates that the TIA was constructed directly over native ground. Previous investigation results also indicate that the groundwater table is below the base of the tailings, but current hydrogeologic conditions characterization is needed to support the conclusion that regional groundwater does not interact with the base of the tailings.

This option is deemed feasible – pending verification of surface water diversion from the TIA and the regional groundwater table residing below the base of the TIA as discussed previously.

6.0 Reclamation Research Components

Additional research is required to address remaining uncertainties with regard to the CSM and to aid in feasibility evaluation of the COs listed in Section 5.1, as several closure options have been identified as potentially feasible or feasible for the TIA. This research will include engineering studies and focused research that will be performed in phases over the next 2 ½ years in preparation of the updated closure and reclamation plan due end of December 2020.

This reclamation research plan will serve as the overarching plan and will be updated annually through 2020 as reclamation research is completed. Sub-plans, such as individual technology evaluations, will be developed as needed throughout the research program. Annual research reports will be provided at the end of each year, which summarize the results and lessons learned from the research and provide the basis for reclamation research refinement for the subsequent year. The schedule is included in Section 6.5.

6.1 Uncertainty

The remaining uncertainties - posed as outstanding questions – were provided in Section 4 and Section 5. These questions pertain to the physical, biological, chemical, geographical, and other technical aspects of the current tailings impoundment area and closure options. The questions have been generally categorized by primary topic; either CSM or CO related, and are listed and are listed on Figure 7. Questions related to the CSM are further categorized by the source of contamination, the fate and transport mechanisms, or the potential receptors. Questions related to the COs are further categorized by approach; namely capping/covering, or by treatment including both active and passive and via biological, chemical, or physical applications.

Other aspects of uncertainty, such as social, cultural, and other non-technical aspects will be developed and addressed through the consultation process and will be incorporated into the research plan in subsequent revisions as needed.

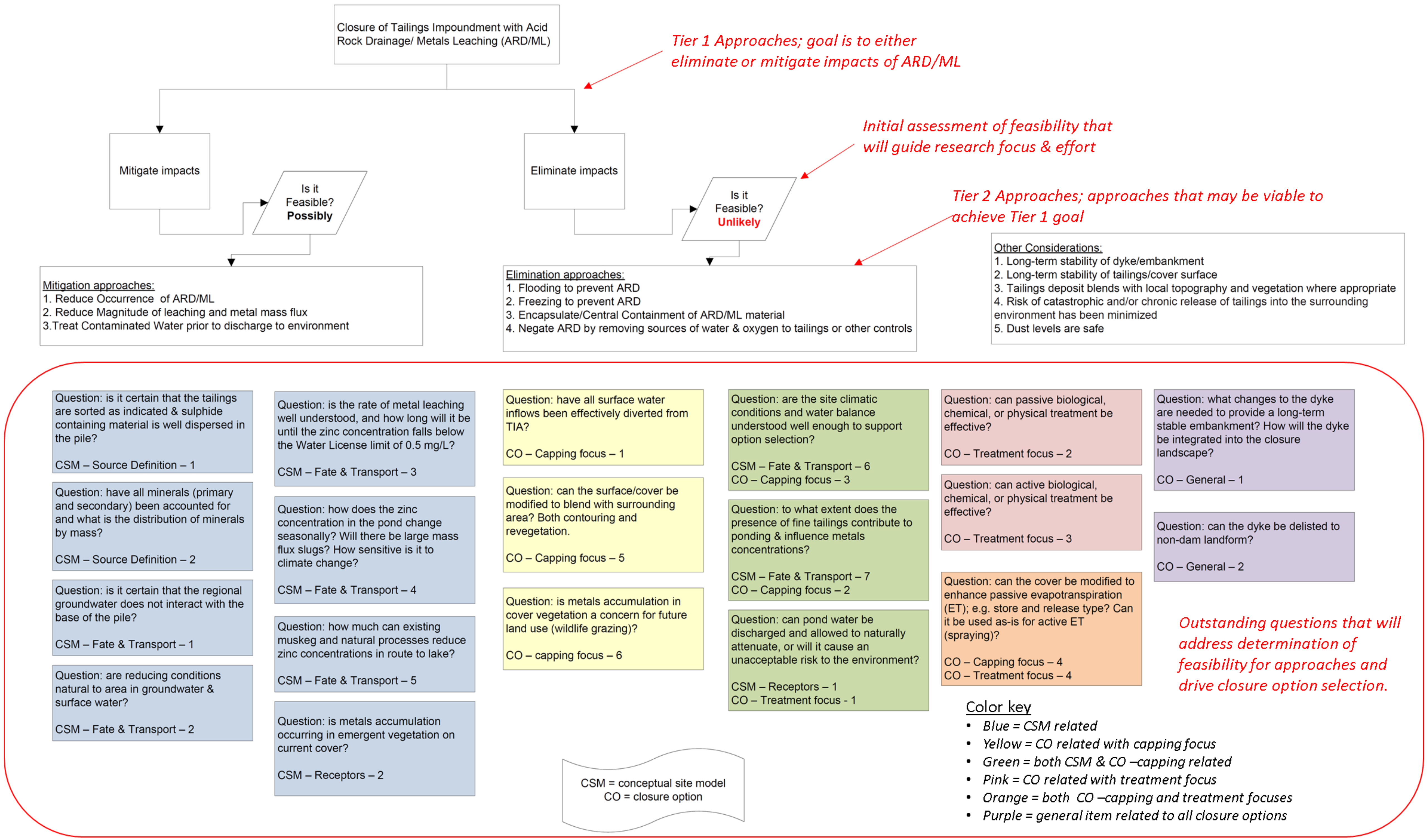

Figure 7 Closure options flowsheet for tailings impoundment with ARD/ML issues

6.2 Research/Study Objective

The purpose or the research/study is to gain a better understanding of the site and to identify feasible closure options for the TIA. The desired outcome of the research/ study is answers to those key questions that pertain to the feasibility of the closure options, enabling the selection of a closure option that best addresses the remaining risks at the site.

6.3 Overview of Tasks

This section describes the tasks necessary to complete the research/study and includes both completed tasks and remaining tasks and scopes of work.

6.3.1 Completed Tasks

The completed tasks containing research/ studies related to TIA closure and reclamation have included, but are not limited to those listed below. Barr has begun a thorough review of this previous work and will assist Teck with the revision of this reclamation research plan as needed, pending the outcome of the review and initiation of year 1 research tasks.

- **Closure and Reclamation Plans**
    - Abandonment and Restoration Plan approved June 1987 for entire Pine Point Mine
    - Plan was updated in 1990 and 1991 during reclamation activities
    - Updated in 2006, "Update to the Closure and Reclamation Plan (Restoration and Abandonment Plan – 2006)"
- **Water Licence Approvals**
    - Original water licence received January 16, 1974 and expired in 1990 (N1L3-0034)
        - Required establishment of Surveillance Network Program (SNP), which included 16 sampling locations
    - Type B Water licence effective June 15, 1993 (N1L3-0035)
    - Type B Water licence from 2007 to 2017 (MV2006L2-0013)
        - Included 10 sampling locations (7 downstream, 1 at tailings discharge, 1 in containment pond, 1 post-treatment)
    - Type B Water licence effective from 2017 to 2027 (MV2017L2-0007)
- **Stakeholder Engagement Plan**
    - Developed and implemented in 2006 for Water Licence Renewal
    - Developed and implemented in 2017 for Water Licence Renewal
- **Discharge Water Quality Review**

- Monitoring data from 1997 to 2005, unpublished results from Muskeg Water Sampling in 1979 and 1980, and 2006 water data from tailings water samples and monitoring stations were reviewed by SRK to provide an overall indication of water quality

- **Active Treatment (sodium hydroxide)**
  - Test work was carried out in 1990 to treat impounded water using Batch treatment process with caustic soda (sodium hydroxide) to form metal hydroxides that would settle out of the water. Process abandoned in 1991 due to health & safety concerns with caustic soda.

- **Active Chemical Treatment (Hydrated Lime) – Current Approach**
  - Lime Silo purchased and installed in July 2006
  - Performed annually in accordance with the Water Treatment Manual (Teck, 2017)

- **Embankment Structure Stability Programs**
  - DSR performed every 10-years for "significant" dam classification (North and West dykes), last DSR performed in 2014
  - Dam Safety Inspections performed annually
  - General inspections performed throughout water ponding period (typically 3)
  - Performed in accordance with Operation, Maintenance, and Surveillance Manual (Golder 2018)

- **Chemical Acid Production Potential Tests**
  - Chemical acid production potential testing conducted on two tailings samples in 1987 indicated an excess of reactive alkalinity to potential acid generation

- **Tailings Leachability Testing**
  - Testing conducted between 1989 and 1992 to perform recirculation column leach testing, dilute pulp leach testing, and evaluate metals removal and hydraulic capacity of muskeg ("wetlands treatment").
  - 1990 Interim report: Column leach testing performed to determine leachability of metals (Zn, Pb, Cd, and Cu) entrained in TIA tailings. Interim results indicated continued Zn leaching.

- **Dustfall Monitoring Program**
  - Started in 1988 and terminated in 1991 following the application of a coarse-gravel cover over 86% of the tailings surface

- **Tailings Vegetation Studies**

- Performed between 1976 and 1987 including a field study with direct vegetation of the Pb-Zn tailings

- **Geochemical, Mineralogical, and Hydrogeological Investigation**
  - Performed March to October 1996 and included nested monitoring wells, thermistor strings, ground water level monitoring, in situ hydraulic conductivity tests, groundwater and pond water sampling, tailings and precipitate sample collection for physical & analytical testing (total and dissolved metals, nutrients, sulphate) & mineralogy (XRD & optical microscopy)
  - Included Geochem modelling with MINTEQA2 using WATEQ4F database and other solubility data available at the time

- **Instrumentation Installation**
  - Two piezometers installed in tailings mass to monitor water levels in pond pore water in 1990
  - Two piezometers installed in north dyke to monitor pore water broke in 1992

- **Preliminary Water Balance**
  - Included in OMS manual. Supporting data spreadsheet provided by Golder (2008) providing water balance estimates under varying precipitation periods using data from 1993 – 2007.

6.3.2 Remaining Tasks and Scopes of Work

The research/study will resolve the remaining uncertainty through a phased approach as illustrated in Figure 8 and Figure 9. The proposed approach includes several tasks to complete over the next 2 to 3 years. The phased approach follows a 'rolling wave' type approach where more detail is provided for near term tasks and less detail is provided for subsequent tasks since those will be more fully developed based on the results of preceding tasks. In general, the research/study includes field investigations, engineering evaluations, and scaled testing trials.

The four main components of remaining work that will be addressed in year 1 are included below, and the following subsections provides a conceptual level scope of work for these tasks. Subsection numbers are used for task reference in Figure 8 and Figure 9. .

- Field investigation for clarity on tailings characterization, groundwater levels and flow patterns, groundwater and surface water quality, vegetation survey, topography, potential material borrow sources, and data to support the basis for current biological, chemical, and physical processes.
- Engineering evaluations for the TIA: geochemical, water balance, and baseline risk
- Concept evaluation for covers/caps and treatment designs
- Engineering evaluation of the dyke: geotechnical/structural

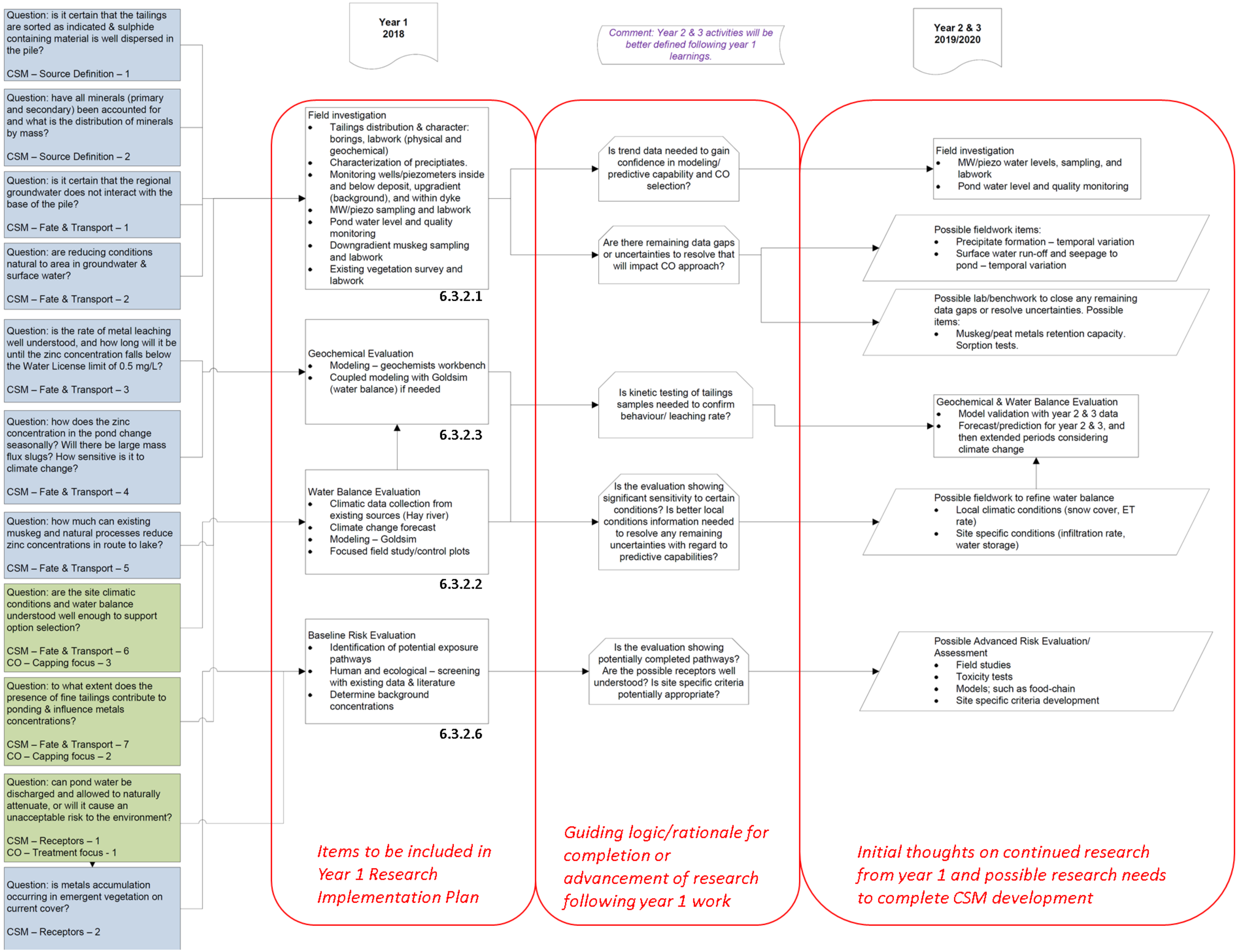

Figure 8 Research flowsheet for CSM related questions

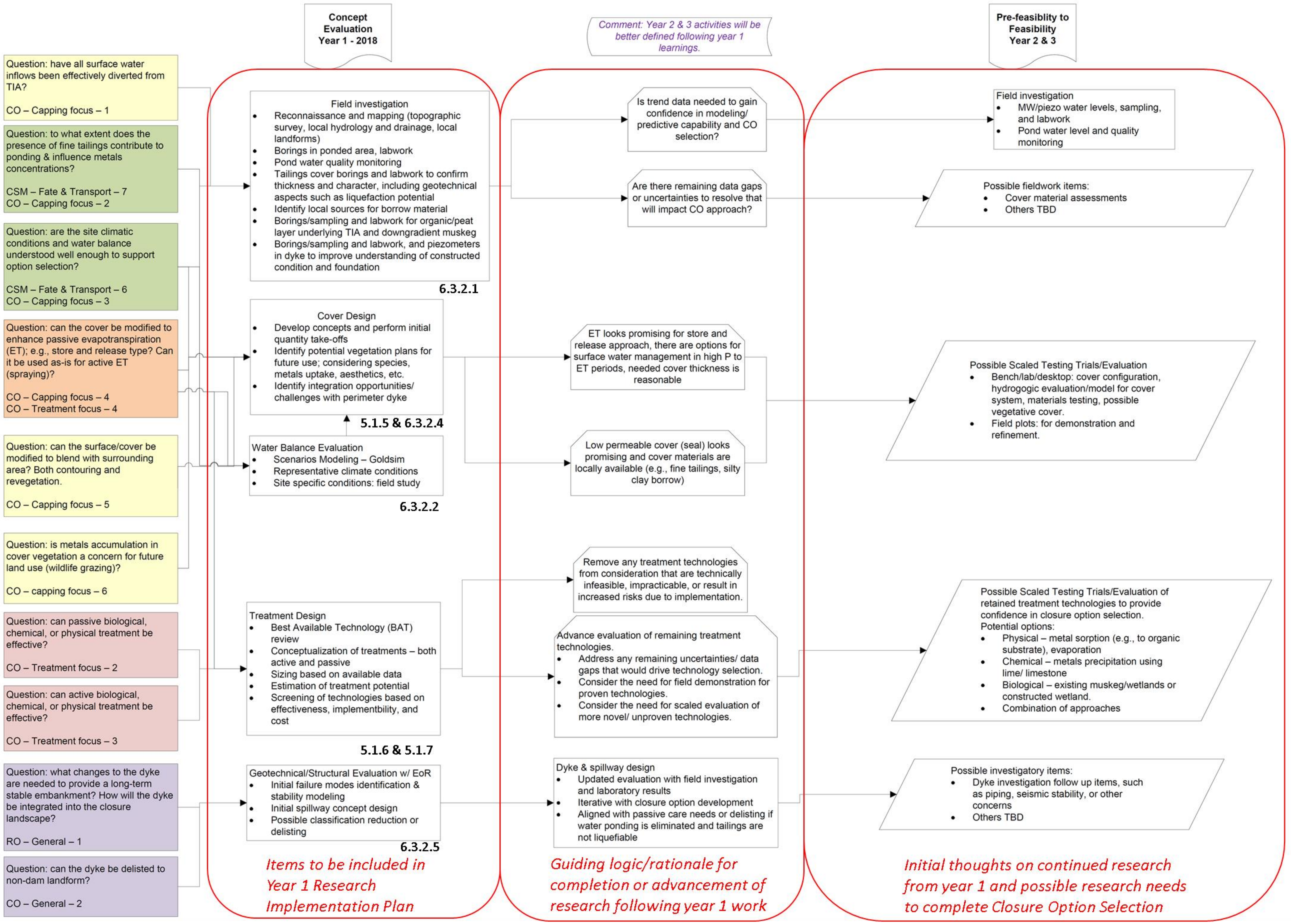

Figure 9 Research flowsheet for CO related questions

6.3.2.1 Field Investigation

A field investigation is recommended to validate previous site data and observations and collect additional data necessary for the development of a geochemical model to predict ARD/ML potential as well as a water balance to better understand water pathways (i.e., infiltration, seepage, etc.). The field investigation would include the collection of various samples, instrumentation installation, and laboratory testing of the collected samples.

General Reconnaissance and Mapping

General reconnaissance of the TIA and surrounding area will be performed to develop the current understanding of the local hydrology and drainage patterns, local landform features and blending opportunities. Topographic mapping will be performed for the area to develop a basemap and aid for closure option development and depiction.

Cover Characteristics

Previous work indicates the cover is about 150 mm thick and consists of coarse sand and gravel material. The thickness and material consistency of the cover needs to be field verified as no construction documentation report is available to provide this information. Chemical testing of the cover material will be performed to assess the presence of mineral precipitates.

Tailings Distribution and Characteristics

Previous works indicates that the tailings are sorted from south (coarser tailings) the north (finer tailings) due to deposition from an elevated trestle. In order to validate the physical distribution of tailings, multiple soil borings or test trenches throughout the TIA will be completed. In particular, it is important to determine the quantity and quality of fine tailings in the vicinity of the North dyke. Due to the ponding of water in this area, work is recommended for late summer/early fall when a surface crust has formed or during winter months to avoid water platform work. Tailings samples will also be collected and analyzed for pertinent geotechnical properties, including those needed to assess liquefaction potential.

Perimeter Dyke

Detailed construction records are not available for the perimeter dyke system. Borings are required to validate current presumptions of dyke construction, including foundation conditions, and to provide samples for geotechnical testing. Testing will focus on parameters of interest for dyke stability evaluation in consideration of long-term passive care needs, including seismicity.

Groundwater

In order to better inform the potential closure options and model the potential long-term behavior of the TIA in closure, improving the understanding of the groundwater conditions in and near the TIA is recommended and would include:

- Advancing several soil borings and/or using geophysical methods to estimate the thickness of the muskeg to the north of the discharge area of the TIA.

- Installing wells up gradient, within and below the TIA and dyke, and to the north of the TIA to determine the local flow regime and water quality.
- Collecting a round of complete hydrochemical analyses for groundwater samples, including all major cations and anions, and trace metals.

Pond Water

Similar to groundwater, an improved understanding of the pond water quantity and quality evolution over the course of the year will benefit development of the CSM and aid in closure option selection. Pond water levels would be monitored at a higher frequency than currently performed, specifically during the freshet and prior to freeze to better understand the annual water budget within the TIA. The quality of water would be monitored in these key time periods as well, which will provide an indication as to the effect of surface run-off and seepage impacts.

Muskeg/Peat

Peat below the TIA will be sampled (via borings or trenches) to assess the conditions (presumed reducing) and metals retention capacity of the media. Down gradient muskeg will be sampled and evaluated for its potential use in continued or advanced passive treatment as discussed in Section 5. Results from previous leachabiity testing conducted with muskeg will be reviewed and used to inform the research plan with regard to muskeg/peat.

Vegetation

A vegetation survey will be performed at the site to identify prevalent species in surrounding areas as well as emergent vegetation within the TIA. Samples of vegetation with in the TIA will be collected for metals analysis to assess whether, and to what extent, metals uptake may be occurring. Vegetation study to support the water balance will also be performed.

6.3.2.2 Water Balance Evaluation

One of the questions that is still unanswered is whether the climatic conditions and water balance are understood well enough to support the selection of a closure option. Some climate drivers of the water balance have a relatively long history of data collection, both at the site and at nearby sites such as Fort Resolution, Hay River, and others. Golder has summarized the available data in their 2018 Operation, Maintenance, and Surveillance Manual. The summarized data includes precipitation, temperature, and monthly estimates of potential lake evaporation. It is assumed that the raw data used in Golder's 2018 OMS Manual will be made available to further summarize the data as averages, ranges, and statistics, at various time intervals (annual, monthly, daily, etc.).

In order to fully characterize the water balance required to evaluate feasible and potentially feasible closure options, some additional data is required. For example, snow water equivalent was assumed to be 10% for all of the collected data; however, the accuracy of this assumption is unknown. Snow losses (i.e., snow distribution and sublimation) mentioned in Golder's report are described as a single average value (31% reduction). There may be benefit to separating the contributions of each source and describing the uncertainty associated with each value. Additionally, evapotranspiration and infiltration were combined into a single value to describe other losses that limited the snow and rain contribution to pond water volumes.

In order to resolve unknowns associated with water balance inputs, additional study is recommended. Some parameters can be estimated through desktop study and literature review but others will require field study. Not all parameters can be collected through a field study (e.g., evapotranspiration of select vegetation as the TIA is not currently supporting significant vegetation) and a desktop study or literature review is required to provide estimates for these parameters. However, solely developing a site-specific water balance through desktop studies and literature review would incorporate significant sources of uncertainty.

Performing at least one (ideally more than one) comprehensive water balance field study on a controlled sample plot is recommended. This study should begin in the first year to provide a better understanding of the intricacies of a cold region water balance for the existing TIA and/or for feasible TIA closure options. Concurrent additional sample plots placed strategically throughout the TIA would reduce spatial uncertainty created by the large footprint of the TIA. Although the data gathered by Golder is useful (e.g., thorough set of precipitation and temperature data), it would be necessary to collect this information in a controlled sample plot, along with the other missing information, to understand and calibrate a snow accumulation and ablation model. The proposed monitoring includes:

- ***Weather***: Precipitation (rain and snow), snow depth or accumulation, snow water equivalent, temperature, relative humidity, wind speed and direction, and radiation (to the sloped, north-facing TIA).
- ***Soil (Cover/Shallow Tailings)***: hydraulic properties of the soil (porosity, grain size distribution, saturated conductivity, etc.), moisture content both in depth and through time, and temperature profile of the soil material.
- ***Water volume***: water level in the pond(s), pond water temperature, hydraulic conductivity of the pond bottom material (to estimate seepage losses versus evaporation losses), and treated and discharged volume.
- ***Vegetation***: Evapotranspiration rates (changes with month and with maturity), interception, rooting depth, and the ability to withstand saturation and drought.

For any model inputs listed above that cannot be studied in the field, a literature review may provide enough information to complete the water balance modeling.

Monitoring should also be conducted on a natural, undisturbed site that represents the potential future use condition of the TIA. Monitoring of a natural site provides an understanding of potential challenges as the TIA surface develops over the long-term (e.g., with more mature vegetation). The modeling may then account for the gradual transition over this time horizon. The natural site selected for monitoring will depend on the potentially feasible closure options, specifically with regard to the cover design. Ideally, the site would be north facing with similar soil characteristics to available borrow material and with vegetation, if any, anticipated for the TIA.

After the first year of monitoring, if the water balance model can be sufficiently calibrated to the collected data, the monitoring may cease. Alternatively, the monitoring may continue to further understand the uncertainties in some of the calibration parameters (such as temperature where precipitation is fully snow or fully rain, or calibrated sublimation rates). Also, once a closure option is selected based on the level of feasibility and other aspects (cultural, social, etc.), the monitoring that is no longer applicable will cease. For example, if it is determined that growing vegetation on the TIA is not feasible due to metal uptake and accumulation, then the monitoring of store and release cover related information may be discontinued.

6.3.2.3 Geochemical Evaluation/Modelling

The primary objective of geochemical modelling is to evaluate the current geochemical conditions at the site, model how those conditions may change over time, and what the potential effect of mitigation will have on future conditions. Modelling will be conducted using Geochemists Workbench (Bethke, 2008) or a similar geochemical modelling software. Results of the efforts will build upon previous geochemical assessments of the tailings to improve understanding of the magnitude and duration of on-going ARD/ML based on current conditions. Specific questions that modelling will attempt to evaluate include the rate of metal leaching, particularly how long it will take zinc concentrations in the TIA to fall below the Water Licence Limit (0.5 mg/L) under current conditions, how concentrations and flow into the TIA pond fluctuate with time, the potential effect(s) of climate change on future conditions, and how these concentrations may vary as a result of the closure options being considered.

Inputs to the model may include chemical composition of water flowing through the system (precipitation, run-off, pore water, groundwater, and pond water), chemical composition of the solid phase minerals (precipitates, cover material, tailings, and native material beneath the tailings), and metal leaching rates. It may also be important to evaluate any mineralogical changes occurring spatially and/or with depth in the tailings basin. Aqueous and solid mineral compositions may be obtained through the use of historical data, published data, and on-Site sample collection and analysis (including borings, monitoring wells or piezometers, test trenches, and surface sampling). Metal leaching rates may be obtained from historical data as well as kinetic testing (bench scale shake flasks). Sample collection and analysis may be paired with field investigation activities discussed above. Results from previous leaching evaluations will be reviewed in detail and will be used to inform any additional testing that may be needed.

6.3.2.4 Cover Design

Research/engineering study will focus on developing the cover concepts for the site as discussed in Section 5. Simple soil (current), store and release, and geo-synthetic type options will be evaluated in the first year. The evaluation will focus on the fundamentals of cover system design and the applied theory to identify opportunities and risks to cover effectiveness. Data collected from the field investigation will be used to assess the simple soil cover performance, and to aid in evaluation of the store and release cover potential. Key aspects: moisture storage, moisture flow, evaporation and transpiration, and oxygen transport will be considered with respect to the cover system and ARD/ML issues with interaction with tailings and mineral precipitates. The cover development approach will leverage existing guides and case histories, including those in the MEND series. A literature search will be completed to learn from other cover systems that have been used in similar settings or conditions that may apply to the TIA. Based on the evaluation in year 1, cover concepts will be carried forward for scaled testing/trials as appropriate to address remaining uncertainties or fill data gaps.

6.3.2.5 Geotechnical/Structural Evaluation

Physical stabillity models have been developed for the perimeter dyke system as part of the OMS Manual development. The stability analyses will be updated with data provided from the field investigation, which will include piezometric levels and foundation conditions (including risk of piping) which were not previously available. Seismic analysis will also be updated, including for liquefaction potential of the tailings. The results from this evaluation will inform (and be iterative with) the closure options development and aid in final dyke and spillway design. Follow up investigatory activities will be completed as necessary throughout the process. This work will be led by the Engineer of Record and coordinated through Teck.

6.3.2.6 Risk Evaluation

A baseline risk evaluation will be completed in the first year to identify potential exposure pathways and receptors for metals at the site. Risk to human and ecological receptors will be screened using existing data and relevant literature – including the use of generic criteria. Naturally occurring background concentrations will be considered in the evaluation. Future study will be based on potentially completed pathways and outstanding issues identified in the baseline evaluation. Site specific criteria development may be considered. Advanced risk evaluation may or may not be needed, and could include field studies, toxicity testing, modeling, and others.

6.4 Linkages to Other Research/Studies

Linkages to past research and studies will be completed in the next revision of this research plan as thorough review of previous work is still underway.

6.5 Project Research Schedule

The reclamation research schedule and deliverables list is provided below.

Item	Activity	Milestones
Reclamation Research Plan – Original	Planning – overarching and concept level	May 1, 2018
Research – Year 1	Implementation of research	Desktop studies, lab or bench work: December 31, 2018 Fieldwork: June 1 – October 1, 2018 (approx.)
Research Report – Year 1	Summary of results and lessons learned from year 1 work	February 1, 2019

Item	Activity	Milestones
Reclamation Research Plan – Revision A	Planning – Advanced concept level	May 1, 2019
Research – Year 2	Implementation of research	Desktop studies, lab or bench work: December 31, 2019 Fieldwork: June 1 – October 1, 2019 (approx..)
Research Report – Year 2	Summary of results and lessons learned from year 2 work	February 1, 2020
Reclamation Research Plan – Revision B	Planning – final version addressing identified uncertainties	May 1, 2020
Research – Year 3	Implementation of research	Desktop studies, lab or bench work: October 31, 2020 Fieldwork: June 1 – October 1, 2020 (approx..)
Research Report – Year 3	Summary of results and lessons learned from year 3 work	November 30, 2020
Closure & Reclamation Plan	Submission of plan	December 31, 2020

Consultation and stakeholder engagement are a critical component to the development of reclamation research and in preparation for submission of a closure and reclamation plan. The current engagement plan associated with the Water Licence is currently under review for applicability and inclusion of this reclamation research and closure and reclamation plan development process.

6.6 Costs

The expected costs for the research/study plan activities as conceptualized in this plan is not currently available, as detailed planning has not been completed to date, and the costs are likely to change through the phased and adaptive approach contained within the plan.

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