WOLVERINE MINE
RECLAMATION AND CLOSURE PLAN
2016-07 – REVISED V.2

Prepared for:

Yukon Government Department of Energy, Mines and Resources

Yukon Water Board

Prepared by:

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In conjunction with

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Vancouver, British Columbia

September 29, 2017

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Date	**Submitted by:**	**Submitted to:**	**Version**
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Executive Summary

On December 30, 2016 Yukon Zinc Corporation (YZC) submitted an updated Reclamation and Closure Plan to reflect updates to the temporary and ultimate closure of the Wolverine Mine, following re-assessment of site conditions after two years of temporary closure (RCP 2016-07). On June 14, 2017, YZC submitted an request to Yukon Government, Department of Energy, Mines and Resources (EMR) to extend the temporary closure period from the currently permitted three years to five years in order for the company to pursue options to re-open the Wolverine Mine. Subsequently, a request was received from EMR on August 8, 2017 to submit an amended version of RCP 2016-07 to reflect the extended five year temporary closure period. This plan (RCP 2016-07.V.2) presents an amended version of RCP 2016-07 to include an extension of the temporary closure period from three years to five years, and resultant changes to the ultimate closure plan consistent with the temporary closure amendments.

Also received on August 8 were comments from the following Yukon Government reviewers:

- Mineral Resources Branch – Yukon Government;
- Environment – Yukon Government;
- Compliance Monitoring and Inspections – Yukon Government;
- Yukon Workers Compensation Health and Safety Board;
- Kaska Dena Council; and
- Lorax Environmental.

Comments from reviewers have also been considered in this amended plan, with requested information updated and/or provided as appropriate.

A summary of the sections that have been amended in this plan is provided in the table below. All other sections remain unchanged.

Should conditions remain unchanged, YZC will submit an update to the RCP in two years, in September 2019. Should mining resume or closure condition change, YZC will submit an updated RCP.

RCP 2016-07	RCP 2016-07.V.2	Amendment	Summary
1 Introduction	1 Introduction	Updated to reflect temporary closure period extension	Updated Project Timetable to reflect 5-year temporary closure period.
1.2 Purpose of the Plan and Changes to Previous Versions	1.2 Purpose of the Plan and Changes to Previous Versions	Updated to reflect temporary closure period extension	• Updated rationale and timeline for submitted and approved Reclamation and Closure Plans. • Updated material changes from RCP 2015-06 and 2016-07.
2.1 Planning Considerations	2.1 Planning Considerations	Updated to reflect activities conducted since submission of RCP 2016-07	• Added list of correspondences with requirements for amended RCP 2016-07. • Updated Table 2-1.
3.1 Climate	3.1 Climate	Updated climate data	Updated temperature and precipitation data with most recent weather station data.
3.2.1 Hydrology	3.2.1 Hydrology	Updated hydrology data	Updated hydrological graphs for stations W9 and W82.
3.3.1 Hydrogeology	3.3.1 Hydrogeology	Updated groundwater level data	As requested in April 17, 2017 letter from Lorax Environmental: • Updated potentiometric elevations to mid-2017 • Added monitoring well water level date from 2009 – 2017 in wells downgradient from the mine
3.3.2 Groundwater Quality	3.3.2 Groundwater Quality	Updated groundwater quality data	• Updated groundwater quality data to reflect downstream distance to help identify trends. • Update groundwater quality with most recent water quality values.
4.1 Mine Features, Facilities and Equipment	4.1 Mine Features, Facilities and Equipment	Updated text to reflect flooded underground workings	Text now reflects pumping from the underground mine to the TSF during temporary closure period
5. Temporary Closure	5. Temporary Closure	Extension of temporary closure period from January 2018 to January 2020	• Yukon Zinc has taken steps to evaluate the feasibility of re-opening the Wolverine Mine under current mineral market conditions. This process continues and includes requesting an extension of the temporary closure period from three years, to five years, which would delay permanent closure of the Wolverine Mine from January 2018 to January 2020. • The site will be maintained in a state that will allow for re-start during this extended temporary closure period.
5.1.1 Site Security	5.1.1 Site Security	Update chemical storage status	• There are 18 bags of copper concentrate and 13 bags of lead concentrate remaining to be shipped off site by the purchaser.

RCP 2016-07	RCP 2016-07.V.2	Amendment	Summary
			• Only 95 tonnes of lime remain on site and will be used in the treatment of the TSF.
5.1.2 Monitoring Activities	5.1.2 Monitoring Activities	Update surface water and groundwater monitoring as per WUL QZ04-065	Environmental monitoring frequency and sites had been reduced following a letter from CMI; however, YZC will return to the sampling frequency and sites outlined in QZ04-065 for the temporary closure period, including monthly surface water sampling, and quarterly groundwater sampling.
		Continued bioreactor monitoring	The bioreactor constructed between Waste Rock Pad #2 and the TSF will continue to be monitored throughout the extended closure period. Results from the test work will inform the permanent closure solution.
		MMER EEM sampling	• Effluent characterization studies under MMER EEM will be required when discharging to Go Creek. • Cycle 4 EEM study will be required to be conducted in late August 2019.
		Vegetation monitoring	Add requirement to conduct vegetation monitoring for metals prior to closure. Small mammal sampling will be conducted if vegetation sampling indicates statistically significant metals contamination.
5.1.3 Maintenance Activities	5.1.3 Maintenance Activities	Increase period for maintenance	Ongoing maintenance of site will be required for the extended temporary closure period and must be considered in the cost accounting.
5.1.3.1 Underground Workings and Openings to Surface	5.1.3.1 Underground Workings and Openings to Surface 5.2.1 Underground Mine Interim Water Management Plan	Defer bulkhead installation	Bulkhead installation had previously been required by October 2017. As the mine will potentially be re-started, access to the underground must be maintained. On June 7, 2017, underground discharge reached the surface of the underground mine adit. Dewatering pumps have been installed, and water levels are maintained by pumping the excess water to the TSF. This system will be maintained throughout the temporary closure period.
5.1.3.2 Tailings Storage Facility (TSF) Area and Water Management Structures	5.1.3.2 Tailings Storage Facility (TSF) Area and Water Management Structures	Add wildlife monitoring	Monitoring for wildlife is also conducted at the TSF pond regularly during the ice-free period.
5.1.3.4 Mine Infrastructure	5.1.3.4 Mine Infrastructure	LTF not decommissioned	The mine infrastructure will be monitored and maintained as per current conditions. The LTF will not be decommissioned until permanent closure is initialized, as it may be required during re-start and subsequent operation of the mine. Decommissioning will be conducted in accordance with an approved plan from Yukon Environment.
5.2 Interim Water and Solution Management Plan	5.2 Interim Water and Solution Management Plan	Update to reflect changes in bulkhead design and	• Remove underground mine portal bioreactor. • Direct all contaminated water to the TSF. • Evaluate potential to treat underground discharge directly.

RCP 2016-07	RCP 2016-07.V.2	Amendment	Summary
		underground discharge	• Evaluate in-situ treatment of the TSF pond. • Install a water treatment plant in summer 2018. • Discharge to Go Creek May – October as required.
-	5.2.1 Water Balance	Updated water balance	Data collected over the temporary closure period has informed an updated water balance for the temporary closure period.
5.2.1 Underground Mine Workings	5.2.2 Underground Mine Workings 5.2.2.1 Adaptive Management Plan Appendix D: Portal Plug Design Report	Updated bulkhead design. Bioreactor installation dependent on water chemistry.	• An update to the bulkhead design was completed in July 2017 and is provided in Appendix D. Mine water will be dewatered to below the bulkhead installation. • If a decision to re-start the mine has not been made by early 2019, the bulkheads will be installed in summer 2019, in preparation for final closure in January 2020. • The updated design is water tight, and as such a bioreactor at the adit will not be required. • The installation of a bioreactor in Wolverine Creek to mitigate potentially contaminated mine water will be dependent on the water chemistry of groundwater and surface water in Wolverine Creek. The installation will be required if the water chemistry meets certain defined trigger levels.
5.2.2 TSF Area	5.2.3 TSF Area 5.2.3.1 Water Treatment	TSF pond water treatment	• TSF supernatant will be treated using an active treatment system. • Appendix E: Assessment and Bench Scale Testing of Water Treatment Options
6. Final Reclamation and Closure Measures	6. Final Reclamation and Closure Measures	Update to reflect changed timelines and changes to temporary closure plan	This section will now include the following, which were deferred from the temporary closure section: • LTF decommissioning • Temporary active water treatment • Increased decommissioning and post-closure environmental sampling • Wolverine Creek monitoring and adaptive management with potential bioreactor installation
6.2.1 TSF Water Treatment	6.2.1 TSF Water Treatment	Add water treatment plant	• As a water treatment plant will be installed during the temporary closure period, it will continue to be used during the permanent closure period until all water is removed from the facility. • Deleted Sections 6.2.1.1 & 6.2.1.2.
6.4 Water Management Structures and Systems	6.4 Water Management Structures and Systems	Change disposal of pipelines	Pipelines and liners will be disposed of in the landfill, not in the TSF.

RCP 2016-07	RCP 2016-07.V.2	Amendment	Summary
6.5.4 Landfill and Waste Storage Areas	6.5.4 Landfill and Waste Storage Areas	Removal of reference to disposal of special and solid waste in TSF	In response to the comment from Yukon Environment, no special or solid waste will be disposed of in the TSF
6.5.5 Material and Equipment Salvage	6.5.5 LTF 6.5.6 Material and Equipment Salvage	LTF will remain operational	LTF will not be decommissioned during temporary closure, but will remain operational for the duration of the permanent closure phase to allow for disposal and treatment of contaminated soils.
6.7 Roads and Other Access	6.7 Roads and Other Access	Added reclamation of quarries	In response to a comment from CMI, stabilization and revegetation of quarries was added.
6.10.1 Risk Assessment	6.10 Risk Assessment	Updated to reflect changes in temporary closure and permanent closure	• Risks include: • TSF failure • Overtopping of dam • Discharge of untreated water
6.10.2 Post-Reclamation Adaptive Management Plan	-	Deleted this section	• Adaptive management is discussed in Section 5.2.2.1. • All other activities will be conducted as planned and approved by this RCP and by EMR.
8 Reclamation and Closure Liability	8 Reclamation and Closure Liability	Update unit rates	• Unit rates have been updated in the temporary and final closure cost estimates to reflect • Costs have been updated to reflect the changes outlined in the above rows of this table

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Glossary of Terms

For consistency in interpretation of the contents contained herein, the following terms are used, as originally defined by the *Reclamation and Closure Planning for Quartz Mining Projects* (Government of Yukon, 2013), Yukon Government Energy, Mines and Resources Quartz Mining Licence QML-0006 and/or Yukon Water Board Type A Water Use Licence QZ0-4065:

- **Temporary Closure** - Unless otherwise agreed to in writing by the Chief, Department of Energy, Mines and Resources:
    - The cessation of development or production that extends for more than a continuous two week period; or
    - Any closure after the start-up date where no ore is mined, or ore or tailings milled for a period exceeding two consecutive months.
- **Permanent Closure (Decommissioning)** – Closure in which there is no intent to resume mining activities at the site, and the mine project proceeds to the reclamation and closure phase. Further defined as:
    - The period in which decommissioning and reclamation activities are completed for the purpose of returning the mine site to pre-mining conditions; or
    - Where Temporary Closure exceeds three continuous years in duration.
- **Post-Closure** - The period following Permanent Closure where all reclamation activities are complete and the site is subject to ongoing operations, maintenance and monitoring.

Acronyms

AMP	Adaptive Management Plan
BQE	BQE Water
CCME	Canadian Water Quality Guidelines for the Protection of Aquatic Life
CLO	Concentrate Load Out Facility
CMI	Yukon Government Compliance Monitoring and Inspections
CPUE	Catch per unit effort
EEM	Environmental Effects Monitoring
EMR	Yukon Government Department of Energy, Mines and Resources
ERC	Electrocell treatment
IX	Ion exchange
LOM	Life-Of-Mine
LTF	Land Treatment Facility
MMER	Metal Mine Effluent Regulations
OMS	Operation, Maintenance and Surveillance Manual
QML	Yukon Government Energy, Mines and Resources Quartz Mining Licence QML-0006
RCP	Reclamation and Closure Plan
RO	Reverse Osmosis
RRDC	Ross River Dena Council
TCP	Temporary Closure Plan
TSF	Tailings Storage Facility
TSS	Total Suspended Solids
WPP	Wildlife Protection Plan
WTP	Water treatment plant
WUL	Yukon Water Board Type A Water Use Licence QZ04-065
YWB	Yukon Water Board
YZC	Yukon Zinc Corporation
ZVI	Zero Valent Iron

Units

°C	degrees Celsius
$	Canadian dollars
gpm	gallons per minute
ha	hectare
km	kilometres
km/h	kilometres per hour
kW	kilowatts
L	litres
m	metres
m^3	cubic meters
m^3/d	cubic metres per day
masl	metres above sea level or elevation, measured in metres above sea level
mg/L	milligrams per litre
mm	millimetres
Mt	million metric tonnes
t	metric tonnes
tpd	metric tonnes per day

Note: All units in this report are assumed to be metric unless specifically stated otherwise.

1 Introduction

1.1 Project Summary

The Wolverine Mine, owned and operated by Yukon Zinc Corporation (YZC), is a zinc-silver-copper-lead-gold underground mine, with on-site milling capabilities of 1,700 tpd to produce copper, lead, and zinc concentrates. The Wolverine Mine is located in the southeastern Yukon near the headwaters of the Wolverine Lake watershed within the Kaska Nation Traditional Territory (Figure 1-1). The original estimated life-of-mine (LOM) was nine years, based on a 5.2 Mt mineable reserve. The site is accessed by aircraft or by vehicle on a 24 km long access road, which connects with the Robert Campbell Highway at km 190.

Figure 1-1: Location of the Wolverine Mine Within the Yukon and Kaska Nation Traditional Territory

Components of the Wolverine Mine include:

- Underground mine;
- Tailings Storage Facility (TSF);
- Seepage collection pond;
- Waste rock storage piles;
- Industrial complex, mill, and accommodations camp;
- Landfill;
- Airstrip; and
- Site access road.

YZC completed major site construction throughout 2009 and 2010. Mill commissioning commenced in 2011 and commercial production of 1,020 tpd or 60% of rate mill capacity over a 30-day period was achieved on March 1, 2012. Production first achieved 1,700 tpd in January 2013. In January 2015 YZC announced that it was temporarily shutting down operations at the Wolverine Mine due to unfavourable market conditions, putting the site in "Temporary Closure". Most employees and contractors were laid off at this time and the mine was put into care and maintenance. Presently, all industrial activity has ceased at the site and the following care and maintenance conditions exist:

- The underground mine is closed and gated;
- The site access road is maintained only during the snow-free period;
- The airstrip is maintained to ensure year-round access;
- There are no industrial activities or processes occurring in the mill;
- No tailings are being produced;
- No waste or ore is being produced or added to existing waste storage areas or stockpiles;
- Energy consumption has been minimized through isolation of essential buildings and machinery and all buildings not in use have been locked off;
- Supply stockpiles, including reagents, have been consolidated, sold, and shipped off-site where possible; and
- Two crews of 3 people each are maintaining the site on 2-and-2 week rotations.

The project timeline from construction through to post-closure is provided in Table 1-1, with the original mine plan compared to the current scenario. There is currently 5+ years of minable reserves identified at the Wolverine Mine. The current scenario has been updated to reflect a five year temporary closure phase, with permanent closure initiated in January 2020.

Table 1-1: Project Timetable

Year	Original Plan	2016-07 Plan	Current Plan
2009 to 2010	Construction Phase	Construction Phase	Construction Phase
2011	Production Ramp-Up	Production Ramp-Up	Production Ramp-Up
2012	Year 1	Year 1	Year 1
2013	Year 2	Year 2	Year 2
2014	Year 3	Year 3	Year 3
2015	Year 4	Mining Halted: Temporary Closure	Mining Halted: Temporary Closure
2016	Year 5	Temporary Closure	Temporary Closure
2017	Year 6	Temporary Closure	Temporary Closure
2018	Year 7	Permanent Closure: Decommissioning begins	Temporary Closure
2019	Year 8	Decommissioning	Temporary Closure
2020	Year 9	Decommissioning complete	Permanent Closure: Decommissioning begins
2021	Permanent Closure	Post-Closure Phase begins	Decommissioning
2022	Decommissioning	Post-Closure Phase	Decommissioning
2023	Post-Closure Phase	Post-Closure Phase	Decommissioning
2024-2034		Post-Closure Phase	Post-Closure Monitoring
2034+			Closure complete

1.2 Purpose of the Plan and Changes to Previous Versions

The most recent approved Reclamation and Closure Plan (RCP) for the Wolverine Mine was submitted July 2015 (Version 2015-06). On December 30, 2016 Yukon Zinc Corporation (YZC) submitted an updated Reclamation and Closure Plan to reflect updates to the temporary and ultimate closure of the Wolverine Mine, following re-assessment of site conditions after two years of temporary closure (RCP 2016-07). On June 14, 2017, YZC submitted an request to Yukon Government, Department of Energy, Mines and Resources (EMR) to extend the temporary closure period from the currently permitted three years to five years in order for the company to pursue options to re-open the Wolverine Mine. Subsequently, a request was received from EMR on August 8, 2017 to submit an amended version of RCP 2016-07 to reflect the extended five year temporary closure period. This plan (RCP 2016-07.V.2) presents an amended version of RCP 2016-07 to include an extension of the temporary closure period from three years to five years, and resultant changes to the ultimate closure plan consistent with the temporary closure amendments.

As per QML-0006 Section 8.0 and WUL QZ04-065 Part E, the RCP recognizes the current condition of the mine, which is non-operational and in a state of temporary closure. As such, the RCP addresses care and maintenance of the mine site during temporary closure and provides an update to the decommissioning and reclamation upon final closure. The decommissioning process outlined in the RCP assumes that the mine has not been operated since January 2015 and that a mechanical water treatment plant does not exist on the site. Final closure, as defined in this RCP, is presumed to commence in January 2020 following five years of temporary closure.

While this RCP (Version 2016-07.V.2) is a comprehensive and inclusive report that incorporates requirements of Yukon Government Energy, Mines and Resources (EMR) Quartz Mining Licence QML-0006 (QML) and Yukon Water Board (YWB) Type A Water Use Licence QZ04-065 (WUL) for the Wolverine Mine, some changes have been made to the previous version to reflect the temporary closure period extension. These changes are summarized above in the Executive Summary for reference.

Material changes in RCP 2016-07 (versions 1 & 2) from the previous RCP (Version 2015-06) include the following:

- Material from Waste Rock Pad #1 and #2 will be placed in the TSF for final closure. This will limit long-term environmental risk of seepage from these areas and reduce the overall land area that requires long-term monitoring and maintenance.
- The TSF will be closed as a dry facility. Free water in the TSF will be treated in situ and dewatered seasonally to Go Creek, in compliance with WUL allowable discharge limits. The TSF will then be covered and capped. Impermeable HDPE cover will prevent generating and subsequent leaching of acid mine drainage.
- The underground mine was not completely mined or paste-backfilled as described in previous RCPs, due to the temporary closure status of the mine. Concrete bulkheads will be constructed in the underground mine adit and in the vent raise to impede water egress.

Material changes in this RCP from RCP 2016-07 include:

- Updated bulkhead design. The updated design is water tight, and therefore does not require a bioreactor to treat water exiting the underground mine. The contingency biopass installed in Wolverine Creek will be installed if trigger concentrations in Wolverine Creek are met.
- Underground groundwater discharge has progressed at a higher rate that previously predicted. As such, an active water treatment plant will be required to treat water accumulating in the TSF from surface runoff and from the underground mine. This RCP has been updated to include the preliminary test work to assess treatability as well as the costs to design, build and operate an active water treatment plant (WTP) during the temporary closure period. The WTP will also be used during the permanent closure period to dewater water collected in the TSF prior to closure of the facility.
- Increased monitoring of surface water sites, piezometric hydrological conditions and EEM requirements to reflect requirements in the WUL and following comments received from regulators following submission of RCP 2016-07.
- Updated unit rates following publication of those rates in February 2017.

In accordance with the *Reclamation and Closure Planning for Quartz Mining Projects* (Government of Yukon, 2013), this RCP summarizes reclamation and closure planning and objectives in Sections 1 and 2; a description of the project area environmental conditions in Section 3; detailed project background information in Section 4; details of the ongoing temporary closure activities in Section 5; final reclamation and closure measures in Section 6; the reclamation and closure execution strategy in Section 7; and reclamation and closure liability in Section 8.

Should conditions remain unchanged, in accordance with the *Mine Site Reclamation and Closure Policy*, and with the *Reclamation and Closure Planning for Quartz Mining Projects – Plan requirements and closure costing guidance* (Government of Yukon, 2013), YZC will submit an update to the RCP in two years, in September 2019.

1.3 Closure Philosophy and Objectives

This RCP incorporates the following overarching objectives for reclamation and closure of the Wolverine Mine site:

- Ensuring the physical and chemical stability of the area;
- Minimizing or eliminating any hazards to human health and safety;
- Protecting the environment from mine-related degradation;
- Restoring any degradation from mine-related activities; and
- Optimizing productive long-term use of the land.

These objectives are to be achieved through the implementation of the following guiding principles:

- The RCP is environmentally sound and technically feasible;
- The mine has been developed such that eventual passive closure of the site is achievable;
- Progressive reclamation measures have been implemented during operations;
- Post-closure land use will be commensurate with surrounding areas;
- Closure will include environmental protection measures that prevent adverse environmental impacts;
- Closure of the operation will include the protection of public health and safety; and

- Closure planning will incorporate and commit to a comprehensive site monitoring program to assess effectiveness of closure monitoring for the long term.

Further, "Fundamental Mine Reclamation and Closure Objectives" are described in the *Reclamation and Closure Planning for Quartz Mining Projects – Plan requirements and closure costing guidance* (Government of Yukon, 2013), with specific objectives for each area detailed in the 'Terrestrial Performance Standards' listed in Schedule D of QML-0006. Schedule D also outlines 'General Standards'. These fundamental objectives and specific objectives are summarized in Table 1-2. The strategy for reclamation and closure presented in this RCP aims to meet these fundamental objectives. Specific design criteria that describe how YZC can meet these objectives is described in Section 1.4.

Since the approval of the original RCP (Version 2006-01), the closure approach has developed from conceptual to more detailed in nature with each version. Due to the premature cessation of operations in January 2015, the reduced volume of material in the TSF has led to the development of an alternate closure strategy. This new strategy maintains a focus on long-term protection of the environment and human health, while limiting liabilities and meeting legislative requirements. The strategy also targets a passive closure scenario with land uses that are commensurate with surrounding areas. This philosophy is in line with the guiding principles outlined above.

The extended temporary closure period will provide an opportunity for Yukon Zinc to further refine its closure strategy, while at the same time allowing Yukon Zinc to evaluate the possibility of mine re-start, in recognition of the value of both the minerals remaining at the Wolverine deposit and of the infrastructure at the Wolverine Mine.

Table 1-2: Wolverine Mine Reclamation and Closure Objectives

Fundamental Value	Fundamental Objective	Area	Specific Objective
Physical Stability	All mine-related structures and facilities are physically stable and performing in accordance with designs.	Buildings and Infrastructure	Removal or stabilization of any structures remaining after closure to ensure physical stability and to remove any threat to public health and safety, re-establishment of vegetative mat over the disturbed areas of the mine site, and removal of all hazardous substances
		Rock Dumps	Reclaimed rock dumps are to be physically and chemically stable in the long term
		Underground Openings	Prevent long-term inadvertent access to underground mine openings from the surface
		Stability of Underground Workings	Prevent the development of hazardous conditions due to the subsidence of surface materials into underground workings and to restore the site to an approved final land use
	All mine-related structures, facilities and processes can withstand severe climatic and seismic events.	Tailings Impoundment	All tailings impoundments and associated components are to be reclaimed to a condition that ensures physical and chemical stability for the long term
		Water Control Structures	Stable for the long term
Chemical Stability	Release of contaminants from mine related waste materials occurs at rates that do not cause unacceptable exposure in the receiving environment.	General	Prevention of significant exposure to or release of substances that could damage the receiving environment
		Contaminated Soils	Prevent significant release of substances that could damage the receiving environment
		Acid Mine Drainage Concerns	Prevent significant impacts to downstream terrestrial and aquatic resources
		Tailings Impoundment	All tailings impoundments and associated components are to be reclaimed to a condition that ensures physical and chemical stability for the long term
		Rock Dumps	Reclaimed rock dumps are to be physically and chemically stable in the long term
Health and Safety	Reclamation eliminates or minimizes existing hazards to the health and safety of the public, workers and area wildlife by achieving conditions similar to local area features.	General	The protection of health and safety of the public and area wildlife by the elimination of unacceptable health hazards
	Reclamation and closure implementation avoids or minimizes adverse health and safety effects on the public, workers and area wildlife.	Terrain Hazards	The protection of wildlife and public health and safety through measures to prevent and protect wildlife and persons from the terrain hazards such as excavations and surface openings
Ecological Conditions and Sustainability	Reclamation and closure activities protect the aquatic, terrestrial and atmospheric environments from mine-related degradation and restore environments that have been degraded by mine-related activities.	General	Reclamation for productive future use of the land where infrastructure (buildings, chemical and fuel storage, roads, sediment ponds, tailings facilities, waste rock storage areas, open pits, etc.) is or will be located
		General	Prevention of significant exposure to or release of substances that could damage the receiving environment
		General	Minimization of the footprint of mine site development
		Erosion Control	Prevent erosion that significantly impacts drainage quality or impedes re-vegetation of reclaimed site
		Re-vegetation	To restore wildlife habitat through the re-establishment of a vegetative mat (food source, cover, hide, etc.) and self-sustaining native vegetation
		Watercourses	Restore watercourses to required standards
		Contaminated Soils	Prevent significant release of substances that could damage the receiving environment
	The mine site supports a self-sustaining biological community that achieves land use objectives.	Re-vegetation	To restore wildlife habitat through the re-establishment of a vegetative mat (food source, cover, hide, etc.) and self-sustaining native vegetation
Land Use	Lands affected by mine-related activities (e.g., building sites, chemical and fuel storage sites, roads, sediment ponds, tailings storage facilities, waste rock storage areas, underground workings, etc.) are restored to conditions that enable and optimize productive long-term use of land. Conditions are typical of surrounding areas or provide for other land uses that meet community expectations.	General	Reclamation for productive future use of the land where infrastructure (buildings, chemical and fuel storage, roads, sediment ponds, tailings facilities, waste rock storage areas, open pits, etc.) is or will be located
		Roads and Trails	Decommissioning of access corridors when they are no longer required
		Buildings and Infrastructure	Removal or stabilization of any structures remaining after closure to ensure physical stability and to remove any threat to public health and safety, re-establishment of vegetative mat over the disturbed areas of the mine site, and removal of all hazardous substance
	Site access is consistent with community land use expectations.	General	Restoration of the site to a condition that is visually acceptable to the community
Aesthetics	Restoration outcomes are visually acceptable.	General	Restoration of the site to a condition that is visually acceptable to the community
Socio-economic Expectations	Reclamation and closure implementation avoids or minimizes adverse socio-economic effects on local and Yukon communities, while maximizing socio-economic benefits.	General	Reclamation for productive future use of the land where infrastructure (buildings, chemical and fuel storage, roads, sediment ponds, tailings facilities, waste rock storage areas, open pits, etc.) is or will be located
		General	Restoration of the site to a condition that is visually acceptable to the community
	Reclamation and closure activities achieve outcomes that meet community and regulatory expectations.	General	Reclamation for productive future use of the land where infrastructure (buildings, chemical and fuel storage, roads, sediment ponds, tailings facilities, waste rock storage areas, open pits, etc.) is or will be located
Long-term Certainty	Minimize the need for long-term operations, maintenance and monitoring after reclamation activities are complete.	General	Minimization or elimination of the need for maintenance and monitoring in the long term
Financial Considerations	Minimize outstanding liability and risks after reclamation activities are complete.	General	Minimization of liability and environmental risk

1.4 Design Criteria

Design criteria for reclamation and closure activities at the Wolverine Mine were primarily informed by the 'General Standards' outlined in Schedule D of QML-0006. These standards detail practices and targets for undertaking reclamation and closure activities. In addition, several other design criteria were used to guide reclamation and closure planning, to ensure that all the components of the Wolverine Mine were encompassed:

- Practices outlined in the *Yukon Revegetation Manual: Practical Approaches and Methods* (Mining and Petroleum Environment Research Group, 2012), in relation to revegetation efforts;
- The following water quality considerations:
    - Historical (pre-mine) water quality norms in surface water and groundwater at the Wolverine Mine site;
    - Trigger levels set out in the *Wolverine Creek Adaptive Management Plan*;
    - Allowable discharge limits, as set out in the WUL; and
    - The *Canadian Water Quality Guidelines for the Protection of Aquatic Life (freshwater)*.
- *Mined Rock and Overburden Piles, Investigation and Design Manual* (Piteau Associates, 1991);
- *Guidelines for Metal Leaching and Acid Rock Drainage at mine sites in British Columbia* (Price and Errington, 1998); and
- *CDA Dam Safety Guidelines* (CDA, 2007) and the complimentary *Application of Dam Safety Guidelines to Mining Dams* (CDA, 2014).

Other references sourced in this document are provided in Section 9.

2 Reclamation and Closure Planning

2.1 Planning Considerations

This RCP has been written to reflect current conditions and liabilities at the Wolverine Mine. The RCP assumes that temporary closure activities (Section 5) will continue to minimize on-site liabilities and that permanent closure (Section 6) will follow the temporary closure phase. This RCP does not assume resumption of mining activities or propose closure activities following those mining activities. Should the status of mining activities at the Wolverine Mine change, the RCP will be updated to reflect those conditions.

In addition to the philosophy and principles previously described, this RCP was written to meet EMR and YWB requirements, as outlined in the following documents:

- *Reclamation and Closure Planning for Quartz Mining Projects – Plan requirements and closure costing guidance* (August 2013);
- QML-0006;
- WUL QZ04-065;
- Conditions listed in Appendix 1 of the "Response to EMR Wolverine Project Reclamation and Closure Plan Approval letter" letter from EMR to YZC, dated December 23, 2015;
- Conditions listed in the "Update to Reclamation and Closure Plan 2015-06" letter from EMR to YZC, dated June 21, 2016;
- Comments received May 25 via email from Andrea Kenward regarding further clarification and information on the biopass design and construction information; tailings facility; and monitoring data and activities;
- Comments received during the July 19 conference call with EMR, Water Resources, and Compliance, Monitoring and Inspections; and
- Requirements and comments outlined in the "Proposed Amendments to Wolverine Mine Reclamation and Closure Plan Version 2016-07", including comments from Yukon Government, Yukon Workers Compensation Health and Safety Board and the Kaska Dena Council.

Specific regulatory requirements for the RCP are outlined in Table 2-1 below, with the corresponding locations in the RCP included.

Table 2-1: Regulatory Requirements for RCP Version 2016-07.V.2.

From QML-0006, Section 8.6:		Section in 2016.V.2 RCP
a	An analysis of the measures required to be implemented to ensure the ongoing physical and chemical stability at the site	2.1 Planning Considerations
b	A description of how the Licensee will meet the performance standards identified in Schedule D of the Licence, unless other standards are agreed to in writing by the Chief in advance of submission of the document	1.3 Closure Philosophy and Objectives
c	Designs for the closure of all structures, works and installations associated with the Undertaking, including dams, impoundment structures, spillways, diversion ditches, waste rock and overburden dumps, the access road and any other roads at the site, and ore stockpiles	6 Final Reclamation and Closure Measures
d	A description of the methodology for the removal of all infrastructure at the site, including the mill, camp, and access road	6 Final Reclamation and Closure Measures
e	A plan and implementation schedule for ensuring the long-term	6.2 Tailings Storage Facility (TSF) Area

	stabilization and closure of the TSF	7.1 Reclamation and Closure Schedule
f	A plan and implementation schedule for a reclamation research program focusing on characterization of soils in the area, establishing test plots, and documenting re-vegetation to support reclamation and closure of the Undertaking	2.2.2 Re-vegetation Trials 6.9.2 Environmental Monitoring
g	Results of ongoing humidity cell testing to monitor any ARD/ML potential of waste rock dumps and paste backfill and any changes to mitigation required to accommodate the results of testing	This test work ceased in 2012. No further test work has been conducted. Results have been presented in previous Annual Reports.
h	A water quality model for flooded mine workings, including a consideration of water samples taken from paste backfill leachate during mining operations	5.2.2 Underground Mine Workings
i	A program and related implementation schedule for progressive reclamation to be carried out while production and development is ongoing at the site	2.2 Reclamation Research
j	A monitoring and maintenance program and implementation schedule to obtain surface and hydrogeological information, and related implementation schedule adequate to verify that performance objectives and discharge requirements applicable for all structures, works and installation are met at closure and post-closure	5.1.2 Monitoring Activities 6.9 Monitoring and Maintenance
k	A cost estimate prepared by an engineer to implement the plan, including a cost estimate for post-closure monitoring, inspections, and interim care and maintenance	8 Reclamation and Closure Liability Appendix F: Wolverine Mine Dam Safety Review Tailing Storage Facility and Earth Structures, Klohn Crippen Berger, August 2017
l	Details respecting maintenance of site security, including any requirements for continuous care by an on-site care-taker	5.1 Site Security, Monitoring and Maintenance 6.9 Monitoring and Maintenance
m	Updates on the collection and further interpretation of hydrogeological information, related geochemical effects and underground discharge rates from mine workings, and effects on receiving environment during closure and post-closure, including a 3-dimensional numerical hydrogeological model for the underground workings must be provided (details or monitoring of geochemical and physical stability of all facilities at the site and other matters as appropriate)	5.1.2.1 Surface Water and Groundwater Monitoring *3-D modelling will be conducted as part of the hydrogeological assessment conducted in 2018 to assess the requirement for groundwater monitoring.*
n	Designs for the construction of engineered hydraulic bulkheads, with an analysis of bulkhead surrounding material competence and grouting requirements, incorporating hydrogeological model and details of how the hydraulic bulkhead may affect groundwater flow	5.2.2 Underground Mine Workings
o	Details of material stockpiles and on site equipment required to ensure that the Licensee can provide adequate response to an unexpected water management event or spill or release of a hazardous substance	5.1.1 Site Security
p	A contingency plan to ensure that mine discharge from backfilled mine workings does not affect the environmental integrity of Wolverine Creek and Little Wolverine Lake	5.2.2.1 Adaptive Management Plan
q	Results of efforts undertaken to test the bioreactor system under site conditions, including any modifications required to be made to the bioreactor proposal to accommodate results of the field trials and any enhanced knowledge of the relevant biological processes under site conditions	5.2.2.1 Adaptive Management Plan
r	Design, maintenance, long-term monitoring and management plans, and	5.2.2.1 Adaptive Management Plan

	implementation schedules for the bioreactor system and creek diversion	
s	Any enhanced understanding of relevant hydrogeological conditions to ensure the bioreactor system is placed to capture groundwater that has encountered the backfilled mine workings	5.2.2.1 Adaptive Management Plan
t	Details of incorporation of technological developments in best management practices	1.4 Design Criteria
u	Details respecting management of a temporary closure as described in paragraph 8.3	5 Temporary Closure
Conditions outlined in Appendix 1 of YG letter - dated December 23, 2015		**Status**
1	Disposal of reagents and other hazardous materials on site	Complete
2	Written work plan for the installation of hydraulic plugs (bulkheads)	Complete – Submitted to YG on July 28, 2017
3	Written plan for environmental monitoring of underground workings AMP for environmental monitoring of underground workings	Completed - Submitted to YG in May 2016
4	Written plan for experimental water treatment systems	Completed - Submitted to YG in May 2016
5	Written plan for water treatment of tailings management facility effluent: Plan	Completed - Submitted August 17, 2017
6	Update environmental monitoring program sampling regime	Completed
Conditions outlined in YG letter - dated June 21, 2016		**Location in 2016.V.2 RCP**
a	A description of existing conditions	3 Environment Description 4 Project Description 5 Temporary Closure
b	A description of the status of the underground cemented plugs, including as-built drawings	5.1.3.1 Underground Workings and Openings to Surface
c	Surveyed volumes of all waste rock on surface	5.1.3.3 Waste Rock and Overburden Dumps
d	Surveyed volumes of tailings and water stored in the tailings management facility	5.2.3 Tailings Storage Facility (TSF) Area
e	Closure methodologies for waste rock management facilities, stockpile pads, and any locations where ore and/or concentrate were stored during operations	6.3 Waste Rock and Overburden Dumps
f	Closure methodologies for the tailings management facility including consideration of both wet (utilizing inert cover material for solids and an overlying wet cover) and dry (landform with encapsulated saturated tailings) closure options	6.2 Tailings Storage Facility (TSF) Area **NOTE: wet cover request no longer required as per May 25, 2017 email from Andrea Kenward**
g	A water treatment and management plan for the underground workings and tailings management facility	6.1 Underground Workings and Openings to Surface 6.2 Tailings Storage Facility (TSF) Area
h	Issued-for-use design drawings, for the current mine configuration, stamped by a Professional Engineer licenced to practice in the Yukon for the following facilities:	
	i. Waste rock management facilities, including cover designs	6.3 Waste Rock and Overburden Dumps
	ii. Tailings management facility, including wet or dry cover designs	6.2 Tailings Storage Facility (TSF) Area
	iii. Mechanical water treatment facilities	6.2 Tailings Storage Facility (TSF) Area
	iv. Any other engineered facility	6 Final Reclamation and Closure Measures
i	Description of all activities during Temporary Closure required ensuring the site is capable of transitioning to Permanent Closure, if necessary. This includes a description of any tailings water sampling and treatment that will occur during the Temporary Closure period in order to advance a	5 Temporary Closure

	"dry" closure option should that option proceed	
j	A detailed costing for the implementation of permanent closure measures including additional research and/or design work required before implementation of the permanent closure plan would be feasible	8 Reclamation and Closure Liability
Conditions outlined in YG letter - dated September 11, 2017		**Location in 2016.V.2 RCP**
1.	Describe how the predicted annual average inflow rate for the underground workings compares to the previously predicted inflow rates (Woo Shin, April 2015)	5.2.1 Water Balance
2.	Calculate the actual underground inflow rates using the volume of the underground workings and compare to the predicted inflow rates used in the water balance. a. Reconcile predicted inflow rates and project predicted actual pond elevation through January 2020 using the reconciled water balance.	5.2.1 Water Balance
3.	Provide clear recommendation from the Engineer of Record on the maximum safe water level in the TSF for the following scenarios: a. Liner is repaired at the North End Slump area b. Liner is not repaired.	Appendix A, Appendix B
4.	Provide clear recommendations from the EOR on the instrumentation and monitoring requirements for the TSF during the current state of temporary closure and if temporary closure is granted an extension. a. Do higher water levels in the TSF trigger more rigorous monitoring as the water level approaches the spillway freeboard?	Appendix B
5.	Provide an updated Operating, Maintenance and Surveillance Manual (OMS) as part of the updated Reclamation and Closure Plan for review and approval by September 30, 2017. a. The EOR recommendation for December 2017 does not allow adequate time for review before the current temporary closure expires in January 2018.	Updated *Tailings Facility Operation, Maintenance and Surveillance Manual* to be submitted by October 31, 2017.

In addition to the regulatory requirements that were considered in the development of this RCP, the following research and information sources were also central in writing this RCP:

- The results of reclamation research described in Section 2.2:
    - Wolverine Creek bioreactor laboratory studies;
    - Waste Rock Pad #2 bioreactor installation; and
    - Re-vegetation trials and site implementation.
- Consultation with water quality experts to determine the best approach for treating free water in the TSF, prior to any dewatering. The assessment to determine the best approach included reviewing site data such as:
    - Selenium speciation results of the free water in the TSF;
    - Results of ongoing environmental monitoring on site;
    - Historical environmental monitoring data;
    - Results of infrastructure inspections;
    - TSF bathymetric survey; and

- Surveys of waste rock stockpiles.

- Consideration of concepts presented in *Closure Assessment Yukon Zinc Corporation Wolverine Mine* (September 11, 2015) by Lorax Environmental Services Ltd. and Ecowest Consultants Inc. for EMR.
- Consideration of concepts presented in *Environmental Risk Assessment Yukon Zinc Corporation Wolverine Mine* (March 26, 2015) by Lorax Environmental Services Ltd. and Ecowest Consultants Inc. for EMR.
- Consideration of professional opinions presented in *Review of YZC's Wolverine Mine Reclamation and Closure Plan 2015-06 Document and Preparation of an Independent Closure Cost Estimate* (November 17, 2015) by SteveJan Consultants Inc. for EMR.
- Consideration of conclusions in the August 2017 *Dam Safety Review: Tailing Storage Facility and Earth Structures* by Klohn Crippen Berger.

2.2 Reclamation Research

Reclamation research was conducted during the operational period and has continued in the temporary closure period to further evaluate the reclamation techniques proposed in earlier versions of the RCP. Reclamation research focuses on refining the components of the proposed bioreactor systems and on comparing various seed mixes for the most effective re-vegetation and sediment and erosion control techniques. The results of this test work are summarized below and have been used to inform the techniques used in this RCP for closure of the Wolverine Mine.

2.2.1 Bioreactor Water Treatment Trials

Surface water and groundwater in the Wolverine Mine area is naturally high in certain metals. One of the main closure issues facing the Wolverine Mine site is the presence of contaminants of concern (copper, selenium, and zinc) in water leaving the mine site. However, the Wolverine Mine is situated in an environment that is conducive to utilizing passive water treatment systems to treat mine water.

Bioreactor treatment trials have been underway since 2010, and are being incorporated into the adaptive management plan outlined in Section 5.2.2.1. Details of the ongoing treatment trials are also described in Section 5.2.2.1.

2.2.2 Re-vegetation Trials

Re-vegetation trials have been ongoing at the Wolverine Mine since construction was completed in 2009. At the end of the summer construction seasons in 2009 and 2010 several exposed areas were seeded and re-vegetation has been successful.

To date, in areas of disturbance, stockpile areas, and along the site access road, YZC has used a 'Roadside Reclamation' seed mix originating from western Canada, the Yukon and/or Alaska containing 40% Violet wheat grass (*Agropyron violaceum*), 25% Arctic Red Fescue (*Festuca saximontana*), 20% Sheep Fescue (*Festuca ovina*), 10% Slender wheat grass (*Agoropyron pauciflоru*), and 5% Tickle Grass (*Agrostis scabra*). The mix was specified to meet the following purity and germination requirements:

- Species must not exceed the following limits for noxious weeds per 25 grams: 0 primary, 5 secondary, 25 total, and 0 sweet clover; and
- Minimum percent of pure living seed must be 70%.

Photo 2-1, taken in August 2011, shows vegetation establishment in Ditch B.

Photo 2-2, taken in July 2012, demonstrate the success of re-vegetation efforts along the access road corridor, two years after seeding. Photo 2-2, taken in July 2012, shows grass cover establishment on the TSF dam face. Photo 2-4, taken in July 2013, show re-vegetation success around the TSF from seeding completed in 2012. Photo 2-5 to Photo 2-8, taken in September 2014, demonstrate the success of progressive reclamation and re-vegetation efforts around site. Given the success of this re-vegetation strategy, the same seed mix will be used during final closure.

Photo 2-1: Looking North at Established Vegetation in Coarser Material Along Ditch B (August 2011)

Photo 2-2: Revegetation Along the Site Access Road Corridor Near km 16 (July 2012)

Photo 2-3: Construction of the Ultimate TSF dam; Note Seeding on the Starter Dam Face has Resulted in ~50% Grass Cover Between the Crest and Construction Zone (July 2012)

Photo 2-4: Looking South at Established Vegetation on Disturbed Ground Around the TSF Following Fall 2012 Seeding (July 2013)

Photo 2-5: Revegetation Slong the TSF (September 2014)

Photo 2-6: Revegetation Along the Road to Wolverine Lake (September 2014)

Photo 2-7: Revegetation at the Overburden Stockpile Below the TSF (September 2014)

Photo 2-8: Revegetation Along the Downstream Face of the TSF Dam (September 2014)

2.2.3 Future Reclamation Research

Any future reclamation research will be carried out as part of the during the temporary closure phase (Section 5). Work described above for the Waste Rock Pad #2 bioreactor is ongoing and results are regularly reported to EMR and YWB.

2.3 Community Engagement

The Wolverine Lake area is sparsely populated and is used occasionally for harvesting, gathering, and trapping by the Kaska First Nation bands from the Yukon, the Ross River Dena Council (RRDC), and the Liard First Nation. In July 2005, YZC signed a *Socio-Economic Participation Agreement* with the RRDC on behalf of the Kaska Nation that provides a basis for participation by all Kaska Nation members in project exploration and mine development and operations activities. This has and will include the review of environmental, social, and economic matters related to activities that support mine development, operation, and closure. The Wolverine Mine has been operated and will be reclaimed in accordance with the *Kaska Socioeconomic Participation Agreement* and the *RRDC Traditional Knowledge Protocol Agreement*.

2.4 Closure Option Selection

The main objectives for closure planning are to minimize environmental concerns and to maximize geotechnical stability. Previous iterations of the RCP envisioned a wet closure of the TSF due to the potentially acid generating nature of the tailings. However, with the initiation of temporary closure and the potential for an early closure scenario, alternative closure scenarios were considered.

Many factors were considered in selecting the best closure option for the Wolverine Mine. As described in Section 2.1, an assessment of the treatability of the water in the TSF was undertaken in Fall 2016 (see Sections 5.2.3 and 6.2.1). The results of this assessment were instrumental in determining which closure option for the TSF (dry closure or wet closure) would best achieve the closure objectives for the site (see Section 1.3).

The closure scenarios described herein apply the best available technology in terms of environmental protection and geotechnical stability, in order to create a closure landscape for the Wolverine Mine that is most conservative.

3 Environment Description

The following section summarizes environmental conditions for the Wolverine Mine and associated infrastructure, including climate, surface water, groundwater, vegetation and wildlife, soil and bedrock, and seismicity.

3.1 Climate

Weather monitoring at the Wolverine Mine consists of temperatures, pressure, precipitation, radiation, wind speed and direction, and relative humidity data collected from an on-site weather station installed at the south end of the airstrip. As shown in Figure 3-1, weather has been relatively comparable at the Wolverine Mine since consistent recording started in 2007. Note that the HOBO weather station does not record precipitation that falls as snow, consequently only precipitation as rain is provided in Figure 3-1.

The project site elevation is approximately 1,350 masl and the area is cold, with a mean temperature of -4°C, a mean daily summer temperature of 16°C and a mean daily winter temperature of -25°C. Minimum temperatures can reach -37°C and maximum temperatures can reach around 25°C. Precipitation falls fairly evenly throughout the year, predominantly as rain from May to September and snow for the balance of the year. The mean annual precipitation is 570 mm, with total snowfall of less than 2 m. Average rainfall is approximately 235 mm per year. Maximum wind speeds are less than 40 km/h and the annual average is 15 km/h.

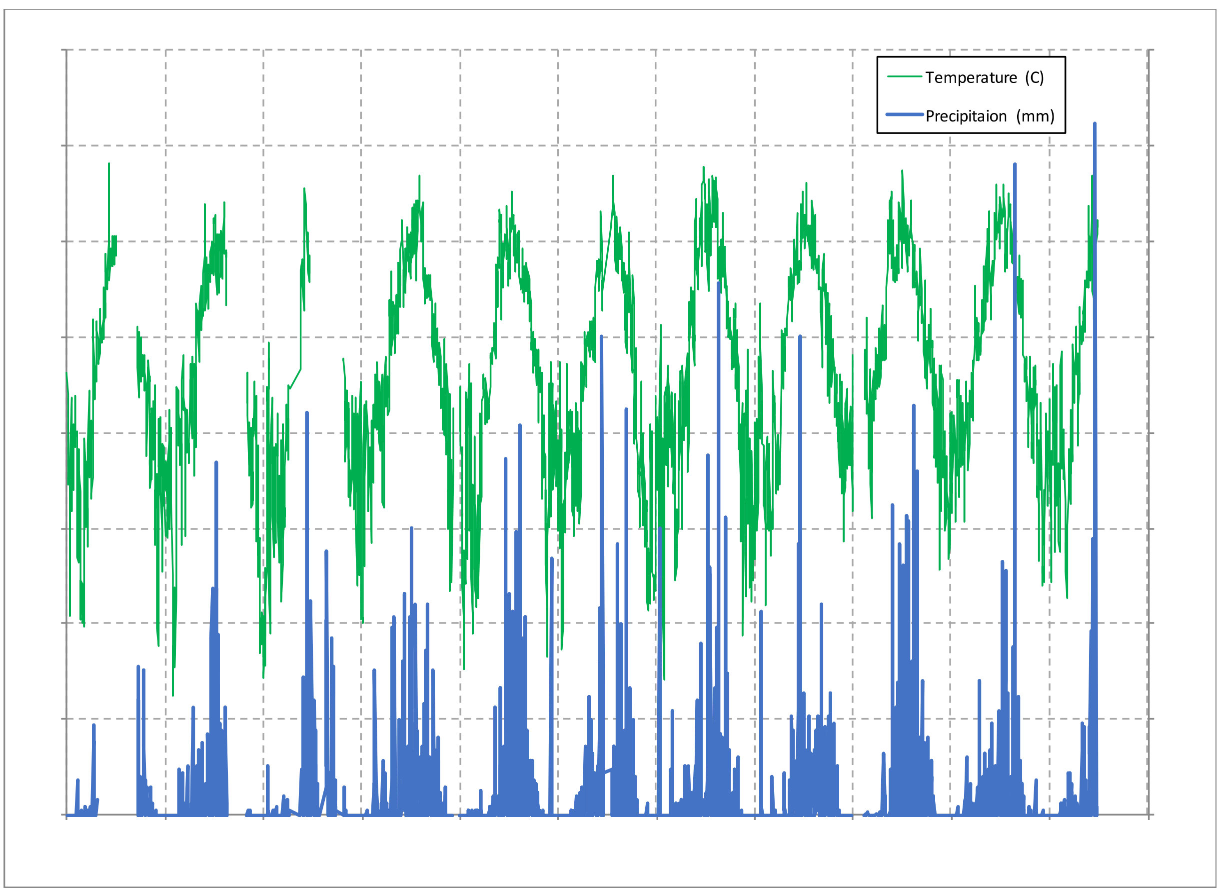


Figure 3-1: Wolverine Mine Daily Precipitation and Average Daily Temperature 2007-2017

3.1.1 Climate Scenarios Considered for Closure

The potential effects of climate change have been evaluated and duly considered in the design and closure management of the TSF. Wide-ranging precipitation conditions (e.g. 100-year dry and 100-year wet) were evaluated in water balance modeling for the TSF in support of this RCP. With the shift to a dry closure, ongoing monitoring and maintenance of the TSF embankment will not be required, as the embankment will be decommissioned. Therefore, the climate change effects will not impact the closure techniques or activities. However, continued monitoring of site meteorological conditions (e.g. precipitation and evaporation) will continue, as will monitoring of runoff from the long-term structures until stable conditions are met.

3.2 Surface Water

The Wolverine Mine is located at the headwaters of the Wolverine Lake watershed and the Go Creek watershed. Go and Bunker Creeks flow into Money Creek, which flows east to Frances Lake in the Liard River drainage. Wolverine Creek flows north to Little Wolverine Lake, which in turn drains to Wolverine Lake and via Nougha Creek, discharges to the Finlayson River. The aquatic ecosystems in the area are generally typified by cold and clean water. Waters in the upper drainage areas around the mine (i.e., Go Creek, Wolverine Creek, small tributaries of Money Creek, Bunker Creek, and Putt Creek) all have limited to no fisheries potential.

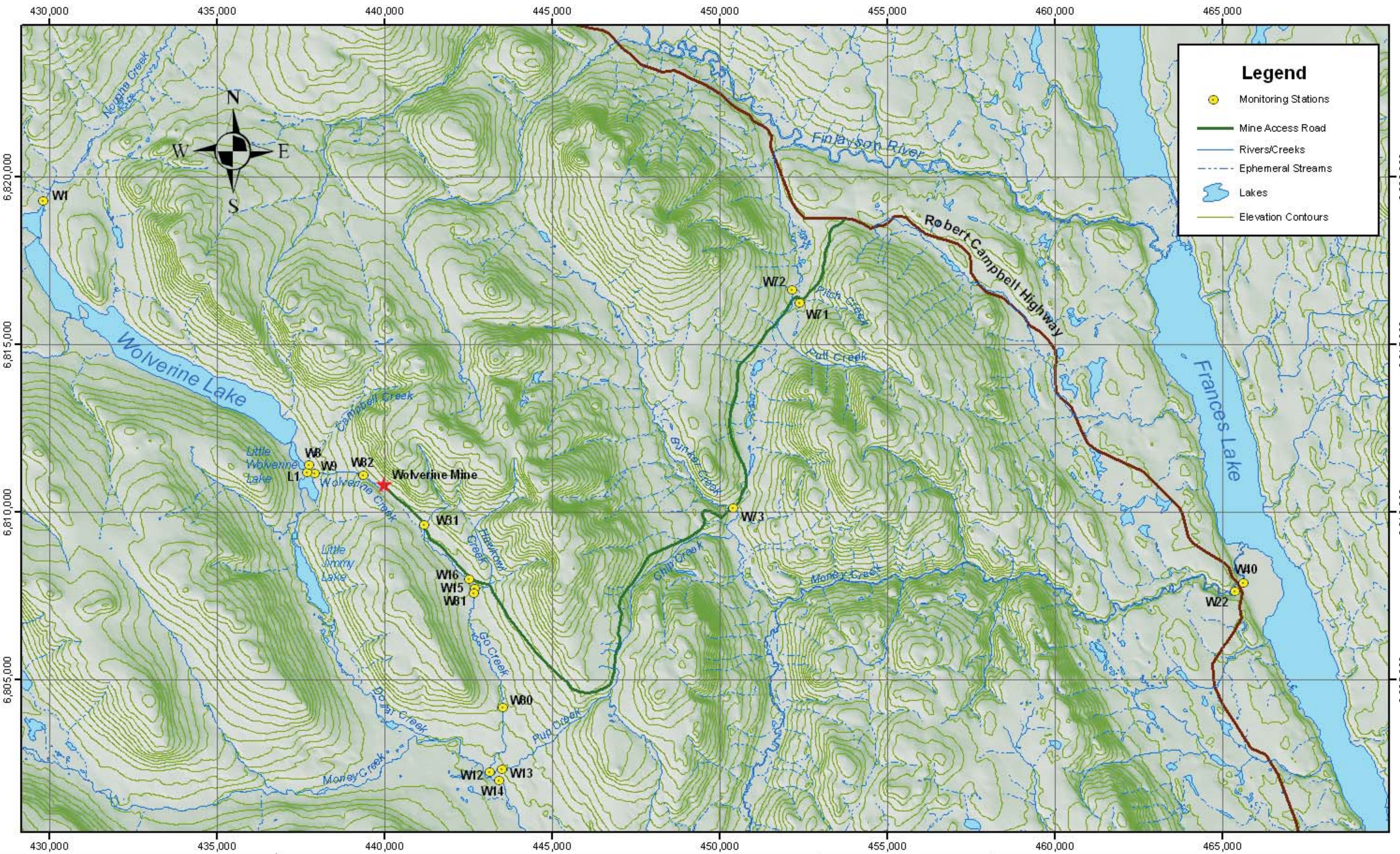
A surface water monitoring program has been established for the Wolverine Mine that provides continuous streamflow data for watercourses in the immediate vicinity of mine site operations as well as more regional coverage (Figure 3-2). Regular monitoring for water quality is also conducted at the sites outlined in Figure 3-2. The hydrological and water chemistry conditions around the mine site are summarized below.

3.2.1 Hydrology

Stations W9 and W82, respectively, have been established on Wolverine Creek at the mouth and in the upper reaches immediately adjacent to the underground operations, respectively. These stations monitor the influence of underground dewatering on flow conditions in Wolverine Creek. Upper Wolverine Creek (station W82) is a narrow creek that freezes to ground in the winter. Flows at this station average 0.005 m^3/s, as shown in Figure 3-3. As Wolverine Creek descends towards Little Wolverine Lake, volumetric flows increase, with average flows just above the confluence of 0.01 m^3/s, on average, shown in Figure 3-5. Typically, the flows in Wolverine Creek are highest during spring freshet, level off during the late summer, and peak again in late fall during rain on snow events.

Monitoring of flow conditions in Go Creek occurs at station W80. Flows have averaged 0.47 m^3/s over the monitoring period. W80 also represents the compliance monitoring point for effluent discharges. Hydrology in Go Creek (Figure 3-5) is characterized by high flows in May and June with decreasing flows throughout the summer. Spikes in flow rate are evident again in October due to rain on snow events. Flows are lowest in the late winter months: February, March, and April.

Regional hydrology is monitored via station W22 on Money Creek. Hydrology in Money Creek is relatively consistent, with measured flows ranging from ~4 m^3/s to ~20 m^3/s; although the data logger recorded some peak flows up to 148 m^3/s (Figure 3-6). On average flow rates are ~8 m^3/s. Similar to other creeks in the area, Money Creek is characterized by high flows in May and June, with decreasing flows throughout the summer, and spikes again in late fall, with the lowest flows in late winter (February through April).



0 1,000 2,000 4,000 6,000 Meters

Projection: UTM Zone 9, NAD 83

DESIGNED BY			**Baseline Characterization Report**
DWG. CHECK			Surface Water Quality Monitoring Stations
DRAWN BY	SSS	April 7, 2010	
SCALE	1:110,000		
PROJECT NO.	474-3		Figure 3-2 REV.

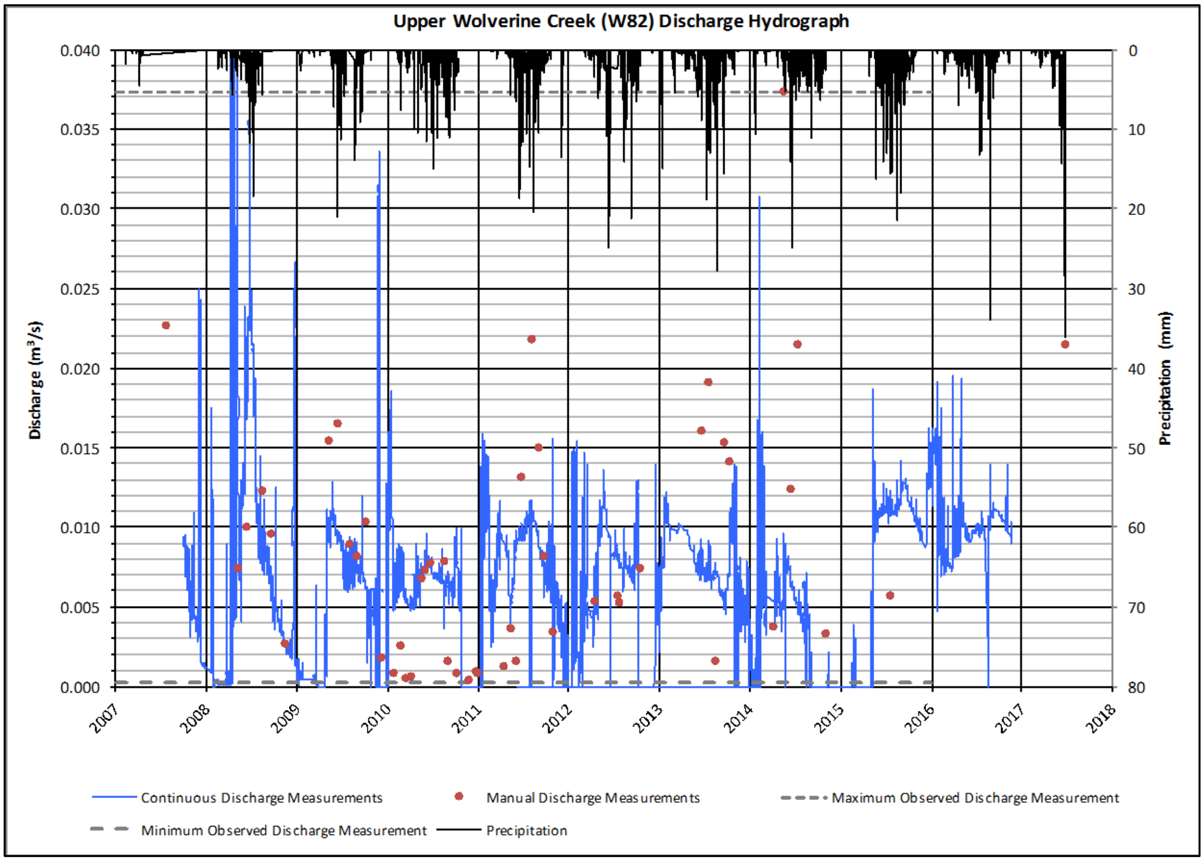


Figure 3-3: W82 Discharge Hydrograph

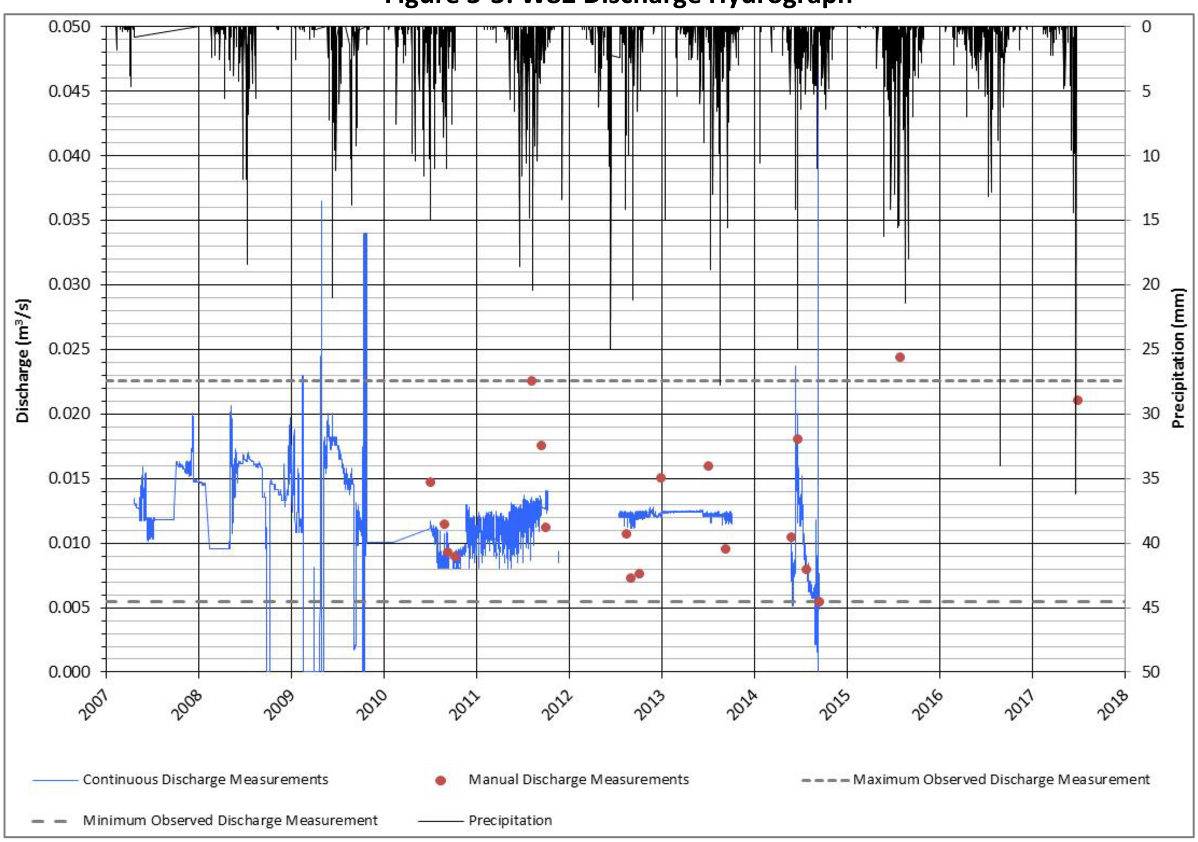


Figure 3-4: W9 Discharge Hydrograph

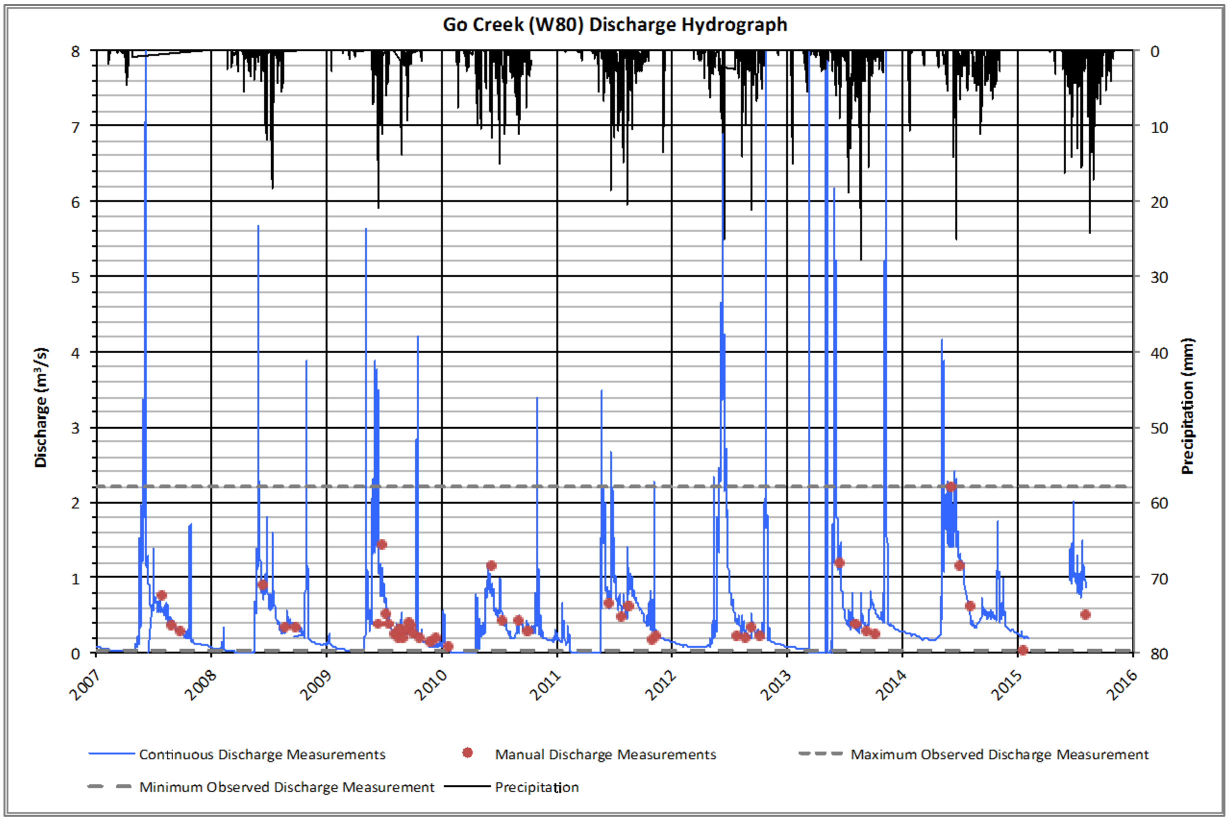


Figure 3-5: W80 Discharge Hydrograph

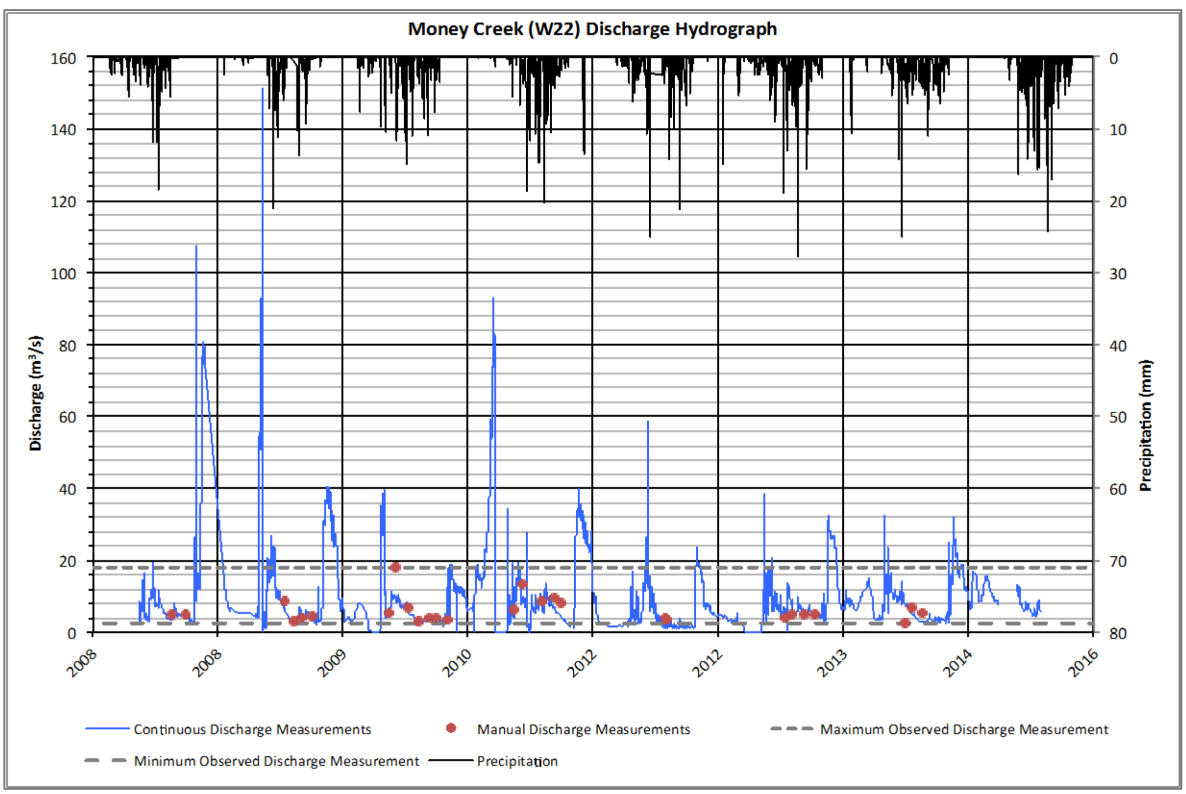


Figure 3-6: W22 Discharge Hydrograph

3.2.2 Surface Water Quality

Surface water quality in the area proximate to the Wolverine Mine is relatively pristine, with high metal concentrations directly adjacent to the ore body in Wolverine Creek. Water chemistry statistics for samples taken 2009-2016 inclusively are shown in Figure 3-7 through Figure 3-17, with water quality sites listed in order moving downstream from the mine. Values that were reported as being less than the reportable detection limit were taken to be half the detection limit when calculating the median, 25th and 75th percentile values. Parameter concentrations are compared to the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME), or the ambient water quality guideline from the Ministry of Environment of British Columbia for sulphate, where applicable. Median hardness was used to calculate hardness dependent guideline concentrations (i.e., cadmium and sulphate).

Wolverine Creek naturally receives drainage from the mineralized area of the Wolverine deposit. As such, concentrations of cadmium, copper, selenium, and zinc in Upper Wolverine Creek (W82) are typically above the CCME guidelines and generally decrease with downstream distance (i.e., W82 is in upper Wolverine Creek and W9 is in lower Wolverine Creek). Metal concentrations above CCME guidelines were also evident at stations along the road route, which is likely tied to the high TSS values experienced in the spring (Figure 3-10). Metal concentrations in the Go Creek and Money Creek watersheds are statistically comparable and show very little fluctuations. These values and trends are consistent with baseline values (Lorax, 2010).

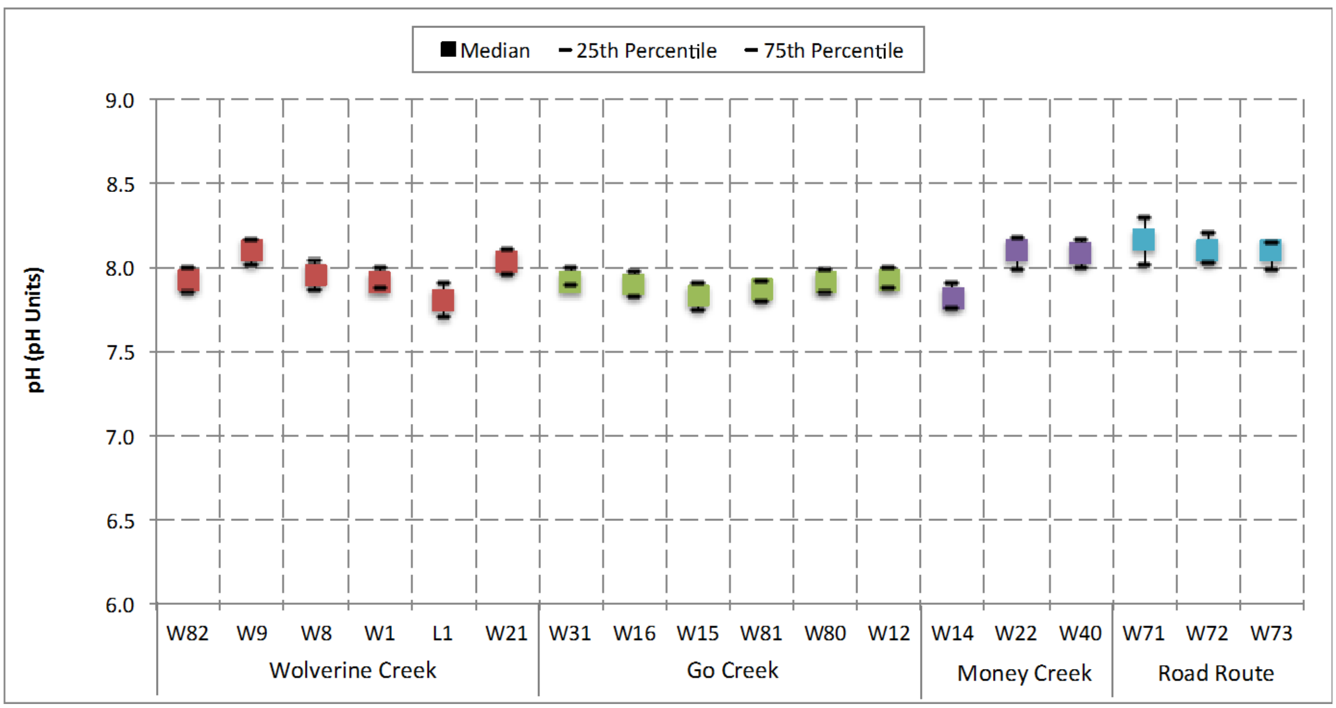


Figure 3-7: Surface Water Chemistry – pH (2009-2016 data)

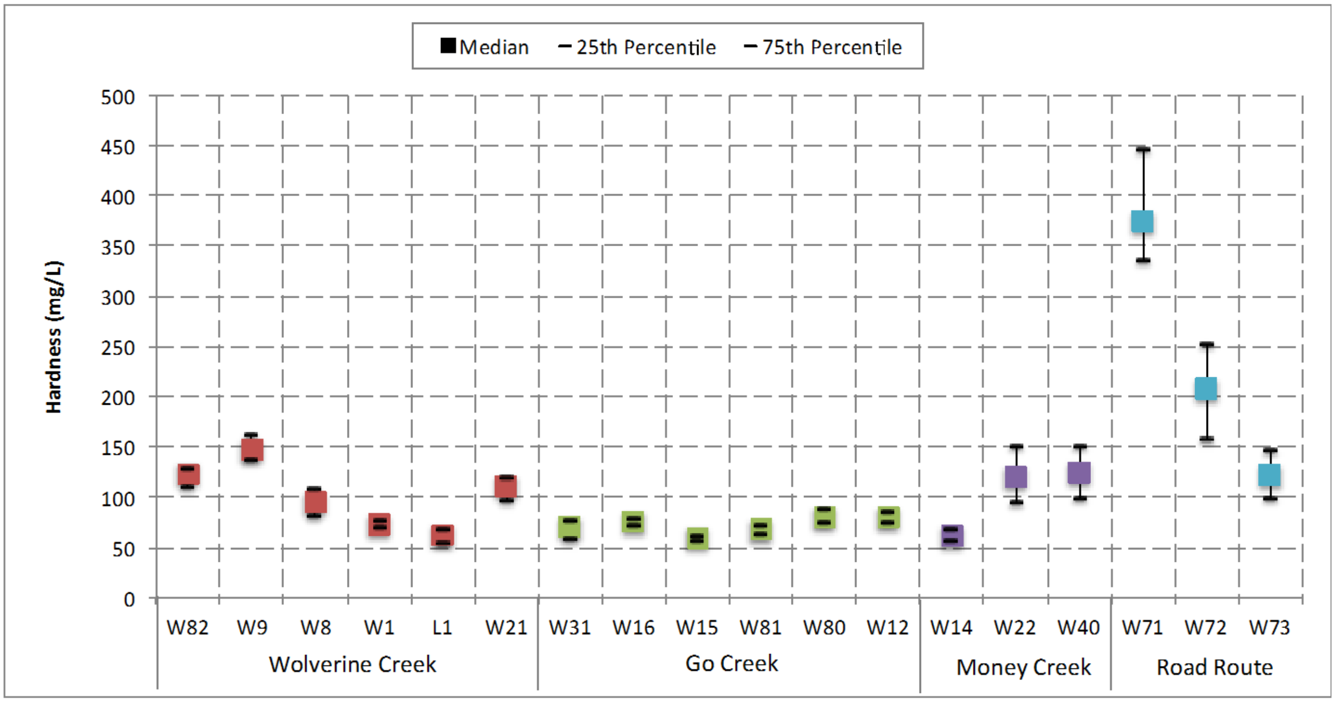


Figure 3-8: Surface Water Chemistry – Hardness (2009-2016 data)

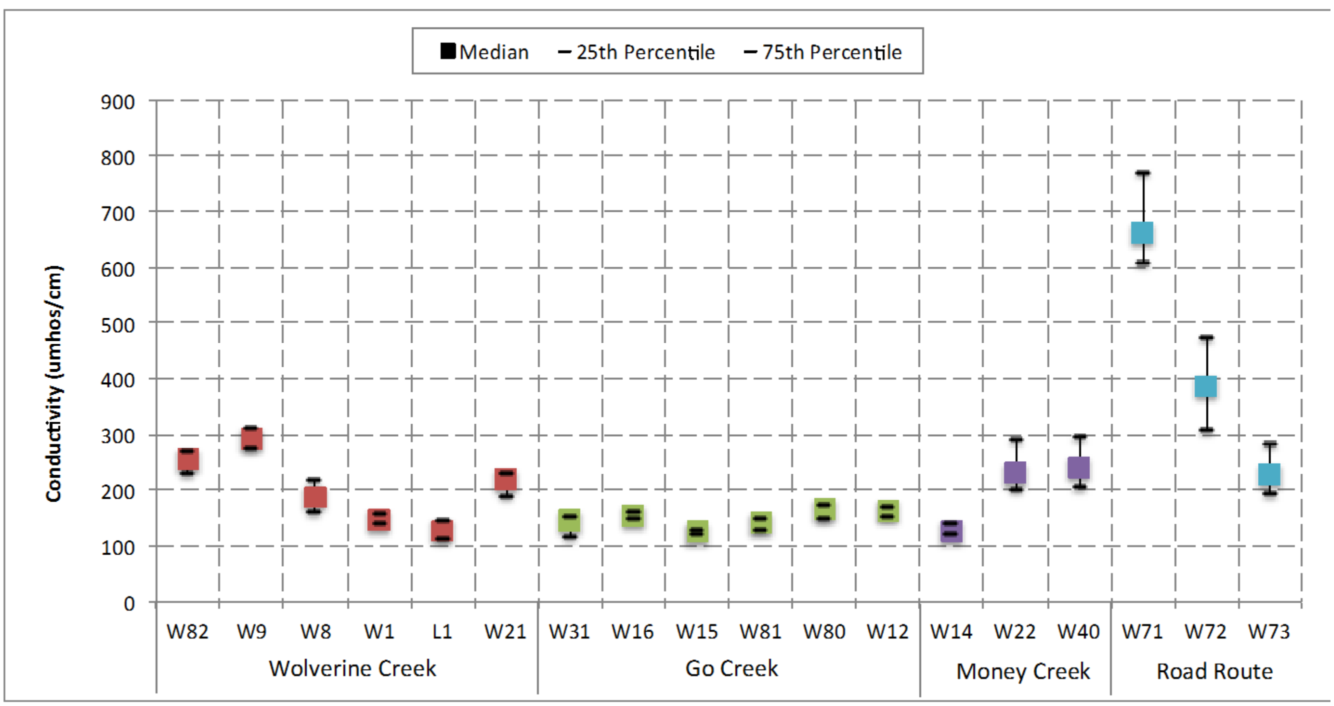


Figure 3-9: Surface Water Chemistry – Conductivity (2009-2016 data)

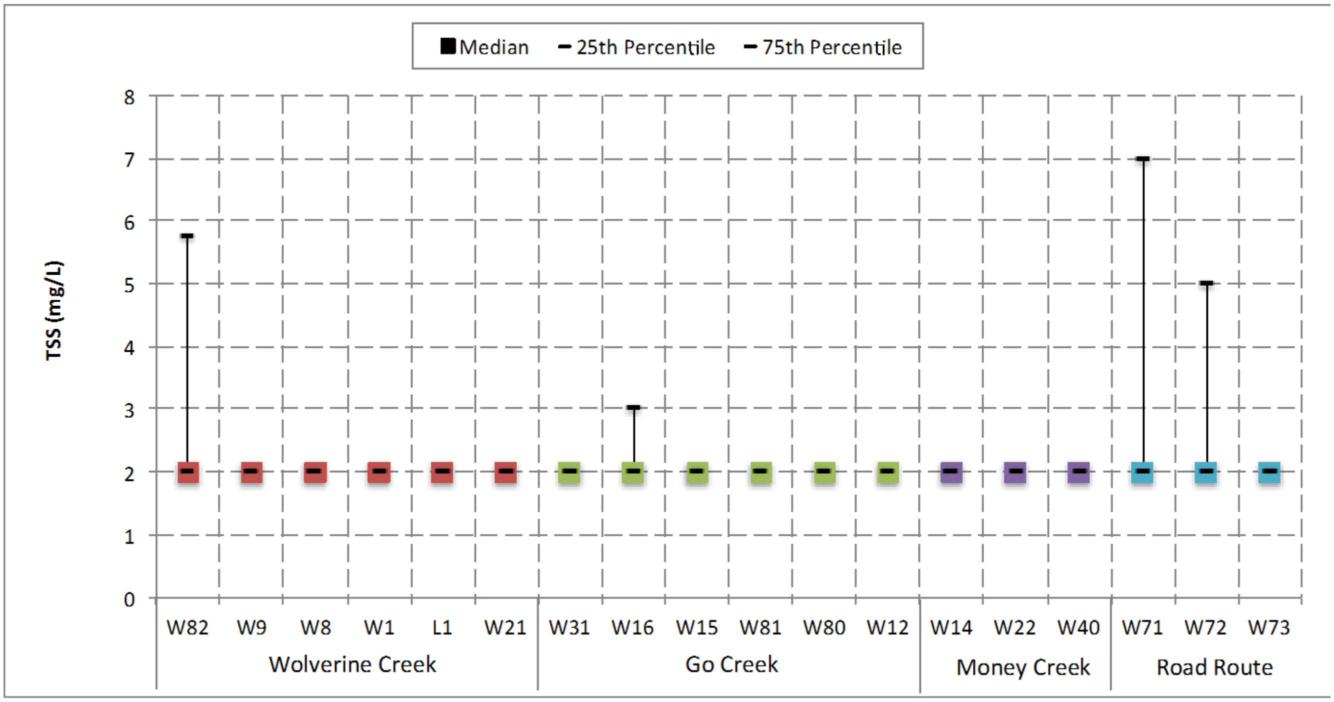


Figure 3-10: Surface Water Chemistry – Total Suspended Solids (2009-2016 data)

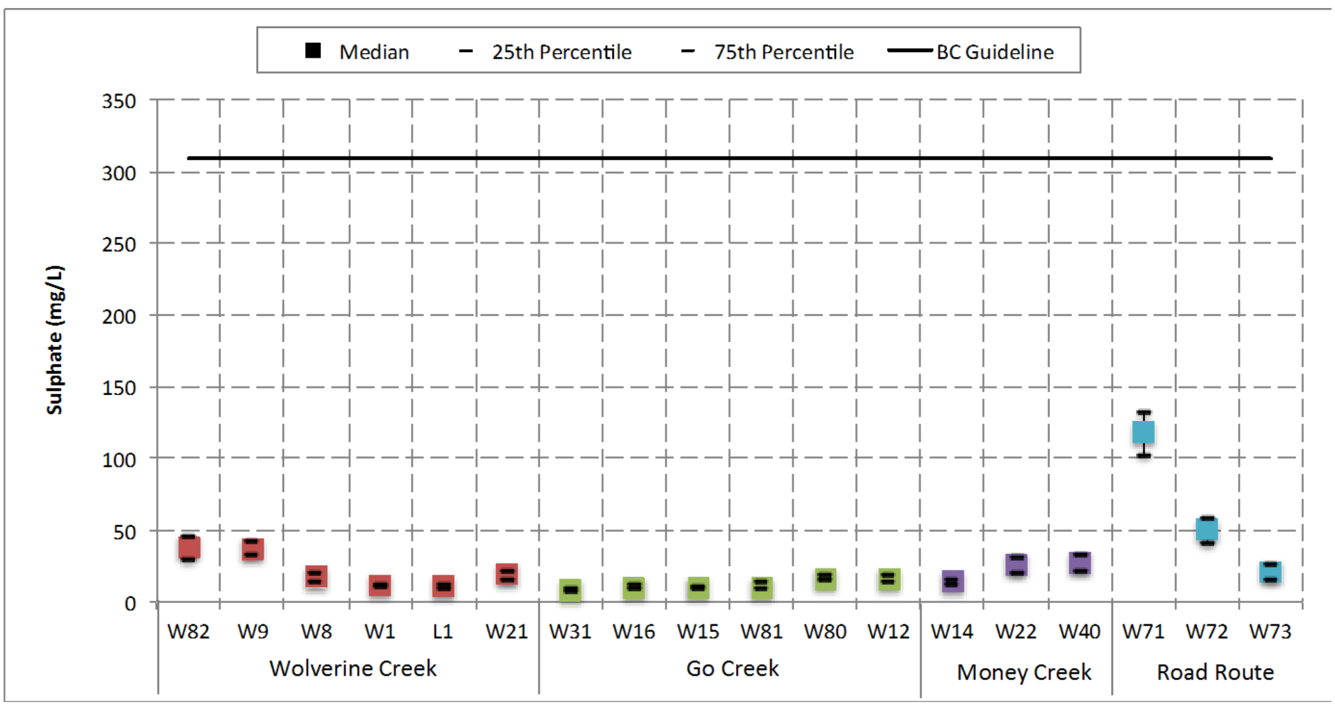


Figure 3-11: Surface Water Chemistry – Sulphate (2009-2016 data)

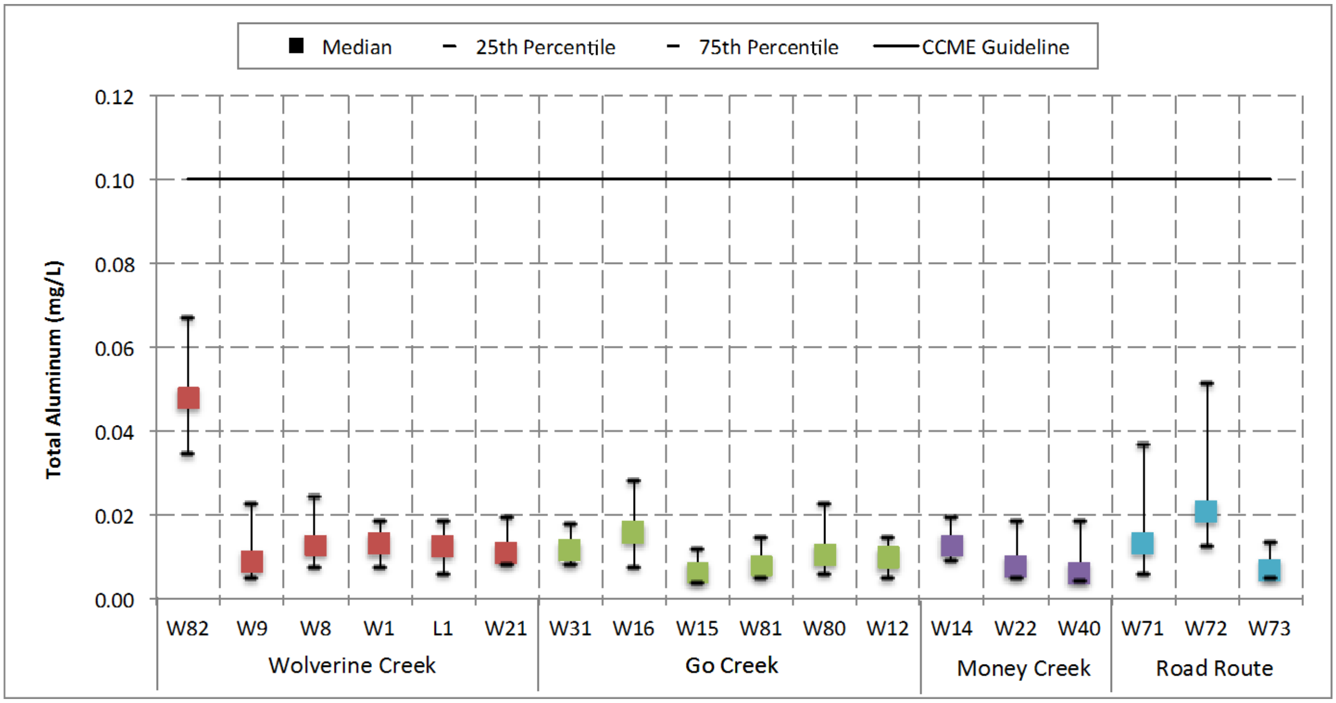


Figure 3-12: Surface Water Chemistry – Total Aluminum (2009-2016 data)

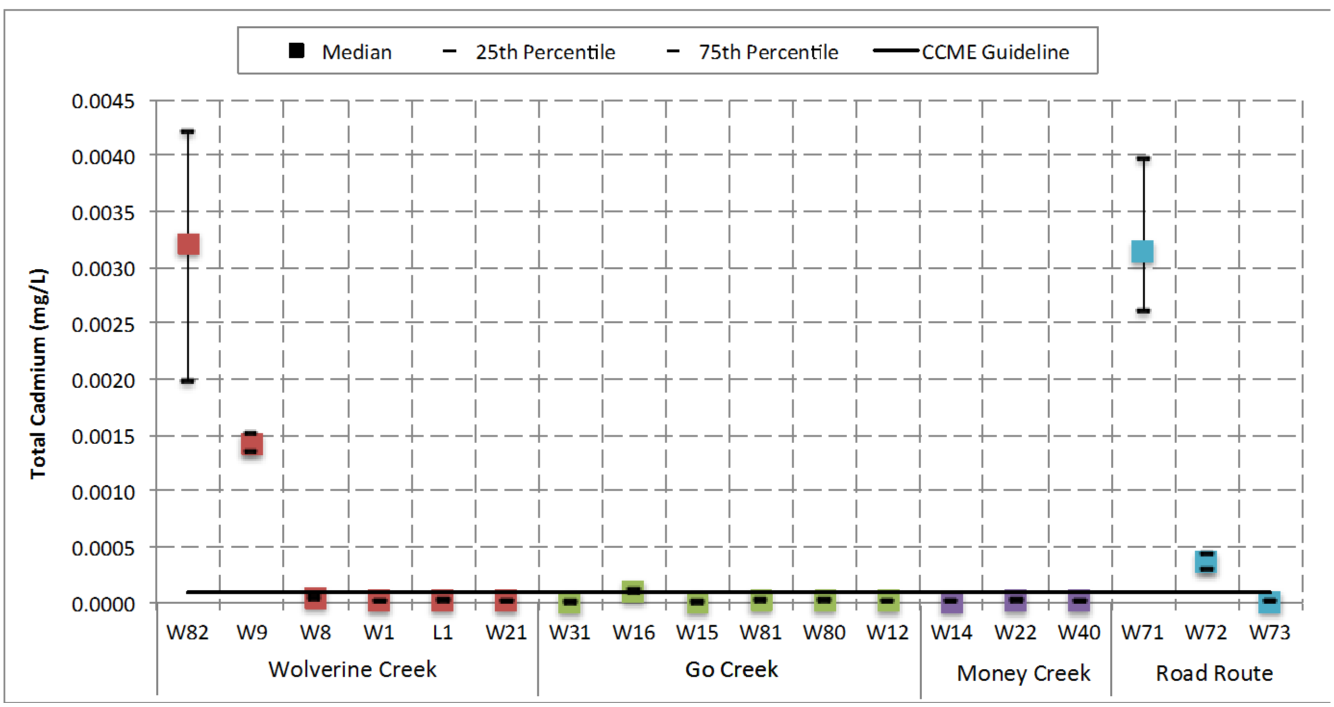


Figure 3-13: Surface Water Chemistry – Total Cadmium (2009-2016 data)

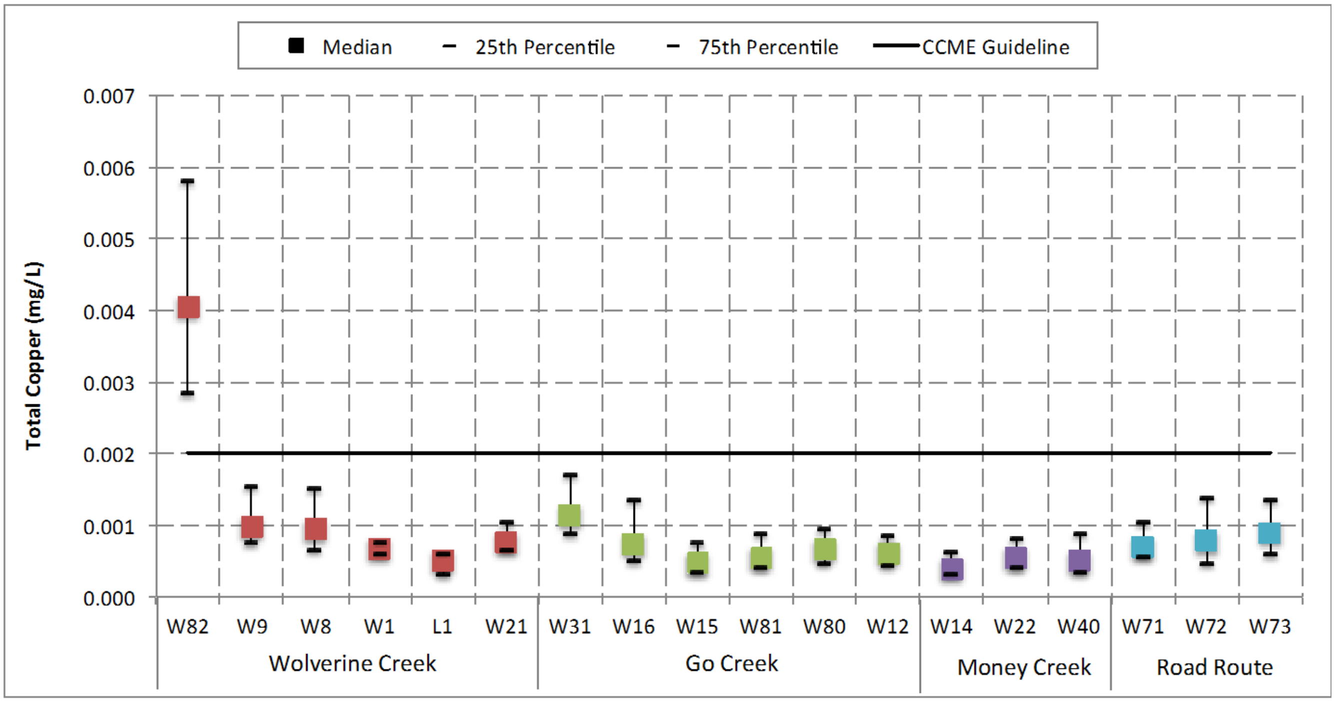


Figure 3-14: Surface Water Chemistry – Total Copper (2009-2016 data)

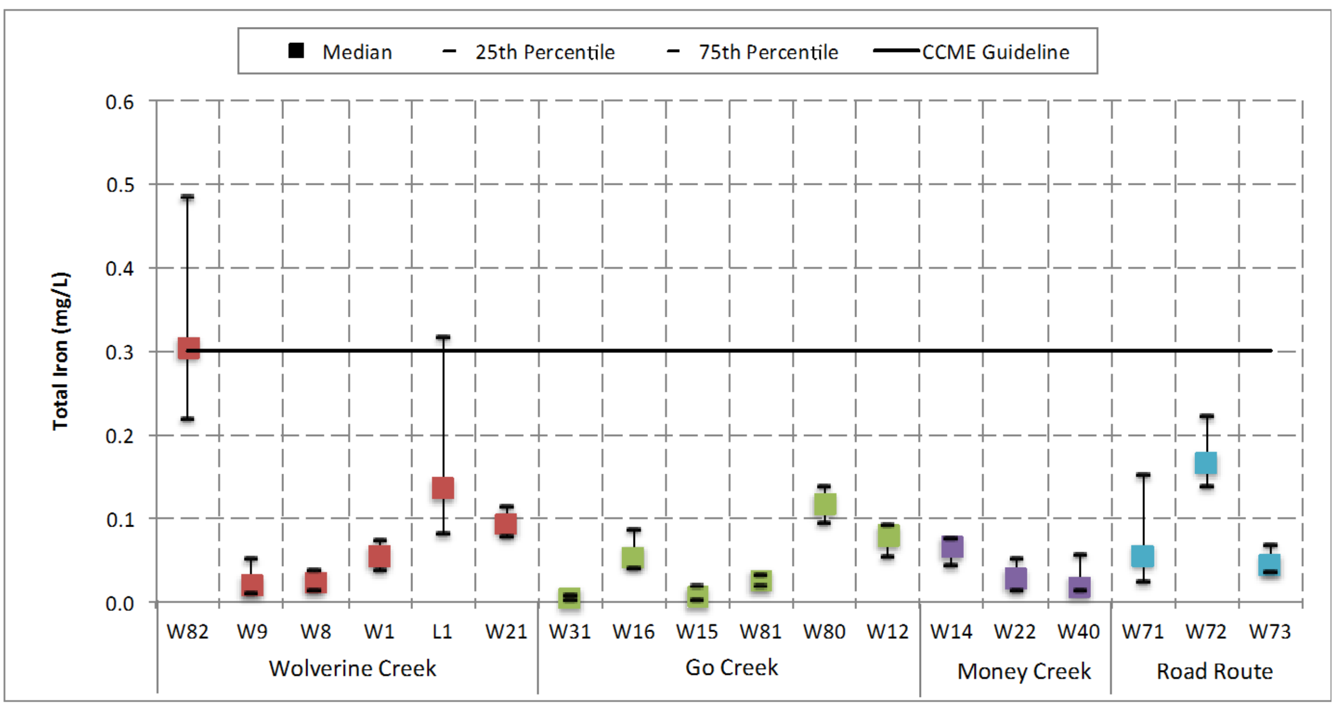


Figure 3-15: Surface Water Chemistry – Total Iron (2009-2016 data)

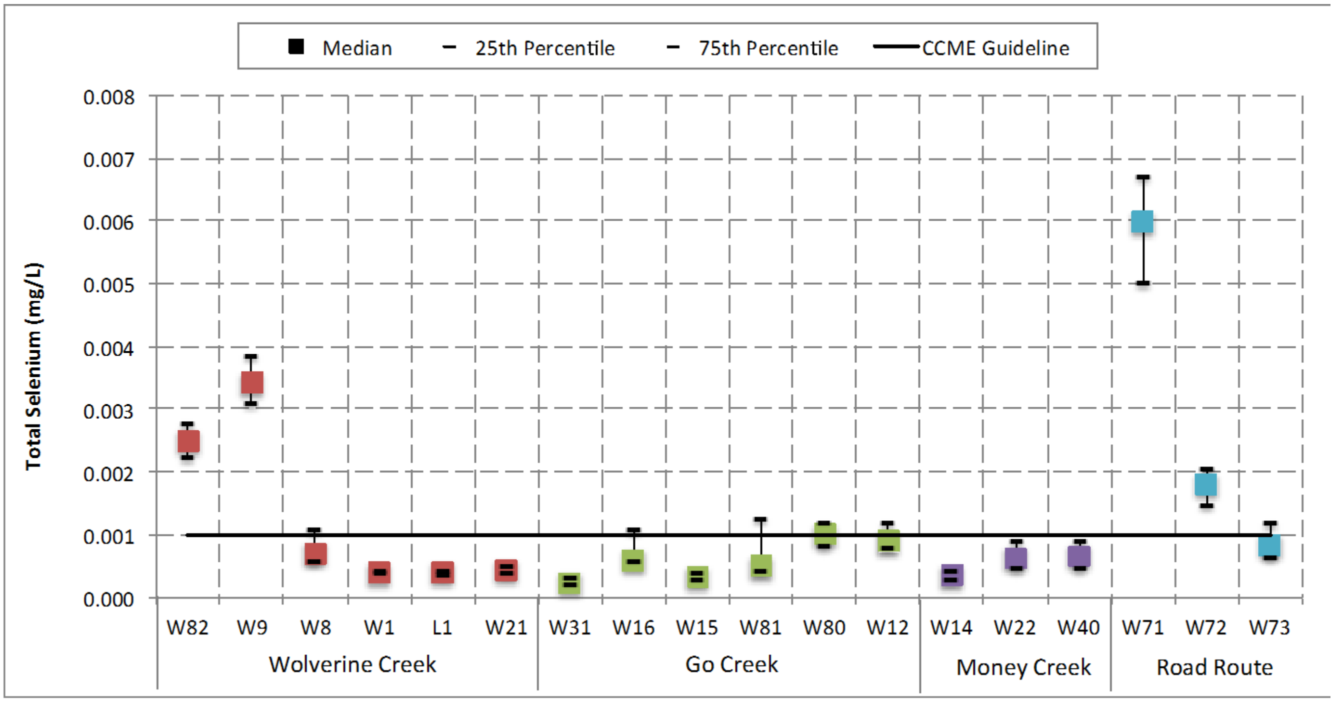


Figure 3-16: Surface Water Chemistry – Total Selenium (2009-2016 data)

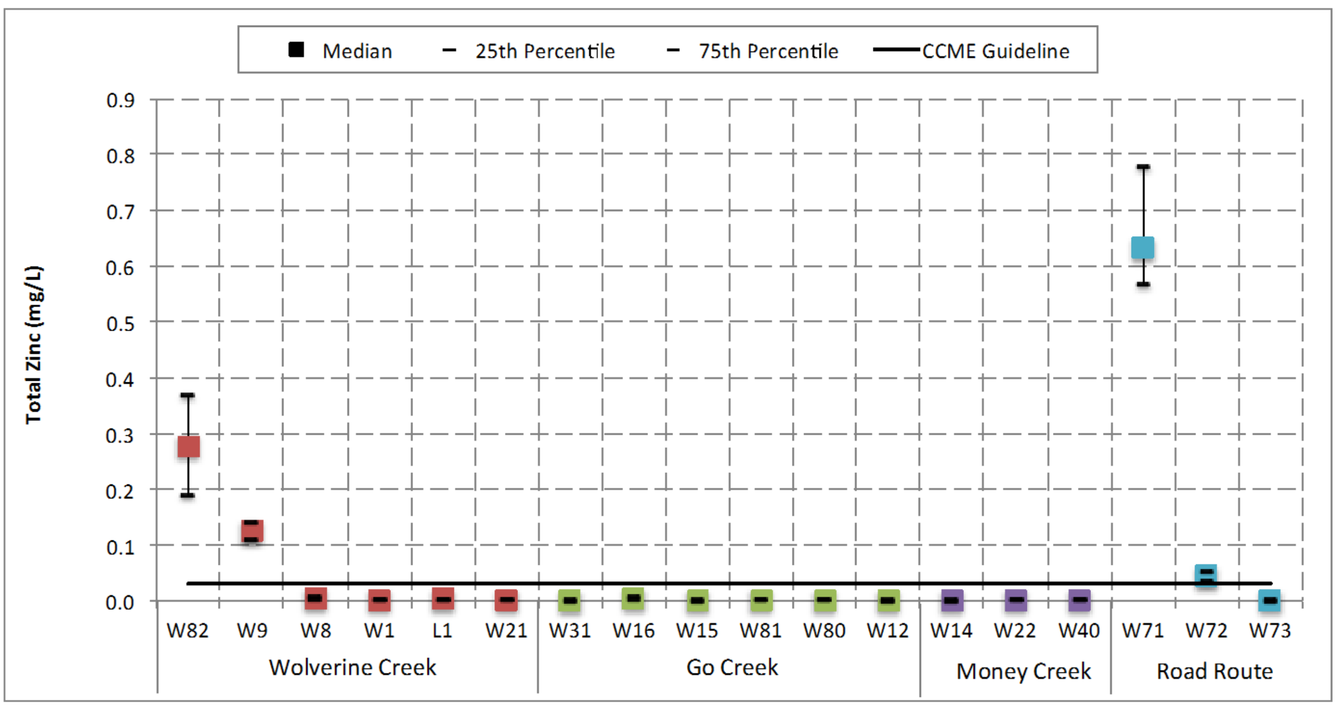


Figure 3-17: Surface Water Chemistry – Total Zinc (2009-2016 data)

3.3 Groundwater

3.3.1 Hydrogeology

Comprehensive analysis of the hydrogeology in the mine site area was developed for the Environmental Assessment (YZC, 2005) to predict the impacts of the underground mine on the Wolverine Creek watershed. Ongoing monitoring is conducted at groundwater monitoring wells throughout the Wolverine Creek and Go Creek basin (Figure 3-21). The conceptual hydrogeologic model plan and cross-sections, and predicted dewatered zones, are shown in Figure 3-22 through Figure 3-26.

Two bedrock aquifers are present in the vicinity of the mine including a shallow unconfined aquifer above the iron formations and a deeper, semi-confined aquifer below the iron formations. The upper and lower iron formation as well as the mineralized zone behave as aquitards and may slow the flow of groundwater. There is a homogeneous and isotropic aquifer inferred to be 150 m in thickness. Water table depths and flow divides were inferred based on ground surface topography, surface water bodies and known water table elevations in close proximity to the mine area. Groundwater is inferred to flow from northeast to southwest near the mine. Precipitation on the ground surface above the mine infiltrates into the ground and recharges the groundwater flow system. Groundwater flows southwestward to discharge locations along Wolverine Creek.

Potentiometric elevations are measured at four vibrating wire piezometers installed in two exploration boreholes (PZ-A and PZ-B) in the Lynx and Wolverine mineralized zones, respectively. Results from ongoing monitoring following mine development are shown in Figure 3-18. Battery failure of the piezometers in 2009 resulted in gaps in the data. A malfunction was discovered with the PZA Deep sensor in June 2014 and in the PZA Shallow sensor in December 2015, therefore data is not presented after those dates.

The shallow piezometers remained relatively constant throughout pre-production and operations, although the PZB shallow piezometer indicates an increase in the water table since mid-2016 in parallel to the PZB deep piezometer. The deep piezometers showed a marked decrease from 2009 to the cessation of operations, which, while originally attributed to an intersection of the mining operations with the well, the PZB Deep piezometer has recovered back to pre-production levels as of mid-2017.

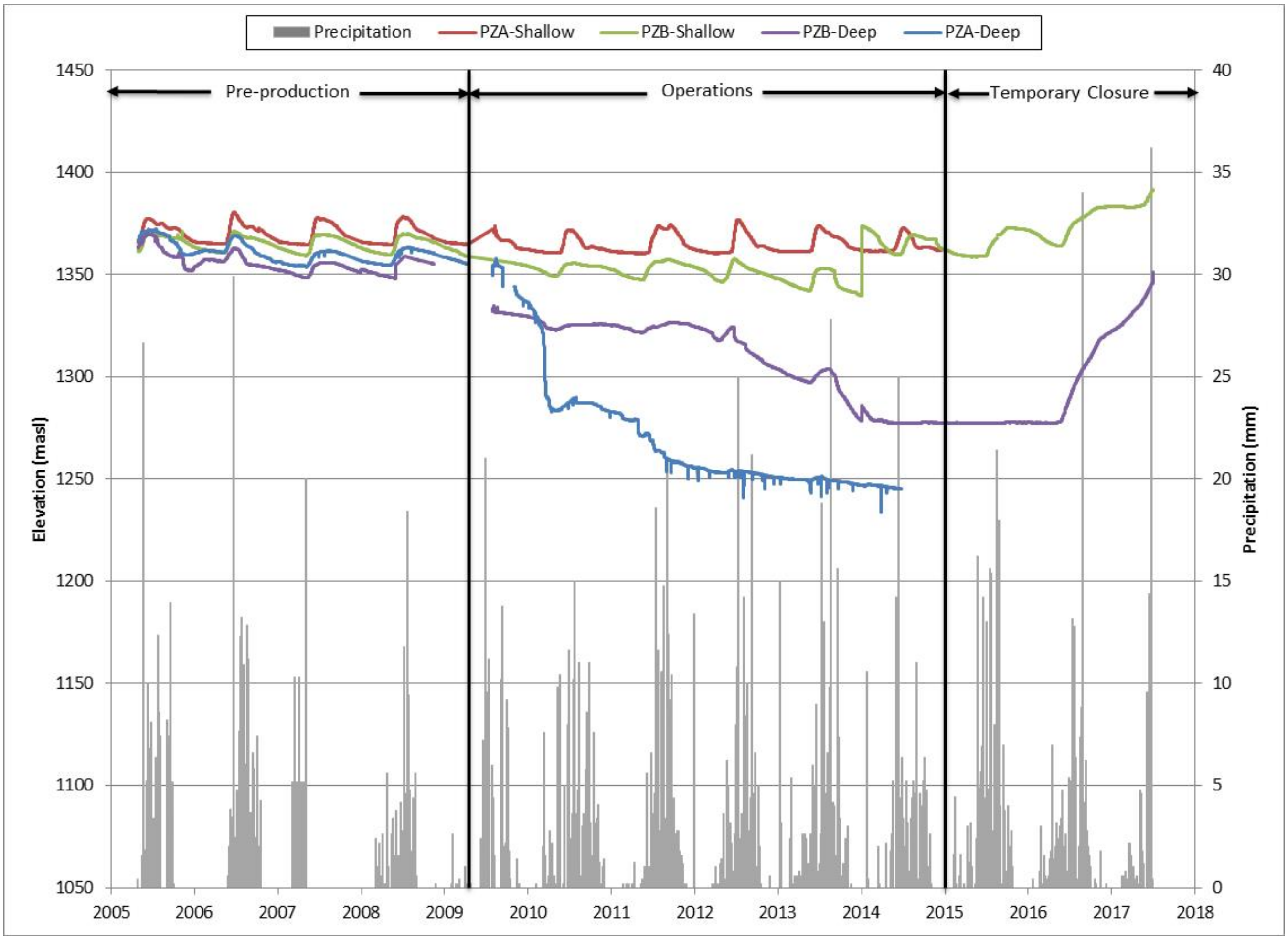
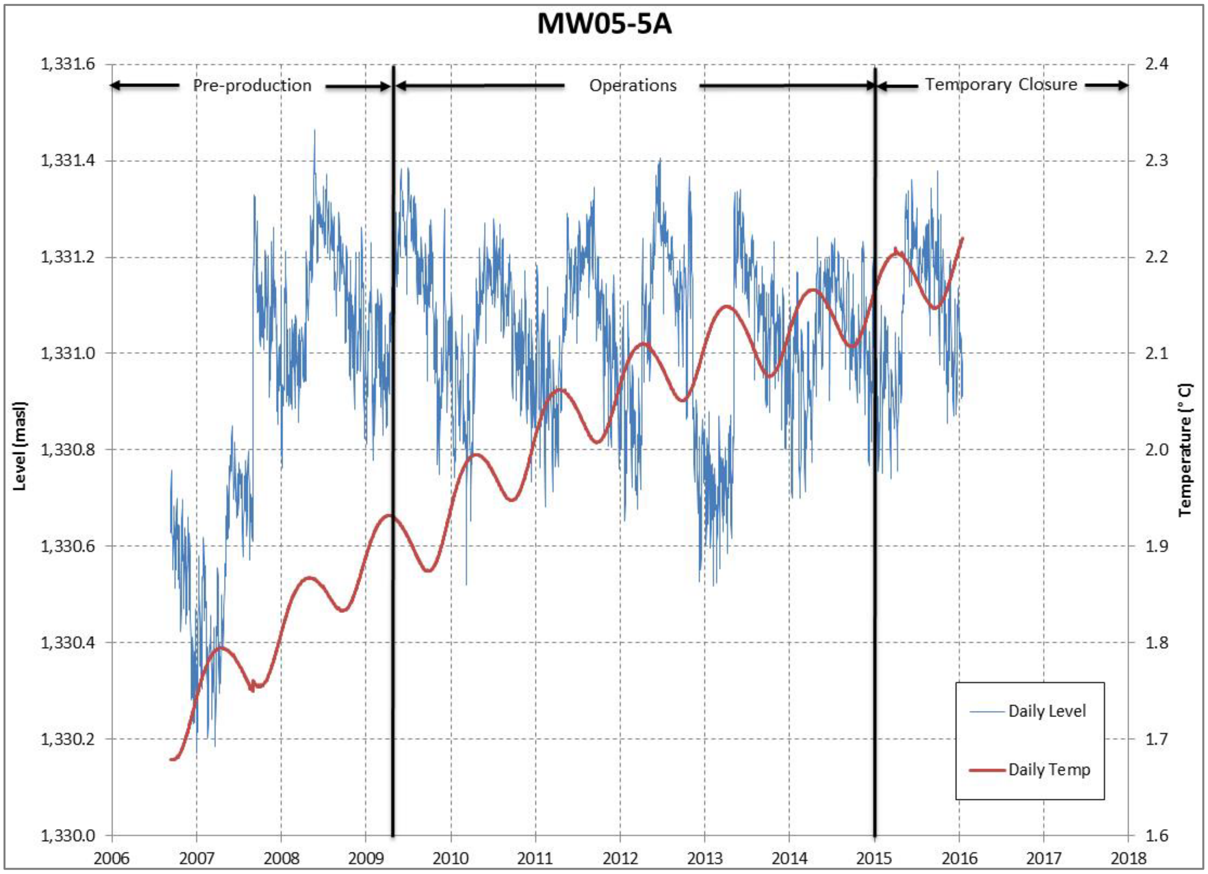


Figure 3-18: 2005-2017 Pieziometric and Precipitation Data

In the vicinity of TSF area, the groundwater table is generally sloping southwest following the trend of the topography. Near the downstream end of the impoundment basin at MW05-7 (Figure 3-21), the piezometric pressure in the bedrock is slightly artesian (few meters above ground) and the water table rises, with the topography, towards the dam abutments. In general, the groundwater table in the overburden is slightly lower than that in the bedrock. Water levels in groundwater wells downstream of the mine (MW05-5 and MW06-11 - Figure 3-19 and Figure 3-20) have been relatively consistent, although water levels in MW06-11 dropped in mid-2011, and values have been relatively constant since. The increase in water level in mind 2007 and mid 2010 in MW05-5A and MW05-5B, respectively, are due to re-installation of the loggers, and not representative of actual water level shifts. The groundwater table exhibits seasonal variation, reaching highest elevation after spring runoff season (Figure 3-19 and Figure 3-20).

The main groundwater aquifer is the 10 m to 20 m thick overburden overlying bedrock within the Go Creek Valley. Downstream of Go Creek valley, which appears to be a hanging valley, the morphology changes to a broader terraced valley where much thicker deposits of post glacial outwash soils provide a larger groundwater flow regime.



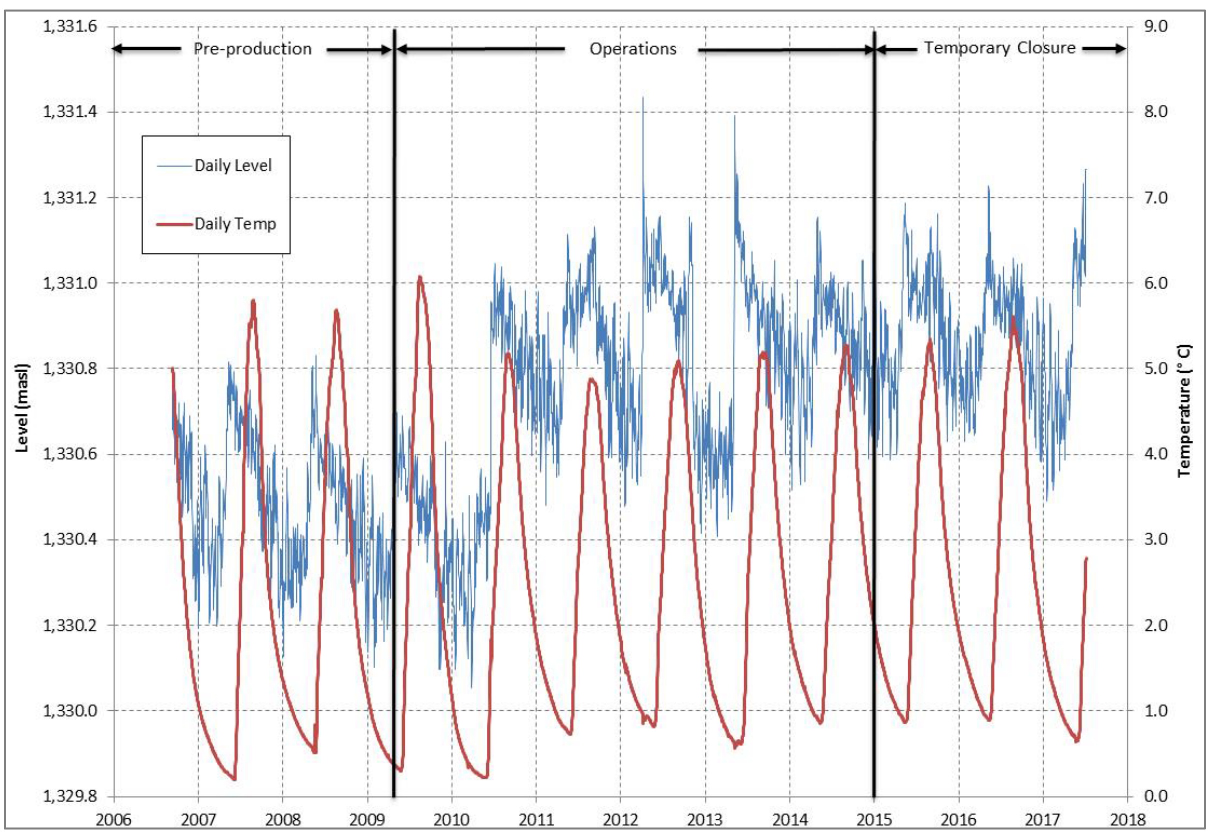


Figure 3-19: Groundwater Well MW05-5 Water Level and Temperature

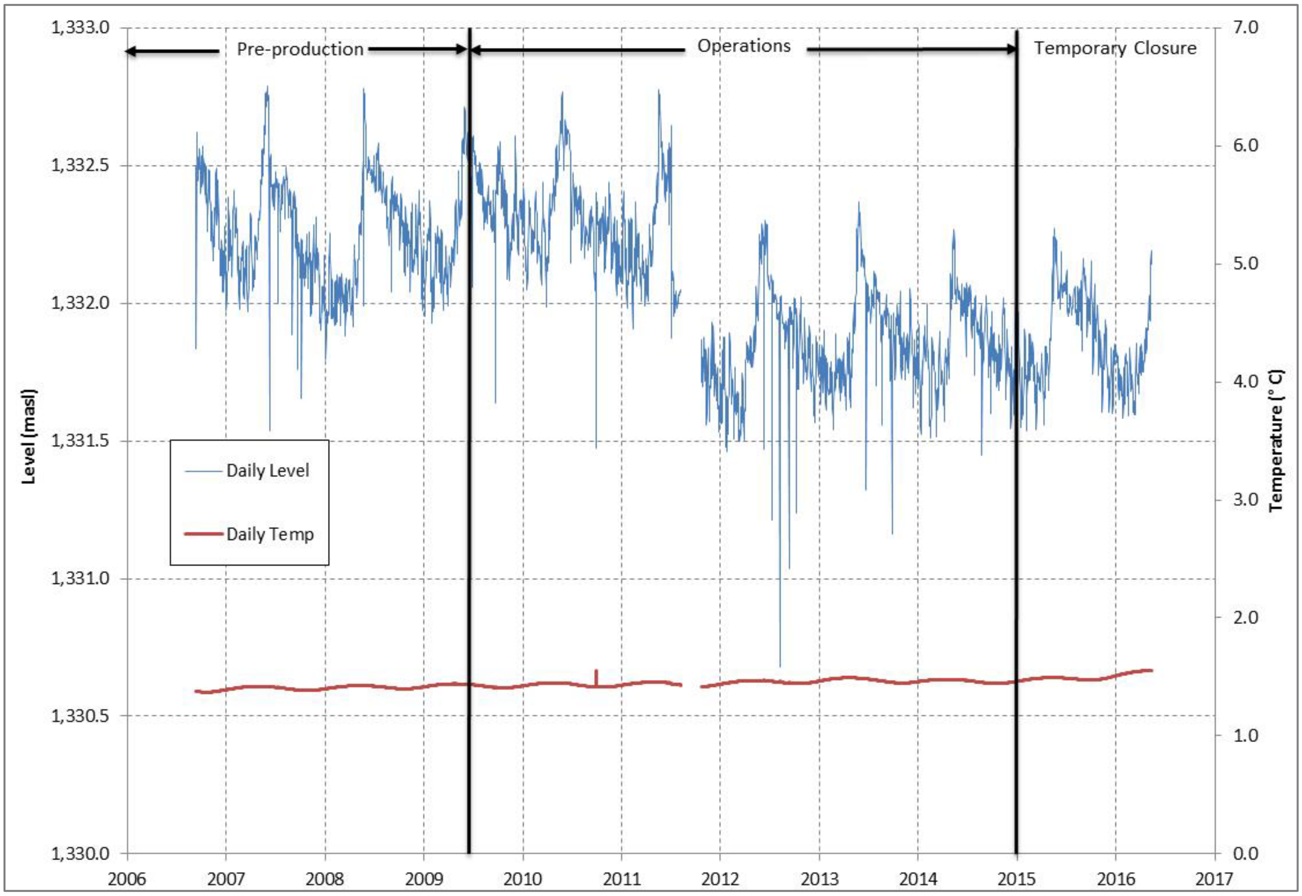
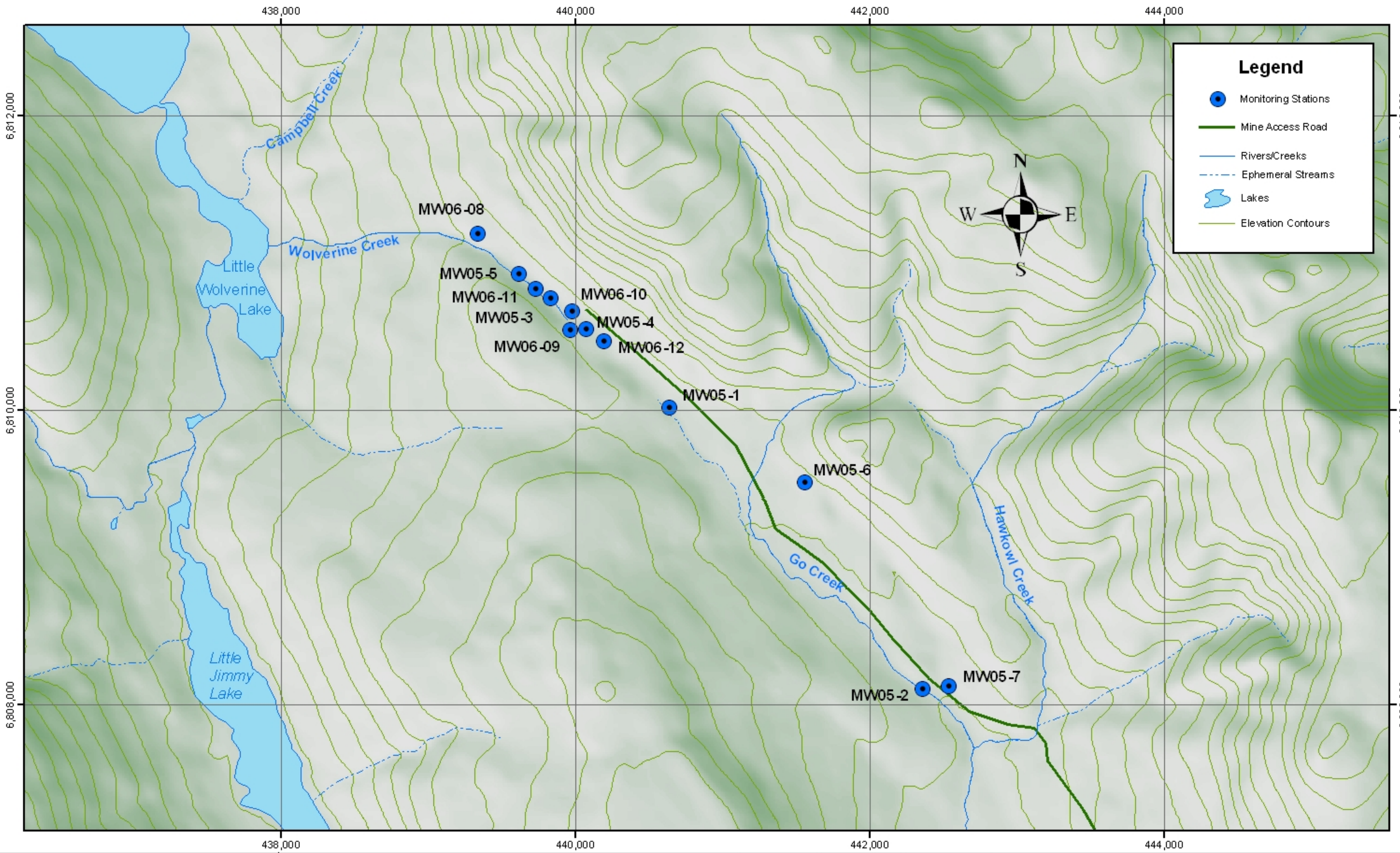


Figure 3-20: Groundwater Well MW06-11S Water Level and Temperature



0 250 500 1,000 1,500 Meters

Projection: UTM Zone 9, NAD 83

LORAX ENVIRONMENTAL

YukonZinc CORP

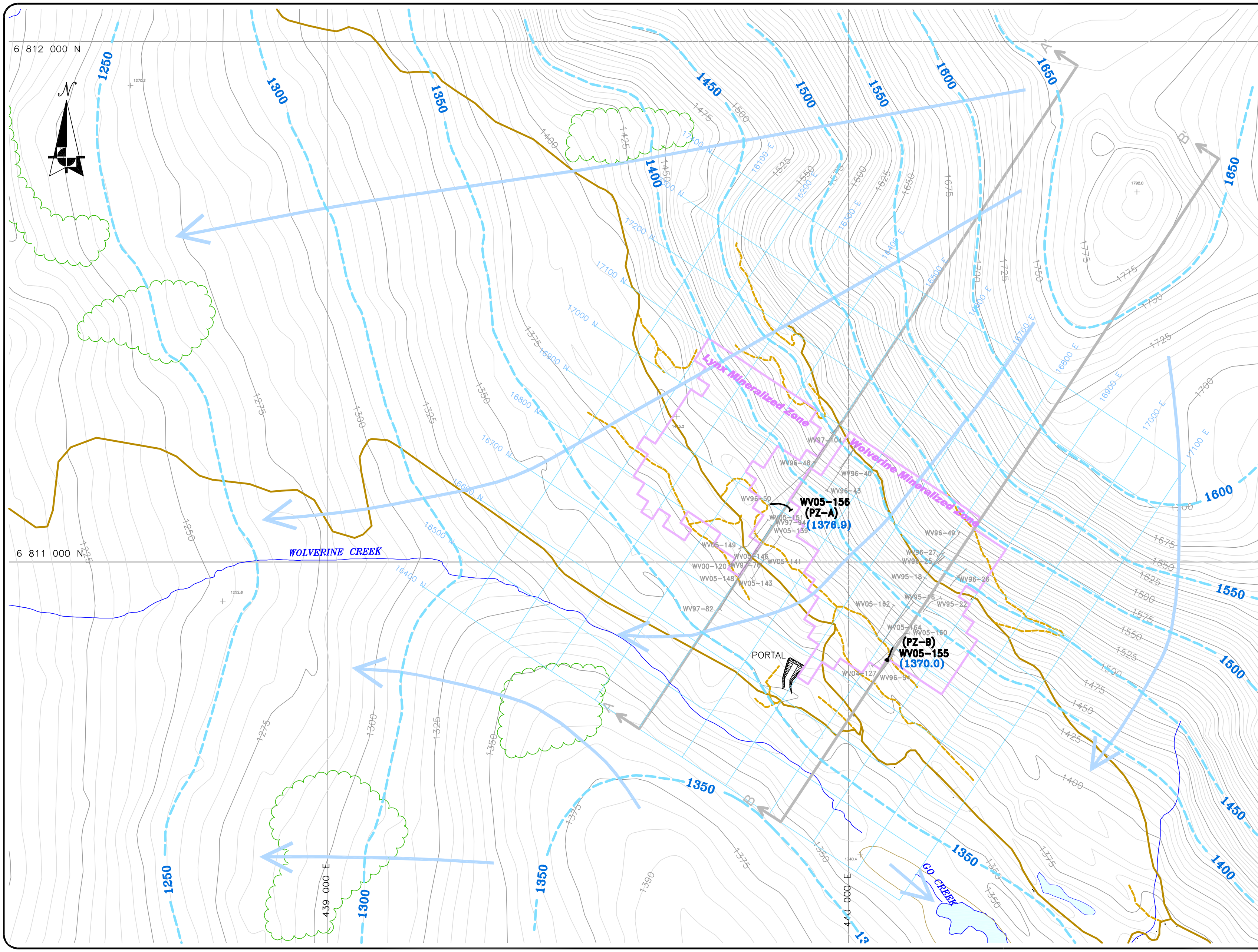
DESIGNED BY		
DWG. CHECK		
DRAWN BY	SSS	April 7, 2010
SCALE	1:25,000	
PROJECT NO.	474-3	

Baseline Characterization Report

Groundwater Monitoring Wells

Figure 3-21

REV.



LEGEND:

- GROUND SURFACE CONTOUR (M ASL) – 5m INTERVAL
- DRAINAGE
- ROAD – MAIN
- ROAD – DRILL ACCESS
- INFERRED GROUNDWATER EQUIPOTENTIAL LINE (M ASL)
- MINERALIZED ZONE
- INFERRED GROUNDWATER FLOW DIRECTION (JULY 1, 2005)
- A A' CROSS SECTION LINES
- WV05-155 PIEZOMETER INSTALLED BY GARTNER LEE IN APRIL 2005 (PROJECTED TO SURFACE)
- (1370.0) GROUNDWATER ELEVATION MEASURED ON JULY 1, 2005 (M ASL)
- WV97-100 ON-SECTION DIAMOND DRILL HOLE (PROJECTED TO SURFACE)

Data Sources:

1. Proposed Roads, contour and drainage data provided by Expatriate Resources on September 22, 2004
2. Claims and mineralized zones from drawings provided by Yukon Zinc Corporation
3. Wolverine Creek watershed boundary provided by Madrone Environmental Services Ltd.

REVIEWED BY : DJ/RF/RM
PREPARED BY : PW
DATE ISSUED : OCTOBER, 2005
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FILE NAME : 50288-4D-01.dwg
REVISION : 1

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Figure 3-22

CONCEPTUAL HYDROGEOLOGIC MODEL PLAN

Date: OCTOBER, 2005

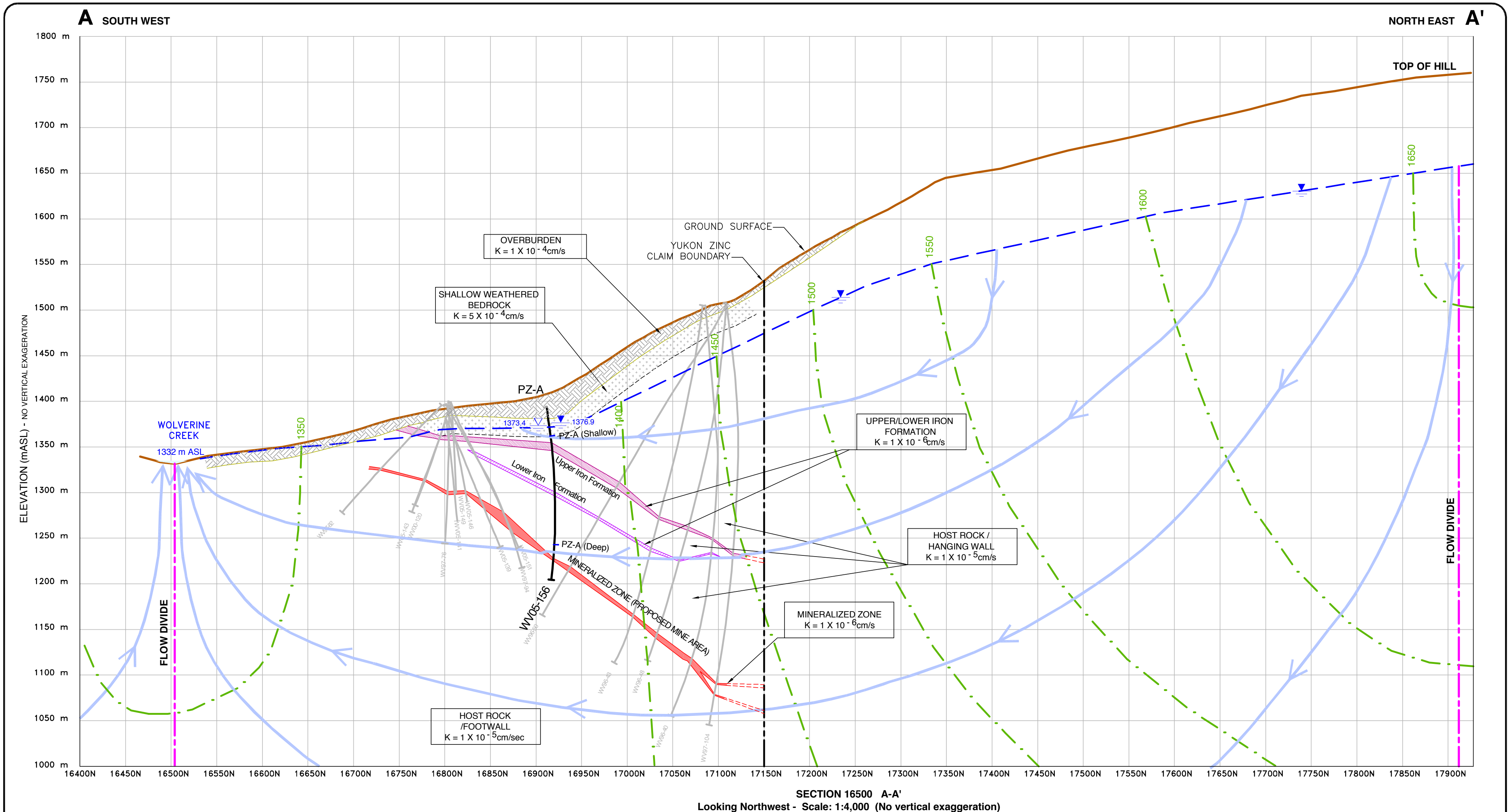
Projection: UTM Zone 9, NAD 27 | **File Name: 50288-4D-01.DWG**

0 50 100 200 300m

Scale 1:7,000

Gartner Lee

Path: S:\AutoCad\acad-Prj\2005\50-288 Wolverine Yukon Zinc\4D-Report-Oct05\ Plotted on: Oct 13, 2005-4:36pm Edited by: NTo



LEGEND:

- OVERBURDEN
- UPPER IRON FORMATION
- LOWER IRON FORMATION
- MINERALIZED ZONE
- SHALLOW WEATHERED BEDROCK
- GROUND WATER FLOW DIVIDE
- GROUNDWATER EQUIPOTENTIAL
- GROUNDWATER FLOWPATH
- WATER TABLE
- SHALLOW GROUNDWATER
- 1373.4 POTENTIOMETRIC ELEVATION (m) MEASURED ON JULY 1, 2005
- DEEP GROUNDWATER
- 1376.9 POTENTIOMETRIC ELEVATION (m) MEASURED ON JULY 1, 2005
- PZ-A PIEZOMETER INSTALLED BY GARTNER LEE IN APRIL 2005
- POINT OF GROUNDWATER ELEVATION MEASUREMENT
- K = HYDRAULIC CONDUCTIVITY (cm/s)
- EXPLORATION DIAMOND DRILL HOLE DRILLED BY OTHERS

REVIEWED BY: DJ/RF/RM
PREPARED BY: NT/PW
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File Name: 50288-4D-02.DWG
Projection: N/A
Date: OCTOBER, 2005

Note:
Hydrostratigraphic layers to be used for interpretation purposes only. Thickness and extent may vary significantly between boreholes.

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Data Sources:
Base Cross Sections Provided by Yukon Zinc Corporation

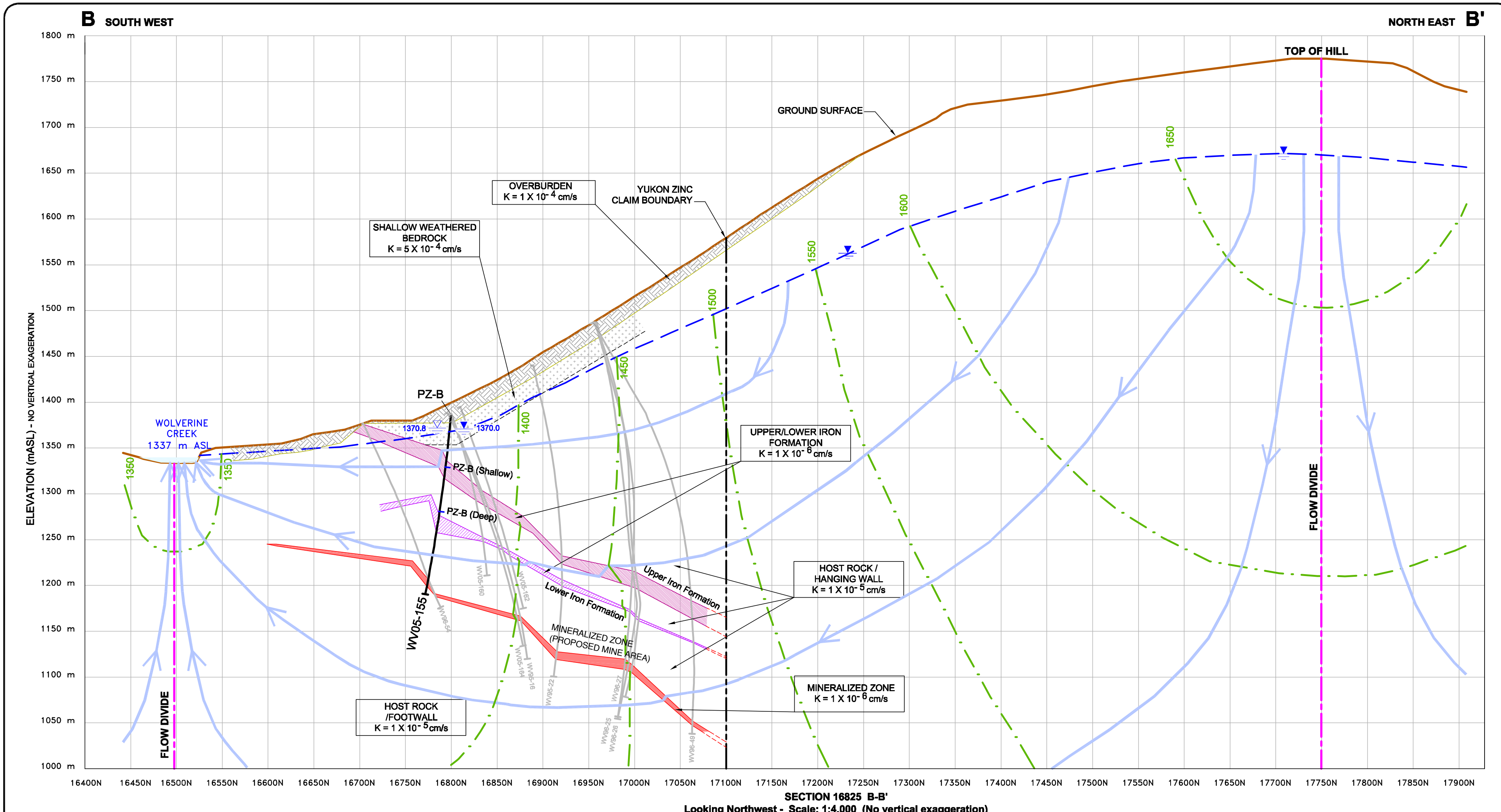
Yukon Zinc CORP

Wolverine Project

Figure 3-23:

CONCEPTUAL HYDROGEOLOGIC MODEL CROSS SECTION A-A' (Pre-Mining)

Path: S:\AutoCad\acad-Prj\2005\50-288 Wolverine Yukon Zinc\4D-Report-Oct05\ Plotted on: Oct 13, 2005-4:42pm Edited by: NTo



SECTION 16825 B-B'
Looking Northwest - Scale: 1:4,000 (No vertical exaggeration)

LEGEND:

- OVERBURDEN
- UPPER IRON FORMATION
- LOWER IRON FORMATION
- MINERALIZED ZONE
- SHALLOW WEATHERED BEDROCK
- GROUND WATER FLOW DIVIDE
- GROUNDWATER EQUIPOTENTIAL
- GROUNDWATER FLOWPATH
- WATER TABLE
- SHALLOW GROUNDWATER
- 1373.4 POTENTIOMETRIC ELEVATION (m) MEASURED ON JULY 1, 2005
- DEEP GROUNDWATER
- 1376.9 POTENTIOMETRIC ELEVATION (m) MEASURED ON JULY 1, 2005
- PZ-A PIEZOMETER INSTALLED BY GARTNER LEE IN APRIL 2005
- POINT OF GROUNDWATER ELEVATION MEASUREMENT
- K = HYDRAULIC CONDUCTIVITY (cm/s)
- EXPLORATION DIAMOND DRILL HOLE DRILLED BY OTHERS

REVIEWED BY: DJ/RF/RM
PREPARED BY: NT/PW
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File Name: 50288-4D-03.DWG
Projection: N/A
Date: OCTOBER, 2005

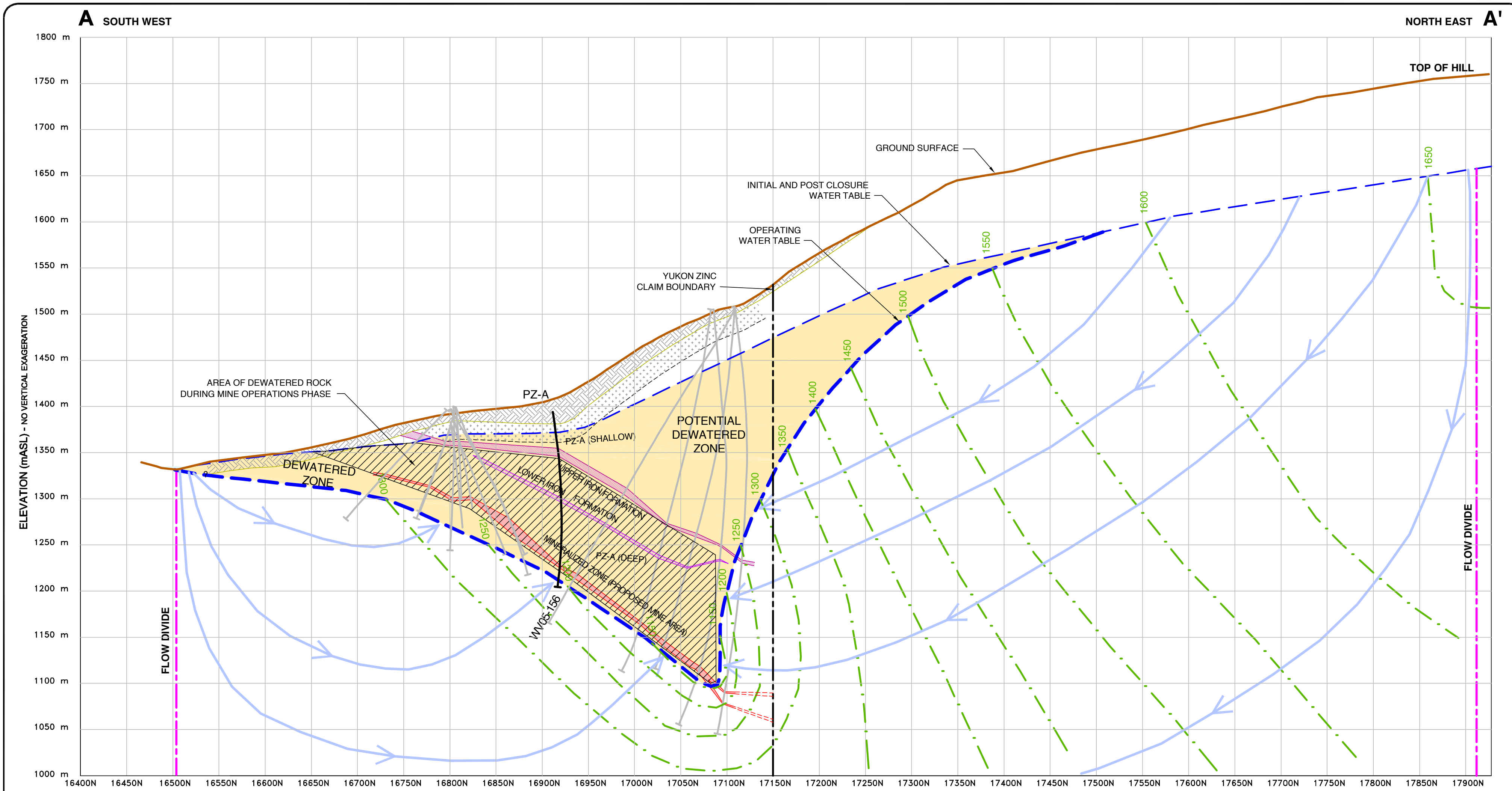
Note:
Hydrostratigraphic layers to be used for interpretation purposes only. Thickness and extent may vary significantly between boreholes.

Gartner Lee

Data Sources:
Base Cross Sections Provided by Yukon Zinc Corporation

YukonZinc CORP
Wolverine Project
Figure 3-24
CONCEPTUAL HYDROGEOLOGIC MODEL CROSS SECTION B-B' (Pre-Mining)

Path: S:\AutoCad\acad-Prj\2005\50-288 Wolverine Yukon Zinc\4D-Report-Oct05\ Plotted on: Oct 13, 2005-4:43pm Edited by: NTo



SECTION 16500 A-A'
Looking Northwest - Scale: 1:4,000 (No vertical exaggeration)

LEGEND:

- OVERBURDEN
- SHALLOW WEATHERED BEDROCK
- MINE DEWATERED ZONE
- UPPER IRON FORMATION
- GROUND WATER FLOW DIVIDE
- INFERRED POTENTIALLY DEWATERED ZONE
- LOWER IRON FORMATION
- INFERRED GROUNDWATER EQUIPOTENTIAL LINE
- INFERRED WATER TABLE DURING MINE OPERATION
- MINERALIZED ZONE
- INFERRED GROUNDWATER FLOW DIRECTION
- WATER TABLE – SUMMER 2005
- PZ-A PIEZOMETER INSTALLED BY GARTNER LEE IN APRIL 2005
- POINT OF GROUNDWATER ELEVATION MEASUREMENT
- K = HYDRAULIC CONDUCTIVITY (cm/s)
- EXPLORATION DIAMOND DRILL HOLE DRILLED BY OTHERS

REVIEWED BY: DJ/RF/RM
PREPARED BY: NT/PW
DATE ISSUED: OCTOBER, 2005
PROJECT NUMBER: 50-288
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REVISION: 1

File Name: 50288-4D-06.DWG
Date: OCTOBER, 2005
Projection: N/A

Notes:
1. Hydrostratigraphic layers to be used for interpretation purposes only. Thickness and extent may vary significantly between boreholes.
2. Inferred groundwater equipotential and flow directions based on limited data and analytical equations.

Data Sources:
Base Cross Sections Provided by Yukon Zinc Corporation

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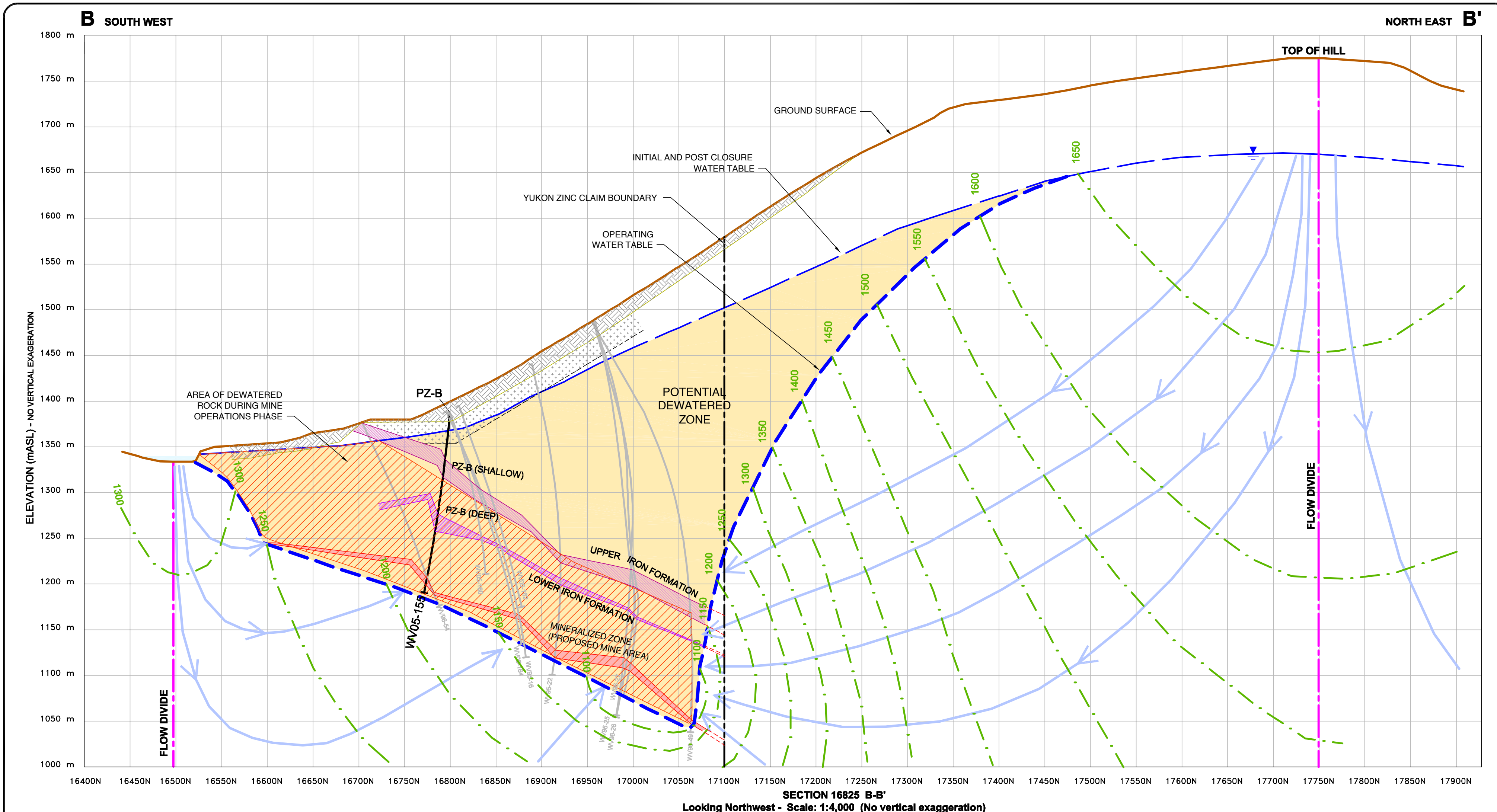
Figure 3-25
CONCEPTUAL HYDROGEOLOGIC MODEL CROSS SECTION A-A' (Operating)

Path: S:\AutoCad\acad-Prj\2005\50-288 Wolverine Yukon Zinc\4D-Report-Oct05\ Plotted on: Oct 31, 2005-10:58am Edited by: pwhiting



SECTION 16825 B-B'
Looking Northwest - Scale: 1:4,000 (No vertical exaggeration)

LEGEND:

- OVERBURDEN
- UPPER IRON FORMATION
- LOWER IRON FORMATION
- MINERALIZED ZONE
- SHALLOW WEATHERED BEDROCK
- GROUND WATER FLOW DIVIDE
- INFERRED GROUNDWATER EQUIPOTENTIAL LINE
- INFERRED GROUNDWATER FLOW DIRECTION
- MINE DEWATERED ZONE
- INFERRED POTENTIALLY DEWATERED ZONE
- INFERRED WATER TABLE DURING MINE OPERATION
- WATER TABLE – SUMMER 2005
- PZ-A PIEZOMETER INSTALLED BY GARTNER LEE IN APRIL 2005; POINT OF GROUNDWATER ELEVATION MEASUREMENT; K = HYDRAULIC CONDUCTIVITY (cm/s)
- EXPLORATION DIAMOND DRILL HOLE DRILLED BY OTHERS

REVIEWED BY: DJ/RF/RM
PREPARED BY: NT/PW
DATE ISSUED: OCTOBER, 2005
PROJECT NUMBER: 50–288
FILE NAME: 50288–4D–05.dwg
REVISION: 1

File Name: 50288-4D-05.DWG
Date: OCTOBER, 2005
Projection: N/A

Notes:
1. Hydrostratigraphic layers to be used for interpretation purposes only. Thickness and extent may vary significantly between boreholes.
2. Inferred groundwater equipotential and flow directions based on limited data and analytical equations.

Data Sources:
Base Cross Sections Provided by Yukon Zinc Corporation

Gartner Lee

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Figure 3-26:
CONCEPTUAL HYDROGEOLOGIC MODEL CROSS SECTION B-B' (Operating)

3.3.2 Groundwater Quality

Groundwater monitoring wells for characterizing baseline groundwater conditions were installed in strategic locations at the mine site during 2005 and 2006. Consistent monitoring of these wells has been ongoing since 2006. The majority of groundwater monitoring wells are located downgradient of the mine area within the upper Wolverine Creek basin (Figure 3-21). Sixteen groundwater monitoring wells have been installed at eight nested locations in the Wolverine Creek basin and monitor the shallow alluvial groundwater system, the shallow bedrock and deeper bedrock aquifers. Groundwater monitoring wells are also installed in the upper Go Creek basin and immediately downgradient of the TSF area. The wells in the Go Creek basin monitor the shallow alluvial and shallow bedrock aquifers.

Water chemistry statistics for samples taken 2009-2017 inclusively are shown in Figure 3-27 through Figure 3-36, with water quality sites listed in order moving downstream from the mine. Values that were reported as being less than the reportable detection limit were taken to be half the detection limit when calculating the median, 25^{th} and 75^{th} percentile values.

Groundwater quality varies significantly in the Wolverine Creek alluvial system over relatively short distances. Groundwater quality at station MW05-3B is naturally elevated in cadmium, copper, selenium, and zinc. Zinc concentrations are very elevated and on the order of 1.8 mg/L. Cadmium and selenium concentrations are also very elevated for alluvial groundwater systems at approximately 0.021 mg/L and 0.008 mg/L, respectively. Groundwater quality at MW05-4B is also characterized by naturally elevated concentrations of cadmium and zinc, although each parameter is present at concentrations approximately an order of magnitude lower than observed at MW05-3B. Selenium concentrations do not appear to be naturally elevated in this portion of the alluvial aquifer. Further downgradient at station MW05-5B, groundwater contains much lower concentrations of cadmium, selenium, and zinc. This suggests a localized natural source of elevated metals in the upper Wolverine Creek basin alluvial aquifer in the vicinity of MW05-3B (Figure 3-21).

Water chemistry in the Wolverine Creek shallow bedrock system, sampled at monitoring well MW05-3A, exhibits naturally elevated cadmium, selenium, and zinc concentrations, similar in magnitude to the concentrations observed for these parameters in the overlying alluvial aquifer. Conversely, elevated concentrations of cadmium and zinc were not observed in MW05-4A. Naturally elevated zinc concentrations are however, observed in well MW06-8S (~1.3 mg/L) and suggest that localized sources are responsible for the widely variable groundwater quality in the alluvial and shallow bedrock aquifers. This tenet is also supported by the locally elevated sulphate concentrations measured in MW06-12S (~250 mg/L), which is not observed elsewhere in the shallow bedrock aquifer.

In the Wolverine Creek deep bedrock aquifer, unlike the alluvial and shallow bedrock systems, baseline groundwater quality is less variable between wells and no parameters are considered to be naturally elevated in the background.

In the Go Creek basin, which has been divided into the Go Creek basin and TSF area, no deep bedrock monitoring wells have been installed and only the shallow aquifer systems are monitored. Most trace metals are present at very low concentrations in both the alluvial and shallow groundwater systems in upper Go Creek, except for dissolved iron concentrations in upper Go Creek alluvial groundwater (~4 mg/L) in well MW05-1B.

Metal concentrations in wells MW05-7B and MW05-2A are present at very low concentrations. Iron concentrations at well MW05-2B are naturally elevated (~10 mg/L). The elevated iron concentrations were not observed in the shallow bedrock well MW05-2A, suggesting that alluvial and shallow bedrock aquifer does not appear to be hydraulically connected.

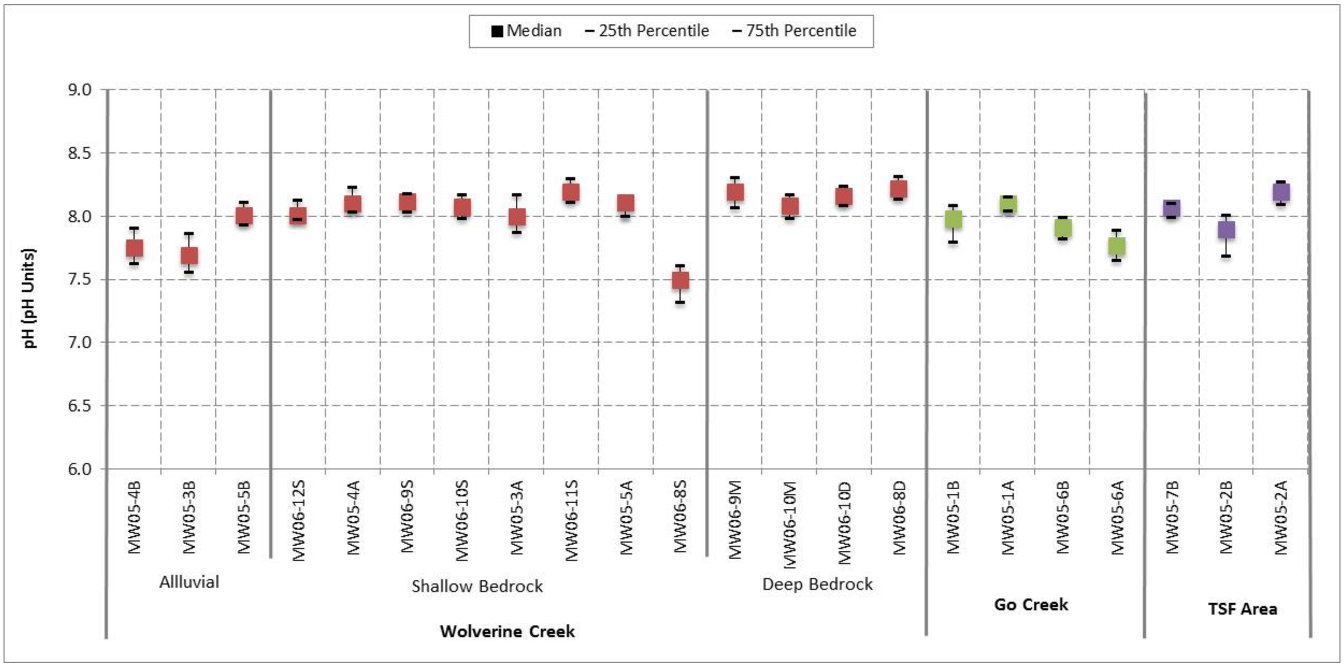


Figure 3-27: Groundwater Chemistry – pH (2009-2017)

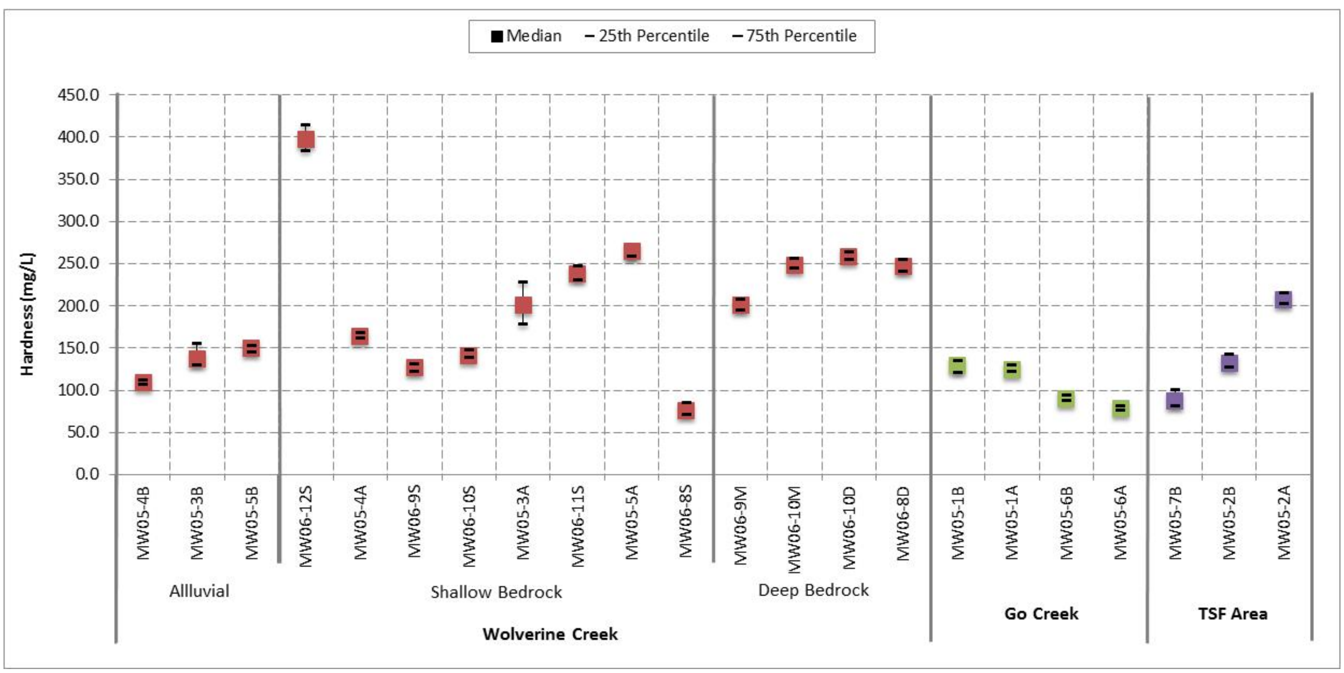


Figure 3-28: Groundwater Chemistry – Hardness (2009-2017)

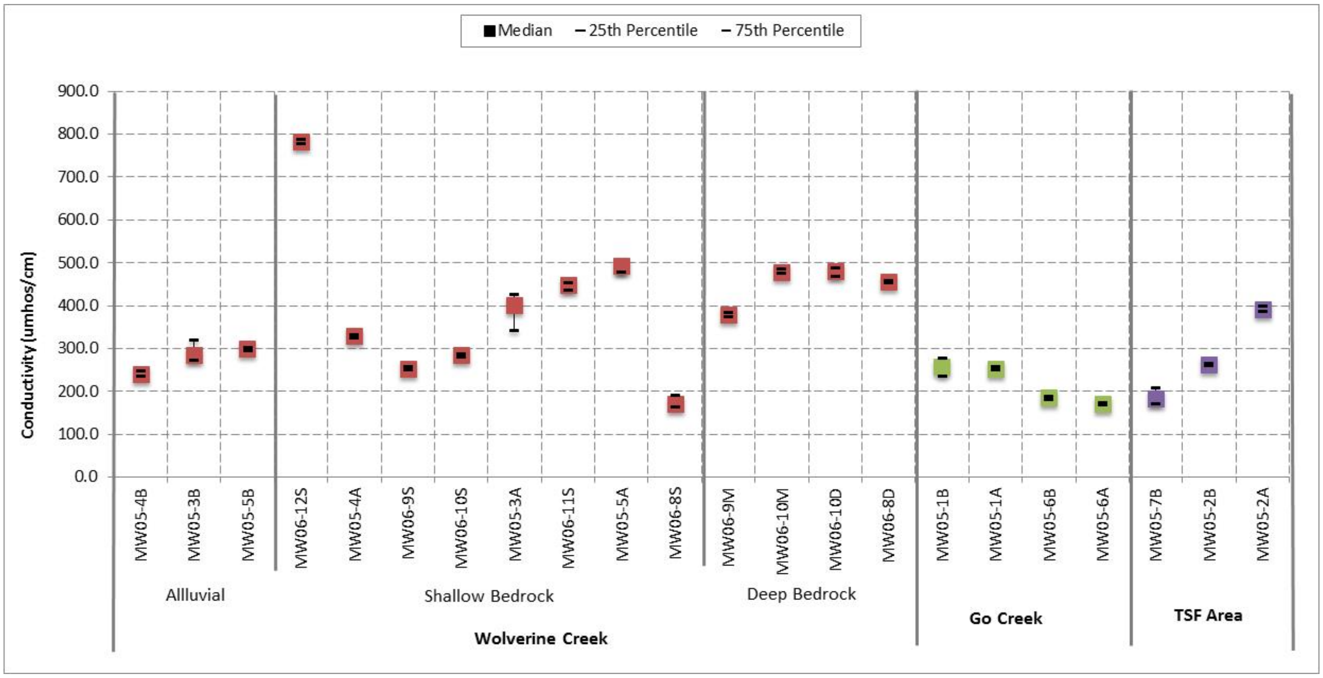


Figure 3-29: Groundwater Chemistry – Conductivity (2009-2017)

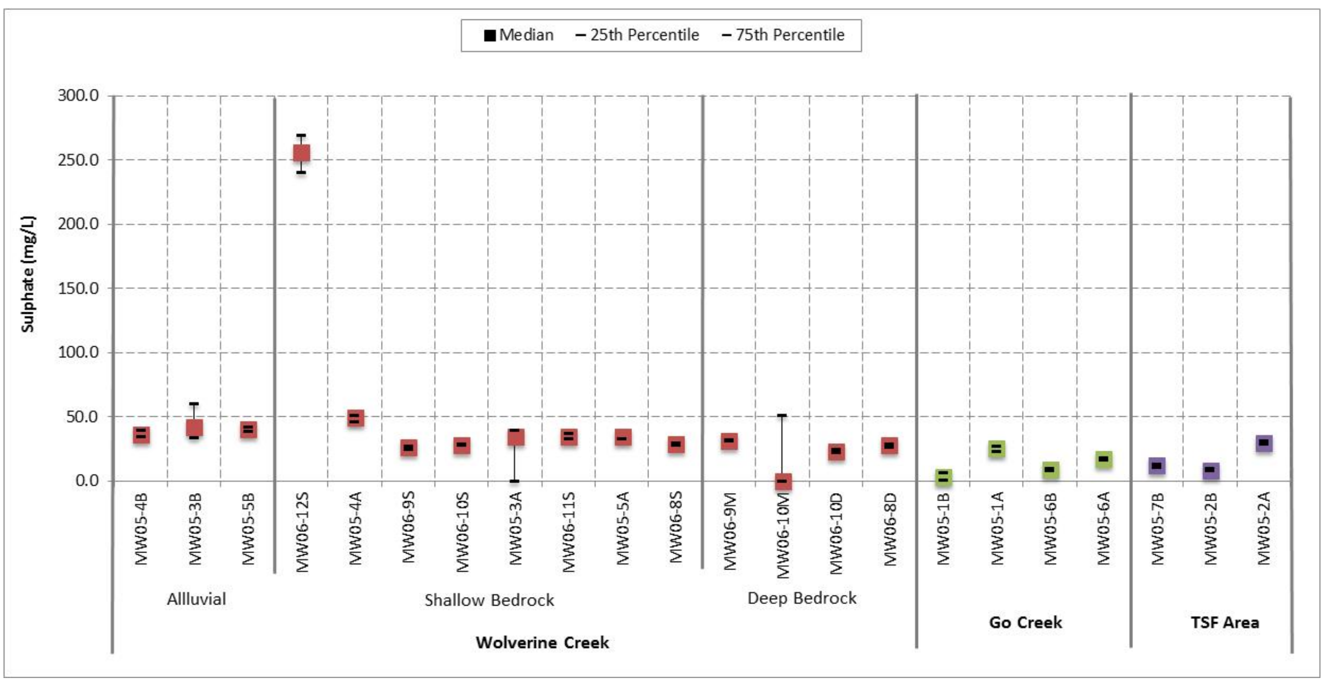


Figure 3-30: Groundwater Chemistry – Sulphate (2009-2017)

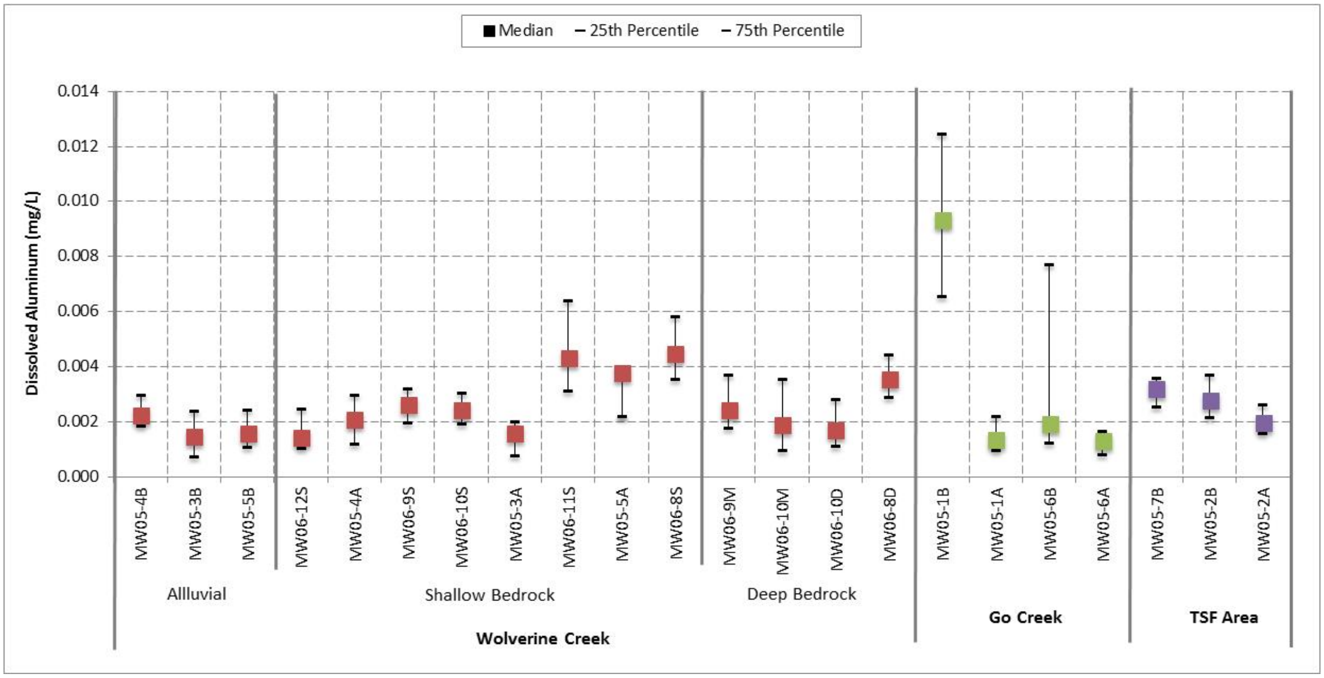


Figure 3-31: Groundwater Chemistry – Dissolved Aluminum (2009-2017)

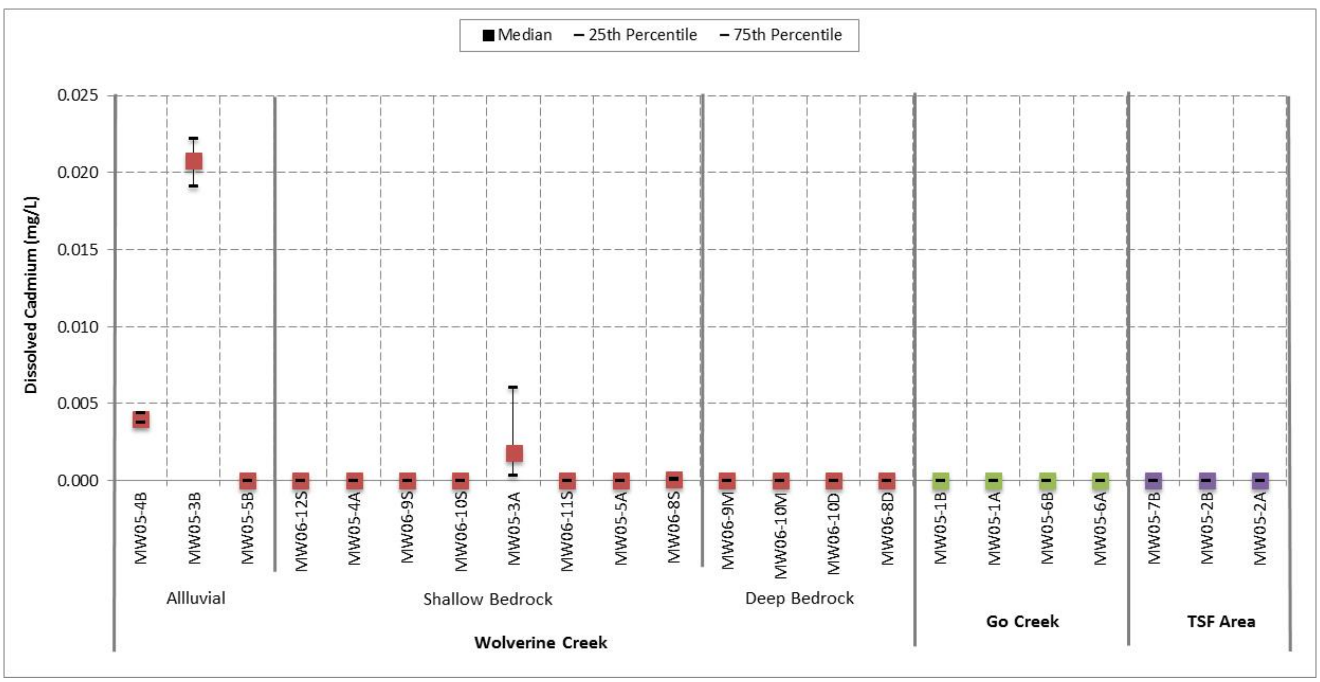


Figure 3-32: Groundwater Chemistry – Dissolved Cadmium (2009-2017)

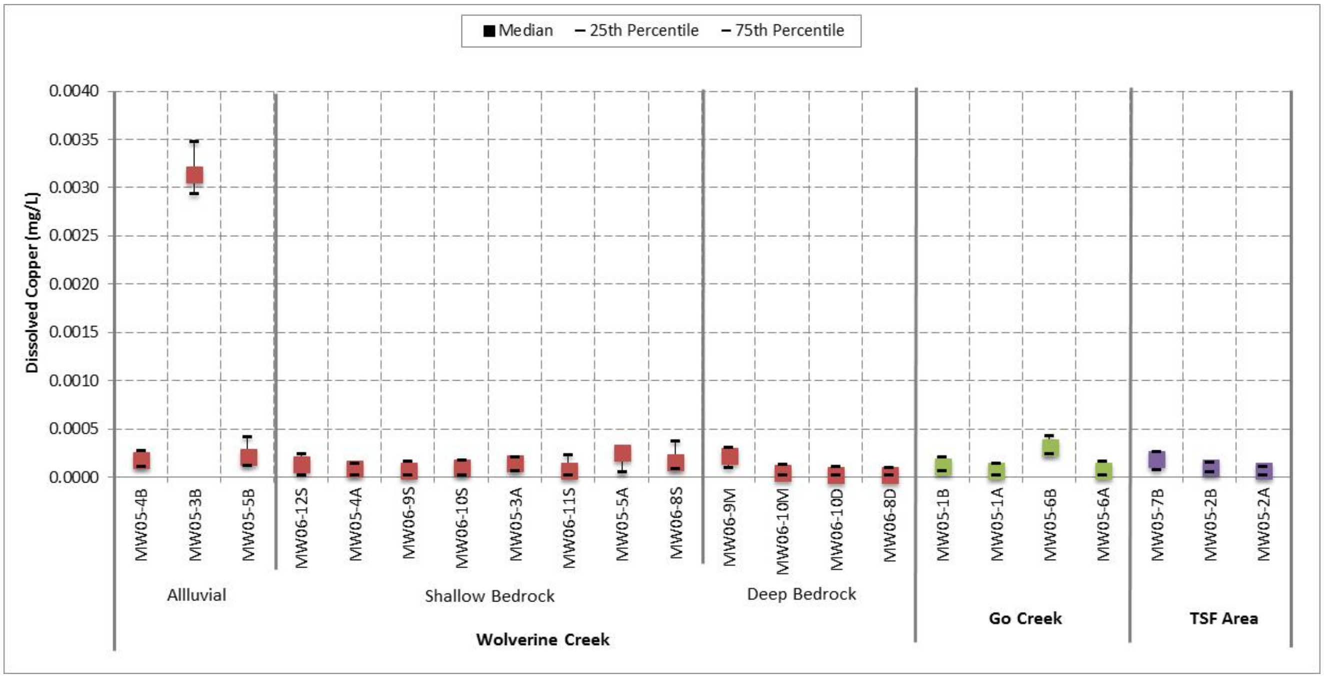


Figure 3-33: Groundwater Chemistry – Dissolved Copper (2009-2017)

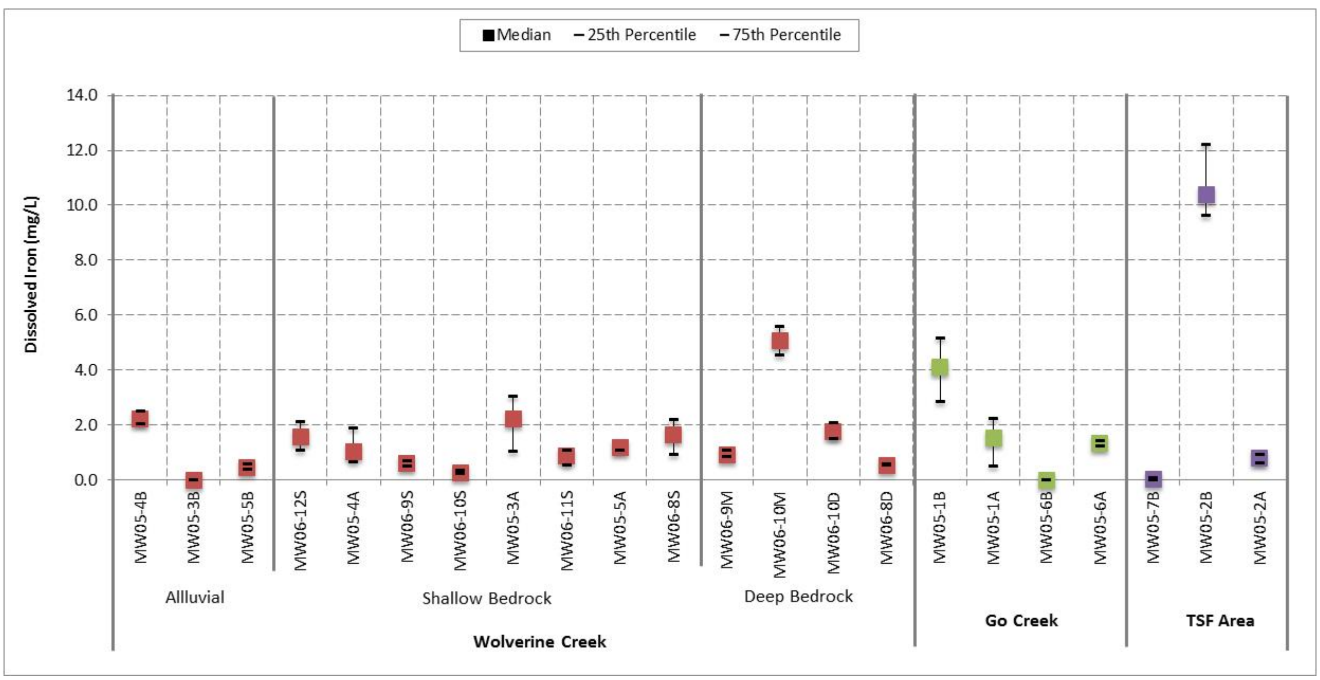


Figure 3-34: Groundwater Chemistry – Dissolved Iron (2009-2017)

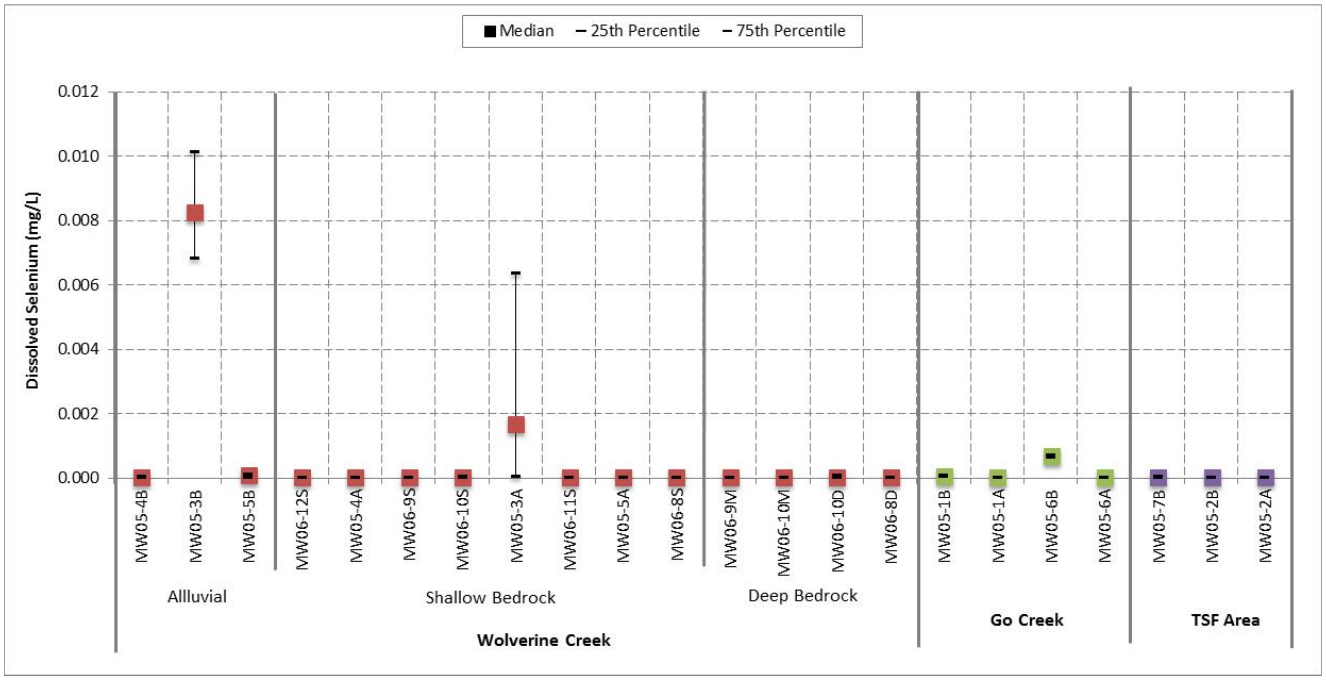


Figure 3-35: Groundwater Chemistry – Dissolved Selenium (2009-2017)

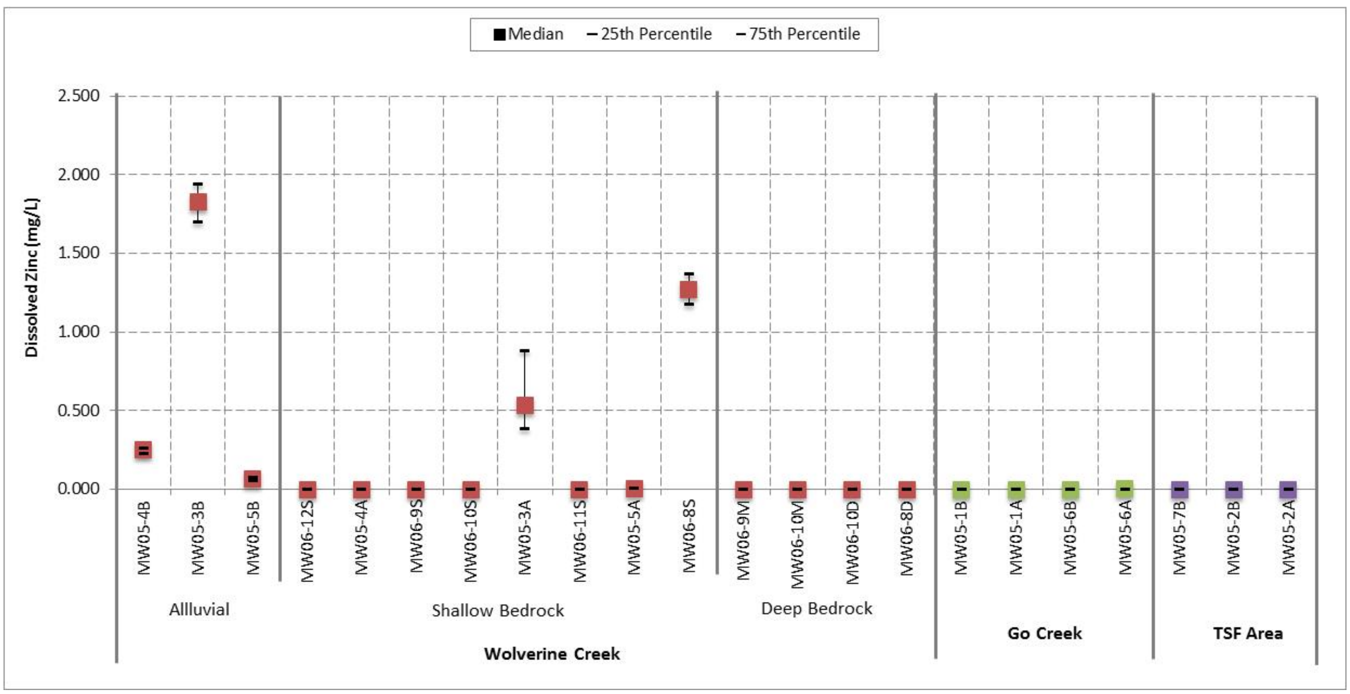


Figure 3-36: Groundwater Chemistry – Dissolved Zinc (2009-2017)

3.4 Vegetation and Wildlife

3.4.1 Aquatic Life

Aquatic life is monitored for the purposes of Metal Mine Effluent Regulations (MMER) Environmental Effects Monitoring (EEM), as per the *Fisheries Act*, at the locations shown in Figure 3-37.

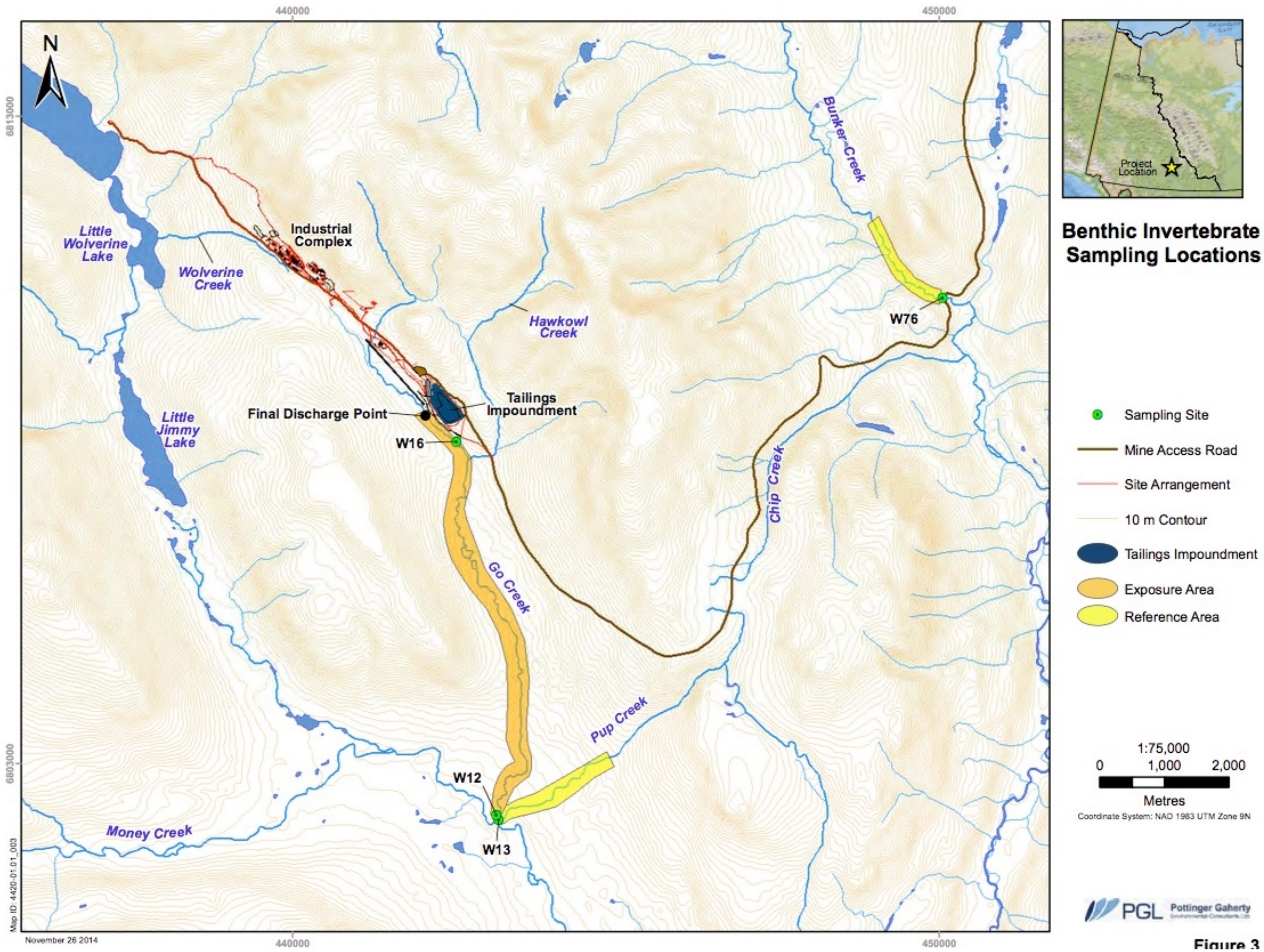


Figure 3-37: MMER EEM Monitoring Locations

Baseline fish surveys were carried out in 1996, 1997, 2004, 2005, and 2014. Results indicated "fish habitat in Money Creek is generally good, with varied in-stream features providing suitable habitat for most life stages of fish species expected to inhabit the area. Many of the first order tributaries to Money Creek (including Go, Pup, and Bunker Creeks) have fast flows and limited habitat diversity that likely limit spawning, rearing, and overwintering potential of these streams." (Lorax, 2014). Results of baseline electrofishing surveys in the exposure and reference areas are summarized in Table 3-1. The number of fish captured in each survey was low in all streams and slimy sculpin was the most abundant species at all sites. Other species encountered during baseline surveys included arctic grayling and bull trout. Snorkel surveys and minnow traps were used in 2014 in addition to electrofishing, but did not yield higher catch numbers.

Table 3-1: Results of Baseline Electrofishing Surveys in Go Creek, Pup Creek and Bunker Creek

Sampling Event	Location		Effort (s)	Species*	Number	CPUE** (#/min)
July 1996	Go Creek	Upper	299	n/a	0	0
		Mid	232	n/a	0	0
		Lower	1366	GR	4	0.176
				CCG	21	0.922
				BT	5	0.220
	Pup Creek	Lower	175	CCG	6	2.057
Sept. 1996	Go Creek	Lower	89	n/a	0	0
Oct. 2004	Pup Creek	Mid	487	n/a	0	0
	Bunker Creek	u/s of road	858	n/a	0	0
		Below road btw beaver dams	972	BT	2	0.123
		Below road d/s of beaver dam	1267	n/a	0	0
Aug. 2005	Go Creek	Upper	300	n/a	0	0
		Mid	1070	n/a	0	0
		Lower	2640	GR	4	0.091
				BT	4	0.091
				CCG	1	0.023
	Pup Creek	Lower	300	n/a	0	0
	Bunker Creek	u/s of road	1770	n/a	0	0
		Below road btw beaver dams	840	n/a	0	0
Sept. 2014	Go Creek	Mid/Upper	4198	BT	1	0.014
		Lower	3527	CCG	1	0.017
				BT	2	0.034
	Pup Creek	Near confluence with Go Creek	not specified	BT	16	n/a
	Bunker Creek	Mid (near bridge)	not specified	n/a	0	0

** GR = Arctic grayling (Thymallus arcticus)*
CCG = Slimy sculpin (Cottus cognatus)
BT = Bull trout (Salvelinus confluentus)
*** CPUE = Catch per Unit Effort*

3.4.2 Benthic Invertebrates and Periphyton

Benthic invertebrate and periphyton monitoring in the mine area was conducted in 1997, 2005, and 2007 in Wolverine Creek, Nougha Creek, Money Creek, Go Creek, Putt Creek, Bunker Creek, and a tributary to little Jimmy Lake. Additional benthic invertebrate sampling was conducted in 2011 and 2014 as part of the EEM cycle 1 and cycle 2 programs.

Benthic invertebrate monitoring was conducted at two sites in Go Creek; a near field site (W16) close to where effluent discharge will eventually occur in upper Go Creek and a far field site (W12) in lower Go Creek just upstream of the confluence with Money Creek. Two reference sites were also monitored, one at the mouth of Pup Creek near Go Creek (W13), the other on Bunker Creek upstream of the road crossing (W76). Stream morphology was most similar between W16 and W13. Site W76 had substantially higher discharge rate than at W16 and W13, and embeddedness was lower at W76 (Lorax Environmental, 2011).

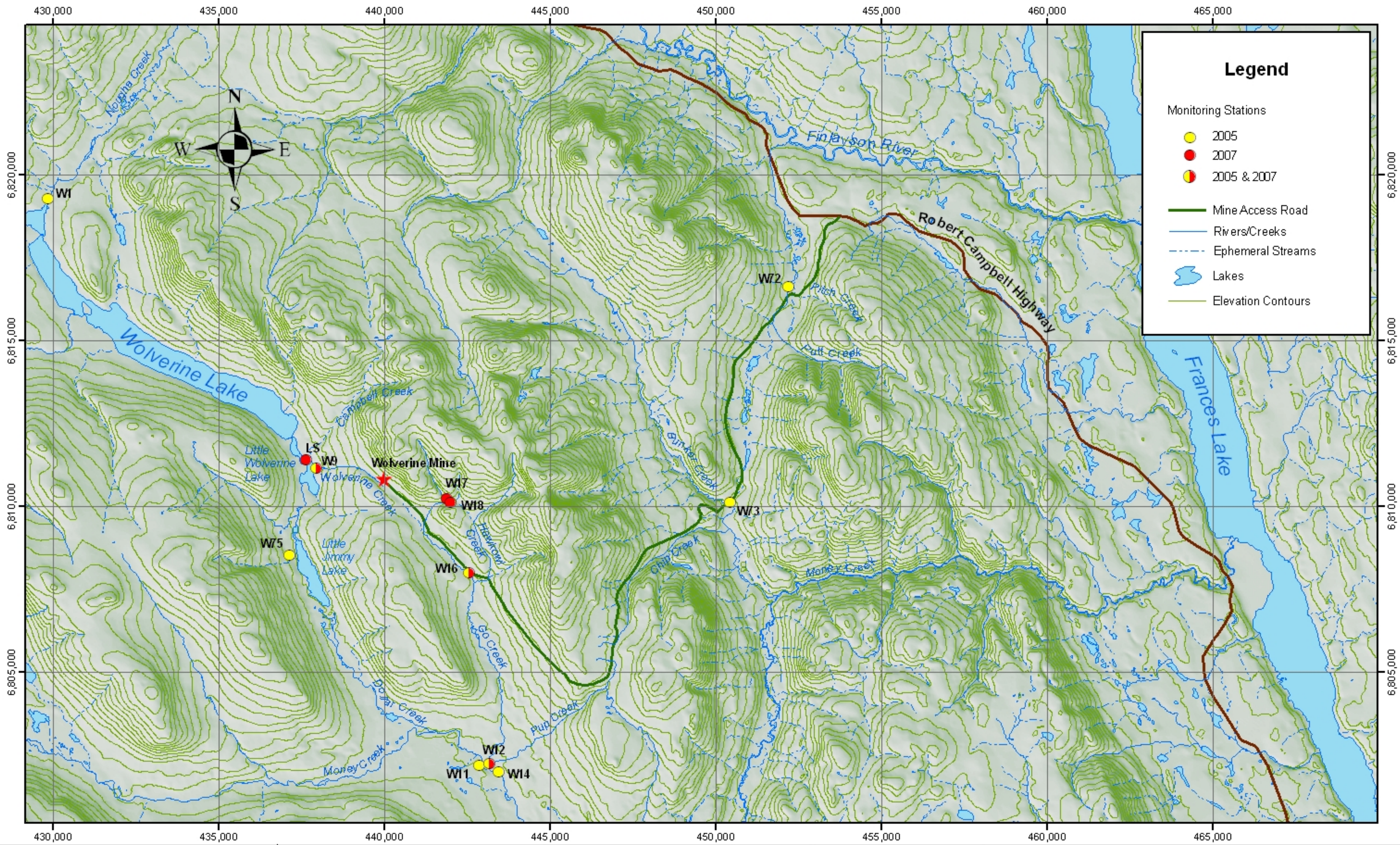
Five replicates of benthic invertebrate samples were collected at each site. Descriptive statistics and statistical endpoints were calculated at the family taxonomic level and the analysis of results is summarized in Table 3-2. Overall, differences were found to be fairly small when taken in an ecological context and not unusual for highly dynamic benthic invertebrate populations.

Table 3-2: Results of Benthic Surveys in Go Creek, Pup Creek and Bunker Creek

Community Indicators	September 2011 Study	September 2014 Study
Total invertebrate density	W12 < W16 = W13 = W76	W12 = W16 = W13 = W76
Mean family richness	W12 > W16 = W13 = W76	W12 = W76 > W16 = W13
Mean Simpson's evenness	W16 < W12 = W13 = W76	W12 < W16 = W13 + W76
Bray Curtis dissimilarity	W16 = W12 > W13 = W76	W12 > W16 = W13 > W76

Periphyton were sampled from riffle habitats in 2005 and 2007 at sites shown on Figure 3-38 (9 sites in 2005, 5 sites in 2007, 3 samples measured in both years). Samples were analyzed for chlorophyll *a* as a measure of biomass, and for taxonomic composition. There was high variability among the 3 replicates taken from each station, high variability among stations sampled in the same year, and high interannual variability at the same station.

Upper Go Creek had the highest average biomass of all the stations. Predominant periphyton and the filamentous red alga *Audouinella violacea* was present, as was moss. Taxonomic composition in Wolverine Creek had relatively low abundance of diatoms; predominant taxa were the colonial chrysophyte *Hydrurus foetidus* and crustose blue-green alga *Chamaesiphon* cf. *incrustans*.



0 1,000 2,000 4,000 6,000 Meters

Projection: UTM Zone 9, NAD 83

LORAX ENVIRONMENTAL

YukonZinc CORP

DESIGNED BY		
DWG. CHECK		
DRAWN BY	SSS	April 7, 2010
SCALE	1:110,000	
PROJECT NO.	474-3	

Baseline Characterization Report

Benthic Invertebrate and Periphyton Monitoring Stations

Figure 3-38

REV.

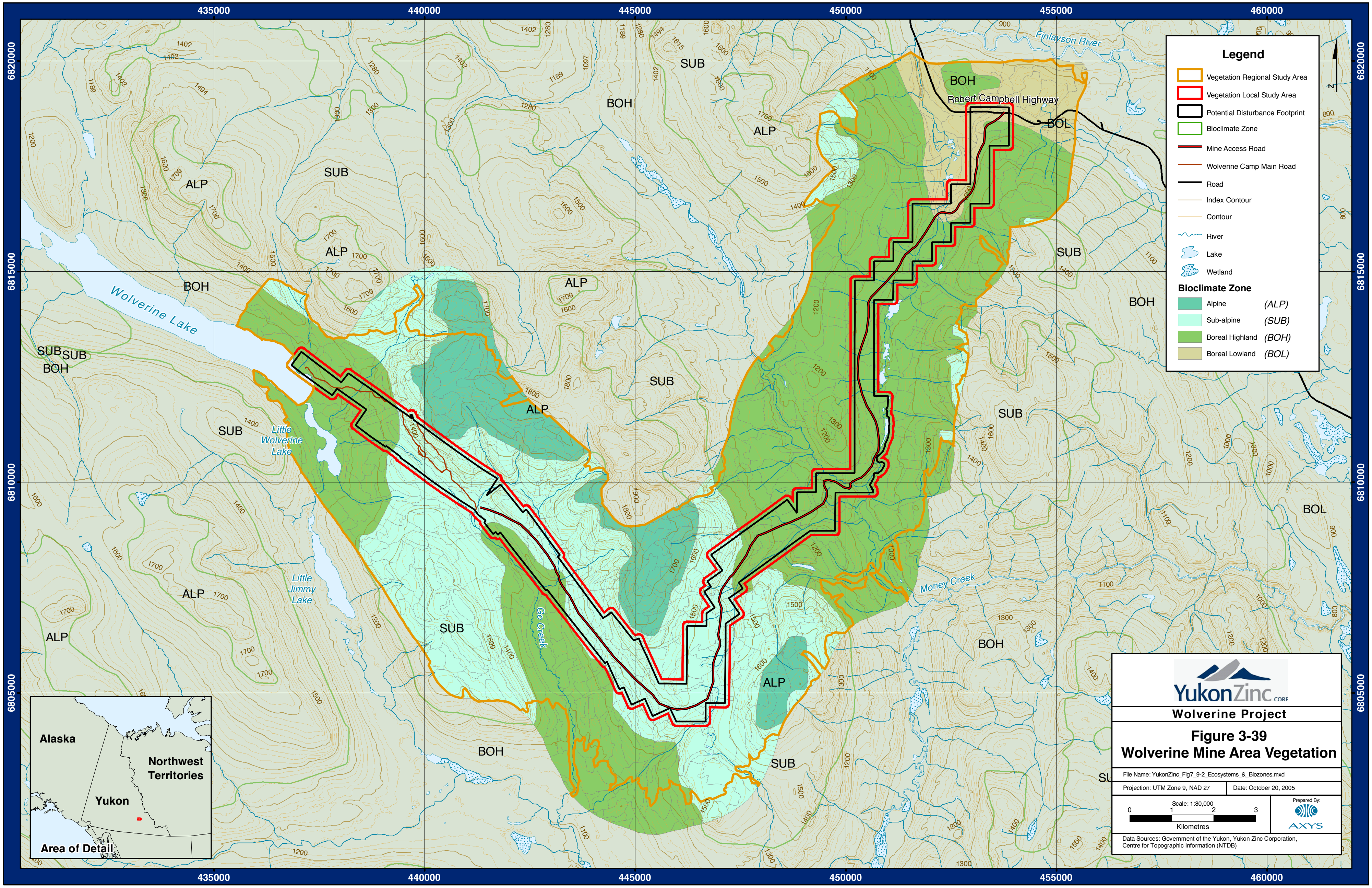
3.4.3 Vegetation

The Wolverine Mine lies within the Liard Basin and Pelly Mountains Ecoregions of the Boreal Cordillera Ecozone and abuts the Yukon Plateau-North Ecoregion (YZC, 2005). The area ranges from approximately 920-1900 masl and covers four elevation bioclimate zones: 'Boreal Lowland', 'Boreal Highland', 'Subalpine', and 'Alpine' (Figure 3-39). Much of the area around the mine is above the altitudinal treeline, which occurs between 1250 m and 1500 masl depending on exposure and cold air drainage and ponding. Discontinuous but widespread permafrost occurs throughout the area, particularly on north-facing slopes, under thick organic soil layers, and in bog complexes. Alpine soils are generally acidic and often show signs of cryoturbation (YZC, 2005).

Mixed stands of subalpine fir (*Abies lasiocarpa*) and white spruce (*Picea glauca*) dominate the landscape of the mine area. These tree species typically occur in open stands with varying understory characteristics depending on soil texture and microclimatic factors. Feathermosses are common understory components in mesic areas with fruiticose lichens becoming the dominant cryptograms in drier sites. Dense trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera ssp. balsamifera*) stands also occur; such stands are usually disturbance initiated and early successional. Black spruce (*Picea mariana*) is the dominant tree species of bogs and bog complexes and occurs primarily in open stands on thick organic soils. Some black spruce stands also occur in upland sites on mineral or thin organic soils and with subalpine fir stands in the project area. Open subalpine fir stands are predominant at and immediately below treeline with individuals becoming krummholz or decumbent at the treeline. Dwarf birch (*Betula glandulosa*)-dominated communities become dominant immediately above the treeline and commonly co-occur with willows and/or ericaceous shrubs. At higher elevations, these communities gradually give way to alpine dwarf-shrub heath and herb communities with various species compositions that are influenced by soil texture (granitic vs. sedimentary). Extreme elevations and aspects are vegetated primarily by lichen or lichen-dwarf shrub communities (YZC, 2005).

3.4.4 Wildlife

Habitats in the vicinity of the Wolverine Mine support a number of wildlife species including woodland caribou, moose, black bear, grizzly bear, wolf, fox, coyote, wolverine, marten, mink, lynx, river otter, beaver, small mammals, raptors, ptarmigan, waterfowl, shorebirds, and a variety of forest songbirds. The Finlayson Lake/River area and the east slope of the Pelly Mountains are part of the Tintina Trench migration corridor and are used extensively by waterfowl and shorebirds including trumpeter swan and sand hill crane on their north-south migration (Sinclair *et al*., 2003). The lakes and small pond-wetland complexes in the region provide breeding and migratory habitat for waterfowl, shorebirds, and other species. The mine site is situated in the southeast portion of the Finlayson Caribou Herd range (YZC, 2009).


Legend
Vegetation Regional Study Area
Vegetation Local Study Area
Potential Disturbance Footprint
Bioclimate Zone
Mine Access Road
Wolverine Camp Main Road
Road
Index Contour
Contour
River
Lake
Wetland
Bioclimate Zone
Alpine (ALP)
Sub-alpine (SUB)
Boreal Highland (BOH)
Boreal Lowland (BOL)
Wolverine Lake
Little Wolverine Lake
Little Jimmy Lake
Go Creek
Money Creek
Finlayson River
Robert Campbell Highway
ALP
SUB
BOH
BOL
435000
440000
445000
450000
455000
460000
6820000
6815000
6810000
6805000
Alaska
Northwest Territories
Yukon
Area of Detail
YukonZinc CORP
Wolverine Project
Figure 3-39
Wolverine Mine Area Vegetation
File Name: YukonZinc_Fig7_9-2_Ecosystems_&_Biozones.mxd
Projection: UTM Zone 9, NAD 27
Date: October 20, 2005
Scale: 1:80,000
0 1 2 3
Kilometres
Prepared By:
AXYS
Data Sources: Government of the Yukon, Yukon Zinc Corporation, Centre for Topographic Information (NTDB)

3.5 Soil and Bedrock

The Wolverine Mine is located in the Campbell Range, at the easternmost limit of the Pelly Mountains and abuts the broad Yukon Plateau to the north and east. The area consists of rolling, glacially scoured mountains with no significant peaks. Elevations on the property range approximately between 1200 and 1400 masl. The main valleys are wide and U-shaped. Glacial till covers the majority of the lower lying valleys and there is significant infilling by post-glacial sediments.

The Wolverine Lake area lies within the limits of the McConnell Glaciation (youngest of the four glaciations in Yukon Territory) and most of the geomorphic features in the area are related to this glaciation. McConnell glacial ice covered this area between 14,000 and 35,000 years ago. As the McConnell ice retreated and down-wasted, a complex network of ice tongues developed in valley bottoms. Morainal deposits are found at lower to mid-elevation and valley floors and may contain a more complex assemblage of glacio-fluvial, colluvial, and fluvial sediments (Mougeot, 1996).

Regional geology is provided in Figure 3-40. The soil map (along with legend) for the mine area is provided in Figure 3-41. The main glacial soils in the vicinity of the tailings impoundment consist of up to 20 m of silty, sand and gravel, with cobbles. The area is underlain by bedrock strata generally paralleling the valley trend, i.e., striking in the direction of the valley. The bedrock consists of an interlayered sequence of volcanoclastic (rhyolite and quartz feldspar) and carbonaceous/argillic sediments, overlain with basalt. The iron formation, which hosts the ore zone, trends northwest-southeast throughout the Wolverine Mine area.

3.5.1 Permafrost

The Wolverine Mine is located within a zone of discontinuous permafrost (Burn, 2002). Cryoturbated soils are evident in the floodplain immediately east of the airstrip and in all alpine areas (Axys Environmental Consulting Ltd., 2005). Periglacial processes were found in the alpine areas of this study, including solifluction lobes, blockfields, sorted polygons, stripes and pushed up stones. Ground ice was also found overlain by organic materials in one of the high elevation soil profiles sampled. A thermokarst feature (Figure 3-41) was found in the glaciolacustrine materials of Putt Creek. In general, permafrost is more or less continuous in the alpine areas (mountain tops) and discontinuous in the upper elevational valleys and the headwaters of Go Creek. Permafrost was not encountered in the TSF area during construction in 2009; further, borrow from the impoundment area did not encounter any frost (Klohn Crippen Berger, 2010).

Along the road, the intersection with the Campbell Highway was relocated to km 190.0 of the Campbell Highway in order to avoid permafrost. Ice content within the discontinuous permafrost in the area towards Putt Creek (from km 0.7 to km 2.9) was found to be generally less than 10% in granular soils. Frozen soil (permafrost) conditions were associated with thick organic cover, most of which are characterized as open, shallow gradient sideslope bog areas with black spruce/moss/larch vegetation.

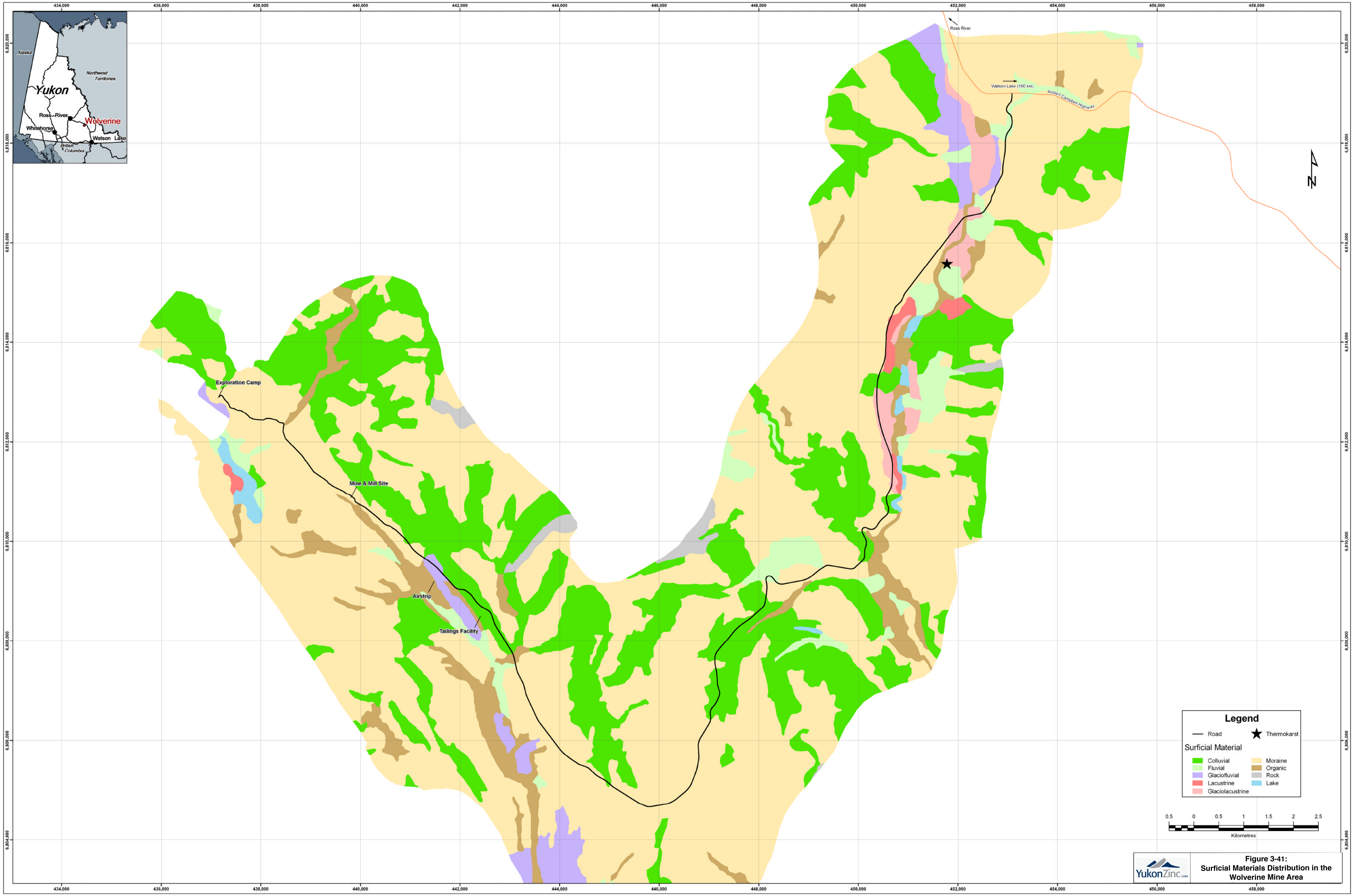


Figure 3-41: Surficial Materials Distribution in the Wolverine Mine Area

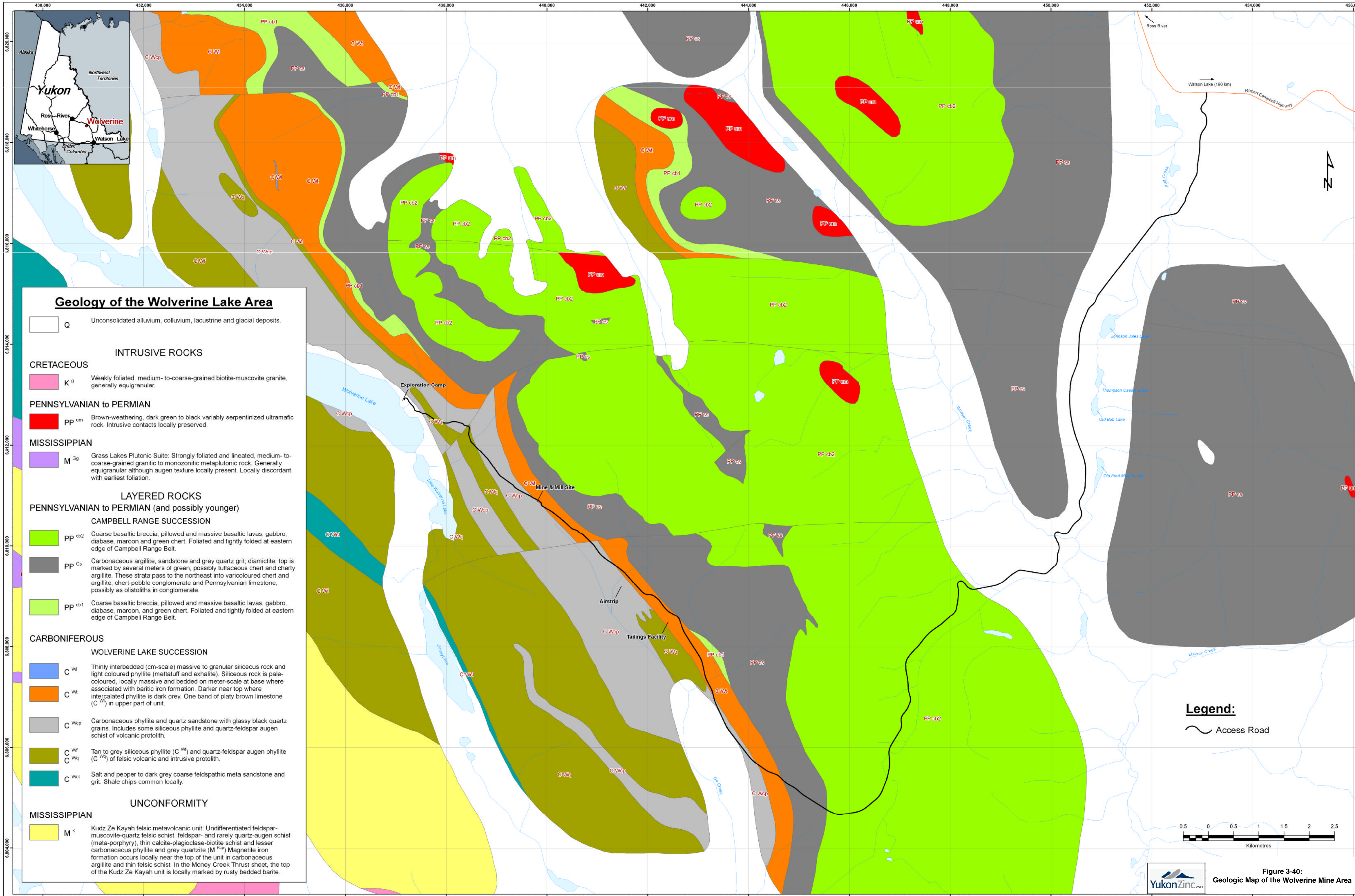
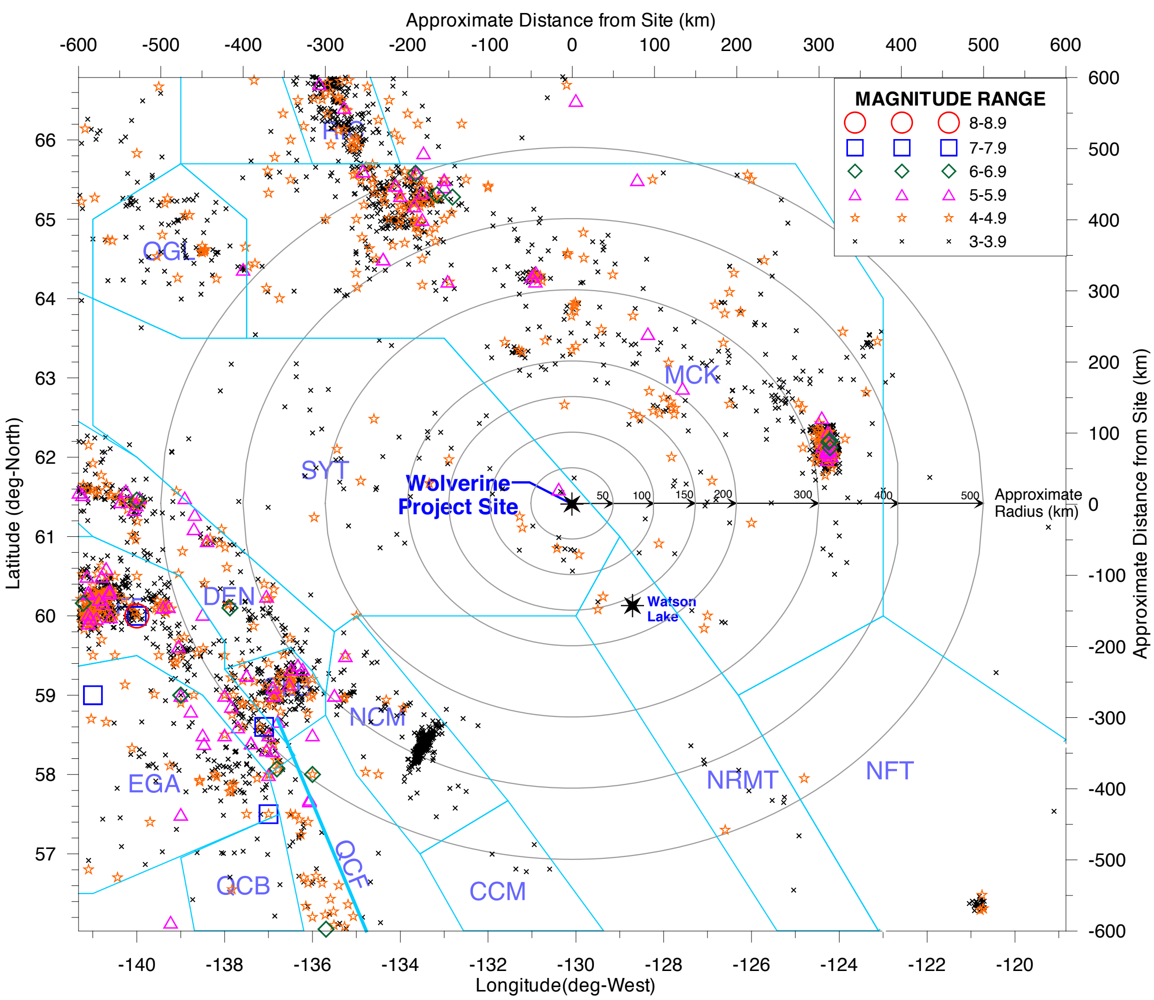


Figure 3-40: Geologic Map of the Wolverine Mine Area

3.6 Seismicity

The most seismically active region near the Wolverine Mine area is along the plate boundaries in the coastal and offshore area. The most significant inland seismicity occurs along segments of the Denali fault zone system, where the seismicity rate is an order of magnitude lower than that in the coastal region. The region between the Denali and Tintina systems is relatively a seismic, with relatively few and small earthquakes.

Data on recent earthquakes that occurred within about 600 km from the mine site (61.41°N and 130.09°W) from September 1899 to December 2005 was extracted from the Canadian Earth Physics Branch/Geological Survey of Canada/Western Canada-Pacific Geoscience Centre database and are shown on Figure 3-42. No earthquakes with magnitude greater than 5 have occurred within 200 km from the site. However, a magnitude 5 event did occur about 28 km northwest of the mine site with a focal depth of 5 km on May 12, 1999.



Notes:
1. Only earthquakes with magnitude M > 3 within a grid of 56.03° N-66.79° N and 118.84° W-141.33° W and from September 1899 to December 2005 are shown.
2. Epicentre data taken from Canadian EPB/GSC/PGC database and
3. Distances from project site are approximate, assuming one degree of latitude and longitude as 111.43 km and 53.37 km, respectively.

GSC-H Model Seismic Souce Zone Boundary
SYT GSC-H Model Seismic Source Zones

Figure 3-42: Map of Recent Regional Epicentres Near the Wolverine Mine

4 Project Description

4.1 Mine Features, Facilities and Equipment

The location of the Wolverine Mine in Yukon is shown in Figure 1-1. Arial views of the TSF area and industrial complex are shown in Figure 4-1 and Figure 4-2, respectively; while the general mine site layout of is illustrated in Figure 4-3. Figure 4-4 and Figure 4-5 provide the layouts for the industrial complex and TSF areas, respectively. Mine infrastructure remains in place during temporary closure and is described further below. Temporary closure conditions are described further in Section 5. The surface facilities and infrastructure at the Wolverine Mine include the following:

- Tailings Storage Facility (TSF);
- Seepage collection pond;
- Waste rock storage piles;
- Industrial complex and camp;
- Land Treatment Facility (LTF);
- Landfill;
- Mine roads;
- Airstrip; and
- Site access road.

Figure 4-1: Tailings Storage Facility Layout

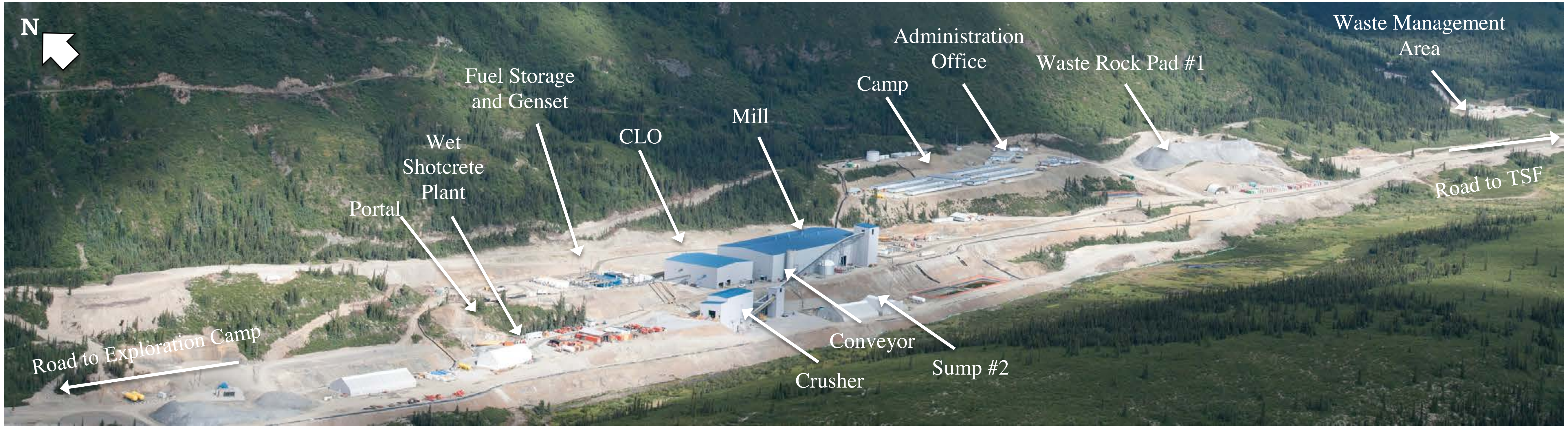


Figure 4-2: Industrial Complex Layout

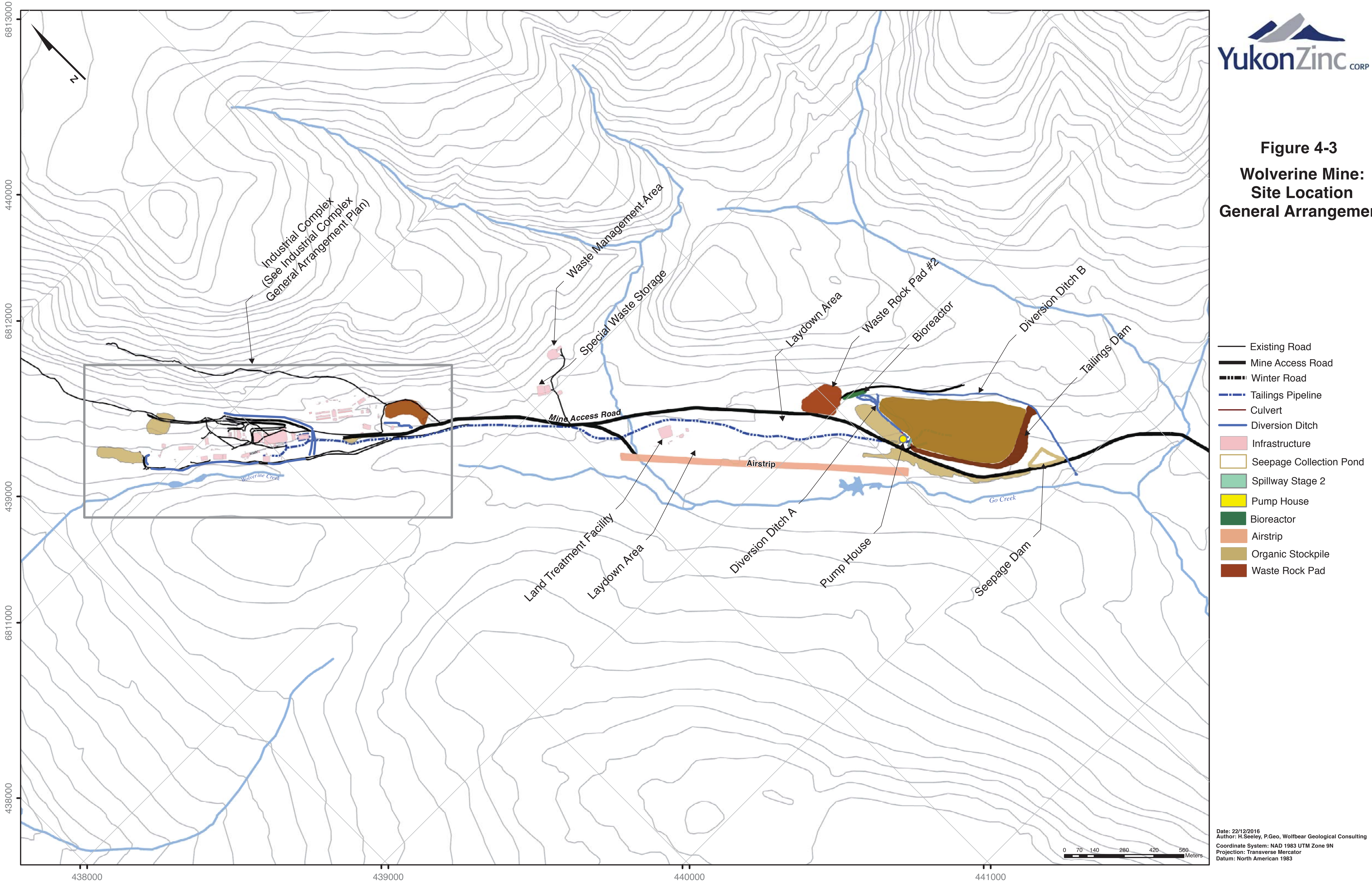


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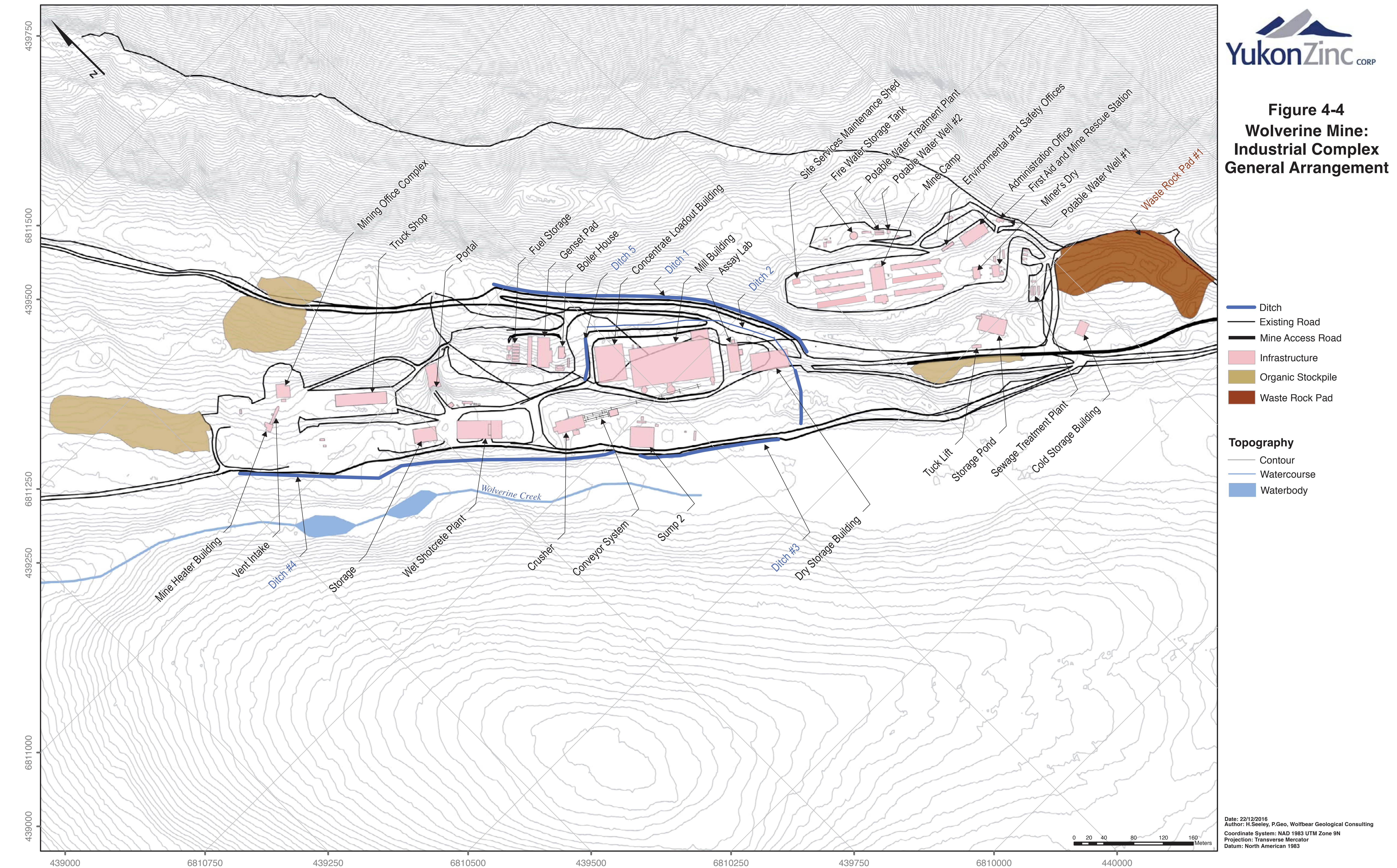
Figure 4-3

Wolverine Mine: Site Location General Arrangement

Date: 22/12/2016
Author: H.Seeley, P.Geo, Wolfbear Geological Consulting

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983


YukonZinc CORP
Figure 4-4
Wolverine Mine:
Industrial Complex
General Arrangement
Ditch
Existing Road
Mine Access Road
Infrastructure
Organic Stockpile
Waste Rock Pad
Topography
Contour
Watercourse
Waterbody
Mining Office Complex
Truck Shop
Portal
Fuel Storage
Genset Pad
Boiler House
Ditch 5
Concentrate Loadout Building
Ditch 1
Mill Building
Assay Lab
Ditch 2
Site Services Maintenance Shed
Fire Water Storage Tank
Potable Water Treatment Plant
Potable Water Well #2
Mine Camp
Environmental and Safety Offices
Administration Office
First Aid and Mine Rescue Station
Miner's Dry
Potable Water Well #1
Waste Rock Pad #1
Wolverine Creek
Mine Heater Building
Vent Intake
Ditch #4
Storage
Wet Shotcrete Plant
Crusher
Conveyor System
Sump 2
Ditch #3
Dry Storage Building
Tuck Lift
Storage Pond
Sewage Treatment Plant
Cold Storage Building
439000
6810750
439250
6810500
439500
6810250
439750
6810000
440000
439750
6811500
439500
6811250
439250
6811000
439000
0 20 40 80 120 160
Meters
Date: 22/12/2016
Author: H.Seeley, P.Geo, Wolfbear Geological Consulting
Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

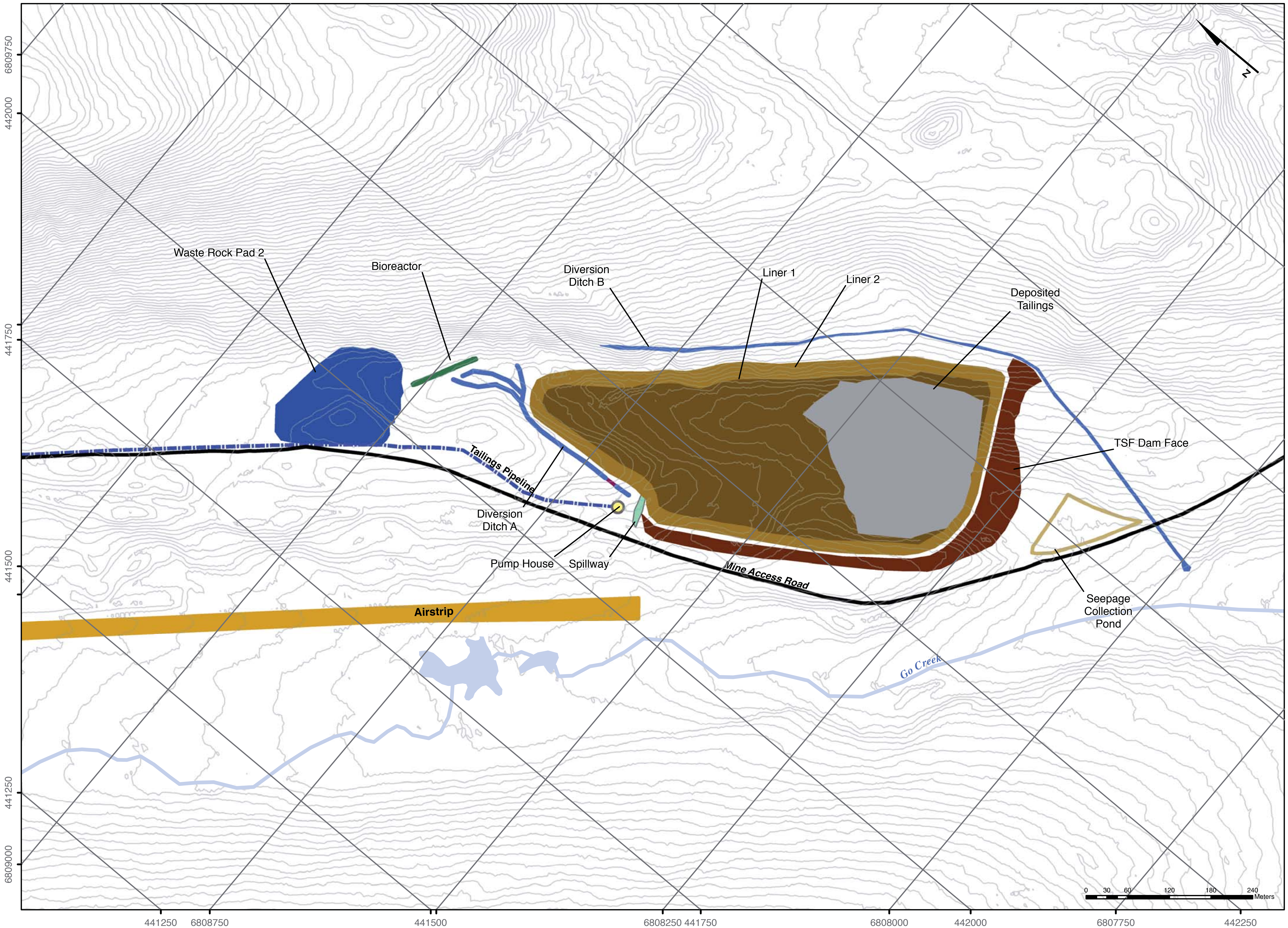


Figure 4-5

Wolverine Mine: Tailings Storage Facility

- Mine Access Road
- Tailings Pipeline
- Culvert
- Diversion Ditch
- Pump House
- Bioreactor
- Liner
- Seepage Collection Pond
- Airstrip
- Waste Rock Pad 2
- Spillway Stage 2
- Deposited Tailings
- TSF Dam Face

Date: 07/12/2016
Author: H.Seeley, P.Geo, Wolfbear Geological Consulting

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

The Wolverine Mine is accessed by a private, 24 km single-lane gravel road with passing bays, connected to the Robert Campbell Highway at km 190. The site access road is restricted by a gate and the road is operated under radio control. The road can be used year-round, subject to snow clearing activities, with minimal load restrictions. Alternate access to the mine site is via a gravel airstrip on site. The airstrip is 1,340 m long, which enables a twin engine aircraft to land on the airstrip with a full passenger load. The airstrip is intended for restricted use only under Visual Flight Rules and is maintained and used year-round.

Diesel fuel for the site power generators and associated operating equipment is supplied from six diesel fuel storage tanks (75,000 L capacity each) and an 8,500 L gasoline tank. Storage is based on two weeks of reserve during normal operations in the event of road problems and/or use restrictions. A fuel truck transports diesel fuel and lubricants to mobile equipment as required.

On-site power generation is provided by eight diesel generator sets, each rated 1,200 rpm, 1.26 MW continuous, 1.45 MW prime power generating at 4,160 V for a total installed generating capacity of 10.08 MW continuous, 11.60 MW prime power. In addition, a number of standby generators are present on site in varying capacities. Fuel requirements during temporary closure have been minimized to reduce fuel consumption.

The underground mine is accessed by a surface ramp that extends from approximately 1,345 masl (the portal entrance) to 1,115 masl (the current lowest elevation). Additional access is through a ventilation raise that has an evacuation route. The underground mine is currently flooding passively with groundwater recharge and is inaccessible. A 2015 geotechnical survey of the main access ramp revealed a number of potential ramp support failures that need to be addressed before the ramp can be safely used. The only pieces of equipment remaining in the underground mine are the electrical transformers, switch gear and communications equipment, a single refuge station, and some pumps and fans.

The process facilities consist of a crusher building, mill building, and concentrate load out facility (CLO). Feed conveyors connect the crusher building to the mill and transport crushed ore to the rod and ball mills. Ancillary facilities include a wet shotcrete plant, assay laboratory, mining office complex, truck shop and camp. Camp infrastructure at the Wolverine Mine consists of six 41-man dormitories, a kitchen, recreation hall, administration office, first aid office, mine rescue station, and dry facilities. Additional support infrastructure includes a maintenance workshop, training room, firewater tank, potable water treatment plant, communication station, and sewage treatment plant.

During mining operations, water from the underground workings and the tailings slurry from the milling process is pumped to the TSF and reclaimed water from the TSF is pumped back to the mill for process water use The TSF is a compacted homogeneous earthfill dam with an impervious geosynthetic liner, built in two stages. The liner covers the base of the TSF impoundment and the upstream face of the dam to the crest. A seepage collection dam downstream of the main dam collects seepage water to be returned to the TSF, or settled prior to discharge into the Go Creek drainage. During temporary closure, the mill is not operational, however, excess groundwater discharge from the underground mine is pumped to the TSF via the mill pumpbox to utilize the pumping and pipeline infrastructure in the mill. Inputs to the TSF during temporary closure are precipitation and surface runoff collected in sumps at the industrial complex, Waste Rock Pad #1, Waste Rock Pad #2 and at the seepage pond and excess groundwater discharge from the underground mine.

Waste rock from the mine is stored on two designated waste rock pads (Waste Rock Pad #1 and #2). Waste Rock Pad #1, located southeast of the camp, was constructed in 2005 to hold development waste prior to operations. Waste Rock Pad #2, located north of the TSF, was constructed in 2011 and holds development waste rock and ore that was not processed prior to the shutdown of the mining operations.

4.2 History of Mining Operations

Exploration of the Wolverine Mine area commenced in the early 1970s. In early 2005 a Type B Water Use Licence QZ01-051 and a Mining Land Use Permit LQ00140 were issued for advanced exploration activities. Under these approvals, YZC completed test mining and detailed infill diamond drilling programs. QML-0006 and WUL QZ04-065 were issued in December 2006 and October 2007, respectively, for the development and operation of the mine.

The Wolverine Mine was designed to operate 365 days per year, 24 hours per day at 1700 tpd of mill feed ore. Project manpower during normal operations requires approximately 370 workers, working on a two-shift basis, with approximately 190 people on site at any one time. The total tonnage mined to date is shown in Table 4-1. The "paste" column indicates tailings returned to the underground mine as paste backfill.

Table 4-1: Mining and Milling Activities Summary

Year	Mined Ore (t)	Milled Ore (t)	Concentrate (t)	Paste (t)	Tailings (t)
2010	26,826	0	0	0	0
2011	142,315	153,352	26,723	0	126,629
2012	441,095	428,955	82,486	86,506	259,963
2013	505,942	419,625	112,629	146,903	260,093
2014	443,867	413,879	100,952	134,502	196,425
2015	35,207	19,594	6,095	2,927	10,572
2016	0	0	0	0	0
Total	**1,595,253**	**1,553,405**	**328,885**	**370,838**	**853,682**

During operations, metal concentrates produced by the milling process were trucked south on the Robert Campbell Highway. Concentrate trucks travelled via Watson Lake to the Stewart Bulk Terminal in Stewart, BC for transportation via ocean freighter to various smelters in Asia.

5 Temporary Closure

This section presents the Temporary Closure Plan (TCP) for the Wolverine Mine and represents the current program of work being carried out by YZC until January 2020. This section has been updated from the previously submitted RCP 2016-07 to reflect an extension of the temporary closure period from three years to five years. The focus of the TCP continues to be to maintain the physical and chemical stability of the Wolverine Mine site, limit liability, and minimize water inputs to the TSF in order to maintain storage capacity and ultimately limit the volume of water requiring treatment in the TSF.

Given that the Wolverine Mine is currently in the temporary closure phase, this TCP details activities that have been completed or are ongoing as part of temporary closure and activities that are planned for the duration of the temporary closure phase, in place of a theoretical plan. A significant amount of clean up and closure work has been completed since operations were halted in January 2015.

Temporary closure activities that have been undertaken to date include:

- Decommissioning and reclaiming the exploration camp area and roads (COMPLETED);
- Consolidating all temporary ore and waste stockpiles to Waste Rock Pad #2 (COMPLETED);
- Constructing a bioreactor water treatment system between Waste Rock Pad #2 and the TSF (COMPLETED);
- Conducting bathymetric surveys of the TSF in 2015 and 2016 (COMPLETED);
- Characterizing of the free water in the TSF (COMPLETED);
- Conducting annual engineering inspections in 2015, 2016, and 2017 (COMPLETED);
- Conduct Dam Safety Review of the TSF (COMPLETED IN 2017);
- Managing excess groundwater discharge from the underground mine workings (ONGOING);
- Transporting all reagents off site (COMPLETE);
- Reclamation land preparation and seeding of areas in the project footprint (ONGOING);
- Maintaining the airstrip and mine roads (ONGOING); and
- Conducting environmental monitoring, including surface water, groundwater, and wildlife (ONGOING).

Proposed and ongoing temporary closure measures are described further below.

5.1 Site Security, Monitoring and Maintenance

5.1.1 Site Security

Since the cessation of mining activities in January 2015, the care and maintenance crew has consolidated mine supplies, including chemicals and equipment to ensure the safety and security of the site. The site is operated by a 3-person care and maintenance crew and access to the site is controlled by a gate on the site access road at the intersection with the Robert Campbell Highway.

There is currently no zinc concentrate remaining on site and there are 18 bags of copper concentrate and 13 bags of lead concentrate remaining to be shipped off site by the purchaser. The CLO has been swept and cleaned out; all reagents have been removed from site except for ~95 tonnes of lime. The remaining lime is securely packaged and stored in sealed freight containers on the site. This lime will be used to treat the depressed pH in the TSF.

No explosives remain on site. The explosives magazines have been emptied, the explosives burned, and the licences returned to Yukon Worker's Compensation Health and Safety Board to be held for YZC.

The existing fuel storage facilities are used in temporary closure and are comprised of six 75,000 L tanks (450,000 L total storage). This is sufficient to supply the smaller gensets as well as the mobile equipment through the 6-month winter period. With sufficient on-site fuel storage capacity for the winter period it is not necessary to keep the site access road open and maintained, which further reduces the site maintenance requirements during temporary closure.

In the event of hazardous substance spill, spill response follows the approved *Spill Contingency Plan* (V2010-03). The Wolverine Mine is equipped with spill response kits at various locations around the site:

- Industrial complex;
- Fuel storage tanks;
- Camp; and
- Airstrip.

5.1.2 Monitoring Activities

Environmental monitoring is conducted in accordance with requirements outlined in Type A Water Use Licence QZ04-065 (WUL), and the *Wolverine Mine Monitoring and Surveillance Plan V2011-03*. Ongoing monitoring consists of monthly and quarterly surface and ground water monitoring, vegetation and wildlife monitoring, and climate monitoring. Periodic monitoring includes monitoring of the TSF and annual geotechnical inspections.

5.1.2.1 Surface Water and Groundwater Monitoring

Water quality monitoring is conducted at surface water stations, groundwater stations, and via piezometric installations above the underground mine. Water chemistry and hydrological results from this monitoring are compared to historical data and the allowable discharge limits outlined in the WUL, and findings are presented in monthly and annual reports to EMR and the YWB. Water quality results are also compared to triggers outlined in the *Wolverine Creek Adaptive Management Plan*, to ensure the protection of the downstream environment. Monitoring of experimental test systems is also conducted to establish treatment effectiveness. These water monitoring programs are described below.

Surface Water Quality Monitoring

Surface water monitoring during temporary closure includes surface water quality and hydrological monitoring in the Wolverine and Go Creek watersheds. The surface water quality sampling program is outlined in Table 5-1 at stations shown on Figure 3-2. During the temporary closure period, many sampling sites have limited accessibility due to freezing conditions, low flow, or inaccessibility by boat during lake freezing or by road when the road is closed in winter. A summary of actual sampling frequencies based on the monitoring programs conducted 2005 – 2017 is provided in Table 5-2. These frequencies are used in sample cost estimates provided in Section 8.

Table 5-1: Surface Water Sampling Program During Temporary Closure

Station Number	Station Location	Watershed	Sampling Frequency
T1	Tailings Barge	TSF	Monthly
W82	Upper Wolverine Creek	Wolverine Creek	Monthly
W9	Wolverine Creek at Little Wolverine Lake		Monthly
W1	Wolverine Lake outlet		Monthly
L1	Little Wolverine Lake		Monthly
W21	Nougha Creek at Campbell Highway		Monthly
W8	Campbell Creek		Monthly
W15	Hawkowl Creek above Go Creek	Go Creek	Monthly
W16	Go Creek below tailings facility		Monthly
W81	Go Creek below Hawkowl Creek		Monthly
W31	Go Creek above TSF		Monthly
W80	Go Creek		Monthly (daily during discharging)
W12	Go Creek above Money Creek		Monthly
W14	Upper Money Creek	Money Creek	Monthly
W22	Money Creek above Campbell Highway		Monthly
W40	Money Creek below Campbell Highway		Monthly
W71	Pitch Creek below road crossing	Site Access Road	Monthly
W72	Light Creek		Monthly
W73	Bunker Creek at road crossing		Monthly

Table 5-2: Surface Water Sampling Frequency

	Jam	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
T1	1	1	1	1	1	1	1	1	1	1	1	1	**12**
W82	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W9	0	0	0	0	0	1	1	1	1	0	0	0	**4**
W1	0	0	0	0	0	1	1	1	1	0	0	0	**4**
L1	0	0	0	0	0	1	1	1	1	0	0	0	**4**
W21	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W8	0	0	0	0	0	1	1	1	1	0	0	0	**4**
W15	1	1	1	1	1	1	1	1	1	1	1	1	**12**
W16	1	1	1	1	1	1	1	1	1	1	1	1	**12**
W81	1	1	1	1	1	1	1	1	1	1	1	1	**12**
W31	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W80	0	0	0	0	31	30	31	31	30	31	0	0	**184**
W12	0	0	0	0	0	1	1	1	1	0	0	0	**4**
W14	0	0	0	0	0	1	1	1	1	0	0	0	**4**
W22	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W40	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W71	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W72	0	0	0	0	1	1	1	1	1	1	0	0	**6**
W73	0	0	0	0	1	1	1	1	1	1	0	0	**6**
Total	**4**	**4**	**4**	**4**	**43**	**43**	**43**	**43**	**43**	**43**	**4**	**4**	**304**

Bioreactor Water Quality Monitoring

There is one active bioreactor on site between Waste Rock Pad #2 and the TSF (see Section 5.2.3). Water quality at the inlets and outlets of these bioreactors will be monitored during snow free conditions. This will ensure that they are functioning as designed and ensure suitable water quality at the outlets. Results of this monitoring is presented for every four month period starting May 31, 2016 and submitted every four months following to EMR.

Groundwater Monitoring

The groundwater monitoring program during temporary closure includes monitoring water level, temperature, and water quality at 24 locations in alluvial, shallow, and deep bedrock in the Wolverine Lake and Go Creek watersheds (Figure 3-21). Groundwater monitoring is conducted at stations and frequencies outlined in Table 5-3. Quarterly sampling for most sites are conducted in accordance with the WUL. However, as described in the *Wolverine Mine Environmental Monitoring of Underground Workings Plan* (May, 2016), monthly sampling at stations MW05-5 and MW06-11 are conducted to evaluate the effect of the underground mine filling on Wolverine Creek.

An assessment of groundwater stations was conducted in 2017, and revealed that many of the stations were compromised due to old tubing having fallen down the wells or frost jacking or well contamination. Therefore, many of the stations cannot be sampled, as summarized in Table 5-4. The temporary closure program includes a hydrogeological assessment to be conducted in 2018 to assess the requirements for continued sampling at the stations, and provide recommendations for repairs/re-establishment of these wells. The assessment will also include the preparation of the 3-D numerical hydrogeological model using MODFLOW or an equivalent software, as required in Section 8.6(m) of the QML. The stations able to be sampled, as summarized in Table 5-4 are used in the costing provided in Section 8.

Table 5-3: Groundwater Sampling Program During Temporary Closure

Groundwater Station	Location	Watershed	Sampling Frequency
MW05-1A, 1B	Airstrip North	Go Creek	Quarterly
MW05-2A, 2B	TSF – Southwest	TSF	Quarterly
MW05-3A, 3B	Mine	Wolverine Creek	Quarterly
MW05-4A, 4B	Mine		Quarterly
MW05-5A, 5B	Mine		Monthly
MW05-6A, 6B	Airstrip East	Go Creek	Quarterly
MW05-7B	Mine	TSF	Quarterly
MW06-8S, 8M, 8D	Mine	Wolverine Creek	Quarterly
MW06-9S, 9M	Mine		Quarterly
MW06-10S, 10M, 10D	Mine		Quarterly
MW06-11S	Mine		Monthly
MW06-12S	Mine		Quarterly
MW08-13	TSF - West	TSF	Quarterly

Table 5-4: Groundwater Sampling Program Frequencies

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
MW05-1A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-1B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-2A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-2B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-3A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-3B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-4A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-4B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-5A	1	1	1	1	1	1	1	1	1	1	1	1	**12**
MW05-5B	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW05-6A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-6B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-7B	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW056-8S	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-8M	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-8D	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-9S	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-9D	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW06-10S	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW06-10M	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-10D	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-11S	1	1	1	1	1	1	1	1	1	1	1	1	**12**
MW06-12S	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW08-13	0	0	1	0	0	1	0	0	1	1	0	0	**4**
Total	**2**	**2**	**16**	**2**	**2**	**16**	**2**	**2**	**16**	**16**	**2**	**2**	**80**

Underground Mine

Four vibrating wire piezometers are installed at two locations (PZ-A and PZ-B) above the underground mine. Both locations have one shallow and one deep piezometer. These piezometers measure the water table above the mine and results delineate any effects from underground mining on the water table. Station PZ-A deep was compromised in 2014 when underground development intersected the logger. Station PZ-A shallow was also compromised in December 201, and hence is no longer reported. Water levels from logger PZ-B are reported in annual reports to EMR.

As groundwater discharge has reached the mine adit, as of June 2017, groundwater discharge rates are monitored via pumping rates as groundwater excess is pumped to the TSF. Groundwater discharge rates are estimated weekly and will continue to be monitored throughout the temporary closure period. Flow rates are provided in the monthly reports submitted to the YWB and EMR.

5.1.2.2 Vegetation, Aquatic Organisms, and Wildlife

Revegetation efforts are monitored at sites that have been seeded. Photographs are taken to document revegetation success from year to year. As detailed in Section 2.2.2, a preferred reclamation seed mix has been determined through vegetation monitoring of seeded areas. Monitoring of these areas will continue throughout the temporary closure period and they will be re-seeded if required.

While aquatic organism monitoring is not required under the monthly monitoring program, as part of the requirements under the *Fisheries Act* MMER a Cycle 3 biological study will be completed in late summer 2017, as per the *MMER EEM Cycle 3 Study Design* submitted September 19, 2016. A *Third Interpretive Report* will be subsequently completed and submitted by December 3, 2017. The study will include benthic invertebrate monitoring and sediment sampling, as per MMER requirements. Subsequent studies will be conducted by September 2020 to meet the requirement to submit the Cycle 4 EEM biological survey report 36 months after the day on which the most recent interpretative report was required to be submitted (i.e., December 5, 2017).

Should effluent discharge commence, subsequent EEM studies will require a fish population survey in addition to the benthic invertebrate studies. Effluent characterization sampling (water chemistry, sub-lethal and acute toxicity testing) will also be carried out once discharge to Go Creek begins. Routine water quality monitoring in the exposure and reference areas, which is not required as per QML-0006 under temporary closure conditions, will resume when discharge to Go Creek begins in order to meet the MMER requirements.

Wildlife monitoring consists of incidental wildlife encounters on site and documentation of all wildlife-related incidents. These events are reported in annual reports to EMR and YWB. While monitoring of small mammals and vegetation is required by the *Wolverine Mine Wildlife Protection Plan V2009-01* (WPP), due to minimal site activities, this monitoring has not been conducted in 2017, as was required in the WPP. Due to the invasive nature of the small mammal sampling program, YZC will conduct vegetation sampling as per the WPP in spring 2019, prior to permanent closure. If statistical metal contamination is detected in the vegetation, a small mammal trapping program will also be conducted. Should the mine re-start, vegetation sampling will be conducted in the spring season following mine re-start.

5.1.2.3 Climate and Water Balance

Climate is monitored during temporary closure by the weather station on the Wolverine Mine site. The weather station is located at the south end of the airstrip and records the following data:

- Temperature;
- Pressure;
- Precipitation;
- Radiation in and out;
- Wind speed and direction; and
- Relative humidity.

Data from the weather station is collected by the care and maintenance crew. Mean monthly temperatures, minimum temperatures, maximum temperatures, average daily temperatures, daily precipitation (as rain), and annual cumulative precipitation are reported in annual reports to EMR.

Inputs to the TSF are also monitored through tracking of water pumped or trucked to the TSF throughout the year. This enables better prediction of inflow rates into the TSF to aid in long-term planning for discharge activities.

5.1.3 Maintenance Activities

The care and maintenance crew on site undertakes all routine maintenance work during temporary closure. Any work outside normal care and maintenance duties is contracted out. The maintenance work is verified annually, as per the requirements outlined in Section 10 of QML-0006. The annual physical inspection for all structures, works and installations must be conducted by an engineer. This inspection includes:

- Seepage collection dams;
- Tailings impoundment structures;
- Waste rock dumps;
- Diversion structures (channels and dams);
- Mill;
- Underground mine;
- Camp infrastructure; and
- Any other engineered structures, works or installations associated with the Wolverine Mine site.

5.1.3.1 Underground Workings and Openings to Surface

The underground mine is currently gated and locked, as the mine is flooding. An early morning inspection on June 7, 2017 indicated that groundwater discharge had reached the mine adit collar. Since then, daily pumping has occurred to pump excess groundwater discharge to the TSF for storage to prevent unintended discharge to the environment. Pumping will continue throughout the temporary closure period, as required. Water management at the underground mine is detailed in Section 5.2.2, including an updated bulkhead design.

Monitoring of the underground mine is conducted daily to ensure structural stability of the collar, functionality of the pumping and piping system and status of the groundwater recharge.

5.1.3.2 Tailings Storage Facility (TSF) Area and Water Management Structures

Temporary closure maintenance activities relating to the TSF primarily involve ensuring the long-term physical stability and integrity of the structure and associated components. The TSF undergoes an annual dam safety inspection by a professional engineer, as per the *Canadian Dam Association Dam Safety Guidelines* (CDA, 2013) and QML-0006. QML-0006 also directs that all diversion structures undergo an annual physical inspection by an engineer. In accordance with the *Wolverine Mine Tailings Facility Operation, Maintenance and Surveillance Manual V2010-01*, maintenance and surveillance activities include:

- Regularly checking diversion ditches, spillways and culverts for accumulation of debris or sediment, or any other form of blockage, and removing blockages as required;
- Visually inspecting diversions, spillways, seepage collection dam and all ditches for cracking, bulging, slumping, or any other indications of slope movement;

- Performing regular performance tests on seepage pond pump;
- Re-grading the dam crest, as required, to prevent local ponding and direct surface runoff towards the seepage pond;
- Repairing erosion gullies, local slumps or slides in the dam face, diversion ditches or spillway channels;
- Repairing damaged liner sections (the geomembrane liner could be damaged by wildlife or ice movement during spring break-up; and
- Monitoring for changes in seepage conditions on the downstream slope or at the toe of the dam.

Routine and/or regular visual inspections of the dam, liner, diversion ditches, seepage collection dam, spillways, pipelines, and pumping infrastructure are carried out on an on-going basis as required. The visual inspections comprise all components of the dam, including the crest, upstream and downstream slopes, abutments, the liner, the water reclaim system, pipelines and pipeline crossings, diversion ditches, and spillways. Event-driven maintenance is conducted in the event of a pipeline leak or break, earthquake, avalanche, or a flood.

An updated OM&S is to be provided by October 31, 2017. Letters regarding the capacity of for water storage in the TSF and confirmation of the instrumentation and monitoring during the temporary closure period are provided in Appendix A and Appendix B.

See Section 5.2.3 for details on water management relating to the TSF area.

Monitoring for wildlife is also conducted at the TSF pond regularly during the ice free period. Should wildlife be detected (i.e., migratory birds landing in the pond) they are deterred. Mechanisms previously used to deter wildlife has included driving around the pond, or, if required, shooting bear bangers off above the pond to encourage the birds to move on.

5.1.3.3 Waste Rock and Overburden Dumps

Currently there are two waste rock pads at the Wolverine Mine site. Waste Rock Pad #1 (Photo 5-1) is located south of the camp and Waste Rock Pad #2 (Photo 5-2) is located north of the TSF. All temporary ore and waste stockpiles were moved to Waste Rock Pad #2 in July and August 2015. Waste Pad #2 was surveyed in August 2016, and the volume of waste and ore on the pad is 10,439 m^3 and 29, 890 m^3, respectively. Waste Pad #1 has not had material placed on it since 2012, and the volume at that time was 91,000 m^3.

Temporary closure maintenance activities relating to the waste rock pads consist of ensuring physical stability, which is accomplished by conducting annual physical inspections, as per QML-006. Care and maintenance crews also monitor the waste rock pads for shifting or slumping on an ongoing basis and after storms.

Waste Rock Pad #1 has a lined sump at the toe that is monitored for liner integrity. Crews check that there are no holes in the liner and that no material around the sump is slumping. Runoff from Waste Rock Pad #2 is currently routed through a bioreactor before entering the TSF, with the option to bypass the bioreactor and discharge directly to the TSF. Bioreactor maintenance is minimal; crews add material to the bioreactor as required, maintain the standpipes, make sure the bioreactor has no blockages, and make sure the bioreactor is functioning as intended.

Photo 5-1: Waste Rock Pad #1, East of the Camp (July 2013)

Photo 5-2: Waste Rock Pad #2, North of the TSF (July 2013)

5.1.3.4 Mine Infrastructure

Exploration Camp and Roads

Closure activities at the exploration camp have been completed. The camp has been decommissioned and the footprint has been seeded. Revegetation in seeded areas has been successful and no other reclamation work is scheduled for the exploration camp. Exploration camp roads will not be maintained during temporary closure, although they will be driveable with an ATV for the purposes of accessing environmental monitoring sites.

Camp

Only a portion of the camp is operated during temporary closure, as the care and maintenance crew does not require the full camp. Parts of the main kitchen and mess hall have been converted into office space and the office building has been shut down. Living accommodation is provided in one half of Bunkhouse #3; all remaining bunkhouses and buildings have been winterised and shut down.

Processing Plant and Other Buildings

A metallurgical and processing crew of ten mill workers and a metallurgical engineer was brought to site in May 2015 to secure the processing plant and remaining site reagents left on site. The completed work included:

- Clean-up of the mill area and other safety-related jobs;
- Wash down of all areas and sumps;
- Emptying the ball mill and rod mill of charge and jacking them onto their cradles and off their pinions;
- Emptying of all flotation cells;
- All pumps were split and left open as appropriate;
- All equipment that requires warm storage was identified and segregated for potential removal from site, or warm storage;
- Filled all gear boxes with oil for long-term preservation;
- Emptied all reagent tanks, flushed any chemicals remaining in the reagent holding tanks to the TSF;
- Ensured that all stored reagents on site are appropriately identified and labelled, repackaged as required, and stored in a secure area (such as the CLO, or prepared lined storage areas); and
- Disposed of any other small amounts of reagents that could be effectively washed to the TSF.

There is no other work planned for the processing plant and mill during temporary closure and the facility is locked. A small area of the plant is accessed to facilitate pumping water through the mill pumpbox from the underground mine pump to the TSF via the tailings pipeline.

Power Generation Infrastructure

The eight primary generators were secured in 2015 and the glycol loop has been emptied into on site storage tanks. The empty glycol line was isolated into short loops, wherever possible, by closing all the system valves.

The current power system and many of the mill pumps and processes are controlled by a DeltaV programmable control system. All powered facilities required for temporary closure have been converted to manual operations with all necessary interlocks. Power during the temporary closure period is provided by a 350 kW Caterpillar genset, along with a smaller 115 kW standby set. These two generators service the camp and other facilities, with an average consumption of 768 L of diesel fuel per day during winter months.

Landfill and Waste Storage Areas

Maintenance for the landfill is in accordance with the Commercial Dump Permit 81-014. The landfill will remain operational throughout temporary closure.

The Special Waste Pad on site has been cleaned up and organised and dirty totes have been washed out and sent to the scrap pile. All other old barrels and scrap material are being collected around site and sorted appropriately.

5.1.3.5 Roads and Other Access

The care and maintenance crew maintains the site access road, except during winter months when the site becomes a fly-in/fly-out operation with regular flights every two weeks to change crews and bring supplies in or out. The mine site roads are maintained as needed and are cleared of snow in the winter. The airstrip and helicopter landing pad are maintained year-round to ensure there is always access to the site.

5.2 Interim Water and Solution Management Plan

This section describes the plans for the management of clean water and contaminated water during the temporary closure phase at the Wolverine Mine site. There are no process solutions generated during the temporary closure period, as all milling and mining activities have ceased. This section has been materially changed to reflect the request for extension of the temporary closure period, the current mine flooding conditions and the comments received on RCP 2016-07. Updated bulkhead designs and a comprehensive dam safety review completed in 2017 have informed this updated water management plan for the temporary closure period. As the mine discharge rates are now know, an updated water balance is provided below, and directly dictates the requirements for water management during the extended temporary closure period and into the permanent closure period. Updated water management plans for the underground mine and the TSF follow.

5.2.1 Water Balance

Water around the project site is managed to prevent contaminated discharge to the environment, and avoid collecting clean water. Clean water is diverted around mine infrastructure, and all potentially contaminated water is pumped or trucked to the TSF. Loads from around the Wolverine Mine are shown in Figure 5-2 and average monthly flow rates are provided in Table 5-5 and in Figure 5-1 based on measurements taken over the temporary closure period (January 2015 to present).

Surface runoff is collected from the industrial complex, the waste rock storage pads, the land treatment facility and in the catchment around the TSF. Runoff and seepage is also collected in the TSF seepage pond, which is pumped back to the TSF as required. As there are only 3-4 people on-site for the majority of the year, use of groundwater for potable water is minimal, but increases in the summer with slightly more on-site activity (i.e., environmental monitoring, site inspections, etc.).

On June 7, 2017 groundwater discharge collecting in the underground mine reached the adit collar and has since been pumped to the TSF via the mill pump box. On average, there is approximately 244 m^3/day of water pumped to the TSF and approximately 95 m^3/day is collected in the TSF as precipitation or as runoff from the TSF catchment. The monthly estimates provided in Table 5-5 assumes freezing conditions in the underground mine December – March, with increasing flow rates peaking in July and August as the ice cover thaws.

Table 5-5: Predicted Monthly Flow Rate and Annual Average Flow Rates for the Temporary Closure Period

Flow Rates (m^3/day)	Underground	Sewage Treatment Plant	Various Surface Runoff	Sump #2	Seepage Pond	Net Precipitation	Water to Tailings (m^3/day)
January	0	0.2	0.2	0.0		0	0
February	0	0.2	0.3	0.0		0	1
March	0	0.2	0.4	0.5		8	9
April	150	0.2	0.6	0.0		134	284
May	300	0.2	23.0	57.3		205	585
June	500	1.0	11.0	111.4	73	257	953
July	400	1.0	113.0	83.0		321	918
August	400	1.0	4.0	12.8		5	423
September	200	0.5	6.0	64.8		174	445
October	200	0.2	0.8	5.2		34	240
November	200	0.2	0.0	0.0		0	200
December	0	0.2	0.0	0.0		0	0
Annual Average	**196**	**0.4**	**13**	**28**	**73**	**95**	**338**

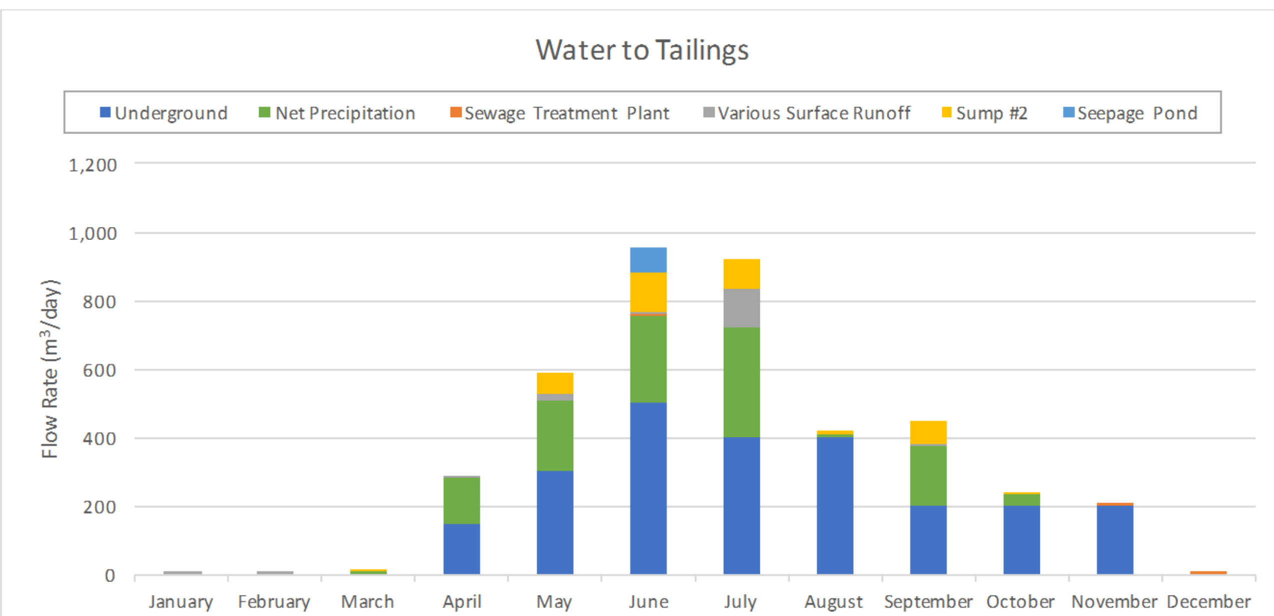


Figure 5-1: Predicted Monthly Discharge to TSF During the Temporary Closure Period

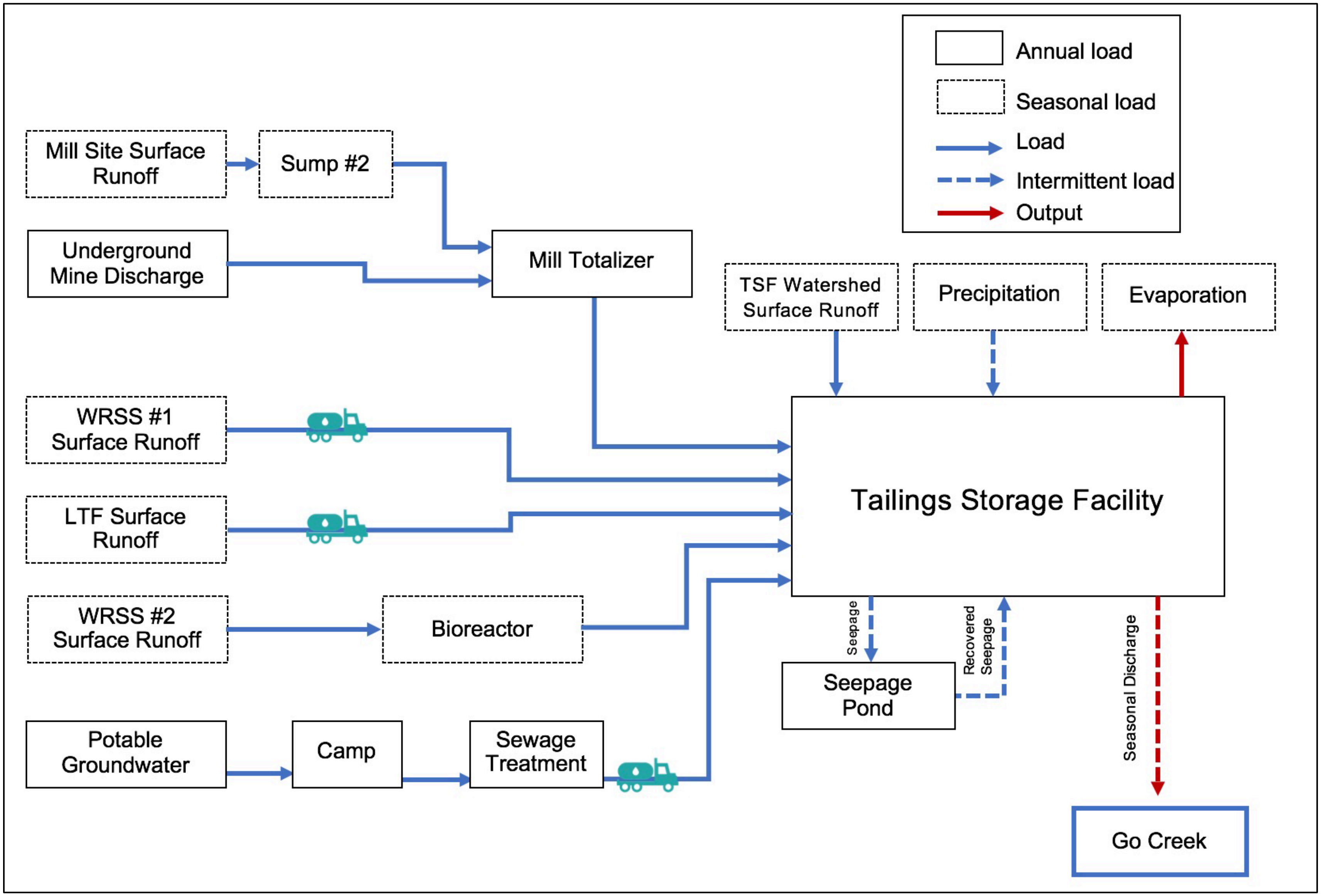


Figure 5-2: Temporary Closure Water Balance Model

As water is accumulating in the TSF, monitoring of the water level in the TSF is conducted weekly to add to the water level monitoring conducted during operations (Figure 5-3). Since December 2014, the elevation in the TSF has increased from 1307.1 m to 1309.0 m (Figure 5-4). This indicates an increase in volume of ~233,099 m^3. Since the underground groundwater has been discharged to the TSF, the cumulative flow discharged to the TSF has been ~713 m^3/day. However, these high flows are likely due to the high rainfall in June and July (Figure 3-18), which resulted in meteoric water collecting in the mine adit, in addition to the groundwater discharge. Recent measurements (August 2017) indicate daily flow rates of ~250 m^3/day, which is consistent with historic inflow rates, which averaged 300 m^3/day in 2012 through 2014.

A recent evaluation conducted by the Engineer of Record, provided in Appendix A, requires that to maintain sufficient freeboard in the tailings below the spillway, the water level cannot exceed 1310.0 m. The current water level is 1309.0 m (August 31, 2017). At a rate of filling of 300 m^3/day (Table 5-5), the pond will reach the 1310 m elevation in November 2018. As such, an active water treatment plant (WTP) is required to facilitate treatment and discharge of water accumulated in the TSF. Details of the WTP are provided in Section 5.2.3.

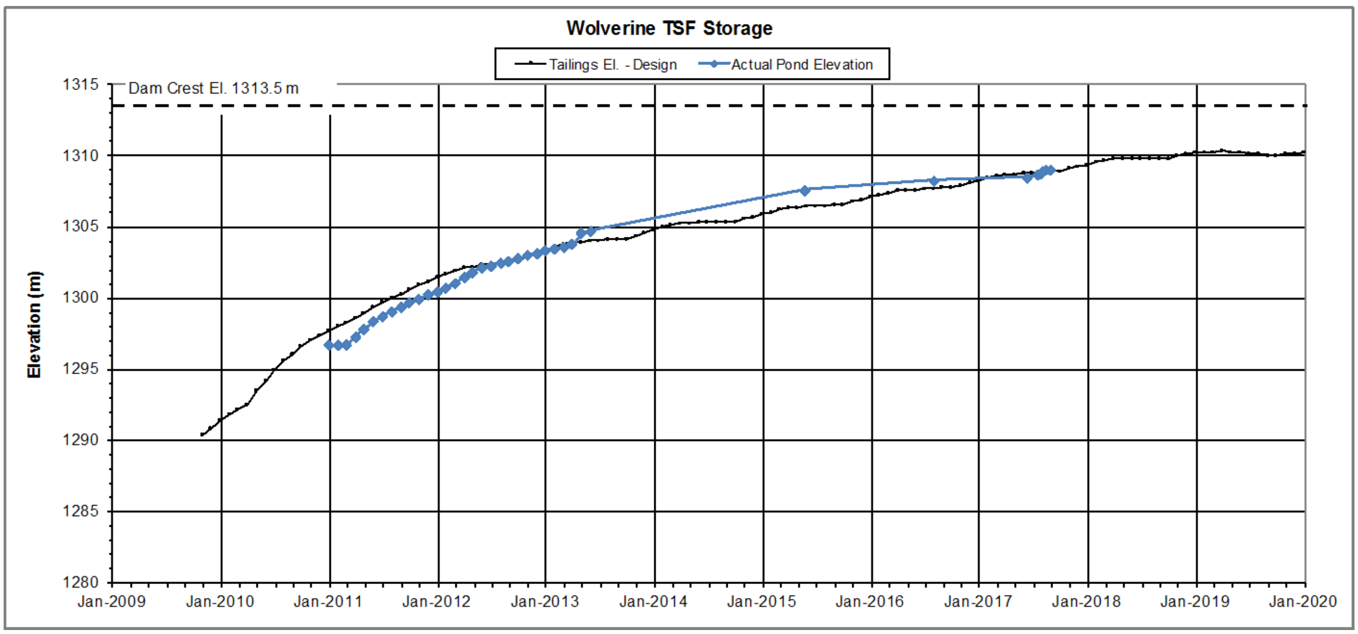


Figure 5-3: TSF Storage Curve, January 2009 to January 2020

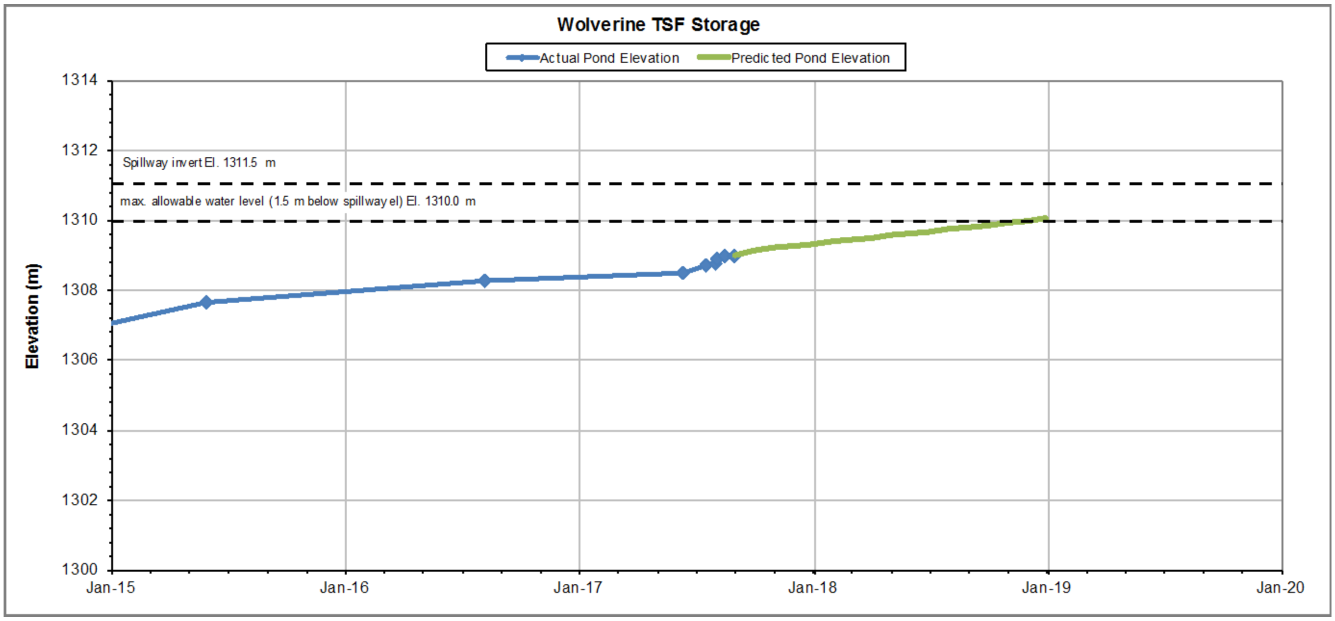


Figure 5-4: TSF Storage Curve, Temporary Closure Period

5.2.2 Underground Mine Workings

The underground mine workings are currently flooding and have been since the cessation of operations in January 2015. In August 2016 an updated volumetric survey of underground workings was conducted to predict flooding rates and key dates. A 150 m^3/d rate of flooding was used based on the inspection conducted in April 2015 (Shin, 2015). With a total underground volume calculated at 168,611 m^3, the mine was expected to be completely flooded to portal elevation by late May 2018. However, as discussed above, the underground mine water reached the adit collar on June 7, 2017. Using the updated known discharge rate, and an updated estimate of mine voids (Table 5-6) an updated estimate of mine water inflow indicates a rate over the January 2015 – June 2017 of just under 200 m^3/day. As summer rates have been measured since the groundwater reached the adit collar in June, a conservative rate of 250 m^3/day on average has been used to estimate underground discharge rates during the temporary closure period.

Table 5-6: Underground Mine Inflow Calculations

	2016 Estimate	2017 Actuals
Underground Volume	168,611 m^3	169,573 m^3
Mine shut down date	January 13, 2015	January 13, 2015
Flooding date	May 2018	June 8, 2017
Inflow Estimate	150 m^3/day	194 m^3/day

A pump and piping system has been installed at the adit of the underground mine (Photo 5-3) to pump excess groundwater recharge from the adit to the TSF. This system is installed above the gated entrance to the mine in the mine collar, as access below the collar is prohibited. The pump is run for a few hours per day as needed to maintain a consistent water level that prevents discharge to the mill pad. Water is pumped from the adit to the pumpbox in the mill, where it is then pumped to the TSF. Water quality has been monitored in the water pumped to the TSF since June, as summarized in Table 5-7, and compared to water quality measured during the 2006 – 2009 dewatering period.

On average, the water in the underground mine when there are no mining operations exceed discharge limits for most metal parameters, with exceedances of cadmium, copper, lead, selenium, and zinc. Groundwater recharge tends to have low concentrations of nitrogen species (i.e., ammonia, nitrate and nitrite) as these are directly tied to mine operations, due to explosives residues. Cyanide is also relatively non-present, with concentrations below the detection limit.

The 2017 samples (Table 5-7) were mostly below discharge limits, except for iron (not shown), zinc and total suspended solids in most samples. The July sample was also in exceedance of the allowable discharge limits for cadmium, copper, lead, and selenium. However, generally the water is of relatively good quality, and indicates it may be amenable to treatment and discharge without being pumped to the TSF.

Photo 5-3: Wolverine Mine Adit Groundwater Pump System (July 13, 2017)

Table 5-7: Underground Mine Water Quality Statistics and 2017 Chemistry Results

Parameter (mg/L)	A License QZ04-065	Dewatering Period Water Quality May 2006 - March 2009 (n=123)			2017 Portal Samples			
	ADL*	Minimum	Average	Maximum	June 7	June 28	July 10	Aug 18
Total Suspended Solids	**15**	1.5	**102.2**	**3630**	**18**	**22.8**	**41.5**	**16**
Ammonial Nitrogen	**5**	0.0025	0.069	0.3115	1.4	1.5	1.1	1.5
Total Arsenic	**0.05**	0.00046	0.0109	**0.451**	0.00519	0.00426	0.0069	0.00537
Total Cadmium	**0.002**	0.00002	**0.0089**	**0.433**	0.000519	0.00112	**0.013**	0.00296
Total Copper	**0.015**	0.00074	**0.1284**	**4.6**	0.00541	0.00631	**0.0419**	0.00421
Total Lead	**0.02**	0.0006	**0.1890**	**7.91**	0.0049	0.0161	**0.198**	0.00414
Total Nickel	**0.5**	0.0003	0.0066	0.108	0.00987	0.0173	0.0185	0.0286
Total Selenium	**0.02**	0.0034	**0.0281**	**0.252**	0.00145	0.00449	**0.0459**	0.00325
Total Zinc	**0.5**	0.003	**0.924**	**45.4**	0.339	**0.516**	**0.981**	**0.624**

*ADL = Allowable discharge limits from Type A Water Use Licence QZ04-065; Bold values indicate exceedances of the ADL

Test work is proposed to be conducted in September 2017 to evaluate whether the underground mine water is amenable to direct treatment using ferric sulphate, similar to the system that was used in 2006-2009. The water treatment test work proposal is provided in Appendix C. Direct treatment of underground mine water will prevent unnecessary discharge to the TSF, and may reduce treatment costs using the active water treatment plant. Should the 2017 test work be successful, underground mine water may be treated directly in spring 2017 for direct discharge to Go Creek. All water discharged to Go Creek will meet discharge limits outlined in the WUL and will only be discharged during May through October.

In advance of permanent closure, two hydrostatic bulkheads (or plugs) will be installed in the underground mine in summer 2019: one in the decline and one in the vent raise, shown in Figure 5-5. The details of the plug designs are provided in Appendix D. Prior to initiating construction, water levels within the mine must be maintained at a level below the Decline Plug, and for an additional 28 days after pouring of the concrete plug or until the design strengths have been achieved. To maintain adequate water levels, it may be necessary to pump the water level down sufficiently before building the form walls, or install a drain pipe through the decline plug to maintain correct water levels. Options to dewater the mine to maintain the 28 days of dry conditions necessary for plug installation, including installing dewatering wells from surface, or pumping directly from within the mine, are currently being evaluated. All necessary safety considerations will be implemented, and approval for work from Yukon Workers Compensation Health and Safety Board will be acquired before starting any work to access the underground mine.

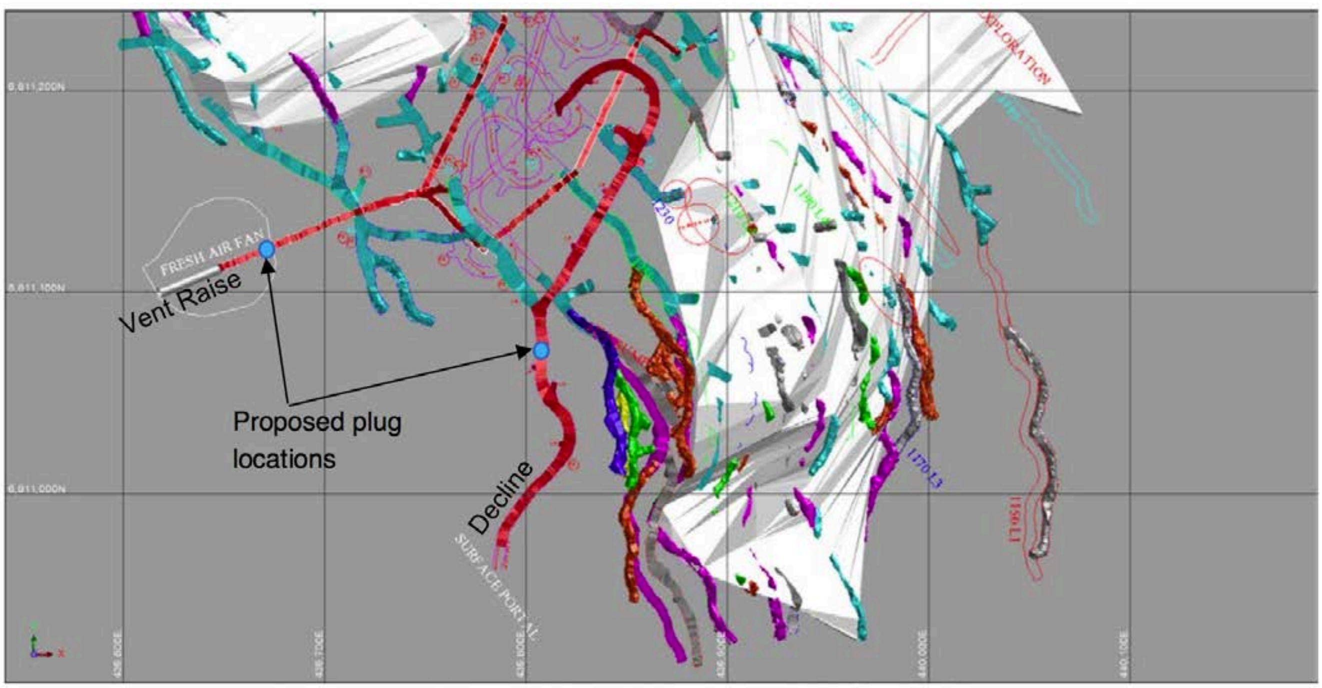


Figure 5-5: Proposed Decline and Vent Rains Plug Locations

The updated plug design is a water-tight design, and therefore, does not require seepage treatment as previously proposed in RCP 2016-07. However, adaptive management of potentially contaminated water in Wolverine Creek is proposed, and is summarized below.

5.2.2.1 Adaptive Management Plan

As described in Section 3.2.2 and 3.3, groundwater that intercepts the underground mine daylights in Wolverine Creek, and is evident by increases in metal concentrations sampled in the alluvial groundwater system and the surface water samples downstream of the mine. An adaptive management plan has been submitted to EMR to identify trends in Wolverine Creek water chemistry and set trigger levels for the requirement to build a biopass system in Wolverine Creek to remediate contaminated groundwater prior to discharge to Wolverine Creek. This adaptive management plan was originally submitted in May 2016, and is summarized below as it pertains to the temporary closure activities.

Quarterly groundwater quality samples are taken at all sites at the Wolverine Mine as required by the WUL. Monthly samples are taken at stations MW05-5 and MW06-11 to identify trends in underground mine affected groundwater systems. Results of surface and groundwater monitoring are summarized monthly and annually in reports to the Yukon Water Board, and Yukon Government Department of Energy, Mines and Resources. These reports provide graphical analyses of surface and groundwater quality monitoring, specifically for copper, selenium and zinc, as these parameters are generally elevated in the area of the Wolverine Mine, and indicate overall metal concentration trends.

For the purposes of the adaptive management plan for Wolverine Creek, copper, selenium and zinc will continue to be used as indicator parameters, with trigger levels attributed to these parameters. However, all contaminants of potential concern (i.e., those limited by the WUL) are considered during evaluation of the monthly monitoring results.

Table 5-8 summarizes the baseline and operational average concentrations for copper, selenium and zinc for the surface and groundwater quality monitoring sites in Wolverine Creek. Concentrations of the main parameters of concern are generally comparable between baseline (1995 – 2008) and during operations (2009 – 2014) for groundwater quality monitoring stations, however, at surface water quality monitoring station W82, the operational average value is consistently greater than the baseline average value by between 40% - 75%.

The trigger concentrations for the surface and groundwater quality stations has been set to 20% times the 95th percentile value from either station MW05-3B or W82 for copper, selenium and zinc, whichever is highest (Table 5-8), in keeping with the guidance from the BC Ministry of Environment for the derivation of water quality objectives (BC MOE, 2013). This is because the concentrations measured at stations MW05-3 and W82 1995 – 2014 exceed the allowable discharge concentrations throughout the monitoring period, evidence of impact from the ore body on groundwater and surface water quality (Figure 5-6 through Figure 5-11).

Table 5-8: Wolverine Creek Trigger Values

Parameter	W82 Concentrations					MW05-3B Concentrations					Trigger Value (mg/L)
	P25	Median	P75	P95	*WQO*	P25	Median	P75	P95	*WQO*	
Copper	0.0027	0.0038	0.0057	0.0126	*0.0151*	0.0029	0.0031	0.0035	0.0045	*0.0054*	**0.0151**
Selenium	0.0022	0.0025	0.0028	0.0045	*0.0053*	0.0069	0.0083	0.0101	0.0115	*0.0138*	**0.0138**
Zinc	0.181	0.272	0.365	0.473	*0.568*	1.700	1.830	1.940	2.558	*3.070*	**3.07**

The concentrations outlined in the licence for discharge to Wolverine Creek are not applicable, as baseline chemistry for many limited parameters in surface water station W82 and in some groundwater stations, exceed those discharge concentrations (Figure 5-6 through Figure 5-11).

When the concentration for copper, selenium or zinc in any groundwater or surface water monitoring station approaches the trigger value, the biopass passive treatment system will be constructed in Wolverine Creek.

Copper, selenium and zinc have been chosen as key indicators for the ore body, and will be indicative of contamination of the groundwater system by water that has contacted the mined areas.

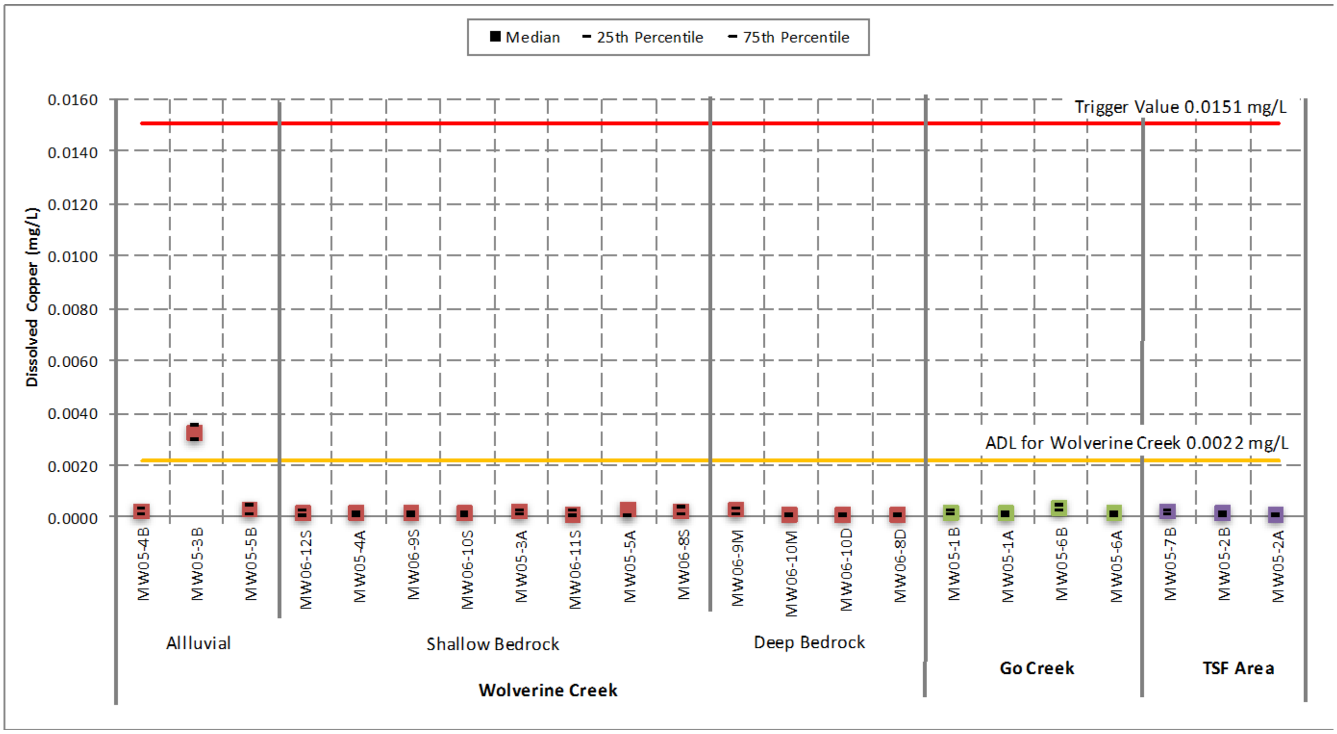


Figure 5-6: Groundwater Copper Concentrations and and Trigger Values

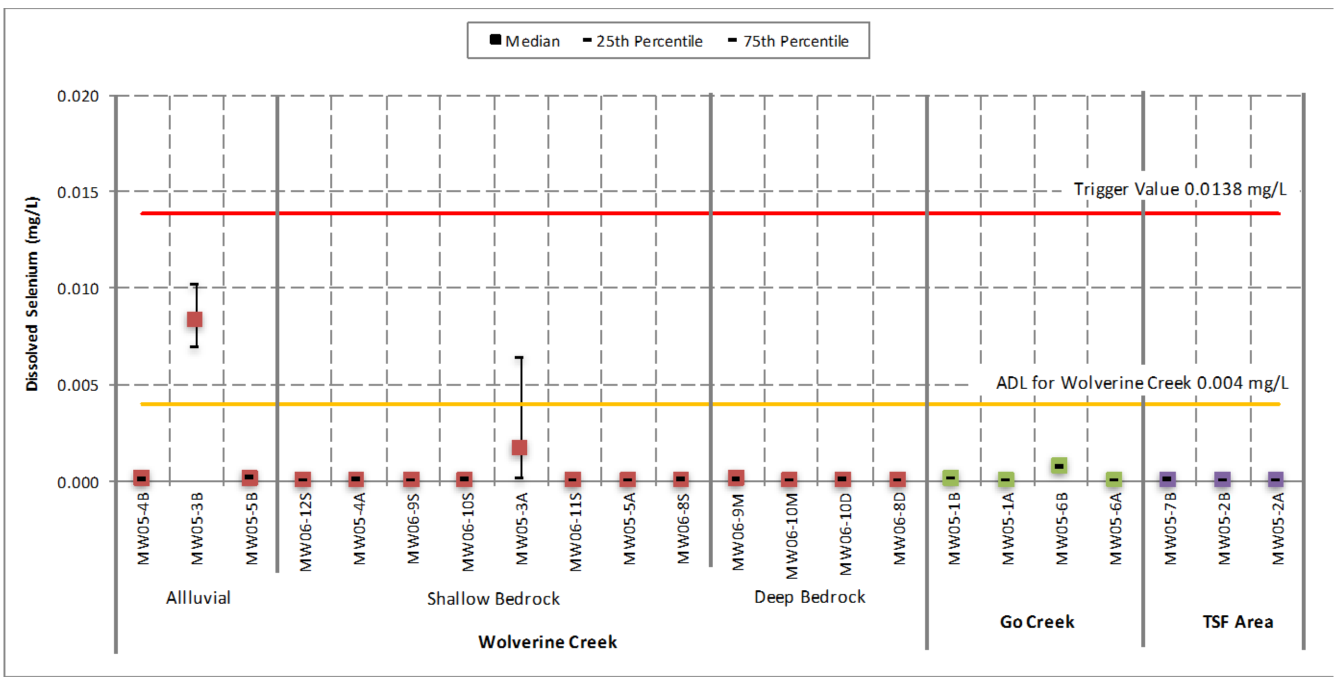


Figure 5-7: Groundwater Selenium Concentrations and and Trigger Values

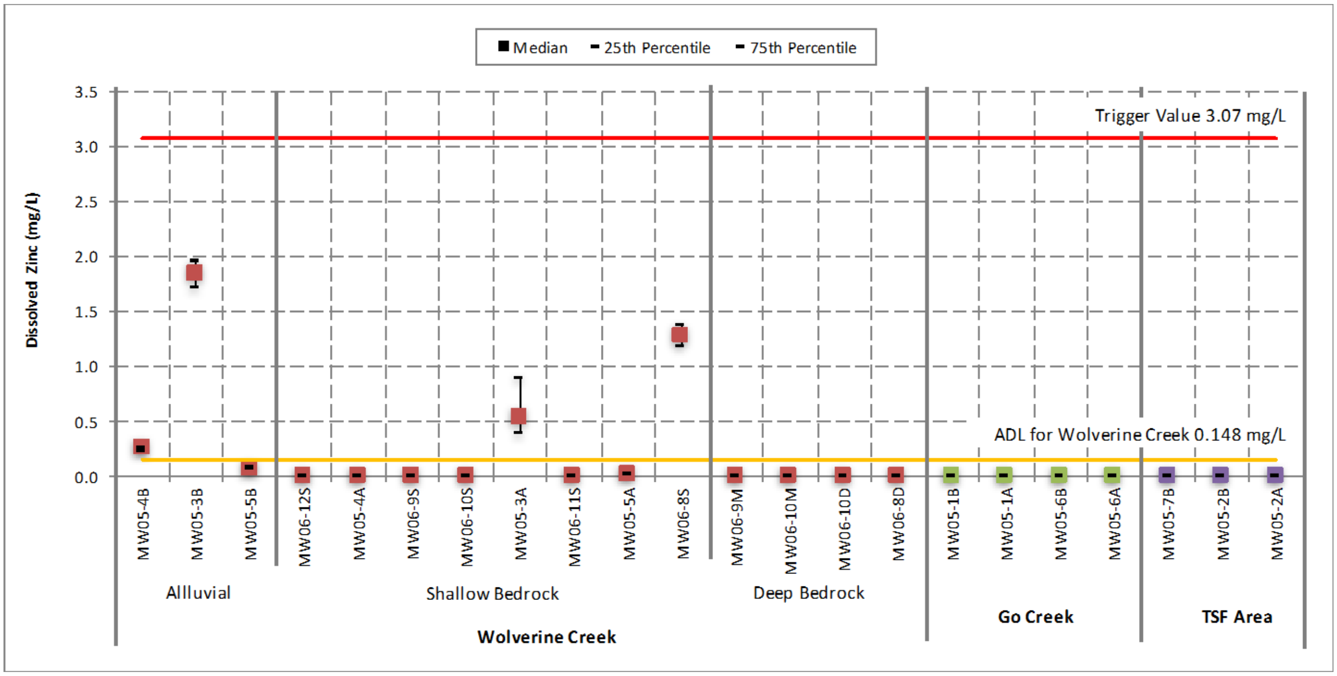


Figure 5-8: Groundwater Zinc Concentrations and and Trigger Values

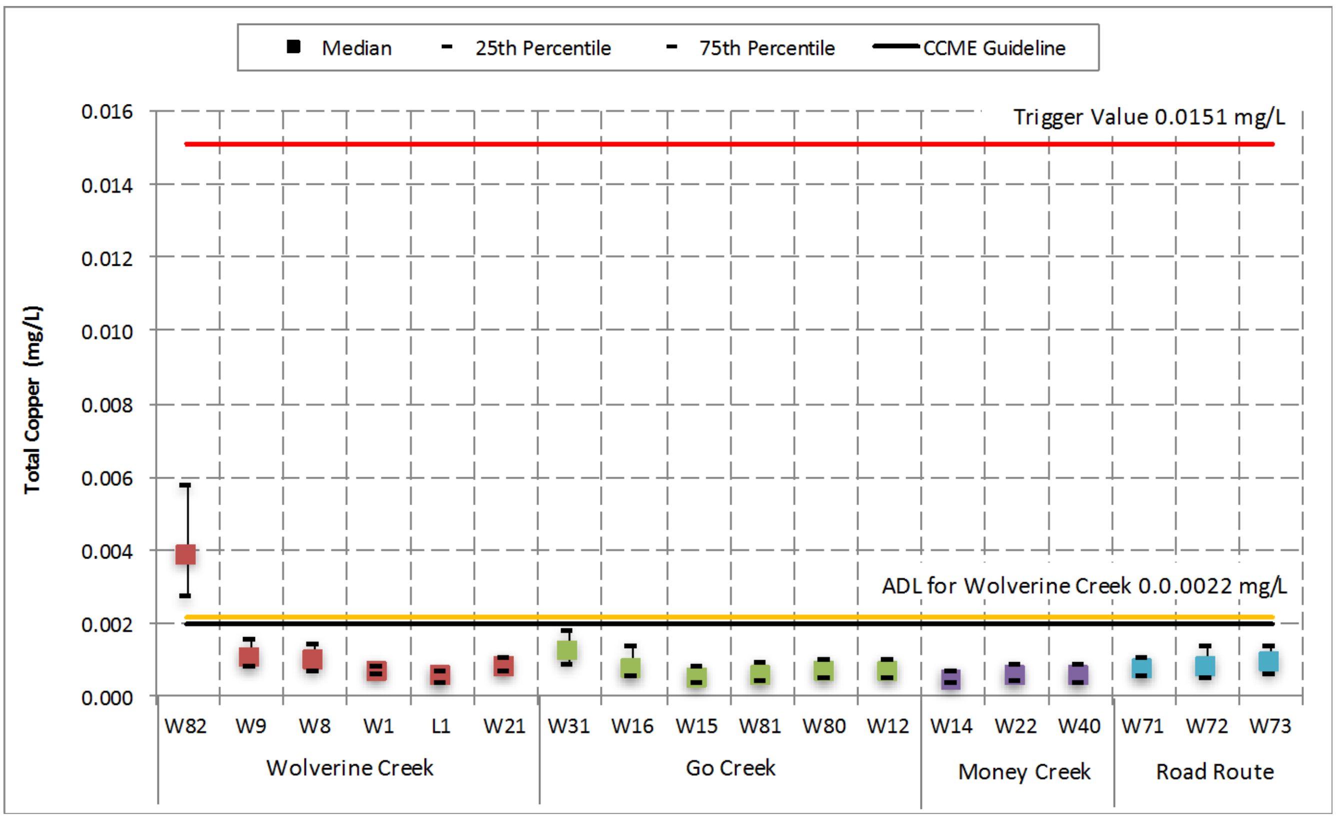


Figure 5-9: Surface Water Copper Concentrations and and Trigger Values

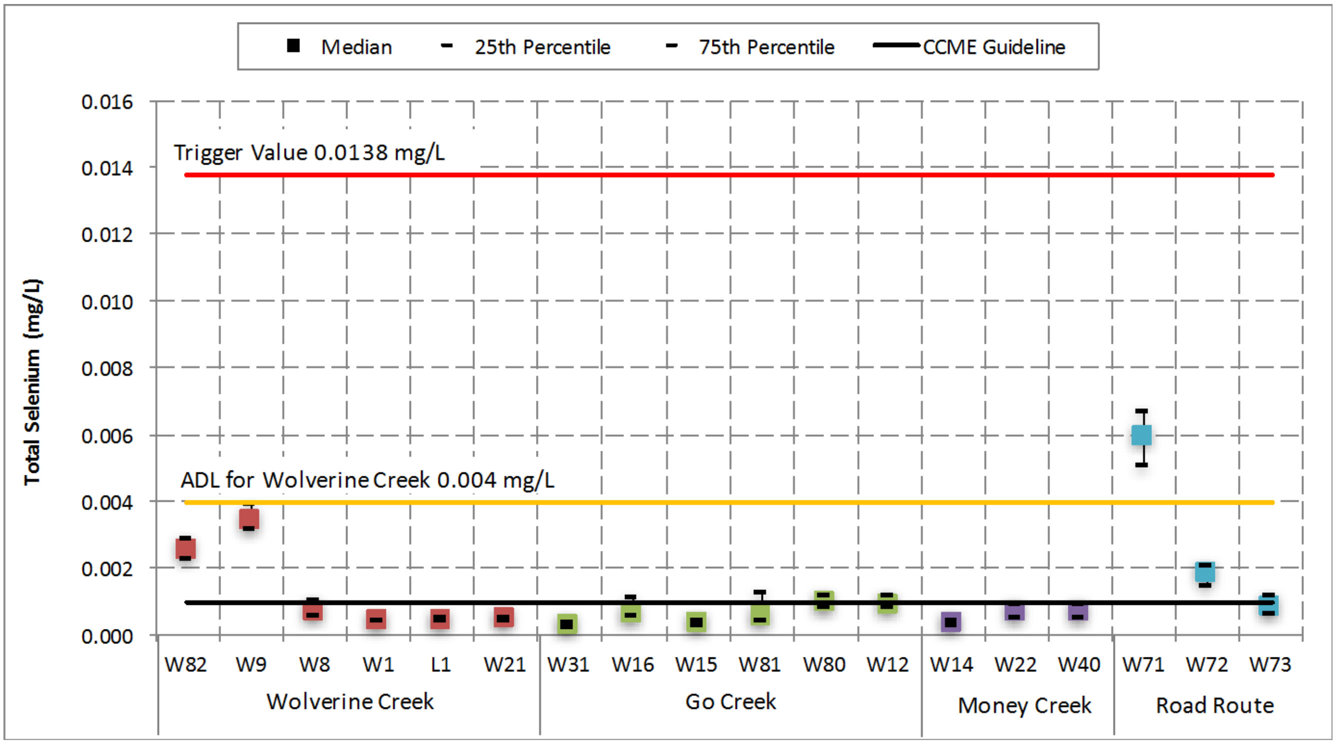


Figure 5-10: Surface Water Selenium Concentrations and and Trigger Values

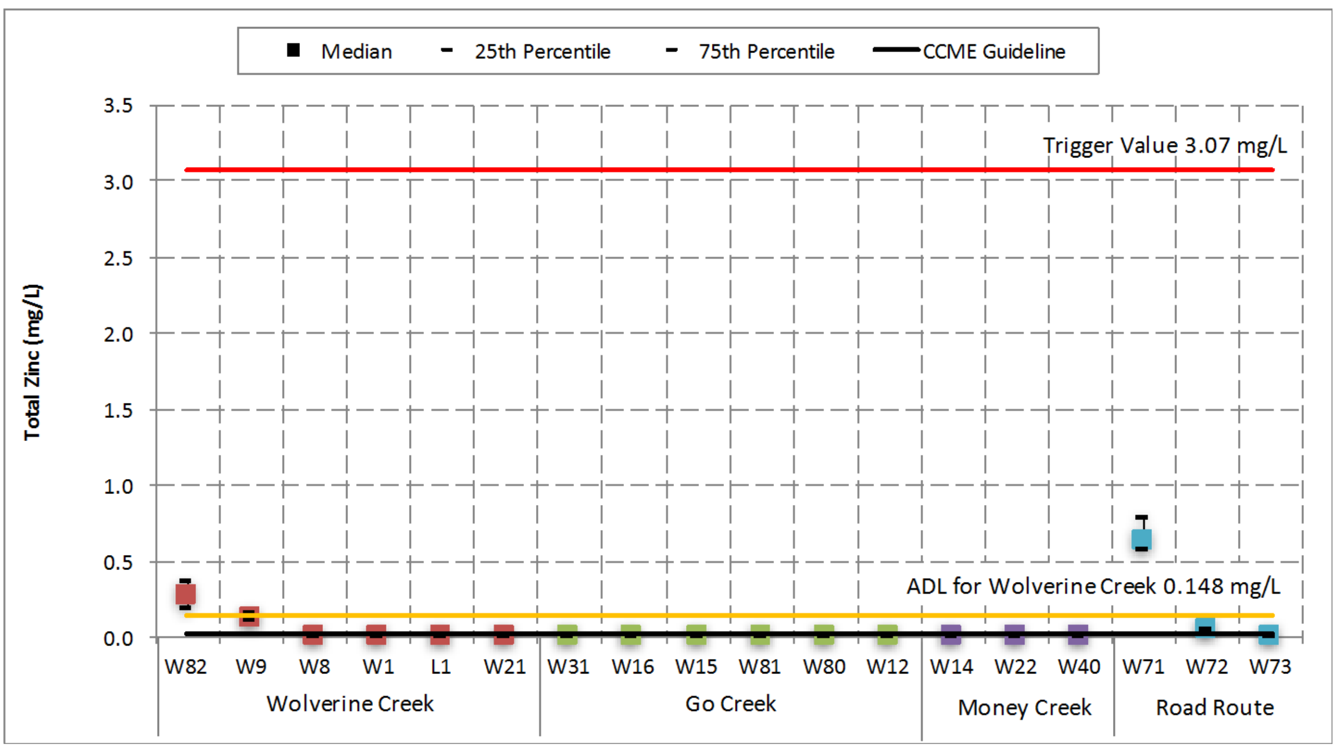


Figure 5-11: Surface Water Zinc Concentrations and and Trigger Values

Biopass Design

Biopass treatment systems are the term used to describe a passive treatment channel, typically containing organic based biological material, which promotes the development of microbes that fix and precipitate the metals in the water passing through the system. Biopass systems can also contain chemical treatment materials, such as limestone, activated carbon or other absorptive materials. Chemical systems utilize lime to neutralize acidity and treat mine water drainage, while activated carbon is an absorptive mechanism to remove contaminants suspended in the effluent. Biological treatment systems generally utilize naturally occurring microbes to precipitate metals as metal sulphides or biologically reduce dissolved metals to solid phase elements.

The proposed biopass system is a biological treatment system, in which the main reaction mechanisms operating include biologically mediated transformations, metal sulphide precipitation, adsorption and co-precipitation (Neculita et al., 2007; Blowes et al., 2000). The mechanisms often change over the life of the bioreactor are more readily available carbon sources are consumed and more complex carbon sources degrade. At the beginning, metals may be removed primarily through adsorption to organic matter, and in an oxidized or slightly reducing environment, can precipitate as hydroxides and carbonates. When a reducing environment has been achieved sulphide co-precipitation dominates, and under very reducing conditions iron sulphides and the associated co-precipitates form (Neculita et al., 2007).

Bioreactors have been used successfully at other mines in the Yukon, both at small scale barrel studies (Minto Mine, Janin, Herbert and Gjertsen, 2015) and at much larger pilot scales (United Keno Hill Mines, Alexco, 2011).

The initial part of development and testing of the Wolverine Creek Biopass system was completed as part of a Royal Roads University Master of Science thesis in early 2012 (Mioska, 2012). In the experimental test work, five columns were filled with varying compositions of gravel and Wolverine Creek substrate organics, and were un-amended (control column) or amended with manure, sewage sludge, zero-valent iron, or wood chips and alfalfa. Selenium, sulphate and the other parameters of concern were lowered most effectively by the control column and by the columns amended with sewage sludge. Sewage sludge greatly increased the rate at which the columns became reducing, thereby increasing sulphide precipitation and cadmium and zinc co-precipitation; however, sewage sludge is a concern for human health reasons, and is therefore not suggested to be used in future design. The addition of zero-valent iron increased the sulphate and selenium removal to almost 100%. The addition of wood chips and alfalfa did not appear to greatly influence the removal mechanisms in the columns, but could affect the long-term success of a treatment system.

Subsequently, in December 2013, test work was initiated at the Yukon College, as part of the work by the Industrial Research Chair, to further the design of the Biopass (Janin, 2014). The four bioreactors were prepared using sediment from Wolverine Creek, incubated, and then fed continuously with dewatering effluent from the Wolverine Mine.

Different solid supports were compared (gravel/sand, gravel/sand/wood/lime and gravel/sand/biochar), as well as with and without ethanol addition to assess the role of ethanol in supporting microbe growth. Residence time was set at 69 days to mimic residence time expected in the proposed Biopass system proposed (assuming underground water flow of 0.5 L/s). The reactors were setup in December 19, 2013 with incubation (no flow) until January 23, 2014.

The columns were run through December 2014. Due to the variability in the influent concentrations, the cadmium, copper and zinc concentrations were also highly variable. Concentrations in the column effluents were comparable between the five treatments, indicating relatively little impact on removal from column amendments. All four columns were effective at achieving the discharge limits for cadmium, selenium and zinc and while none of the columns achieved the discharge limit for arsenic, the ethanol-biochar column (C8) was most effective. The ethanol-biochar column was also most effective at removing selenium, with concentrations less than the detectable limit (0.7 µg/L) in many instances.

These results indicate that while ethanol addition may enhance microbial activity (and hence metal co-precipitation), it is not necessary to meet the discharge objectives. Additionally, the inclusion of carbon amendments (wood) and sources of alkalinity (limestone) did not significantly change the quality of the effluent over the duration of the experiment (~320 days). The addition of zero-valent iron however, drastically improved the removal of selenium and sulphate, and while the wood chip/alfalfa amendments didn't appear to change the results, they are likely to provide long-term carbon sources.

2016 Pilot Bioreactor

In late May 2016 YZC commenced construction of a field scale bioreactor to test the effectiveness of in treating runoff from waste rock and ore stockpiles. The bioreactor was constructed in between waste pad #2 and the north end of the TSF. Following temporary closure of the mine in 2015, waste rock and ore temporarily stored near the mine portal was consolidated at the lined area and the facility remains in operation. Runoff from Waste Pad #2 collects at the south end, and discharges via a pipe and hose to the north end of the TSF.

Construction of the field scale bioreactor began in late May 2016. Construction activities consisted of cut and fill activities to create a stable 2% grade that the bioreactor could be excavated within. Once level, a trench for the bioreactor was dug (Photo 5-4), lined with geotextile fabric (Photo 5-5) and impermeable liner. The substrate material for the bioreactor was a mixture of locally sourced gravel, wood chips, and peat material excavated from the upper Go Creek area (Photo 5-6). It was mixed on surface with a back-hoe, then placed in the lined bioreactor trench (Photo 5-7). Influent to the bioreactor was from the original pipeline from Waste Pad #2, into a plastic tote, then distributed into the bioreactor at the upper end through a gravel pad (Photo 5-8). The final system also included two slotted pipe structures to enable sampling at two points within the bioreactor.

A final survey of the bioreactor mid-way through filling of the substrate was conducted on August 6, 2016, and is provided in Figure 5-12.

Photo 5-4: Bioreactor Trench (July 11, 2016)

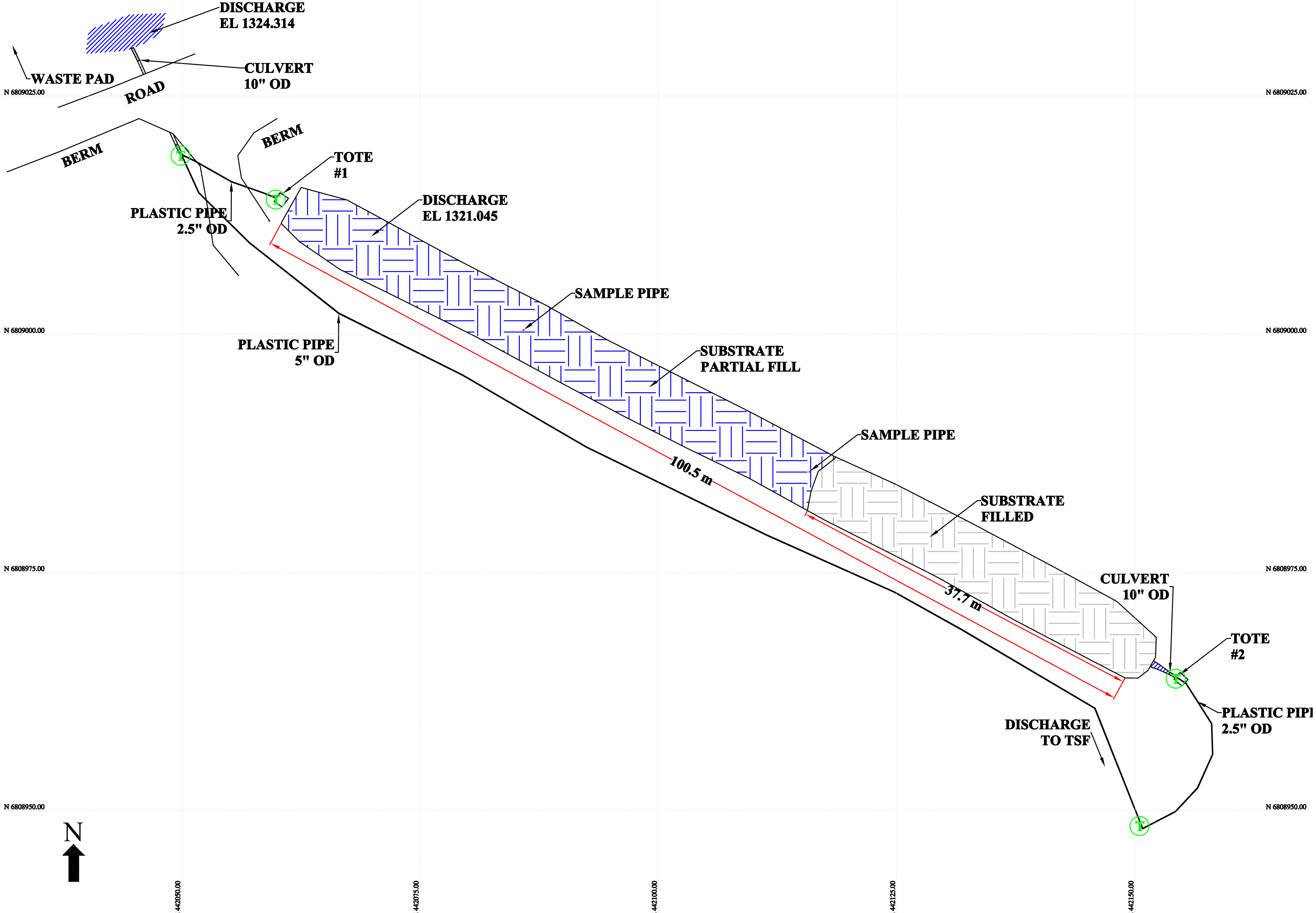
Photo 5-5: Bioreactor Trench Lined with Geotextile Fabric (July 12, 2016)

Photo 5-6: Bioreactor Substrate Material (May 31, 2016)

Photo 5-7: Bioreactor Filled with Substrate Material (July 16, 2016)

Photo 5-8: Bioreactor Influent System (July 16, 2016)

PLAN VIEW



NOTES

1. SURVEY DATE - AUGUST 06, 2016
2. SURVEY ELEVATIONS BASED ON TOP OF SURFACE
3. SUBSTRATE PARTIALLY FILLED IN BLUE HATCH AND SUBSTRATE COMPLETELY FILLED IN GRAY HATCH
4. CULVERT ANGLE (FROM WASTE PAD) = 2.7°

PROJECT
YUKON ZINC CORP.
WOLVERINE MINE

TITLE
WOLVERINE MINE
BIOPASS
SURVEY ASBUILT

DRAWING

DATE:	AUGUST 06, 2016
SCALE:	1:400
SIZE:	ANSI B
DWG No.:	2016_YZC_BP
REV.:	0

YUKON ZINC CORP.

YukonZinc CORP

701-475 Howe St.
Vancouver, BC V6C 2B3
P: +1 604 682 5474
F: +1 604 682 5404
www.yukonzinc.com

FIGURE 1

Water quality and flow rates are measured in the inlet and outlet totes located at either end of the bioreactor. Flow rates are measured at a v-notch weir in the totes. Flows measured in August and September ranged from 7 L/hour to 20 L/hour. Water quality samples were taken in August, September and October 2016, and in June and July 2017, and results for cadmium, copper, selenium and zinc are provided below. The bioreactor was initially very effective at removing metals to orders of magnitude below the inlet concentrations, with all parameters in the outlet below the Type A WUL discharge limit, except for concentrations of iron and TSS, in the 2016 and June 2017 samples. Reductions in sulphate, cadmium, and zinc indicate that sulphate reducing conditions have been achieved in the bioreactor. Selenium concentrations were lowered by 98% to below the discharge limit. Manganese and aluminum concentrations also increased, which is typical for reducing, anoxic systems. These increases can be mitigated by allowing the water to be aerated prior to discharge, typically by allowing the effluent to flow over rocky channels, or through the use of limestone channels, if required. TSS concentration increases are also likely just a relic of solids settling, which will likely decrease as the bioreactor system reaches steady state.

Increases in metal concentrations in the July samples were due to the pumping of Sump #2 sludge to the Waste Pad #2 in early July, which resulted in sedimentation of the discharge pipe into the bioreactor, and water from Waste Pad #2 no longer discharging to the bioreactor. The pipe screen was cleaned out in late August, and results indicate chemistry was improved and again met discharge limits.

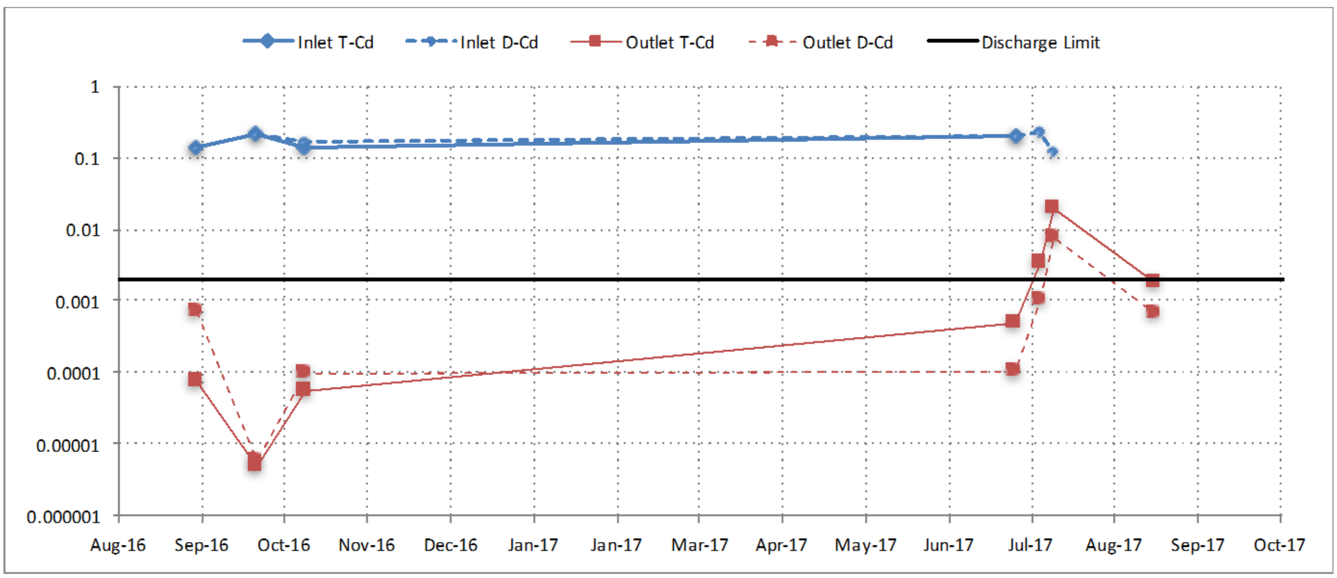


Figure 5-13: Waste Pad #2 Bioreactor Water Quality Results - Cadmium

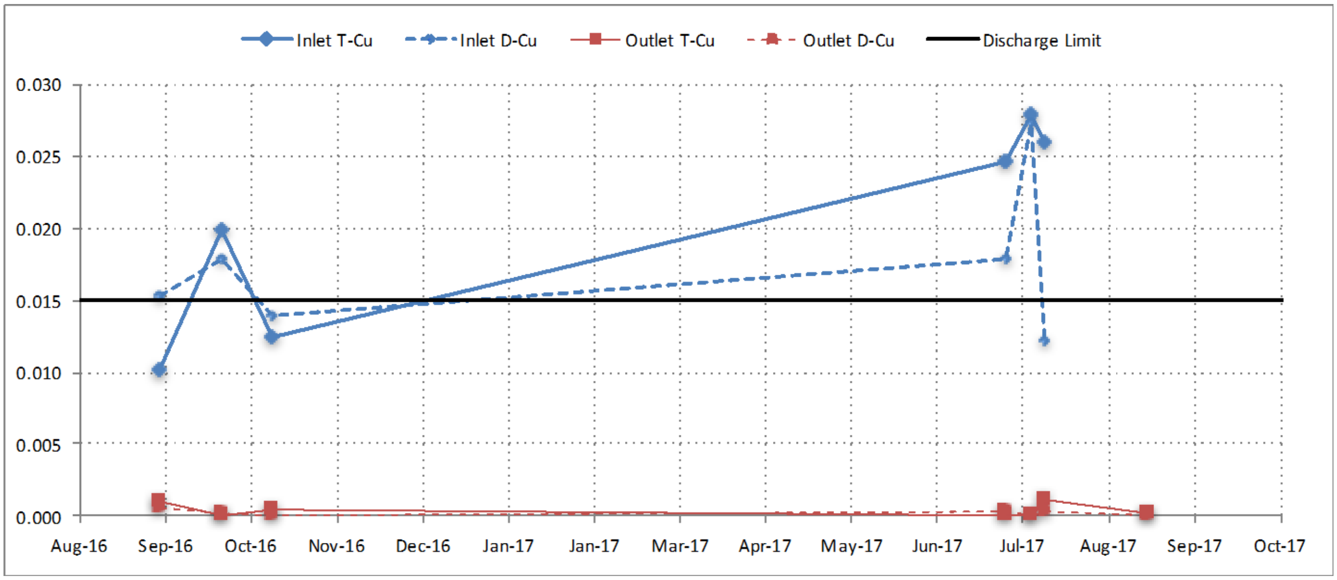


Figure 5-14: Waste Pad #2 Bioreactor Water Quality Results - Copper

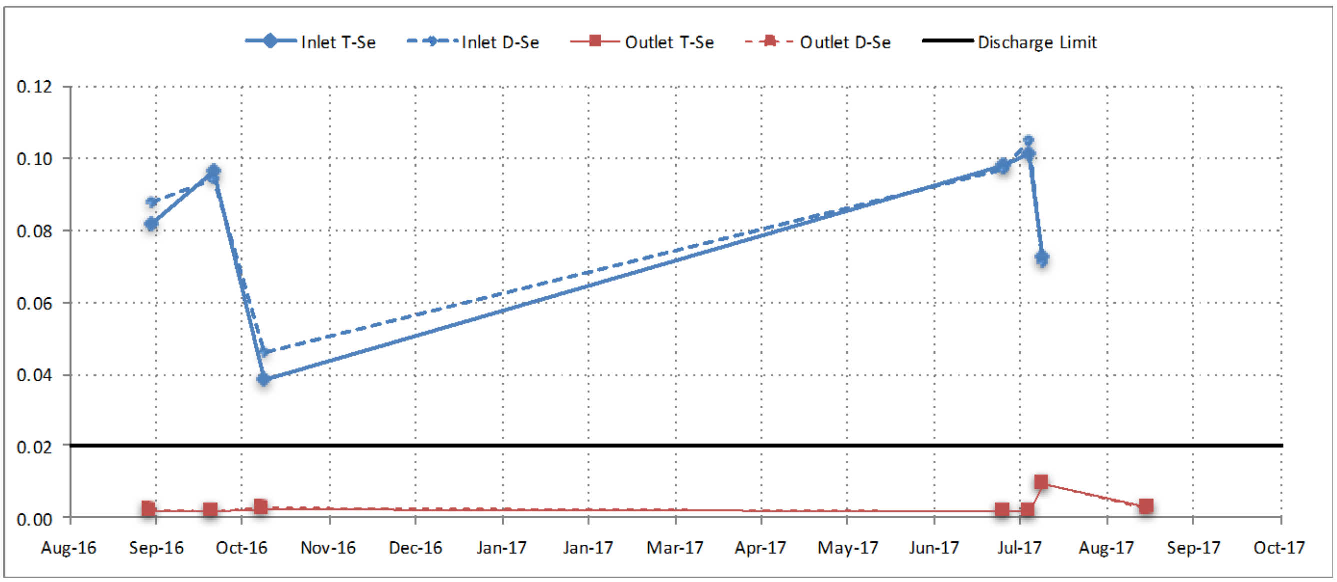


Figure 5-15: Waste Pad #2 Bioreactor Water Quality Results - Selenium

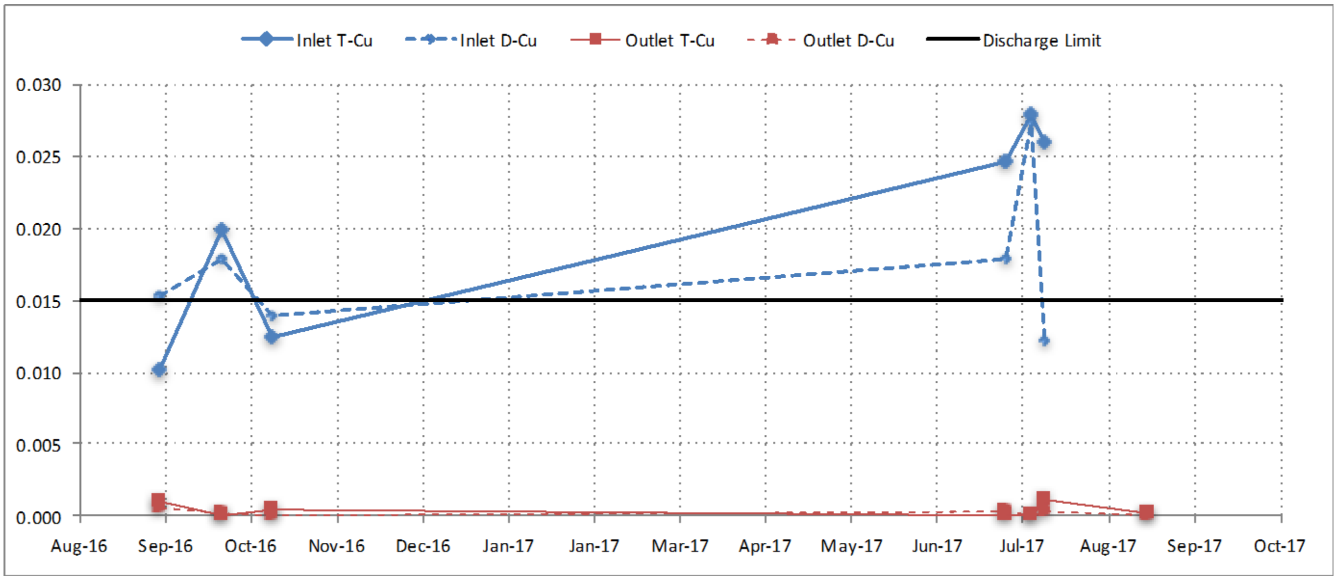


Figure 5-16: Waste Pad #2 Bioreactor Water Quality Results - Zinc

Updated Biopass Design

The Biopass system will be constructed in the Wolverine Creek channel along the stretch of creek that is known to contain higher metal concentrations and could potentially receive groundwater with high selenium and other metal concentrations derived from mine water. Un-impacted water in Wolverine Creek, upstream of the Biopass channel, will be diverted along the western margin of Wolverine Creek in a lined channel and re-introduced into Wolverine Creek below the biopass (see Figures 5-1, 5-2 and 5-3).

While the initial biopass was designed to be 2.5 m deep, 3.5 m wide and 400 m long, the preliminary biopass detailed below will be only 100 m long (Figure 5-18). The intent is to build a larger bioreactor, if required, following treatment results of the preliminary bioreactor.

The biopass is designed to treat groundwater that discharges into upper Wolverine Creek. Groundwater discharge rates in the treatment area are expected to be on the order of 0.5 L/s, and both the laboratory research projects conducted in 2012 and in 2013 ran at rates that mimicked this flow rate, therefore the planned biopass is designed to treat for this flow rate.

The groundwater that discharges into the biopass will be biologically treated while moving in a down-slope direction. Collected groundwater will flow upwards and through the organic substrate where treatment will occur. Before joining Wolverine Creek, effluent from the Biopass system will be collected in a lined collection pond to enable pump back of the discharge, should water quality objectives not be met.

If water quality is acceptable, the collection pond will overflow into a French drain that discharges into Wolverine Creek. While the water exiting from the Biopass system is expected to be depleted of oxygen, this water will be combined with the diverted well-oxygenated water from upper Wolverine Creek. Moreover, this combined flow will then traverse steep terrain for approximately 1000 m before reaching the mouth of Wolverine Creek and is expected to be fully oxygenated by the time it reaches this fish-bearing reach.

Deep groundwater that does not enter into Wolverine Creek will flow towards Little Wolverine Lake where no impacts to water quality are predicted to occur.

The discharge rates that can be treated will depend on the porosity of the organic substrate layer; however, a biopass 3.5 m wide, 2.5 m deep and 100 m long that slopes to 2.5 m wide at the bottom results in a 625 m^3 of treatment volume. At 0.5 L/s, this results in a hydraulic retention time of ~14.5 days, or just under 3.5 days at a flow rate of 2 L/s. For comparison, the maximum flow rate measured in the underground in 2014 was or 4.84 L/s, which would decrease the hydraulic retention time in the biopass to 1.5 days.

Flow rates will be highest during spring melt (May and June), however, water quality at this time is expected to be dominated by snow melt, and should therefore have negligible contaminants.

Biopass construction materials are summarized in Table 5-9 and based on previous experimental test work (Mioska, 2012; Janin, 2014), and should total the full 625 m^3 volume of the biopass.

Table 5-9: Wolverine Creek Biopass Construction Materials

Material	Volume
Gravel: Consistent material of small, crushed rock (between 3/8" to 2" diameter). May use what is available on-site. Rinse prior to use, if possible. Larger sized cobble is also required for the French drain at the outlet of the collection pond.	< 2" gravel: 350 m^3 Cobble: 10 m^3
Creek Substrate: The existing creek substrate is a natural source of microbes and carbon. Therefore the material excavated from the creek bed should be saved and mixed with the gravel.	Volume excavated from frozen creek bed
Peat: Highly sorbent and introduces micro-environments for mineral precipitation reactions. The peat adjacent to the creek, and excavated as part of the biopass channel excavation may be sufficient for this requirement.	50 m^3
Wood Chips: While the carbon amendments in the laboratory scale experiments did not appear to effect the discharge concentrations, they may require more time to become biologically available to the microbes, and will offer a more long term, sustainable source of carbon, once the readily available sources have been consumed. On-site poplar and spruce may be chipped for this usage.	50 m^3
Zero-valent iron: In the 2012 experimental results, the addition of zero-valent iron (e.g., steel wool) drastically improved the selenium removal. Steel wool pads can be used, or, if non-galvanized scrap iron is available (e.g., rusty nails, shotcrete mesh), this can be cut into small pieces and used within the biopass.	100 steel wool pads (or available scrap iron)

Pilot Test System

As outlined under Section 8.6(q) a field trial to test the bioreactor under field conditions is required. To conducted this test, the water pumped from the underground mine in advance of bulkhead installation (Section 5.2.2) will be trucked to the waste pad #2 bioreactor. The water from waste pad #2 will be diverted to the tailings, and water intercepted from the underground mine will be pumped to the bioreactor. Water quality samples will be taken at the inlet and outlet over the duration of the test to evaluate the efficacy of the bioreactor to treat underground mine water. At least five bed volumes (or ~25 m^3 x 5) or 8 water truck loads should be passed through the bioreactor.

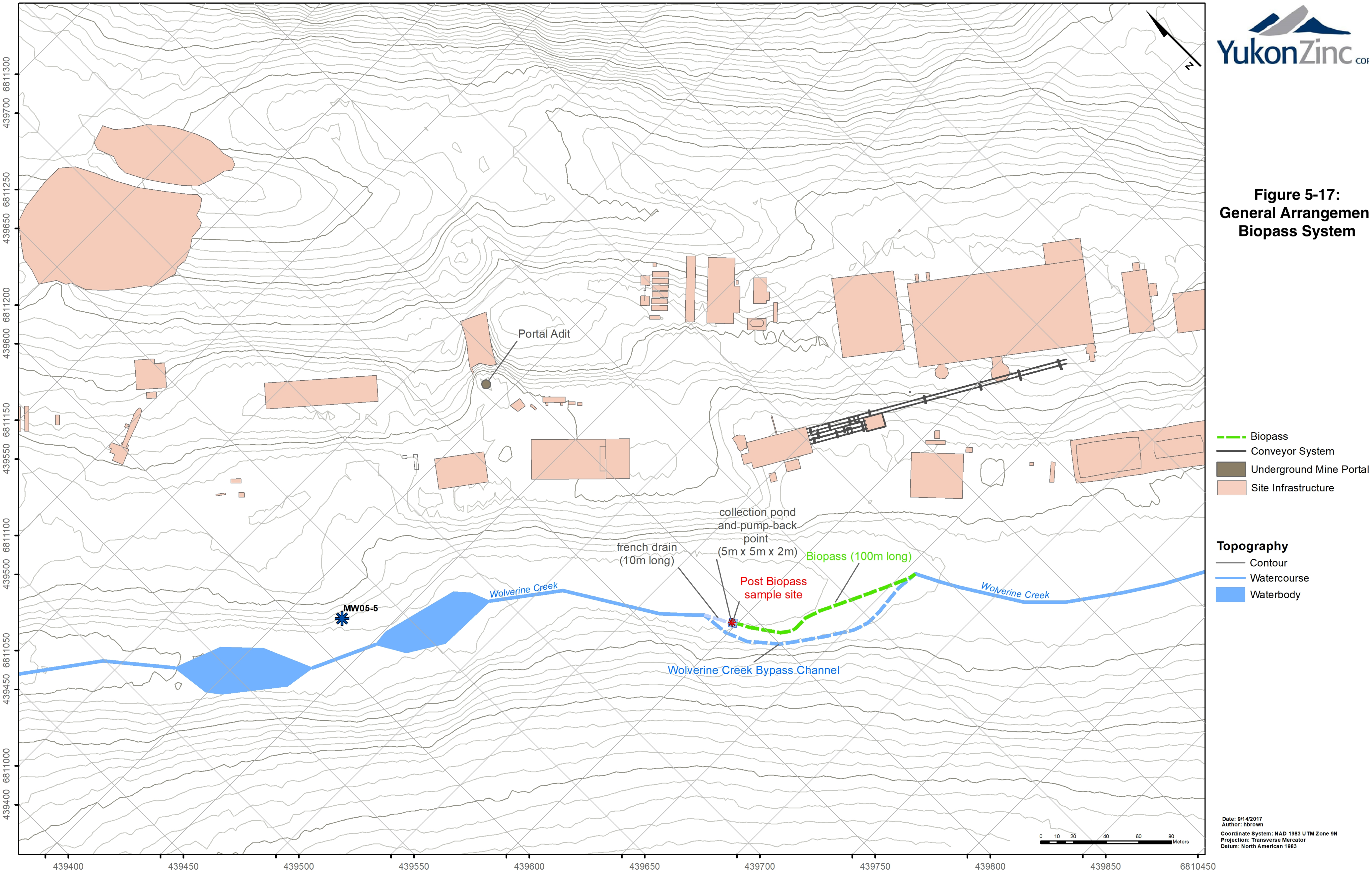
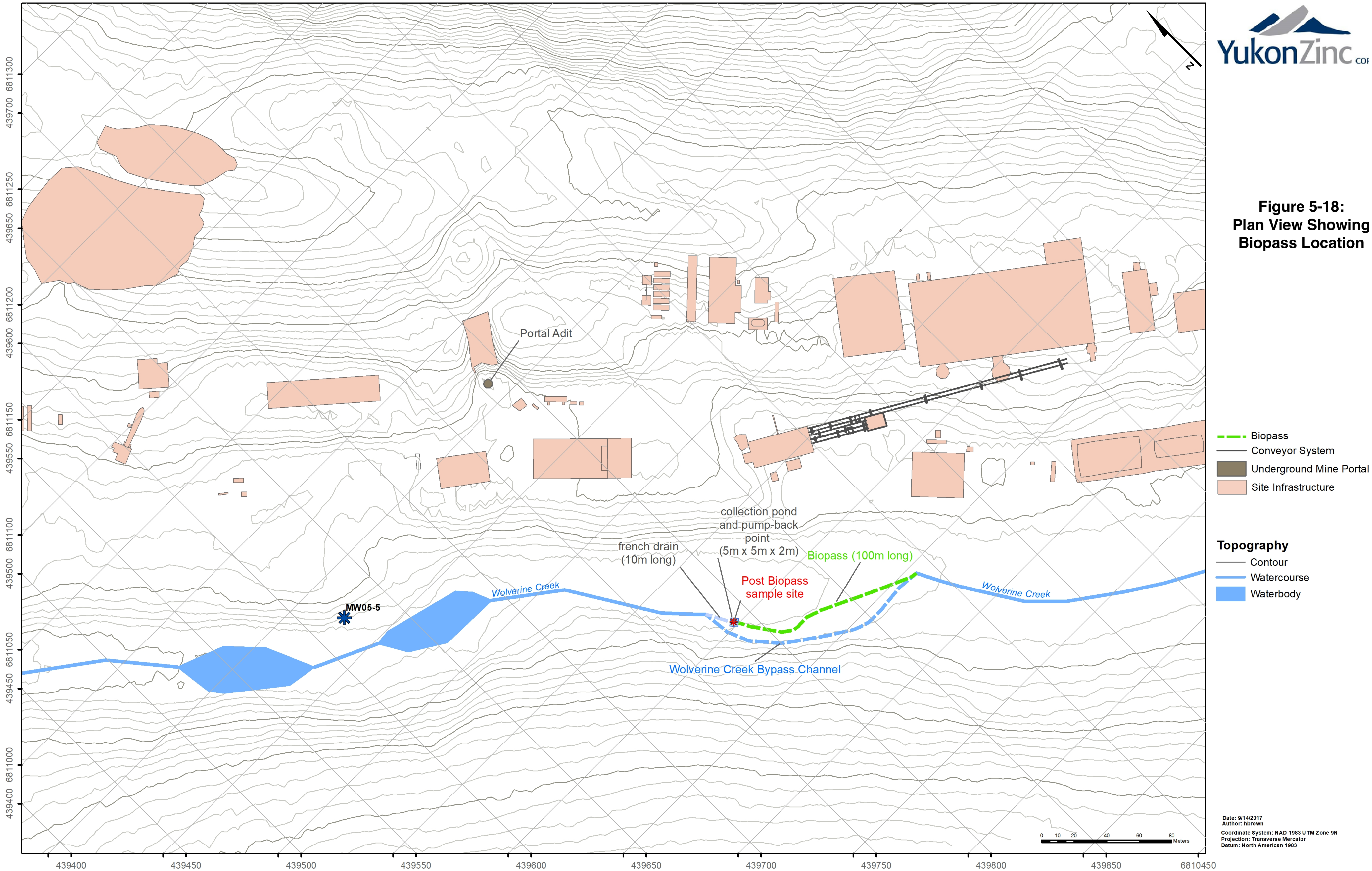


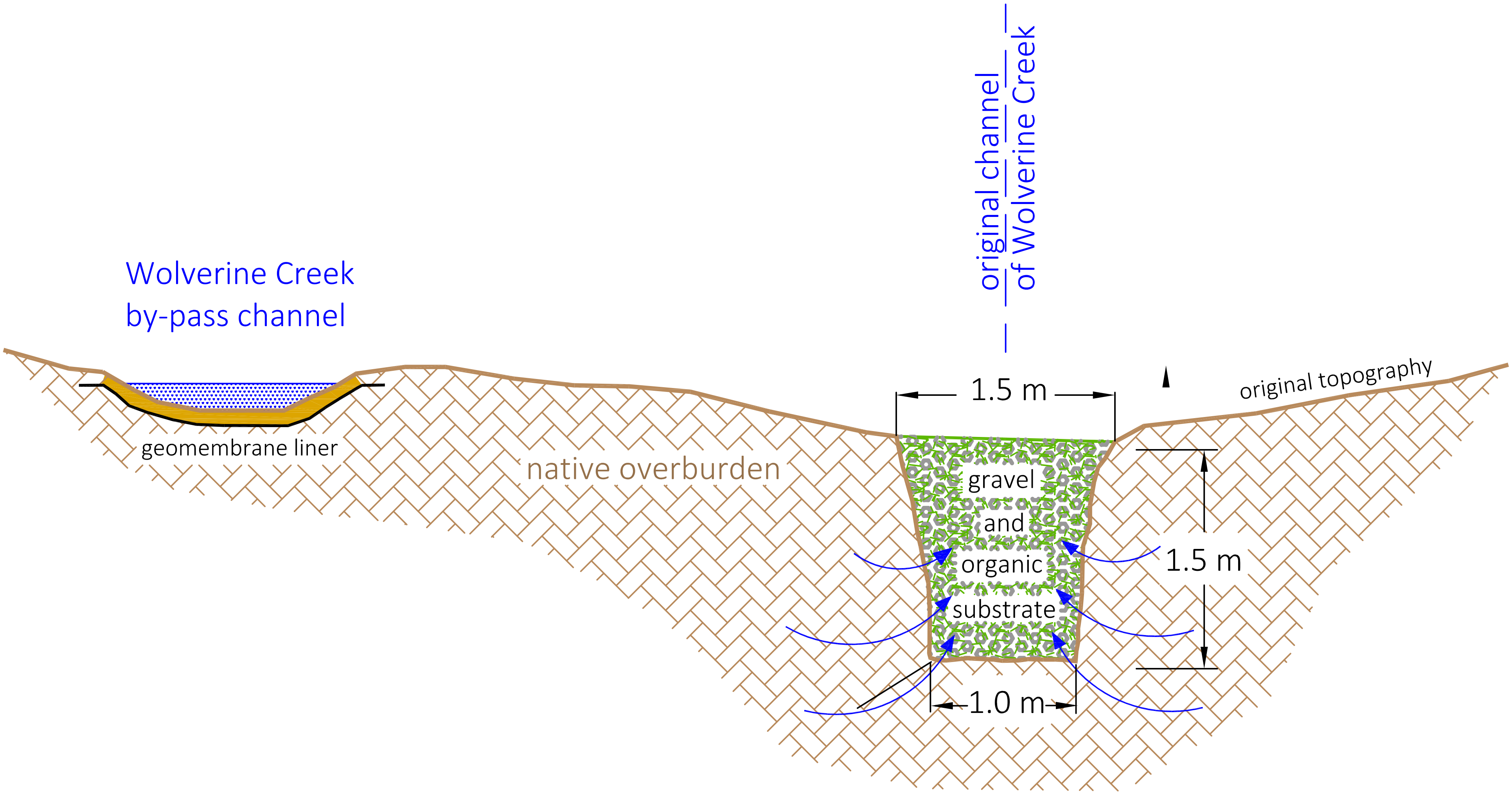
Figure 5-17:
General Arrangemen
Biopass System

Date: 9/14/2017
Author: hbrown

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

Figure 5-18: Plan View Showing Biopass Location





Yukon Zinc Corporation
Wolverine Mine
Yukon

Figure 5-19:
Biopass Section A-A'

ASTERISK MINING SERVICES LTD.
VANCOUVER, BC

26 October 2015 | DWG No. 1510YZC-003

5.2.3 Tailings Storage Facility (TSF) Area

The TSF is currently used as the main water management infrastructure for the Wolverine Mine. In August 2017, the total volume stored in the TSF is ~1,197,515 m^3 based on a water elevation of 1309 m. Approximately 530,000 m^3 is occupied by saturated tailings with the rest occupied by free water. Monitoring of inflow into the TSF indicates that flows into the TSF through precipitation either directly on the TSF or on other site infrastructure that is subsequently pumped/trucked to the TSF, is ~50,000 m^3/year (Table 5-5). Flows from underground have been variable, but have reached as high as 600 m^3/day, and while recently, in late August, flows have decreased significantly, down to 80 m^3/day, underground discharge pumped to the TSF is a significant consideration in managing volumes in the TSF.

As discussed above, without intervention the TSF pond will reach the 1310 m elevation in November 2018. As such, an active water treatment plant (WTP) is required to facilitate treatment and discharge of water accumulated in the TSF. The plant will be sized to treat 1,200 m^3/day, and will discharge water over the May to October discharge period. The water treatment will result in a net decrease of water stored in the TSF over the temporary closure period, as shown in Figure 5-20, assuming water treatment starts in July 2018 at a rate of 1,200 m^3/day. Details of the WTP are provided below.

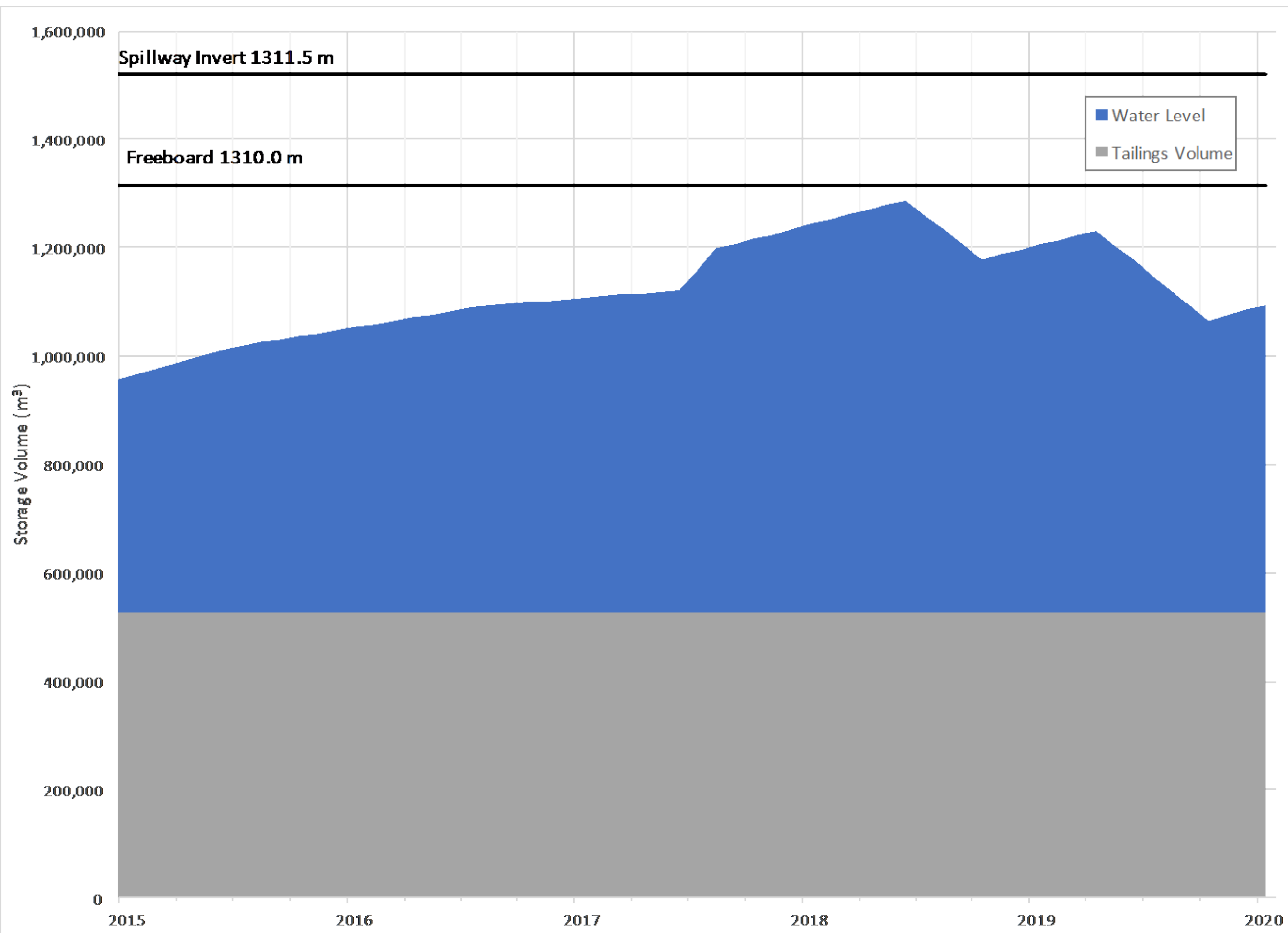


Figure 5-20: TSF Storage Balance Temporary Closure Period

5.2.3.1 Water Treatment

BQE Water (BQE) was engaged by YZC in 2017 to assess treatment options and provide recommendations for treatment of the water stored in the TSF (Appendix E). BQE completed an assessment of different treatment options for removing all constituents of concern; a selection of the most appropriate methods for lab scale testing; treatability testing of the selected treatment options to demonstrate the level of contaminant removal achievable; and development of the overall process flowsheet based on the results of tests along with scoping level cost estimates for possible implementation of the recommended treatment at Wolverine.

The key constituents of concern to be removed from the water are summarized in Table 5-10.

Table 5-10: TSF Contaminants of Concern for Treatment

Dissolved Species	Concentration in Feed, mg/L	Treatment Target, mg/L
Cu	0.429	0.015
Pb	0.11	0.02
Cd	0.0103	0.002
Zn	1.5	0.5
Ag	0.00370	0.001
Se	1.73	0.02
WAD CN	0.0513	0.025

The chemical assays of Wolverine tailings pond water revealed the following:

- Three different classes of contaminants are present in the current tailings pond water that require removal to ultralow levels for discharge: heavy metals, selenium, and WAD cyanide.
- A significant portion of the total selenium present in the water is selenocyanate and "unknown" organoselenium species that are not normally present in mine impacted waters. A significant level of removal of these species is required to meet the discharge limit yet little is known about the removal efficiency of these species by treatment systems typically considered by the mining industry.
- The water composition is indicative of highly reducing conditions in the tailings pond with elevated organic carbon and thiosulphate levels, low dissolved oxygen level, and reduced selenium species dominating in the water column.

Based on BQE's assessment, there is no single stage treatment that would be able to remove all three classes of contaminants at the same time to the required discharge limits while producing stable residue suitable for long term disposal in the tailings pond. Instead, several treatment steps will be required to comprehensively address the contamination in the pond. Recognizing this, BQE evaluated a wide range of treatment options and narrowed these down using a set of selection criteria that take into account technical ability, residue management, risks, and costs.

The options that were advanced to bench scale testing included: sulphidization with ferric addition for metals removal, ion exchange (IX) and electrocell treatment (ERC) for selenium removal, and activated carbon adsorption and IX for polishing WAD cyanide removal. In addition, Reverse Osmosis (RO) passed through the screening criteria with the caveat that it would have to be combined with other treatment steps to ensure that all contaminants end up reporting into stable, compact solid residue.

Based on the results of BQE's assessment and bench scale tests, BQE recommends that the full scale treatment be composed of the steps summarized in Table 18-4 in shown in Figure 5-21. During temporary closure, when no new tailings are being deposited, an additional desaturation of RO retentate will need to be added to the flowsheet and recycled to the TSF pond.

Table 5-11: Recommended Treatment for Full Scale Implementation

Treatment Step	Objective	Bench Scale Test Verification
Sulphidization with ferric iron addition	Removal of all heavy metals of concern from water into solid residue suitable for disposal or blending with flotation concentrate produced at site Pre-treatment for suspended solids removal upstream of RO. Removal of WAD cyanide concentrated by RO.	Verified in study
Reverse Osmosis	Rejection of selenium and WAD cyanide	Bench scale testing not representative of actual performance
ERC treatment	Removal of selenium from RO reject water into stable solid residue suitable for disposal in the tailings pond	Verified in study

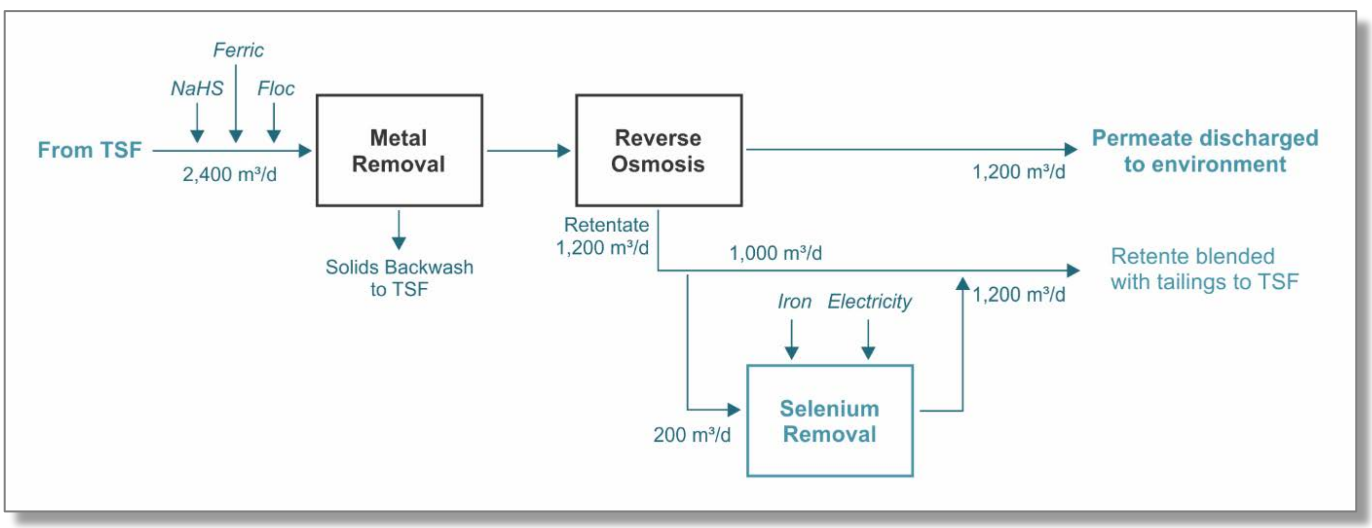


Figure 5-21: Water Treatment Plant Flowsheet

A proposal to complete the design, construction, installation and operation of the WTP has also been prepared by BQE, and the costing has been included in the cost estimates provided in Section 8.1.

6 Final Reclamation and Closure Measures

This section presents the final reclamation and closure plan for all components of the Wolverine Mine site. Final closure activities are expected to commence following 5 years of temporary closure. As such, final closure activities would commence in January 2020, unless approval from the Chief is received to extend the temporary closure period. The activities outlined below are designed to meet or exceed the objectives outlined in Table 1-2.

Decommissioning and reclamation will be conducted during a 2-3 year period; the timing of facility closures is dependent on the purpose of the facility and its future use and environmental considerations. For example, mine site roads will need to be left usable until the end of the closure period, as they will be used to truck decommissioned infrastructure from site.

The experimental test work conducted during the temporary closure period will continue to inform the treatment of effluent from the underground mine and TSF into the decommissioning phase. The conceptual closure plan for the TSF will also be finalized by the engineer of record to meet the *Canadian Dam Association Dam Safety Guidelines*, prior to final decommissioning of the TSF.

During decommissioning and the early closure period, soils will be tested for contaminants in all areas where ore, concentrate, waste rock, solid wastes, special wastes, fuel, and chemicals were stored or handled at the site. If contamination is found, the contaminated soil will be removed from the area and disposed of in the TSF.

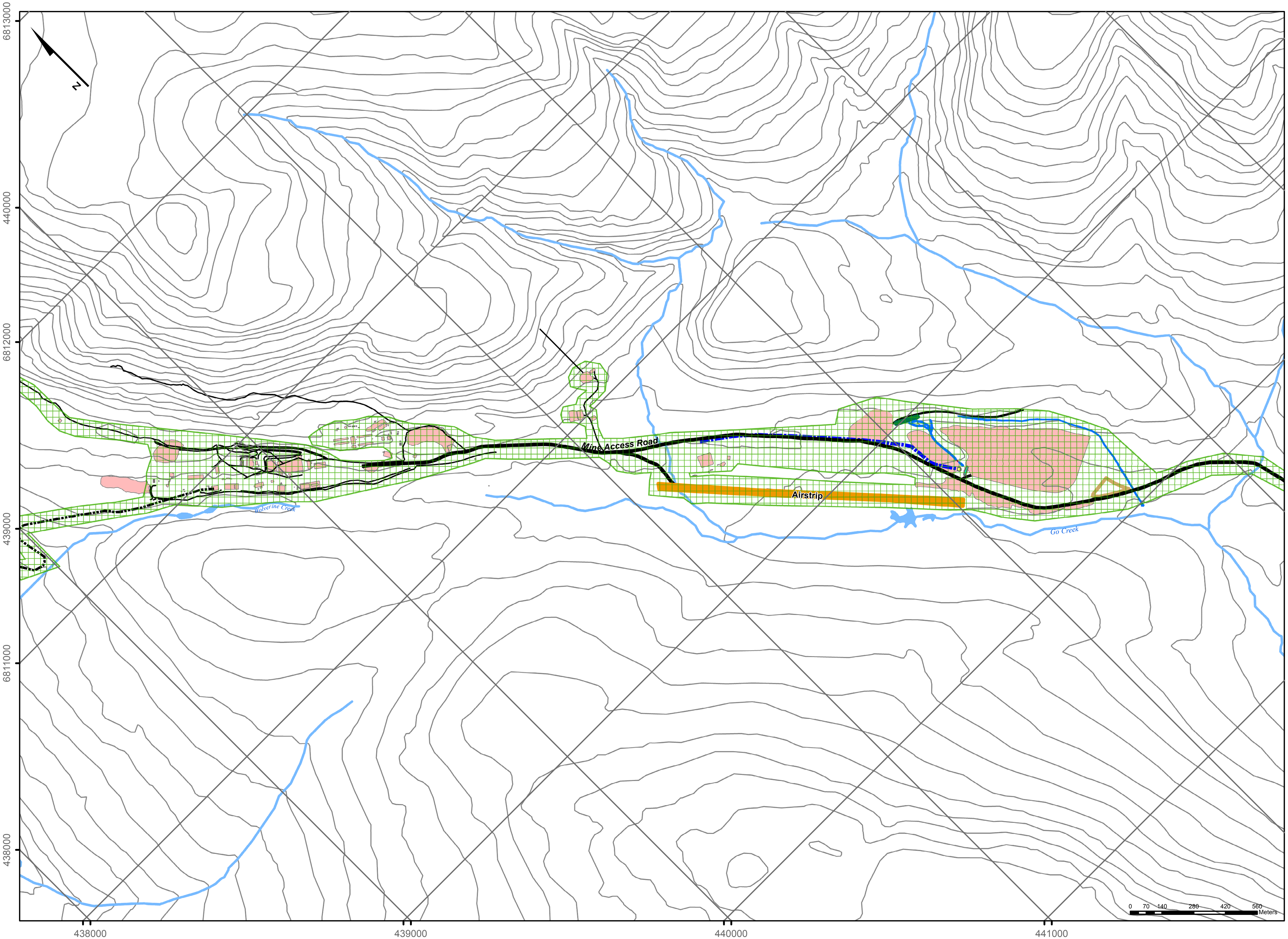
Once infrastructure is removed, slopes will be stabilized by contouring and leveling to provide land forms that conform to the surrounding terrain and provide suitable seedbeds. Erosion features will be minimized on re-sloped surfaces, runoff will be diverted away from steep slopes, and settling ponds and diversion ditches will be used as necessary.

The total area of disturbance at the Wolverine Mine site is summarized in Table 6-1 and shown in Figure 6-1. A total of 88 ha is required to be reclaimed. These areas will be revegetated based on the reclamation research that has been conducted on the Wolverine Mine site to date (Section 2.2.2).

Details of the reclamation and closure activities for the mine, TSF, waste rock dumps, mine infrastructure, and associated monitoring and maintenance is described below.

Table 6-1: Mine Components and Area of Disturbance

Component	Quantity (ha)
Industrial Complex Area	**21.7**
Mill Buildings, Truck Shop, Offices	14.5
Diversion Ditches	0.5
Organic Stockpiles	2.4
Camp and Support Facilities	2.8
Landfill	1.5
TSF Area	**28.1**
Impoundment	16.6
Dam Face	2.4
Diversions	0.5
Seepage Recovery Pond	0.8
Tailings Lines Corridor	1.8
Organic Stockpiles and Borrow Areas	6.0
Site Access Road	**31.2**
Mine Site Roads	**7.0**
TOTAL	**88**



YukonZinc CORP

Figure 6-1

Wolverine Mine: Site Disturbance

- Existing Road
- Mine Access Road
- Winter Road
- Tailings Pipeline
- Culvert
- Diversion Ditch
- Area of Disturbance
- Infrastructure
- Seepage Collection Pond
- Spillway Stage 2
- Pump House
- Bioreactor
- Airstrip

Date: 14/12/2016
Author: H.Seeley, P.Geo, Wolfbear Geological Consulting

Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

6.1 Underground Workings and Openings to Surface

The two surface openings (main portal and ventilation raise) will have been sealed with hydraulic bulkheads during the temporary closure phase (see Section 5.2.2). The installation of these watertight bulkheads will prevent access to the underground mine workings in order to protect human health and safety, and limit conflicts with wildlife. Hydraulic pressure buildup behind the bulkheads is not expected to pose a risk, as once the underground mine has finished flooding the water table is not expected to surpass the levels of the main portal and ventilation raise where the bulkheads are located.

The nature of surface disturbance from the underground mine workings is limited to the mine access points: the portal area and ventilation raise area. Land preparation and revegetation of these areas will be undertaken in conjunction with the reclamation of the industrial complex area during the decommissioning phase. Revegetation methodology will be based on reclamation research conducted to date at the mine site (see Section 2.2.2). Revegetation success will be monitored as described in Section 6.9.2.

6.2 Tailings Storage Facility (TSF) Area

Ultimately, all free water in the TSF will be dewatered; however the tailings will remain saturated to prevent acid generation. The facility with be enveloped with an impermeable cover. This approach will limit risks to human health and safety and the environment, and will maintain physical and chemical stability via the final TSF landform. In its final landform, surface water will be diverted off of, or around, the TSF to the Go Creek drainage.

During the decommissioning phase, materials from Waste Rock Pad #1 and #2 (including the liners) will be deposited into the TSF. The total volume of waste rock is ~135,000 m^3 (Figure 6-2). The dam and the Stage 2 area will be modified to reduce the overall area of the TSF and subsequently reduce the overall size of the TSF landform. As part of the decommissioning phase, the Stage 2 area will be deconstructed and the footprint of the TSF will be confined to the Stage 1 area. The tailings discharge pipeline will be disposed of in the TSF. Dam material above the tailings level will be removed and will be used as non-acid generating cover material for the final TSF landform. This modification will enable the declassification of the dam. The seepage recovery dam will be decommissioned in conjunction with the site access road, as the dam is formed by a section of mine road.

Conceptual schematics for deconstruction of the TSF are provided in Figure 6-2 and the ultimate design will be verified by the engineer of record prior to final construction.

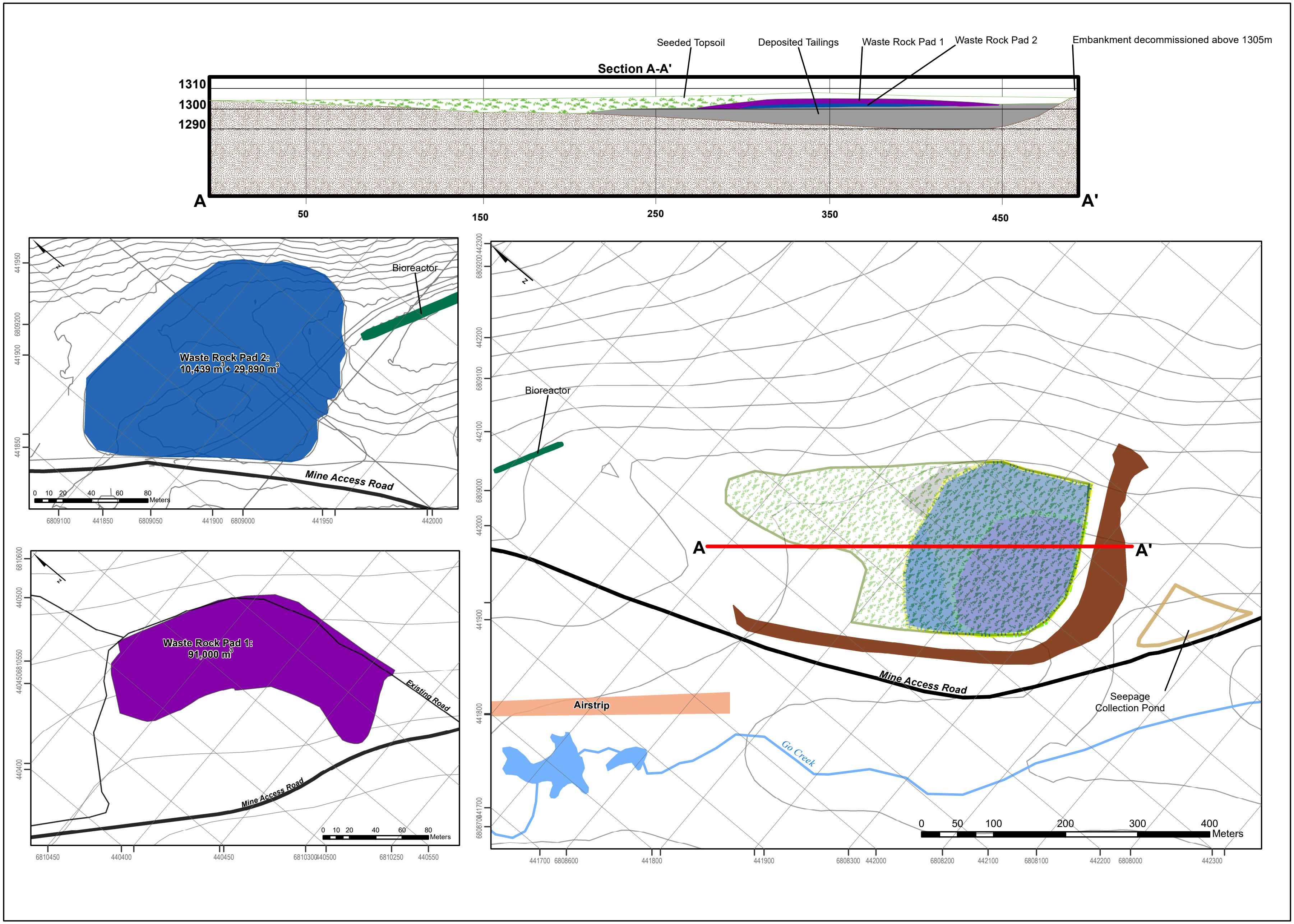


Figure 6-2: Conceptual Waste Storage Closure Plan

Site Infrastructure

- Mine Access Road
- TSF Dam Face
- Seepage Collection Pond
- Airstrip
- Waste Rock Pad 1
- Waste Rock Pad 2
- Bioreactor
- Deposited Tailings
- TSF Footprint

Topography

- Contour
- Watercourse
- Waterbody

Date: 9/15/2017
Author: H.Seeley, P.Geo, Wolfbear Geological Consulting
Coordinate System: NAD 1983 UTM Zone 9N
Projection: Transverse Mercator
Datum: North American 1983

CONCEPTUAL
NOT FOR
CONSTRUCTION

The solids portion of the tailings material (a sand-silt mixture with relatively low permeability) is considered to be potentially acid generating, based on static and kinetic testing of composite tailings samples. Static testing indicated that tailings material contains significant quantities of sulphide-sulphur and lesser quantities of neutralization potential. Humidity cell tests indicated that the onset of acid generation under laboratory conditions could take five years for the diluted ore tailings sample. As such, this material will be kept saturated with water retained in the pore space of the tailings. Also, by surrounding the tailings and waste rock material with an impermeable liner and layering clay/sand and organics over the top to protect the liner, the potential effects of any potential acid generation are mitigated.

The TSF landform will be covered with organics and overburden material, and seeded based on the reclamation research that has been conducted on the Wolverine Mine site to date (Section 2.2.2). Landform design will aim to reclaim the land to restore wildlife habitat through the re-establishment of a self-sustaining vegetative mat that remains protective of the liner. Detailed design of the TSF landform will be completed prior to construction. Physical and chemical stability of the TSF landform will be monitored during the decommissioning and post-closure phases. No long-term maintenance is expected once the landform is established. Water treatment of any seepage is not anticipated to be required, as the TSF landform is lined to prevent against seepage and the cover will be impermeable, thus there should be no seepage from the capped TSF. Any surface water runoff in the TSF landform area should not be affected by the chemistry of the tailings and waste embalmed in the TSF landform.

6.2.1 Tailings Storage Facility (TSF) Water Treatment

During the decommissioning phase, the TSF supernatant water will be treated via the water treatment plant described in Section 5.2.3.1. At a rate or 1,200 m^3/day, with discharge during May to October, it will take ~4 treatment seasons to fully dewater the facility down to the level of the waste rock and tailings (Figure 6-3).

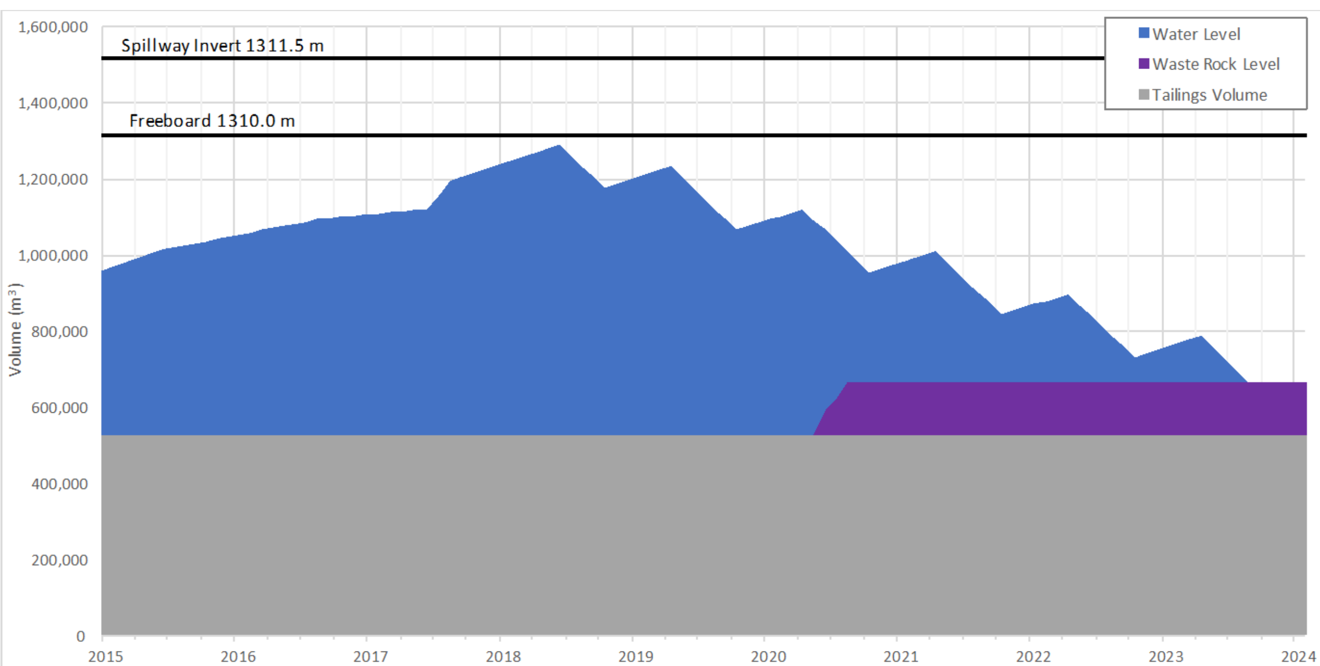


Figure 6-3: TSF Storage Balance Permanent Closure Period

6.3 Waste Rock and Overburden Dumps

There are two lined waste rock pads on site containing waste rock generated from underground mining:

- Waste Rock Pad #1, located south of the camp; and
- Waste Rock Pad #2 located north of the TSF.

These waste rock pads and their liners will be deposited into the TSF during the decommissioning phase. Following this work, the footprints of the waste rock pads will be reclaimed in conjunction with the industrial complex area reclamation. This will eliminate any requirement for long-term seepage quality monitoring and possible treatment. It will also eliminate any requirement to monitor physical stability of the waste rock pads.

All temporary ore piles were moved to Waste Rock Pad #2 during temporary closure. Reclamation of the footprint areas will be carried out in conjunction with the reclamation of the industrial complex area.

6.4 Water Management Structures and Systems

Drainage structures within the industrial complex area (collection ditches 2, 3, and 5 - Figure 4-4) consist of geomembrane-lined open channels to transport storm water to a collection pond (sump #2) prior to being pumped to the TSF. The collection ditches and sump #2 will be decommissioned following the removal of all industrial complex structures. Liners will be removed and landfilled, and the ditches and sump backfilled with coarse material. Drainage will be allowed to flow naturally back to the receiving environment.

Ditch 1 which is located upslope of the industrial complex and is used to divert non-contact surface runoff around the area, will be decommissioned once infrastructure footprints and collection ditches have been reclaimed. Diversion ditches A and B (Figure 4-5) and upgradient underdrains will be decommissioned. Ditches will be re-contoured consistent with the original topography. Disturbed areas along the ditch alignments will be re-vegetated.

The tailings and water reclaim pipelines will be dismantled and disposed of in the landfill. The pipeline corridor will be seeded as barren ground is exposed with pipeline removal.

6.5 Mine Infrastructure

6.5.1 Camp

The camp facilities will be progressively removed and sold as onsite personnel requirements decrease. Facilities will remain in place for care and maintenance staff until the end of the decommissioning phase. Sewage treatment facilities will also be decommissioned and salvageable material removed from site. The water supply wells will be decommissioned once the potable water treatment and camp facilities are no longer required. The pump houses and the buried distribution system will be removed for salvage or, if deemed appropriate, the distribution system will remain buried in situ to minimize subsequent surface disturbance associated with removal. Water wells will be backfilled throughout their entire length with a combination of concrete and grout and the top 5 m will be completely cemented. Following decommissioning, the camp area will be re-contoured, soil growth medium will be added, and the area will be revegetated.

6.5.2 Industrial Complex

All materials from the industrial complex buildings will be completely dismantled and removed, with the exception of concrete foundations, which will be buried in situ. Equipment with marketable value will be sold and the remaining assets will be disposed of through demolition and salvage contracts. In the event that it is uneconomical to remove non-hazardous materials from the site, such material will be buried in the landfill. Following demolition and dismantling of the industrial complex area, approximately 22 ha of area will require soil placement and reseeding.

6.5.3 Power Generation Infrastructure

All gensets will be de-activated, packaged, and transported off the mine site to be sold. Distribution power lines will be re-spooled and sold as scrap. Power poles and distribution lines to other facilities will be salvaged or buried in the landfill. For any poles that are treated with a preservative such as creosote, the contaminated portion of the poles will be disposed of in accordance with Yukon Special Waste Regulations. The glycol loop has been emptied and the used glycol is stored in tanks. The used glycol will be transported offsite for permanent disposal or recycling.

6.5.4 Landfill and Waste Storage Areas

Decommissioning and demolition activities will generate some non-hazardous waste material that will be disposed of in the landfill area. At the end of the decommissioning phase, the landfill and storage areas will be covered with a 250 mm thick compacted layer of glacial till and graded to encourage the shedding of water. The sites will then be revegetated.

6.5.5 Land Treatment Facility (LTF)

The LTF was constructed in 2008 to treat contaminated soil produced through advanced exploration, construction and operational activities at the Wolverine Mine. The material stored in the LTF is segregated into oil-contaminated, diesel-contaminated, gas-contaminated, and glycol-contaminated soil. The LTF was also intended to accept any contaminated material excavated during decommissioning and reclamation of the industrial complex footprint.

Soils present in the land treatment facility during the final year of operation will be tested to determine if material is acceptable for use in reclamation programs around the industrial complex. Depending on the level of contamination, contaminated soils excavated during decommissioning may be placed in the land treatment facility for remediation for subsequent use in reclamation activities in the closure phase. If the various soils are found to contain residual contamination that does not permit use in reclamation, they will be hauled off site to an approved facility.

Once soils are removed from the facility, in accordance with an approved plan from Yukon Environment, the facility will be decommissioned, the liner disposed of in the landfill, and the area revegetated.

6.5.6 Material and Equipment Salvage

All salvageable material will be sold and removed from the site. Material that has no scrap value will be disposed of in the landfill. Materials will be examined to ensure that all hazardous materials have been removed for proper disposal. All fixed and mobile equipment with marketable value will be removed and sold. All fixed materials currently underground inside the mine will be left in place, as the mine will have flooded during temporary closure. Equipment that cannot be sold or is deemed to be hazardous will be disposed of in a proper manner.

6.6 Hazardous Materials

Fuels and lubricants required during the decommissioning phase will be ordered on an as-needed basis with the objective of reducing the inventory of remaining fuels during decommissioning. Fuels remaining at the end of the decommissioning phase will be returned to the original supplier or sold. All tanks will be emptied of their contents in accordance with the *Yukon Environment Act*. Excess fuel storage tanks will be hauled away for resale or salvage.

Any reagents or chemicals remaining on site that are not required for closure will be disposed of in an appropriate manner. Explosives magazines have been removed during the temporary closure phase.

6.7 Roads and Other Access

The site access road will be decommissioned at the end of the decommissioning phase, which will require the following activities:

- Remove all culverts and drainage structures offsite for permanent disposal at an appropriate location.
- Trenches resulting from the removal of culverts will be swaled or contoured to match the surrounding topography. Erosion protection will be installed where required within the remaining swales, to a point where the reclaimed watercourse intersects its original course.
- The Bunker Creek Bridge at km 10 will be removed and the abutments will be excavated to the level of the rip-rap placed during construction.
- In smaller cuts and fills ditches will be filled in and the soils contoured to match the surrounding topography. Where ditches are planned to be left intact in some steeper sections, existing ditch erosion protection may be left in place.
- In large cuts and fills the embankment or excavation footprint will be contoured to a lesser extent, but all slopes will be altered to better match the surrounding topography.
- Organic stripping materials placed at the toe of fills during the original construction phase will be contoured along the downhill side to act as a sediment filter and to re-establish vegetation.
- Surfaces with less than 25% slope will be scarified to better receive seeding.
- Staging areas and roadside stockpiles will be contoured.
- All remaining borrow sources and quarries will be stabilized and contoured to prevent surface erosion and seeded.

Once all decommissioning activities have been completed and use of the site access road is no longer required, a permanent rock barricade will be installed near km 14. This location has been selected on a 10% ascending gradient, some 3 km north of the glacio-fluvial plateau that separates the upper Money Creek and Go Creek drainages. The location will deny access to highway vehicles, all-terrain vehicles and snowmobiles, should they proceed along the reclaimed road corridor from the highway. The site access road will also be barricaded at the junction with the Robert Campbell Highway.

6.8 Borrow Materials Planning

Glacial till for reclaiming disturbed areas will be supplied from borrow source areas around the mine site and from stockpiled areas at the industrial complex and adjacent to the TSF area (Figure 4-2 and Figure 4-3). Potential additional locations include areas adjacent to TSF and along the site access road (km 11, 17, 27).

6.9 Monitoring and Maintenance

6.9.1 Tailings Storage Facility (TSF) Dam

During the decommissioning phase (2020-2023), the TSF dam will be maintained in accordance with the *Wolverine Mine Tailings Facility Operation, Maintenance and Surveillance Manual* (currently being updated as per the Dam Safety Review - Appendix F). The physical and seepage conditions in the dam and area directly downstream of the dam will be monitored as follows:

- Quarterly: visual monitoring by mine personnel, along with the water sampling program, until safe long-term trends are indicated;
- Intermediate: annual review of monitoring data and performance of the TSF by a designated independent TSF engineer;
- Comprehensive: dam safety review by dam engineer prior to decommissioning; and
- Special Reviews: site visit and review of monitoring data are required after the occurrence of any potentially damaging events (e.g., floods, earthquakes) or unusual observations (e.g., cracks, sinkhole formation).

During the construction of the TSF landform, the crest of the dam will be used as NAG fill for the landform cover. As a result, the dam will be declassified and long-term post-closure dam safety monitoring and inspections will not be required. However, the landform will be monitored for surficial erosion, stability, vegetation establishment, and overall performance.

6.9.2 Environmental Monitoring

During the decommissioning phase (2020-2023), surface water and groundwater monitoring will be conducted in accordance with the WUL, as outlined in Table 6-2 and Table 6-3. Once the site is fully decommissioned (>2024), annual monitoring of surface water and groundwater will be conducted for 10 years to ensure stable chemistry and flow in surface and ground water systems. Once steady state conditions have been reached, the sampling sites and frequencies should be re-evaluated.

Table 6-2: Surface Water Quality Sampling Program During Closure

Station Number	Station Location	Watershed	Sampling Frequency	
			Decommissioning (2020-2023)	**Post-closure (2024-2034)**
T1	Tailings Barge	TSF	Monthly	Annually
W82	Upper Wolverine Creek	Wolverine Creek	Monthly	Annually
W9	Wolverine Creek at Little Wolverine Lake		Monthly	Annually
W1	Wolverine Lake outlet		Monthly	Annually
L1	Little Wolverine Lake		Monthly	Annually
W21	Nougha Creek at Campbell Highway		Monthly	Annually
W8	Campbell Creek		Monthly	Annually
W15	Hawkowl Creek above Go Creek	Go Creek	Monthly	Annually
W16	Go Creek below tailings facility		Monthly	Annually
W81	Go Creek below Hawkowl Creek		Monthly	Annually
W31	Go Creek above TSF		Monthly	Annually
W80*	Go Creek		Monthly (Daily when discharging)	Annually
W12	Go Creek above Money Creek		Monthly	Annually
W14	Upper Money Creek	Money Creek	Monthly	Annually
W22	Money Creek above Campbell Highway		Monthly	Annually
W40	Money Creek below Campbell Highway		Monthly	Annually
W71	Pitch Creek below road crossing	Site Access Road	Monthly	Annually
W72	Light Creek		Monthly	Annually
W73	Bunker Creek at road crossing		Monthly	Annually

Table 6-3: Groundwater Quality Sampling Program During Closure

Groundwater Well	Watershed	Decommissioning (2020-2023)	Post-closure (2024-2034)
MW05-1A, 1B	Go Creek	Quarterly	Annually
MW05-2A, 2B	TSF	Quarterly	Annually
MW05-3A, 3B	Wolverine Creek	Quarterly	Annually
MW05-4A, 4B		Quarterly	Annually
MW05-5A, 5B		Quarterly	Annually
MW05-6A, 6B	Go Creek	Quarterly	Annually
MW05-7B	TSF	Quarterly	Annually
MW06-8S, 8M, 8D	Wolverine Creek	Quarterly	Annually
MW06-9S, 9M		Quarterly	Annually
MW06-10S, 10M, 10D		Quarterly	Annually
MW06-11S		Quarterly	Annually
MW06-12S		Quarterly	Annually
MW08-13	TSF	Quarterly	Annually

Reclamation monitoring will be completed annually during the first three years after permanent closure (2024-2027). Monitoring will include areas of disturbance that have been reclaimed including: waste rock pad areas, industrial complex area, the LTF area, landfill, exploration camp area, and mine roads. Vegetation establishment and self-sufficiency will be monitored, as well as whether fertilization is required to help vegetation communities achieve self-sufficiency. Metal uptake in vegetation will also be monitored to ensure that no uptake of metals is occurring in the vegetation. Monitoring will continue on an annual basis during the 10 year post-closure phase, until all areas have been successfully revegetated and meet the terrestrial performance standards outlined in QML-0006, including:

- Vegetation must be self-sustaining 3 to 5 years after the last application of re-seeding, maintenance, or fertilization.
- The vegetative cover must be capable of self-regeneration without continued dependence of fertilizer or re-seeding.
- Establishment of a vegetative cover with sufficient density and species diversity to stabilize the surface against the effects of long-term erosion.
- No uptake of metals by vegetation.

The site access road barriers will also be monitored annually to ensure that the mine site remains inaccessible to the public.

6.10 Performance Uncertainty and Risk Management

Prior to the construction and operation of the Wolverine Mine, the TSF was to be closed as a ‘wet facility’. Owing to the premature cessation of operations, the closure concept was re-evaluated to determine the best option to preserve human health and safety, and the environment. In this RCP, the final closure concept was selected to mitigate long-term risks and to best meet the reclamation and closure objectives for the Wolverine Mine (outlined in Table 1-2).

The most consequential risk to the environment and human health would be as a result of the failure of the TSF dam prior to complete decommissioning. To mitigate this risk, an evaluation of the TSF as a water management facility was conducted in 2017 (Appendix A) and water management and treatment will be conducted to maintain an appropriate water level as advised in that evaluation. Additionally, TSF dam monitoring will be carried out as per the *Tailings Facility Operation, Maintenance and Surveillance Manual* during the decommissioning phase. Following the construction of the final TSF landform, the dam will be declassified, which will significantly reduce risks associated with the TSF dam. Not only will the physical structure pose less risk of failure, in dewatering the TSF and closing it as a dry, covered facility, the risk of a release or breach event to the Go Creek drainage is eliminated.

The other key risk is discharge of contaminated water to the environment. This could occur through unplanned discharge from the underground mine, or overtopping of the spillway at the TSF. This risk has been mitigated through the proposed construction and operation of a water treatment plant, and adaptive management for a bioreactor in Wolverine Creek. Sequential decommissioning starting during the temporary closure period will significantly de-risk the mine during the permanent closure phase.

7 Reclamation and Closure Execution Strategy and Schedule

7.1 Reclamation and Closure Schedule

This section describes the timing, sequencing, and duration of all reclamation and closure activities. Table 7-1 details the closure activities for each mine component, by phase (temporary closure, decommissioning, and post-closure). Progressive reclamation activities will continue throughout the temporary closure phase; specific activities and undertakings are described in Section 5. Reclamation research remaining to be completed during temporary closure is included in Table 7-1. Overall monitoring and maintenance applicable to all mining components for the decommissioning and post-closure phases is described in Section 6.9.

Table 7-1: Wolverine Mine Reclamation and Closure Schedule

Component	Temporary Closure Present to January 2020	Decommissioning January 2020 to December 2023	Post-Closure January 2024 to 2034
Underground Mine	• Excess underground discharge will be pumped to the TSF. • The hydraulic bulkheads for the portal and ventilation raise will be installed during 2019. • Underground mine water may be treated in sump #2 if appropriate. Discharge to Go Creek will occur in May – October if water quality discharge limits are met.	• Watertight bulkheads are not expected to discharge water. • Water quality in Wolverine Creek will be adaptively managed. • Bioreactor in Wolverine Creek will only be installed if required to mitigate water quality effects. • The portal apron will be reclaimed.	• Water quality in Wolverine Creek will be monitored. • The bulkheads will be monitored to ensure they are functioning as planned. • Revegetation will be monitored to ensure it is meeting reclamation objectives.
TSF	• The TSF will continue to receive water from site and from the underground mine. • Design and installation of a water treatment plant will occur in early 2018. • Treatment and discharge of water stored in the TSF will occur May to October at a rate of 1,200 m^3/day.	• The free water in the TSF will be treated prior to dewatering and discharging to Go Creek. • Waste Rock Pads #1 and #2 (including liners) will be deposited into the TSF. • The TSF dam material above the tailings level will be removed. This material will be used as NAG cover material for the final TSF landform. • The Stage 2 area will be deconstructed and the footprint of the TSF will be confined to the Stage 1 area. • The TSF will be closed as a dry facility with an impermeable cover. Surface water will be diverted off of, or around the final TSF landform.	• Monitoring of the final TSF landform will be ongoing during post-closure. Landform stability will be monitored to ensure the final TSF landform is performing as designed.
Seepage collection pond	The seepage collection pond will operate throughout temporary closure.	The seepage collection pond will be decommissioned with road.	Reclamation monitoring will be ongoing during post-closure.
Waste rock and overburden dumps	• Waste Rock Pad #1 and Waste Rock Pad #2 will remain in place during temporary closure. • Waste Rock Pad #2 bioreactor trials will continue through the temporary closure phase.	• Waste Rock Pad #1 and Waste Rock Pad #2 (including liners) will be deposited into the TSF. • The footprints of Waste Rock Pad #1 and #2 will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Ore stockpiles and pads	The temporary ore stockpiles have been consolidated into Waste Rock Pad #2.	The footprints of any ore stockpiles will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Industrial complex	The industrial complex has been cleaned up to meet health and safety and temporary closure requirements. Materials are being salvaged and assets are being sold.	The industrial complex will be decommissioned and the footprint will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Camp and Administration Complex	The camp and administration buildings will remain in operation in a limited capacity throughout temporary closure.	• The camp and administration buildings will be decommissioned and the footprint will be reclaimed. • Any facilities required for decommissioning crews will be the responsibility of the decommissioning contractor.	Reclamation monitoring will be ongoing during post-closure.

Component	Temporary Closure Present to January 2020	Decommissioning January 2020 to December 2023	Post-Closure January 2024 to 2034
Land treatment facility (LTF)	The LTF will remain operational.	• The LTF will accept any hydrocarbon contaminated material in the early years of decommissioning. • Once soil quality objectives are met, the soil will be used in reclamation. • The LTF will be decommissioned in accordance with approvals from Yukon Environment. • The footprint will be revegetated.	• Reclamation monitoring will be ongoing during post-closure.
Landfill	The landfill will remain operational throughout temporary closure.	The landfill will be closed at the end of decommissioning phase.	Reclamation monitoring will be ongoing during post-closure.
Exploration camp and roads	• The exploration camp has been decommissioned and the footprint has been reclaimed. • Critical roads will be drivable by ATV, for the purpose of accessing environmental monitoring sites.	• Critical roads will remain drivable by ATV until the end of the decommissioning phase. • The road footprints will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Mine roads	The mine roads will continue to be maintained year-round.	• Critical mine roads will remain open until the end of the decommissioning phase. • The mine roads footprints will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Airstrip	The airstrip will continue to be maintained year-round.	• The airstrip will remain operational until the end of the decommissioning phase. • The airstrip footprint will be reclaimed.	Reclamation monitoring will be ongoing during post-closure.
Site access road	The site access road will continue to be maintained during snow-free months.	The site access road will remain operational for the decommissioning phase. The road will be deactivated and reclaimed at the end of the decommissioning phase.	Reclamation monitoring will be ongoing during post-closure.

7.2 Execution Strategy

This section describes the human resource requirements for the execution of the RCP. Human resource requirements for each mine component are summarized in Table 7-2 by phase. Contractors will be retained to carry out most closure activities, as YZC has only a small number of full-time site staff. Environmental monitoring during the decommissioning and post-closure phases will be undertaken by YZC employees, or contractors (see Section 6.9).

Table 7-2: Human Resource Requirements for Closure

Closure Component		Personnel Required		
		Temporary Closure Present to January 2018	**Decommissioning January 2018 to December 2020**	**Post-Closure January 2021 to 2027**
Underground mine	Installation of hydraulic bulkheads and closure of underground mine portals	• Lead engineer • Senior environmental consultant • Site staff • Installation contractor	• Geotechnical engineer	• Geotechnical engineer
	Wolverine Creek bioreactor construction	• Site Supervisor • Senior environmental consultant • Site staff	• Site Supervisor • Senior environmental consultant • Site staff	• Reclamation monitor
TSF	Water treatment field-scale studies: • In situ TSF water treatment • Waste Rock Pad #2 Bioreactor ongoing trials	• Site Supervisor • Senior environmental consultant • Site staff	N/A	N/A
	Water treatment and dewatering	• Site Supervisor • Senior environmental consultant • Site staff • Water treatment design and installation consultants	• Site Supervisor • Senior environmental consultant • Site staff • Water treatment workers	N/A
	Final landform	N/A	• Site Supervisor • Senior environmental consultant • Site staff • Construction workers	• Reclamation monitor
Land Reclamation and Revegetation: • Industrial complex, including • Seepage collection pond		N/A	• Site Supervisor • Senior environmental consultant	• Reclamation monitor

Closure Component	Personnel Required		
	Temporary Closure Present to January 2018	Decommissioning January 2018 to December 2020	Post-Closure January 2021 to 2027
underground mine portal • Waste rock / stockpile footprints • Camp • Mine roads • Airstrip • Landfill • LTF • Exploration camp and roads • Site access road		• Site staff • Construction workers	

8 Reclamation and Closure Liability

The closure cost estimate has been prepared to include costs for the extended temporary closure period, the decommissioning period and the post-closure period. The costing assumes permanent closure is undertaken directly after temporary closure, and there is no re-start of the mine or change in site conditions. The cost estimates assume that work will be undertaken by a third party contractor and use best available costing information. Although the cost estimates rely on rates for contractors, as directed by the *Reclamation and Closure Planning for Quartz Mining Projects – Plan requirements and closure costing guidance* document, it should be noted that YZC has the majority of required equipment on site, which will save a considerable amount of actual cost.

Unit rates for equipment for dry conditions were obtained from Government of Yukon Third Party Equipment Rental Rates (YGS, 2017) and focused on contractors and rates published out of Whitehorse, Ross River, and Watson Lake. Where possible, rates out of Ross River have been used.

Personnel rates are derived from the *Fair Wage Schedule,* effective April 1, 2017 (YG, 2017), with an applied loading rate to include costs above the base wage such as overtime, Canada Pension Plan, Employment Insurance, and worker's compensation.

An inflation rate of 1.84% was used, based on the Bank of Canada rates for the past 17 years.

An interest rate of 12% was used based on provided interest rates from YZC's current lenders.

The unit rates used in these cost estimates are summarized in Table 8-1.

Table 8-1: Unit Rates Used to Calculate the Temporary Closure and Permanent Closure Cost Estimates

Equipment	Hourly Rate	Daily Rate
Cat D8N Dozer	$350.00	
A30D Rock Truck	$300.00	
Compactor	$185.00	
Cat 320CL Excavator	$175.00	
Cat 320 Excavator + Hammer	$220.00	
Cat 14G Grader	$185.00	
Cat 950H Loader	$195.00	
Crane 30 ton	$195.00	
Light-duty vehicle		$125.00
Personnel	**Applied Loading Rate (1.5 x hourly rate)**	**Monthly Rate**
Labourer	$35.58	
Camp Helper	$35.58	
First Aid Attendant	$35.58	
Head Cook	$44.21	
Tradesman	$49.31	
Site Supervisor	$59.85	
Design Engineer	$104.00	
Project Engineer	$140.00	
Environmental Consultant	$130.00	
Project Manager		$11,204
Site Caretaker		$8,853
Environmental Monitoring Consultants		$17,569
Misc. Costs	**Units**	**Cost**
Excavation of Soil in Stockpile	m^3	$5
Supply and place geotextile	m^2	$12
Load, haul and place topsoil	m^3	$5
Load, haul and place tailings cover (CIM)	m^3	$7
Load, haul and place rock cover, organics, granular till and clay	m^3	$8
Drill, Blast and Haul Rip Rap	m^3	$22
Place Rip Rap	m^3	$14
Camp Costs	day/person	$100
Concrete	m^3	$85
Culvert Removal (<1200mm)	each	$1,500
Culvert Removal (>1200mm or multiple/location)	each	$5,000
Flights	each	$3,855
Revegetation Rates	**Units**	**Cost**
Scarify	ha	$500
Revegetation Seed Mix	kg	$13

Revegetation Rates	Units	Cost
Fertilizer	kg	$1
Seed and Fertilizer Application	ha	$1,500
Erosion barrier	per linear km	$3,000
Water Treatment Rates	**Units**	**Cost**
Water Treatment Cost	m^3	$2.09
Monitoring Rates	**Units**	**Cost**
Surface water quality analysis	Sample set	$225
Groundwater quality analysis	Sample set	$125
Rainbow Trout LC50	Sample set	$300
Metals in Vegetation analysis	Sample set	$95
Metals in small mammals analysis	Sample set	$138
Fish species	Sample set	$300
Invertebrate species	Sample set	$215
Plant species	Sample set	$200
Algal species	Sample set	$200

8.1 Temporary Closure Cost Estimate

This RCP outlines a temporary closure period of five years, starting in January 2015 and ending in January 2020. As this plan is submitted in September 2017, the third year of temporary closure is essential ended, and therefore, costing has only been provided for year 4 and 5 of temporary closure (i.e., January 2018 – January 2020). The only costs for 2017 that have been included are for the update to the *Tailings Storage Facility Operating, Maintenance and Surveillance Manual* and the design of the water treatment plant. Table 8-2 provides a summary of reclamation and closure costs for the temporary closure phase. Details are provided in Appendix G. The temporary closure cost estimate includes the following assumptions:

- A minimum crew is maintained at site, with additional training as required to fulfill all functions, such as first aid and environmental monitoring. Rotations are assumed to be 21 days in and 21 days out.
- Minimal power requirements, allowing for the use of smaller gensets and a corresponding significant reduction in diesel consumption which is currently being applied at the site.
- The site access road is operated six months per year, from May to October. The project is operated on a “fly in-fly out” basis from November to April.
- The airstrip and local site roads will be maintained year-round.

The proposed TCP assumes a full time staff of six workers in total, on two three-person rotating crews working two weeks “on” followed by two weeks “off”. As such, there are only three full-time workers on site at any given time. Occasionally a work plan will require additional temporary assistance, primarily for equipment maintenance and operation. In this case, additional specialist operators and mechanics have been assumed depending on the optional programs enacted.

The 2016-07 RCP estimated the temporary closure costs at $1.33 M dollars. The current estimate is $9.7M after inflation and net present value have been calculated. This is due to several significant changes:

- Extension of the temporary closure period from 1 year to 25 months;
- Updates to personnel and equipment rates;
- Updates to bulkhead installation rates and addition of underground rehabilitation; and
- Addition of water treatment plant to be installed during the temporary closure period.

Several of these costs may be completed by Yukon Zinc within the next 6 months; therefore, careful weighting of how these values are incorporated into security bonding should be considered.

Table 8-2: Summary of Temporary Closure Costs (December 31, 2017 – January 31, 2020)

Work Item Description	Total Cost
Organization, Security and Overhead	
Site Supervisor	$280,100
Site Caretaker	$221,325
Camp Costs	$228,000
Camp Vehicles	$285,000
Flights	$192,750
Site maintenance costs Summer	$126,000
Site maintenance costs Winter	$260,000
Sub Total	**$1,593,175**
Maintenance	
Repair slump at TSF	$18,400
Bulkhead installation	$3,143,200
Update Tailings Dam OM&S	$20,000
Sub Total	**$3,181,600**
Monitoring	
Environmental Monitoring Consultants	$439,231
Water Quality Analytical	$161,600
Hydrogeological assessment of groundwater wells	$120,000
EEM Sublethal Toxicity Testing (2/year)	$5,490
Metals in Vegetation analysis	$11,340
Geotechnical Inspections	$50,000
Sub Total	**$787,661**
Water Treatment	
Design WTP	$828,000
Capital WTP	$3,500,000
Water Treatment Cost	$920,000
Sub Total	**$5,248,000**
Sub Total	$10,10,810,436
10% Contingency	*$1,081,044*
Total	$11,891,480
Inflation	$12,207,971
NPV	**$10,382,740**

8.2 Final Reclamation and Closure Cost Estimate

The final reclamation and closure cost estimate is reflective of activities taking place from January 2020 onwards. The decommissioning phase is assumed to be from January 2020 to December 2023 (4 years), and the post-closure phase is assumed to be from 2024 to 2024 (10 years). The estimates have assumed de-classification of the TSF, and that 10 years of post-closure monitoring is sufficient to establish steady state conditions and achievement of closure objectives. Table 8-3 provides a summary of reclamation and closure costs for the decommissioning and post-closure phases. Details are provided in Appendix G.

The total estimated cost for the permanent closure phase is approximately $6.4M. In combination with the estimated temporary closure costs, it will cost an estimated $16.1M to reclaim and close the Wolverine Mine.

Table 8-3: Summary of Final Reclamation and Closure Costs (Decomissioning and Post-Closure Phases)

Work Item Description	Decommissioning Phase (2020-2023)	Post-closure Phase (2024-2034)
Organization, Security and Overhead		
Personnel	$1,574,292.00	$279,692.50
Camp Costs	$978,400.00	-
Transportation	$210,315.00	$77,100.00
Sub Total	**$2,763,007.00**	**$356,792.50**
Decommissioning		
Tailings Storage Facility		
Decommission Diversion Ditches	$32,255.00	-
Remove Tailings & Reclaim Pipeline	$83,949.00	-
Water Treatment	$31,319.60	-
Construct Final TSF Landform	$604,150.00	-
Industrial Complex		
Industrial Complex + Office Buildings	$541,772.04	-
Power Supply - Gensets	$46,951.66	-
Site Diversions	$39,375.00	-
Water Supply Wells	$10,562.24	-
Explosive Magazines	$225.00	-
Industrial Reagents Fuels and Waste	$210,000.00	-
Spill Cleanup	$30,000.00	-
Waste Rock Pads	$896,800.00	-
Stockpiles	$3,600.00	-
Land Treatment Facility	$8,284.10	-
Landfill	$4,500.00	-
Mine Site Roads	$118,850.00	-
Demolition Overhead	$79,850.00	-
Access Road		
Decommission and Reclaim Access Road	$511,472.50	-
Reclaim Seepage Recovery Dam	$17,400.00	-
Sub Total	**$3,271,316.14**	**$0.00**
Monitoring		
MMER Monitoring	$183,660.00	-
Water Quality Analysis	$313,600.00	$56,750.00

Work Item Description	Decommissioning Phase (2020-2023)	Post-closure Phase (2024-2034)
Metals in Vegetation analysis	$11,340.00	$11,340.00
Hydrogeological assessment of groundwater wells	-	-
Geotechnical Inspections	$180,000.00	$235,000.00
Sub Total	**$688,600.00**	**$303,090.00**
Water Treatment		
Design WTP	-	-
Capital WTP	-	-
Water Treatment Cost	$1,840,000.00	-
Sub Total	**$1,840,000.00**	**$0.00**
Sub Total	$8,562,923.14	$659,882.50
10% Contingency	$856,292.31	$65,988.25
Total	**$9,419,215.45**	**$725,870.75**
Inflation	$10,121,117.97	$931,665.73
NPV	$6,108,809.57	$306,435.55
TOTAL SECURITY REQUIREMENT	**$6,415,245.12**	

8.2.1 Basis of Costing

The final closure cost estimate is based on the following assumptions and rationale:

- No salvage value is included in the estimate.
- An inflation rate of 1.84% was used, based on the Bank of Canada rates for the past 17 years.
- An interest rate of 12% was used based on provided interest rates from YZC's current lenders.
- Reclamation and decommissioning costs are based on the cost to have the work completed by a third party contractor.
- The excess liner from the TSF will be able to be used as an impermeable cover in the final TSF landform construction.
- Costs associated with closure monitoring, and in particular surface water quality and groundwater quality analytical, are based on current costs incurred by YZC.
- Non-acid generating fill and rock and glacial till will be available within the project area for closure activities.
- Decommissioning and post-closure phases are assumed to be complete 14 years after the commencement of permanent closure.
- A 10% contingency has been applied to all closure costs.

A number of personnel will be required onsite to implement the various decommissioning, closure and reclamation activities. The majority of these activities will be undertaken during the snow-free period (May to October) and directed by an onsite supervisor.

8.2.2 Contingency Measures

Several contingency measures have been discussed, but have not been included in the overall costs for temporary and decommissioning, including metals in small mammals analysis, and the installation of the Wolverine Creek bioreactor. These costs are summarized in Table 8-4.

Table 8-4: Summary of Contingency Measure Costs

Work Item Description	Cost
Metals in small mammals analysis	$13,800
Wolverine Creek Bioreactor Installation	
Bioreactor material	Accessible on site
Bioreactor material	$3,750
Bioreactor material	$3,750
Bioreactor material	$1,200
Excavate bypass channel	$2,625
Excavate bypass channel	$4,500
Install geomembrane liner and gravel	$1,750
Labour for channel construction	$1,067
Excavate upper Wolverine Creek for bioreactor	$2,625
Excavate upper Wolverine Creek for bioreactor	$4,500
Install bioreactor mix material	$2,625
Labour for bioreactor construction	$1,067
Compact the top of the bioreactor	$1,850
Construct collection pond and French drain	$2,625
Total	**$47,735**
10% Contingency	**$4,773**
Grand TOTAL	**$52,508**

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Appendix A: Wolverine Mine Water Storage in TSF, August 31, 2017

August 31, 2017

Yukon Zinc Corporation
Suite 705 – 1030 West Georgia Street
Vancouver, British Columbia
V6E 2Y3

Peter Mah
Interim Chief Operating Officer

Dear Mr. Mah:

Wolverine Mine
Water Storage in TSF

1 INTRODUCTION

Yukon Zinc Corporation (YZC) was requested by Chief Mine Engineer, Paul Christman, of the Yukon Energy, Mines and Resources in a letter dated August 8, 2017 to have the Engineer of Record for the Wolverine Mine tailings facility prepare a letter "providing a review and recommendation on the intended use of the TSF as a water retention structure until the excess supernatant water can be discharged".

2 TAILINGS FACILITY DESIGN

The Wolverine tailings storage facility (TSF) was designed to store a combination of tailings and water. The containment is a combination of constructed earthfill embankment and natural topography. The entire facility is lined with an geosynthetic geomembrane liner. Wolverine Mine operated approximately 4 years and then entered care and maintenance in January, 2015. Since then only water has been directed into the tailings facility from various sources on site. The dam was designed to withstand the weight of tailings directly against the embankment. Water will exert less pressure on the embankment and does not adversely impact the geotechnical stability of the dam.

The tailings facility was designed, however, to be constructed and operated to limit risks to the environment and the geomembrane liner is an important component to mitigate seepage. The presence of tailings over the liner significantly reduces seepage from potential defects in the liner. In contrast, water ponded directly on defects in the liner would result in greater seepage than if tailings were present.

The tailings deposition strategy for the TSF was to have tailings discharged near the dam and have the pond well back from the dam crest. Currently the pond and reclaim system are located at the highest

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cross section of the dam and the pond could be released to the environment if there was a dam stability incident.

If the pond level continues to increase, there is a risk of a discharge of tailings pond water to the environment through the spillway and to discharge into Go Creek. KCB anticipate that this water would not meet discharge requirements without treatment.

3 PLAN FOR WATER TREATMENT

YZC have provided a plan from BQE (BQE, 2017) which outlines the scope for a water treatment facility which will allow removal of the pond from the tailings facility. The plan is to progressively treat an estimated 800,000 m^3 of water from the pond, along with planned inflows from a restart of mining activities over 6 years. The BQE plan is based on an assumed starting pond volume of 800,000 m^3 of water.

The current volume of water in the TSF has been estimated to range between 500,000 m^3 and 800,000 m^3, which should be verified by completing a bathymetric survey of the tailings surface and comparing this to the original liner survey.

4 RECOMMENDATIONS

The use of the TSF as a temporary storage of water is acceptable, provided the water treatment system is in place and functioning prior the pond level reaching El. 1310 m. This is approximately 1.5 m greater than the current pond level. This elevation is 1.5 m below the invert of the spillway and provides space for the restart of tailings deposition, commissioning of the water treatment plant, and winter storage of water while limiting the risk of an uncontrolled release of pond water through the spillway, except during a very high return period storm event.

KCB also recommend that as part of the restart plan, tailings deposition start near the embankment to move the water pond away from the embankment to further mitigate the likelihood of seepage through the dam and potential influences on its stability. A wider beach against the dam could also potentially reduce the consequences of failure in the event of slope instability.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

PROFESSIONAL ENGINEER YUKON H. N. McLEOD

Aug 31, 2017

Harvey McLeod, P.Eng.
Geotechnical Engineer

PF:kc

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Appendix B: Wolverine Tailings Storage Facility Temporary Closure Update, September 29, 2017

Klohn Crippen Berger

September 29, 2017

Yukon Zinc Corporation
Suite 705 – 1030 West Georgia Street
Vancouver, British Columbia
V6E 2Y3

Peter Mah
Interim Chief Operating Officer

Dear Mr. Mah:

Wolverine Tailings Storage Facility
Temporary Closure Update

1 INTRODUCTION

Yukon Zinc Corporation (YZC) was requested by Director, Mineral Resources, Robert Holmes, of the Yukon Energy, Mines and Resources in a letter dated September 11, 2017 to provide a recommendation on the maximum safe water levels in the TSF with respect to the slump at the north end of the TSF and to provide recommendations on instrumentation and monitoring requirements during temporary closure.

2 WATER LEVEL WITH RESPECT TO SLUMP AT NORTH END OF TSF

The slump area at the north end of the TSF is partially inundated with water and possibly tailings. However, the slump does not present a dam safety risk to the TSF. The slump is in a cut slope opposite the main embankment. The slump does present a hazard for the potential release of contaminated water or tailings if the liner is damaged. Monitoring of seepage pond chemistry should be conducted if the seepage pond were to be discharged to the environment. Otherwise, the seepage pond should be pumped back to the TSF to prevent discharge to the environment.

The current pond level is approximately 1309.05. m which is approximately 2.5 m below the invert of the spillway. The slump and liner should be repaired as soon as practically possible and before any additional tailings are placed within the tailings facility (KCB, 2017a). Once the slump and liner are repaired, and the maximum recommended water level is 1310 m (KCB, 2017b) without having a fully functional water treatment plant.

3 INSTRUMENTATION DURING TEMPORARY CARE AND MAINTENANCE

The current instrumentation for monitoring the performance includes 6 survey monuments and 4 piezometers. The dam is surveyed annually and the piezometers are connected to dataloggers and read the water level every 12 hours. The piezometer data should be downloaded and reviewed at least annually during temporary closure and reported on as part of the annual dam safety inspection. Originally 8 piezometers were installed but four are no longer functioning. The remaining functioning instruments monitor the water level at key sections in both the dam fill and the dam foundation.

Inclinometers were installed in the dam but were damaged during the first dam raise and are no longer functional. Inclinometers are not required during temporary closure.

The operational instrumentation and reading frequency is sufficient to monitor the TSF during temporary closure. The instrumentation and reading frequency is also sufficient for a potential increase in the pond level up to 1310 m. If any of the remaining piezometers cease to function, a review of the instrumentation should be conducted and replacement instruments installed.

Seepage from the TSF reports to the seepage collection dam. Water quality samples are taken from the seepage collection pond and from the under drain discharge point and these are reported on by YZC. The monitoring is sufficient for temporary closure.

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Yukon Zinc Corporation (Client) for the specific application to the Wolverine Tailings Facility. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

PROFESSIONAL
YUKON
PAMELA FINES
TERRITORY
ENGINEER

29-Sep-2017

Pamela Fines, M.A.Sc., P.Eng.
Associate / Manager

REFERENCES

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Klohn Crippen Berger Ltd. 2017b. “Wolverine Mine, Water Storage in TSF” August

Appendix C: 2017 Underground Mine Water and TSF Pond Water Treatment Tests for Wolverine, SRK Consulting, August 30, 2017

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Memo

To:	Mr. Jing You Lu	**Client:**	Yukon Zinc Corporation
From:	Soren Jensen	**Project No:**	1CY004.000
Cc:	Mary Mioska	**Date:**	August 30, 2017
Subject:	2017 Underground Mine Water and TSF Pond Water Treatment Tests for Wolverine		

1 Background and Objectives

This memo describes a proposed plan for testing methods for removing selenium and metals from water stored in the Tailings Storage Facility (TSF) and in the underground mine at Yukon Zinc Corporation's (YZC) Wolverine Mine. The Tailings Storage Facility (TSF) at Wolverine currently holds approximately 700,000 m^3 of ponded water, which has elevated concentrations of selenium and total metals. The underground working were allowed to flood when operation ceased in February 2015. In 2017, the water level in the workings reached the portal level. The underground mine water is reportedly pumped to the TSF at a rate of about 200 m^3/day.

Options for treating and discharging water ponded in the TSF were assessed by SRK in 2016 (SRK, 2016). In 2017, YZC commissioned a second water treatment study to look at options for implementing short-term and longer term water treatment as part of a plan to restart the mine operation. The water treatment options considered for the closure plan are equally relevant as short-term water treatment methods for start-up of the mine. In both cases, a treatment campaign must be implemented to reduce the inventory of water in the TSF, ideally over a single season. In the 2016 water treatment assessment, SRK identified two water treatment options as most likely to be feasible for implementation at site:

- In-situ biological reduction combined with ferric/lime treatment, and
- Zero-valent iron treatment combined with ferric/lime treatment.

Other available treatment methods were deemed to be marginal or unsuitable for use in campaign-based treatment.

In 2016 it was estimated that the TSF would take approximately 5 years to fill, which left sufficient time for evaluating and designing an appropriate treatment system. However, with the addition of 200 m^3/day of underground mine water, treatment could be required much sooner. Therefore, need to take more immediate steps to evaluating options and developing a plan for implementing water treatment for the site.

The test plan proposed here includes two parts both of which could address the requirement to treat and discharge water as soon as next spring (spring 2018):

- Tests for treating underground mine water with ferric coagulant and lime to meet discharge quality limits stipulated in the mine's water use license (WUL QZ04-065)

- Pilot-scale tests for removal of selenium and metals using zero valent iron and lime treatment.

Section **Error! Reference source not found.** describes the proposed approach, test parameters and set-up, equipment required, schedule, staffing and equipment cost estimate for treating underground mine water. Section 0 describes the proposed tests for zero valent iron treatment.

2 Underground Mine Water Treatment

2.1 Approach

The proposed approach for testing treatment of underground mine water involves a ferric co-precipitation step followed by lime water treatment. Ferric co-precipitation has been used previously to treat underground mine water at Wolverine for selenium and dissolved metals and may be sufficient for meeting discharge quality limits. However, a subsequent lime treatment step may be required to remove residual dissolved metals. Lime treatment is not expected to affect selenium concentrations and can therefore not be used as a stand-alone process to achieve discharge treatment targets.

Figure 1 shows a process of flow diagram for the proposed ferric and lime treatment process. First, ferric sulphate will be mixed with the mine water in a tank. From there, the treated water will flow to a clarifier tank. Flocculant will be added to facilitate settling of ferric sludge. Overflow from the ferric settling tank will flow to an aerated lime mix tank where pH will be increased to between 9.5 and 10.5. Aeration will facilitate conversion of ferrous to ferric iron. Flocculant will be added to the overflow from the mix tank as it flows to the hydroxide settling tank. The treatment effluent will overflow from the hydroxide settling tank. Water quality samples will be collected from the overflow of both settling tanks.

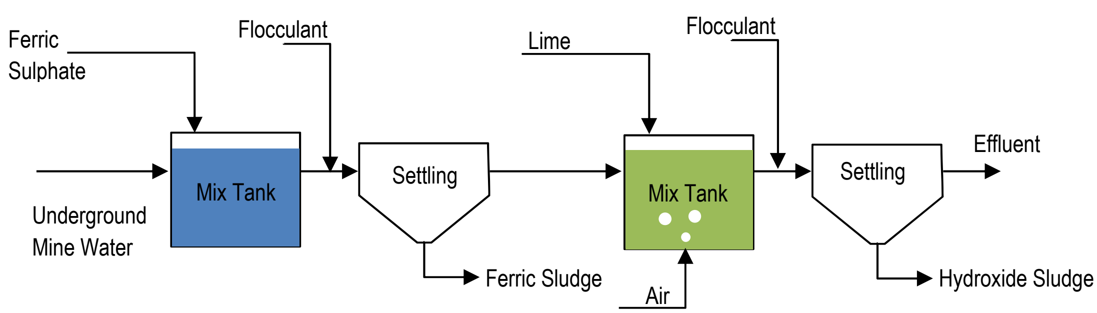

Figure 1 Process Flow Diagram Underground Mine Water Treatment

2.2 Test Matrix

The proposed tests will evaluate:

- Selenium speciation of the feed water;
- Effect of ferric dose on selenium removal;
- Effect of lime dose (i.e. pH) on dissolved metals removal.

Table 1 shows a summary of proposed process conditions. Tests 1 through 4 would be repeated a number of times using different If selenium in the underground mine water primarily is on the more oxidized selenate form it may not be possible to achieve an effluent concentration as low as 0.020 mg/L, which is the discharge quality standard for Wolverine. If this is the case, the zero valent treatment method describe in Section 3 may be a viable options for treating underground mine water. Alternatively, options for using biological treatment in a gravel reactor can be explored.

Table 1 Proposed Test Matrix

Test	Description	Ferric Dose	Lime
1	Low Ferric + Lime	Low (10 mg/L Fe3+)	To pH 9.5
2	Med. Ferric + Lime	Medium (30 mg/L Fe3+)	To pH 9.5
3	High Ferric + Lime	High (60 mg/L Fe3+)	To pH 9.5
4	Med. Ferric + High Lime	Medium (30 mg/L Fe3+)	To pH 10.5

2.3 Equipment Required

Suggested equipment for the test is listed in Table 2 along with possible suppliers and estimated costs.

Table 2 Suggested Test Equipment and Water Quality Analyses

Equipment	Qty	Description	Possible Supplier	Estimated Cost
Ferric Sulphate	5 L	5 L 40% Ferric Sulphate (only if not available on site)	Cleartech	$200
Hydrated Lime	20 kg	20 kg bag of hydrated lime (only if not available on site)	Cleartech	$200
Mix Tanks	10	Five Gal Pails	Home Depot	$100
15 Gal Inductor Tanks	2	Polymer inductor tanks with stand	Local home brewer supplier or Barr Plastics	$900
Feed Pump	2	1/2 HP Submersible Pump	Home Depot	$700
Effluent Pump	1	1/2 HP Submersible Pump	Home Depot	$400
Rotameters	2	Rotameters for manual flow measurement and control	McMaster-Carr	$600
Feed water barrel	1	55 Gal plastic drum or similar	Local supplier	$300
Valves and fittings	1 lot	various valves, pipes and fittings	McMaster-Carr	$800
Floc, Ferric and Lime Metering Pumps	1	Small metering pump for dosing lime slurry	McMaster-Carr	$4,400
Floc mixers	2	Small overhead lab mixer	Cole-Parmer	$1,600
Lime and Process Mixer	3	For mixing process water with lime	McMaster-Carr	$2,200
15% Contingency		General allowance		$1,900
			SUM	**$14,300**

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2.4 Test Set-up

The test setup would proceed as follows:

- The tests would be carried out in an in-door or sheltered and heated location with easy access to underground mine water. Tables or ply-wood and 2-by-4s are expected to be available for construction of platforms.
- Test equipment would be assembled to the extent possible prior to shipping in crates to site.
- Equipment assembly, set-up and testing is expected to take 2 working days.

2.5 Schedule, Duration and Monitoring

The tests can be completed on site mid-to late September 2017. The underground mine water treatment tests are expected to last 5 days: 2 days for setup, 3 days to run tests and half a day for decommissioning. This does not include travel to site. The tests can be completed in conjunction with the zero valent iron tests described in Section 3.

2.6 Staffing

SRK proposes to send two water treatment specialists to site to carry out the tests.

3 Zero Valent Iron Treatment

3.1 Approach

Zero Valent Iron (ZVI) treatment relies on the reducing potential of iron metal. When selenite (SeO_4^{2-}) comes into contact with ZVI it is reduced to selenite (SeO_3^{2-}) or elemental selenium. Elemental selenium is a solid, which can be removed by coagulation and settling. Selenite is soluble but can be removed from solution by co-precipitation with ferric hydroxide.

As ZVI reduces selenium, the iron oxidizes to ferrous iron (Fe^{2+}), which at neutral conditions and in the presence of air will oxidize to ferric iron (Fe^{3+}) and precipitate as ferric hydroxide ($Fe(OH)_3$). Thus, the ferric hydroxide formed in the reduction-oxidation process will facilitate subsequent removal of selenite formed in the same process.

SRK proposes to test ZVI treatment using a recirculating up-flow reactor as shown on the schematic in Figure 2. Feed water and recirculated water will be pumped up through a bed of granular ZVI iron in order to maximize contact with the surface of the granules. Treated effluent would overflow the reactor by gravity at the same rate effluent is pumped to the system.

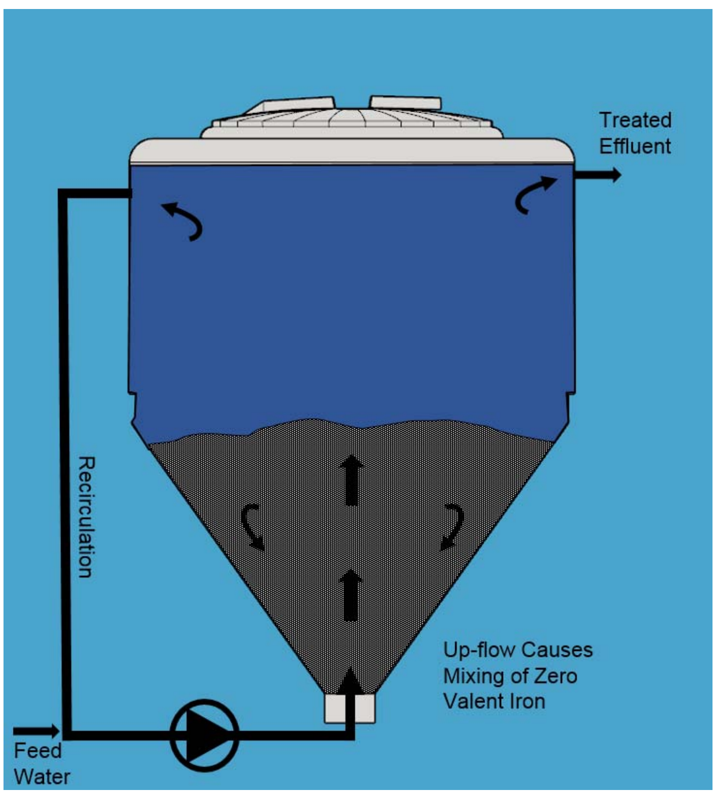

Figure 2 Cross Section of Inductor Tank

3.2 Test Matrix

Two tests will be carried out: a kinetic test and a ZVI depletion test. The kinetic test will evaluate the effect of mean hydraulic residence time and recirculation rate, which in turn will inform full-scale reactor and pump sizing – and by extension capital cost. The ZVI depletion test will determine the rate at which the reducing potential of the ZVI becomes depleted and in turn how much ZVI is required to treat a given volume of water. The total cost of granular ZVI can be estimated based on the depletion test.

Table 3 shows a summary of the proposed kinetic tests. The depletion tests will be carried out by running one of the kinetic tests for an extended period of time until the treatment performance deteriorates.

Table 3 Proposed Test Matrix for the Kinetic ZVI Test

Test	Mean Hydraulic Residence Time (each reactor)	Feed Flow Rate		ZVI Volume	Recirculation Rate	
	min	L/min	gpm	Gal	gpm	Bed Volumes
1	5	11.4	3.0	3.0	10	17
2	10	5.7	1.5	3.0	10	33
3	15	3.8	1.0	3.0	10	50

Notes: Source, SRK: ZVI Tests.xlsx

3.3 Equipment Required

Suggested equipment for the ZVI tests is listed in Table 4 along with estimated costs.

Table 4 Suggested Equipment for ZVI Tests

Equipment	Qty	Description	Possible Supplier	Estimated Cost
Granular Zero Valent Iron	300 lbs	12 gal of ZVI for kinetic and depletion tests	Hepure or similar supplier	$1,100
15 Gal Inductor Tanks	2	Polymer inductor tanks with stand	Local home brewer supplier or Barr Plastics	$880
Recirculation Pumps	2	3/4 HP Jet Pumps	Home Depot	$825
Feed Pumps	2	Small submersible pumps	McMaster-Carr	$550
Rotameters	2	Rotameters for manual flow measurement and control	McMaster-Carr	$550
Feed water barrel	1	55 Gal plastic drum or similar	Local supplier	$220
Valves and fittings	1 lot	various valves, pipes and fittings	McMaster-Carr	$660
Lime metering pump	1	Small metering pump for dosing lime slurry	McMaster-Carr	$770
Mixer	1	For mixing process water with lime	McMaster-Carr	$440
5 Gal Buckets	10	For various uses	Home Depot	$55
Shipping	1	General allowance		$1,650
Contingency	15%			$1,155
			SUM	**$8,855**

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3.4 Test Set-up

A schematic of the complete pilot plant setup is shown in Figure 3. The process would consist of a feed/tailings water barrel and two stages of ZVI treatment followed by lime addition and settling. Ferric sulphate may be added to the overflow of the first reactor to facilitate removal of selenite generated in the first stage. The test set-up consists of readily available pumps and vessels. Proposed test conditions are discussed in Section 3.2.

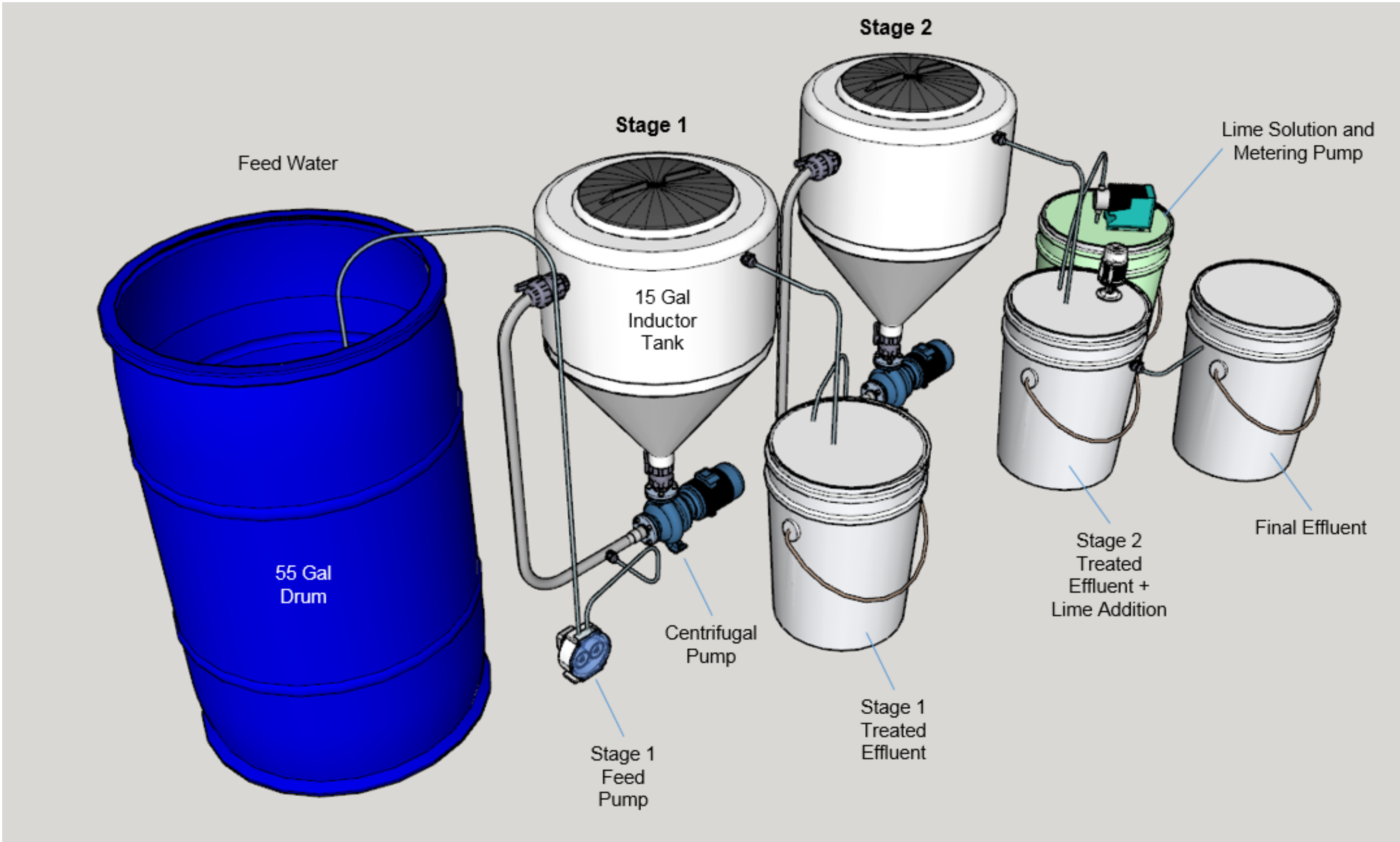


Figure 3 Proposed ZVI Test Setup

3.5 Schedule and Duration

SRK proposes to carry out the ZVI tests concurrently with ferric-coprecipitation tests on site in September 2017. The site visit will also allow for an assessment of options for scaling up the treatment method. Equipment assembly will take approximately 2 days and the tests will take approximately 3 days followed by 1 day of decommissioning. Water quality samples collected during the test will be sent for analysis by an analytical lab off site.

3.6 Staffing

SRK proposes to send two water treatment specialists to site to carry out the tests.

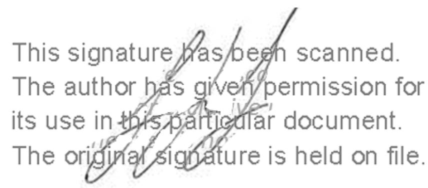
4 Cost Estimate

Estimated costs for equipment, shipping, water quality analyses, installation, testing, monitoring and reporting are provided in a separate proposal.

5 Next Steps

SRK recommend that YZC takes steps to demonstrate the viability of the treatment methods for underground mine water and TSF pond water this year with the aim of treating and discharging water from the mine next year in 2018. SRK would be pleased to arrange a meeting or conference call to discuss the merit of completing the proposed tests and the test details.

This memo was prepared by SRK Consulting (Canada) Inc.



Soren Jensen, PEng
Environmental Engineer

and reviewed by

Jennifer Foster, PEng
Process Engineer

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The opinions expressed in this report have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

6 References

SRK. 2016. Wolverine Mine Water Treatment Assessment. Report prepared for Yukon Zinc Corporation. Issued December 2016.

Appendix D: Portal Plug Design for Yukon Zinc Corp. Wolverine Mine – Yukon Territories, Golder Associates Ltd., July 2017

24 July 2017 | Reference No. 1778120-002-L-Rev0-1000

Peter Mah
Yukon Zinc Corporation
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Vancouver, BC
V6E 2Y3

PORTAL PLUG DESIGN FOR YUKON ZINC CORP. WOLVERINE MINE – YUKON TERRITORIES

Dear Mr. Mah,

As requested, Golder Associates Ltd. (Golder) has conducted a conceptual design of two hydrostatic bulkheads (or plugs) for Yukon Zinc Corporation's (YZC) Wolverine Mine in the Yukon Territory. The design will form a portion of YZC's reporting requirements to Yukon Energy, Mines and Resources for the closure of the Wolverine Mine.

The scope of this letter is limited to the conceptual design of these two hydrostatic bulkheads as presented in Golder's Proposal No. P1778120-001-P-Rev1-1000, 24 May 2017, and uses the same assumptions and limitations made in that proposal. In this context, the reader is referred to the attachment entitled "*Important Information and Limitations of this Report*", which follows the text but forms an integral part of this document and affects the proper use and interpretation of this letter.

1.0 INTRODUCTION

1.1 Background

We understand that the main decline at the Wolverine Mine was first driven in 2005 to access the volcanic massive sulphide Wolverine Deposit. A vent raise was excavated shortly after the decline had been developed for ventilation purposes. Mining of the Wolverine Deposit was carried out until early 2015, when YZC decided to temporarily shut down operations due to unfavorable markets for copper, lead and zinc. Two plugs are required to close the openings to surface to reduce mine water from entering the environment. The proposed locations of these two plugs, the Decline Plug and the Vent Raise Plug, are shown in plan on Plate 1.

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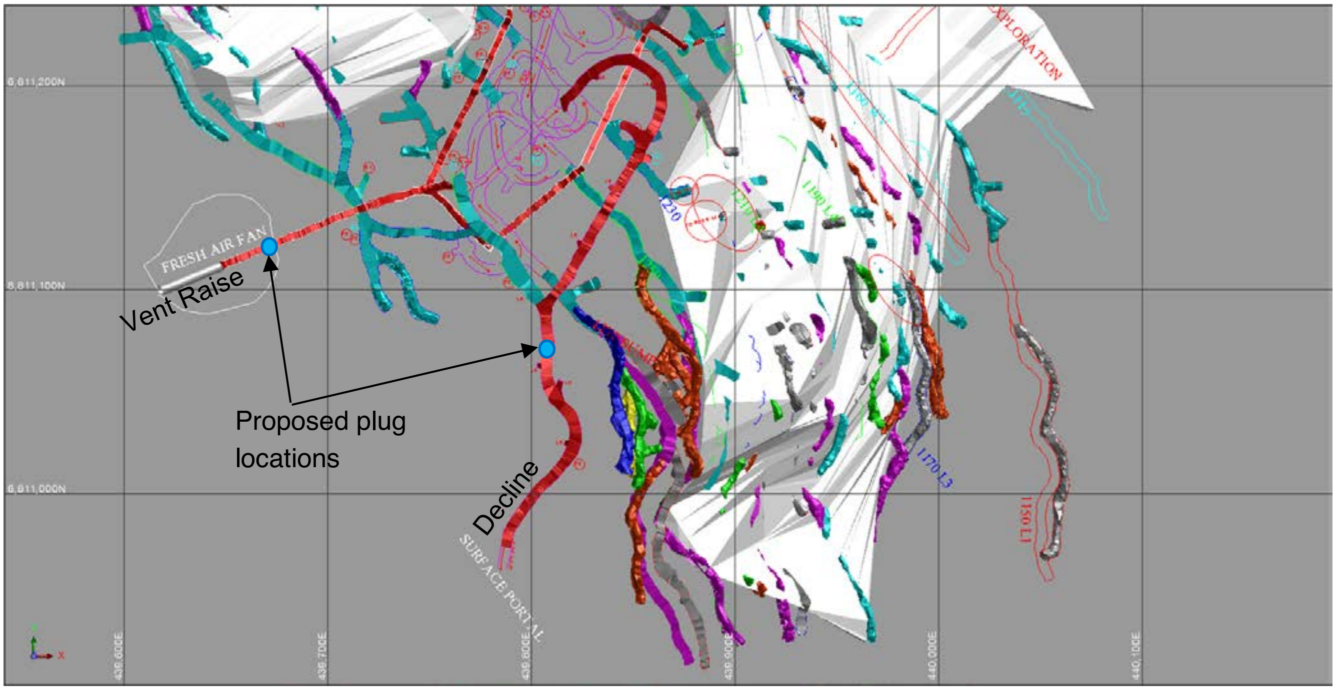

Plate 1: Proposed Decline and Vent Raise Plug Locations

1.2 Methodology

Site information provided by YZC has been used to gain an understanding of site conditions for the development of this conceptual design. As such, a site reconnaissance to confirm the assumed conditions at the proposed plug locations must be carried out by Golder prior to preparing "Issued for Construction" drawings and specifications.

2.0 DATA REVIEW

The general geologic setting of the Wolverine Mine was assessed based on a review of available background information on unpublished geological and topographical maps, and reports provided by YZC. A geotechnical assessment of the decline at the proposed location of the Decline Plug was conducted by Dr. Khosrow Aref of Rockland Engineering (Rockland 2006). The underground mine layout shown in Figure 1 was developed from as-built drawings provided by YZC.

2.1 Site Geology

The bedrock geology at the portal area consists of argillitic sediments and rhyolitic volcaniclastic rocks of the Devonian-Carboniferous age, which host the polymetallic volcanogenic massive sulphide Wolverine deposit (Rockland 2006).

A limited amount of geological mapping was conducted along the decline at the proposed location of the Decline Plug. The following is an excerpt from the Rockland (2006) report describing the various lithological units.

> *"The argillite is a dark grey to black, carbonaceous to graphitic fine grain sedimentary rock type. It occurs as thick beds to fine laminations. It often contains 1–5% disseminated pyrite, and up to 10% siliceous bands.*
>
> *The graphitic argillite consists of black, massive and unconsolidated, fine argillitic mud. This often contains 1–5% quartz and carbonate veins.*
>
> *The siliceous siltstone is a light grey to greenish grey unit, consisting of 0.5–2cm siliceous beds interbedded with 1–2mm sericite laminations. This rock type is generally only a few meters thick and occurs below the calcite pyrite exhalite rock type.*
>
> *The calcite pyrite exhalite consists of wispy to irregular bands of calcite, siderite, silica, and pyrite. This rock type occurs tens of meters above the massive sulphide orebody.*
>
> *These include massive sulphide, pyrite and sphalerite-rich, laminated massive sulphide, sphalerite-rich massive sulphide, pyrite and sphalerite-rich, replacement texture massive sulphide, replacement textured massive chalcopyrite, stringer style chalcopyrite.*
>
> *The chlorite altered argillite rock type is well foliated and locally intensely deformed.*
>
> *The sericite altered rhyolite or argillite occurred in the HW between the massive sulphide and the argillite. This unit was contained between two or more faults and is only found within a 20m space in the HW. This rock type is intensely sericite altered, and shows very little primary textures."*

It is noted that the area above the proposed plug locations consists of a significant thickness of overburden and weathered bedrock, to depths of 15 m of overburden and 15 m of weathered bedrock.

2.2 Hydrogeological Conditions

A pre-mining hydrogeological model was developed in 2005 to study the impact of mining on the Wolverine Creek watershed. The following is an exert from a YZC (2016) internal report.

> *"Two bedrock aquifers are present in the vicinity of the mine including a shallow unconfined aquifer above the iron formations and a deeper, semi-confined aquifer below the iron formations. The upper and lower iron formation as well as the mineralized zone behave as aquitards and may slow the flow of groundwater. There is a homogeneous and isotropic aquifer inferred to be 150 m in thickness. Water table depths and flow divides were inferred based on ground surface topography, surface water bodies and known water table elevations in close proximity to the mine area. Groundwater is inferred to flow from northeast to southwest near the mine. Precipitation on the ground surface above the mine infiltrates into the ground and recharges the groundwater flow system. Groundwater flows southwestward to discharge locations along Wolverine Creek.*
>
> *Potentiometric elevations are measured at four vibrating wire piezometers installed in two exploration boreholes (PZ-A and PZ-B) in the Lynx and Wolverine mineralized zones, respectively. Results from ongoing monitoring following mine development are shown in* [Plate 2]*."*

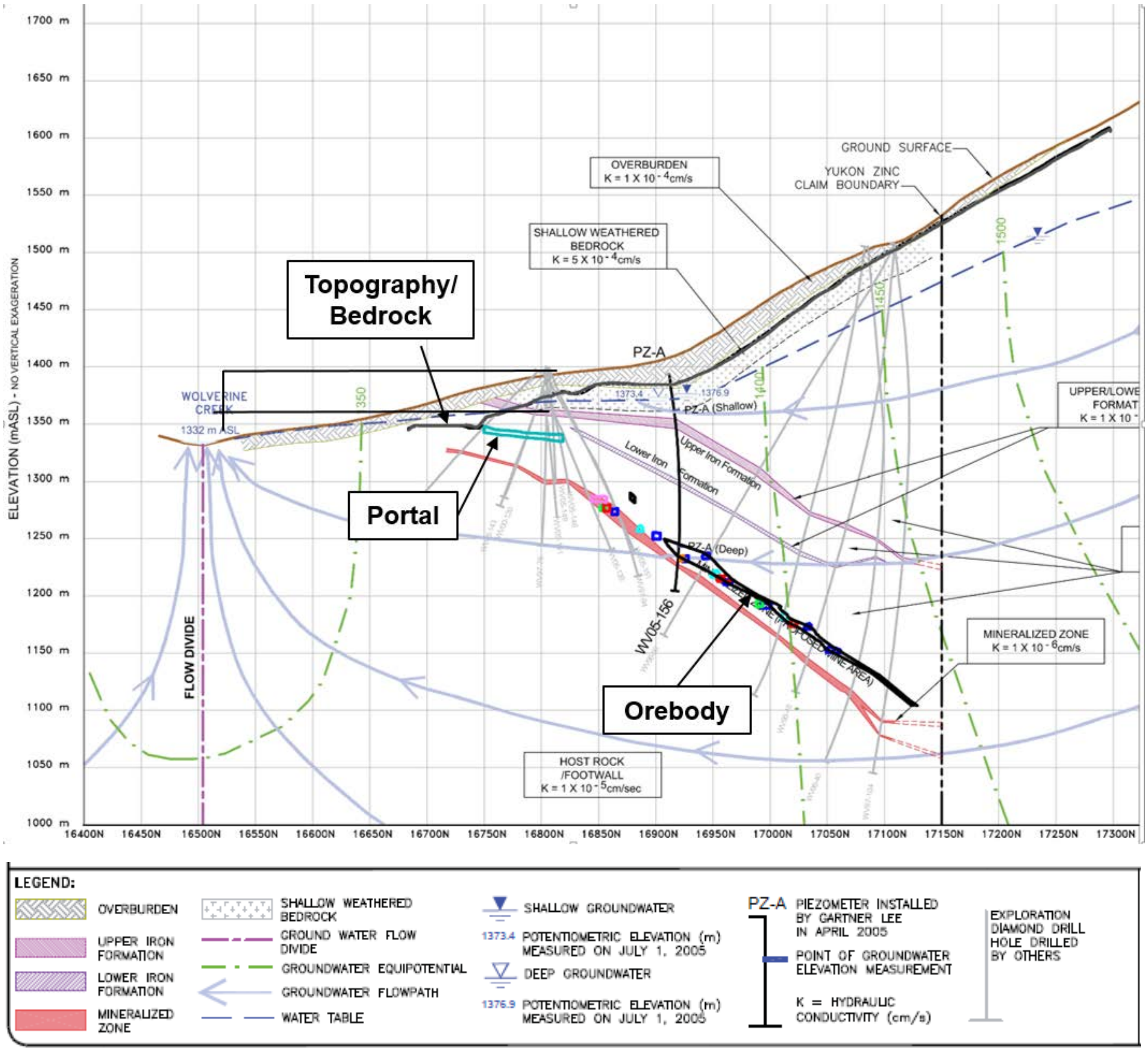

Plate 2: Hydrogeological Model (Pre-Mining) with the Decline and Orebody Superimposed

The mining actives resulted in increasing the continuity of the groundwater system such that the expected hydraulic head at the decline and vent raise plug locations is equal to the groundwater equipotential at the furthest extent of the mining. In this case, it is assumed that the mining has imposed a water table elevation of approximately 1430 mASL, or approximately 100 m of hydraulic head at the proposed plug locations.

2.3 Rock Mass Characterisation

A review of core logging data, provided by YZC and the rock mass quality from Dr. Aref (Rockland 2006) was carried out to identify rock types, and zones along the decline and vent raise where the rock conditions would be favorable for potential construction of the hydrostatic plugs.

Complete geotechnical core logging information was not available from all boreholes, nor from each proposed location considered for potential construction of the Decline and Vent Raise Plugs. As such, Golder relied upon the borehole logs to characterise the rock quality along the vent raise, wall mapping photographs along the decline, and the rock quality descriptions along the decline provided in Rockland (2006). Table 1 summarizes the available rock mass quality data for the lithologies anticipated to be encountered along the decline and vent raise.

Table 1: Summary of Assumed Rock Mass Quality at Proposed Plug Locations

Rock Type	Location	RMR	Q	Field Estimated Rock Strength
Argillite	Decline Plug	18–35	0.01–1	R3
Calcite Pyrite Exhalite	Decline Plug	52–70	1.9–9	R4
Massive Sulphides	Vent Raise Plug	49–67	4.1–6.6	R4-R5

Of the geotechnical data provided, the rock mass quality of the calcite pyrite exhalite unit, reported as being of Fair to Good rock mass quality (Rockland 2016) is believed to be the more favourable unit along the decline in which to potentially construct the Decline Plug. The identified location for the Vent Raise Plug is within the massive sulphide unit, which also is reported as being of Fair to Good rock mass quality.

The commercially available software RocLab™ – a laboratory and rock mass property estimation package provided by Rocscience Inc. – was used to estimate the rock strength parameters for the argillite, calcite pyrite exhalite and massive sulphide units present along the decline and vent raise. The estimated parameters are summarized below in Table 2.

Table 2: Rock Mass Material Strength Parameters

Rock Type	GSI	Conf. Pressure (σ_n, MPa)	Mohr-Coulomb Parameters		
			C (MPa)	Phi (°)	σ_t (MPa)
Argillite	25	0.5	0.1	32	0.41
Calcite Pyrite Exhalite	55	0.5	0.5	49	1.08
Massive Sulphides	65	0.5	0.8	65	1.90

GSI – Geological Strength Index (Hoek, 2007).

σ_n – Confining pressure, defined as 0.5 MPa (Lang, 1999).

c – cohesion.

phi – friction angle of the rock mass assuming a confining pressure of 0.5 MPa.

σ_t – shear strength of the rockmass.

2.4 Geometry of Decline and Vent Raise

Golder assumes that the decline was driven using traditional drill and blast techniques to dimensions required for mechanised mining, (i.e., the use of scooptrams, load haul dump trucks and drill jumbos). The as-built model of the decline at the proposed location of the Decline Plug is approximately 5.7 m wide by 5.1 m high at a downwards grade of approximately 10.5% (6°). The vent raise is approximately 3.1 m wide by 4.6 m high, and was excavated sub-horizontally, with an average grade of 43% (23°).

Due to the construction methods for the decline and raise, as well as photographs provided by YZC, it has been assumed that the tunnel walls and back at the proposed plug locations are rough to very rough and relatively free of installed services or shotcrete, but that welded wire mesh and rock bolts cover all or a portion of the areas where the plugs are proposed to be constructed.

3.0 DESIGN

The engineering criteria used for the design of these parallel-sided concrete plug designs (i.e., calculation of required length) take into account the width and height of the tunnels to be closed off, the anticipated hydrostatic pressure and the allowable shear stress of the rock or concrete, whichever is less. In this respect, consideration should be given to the characteristics of the rock at the location of the plugs and the final location of the plug should consider the rock type, planes of weakness, open fractures, and weathering.

3.1 Considerations for Plug Design

The decline and vent raise openings are to be secured for final closure of the underground at the Wolverine Mine. As the water table at equilibrium is higher than the elevation of the decline and vent raise openings, the plugs are designed to minimise to the extent possible leakage of mine water from the underground into the environment.

The portal area of each plug are within the discontinuous permafrost (Yukon Zinc Corp, 2016) – see page 47, Wolverine Mine Reclamation and Closure Plan 2016-17. It is estimated that the active mining has melted any permafrost within the area. While annual freeze and thaw cycles are expected to continue, the plug locations are to be located within the bedrock where it will be unaffected by these cycles. Pressures due to ice behind the plugs have not been considered.

3.2 Criteria for Design

The required plug lengths were assessed based on the following five criteria:

- Punching shear strength of the concrete, intact rock and the bedrock-to-concrete interface for a grouted plug.
- Tensile failure of the non-reinforced concrete plug (i.e., deep beam failure).
- Hydraulic jacking of the rock surrounding the plug.
- Failure due to seepage of water around the plug which could result in erosion of the tunnel wall and eventual failure of the plug.
- Consideration for long term disintegration of the concrete as a result of the potentially acidic or sulphate attack or alkali aggregate reactivity.

The recommended design factors of safety for each of these failure modes are summarized below in Table 3. Design calculations for the potential Decline and Vent Raise Plug length are included in Attachment 1.

Table 3: Recommended Factor of Safety for Each Failure Mode

Failure Mode	Design Criteria
Punching shear failure along rock/concrete contact or through rock mass	F.S. > 3 normal condition F.S. > 1.5 earthquake or dynamic load condition
Deep beam flexure	F.S. > 3 normal condition F.S. > 1.5 earthquake or dynamic load condition
Hydraulic jacking of rock surrounding plug	F.S. > 1.3 normal condition (total stress analysis) F.S. > 1.1 earthquake or dynamic load condition (total stress analysis)
Excessive seepage around plug and possible downstream erosion	Maximum hydraulic gradient based on empirical design methods.
Long term disintegration of concrete	Concrete to be designed to appropriate standards for resistance to acid attack, sulfate attack, and alkali aggregate reactivity. Sensitivity of other construction materials to be determined on a case-by-case basis.

4.0 PLUG LENGTHS

The recommended plug length, considering the above design criteria are summarized below in Table 4.

Table 4: Recommended Plug Length† Calculated for Design Criteria

Plug Location	Punching Shear (m)	Pressure Gradient (m)	Deep Beam Bending (m)
Decline Plug	4.5	2.1	4.5
Vent Raise Plug	2.0	2.0	3.6

† 0.5 m has been added to the calculated lengths to account for the potential plug degradation as a result of an acidic mine water environment.

The height of the decline and vent raise tunnels, 5.1 m and 4.6 m respectively, result in a plug length to maximum height ratios of 1.25 or greater. Therefore, the plug design lengths are controlled by the beam analysis for a non-reinforced concrete plug.

The plug location identified for the Decline Plug suggests that there is minimal amount of argillite in one of the ribs. For the design of this plug, this relatively small amount of argillite was not considered in the design at this stage. However, if upon inspection it is determine that the argillite is significantly more than anticipated, this could affect the design plug length at this location, resulting in a longer plug.

While geological and geotechnical core logging is available for boreholes close to the vent raise, actual mapping along the vent has not been conducted at this stage and therefore the rock type and quality is inferred. Plug length recommendations may vary depending on rock quality conditions at the time of inspection.

The proposed plug locations for the Decline and Vent Raise Plugs are approximately 60 m below ground surface. However, bedrock mapping shows that within these areas there is a substantial amount of overburden (approx. 15 m) and weathered bedrock (approx. 15 m). The Norwegian criteria for hydraulic jacking indicates that to resist fracturing or jacking, approximately 50 m of rock cover is required above the location of each of the Decline and Vent Raise Plugs. Depending on the condition of the weathered bedrock, it may be necessary to conduct additional drilling or underground in-situ stress testing to confirm that the hydraulic pressures will not force open existing discontinuities, resulting in failure of the plug and increased leakage and groundwater seepage to surface.

The ore body at the Wolverine Mine is a massive sulfide deposit. As such, it is expected that the groundwater chemistry will be acidic. Therefore, we recommended that the binder used in the concrete be resistant to sulfate attack and that an additional 0.5 m be added to the plug length to account for long term disintegration of the plug.

5.0 CONSTRUCTION CONSIDERATIONS

5.1 Drawings

The extent and arrangement of the work is shown on the following Figures:

Figure 1 – Site Location Plan

Figure 2 – Decline Plug Location and Design

Figure 3 – Vent Raise Plug Location and Design

Figure 4 – Standpipe Layout and Installation Guidelines – Decline Plug

Figure 5 – Standpipe Layout and Installation Guidelines – Vent Raise Plug

Figure 6 – Formwork Elevation and Section – Decline Plug

Figure 7 – Formwork Details and Notes – Decline Plug

Figure 8 – Formwork Elevation and Section – Vent Raise Plug

Figure 9 – Formwork Details and Notes – Vent Raise Plug

5.2 Plug Area Preparation

5.2.1 Shear Key Excavation

Depending on the rock quality of the argillite in the rib and floor at the decline plug location, it may be necessary to key in the plug with the rock in the floor of the decline. If necessary, this would be done by cutting a notch into the floor approximately 0.75 m into the plug extension. The trench should be approximately 0.5 m wide by 0.5 m deep.

5.2.2 Foundation Preparation

All surfaces of the existing decline and vent raise should be completely clean (including air/water jetting) and free of debris. Loose, semi-detached and unsound (i.e., hollow sounding) segments should be chipped or scaled to expose the underlying bedrock. All surfaces should be roughened by chipping to ensure that adequate foundation bonding is achieved between the bedrock and the concrete plug.

Some chipping of the tunnel liner and the removal of low protrusions in the back of the tunnel and overhanging areas in the walls may be necessary to minimize the trapping of air and the potential formation of voids. The placement of pipes into the high areas that vent out through the formwork may be required at the time of construction.

5.2.3 Water Handling

Prior to initiating construction, water levels within the mine must be maintained at a level below the Decline Plug, and for an additional 28 days after pouring of the concrete plug or until the design strengths have been achieved. To maintain adequate water levels, it may be necessary to pump the water level down sufficiently before building the formwalls, or install a drain pipe through the decline plug to maintain correct water levels. For the purposes of this report, it is assumed that the water level will be drawn down sufficiently and therefore a drain pipe is not required.

5.3 Formwork

5.3.1 General Guidelines

Design drawings for the decline and vent raise formwalls is provided in Figures 6 to 9. The design has been completed by an engineer, registered in the Yukon. Conditions and limitations of the designs, as included in the notes, must be followed.

5.3.2 Standpipe Installation

To guide the alignment of the grout holes to intersect the concrete-to-bedrock interface at the prescribed distances from the face of plug and spacing around the perimeter of the interface, nominal 50 mm (2-inch) inner diameter, Schedule 80, steel pipes should be installed as shown on Figures 4 and 5.

5.3.3 Thermistor Installation

To monitor curing temperatures, one single node thermistor should be hung at the core of each plug, and a second thermistor installed a minimum of 1 m into the rib, at some location along the length of the plug extension. The thermistor at the core can be fixed in place using tie-wire, while the thermistor installed into the rib can be grouted in place.

5.4 Materials

5.4.1 Concrete Mix

For ease of construction, it is desired that the concrete flows easily between the forms and requires little placement labour. Therefore, the use of Self-Consolidating Concrete (SCC) is recommended to increase the workability and eliminate the requirement to vibrate the concrete.

A typical mix design used for this purpose should meet or exceeded the following general guidelines for SCC concrete:

- Type MS, moderate sulphate resistant cement.
- Class F fly ash at 65% by weight of the batch should be used to reduce the heat of hydration and help avoid thermal shrinkage cracking during curing.
- 56-day Unconfined Compressive Strength (UCS) = 25 MPa.
- Maximum aggregate size = 20 mm.
- Slump (before admixture) = 50 ± 10 mm.
- Slump flow (after admixture) = 710 ± 25 mm.
- Entrained Air ≤ 2%, minimal.

In addition to the above general guidelines, based on Golders experience, the following should be considered with respect to the developing the SCC mix design:

- Admixtures should be applied to the concrete by representatives of the admixture supplier, BASF, or an approved alternate. Some of the admixtures will be applied at the batch plant and others on site.
- Admixtures are expected to include high-range water reducing admixtures and a hydration retarder. Measurements of slump flow carried out before and after admixture addition should be performed in accordance with an industry accepted standard.
- The fly ash used in the mix will be Class F with the requirements that the CaO content will not exceed 10 percent and the Loss on Ignition will not exceed 6 percent. In addition, the Sulfate Resistance Factor R of the fly ash must be less than 0.75, where:

$$R = (CaO\% - 5\%) / (Fe_2O_3\%)$$

- The concrete design should stipulate the required testing for quality control of the concrete, including the number of tests to be conducted and the time interval for the cured specimens (e.g., 7 days, 14 days, 28 days and/or 56 days).
- Any proposed mix design from the concrete supplier should be tested, at the batch plant, prior to pouring the plugs. The peak temperature of hydration during curing for the proposed mix design should be established, on site, prior to commencing construction activities.
- The fine aggregate will consist of clean, washed, siliceous sand of uniform gradation.

- The coarse aggregate will be, clean, washed, crushed gravel with a maximum size of 20 mm. It must comprise hard, strong, durable pieces, free of deleterious substances and adherent coatings containing no flat or elongated particles in excess of 15% by weight.
- Water used in mixing concrete will be potable quality, free of oil, acid, alkali, organic matter and other deleterious substances.

To reduce the potential for the development of delayed ettringite formation, which can cause internal expansion and cracking of the concrete and thus decrease the long-term durability of the concrete, the maximum concrete temperature during curing should not exceed 70°C. Temperature is controlled by reducing the use of Ordinary Portland Cement by replacing a portion with either fly ash or a granulated blast furnace slag.

Additionally, to minimize the potential for thermal cracking, experience has shown that the difference in temperature between the core of the plug and the surrounding bedrock should not exceed 3°C. Thermal cracking will occur when contraction due to cooling at the surface causes tensile stresses that exceed the tensile strength of the concrete.

We suggest that the local concrete admixtures technical product representative be contacted to work with YZC to develop the specified mix design and conduct all testing and batching.

5.4.2 Ultrafine Cement

Ultrafine cement should be used to carry out contact and consolidation grouting activities. Acceptable ultrafine cements for pressure grouting activities include US Grout, Ultrafine VX (supplied with manufacturer recommended superplasticizer).

5.4.3 Type HE Cement

It is anticipated that the majority of contact and consolidation grouting activities (particularly in the floor and rib of the decline where there is anticipated to be an argillitic contact) will be completed with ultrafine cement. However, if during injection, grout takes exceeding 100 kg/m stage length are encountered, it may be necessary to thicken the grout being injected to coarser grind, Type HE based cementitious grouts.

5.5 Concrete

5.5.1 Concrete Delivery

Delivery of the concrete to the plug locations will need to be considered and options assessed to determine the preferred method. The more likely option for delivery is to hang a 6-inch slickline along the floor and rib of the decline and vent raise tunnels. This option will need to consider:

- safety risks
- cost
- risk of blockage/disruption during concrete delivery

- distance from batch plant to delivery points (i.e., length travelled by concrete trucks)
- potential for physical obstruction of the plug construction due to delivery system

It is anticipated that concrete will be supplied to the portal and vent openings on surface in ready-mix trucks on a schedule determined in co-operation between the on-site batch plant and the admixture chemical representative.

It is strongly recommended that a "dry run" is carried out by transporting concrete from surface to the downstream side of the constructed formwall using the proposed concrete mix. This will allow the YZC and all contractors to test the procedures and infrastructure prior to pouring in order to reduce the potential for cold joints.

5.5.2 Placement

- Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned of all hardened concrete and foreign materials. All debris shall be removed from the forms and all forms shall be thoroughly soaked with water.
- Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable and within one hour of the time of mixing unless a retarding agent is used. To prevent segregation during concrete placement, concrete shall not be dropped freely from the end of the chute more than 1.5 m.
- When concrete placement has commenced, it shall be carried on continuously until complete in order to prevent horizontal cold joints within each pour.
- YZC or the contractor shall ensure that the necessary materials and equipment are available, and the equipment is in good working order so that an uninterrupted pour is assured.
- To reduce the potential for thermal cracking of the plug during curing, the temperature of the concrete during placement shall be 8 °C to 15 °C. Given these requirements, it may be necessary to use heated water during the concrete batching process.
- Chemical admixtures for the self-consolidating concrete should only be added at the collar of the slick line.

5.6 Cold Joints

A cold joint is an unplanned joint resulting when a concrete surface hardens before the next batch of concrete is placed against it. In the event of equipment breakdown, or other unavoidable prolonged interruption of continuous placing which results in concrete hardening to the extent that a cold joint will be formed, YZC should immediately apply a concrete retardant (BASF MasterFinish EA 48 Deep or approved equivalent) to the surface of the concrete. Once the bulk of the concrete has set, the retarded surface matrix can be removed to expose the aggregate to which subsequently placed concrete can bond.

5.7 Grouting

5.7.1 Contact Grouting

A water tight contact along the concrete-to-rock interface is of importance in developing the plug length required to establish the design hydraulic gradient. Contact grouting over the entire length of the plug extension will be required to ensure that these two zones of concerns are properly sealed, Figures 4 and 5.

Grouting of this concrete/rock interface, especially that carried out to fill any voids found at the top of the bulkhead should be performed with Type III Portland cement/Class F fly ash (mixed in the ratio 2:1) grout.

5.7.2 Consolidation Grouting

Consolidation grouting is essential to ensure that rock discontinuities are adequately filled and sealed to reduce the hydraulic conductivity of the rock mass in the immediate area around the plug. Additionally, given the proximity of the plug to the ground surface, and limited amount of rock cover above the plug location, consolidation grouting is required to ensure that the surrounding rock mass can withstand the design head. As such, the secondary grouting will take place by drilling out Ring A 2.5 metres deeper than the concrete / bedrock interface after the contact grouting has been completed to ensure that the rock mass around the entire perimeter of the plug extension has been grouted.

Grouting pressure will be approximately 1.3 MPa to 2.0 MPa corresponding to approximately 1.3 to 2.0 times the hydraulic head applied to the bulkheads once the groundwater has reached equilibrium. At this injection pressure, some hydraulic jacking of existing discontinuities can be expected. Such jacking is deemed to be beneficial to the consolidation of the surrounding rock mass in this case. However, such activity must be monitored in real-time, with in-line pressure transducers and magnetic flow meters during injection. The details of grouting quality control / quality assurance during construction should be determined prior to construction.

5.8 Completion

Upon completion of the plug and the consolidation grouting, the length between the portal and vent entrance should be maintained such that monitoring and assessment of the plug can be done on an annual basis until the groundwater has reached equilibrium or for 5 years, whichever is shorter. The purpose of this monitoring is to confirm that the plug is performing as per the requirements and that leakage.

Observations, including photographs, will be made and recorded by experienced underground personnel. Inspections will include the following items:

- Condition of the portal doors and locks.
- Ice or sediment buildup that may affect the water drainage.
- Condition of ground support.
- Recording the pressure on the dial gauge.
- Water seepage. Indications of water seepage will be recorded, both through and around the bulkhead, into the drift, and at the ground surface between the Decline and Ventilation portals.
- Estimation of the discharge rate (e.g., by using the fill time of a five gallon bucket).

6.0 SAFETY CONSIDERATIONS

The construction of the Decline and Vent Raise Plugs will involve the typical hazards associated with underground construction. It is expected that all hazards can be managed without introducing unreasonable risk.

A risk assessment of all hazards would be performed in subsequent stages of design and in the planning stages for construction, specifically to address the confined space entry to the proposed location of the Decline and Vent Raise Plugs to address this hazard and plan appropriate ventilation and entry procedures prior to rehabilitation of the tunnel, construction of the formwalls and plugs.

7.0 CLOSURE

As no site visit has been completed at this time, the design of each plug as presented in this letter has been based on the information obtained during the data review and as-built information provided by YZC. A site reconnaissance to confirm the assumed conditions at the proposed plug locations must be carried out by Golder prior to preparing "Issued for Construction" drawings and specifications. The reader is referred to the Study Limitations, which follows the text and forms an integral part of this memorandum.

We trust this letter is sufficient for your immediate requirements. Should you have questions or comments please contact the undersigned at your earliest convenience.

Yours very truly,

GOLDER ASSOCIATES LTD.

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Reviewed By:

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ALP/GRB/DTK/rs/cr

Attachments: Study Limitations
Figures 1 to 9
Attachment 1: Plug Length Design Calculations

https://golderassociates.sharepoint.com/sites/14126g/deliverables/3. issued/1778120-002-l-rev0-1000/1778120-002-l-rev0-1000-plug design letter 24jul_17.docx

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STUDY LIMITATIONS

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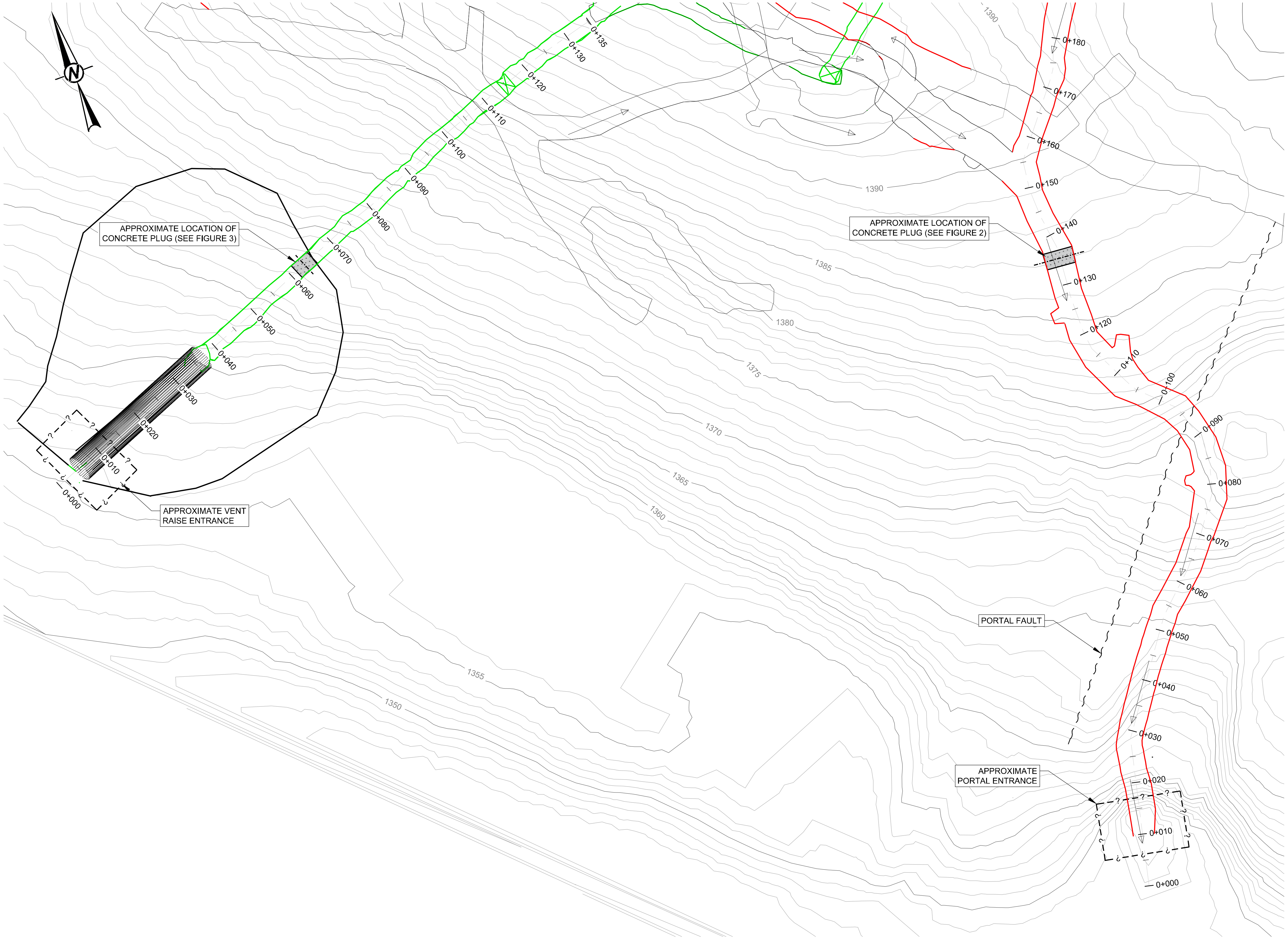

LEGEND

- DECLINE EXTENTS
- VENT RAISE EXTENTS
- EXISTING GROUND CONTOURS (1 m INTERVALS)
- AIR FLOW DIRECTION - PRE MINE FLOODING
- PORTAL FAULT

REFERENCE(S)

1. BASE DRAWINGS PROVIDED BY CLIENT. FILES: YZC_Asbuilt_VentRaise.dxf, YZC_Asbuilt_Decline_DownTo1300EL.dxf AND Surface Faults Portal Area UTMNAD83Zn9.dxf DATED: 17 MAY 2017.

PRELIMINARY DRAWINGS

NOT FOR CONSTRUCTION

0 20 40

1:800 METRES

REV.	YYYY-MM-DD	DESCRIPTION	DESIGNED	PREPARED	REVIEWED	APPROVED
A	2017-07-24	PRELIMINARY - ISSUED FOR USE	IP	BL	AP	

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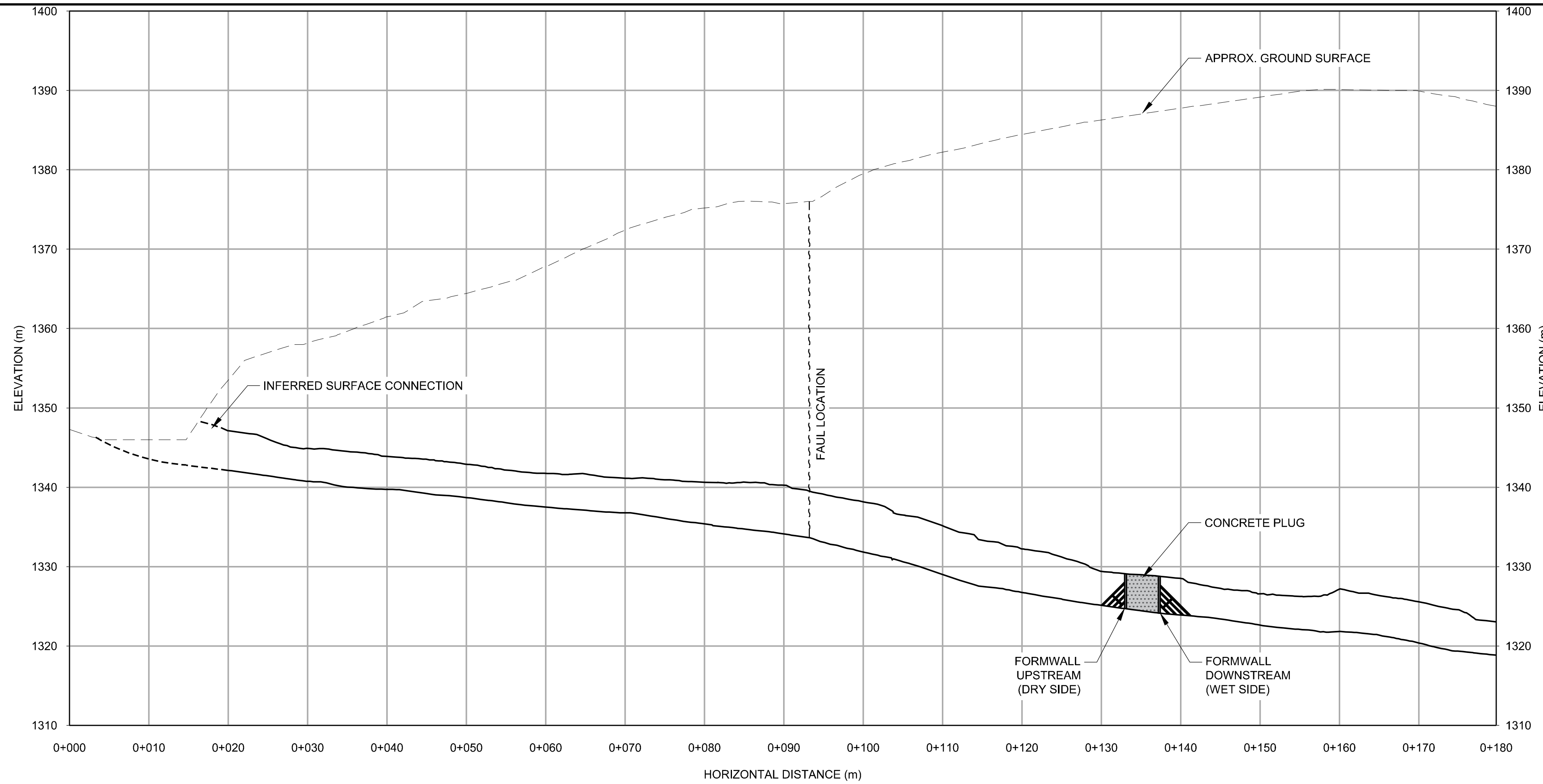
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
SITE PLAN

PROJECT NO.	PHASE	REV.	of	FIGURE
1778120	2000	A		1



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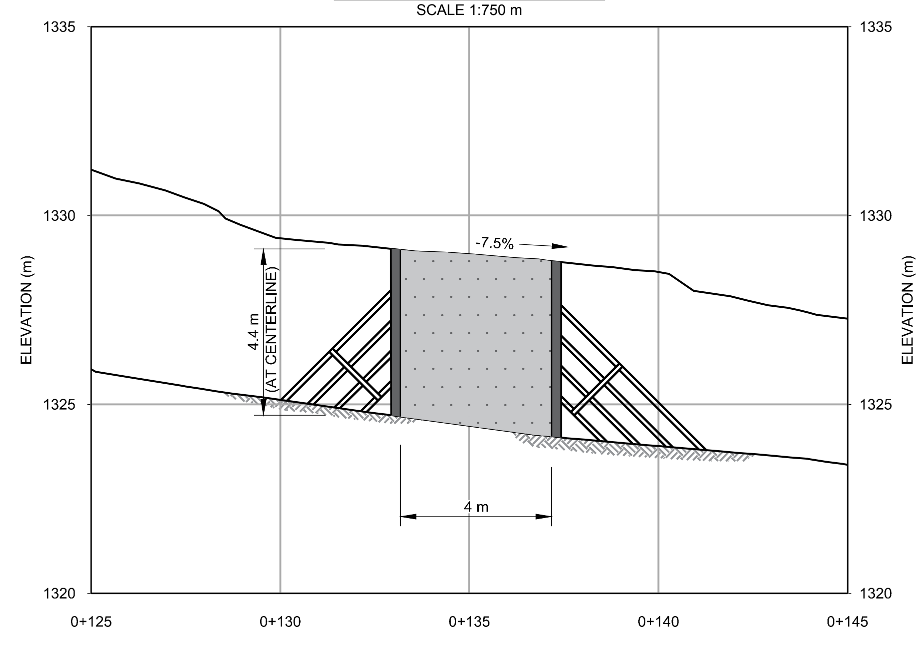
SCALE 1:750 m



PLUG DESIGN DETAIL
SCALE 1:200 m

LEGEND

CONCRETE PLUG

NOTES

APPROXIMATE CONSTRUCTION SEQUENCE:

1. REHAB OF THE TUNNEL TO THE PLUG LOCATION WILL BE REQUIRED. (APPROXIMATELY 140 m).
2. THOROUGHLY SCALE, MUCK OUT FLOOR, AND CLEAN (WITH COMPRESSED AIR AND WATER) A ZONE 5 m EITHER SIDE OF PROPOSED FORMWALL LOCATIONS.
3. CONSTRUCT FORMWALL ON THE DOWNSTREAM SIDE OF THE PLUG.
4. CONSTRUCT FORMWALL ON THE UPSTREAM SIDE OF THE PLUG.
5. CLEAN FLOOR, RIBS AND BACK.
6. INSTALL GROUTING STANDPIPES (50 mm INSIDE DIAMETER, SCHED 40 PIPE).
7. REMOVE, CUT DOWN ANY MESH/SCREENING.
8. PUMP IN CONCRETE (SELF CONSOLIDATING CONCRETE) BETWEEN FORMWALLS.
9. WATER LEVEL TO BE AT LEVEL TO ALLOW 28 DAY CURE OF CONCRETE.
10. ALLOW PLUG CORE TO COOL TO ORIGINAL ROCK MASS TEMPERATURE.
11. REMOVE UPSTREAM FORMWALL AND DRILL OUT STANDPIPES, IF NECESSARY.
12. CONDUCT PRIMARY AND SECONDARY ULTRAFINE CEMENT (GROUTING) THROUGH THE SCHED 80 STANDPIPES.

REFERENCE(S)

1. BASE DRAWINGS PROVIDED BY YUKON ZINC CORP. FILES: YZC_Asbuilt_VentRaise.dxf, YZC_Asbuilt_Decline_DownTo1300EL.dxf AND Surface Faults Portal Area UTMNAD83Zn9.dxf DATED: 17 MAY 2017.
2. EXISTING TOPOGRAPHY PROVIDED BY YUKON ZINC CORP.

PRELIMINARY DRAWINGS

NOT FOR CONSTRUCTION

0 5 10
1:200 METRES

0 12.5 25
1:750 METRES

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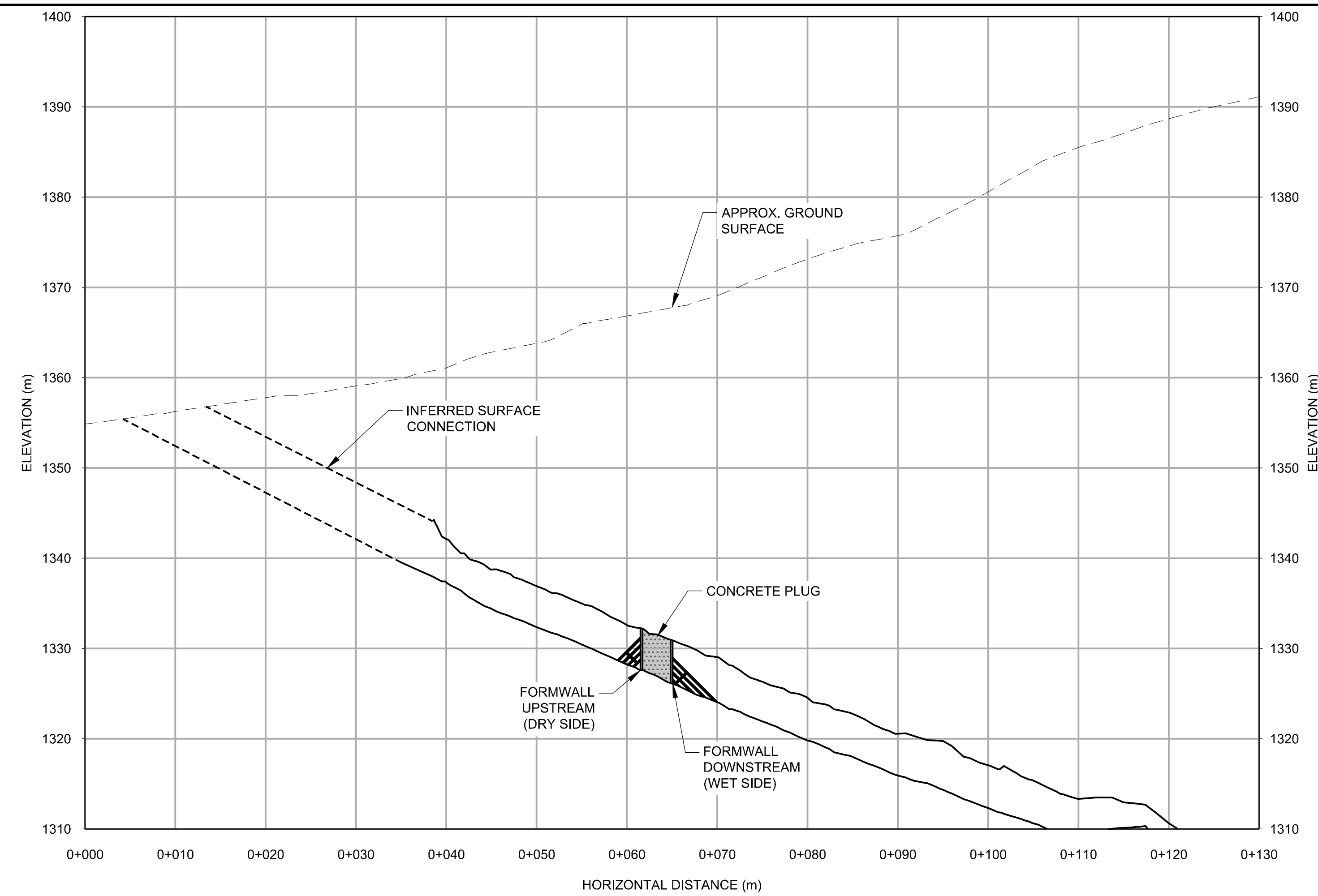
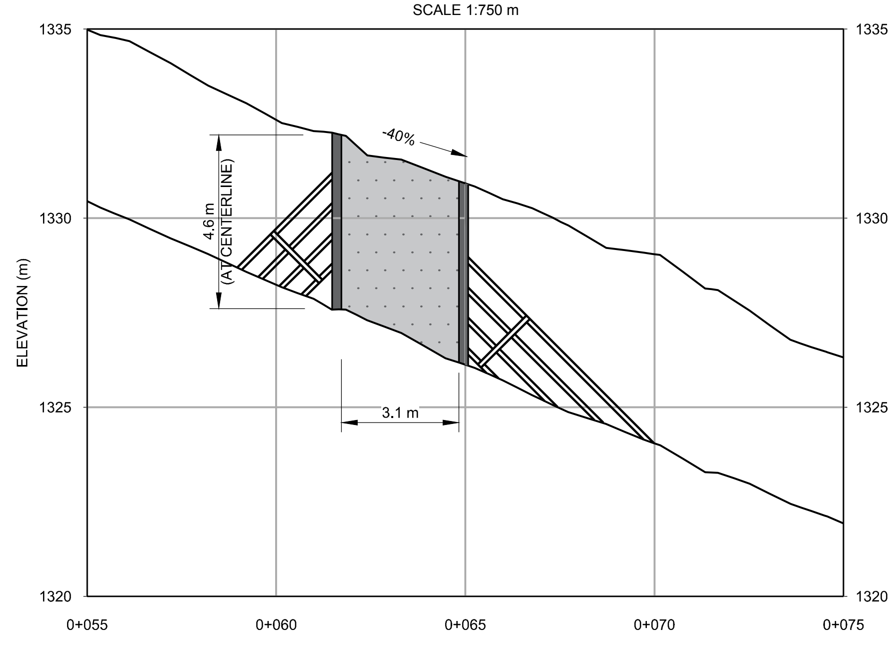
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
PORTAL PLUG DESIGN

PROJECT NO.	PHASE	REV.	of	FIGURE
1778120	2000	A		2



PLUG DESIGN LOCATION
SCALE 1:750 m



PLUG DESIGN DETAIL
SCALE 1:200 m

LEGEND

CONCRETE PLUG

NOTES

APPROXIMATE CONSTRUCTION SEQUENCE:

1. REHAB OF THE TUNNEL TO THE PLUG LOCATION WILL BE REQUIRED. (APPROXIMATELY 60-70 m).
2. THOROUGHLY SCALE, MUCK OUT FLOOR, AND CLEAN (WITH COMPRESSED AIR AND WATER) A ZONE 5 m EITHER SIDE OF PROPOSED FORMWALL LOCATIONS.
3. CONSTRUCT FORMWALL ON THE DOWNSTREAM SIDE OF THE PLUG.
4. CONSTRUCT FORMWALL ON THE UPSTREAM SIDE OF THE PLUG.
5. CLEAN FLOOR, RIBS AND BACK.
6. INSTALL GROUTING STANDPIPES (50 mm INSIDE DIAMETER, SCHED 40 PIPE).
7. REMOVE, CUT DOWN ANY MESH/SCREENING.
8. PUMP IN CONCRETE (SELF CONSOLIDATING CONCRETE) BETWEEN FORMWALLS.
9. WATER LEVEL TO BE AT LEVEL TO ALLOW 28 DAY CURE OF CONCRETE.
10. ALLOW PLUG CORE TO COOL TO ORIGINAL ROCK MASS TEMPERATURE.
11. REMOVE UPSTREAM FORMWALL AND DRILL OUT STANDPIPES, IF NECESSARY.
12. CONDUCT PRIMARY AND SECONDARY ULTRAFINE CEMENT (GROUTING) THROUGH THE SCHED 80 STANDPIPES.

REFERENCE(S)

1. BASE DRAWINGS PROVIDED BY YUKON ZINC CORP. FILES: YZC_Asbuilt_VentRaise.dxf, YZC_Asbuilt_Decline_DownTo1300EL.dxf AND Surface Faults Portal Area UTMNAD83Zn9.dxf DATED: 17 MAY 2017.
2. EXISTING TOPOGRAPHY PROVIDED BY YUKON ZINC CORP.

PRELIMINARY DRAWINGS

NOT FOR CONSTRUCTION

0 5 10
1:200 METRES

0 12.5 25
1:750 METRES

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PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
VENT RAISE PLUG DESIGN

PROJECT NO.	PHASE	REV.	of	FIGURE
1778120	2000	A		3

25 mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

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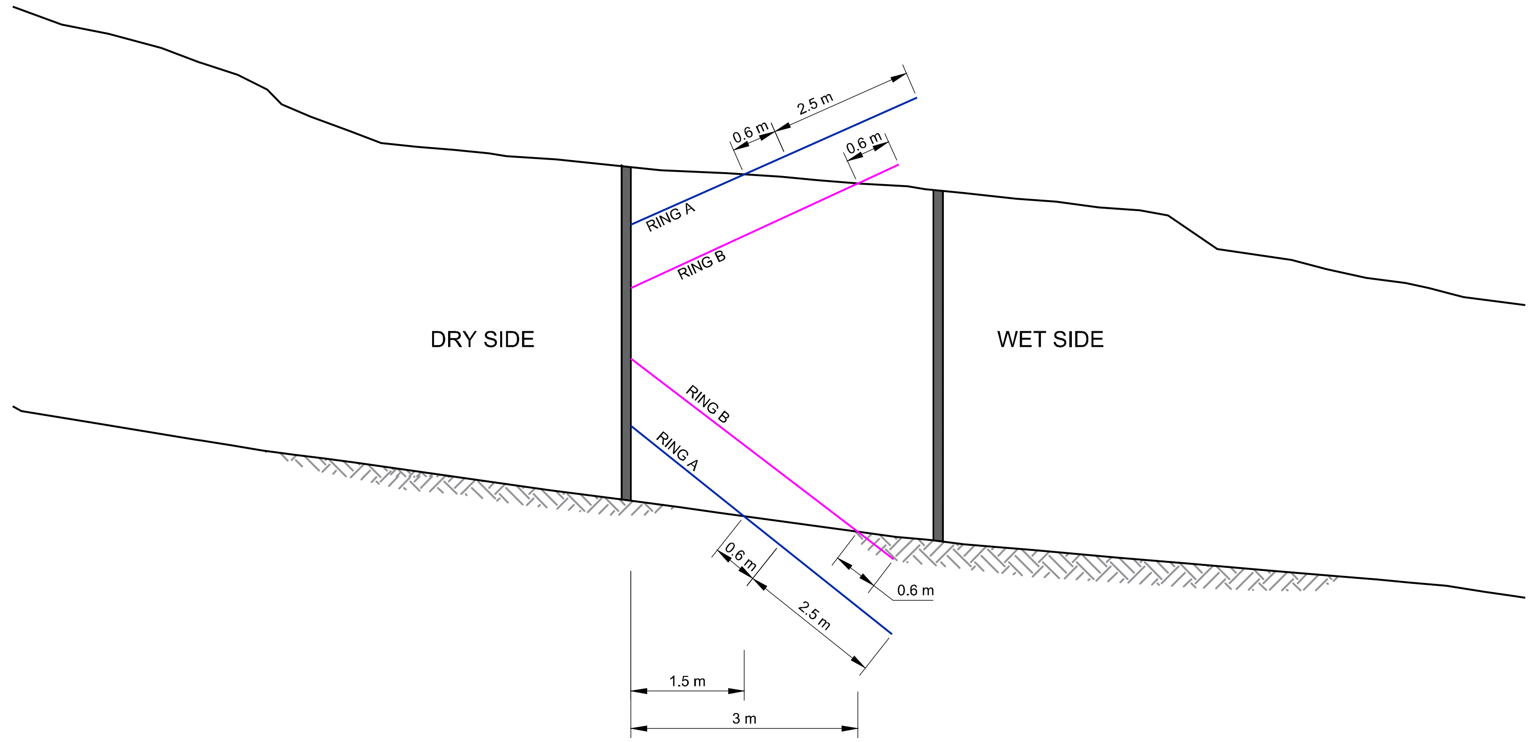


LONGVIEW SCHEMATIC
NOT TO SCALE

GROUT STANDPIPES

LAYOUT

The grout standpipes must be accessible when the forms are stripped and are designed to hit the concrete / bedrock interface at distances of 1.5 m and 3.0 m from the free face of the plug. The location of the collars (on the back of the formwork) will depend on the rock profile where the pipes end up, and on the operational envelope of the proposed drill. The toes are designed to hit the concrete / bedrock interface as shown.

An example methodology to layout the grout standpipes is included below.

A. Before the formwork is constructed:

1. At distances of 1.5 m and 3 m from the proposed dry face of the plug, spray paint a line exactly perpendicular to the centreline of the drift around the perimeter.
2. Layout the toes of the standpipes for Rings A and B as shown.

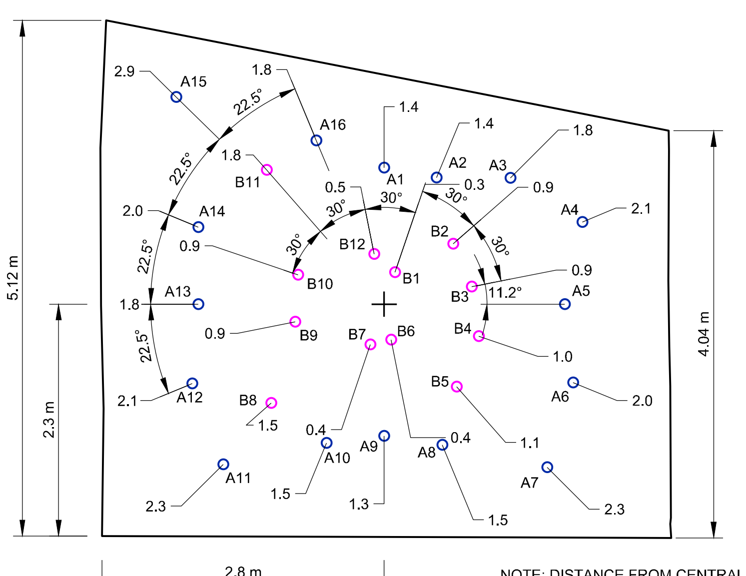
INSTALLATION

1. Install nominal 50 mm (2 inch) diameter, Steel Schedule 80 standpipes between the marked-up collars at face and points on the bedrock. Rings A and B intersect bedrock at distances of 1.5 m and 3.0 m from the formwork, respectively.
2. Duct tape the back ends (end farthest from the formwork) of the standpipes closed. Attach the back ends of the standpipes to the bedrock using steel straps, securely anchored to the bedrock.
3. The end of the standpipe closest to the formwork should be threaded and fitted with a coupler. Stuff this end of the standpipe with a cloth rag to protect the threads on the inside of the coupler. Pull enough of the cloth over the outside of the coupler and secure it using rebar tie wire.
4. Glue a styrofoam "seating" square onto the backside of the formwork, at the centre of the standpipe collar, and cut a circle out into which to rest the standpipe. After the pour, the styrofoam pads will pull away when the formwork is stripped.
5. Strip the formwork and pull out the cloth rags from the grout hole collars. Screw 50-mm diameter (2 inch) nipples into the exposed couplers to protect the treads.
6. Additional grout standpipes may be required to infill "holes" in the back of the heading depending on the actual rock profile (to be determined on site).

GROUTING PROCEDURES

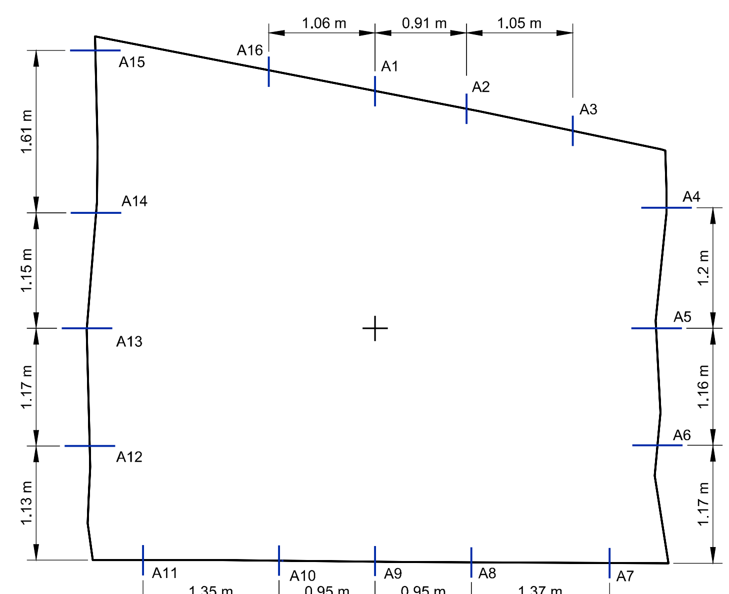
A. Carry out contact **Grouting** around the plug through pre-installed standpipes.
   1. Drill all primary holes in Rings A and B to 0.6 m beyond the concrete/bedrock interface.

B. Carry out consolidation grouting of bedrock around the plug through the pre-installed standpipes.
   1. Drill the primary grout holes in Ring A 2.5 m beyond the concrete bedrock interface.

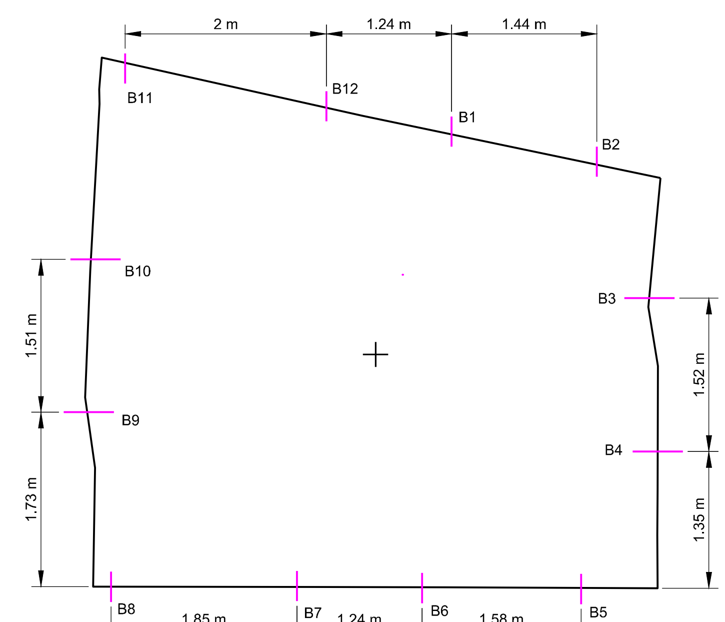


NOTE: DISTANCE FROM CENTRAL REFERENCE POINT IN METRES.

MARKUP OF ALL GROUT HOLES (FACE)
(LOOKING TOWARDS WET SIDE)



TOE SPACING AT 1.5 m (RING A)
(LOOKING TOWARDS WET SIDE)



TOE SPACING AT 3 m (RING B)
(LOOKING TOWARDS WET SIDE)

REFERENCE(S)

1. BASE DRAWINGS PROVIDED BY YUKON ZINC CORP. FILES: YZC_Asbuilt_VentRaise.dxf, YZC_Asbuilt_Decline_DownTo1300EL.dxf AND Surface Faults Portal Area UTMNAD83Zn9.dxf DATED: 17 MAY 2017.
2. EXISTING TOPOGRAPHY PROVIDED BY YUKON ZINC CORP.

PRELIMINARY DRAWINGS

NOT FOR CONSTRUCTION

SCHEMATIC ONLY
NOT TO SCALE

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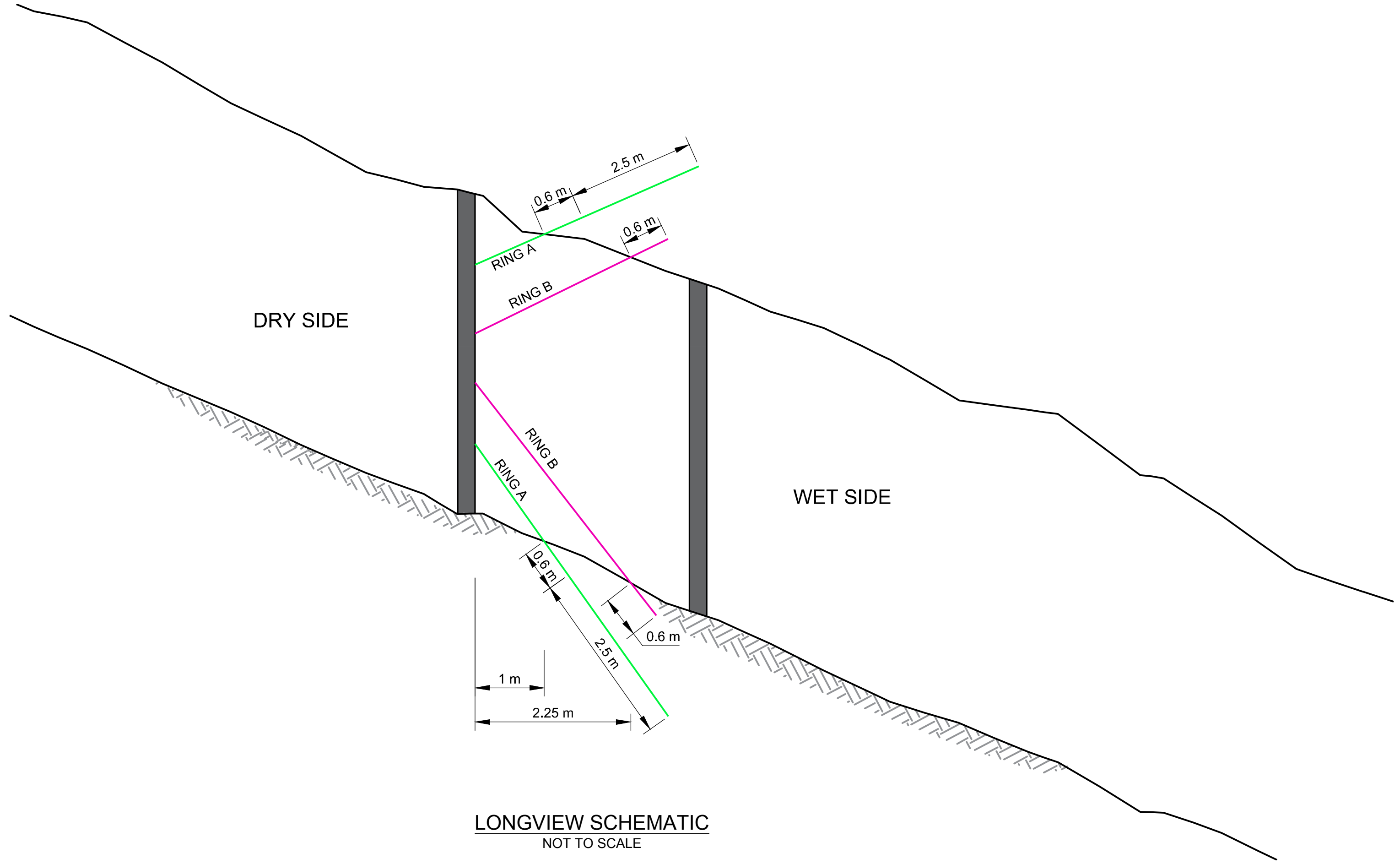
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
STANDPIPE LAYOUT AND INSTALLATION GUIDELINES (DECLINE PLUG)

PROJECT NO.	PHASE	REV.	of	FIGURE
1778120	2000	A		4



LONGVIEW SCHEMATIC
NOT TO SCALE

GROUT STANDPIPES

LAYOUT

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An example methodology to layout the grout standpipes is included below.

A. Before the formwork is constructed:

1. At distances of 1.5 m and 3 m from the proposed dry face of the plug, spray paint a line exactly perpendicular to the centreline of the drift around the perimeter.
2. Layout the toes of the standpipes for Rings A and B as shown.

INSTALLATION

1. Install nominal 50 mm (2 inch) diameter, Steel Schedule 80 standpipes between the marked-up collars at face and points on the bedrock. Rings A and B intersect bedrock at distances of 1.5 m and 3.0 m from the formwork, respectively.
2. Duct tape the back ends (end farthest from the formwork) of the standpipes closed. Attach the back ends of the standpipes to the bedrock using steel straps, securely anchored to the bedrock.
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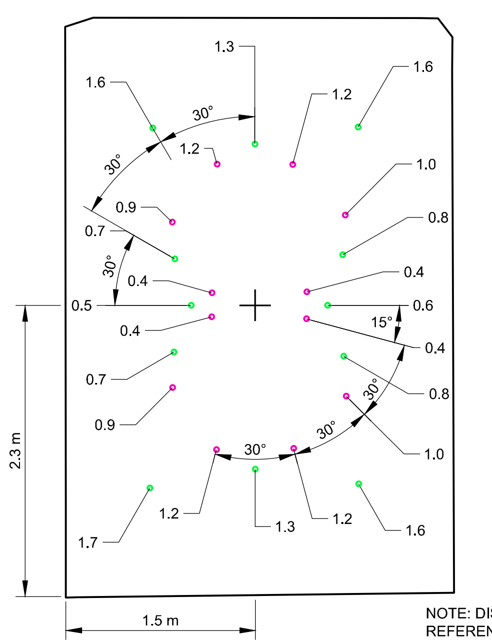
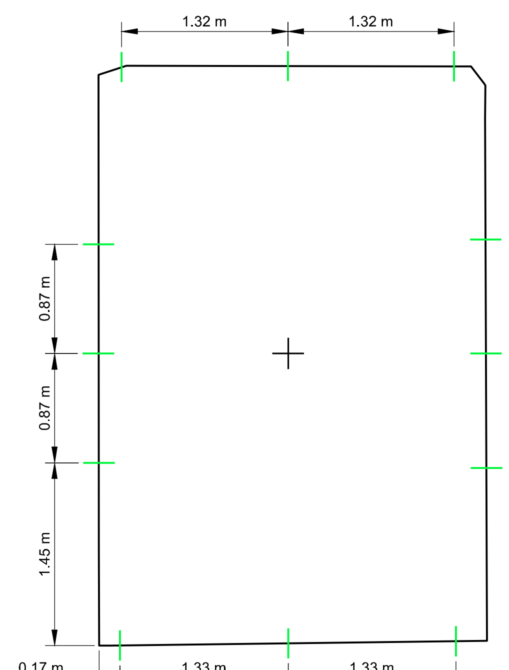
   1. Drill the primary grout holes in Ring A 2.5 m beyond the concrete bedrock interface.

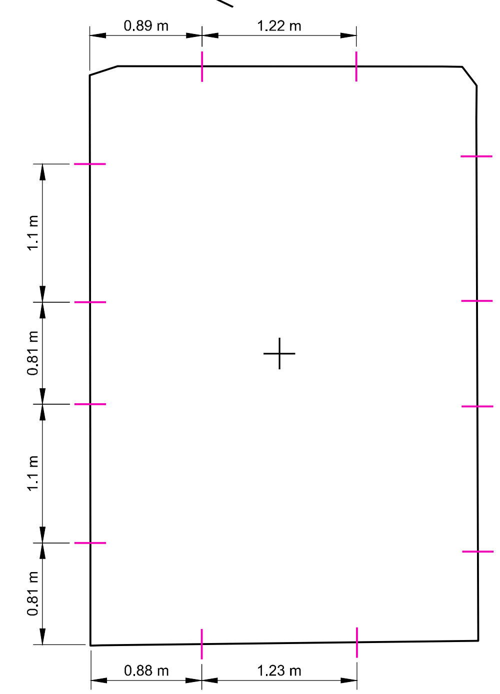


NOTE: DISTANCE FROM CENTRAL REFERENCE POINT IN METRES.

MARKUP OF ALL GROUT HOLES (FACE)
(LOOKING TOWARDS WET SIDE)



TOE SPACING AT 1.0 m (RING A)
(LOOKING TOWARDS WET SIDE)



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(LOOKING TOWARDS WET SIDE)

REFERENCE(S)

1. BASE DRAWINGS PROVIDED BY YUKON ZINC CORP. FILES: YZC_Asbuilt_VentRaise.dxf, YZC_Asbuilt_Decline_DownTo1300EL.dxf AND Surface Faults Portal Area UTMNAD83Zn9.dxf DATED: 17 MAY 2017.
2. EXISTING TOPOGRAPHY PROVIDED BY YUKON ZINC CORP.

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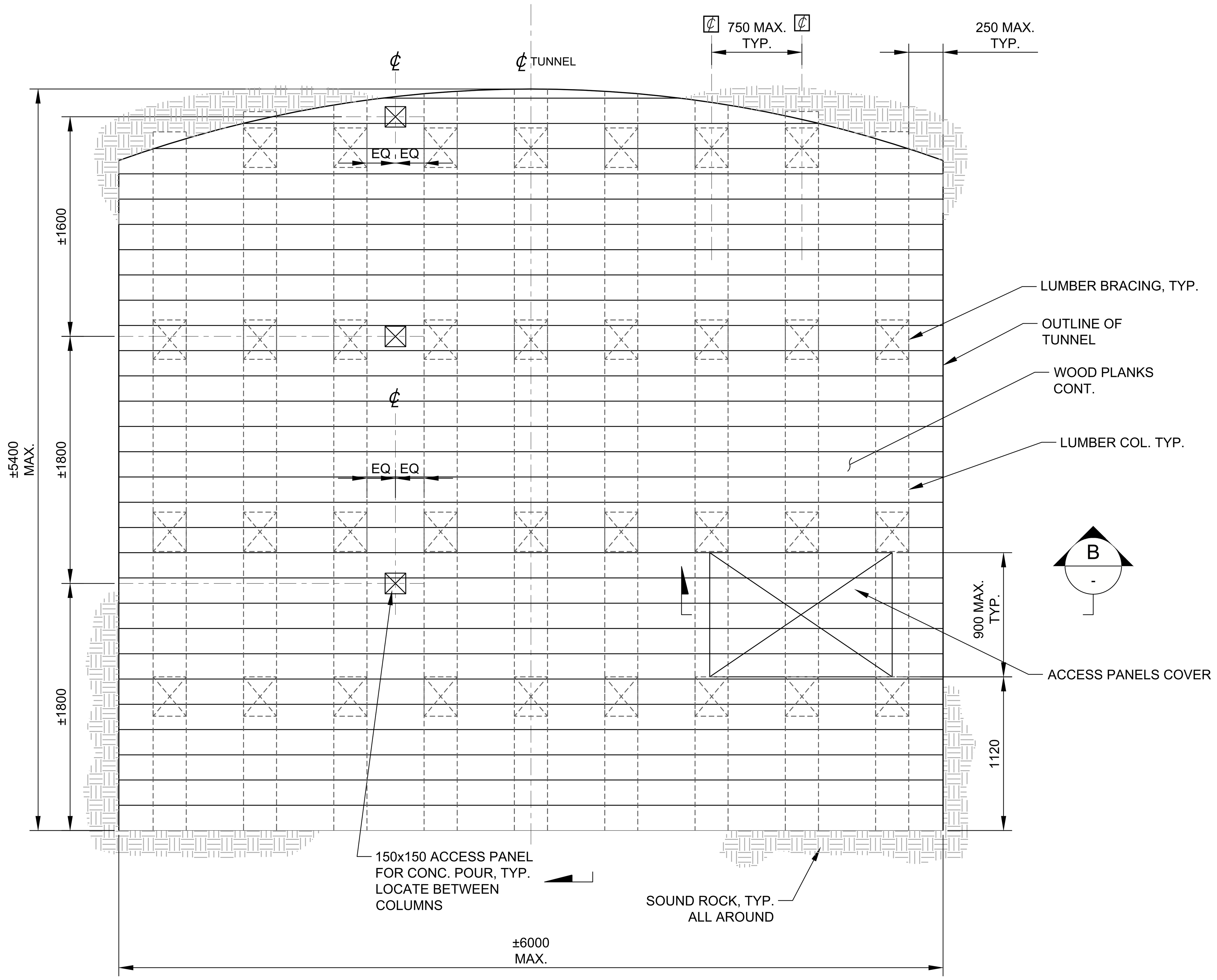
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

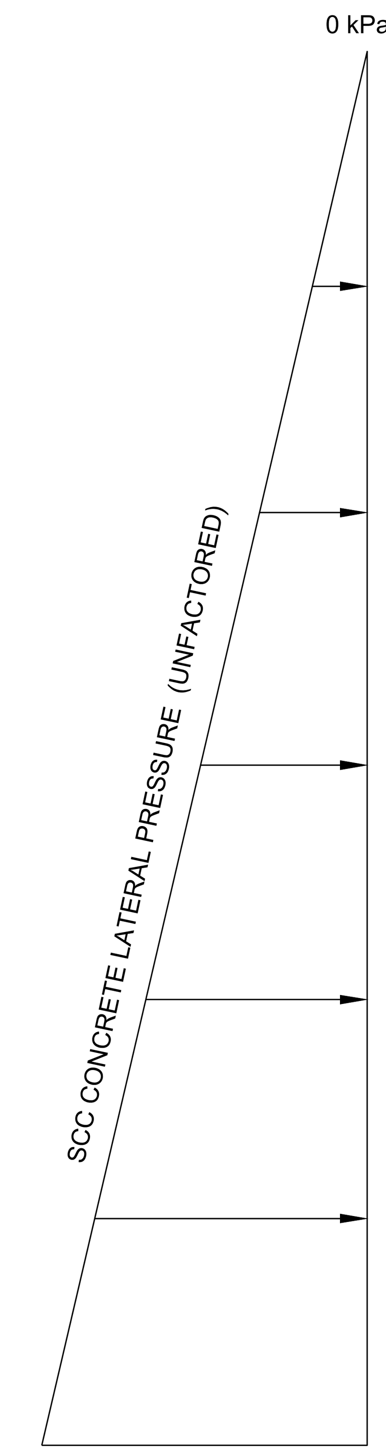
TITLE
STANDPIPE LAYOUT AND INSTALLATION GUIDELINES (VENT RAISE PLUG)

PROJECT NO.	PHASE	REV.	of	FIGURE
1778120	2000	A		5

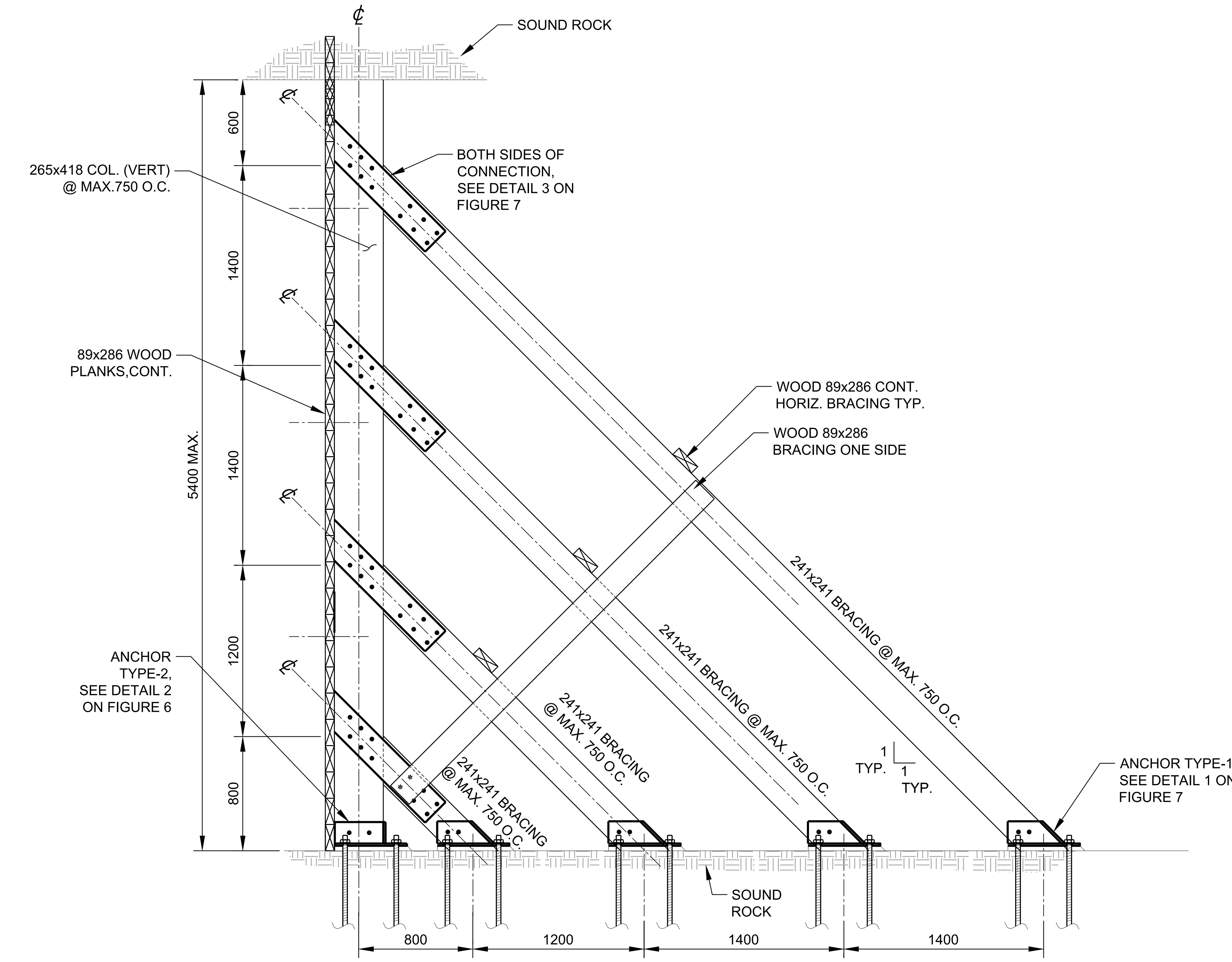


FORMWORK ELEVATION

SCALE 1:25

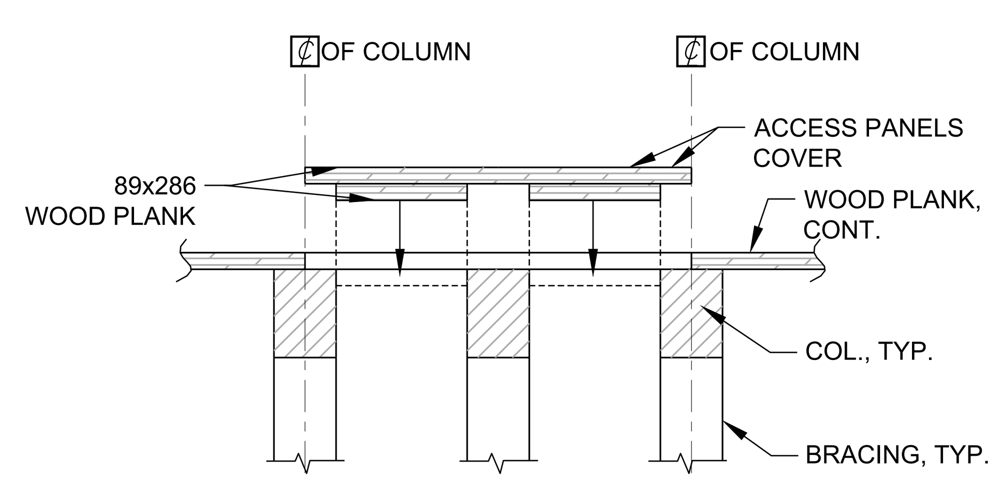


150 kPa
FORMWORK DESIGNED TO WITHSTRAND MAX. 5400 SCC HYDROSTATIC HEAD WIT HNO STRENGTH GAIN IN CONCRETE.



SCALE 1:25 A SECTION

NOTE:
ALL LENGTH MEASUREMENTS SHOWN ARE BASED ON MEMBER CENTER LINES, U.N.O.



SCALE 1:25 B SECTION

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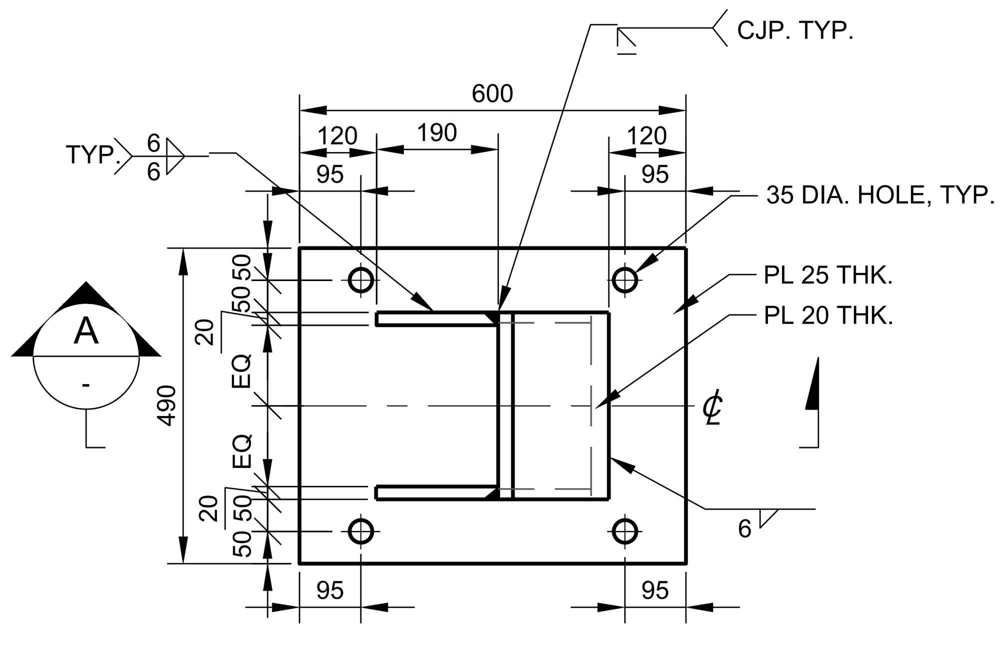
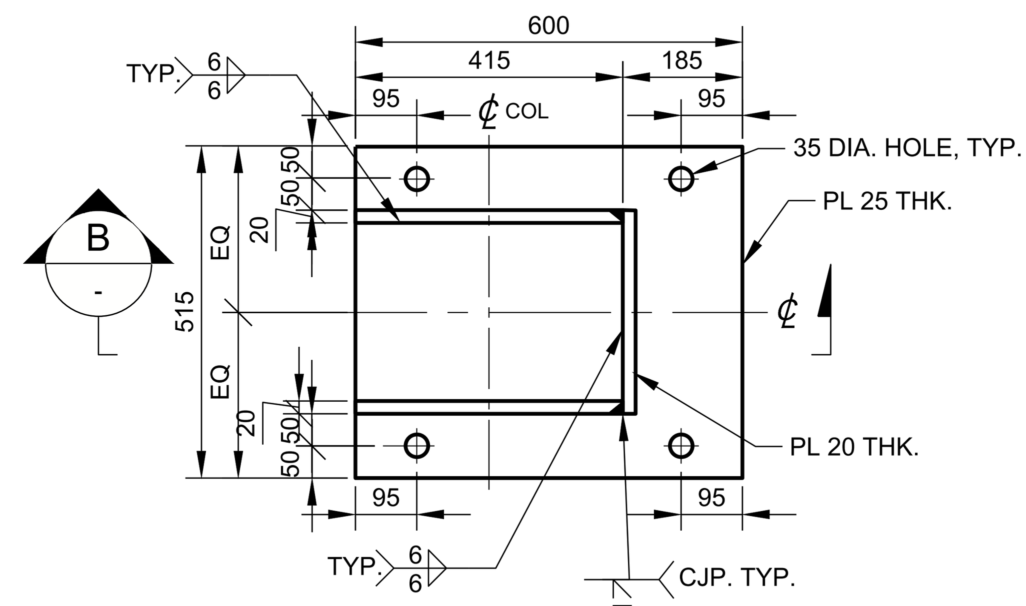
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
FORMWORK ELEVATION AND SECTION - DECLINE PLUG

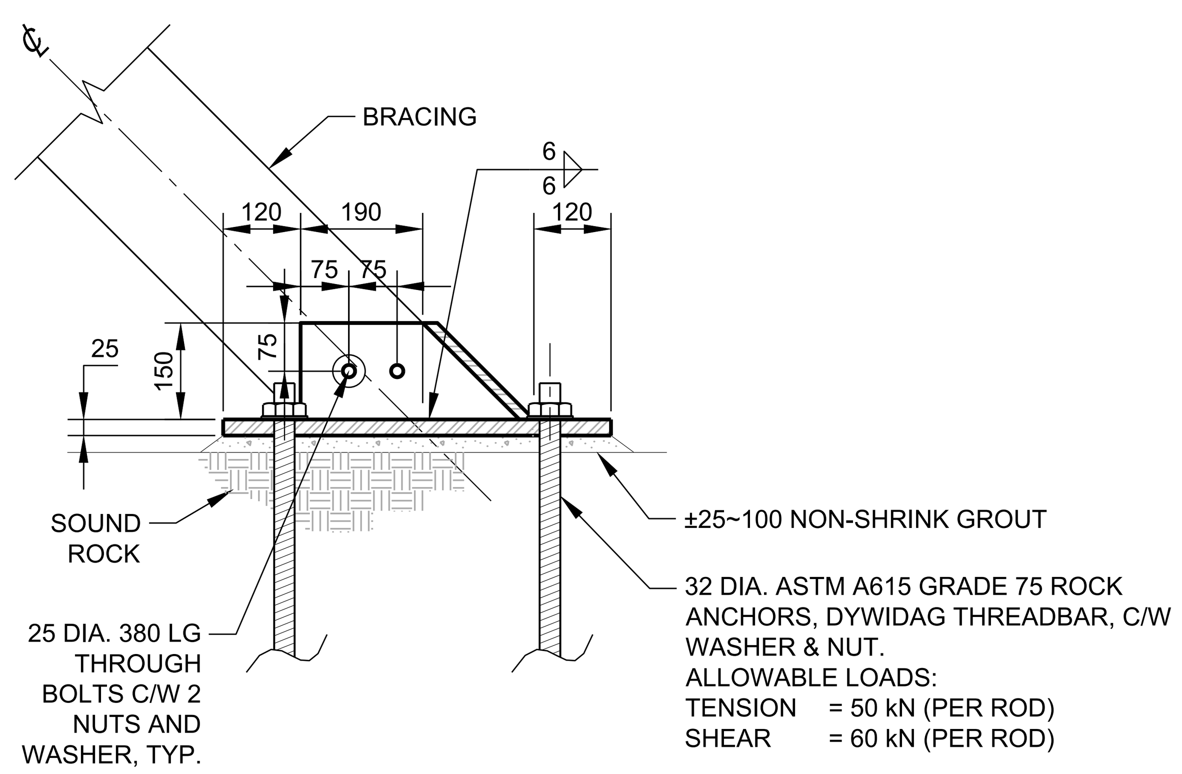
PROJECT NO.	PHASE	REV.	FIGURE
1778120	2000	B	6



SCALE 1:10 (1) DETAIL FIG 6



SCALE 1:10 (2) DETAIL FIG 6



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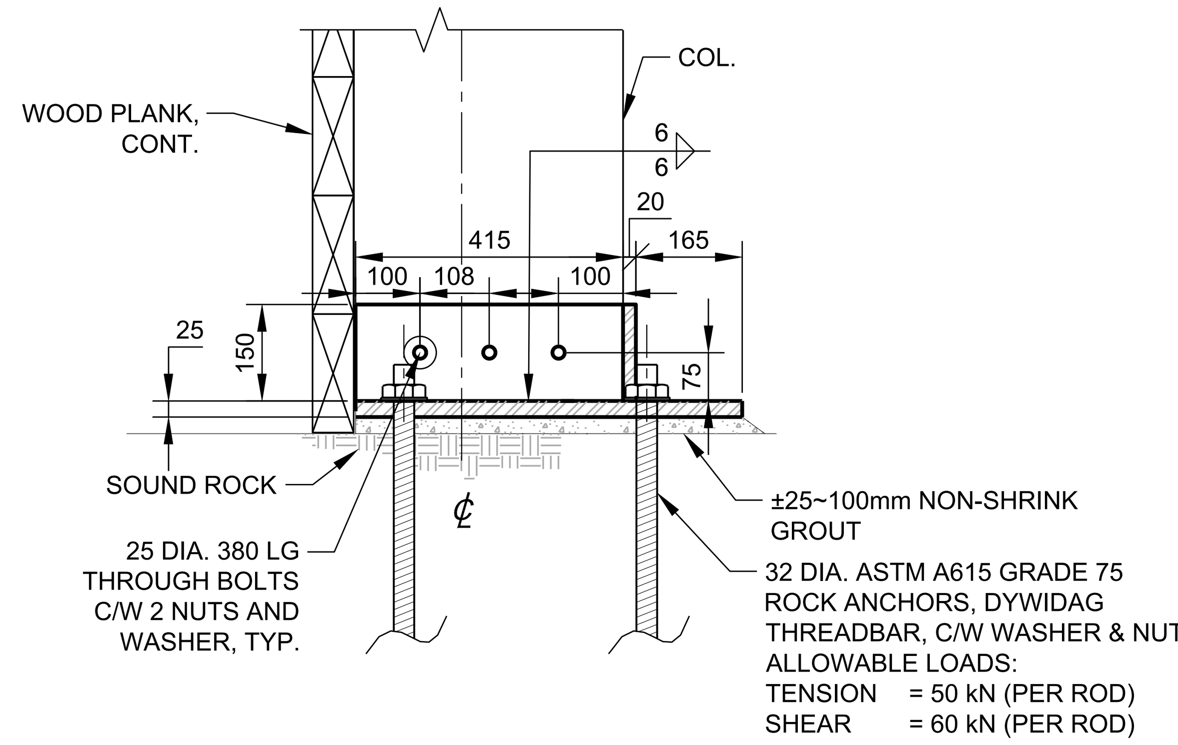

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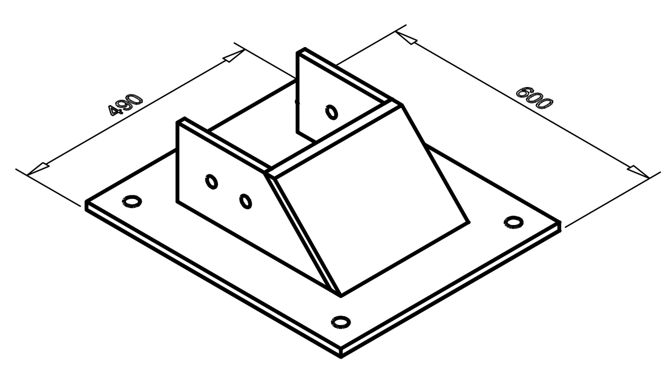
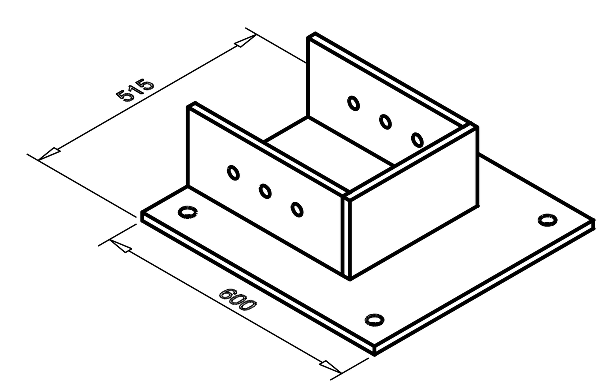


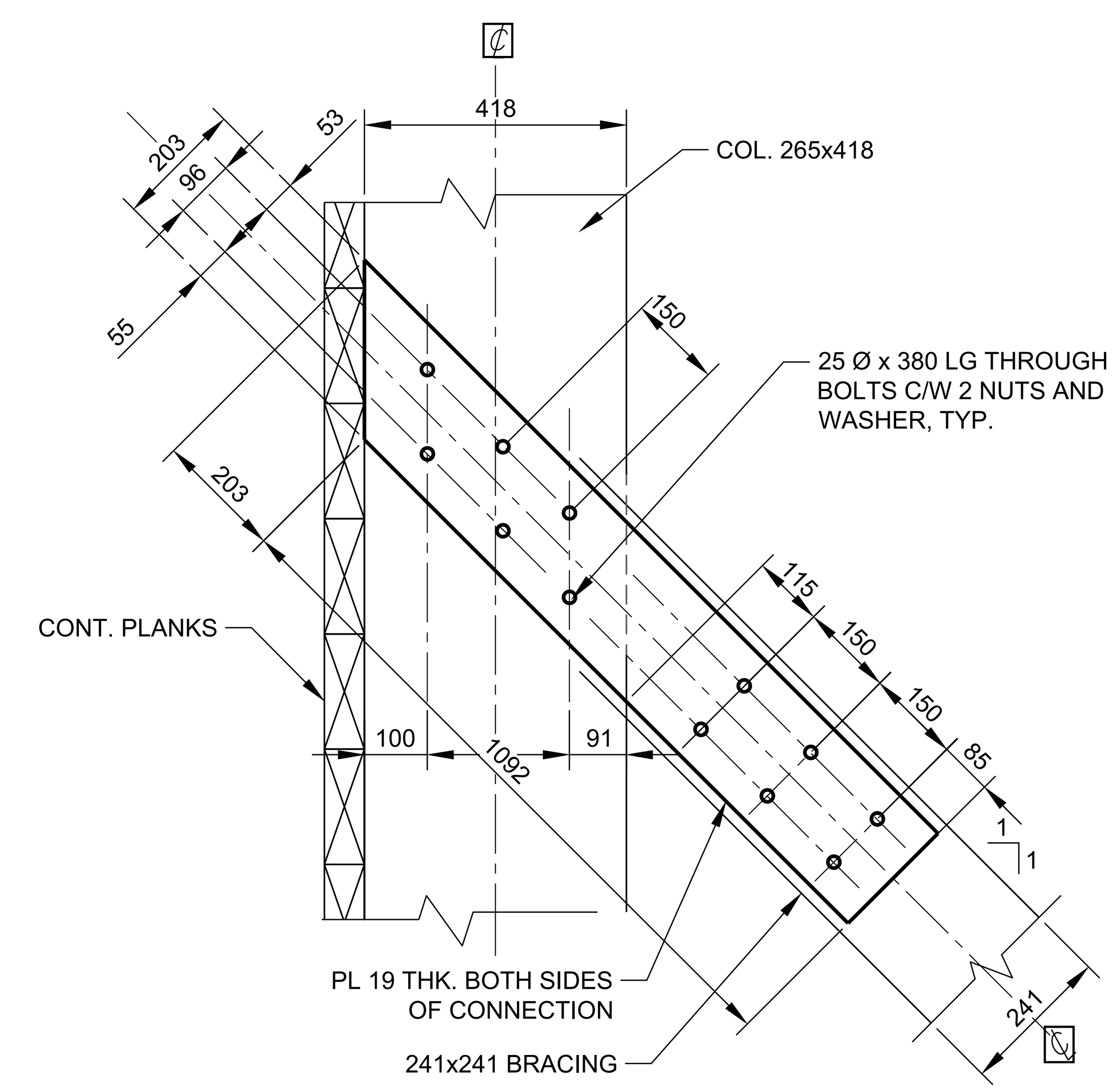
ISOMETRIC VIEW - ANCHOR TYPE 1

NTS



ISOMETRIC VIEW - ANCHOR TYPE 2

NTS



SCALE 1:10 (3) DETAIL FIG 6

NOTES

1. ALL DIMENSIONS ARE IN mm. UNLESS NOTED OTHERWISE.
2. FORMWORK DESIGN IS IN ACCORDANCE WITH:
   - CAN/CSA S269.3 - CONCRETE FORMWORK
   - CAN/CSA 086.1 - ENGINEERING DESIGN IN WOOD
   - CAN/CSA S16 - LIMIT STATES DESIGN OF STEEL STRUCTURES
3. FORMWORK SHALL BE USED UNDER DRY SERVICE CONDITIONS.
4. SCC CONCRETE PLACEMENT SHOULD NOT EXCEED 1500mm IN HEIGHT PER HOUR.
5. THE DESIGN LOADS SHALL NOT BE EXCEEDED DURING CONSTRUCTION. THE CONTRACTOR SHALL MAKE ADEQUATE PROVISIONS FOR CONSTRUCTION LOADS INCLUDING TEMPORARY BRACING TO KEEP THE STRUCTURE PLUMB AND IN TRUE ALIGNMENT AT ALL PHASES OF CONSTRUCTION.
6. ROCK ANCHOR EMBEDMENT SHALL BE DETERMINED BY A GEOTECHNICAL ENGINEER BASED ON THE GIVEN ALLOWABLE LOADS.
7. FORMWORK SHALL BE ASSEMBLED, ERECTED, AND STRIPPED UNDER THE SUPERVISION OF A COMPETENT PERSON. ALL WORKERS SHALL BE GIVEN CLEAR INSTRUCTIONS BY SUPERVISORS ON ERECTION HAZARD AND ON NECESSARY SAFETY PRECAUTIONS.
8. COMPLETED ASSEMBLY TO BE INSPECTED BY COMPETENT PERSON PRIOR TO PLACING CONCRETE.
9. CONTINUOUS MONITORING OF THE FORMWORK SHALL OCCUR DURING THE CONCRETE PLACEMENT. STOP THE FLOW OF CONCRETE AS SOON AS POSSIBLE AFTER DETECTING CONCRETE BLEED THROUGH THE LEVEL HOLES, SO AS TO LIMIT SURCHARGE LOADING ON FORMWORK.
10. PLACEMENT OF CONCRET MUST STOP IF ANY WEAKNESS, UNDUE SETTLEMENT OR EXCEED DISTORTION OF FORMWORK OCCURES, AND MAY ONLY RESTART AFTER THE FORMWORK BEEN REPAIRED OR STRENGTHENED BY THE ENGINEER.
11. THE CONTRACTOR SHALL REVIEW ALL THE DETAILS AND DIMENSIONS AND REPORT ANY DISCREPANCIES TO THE ENGINEER BEFORE PROCEEDING WITH FABRICATION.
12. IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO SAFEGUARD ALL EXISTING STRUCTURES AFFECTED BY CONSTRUCTION.
13. GOLDER ASSOCIATES SHALL NOT BE RESPONSIBLE FOR CONSTRUCTION SAFETY, MEANS, TECHNIQUES AND CONSTRUCTION PROCEDURES, OR ANY TEMPORARY WORK AS MAY BE REQUIRED BY THE CONTRACTOR TO BUILD AND COMPLETE THE STRUCTURE IN CONFORMITY WITH THE CONTRACT DOCUMENTS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OVERALL PROJECT SAFETY AND SHALL CONFORM TO OCCUPATIONAL HEALTH AND SAFETY GUIDELINES AND REGULATIONS.
14. STRUCTURAL STEEL:
   - CAN/CSA G40.20/G40.21, GRADE 300W FOR PLATES.
   - BOLT ASSEMBLIES (BOLTS, NUTS AND WASHERS) HIGH STRENGTH ASTM A325 TYPE-1 BOLTS, NUTS AND WASHERS SNUG TIGHTENED UNLESS NOTED OTHERWISE.
16. GROUT:
   - GROUT MATERIALS AND PLACEMENT SHALL CONFORM TO THE REQUIREMENTS OF CSA A23.1.
   - NO GROUTING SHALL BE STARTED UNDER BASE PLATES UNTIL THE STRUCTURES HAVE BEEN ALIGNED, LEVELED, PLUMBED AND FULLY BRACED AND ARE SECURELY HELD IN PLACE BY THEIR PERMANENT CONNECTION.
   - USE NON-METALIC, NON-SHRINK GROUT WITH MINIMUM 28-DAY COMPRESSIVE STRENGTH 50 MPa.
17. WOOD AND ACCESSORIES:
   A. COMPLY WITH THE LATEST EDITION OF THE FOLLOWING EXCEPT WHERE MORE STRINGENT REQUIREMENTS ARE SHOWN OR SPECIFIED:
   - CSA B111 - WIRE NAILS, SPIKES AND STAPLES
   - CAN/CSA 086-01 (086S1-05) - ENGINEERING DESIGN IN WOOD (WITH SUPPLEMENT)
   - CAN/CSA 0141 - SOFTWOOD LUMBER
   - NLGA - STANDARD GRADING RULES FOR CANADIAN LUMBER
   B. MATERIALS:
   - ALL TIMBER ELEMENTS TO BE D. FIR-L No.1 OR BETTER
   - LUMBER MATERIAL SHALL BE SEASONED AND HAVE A MOISTURE CONTENT LESS THAN 19% AT TIME OF CONSTRUCTION.
   - NAILS SHALL CONFORM TO CSA B1
   - SCREWS SHALL CONFORM TO ANSI/ASME B18.6.1
18. WELDING:
   - CSA W48 WELDING ELECTRODES. E49XX
   - FILLER METALS AND WELDING FLUXES SHALL COMPLY WITH THE FOLLOWING STANDARD: CSA W48 FILLER METALS AND ALLIED MATERIALS FOR METAL ARC WELDING.
   - WELDING PROCEDURES, MATERIALS, AND QUALITY STANDARDS SHALL CONFORM TO THE REQUIREMENTS OF CSA W59 "WELDED STEEL CONSTRUCTION (METAL ARC WELDING).
   - ALL WELDING MUST BE PERFORMED BY A WELDER OR AN IRONWORKER CERTIFIED BY CWB W47.1 STANDARD "CERTIFICATION OF COMPANIES FOR FUSION WELDING OF STEEL".
   - THE PROCEDURES AND THE CRITERIA OF ACCEPTABILITY FOR THE INSPECTION OF ALL WELDS MUST BE IN ACCORDANCE WITH CSA W59 FOLLOWING CLAUSES.
     -CLAUSE 11.5.4 FOR STRUCTURES WITH STATIC LOADS.
     -CLAUSE 12.5.4 FOR STRUCTURES WITH DYNAMIC LOADS.
     -THE WELDER MUST VISUALLY INSPECT ALL WELDS.
     -ALL WELDS THAT DO NOT MEET THE CRITERIA FOR ACCEPTABILITY OF CSA W59 SHALL BE REPAIRED OR REMOVED AND RE-WELDED AND RE-TESTED.
19. ALL PLANK, COLUMN, BRACES TO BE WOOD MATERAIL. ALL CONNECTIONS, BOLT PLATES TO BE STEEL PLATE MATERIAL.

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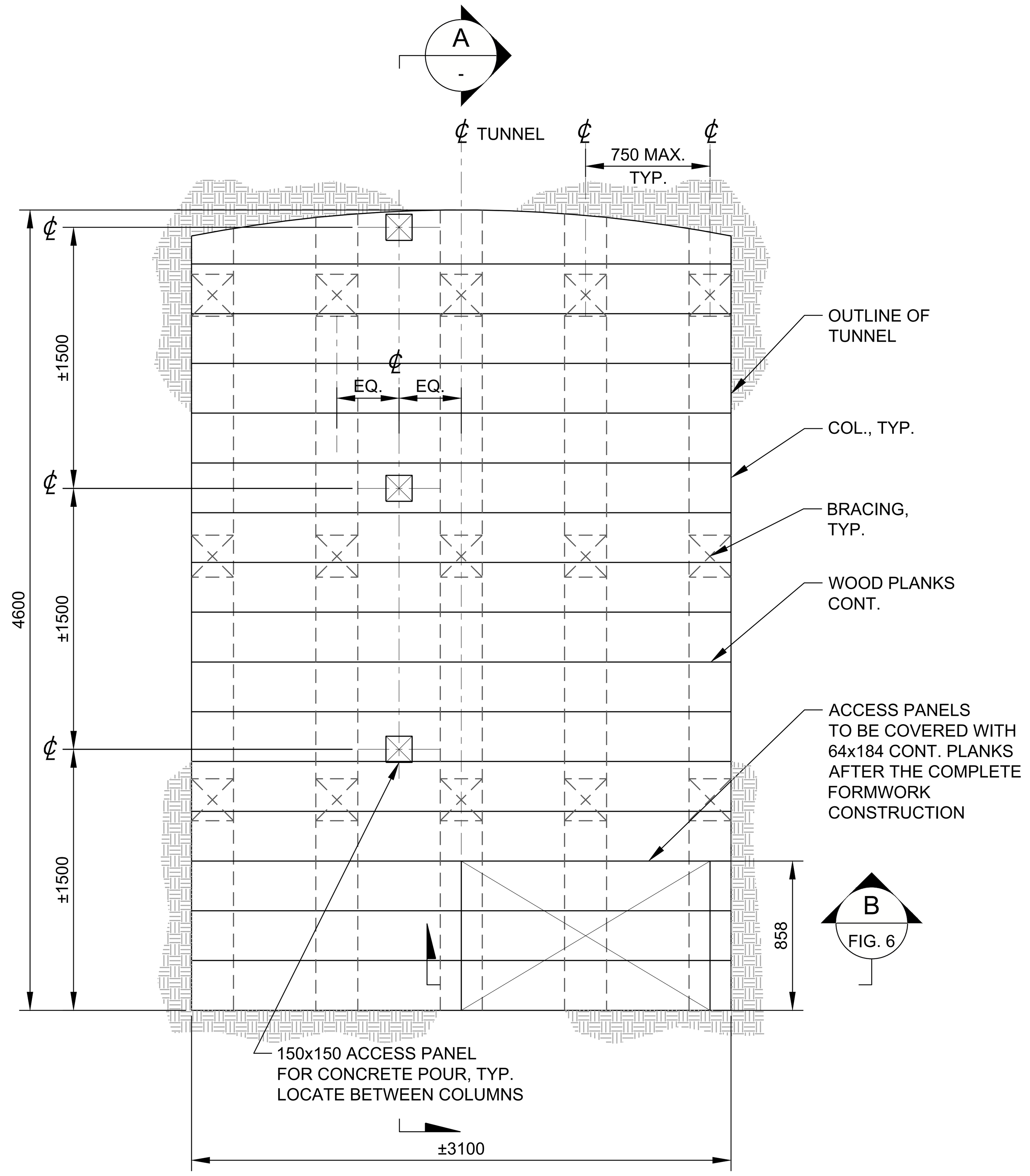
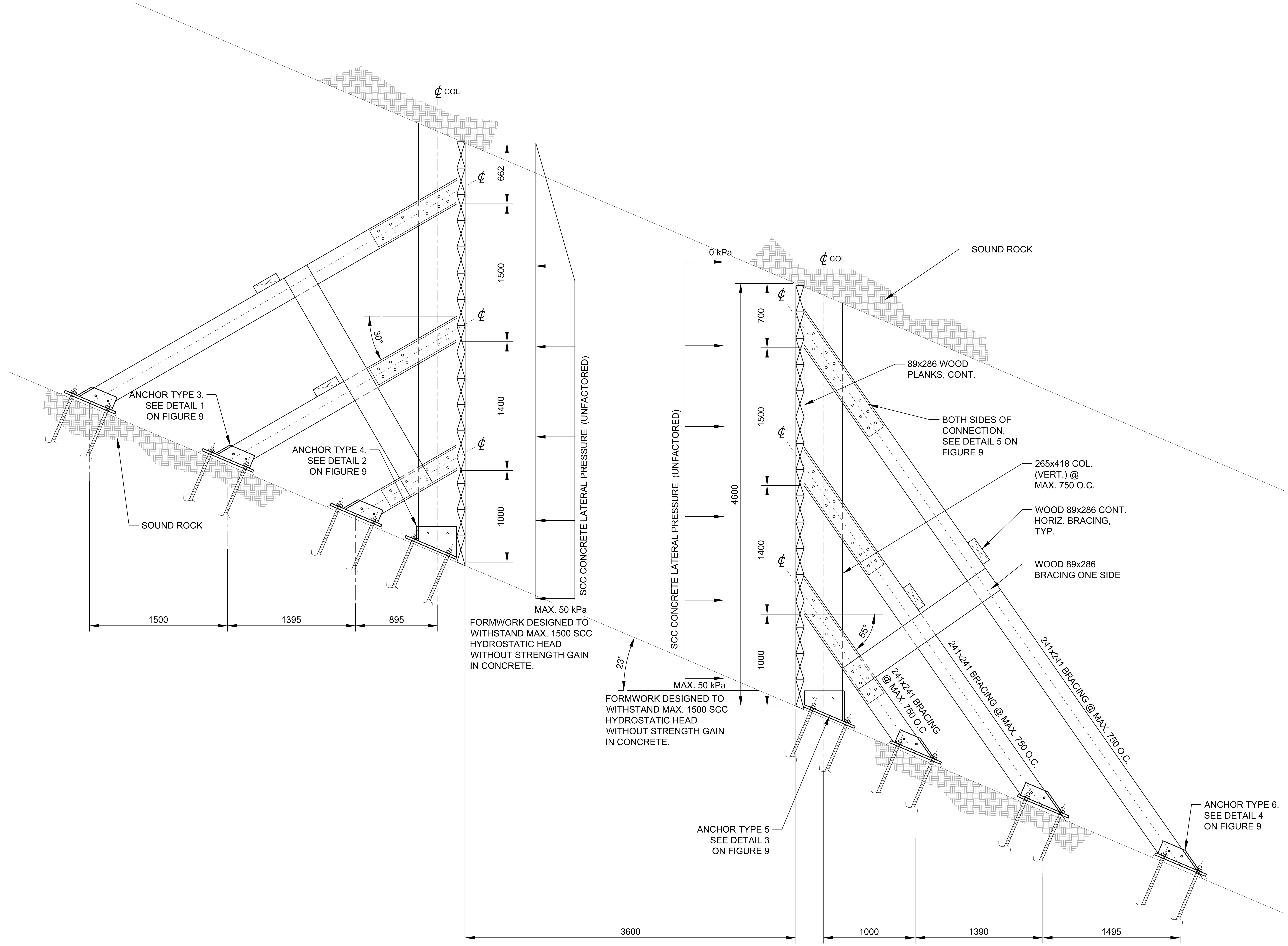
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
FORMWORK DETAILS AND NOTES - DECLINE PLUG

PROJECT NO.	PHASE	REV.	FIGURE
1778120	2000	B	7



FORMWORK ELEVATION
SCALE 1:25



SCALE 1:25 A - SECTION

NOTES:

1. SEE FIGURE 7 FOR GENERAL NOTES.
2. ALL LENGTH MEASUREMENTS SHOWN ARE BASED ON MEMBER CENTER LINES, U.N.O.

PRELIMINARY DRAWING

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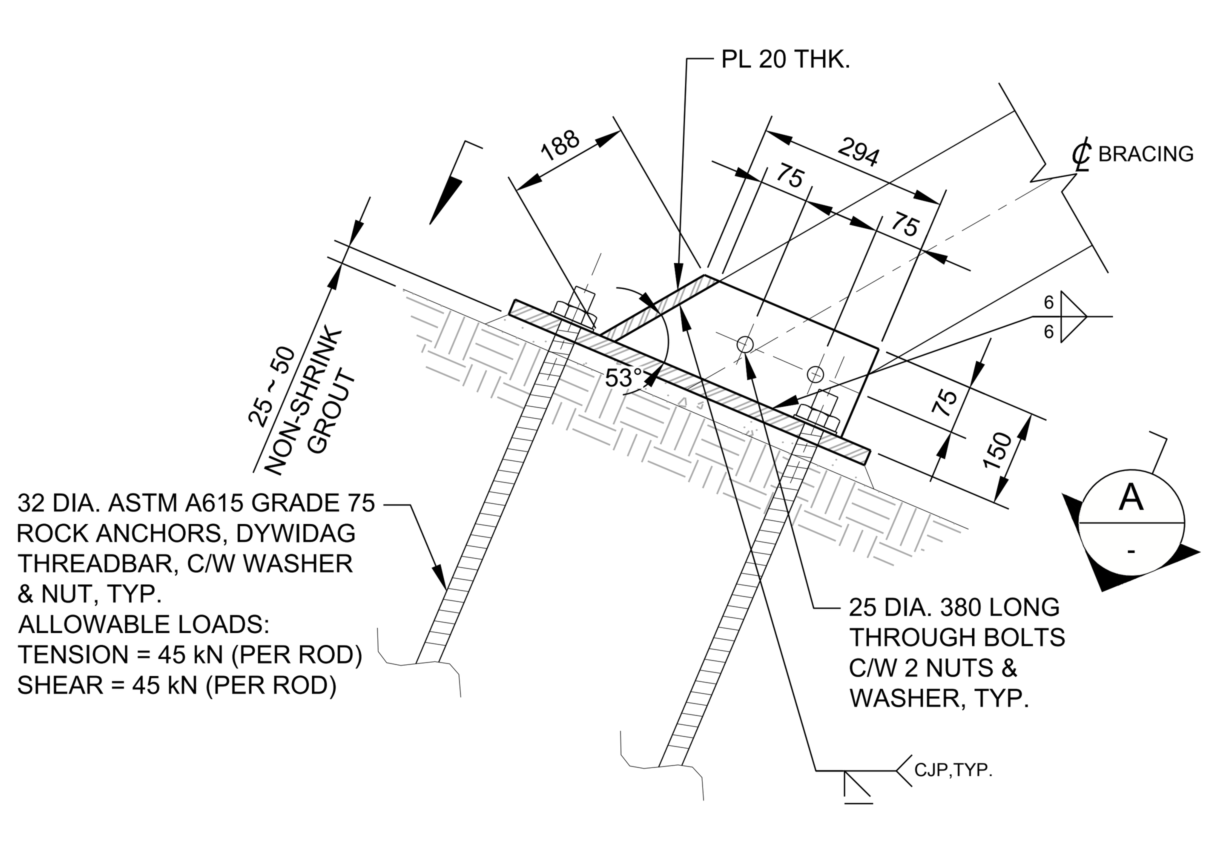
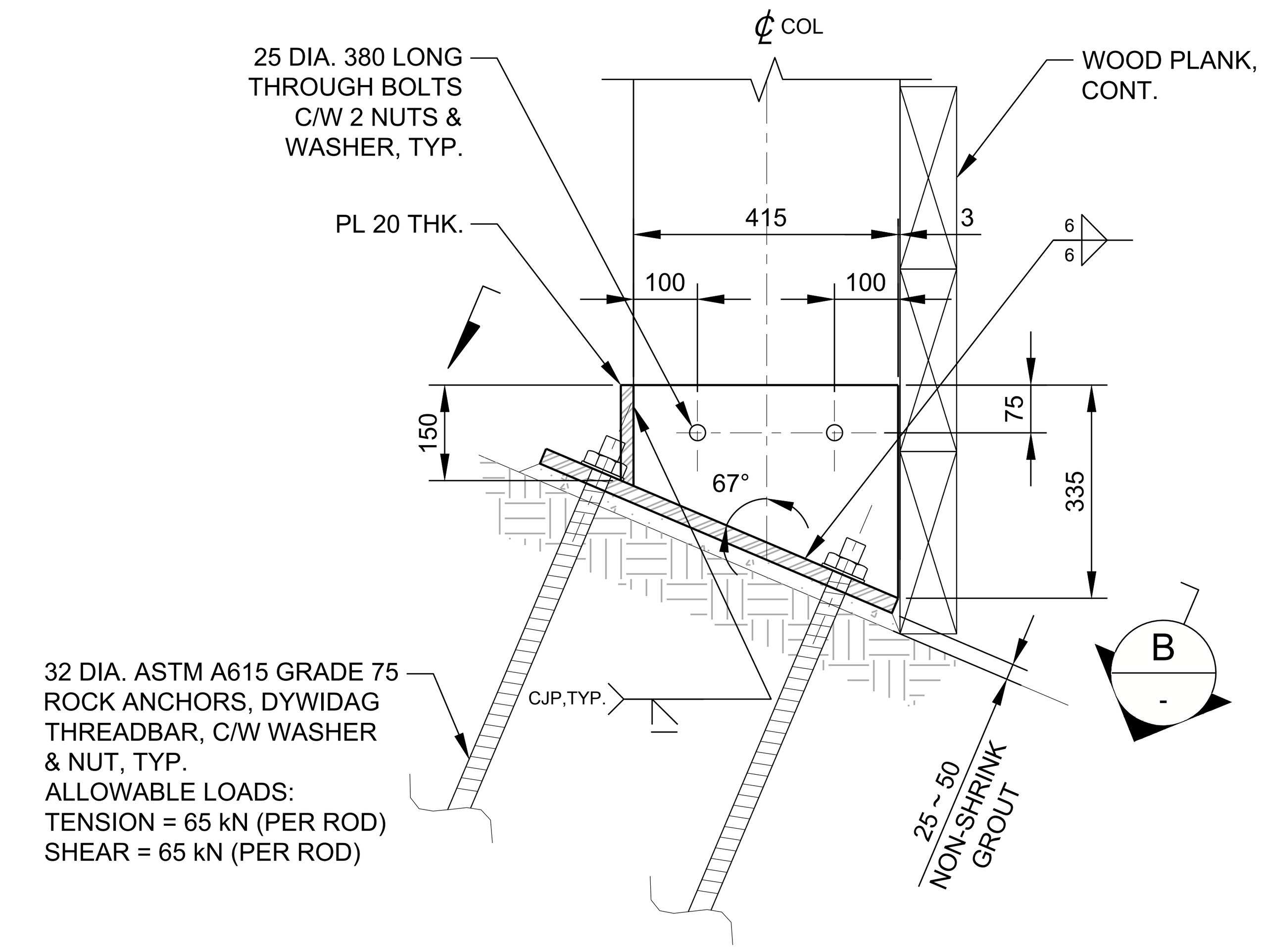
PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
FRAMEWORK ELEVATION AND SECTION - VENT RAISE PLUG

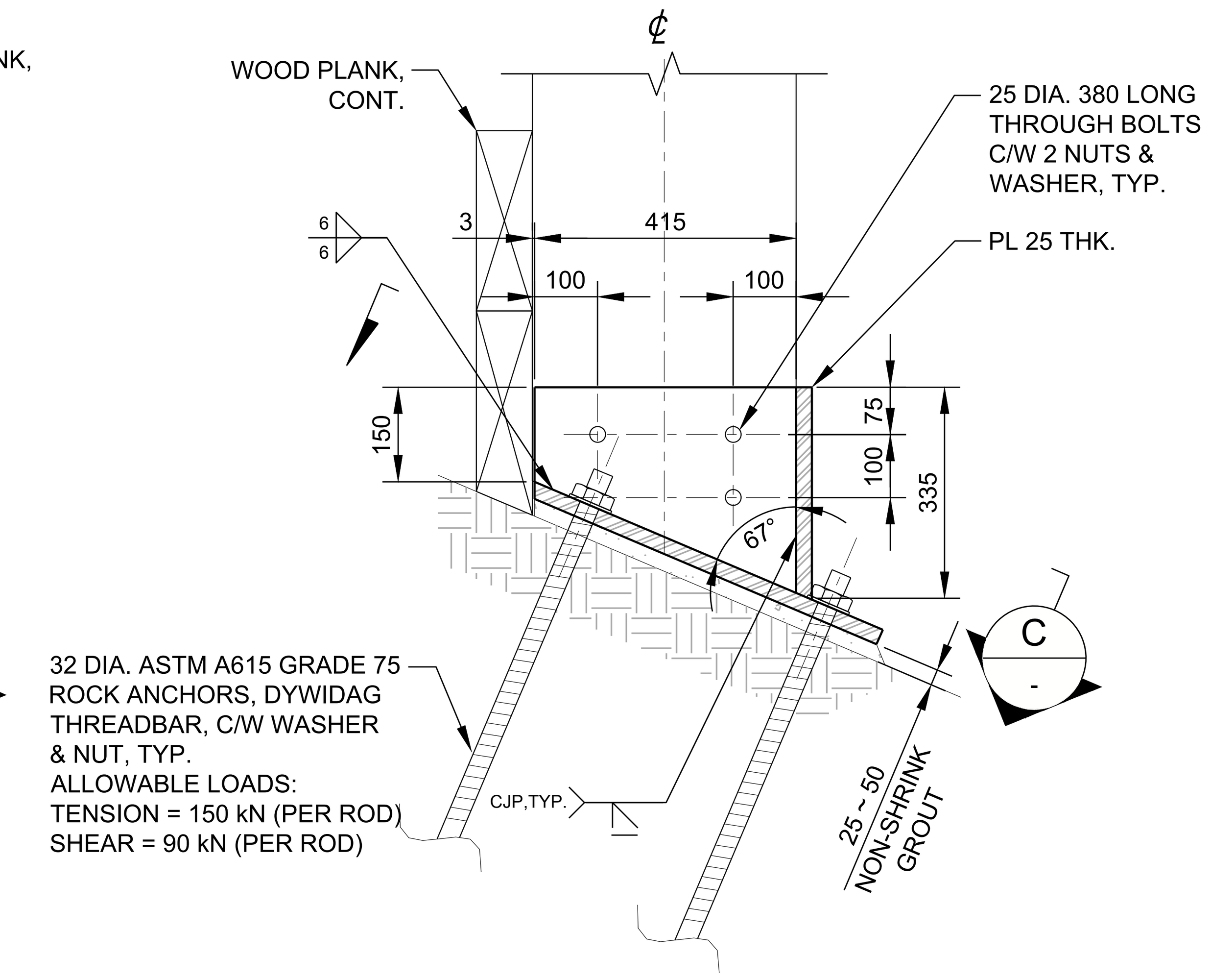
PROJECT NO.	PHASE	REV.	FIGURE
1778120	2000	A	8



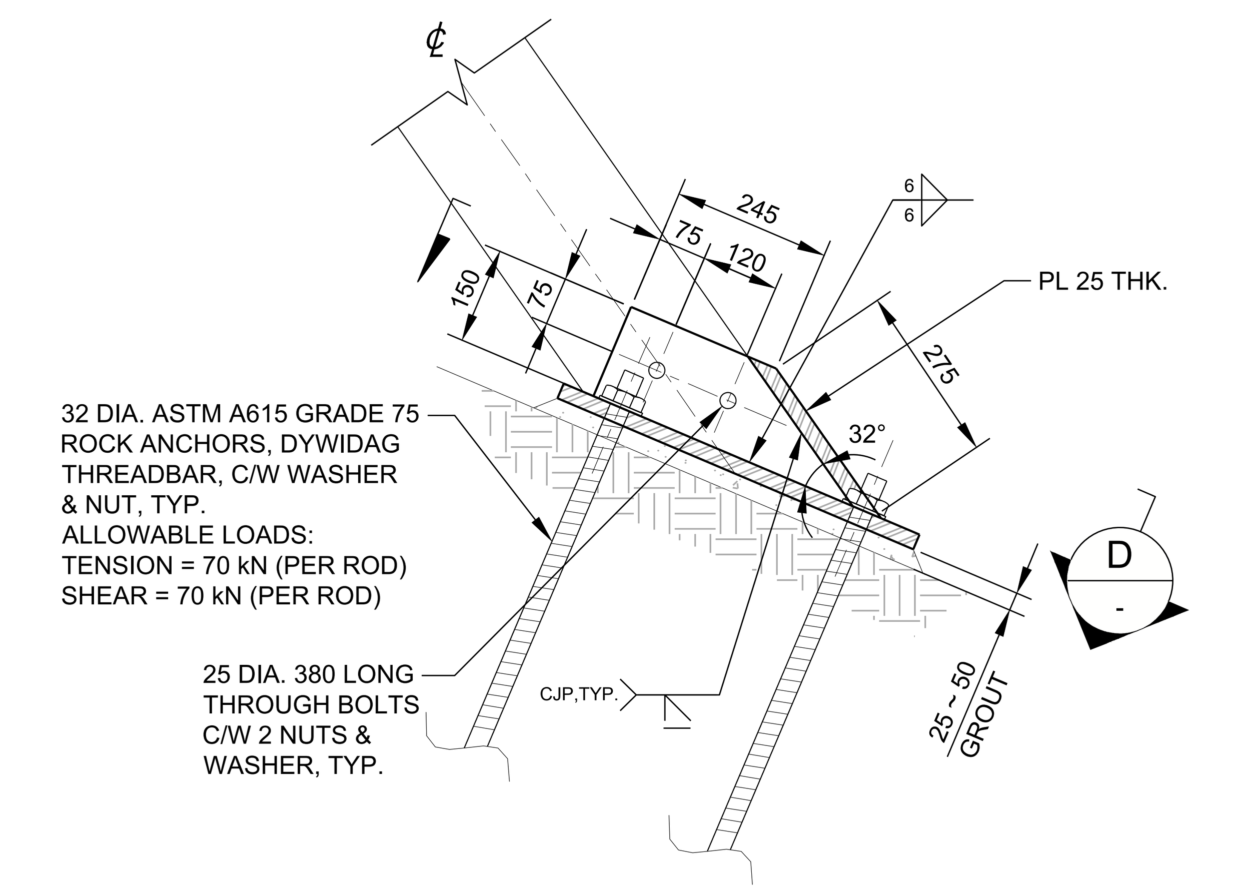
SCALE 1:25 1 ANCHOR TYPE 3 DETAIL FIG. 8



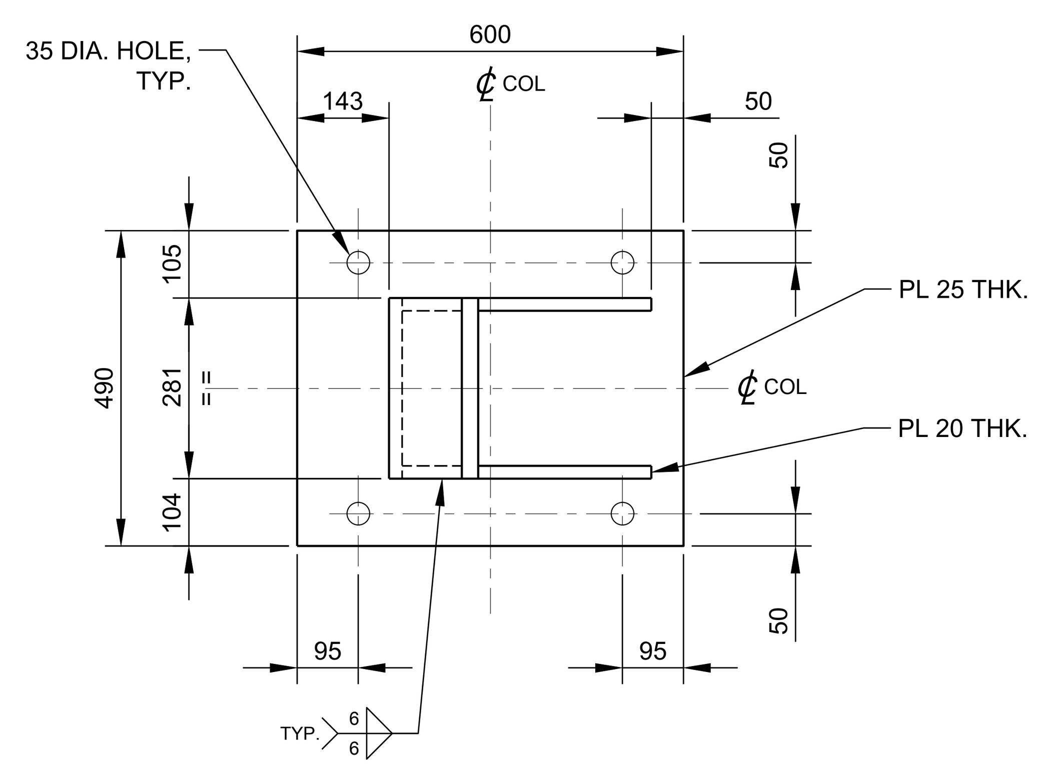
SCALE 1:25 2 ANCHOR TYPE 4 DETAIL FIG. 8



SCALE 1:25 3 ANCHOR TYPE 5 DETAIL FIG. 8



SCALE 1:25 4 ANCHOR TYPE 6 DETAIL FIG. 8



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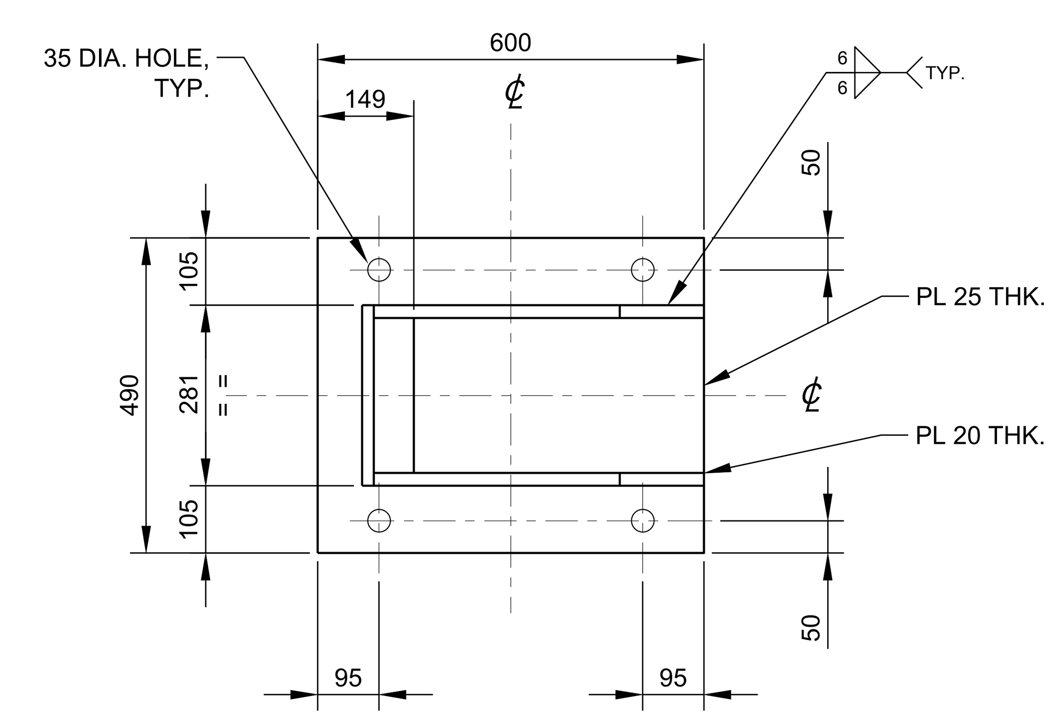

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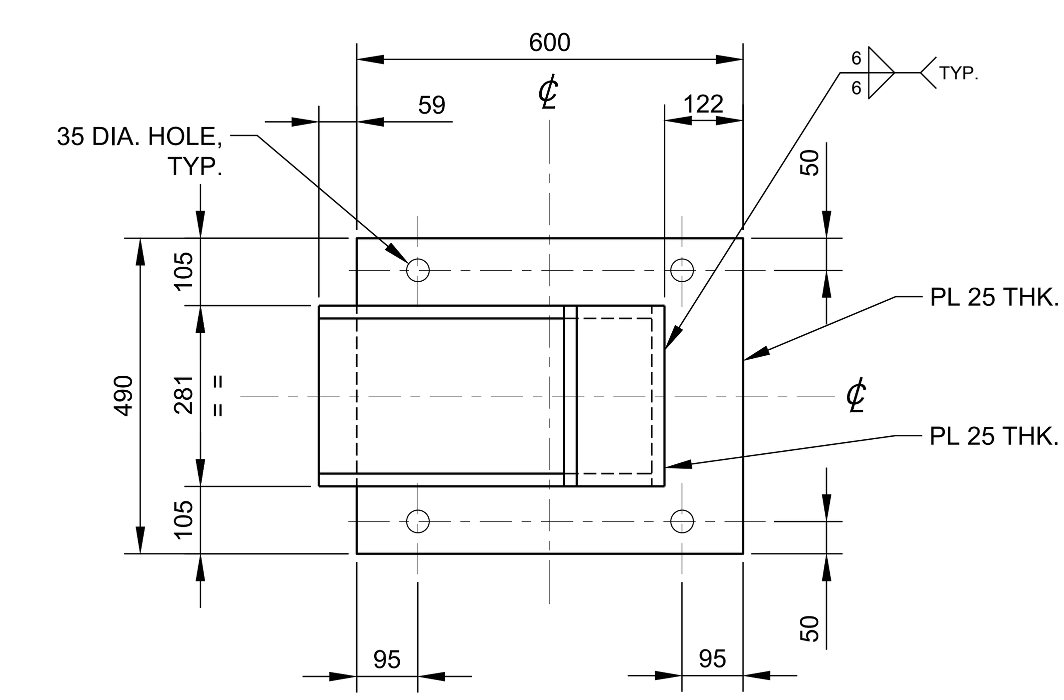

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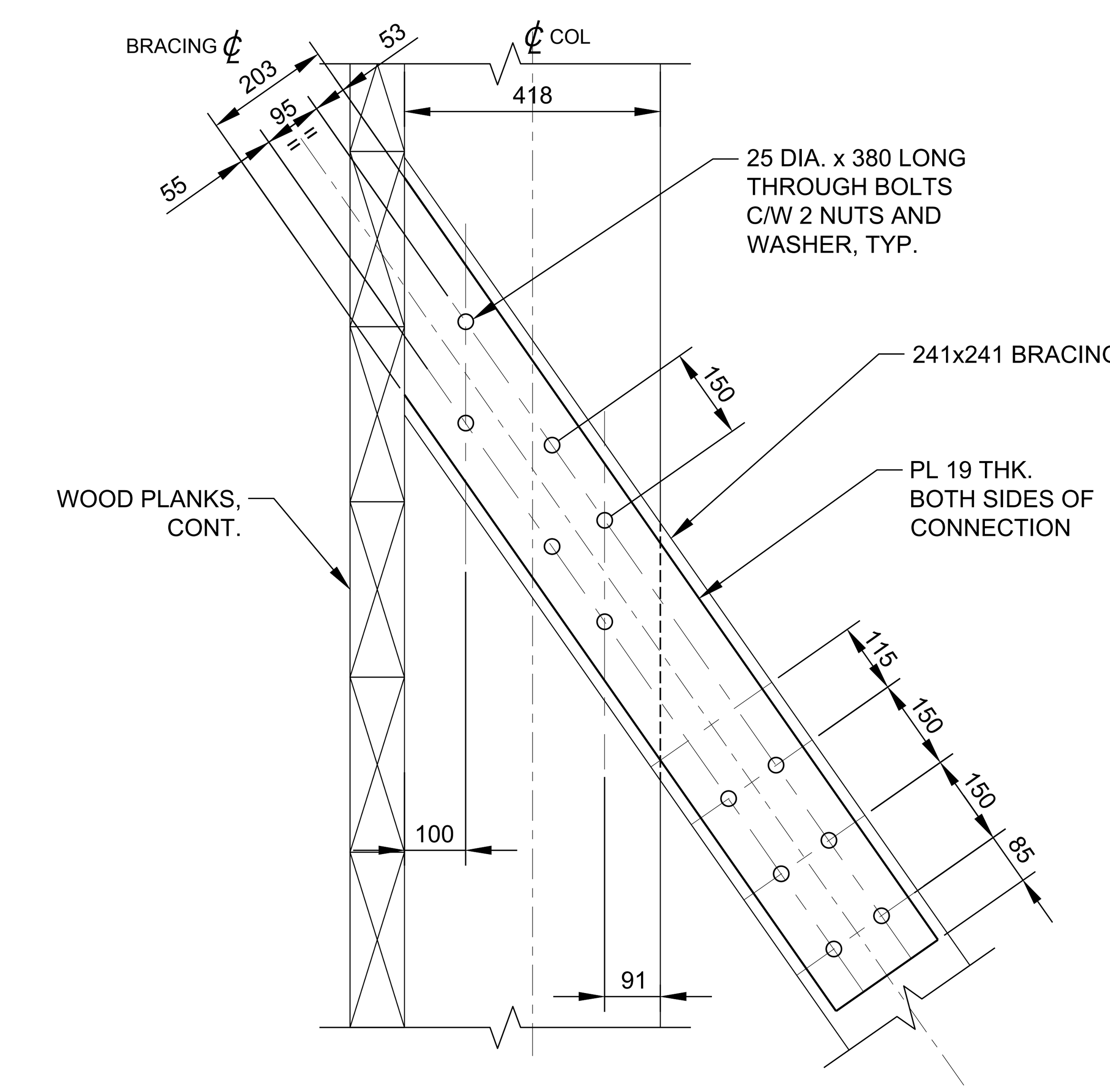
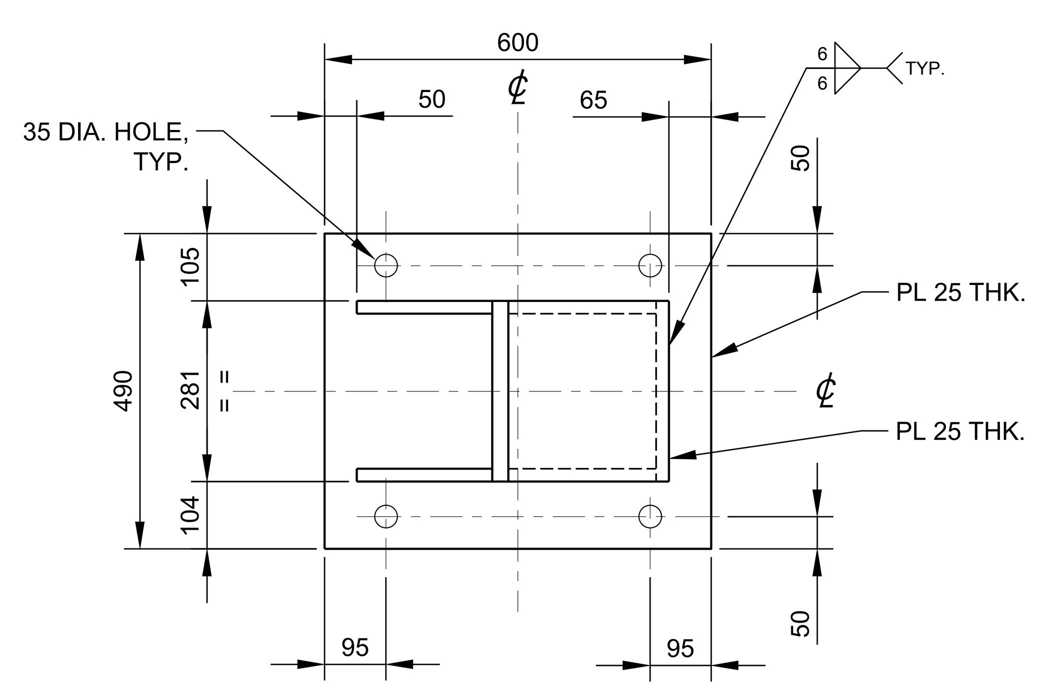


SCALE 1:25 5 DETAIL FIG. 8



SCALE 1:25 D SECTION -

NOTES:

1. SEE FIGURE 7 FOR GENERAL NOTES.
2. ALL LENGTH MEASUREMENTS SHOWN ARE BASED ON MEMBER CENTER LINES, U.N.O.

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PROJECT
WOLVERINE MINE
UNDERGROUND PLUG DESIGN

TITLE
FRAMEWORK ELEVATION AND SECTION - VENT RAISE PLUG

PROJECT NO.	PHASE	REV.	FIGURE
1778120	2000	A	9

ATTACHMENT 1
Plug Length Design Calculations

1.0 CALCULATIONS

1.1 Punching Shear

Punching shear failure is the mechanism whereby the pressure applied (i.e., by mud flow or retained water) causes the plug to move relative to the rock by shearing either through the rock mass, the concrete, or along the rock-concrete interface. The design concept assumes that the load would be transmitted from the concrete plug to the rock as punching shear around the perimeter of the plug and along its full length.

The plug length requirement to resist punching shear was evaluated using the formula developed by Garrett & Campbell-Pitt (1961), where the design length (L) for a plug is given by:

$$L = (P_f A) / P_e f_s$$

Where:

P_f = applied fluid pressure (Pa) = ρ g H
H = head of fluid on plug (m)
ρ = density of fluid (kg/m^3)
g = gravitational constant (9.81 m/s^2)
A = area of the plug upstream face (m^2)
P_e = cross-section perimeter of the plug (m)
f_s = allowable shear stress of the rock or concrete at the interface, whichever is lesser (Pa)

In competent rock, Garrett & Campbell-Pitt suggest that 0.59 MPa for ungrouted plugs, or 0.83 MPa for grouted plugs, may be used for the allowable shear stress at the concrete-bedrock interface. Grouted plugs are those where the concrete-bedrock interface contact has been pressure grouted to twice the hydrostatic head.

Benson (1989) provided allowable shear stresses used for design of civil engineering plugs. The values presented in the table below incorporate a Factor of Safety of 3 (Lang, 1999). The values shown in brackets indicate the values of allowable shear stress without the factor of safety. The allowable shear stresses without the factor of safety for good quality rock agree with the values proposed by Garrett & Campbell-Pitt (1961).

Table 1: Allowable Shear Stress (adapted from Benson, 1989)

General Rock Condition RMR – Rock Mass Rating	Allowable Shear Stress (psi)
Very Good Rock (Massive, hard, widely jointed) 81 < RMR < 100	75 (225)
Good Rock (Hard to mod. hard, moderately jointed) 61 < RMR < 80	45 (135)
Fair Rock (Moderate to weak, moderately jointed) 41 < RMR < 60	30 (90)
Poor Rock (Weak, closely jointed or sheared) 21 < RMR < 40	15 (45)
Very Poor Rock (Very weak, possibly erodible) RMR < 20	7.5 (22.5)

Alternatively, where the grouting of the rock-concrete interface and subsequent consolidation of the surrounding rock mass to an applied pressure of twice the hydraulic head is carried out, it is reasonable to assume that there will be some confining pressure created with the rock mass near this interface. It is common to consider a confining pressure of 72.5 psi due to such grouting (Lang, 1999). However, it has been our experience that the confining pressure could correspond to as much as one-third of the applied grouting pressure.

The location of the decline plug is located within the Calcite Pyrite Exhalite unit, with a small portion of the argillite unit present in the rib and possibly the floor. The location of the vent raise plug was selected based on the drill core data from borehole WV09-216 which paralleled the raise. At an approximate location of 60 m from the opening to surface the borehole encountered massive sulfides.

1.2 Deep Beam Failure

According to Section 10.7.1 of the ACI 318-11 (American Concrete Institute's Building Code Requirements for Reinforced Concrete), a plug fits into the category of a deep beam when the ratio of the plug width to plug length is greater than or equal to 1.25. This means that if the design for punching shear results in a plug length that is less than approximately the maximum dimension of the tunnel, the design should be checked for resistance to deep beam flexure (Lang, 1999).

The design concept is that the length of an unreinforced, concrete plug must be sufficient to keep the tensile bending stresses in the downstream face of the plug below the ACI allowable concrete tensile stress. Because of the inherent difficulties in placing the concrete on the invert and crown of the tunnel, the beam is conservatively assumed to be a one-way beam spanning between the sidewalls (i.e., the plug carried load at the walls, but no load from roof to floor of the tunnel).

The design length (L) for a plug when considering Deep Beam Flexure[1,2] is given by:

$$L = \sqrt{\frac{6Mu}{b(f_t)}}$$

Where the Factored Design Bending Moment (*Mu*) is defined as:

$$Mu = \frac{Mn}{\phi}$$

And for a tunnel width (*l*), the Maximum Bending Moment (*Mn*) as:

$$Mn = \frac{wl^2}{8}$$

ACI 318-11, Section 9.3.5 directs that a capacity or strength reduction factor (ϕ) of 0.65 must be used in the calculation of the *Mu*.

The Fluid Load (w) in kN/m, or the load per meter for a 1 m high beam is defined as:

$w = (H\, \rho_w\, \alpha)$ x 9.81 kg·m/sec^2 / 1000 N/kN

Where:

α = Load factor (ACI 318-11, Section 9.2.5 requires a load factor of 1.4 for definable fluid loads)

ρ_w = Density of fluid (kg/m^3)

H = Head of fluid acting on plug

Further, ACI 318-11 Section 22.5.1 directs that the Allowable Tensile Stress (ft) in the downstream face be:

$$f_t = 5\sqrt{f_c} \text{ (US imperial); or}$$

$$f_t = 415.2\sqrt{f_c} \text{ (metric)}$$

Where:

f_c = Unconfined Compressive Strength of Concrete (MPa)

The resulting units for f_t are kPa.

Note: In the calculation of the plug length (L) for a rectangular width plug of unit width (b):

(1) Moment of Inertia = $bL^2 / 12$, and the centroidal distance = L/2, yielding $f_t = 6Mu/bL^2$

(2) b = unit height of beam = 1 m.

1.3 Hydraulic Gradient

The design maximum hydraulic gradient (HG_{max}) is defined as the ratio between the maximum applied hydraulic head and plug length. HG_{max} should not exceed an acceptable maximum value estimated for the plug location. It should be noted that exceeding the recommended maximum hydraulic gradient may lead to an increase in flow without necessarily progressing to a catastrophic hydraulic failure.

Recommended guidelines to estimate HG_{max} differ for civil and mining engineering projects. Based on experience gained with underground hydroelectric projects, the table below presents empirical guidelines for allowable hydraulic gradients for tunnel plugs, as proposed by Benson (1989). Benson recognized that higher values of hydraulic gradient could be used if grouting was carried out during the plug construction. These civil engineering guidelines are quite conservative when compared to mining plug applications, as they incorporate a Factor of Safety of 3 (Lang, 1999).

Table 2: Summary of Recommended Civil Practice Guidelines for Acceptable Hydraulic Gradients for Tunnel Plugs (adapted from Benson, 1989)

General Rock Condition RMR – Rock Mass Rating	Maximum Allowable Hydraulic Gradient (ft/ft)	Maximum Allowable Pressure Gradient (psi/ft)
Very Good Rock (Massive, hard, widely jointed) 81 < RMR < 100	15 – 30 (45 – 90)	6.6 – 13.2 (19.8 – 39.6)
Good Rock (Hard to mod. hard, moderately jointed) 61 < RMR < 80	10 – 14 (30 – 42)	4.4 – 6.2 (13.2 – 18.6)
Fair Rock (Moderate to weak, moderately jointed) 41 < RMR < 60	7 – 9 (21 – 27)	3.1 – 4.0 (9.3 – 12.0)
Poor Rock (Weak, closely jointed or sheared) 21 < RMR < 40	5 – 6 (15 – 18)	2.2 – 2.7 (6.6 – 8.0)
Very Poor Rock (Very weak, possibly erodible) RMR < 20	3 – 4 (9 to 12)	1.3 – 1.8 (4.0 – 5.4)

Note: Values in brackets provided above are the un-factored allowable hydraulic/pressure gradients.

From the South African mining practice, based on high rock mass quality and very strong quartzite, checks of the length of the plug are carried out to ensure that the pressure gradient (P/L) across the plug does not exceed the following criteria:

P/L ≤ 20.8 psi/ft where the contact between the plug and the rock is ungrouted, or

≤ 161 psi/ft where the applied grouting of the rock-concrete interface around the plug is at least twice the design hydrostatic pressure.

Where:

P = design fluid head (or pressure) (psi)

L = length of plug (ft)

Garrett and Campbell-Pitt (1958) recommended that a leakage Factor of Safety between 4 and 10 be used, depending on fracture conditions, the concentration of induced stresses, the rock porosity, and the rock mass acceptance of grout.

It has been our experience that the range recommended by Garrett and Campbell-Pitt (1958) can be subdivided based on the RMR as presented below in Table A-4. The safety factors for dynamic loading conditions are slightly less than those required under static conditions due to the short duration of such dynamic loads.

Table 3: Hyrdaulic Gradient - Range of Possible Factors of Safety

General Rock Condition RMR – Rock Mass Rating	Static Loading Conditions	Dynamic Loading Conditions
Very Good Rock (Massive, hard, widely jointed) 81 < RMR < 100	4	2
Good Rock (Hard to mod. hard, moderately jointed) 61 < RMR < 80	5.5	3.5
Fair Rock (Moderate to weak, moderately jointed) 41 < RMR < 60	7	5
Poor Rock (Weak, closely jointed or sheared) 21 < RMR < 40	8.5	6.5
Very Poor Rock (Very weak, possibly erodible) RMR < 20	10	8

Note: Based on Garrett and Campbell-Pitt (1958).

1.4 Hydraulic Jacking – Norwegian Criteria

The Norwegian Criterion for unlined pressure tunnels can also be applied in many cases for checking plug siting for overall stability against hydraulic jacking (e.g. hydrojacking). Typically, these guidelines require that the maximum static water pressure should be less than the minor principal rock stress, reduced by a defined Factor of Safety. This means that adequate rock/overburden cover must always be available at the tunnel/plug site to ensure that opening of existing discontinuities in the rock mass surrounding the plug does not occur.

This can be estimated using a criterion developed in Norway suitable for sloping topography (Bergh-Christensen, 1988). It should be recognized that this criterion is considered to be conservative as it uses total pressure instead of effective in checking that the minimum cover thickness required is adequate against this type of fracture propagation.

The Norwegian hydrojacking criterion is expressed as follows:

$$C_{RM} = \frac{\gamma_w \, h_s \, FS}{\gamma_r \cos\beta}$$

Where:

C_{RM} = Minimum rock cover measured from the tunnel obliquely to the nearest point on the ground surface (m)

h_s = Static design water head (m)

γ_w = Unit weight of water (MN/m^3) = 0.01

γ_r = Unit weight of rock (MN/m^3) = 0.0255 (marble or skarn)

β = Average slope angle of hillside (varies with the slope)

FS = Factor of Safety = 1.3 (static), 1.1 (dynamic)

Appendix E: Assessment and Bench Scale Testing of Water Treatment Options for Wolverine Tailings Supernatant, BQE Water, August 29, 2017

BQE Water

Assessment and Bench Scale Testing of Water Treatment Options for Wolverine Tailings Supernatant

Rev C

16028

August 29, 2017

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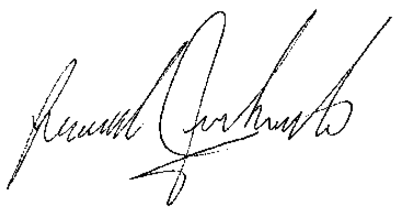

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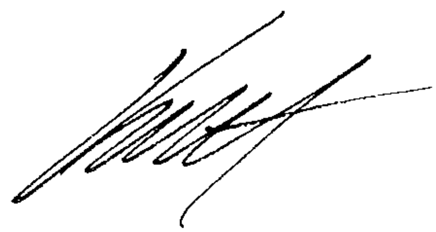

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Confidentiality

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Table of Contents

1. Executive Summary

This report presents the results of BQE Water's evaluation and recommendations for treatment of water stored in the Wolverine Mine Tailings Storage Facility. The report summarizes bench scale testing and includes recommendations for full scale treatment implementation and preliminary capital and operating cost estimates.

The Wolverine Mine tailings pond water can be characterized as follows:

- Three different classes of contaminants that require removal to ultralow levels for discharge: heavy metals, selenium, and WAD cyanide.
- A significant portion of the total selenium present in the water is selenocyanate and "unknown" organoselenium species that are not normally present in mine impacted waters. A significant level of removal of these species is required to meet the discharge limit yet little is known about the removal efficiency of these species by treatment systems typically considered by the mining industry. Furthermore, the concentration of selenocyanate and organoselenium show an appreciable increase between 2016 and 2017.
- The water composition is indicative of highly reducing conditions in the tailings pond with elevated organic carbon and thiosulphate levels, low dissolved oxygen level, and reduced selenium species dominating in the water column.

Based on BQE's assessment, there is no single stage treatment that would be able to remove all three classes of contaminants at the same time to the required discharge limits while producing stable residue suitable for long term disposal in the tailings pond. Instead, several treatment steps will be required to comprehensively address the contamination in the pond. Recognizing this, BQE evaluated a wide range of treatment options and narrowed these down using a set of selection criteria that take into account technical ability, residue management, risks, and costs.

The options that were advanced to bench scale testing included: sulphidization with ferric addition for metals removal, ion exchange (IX) and electrocell treatment (ERC) for selenium removal, and activated carbon adsorption and IX for polishing WAD cyanide removal. In addition, Reverse Osmosis (RO) passed through the screening criteria with the caveat that it would have to be combined with other treatment steps to ensure that all contaminants end up reporting into stable, compact solid residue.

The results of the bench scale tests revealed the following:

- Sulphidization with ferric iron addition achieves the removal of all heavy metals of concern, e.g. Cu, Cd, and Pb below their respective discharge limits. This treatment showed evidence of removal of WAD cyanide, although WAD cyanide assays were subject to inconsistency in the test campaign.
- IX removes all selenium species to levels below the required discharge limit. However, the capture of selenocyanate and organo-selenium species by the resin is irreversible and the capacity of the resin used as a single use/disposable adsorbent is too low to make this treatment option economically feasible.
- ERC treatment removes selenium to below the discharge limit without the use of IX upstream, making ERC a viable option particularly in combination with RO.

- IX removes WAD cyanide to well below the required discharge limit and could be used as polishing treatment step if needed.

Based on the results of BQE's assessment and bench scale tests, BQE recommends that the full scale treatment be composed of three steps:

1. Sulphidization with ferric iron addition for metals and WAD cyanide removal into solids
2. RO for selenium and WAD cyanide removal into retentate while discharging clean permeate
3. ERC for selenium removal from RO retentate to avoid buildup of contaminants in the tailings pond

The scoping level capital cost estimate for the recommended treatment system designed to discharge 1,200 m^3/day of the tailings supernatant water into the environment during mine operation is ~ $3.1M CAD and the annual operating cost excluding O&M labour is ~ $460,000/a based on 6 months per year of plant operation. It should be noted that the operating cost includes one complete replacement of membranes in the RO unit per year to mitigate the risk of membrane fouling. In the event that the treatment plant is to be used for closure or discharge of water from the tailings pond when no new tailings are being deposited, an additional capital cost of approximately $400,000 will be needed for desaturation of RO retentate recycled to the pond. Based on BQE's preliminary mass balances, assuming the starting pond volume of 800,000 m^3 and average pond influent of 200 to 300 m^3/day, the tailings pond could be dewatered and all contaminants removed within 4-5 operating seasons.

2. Project Background

Currently, there is a significant volume of mine impacted water stored in the tailings pond at the Wolverine Mine. This pond would need to be treated and dewatered whether for closure and remediation or as part of the Wolverine Mine re-start. Treatment of approximately 1,200 m^3/day of wastewater will be needed to draw down the pond volume sustainably and account for future contact water. This treatability study was undertaken to assess technical feasibility and economics of treatment of the tailings supernatant to the applicable discharge limits. BQE Water was retained to perform the selection of the most suitable treatment process and laboratory scale testing to demonstrate the achievability of treatment targets and provide scoping level estimate of treatment costs. This report presents the methodology used for selecting treatment options and results of the treatability tests carried out at BQE Water's laboratory in Vancouver along with preliminary estimate of treatment costs and recommendations to mitigate implementation risks.

3. Project Objectives

The objectives of this program were as follows:

- Assess different treatment options for removing all constituents of concern and select the most appropriate methods for lab scale testing
- Perform treatability testing of the selected treatment options to demonstrate the level of contaminant removal achievable
- Develop overall process flowsheet based on the results of tests along with scoping level cost estimates for possible implementation of the recommended treatment at Wolverine
- Recommend next steps and future work

Table 3-1 summarizes the constituents of concern that need to be removed from the Wolverine tailings supernatant and the applicable discharge limits.

Table 3-1 Contaminants of concern contained in tailings supernatant and respective treatment targets

Dissolved species	Concentration in Feed, mg/L	Treatment Target, mg/L
Cu	0.429	0.015
Pb	0.11	0.02
Cd	0.0103	0.002
Zn	1.5	0.5
Ag	0.00370	0.001
Se	1.73	0.02
WAD CN	0.0513	0.025

4. Assessment of the Treatment Options

This section presents the following:

- Criteria for evaluating treatment options
- Options for metals removal
- Options for selenium removal
- Options for WAD cyanide removal

Based on this analysis, the most suitable options were selected for lab scale testing.

4.1 Criteria for Evaluating Treatment Options

In order to arrive at a treatment system that represents not only a good technical fit but that can also be implemented cost effectively and without introducing unnecessary risks, it is important to establish a set of criteria by which different treatment options are evaluated. The following criteria were applied by BQE Water for the Wolverine project.

- Composition of wastewater including speciation of selenium
- Ability to reach end-of-pipe discharge targets
- Risk of effluent toxicity and/or impacts on receiving environment created by treatment process
- Character of treatment residue and options for residue management (short and long term)
- Ease of implementation including both integration into existing site water management scheme, and plant operability
- Capital and operating cost of treatment
- Impact of seasonality on treatment system in the context of a 5 month operating season
- Industrial scale experience from similar sites

It should be noted that the same set of criteria was applied to all types of treatment regardless of constituents being targeted, i.e. metals, selenium, and WAD cyanide.

4.2 Treatment Options for Metals Removal

There are principally two options for removing metals from mine water broadly applied in the mining industry and these include:

- Lime/hydroxide precipitation often referred to as either HDS or LDS process, and
- Sulphide precipitation

The following section compares these methods.

Lime/hydroxide precipitation - High Density Sludge (HDS) and Low Density Sludge (LDS) Process

HDS treatment involves the precipitation of metals as amorphous metal hydroxides and simultaneous precipitation of gypsum. The formation of gypsum helps to separate amorphous hydroxides from treated water and densify waste sludge solids. In order for HDS to be a suitable method for treating mine impacted water, the water must have several characteristics:

- Contain sulphate at concentrations greater than 2,000 mg/L
- acidic pH < 4, and/or
- Contain elevated concentrations of dissolved metals including iron and other heavy metals such as copper, zinc, nickel etc.

Tailings supernatant water at Wolverine is neutral pH water with very low levels of dissolved metals and sulphate concentration of less than 2,000 mg/L. Consequently it meets none of the criteria above.

One other pre-requisite to applying lime treatment either as HDS or as LDS process is that metal discharge limits for all metals of concern need to be lenient enough to allow the use of a single pH set-point in the process to meet all effluent water quality targets. This is because one of the main limitations of lime treatment is that it has only one degree of freedom for metals removal, i.e. the pH set-point. Figure 4-1 shows that different metals exhibit minimum solubility at different pH. It follows that relying on one pH set-point may not be sufficient to ensure that all metals are removed to their discharge target. In the case of Wolverine water, the concern is that lead, cadmium, and copper may not be able to be able to reach the required limits in one stage lime treatment.

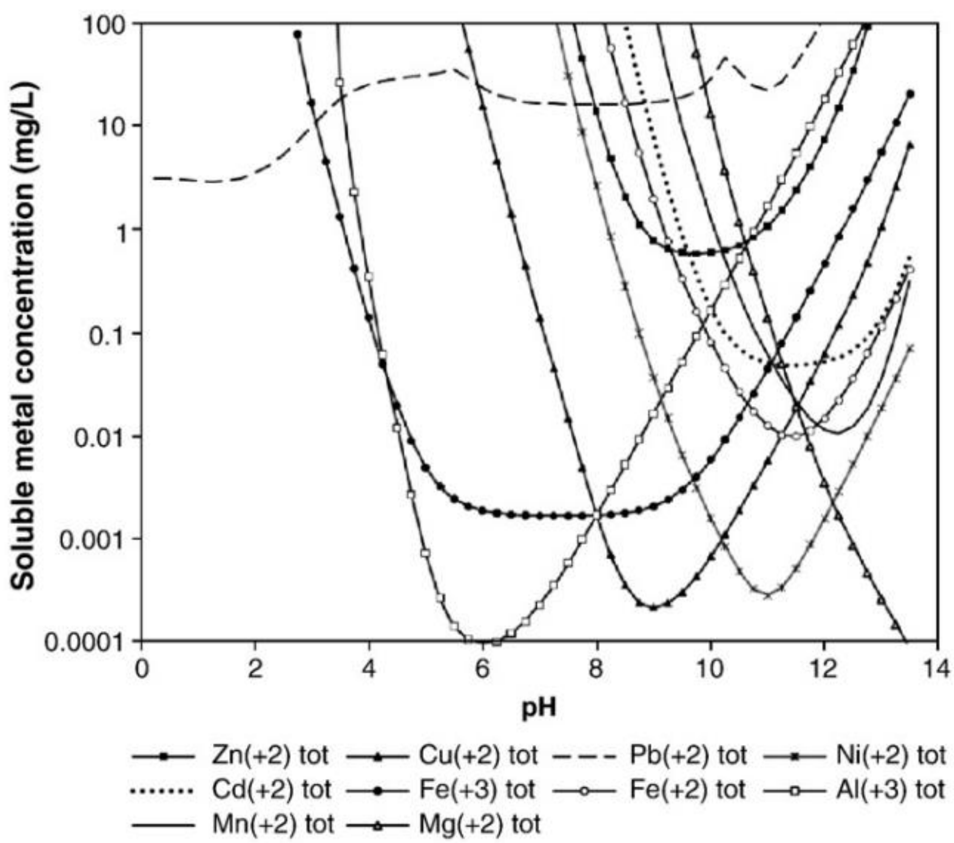

Figure 4-1 Solubility of Metal Hydroxides (Lewis 2010)

The other disadvantage of lime treatment is the cost of implementation where lime reactors have to be designed for long retention time to fully utilize solid lime, and solid-liquid separation stage is designed based on the slow settling rate of lime sludge solids. Finally, the concerns about long term storage of waste metal sludge residue from lime treatment and associated potential long term liabilities may render lime treatment not suitable as a treatment option depending on site specific factors.

The main advantage of lime treatment is that it has been historically applied at many mine sites and that the industry and regulators are familiar with it. That said, new application of lime treatment are becoming fewer and fewer as modern regulations have create the need to apply advanced treatment that can provide better effluent water quality than lime treatment while reducing waste residue and potential long term liabilities.

Sulphide Precipitation

Sulphide precipitation uses the high affinity of sulphide ions towards heavy metals to remove metals from mine wastewater in the form of insoluble metal sulphide solids. The advantages of sulphide precipitation include the following:

- Ability to reach ultralow discharge limits that are much lower for most metals compared to those achievable by lime treatment
- Two degrees of freedom for metals removal including pH and ORP;
- Fast irreversible reactions that minimizes the size of metal precipitation reactors
- High specific gravity of metal sulphide solids and distinct particle of solids that settle faster than hydroxide solids yielding smaller solid-liquid separation equipment footprint
- Potential for blending of the solids produced by water treatment into metal sulphide flotation concentrates produced at mine sites due to compatibility of the solids and their small quantity compared to the concentrate production

Figure 4-2 demonstrates the discharge limits achievable by sulphide precipitation. Comparing figures 4-1 and 4-2 and considering the discharge targets for Cu, Pb, and Cd shown in Table 3-1, it is clear that sulphide precipitation provides a distinct advantage for water treatment at Wolverine.

The main limitations of sulphide precipitation include the following:

- Inability to remove metals that do not precipitate as metal sulphides such as aluminum
- High reagent cost in situations when the water contains elevated iron concentration which not only consumes sulphide but may also render the residue solids unsuitable for blending with metal sulphide concentrates

None of these are an issue in the case of Wolverine tailings supernatant treatment.

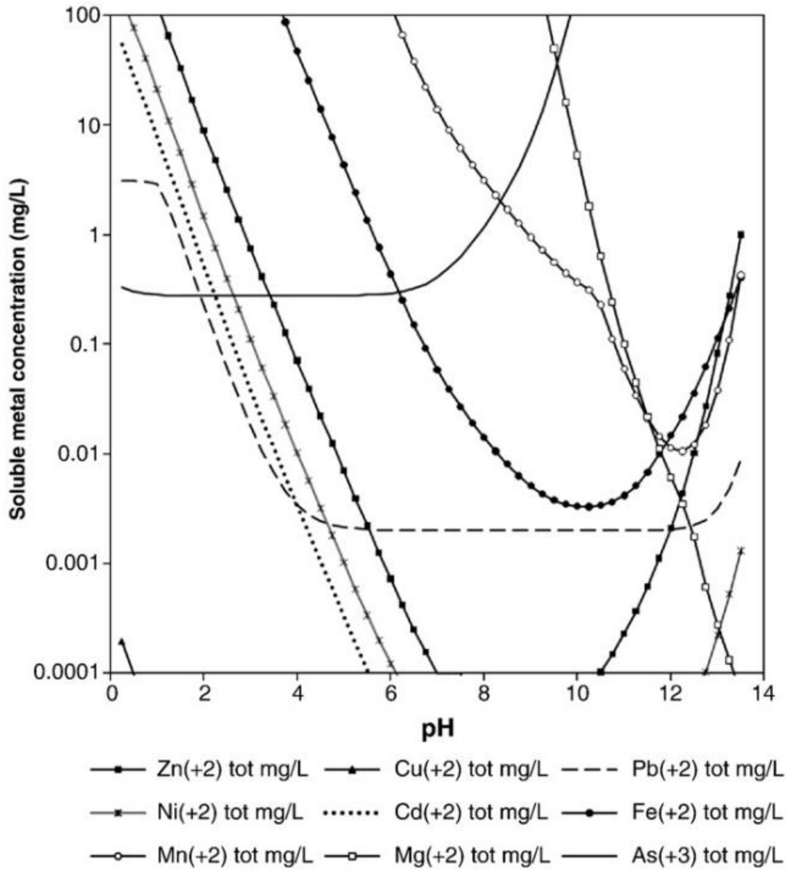

Figure 4-2 Solubilities of Various Metal Sulphides (Lewis 2010)

Over the last two decades, BQE Water have designed, commissioned, and operated 15 large scale water treatment plants using sulphide precipitation for metals removal and/or recovery from mining effluents. The process scale-up and scale-down is well proven with the smallest industrial plant treating approximately 40 m^3/hr and the largest plant treating over 1,000 m^3/hr of wastewater successfully. Although relatively new compared to lime treatment, sulphide precipitation was recognized as the Best Available Technology Economically Available (BATEA) in the Mine Effluent Neutral Drainage (MEND) 2014 study completed by Environment Canada assessing different treatment processes for mining impacted waters. (Study to Identify BATEA for the Management and Control of Effluent Quality from Mines, MEND Report 3.50.01, Sept 2014[1]).

Summary of Selection of Treatment for Metal Removal

Using the evaluation criteria from Section 4.1, Table 4-1 below summarizes the basis of the selection of water treatment option for metals removal at Wolverine.

[1] Report retrieved from the following URL: https://www.hatch.ca/News_Publications/News/2014/MEND-Report-3.50.1.pdf

Table 4-1 Summary of Metal Removal Treatment Selection for Wolverine mine

Evaluation Criteria	Lime treatment	Sulphide precipitation	Recommendation
Raw water quality	Sulphate and TDS below levels suitable for HDS Lime treatment. LDS lime treatment may present problems with fine metals hydroxides settling	Negligible Fe and Al in water	Sulphide
Compliance with end-of-pipe limits	Expect difficulty with Cu, Cd, and Pb limits	No difficulty based on experience from industrial plants	Sulphide
Residue generation and management	Lime sludge probably stored in tailings pond in perpetuity	Blended with concentrate and shipped off site	Sulphide
Risk of effluent toxicity	None expected	None expected	Lime or Sulphide
Ease of implementation	Larger footprint than sulphide	Can be modular with very small footprint	Sulphide
Cost of treatment	Higher capex than sulphide	Low opex due to low metals loading	Sulphide
Industrial Experience	Established	Established	Lime or Sulphide

Based on the assessment presented in this table, sulphide treatment is recommended for lab scale treatability testing.

4.3 Treatment Options for Selenium Removal

The treatment processes most commonly considered for selenium removal from mine impacted waters include the following:

- Co-precipitation with ferric iron
- Biological selenium reduction
- Selective IX combined with ERC of selenium (Selen-IX)or direct ERC
- Membrane treatment such as Reverse Osmosis (RO) or Nanofiltration (NF)
- Zero Valent Iron (ZVI)

Unlike metals removal, the selection of appropriate selenium treatment option is greatly influenced by the chemical speciation of selenium in the raw water. Selenium can be present in four different oxidation states and in multitude of different chemical species and each species responds differently to different treatment methods. Therefore, a section dealing specifically with the influence of selenium speciation in Wolverine tailings pond water on treatment process selection is presented first prior to the discussion of actual treatment options in more detail.

Speciation of Selenium in Wolverine Tailings Pond Water

The results of chemical analysis of tailings pond water samples collected in August 2016 and June 2017, salient to the discussion about selenium treatment, are summarized in Table 4-2.

Table 4-2 Speciation of Dissolved Selenium and other Salient Parameters in Samples of Wolverine Mine Water Collected in August 2016 and June 2017.

Analyte	Unit	T1-1 2016	T1-2 2016	T1-3 2016	BQE Analysis 2017
Selenite - Se (IV)	µg/L	910	967	958	174
Selenate - Se(VI)	µg/L	369	382	368	494
Selenocyanate – Se(-II)	µg/L	133	151	146	728
Unknown Se Species	µg/L	13.7	13.9	15.4	45.6
Thiocyanate	mg/L	-	-	-	54.1
TOC	mg/L	-	-	-	40.4
Dissolved Oxygen	mg/L	-	-	-	< 1

The main takeaways from the data presented in Table 4-2 are as follows:

- Wolverine tailings supernatant contains elevated levels of selenocyanate which is atypical for mine impacted waters that usually contain selenate as the dominant species and sometimes small amounts of selenite.
- The fact that reduced selenium species including selenite and selenocyanate account for more than $2/3^{rd}$ of total selenium while selenate (species with the highest oxidation state) accounts for less than $1/3^{rd}$ of the total selenium present in the water indicates that there is a reducing environment in the tailings supernatant.
- The prevalence of reducing conditions in the pond is further confirmed by the presence of elevated concentration of thiosulphate which is expected to undergo oxidation to sulphate.
- The persistence of reducing conditions in the tailings pond many years after the stoppage of mining may at least partially be explained by the presence of organic carbon. Organic carbon stimulates biological activity and keeps the pond under anoxic conditions.
- The fact that more than 40 µg/L of total selenium is present as “unknown” species provides an indication that there is likely organo-selenium present in the pond. Selenate, selenite, and selenocyanate are all known inorganic forms of dissolved selenium while organo-selenium typically reports to the unknown fraction during the speciation assays. Moreover, the comparison of the speciation results from 2016 and 2017 indicate that the concentration of organo-selenium has increased.

Impact of the speciation analysis on treatment can be summarized as follows:

- Any treatment method selected for Wolverine must be able to remove all selenium species, i.e. selenate, selenite, and selenocyanate, and organo-selenium with a high degree of efficiency to meet the effluent limit of 20 µg/L consistently.
- The need to remove selenocyanate to meet the discharge limit of 20 µg/L introduces a major uncertainty into the overall treatment because little is known about selenocyanate removal by most of the treatment methods with the exception of Reverse Osmosis. Moreover, water

treatment at Wolverine will not be able to be designed based on or modeled after any existing water treatment in the mining industry.

Ferric Co-precipitation

Ferric co-precipitation involves the injection of ferric iron into the wastewater followed by the precipitation of ferric oxyhydroxide solids which act as an adsorbent for various constituents dissolved in the water. Ferric co-precipitation is an inexpensive and effective method of removing selenite but is ineffective at removing selenate and selenocyanate. It follows that **ferric precipitation alone cannot be used to achieve the target effluent water quality** although it may be used as a pre-treatment step to remove selenite upstream of other treatment for selenate and selenocyanate.

Membrane Treatment by Reverse Osmosis (RO)

Reverse Osmosis is a membrane process that separate water from ionic constituents dissolved in it. The processes is purely physical in nature relying on high pressure gradient and electrostatic repulsion between the membrane surface and the dissolved charged constituents in water. The RO process does not rely on chemical reactions and is capable of removing all ionic species with high efficiency, typically greater than 99%. Water passes through the membrane under pressure to the clean permeate side while ions are retained and concentrated on the dirty/retentate side of the membrane and subsequently report to the “reject” stream.

Since all selenium species are ionic at neutral pH, **RO will reject all selenium species with high efficiency**. The reject stream represents liquid waste that must be managed. Depending on the feed water chemistry, up to 50% of the feed to the membrane process may end up as waste brine. This is why membrane treatment must often be combined with some other treatment applied to the reject stream to provide a comprehensive treatment option that does not leave long term liabilities in the form of large volume of highly concentrated waste brine.

Biological Selenium Reduction

Biological selenium reduction reduces selenate and selenite to elemental selenium in the form of nanoparticles inside microbial biomass. The process requires the injection of organic electron donor such as ethanol and nutrients including ammonia and phosphorus into the bioreactor in order to promote and sustain microbial activity. Temperature control is required. As with any biological process, it is impossible to guarantee that the only reaction taking place in the system is the target selenium reduction. Instead many different reactions and by-products can be generated during the treatment. **Some of the by-products include organics, ammonia, nitrite, sulphide, and organo-selenium all of which increase the risk of either acute or chronic effluent toxicity** [1 & 2].

The main residue of treatment is waste biomass laden with selenium nanoparticles. Little is known about the long term stability of selenium in this type of residue. However, the biological nature of the residue guarantees that changes will occur as biomass decays, potentially exposing selenium nanoparticles for possible transformation into dissolved forms including organoselenium. While the removal of selenate and selenite by the biological system has been demonstrated on an industrial scale, it is not clear whether selenocyanate can be removed partially or at all. In fact there is some evidence that suggests that selenocyanate is produced as one of the by-product of biological selenium reduction [3].

IX Combined with ERC Treatment and/or Direct ERC

Selective IX can be combined with electroreduction of selenium in ERC using sacrificial anodes made of iron to remove selenium from mine impacted waters to reach ultralow discharge limits. Sometimes, depending on water quality, effluent targets, and wastewater flow, ERC treatment can be applied directly without the IX step.

The main advantage of IX and ERC treatment applied either alone or in combination, is that it can achieve end-of-pipe selenium concentrations below 1 µg/L and do so without introducing any new chemicals into the treated water that were not there in the first place. As such IX and ERC do not pose any risk of causing acute effluent toxicity. That said, the removal of selenocyanate by IX and ERC treatment has not been tested previously because selenocyanate is not normally present in mine water in any appreciable quantity.

Selenium removed from water by IX and ERC reports to solid residue composed mainly of mixed iron oxides (Fe account for ~ 50% of dry weight of residue) with relatively small amount of elemental selenium. During several previous projects it was demonstrated that the residue is extremely stable and does not release selenium under a wide range of conditions including the exposure to strong oxidants, acids, and bases. **Recent pilot testing demonstrated that IX/ERC residue is very stable and can be blended with tailings stored in a tailings pond.**

Zero Valent Iron (ZVI)

Zero-valent iron system typically comprises packed beds of iron particles where water flows through the bed of ZVI and selenium is captured by the iron particles. The mechanism of selenium capture by ZVI involves a series of electrochemical reactions which occur at the interface between the iron oxide layer formed adjacent to the surface of unreacted iron and solution containing selenium. These reactions lead to selenium reduction to selenite and elemental selenium which remain trapped within the oxide layer on ZVI surface. **The main challenge and limitation of the ZVI process is passivation of ZVI particle surface** which happens as the iron oxide layer grows, making the diffusion of selenium from feed water to the reaction zone more difficult. This reduces the selenium removal efficiency and capacity of ZVI as an adsorbent. Once utilized, the spent sorbent materials require disposal or landfill. **Due to ZVI passivation, the supply of fresh ZVI is an ongoing and significant operating expense**. Although the surface of ZVI can, at least in principle, be refreshed through polishing/abrasion/chemical contact, these processes have not been successfully applied at industrial scale and even in the pilot scale did not always restore the ZVI removal efficiency, aside from adding cost and complexity to the treatment system.

In addition, the kinetics of selenate removal using ZVI is slow. Often, ZVI must be in contact with selenium-containing water for hours in order to remove selenium effectively. As a result, **ZVI reactor vessels are large as they must not only provide long enough retention time but also house large inventory of ZVI sorbent**. This makes ZVI a difficult option to implement.

Similar to IX, ERC treatment, and biological selenium reduction, the removal of selenocyanate by ZVI is unknown.

Summary of Selection of Treatment Option for Selenium Removal

Table 4-3 provides a summary of the evaluation of different treatment options for selenium using the criteria developed in Section 4.1.

Table 4-3 Summary of Selenium Removal Treatment Selection for Wolverine mine

Evaluation Criteria	Ferric	Bio	IX+ERC or ERC direct	Membrane	ZVI
Compliance with end-of-pipe limits	Not suitable	Potentially suitable	Potentially suitable	Suitable	Potentially suitable
Residue generation and management	Suitable	Not suitable	Suitable	Not suitable without brine management	Suitable
Risk of effluent toxicity	Suitable	Not suitable	Suitable	Suitable	Suitable
Effect of seasonality (5 month operation per year)	Suitable	Not suitable	Suitable	Suitable	Suitable
Ease of implementation	Suitable	Potentially suitable	Potentially Suitable	Suitable	Not suitable
Cost of treatment	Suitable	Potentially suitable	Potentially suitable	Suitable	Not suitable
Industrial Experience	Yes	Yes	Field Pilot	Yes	Field Pilot

As can be seen from this table and from the previous discussion above, selecting the most suitable option for selenium removal from Wolverine tailings pond supernatant is not a simple task.

Furthermore, as discussed previously, due to the need to remove selenocyanate, the Wolverine water treatment will not be able to benefit by referencing any existing industrial scale treatment plant in the mining industry. Nevertheless, Table 4-3 shows that treatment options can be narrowed down as follows:

- Ferric precipitation alone will not suffice in meeting the effluent discharge limit of 20 µg/L because it only removes selenite but it can nevertheless significantly reduce the concentration of total selenium.
- Biological selenium reduction is eliminated because of the risks associated with effluent toxicity, residue stability, and the difficulty with re-starting a biological treatment process every year for 5 months of operation.
- ZVI is eliminated because of the expected large tonnage of iron required to achieve and maintain high efficiency of selenium removal and the associated high costs of implementation.

RO treatment is anticipated to be effective at generating treated water suitable for discharge. However, the application of RO must be combined with another treatment step that would remove selenium from the liquid waste stream produced as a by-product of RO. IX with ERC or ERC alone may be able to satisfy all of the project requirements but only if they can remove selenocyanate. Consequently, BQE's selected the following two treatment options for lab scale testing:

- IX combined with ERC treatment and ferric precipitation built into heavy metals removal step upstream of selenium removal
- Direct ERC treatment

4.4 Treatment for WAD Cyanide

One of the challenges of WAD cyanide removal from the Wolverine tailings supernatant is that the WAD cyanide concentration in the water is very low (< 200 µg/L) and it needs to be removed to below 25 µg/L. Furthermore, as discussed in Section 4.3, the water contains elevated level of organic carbon. This eliminates the use of any of the conventional methods for cyanide destruction using strong oxidizing reagents including SO_2/Air, peroxide, chlorination, and Caro's acid. These methods would require high capital and operating costs to achieve the very low concentration in the effluent and elevated consumption of reagents consumed by organic compounds in the water. Instead, three other methods of WAD cyanide treatment will be tested as they can all be easily incorporated into the treatment for heavy metals without adding any capital or operating cost. These methods described below can also be implemented as a separate treatment step in a cost effective manner.

Iron Cyanide Precipitation

Iron cyanide complexes form quickly and can be precipitated in the presence of base metals. Ferric iron addition in the metals removal step may help promote scavenging of WAD cyanide in the solids produced in this step although the limited solubility of ferric iron may limit the extent of WAD cyanide removal.

Conversion to Thiocyanate

Cyanide can be converted to the less toxic thiocyanate when reacted with sulphur containing compounds in the presence of oxygen. This reaction is common in cyanidation of ore rich in sulphide and polysulphide minerals such pyrhotite and pyrite. In the context of water treatment, the conversion to thiocyanate can occur in sulphide precipitation reactors and can be useful especially when dealing with sub mg/L levels of WAD cyanide removal. This is because typically there is no regulatory limit for thiocyanate, and at sub-ppm levels, thiocyanate is not known to cause fish toxicity and is relatively stable compared to for example thiosulphate.

Both precipitation with iron and conversion to thiocyanate will be tested and evaluated as part of the heavy metals removal process.

Adsorption

Cyanide and metal cyanide complexes are known to exhibit high affinity to IX resins and activated carbon. Adsorbents are typically used for cyanide polishing, but regeneration of the adsorbent media is also possible and allows its re-use and expands its application further. The main advantage of using adsorbents to remove cyanide is that no major by-product of treatment is generated and cyanide and its complexes are removed from the solution without changing its chemical nature. Another advantage of adsorption is that it can achieve ultralow concentrations of residual WAD cyanide in the treated water. Given the small mass load of cyanide present in the water, with or without regeneration of the adsorbent media, and the treatment target of 25 µg/L, adsorption may be very cost effective, especially when applied for final effluent polishing if required.

5. Experimental Methodology

5.1 Chemical Reagents

Table 5-1 lists the reagents used during the bench scale testing of the Wolverine mine water as well as the concentration of the stock solutions that were used.

Table 5-1 List of reagents used during the bench scale testing of Wolverine mine water.

Reagent	Purity (bulk)	Source	Stock Concentration
Ferric Sulphate	22% Fe	Sigma Aldrich	7.7 -24 g/L Fe
NaHS	72%	Acros Organics	10 g/L S
Floc	100%	BASF	1 g/L Floc
NaOH	98%	Anachemia	4 to 40 g/L NaOH
HCl	31%	Anachemia	1 N HCL
Na_2SO_4	98%	Univar	82 g/L

5.2 Chemical Assays

Table 5-2 lists the types of assays that were performed on the Wolverine mine water during this campaign as well as the third party lab performing the assays and the standard methods that were following in conducting the assays.

Table 5-2 List of assays conducted on Wolverine mine water

Analyte	Method	Assay Provider	Standard Method used	Preserved
Alkalinity	Acid titration	BQE Water Lab	Standard Methods for the Examination of Water and Waste water, 21st Edition. Alkalinity 2320	n/a
Anions	Ion Chromatography with Chemical Suppression of Eluent Conductivity	CARO	APHA 4110 B	n/a
BOD	Dissolved Oxygen Meter	CARO	APHA 5210 B	n/a
COD	Closed Reflux, Colorimetry	CARO	APHA 5220 D*	H2SO4
Nitrogen, NH_3	Automated Colorimetry (Phenate)	CARO	APHA 4500-NH3 G*	H2SO4
SAD cyanide	Flow Injection Analysis with In-Line Ultraviolet Digestion and Amperometric Detection	CARO	ASTM D7511-12	NaOH
TOC	High Temperature Combustion, Infrared CO2 Detection	CARO	APHA 5310 B	H3PO4

Analyte	Method	Assay Provider	Standard Method used	Preserved
Total Metals	HNO_3+HCl Hot Block Digestion / Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	CARO	APHA 3030 E* / APHA 3125 B	HNO3
WAD Cyanide	Flow Injection Analysis with Gas Diffusion Separation and Amperometric Detection	CARO	ASTM D6888-09	NaOH
Se Speciation	AnIX HPLC-ICPMS	ALS	Miekeley Spect. Acta B 60 (2005) 633-641	n/a

5.3 Feed Water Sample Arrival and Storage

Samples of Wolverine tailings supernatant water were received by the BQE laboratory in Vancouver on June 13, 2017. The water arrived in 18 x 10L containers and 20 x 1L containers. Upon arrival, water from all of the containers was mixed together in one 200L drum. The drum was then covered. Stored at ambient temperature in the laboratory and samples were withdrawn for testing purposes as required.

5.4 Metals Removal using Sulphidization with and without Ferric Addition

Sulphidization tests with and without ferric addition were carried out to remove Cu, Cd, Pb, Zn and selenite from samples of Wolverine tailings supernatant. All tests were conducted in batch tests using a bench scale reactor of 200 mL equipped with pH and ORP probes. The pH set-point was pH 4.4 and no pH adjustment via acid or base was required during the sulphidation. During tests where ferric iron was added, sodium hydroxide was added to adjust the solution pH back to the pH set-point and the consumption of sodium hydroxide was recorded. Sulphide dosage was always 5 mg/L and ferric iron dosage was always 20 mg/L. The test typically lasted no more than 10 minutes. Samples of treated water were withdrawn from the reactor via a syringe and filtered using a 0.45 micron syringe filter. Flocculent was applied to settle solids before solution reported to the Selen-IX™ column.

To optimize the metals removal and selenite removal step, a series of tests were completed using ferric addition and sulphide addition alone and in combination including different sequences of reagents additions.

5.5 Selen-IX™

5.5.1 Ion Exchange (IX)

Ion-exchange tests were carried out using packed bed columns made of 0.8 cm inner diameter clear PVC columns in a down-flow configuration and the resin bed height of 25 cm. The aspect ratio of the columns was sized so as to produce results representative of full scale performance. The volume of resin held in the column was 50 mL and is referred to as one Bed Volume (BV). The columns were loaded at a solution flowrate of 9 BV/hr and regenerated using sodium sulphate solution flow of 1.5 BV/hr controlled by a variable speed peristaltic pump. Pump tubing for both pumps was calibrated daily and flow checks were performed throughout the testing to confirm the flow rate. Faster rate was used in loading and slower rate in regeneration and wash. Grab samples were taken from the discharge line of the columns. Composite samples for the columns were collected in a single beaker. The solution of 50 g/L Na2SO4 was used for resin regeneration.

5.5.2 ERC Treatment (ERC)

Selenium-rich spent regenerant produced by regeneration of the IX columns is normally treated in the ERC that allows recycling and re-use of the treated regenerant in the IX circuit. However, the volume of the spent regenerant produced from the small bench scale column tests was insufficient to run the ERC. Therefore, synthetic spent regenerant solution was prepared for ERC testing that mimicked the chemistry of the composite samples collected during the IX regeneration.

The bench scale electrocell includes a stainless steel cathode and an iron anode with approximately 0.025 m^2 of anode area and the gap between cathode and anode of approximately 10 mm. The cell was operated at a constant DC current of 12A applied to the electrocell via a DC power supply. All reagent additions and measurements in the ERC circuit are automated and the consumptions are recorded in a computer. Samples of solution were withdrawn from the electrocell periodically to assess the kinetics of selenium removal and determine the electric charge and total iron consumption to reach the target discharge limit.

5.6 WAD Cyanide Removal by Activated Carbon and IX Resin

In addition to WAD cyanide removal in the metals precipitation stage with sulphide and ferric iron addition, WAD cyanide removal was also investigated using activated carbon and M500 SBA resin. Although these adsorbents would be used as the last/polishing treatment step in the full scale treatment plant, the need to avoid project delays and interruptions caused by lab tests for selenium removal taking place concurrently, the decision was made to test the WAD cyanide removal ability of each adsorbents using water treated for metals removal only. Two sets of tests were completed with activated carbon and resin, respectively. One set of tests was carried out at pH 7.5, the other at pH 9. During the tests, 10 ml of activated carbon or resin were contacted with 90 ml of water in a beaker placed on a shaker for 7 minutes simulating 9 BV/hr loading rate in continuous flow through adsorption column. The solutions was decanted from the beaker, sampled for WAD cyanide assays, and then 90 mL of fresh feed water was added into the beaker with the carbon and resin. This procedure was repeated multiple times.

5.7 QA/QC

BQE Water lab maintain rigorous QA/QC for sampling to avoid contamination and ensure confidence in the assay results.

BQE worked with CARO Analytical Services for metals, anions and other assays. Selenium speciation was provided by ALS Environmental. Metals were analysed by ICP-MS, anions by IC and WAD cyanide by amperomectric. Selenium species were analyzed by an IX HPLC-ICPMS.

Standard sample handling, filtration and preservation procedures were followed to ensure sample integrity. Feed samples were sent out for assay periodically to monitor the metals and cyanide levels over the campaign. Split and duplicate samples were sent out during the campaign to ensure assay accuracy.

Tests were performed by trained laboratory staff. The training included demonstration of proficiency in performing IX and ERC tests.

In house pH and ORP analyses were conducted following the Standard Methods for the Examination of Water and Waste water, 21st Edition. Clesceri, L. S., A. E. Greenberg, A. E., and Eaton, A. D. Rice, E.U., eds. American Public Health Association; Washington DC; 2005.

All glassware was cleaned, acid washed with 10% v/v HCl, and rinsed thoroughly with DI water.

Each instrument was operated by trained staff members. The instruments were calibrated according to manufacturer guidelines and in accordance to the relevant SOPs. Analytical balance, pipettes, micro-pumps, and other measuring devices were calibrated frequently.

6. Treatability Testing Results and Discussion

Test results are presented in the following sequence:

- Tailings supernatant characterization
- Metals removal using sulphide precipitation
- Selenium removal using the combination of IX and ERC
- Selenium removal using ERC alone
- WAD cyanide removal using activated carbon and IX resin

6.1 Tailings Supernatant Characterization

6.1.1 Chemical Assays

Table 6-1 shows the summary of assays for metals, anions, organic carbon, and cyanide completed on the sample of tailings supernatant shipped from Wolverine to BQE laboratory in Vancouver. Only the results salient to the treatability assessment are shown in this table.

Table 6-1 Summary of tailings supernatant water analysis (July 2017)

Analyte	Total Concentration	Detection Limit
	mg/L	mg/L
Chloride	18.2	0.1
Fluoride	<1.00	0.1
Nitrate (as N)	<0.100	0.01
Nitrite (as N)	<0.100	0.01
Sulfate	1810	1
Alkalinity	<10	10
Ammonia, Total (as N)	1.46	0.02
Carbon, Total Organic	40.4	0.5
Cyanide, Total	0.233	0.002
Cyanide, WAD	0.0513	0.002
Thiocyanate	54.1	0.1
Ag	0.00370	5E-05
Cd	0.0103	1E-05
Ca	765	0.2
Cu	0.429	0.0002
Fe	0.011	0.01
Pb	0.11	0.0001
Mg	3.38	0.01
Mn	0.496	0.0002

Analyte	Total Concentration	Detection Limit
P	0.115	0.05
K	69	0.1
Se	1.73	0.0005
Si	2.6	1
Na	264	0.1
Sr	2.89	0.001
Zn	1.5	0.004

It should be noted that total and dissolved concentrations of all of the constituents listed in Table 6-1 were very close to each other and are within the range of the analytical error. The water is saturated with respect to gypsum as confirmed by the levels of calcium and sulphate, and contains significant amount of TOC and thiocyanate.

6.1.2 Selenium Speciation

The results of chemical analysis of tailings pond water samples collected in August 2016 and June 2017, salient to the discussion about selenium treatment, are summarized in Table 6-2.

Table 6-2 Speciation of dissolved selenium in samples of Wolverine mine water

Analyte	Unit	Sample T1-1	Sample T1-2	Sample T1-3	BQE Analysis
Selenium +4	µg/L	910	967	958	174
Selenium +6	µg/L	369	382	368	494
Selenocyanate	µg/L	133	151	146	728
Unknown Se Species	µg/L	13.7	13.9	15.4	45.6
TOC	mg/L	-	-	-	40.4

The most significant observations from the speciation results shown in Table 6-2 can be summarized as follows:

- Selenocyanate represents a significant portion of total selenium and needs to be removed in order to achieve compliance with the selenium discharge limit of 20 µg/L. This introduces uncertainty into the overall treatment because selenocyanate is not normally present in mine water and little is known about the efficiency of selenocyanate removal by conventional treatment systems
- Reducing conditions prevail in the tailings supernatant as evidenced by the fact that Se(VI) (selenate) accounts for only ~ 30% of total selenium with the remainder being selenium present in more reduced forms
- The presence of significant level of "unknown selenium" fraction together with elevated organic carbon raises the probability that the water is biologically active and contain organo-selenium species that are difficult to speciate accurately
- The concentration of selenocyanate and organoselenium have increased significantly since 2016 while the concentration of selenite has decreased. Since the total dissolved selenium concentration remains more or less constant, it appears that biological activity in the pond probably converted selenite to selenocyanate and organoselenium.

A detailed discussion of the results of selenium speciation and their impact on the selection of treatment options for selenium removal was presented in Section 4.

Based on the results of chemical analysis, there is a distinct possibility that biological activity in the pond generates organoselenium and/or selenocyanate species. This is not desirable from the remediation perspective because organoselenium is highly bioaccumulative and known to cause chronic toxicity when discharged into the receiving environment. Regulatory agencies are aware of this and new regulations are taking this into account. For example the newly revised Canadian federal MMER regulations now mandate monitoring and reporting of selenium levels in fish tissue when water containing more than 10 µg/L is discharged into the environment or the end-of-pipe average annual concentration is greater than 5 µg/L.

6.1.3 Changes in Feed Water Observed During the Campaign

Over the course of the test program, it was noticed that physical and chemical properties of the feed water changed. The color of the solution changed from mostly clear with some white fine suspended solids to light green in a matter of days. The pH also changed from pH 4 measured upon arrival to pH 7.5 after one week. The dissolved oxygen (DO) level measured upon arrival was 0.8 mg/L. After 2 weeks and following 30 minutes of vigorous agitation the DO increased to 5 mg/L. These observations indicate that the water samples were probably biologically active.

Water from 1st shipment. Jul 20

Water from 2nd shipment. Jul 28

Figure 6-1 Images of water samples shipped to BQE Water's lab in Vancouver.

Figure 6-1 shows images of the water samples shipped to BQE Water's lab in Vancouver. The image on the left shows initial sample after one month of storage in BQE lab. The image on the right shows the second sample immediately after its arrival.

6.2 Metals Removal

Table 6-3 summarizes the results of the metals removal tests.

Table 6-3 Results of metals removal from Wolverine mine water using sulphidization.

Constituent of Concern	Concentration in Raw Water	Discharge Limit mg/L	Concentrations of Constituents of Concern in Treated Water [mg/L]			
			Sulphide only	Sulphide Followed by Ferric addition	Ferric Addition only	Ferric Addition Followed by Sulphide
Cu,	0.429	0.015	0.00621	0.149	0.498	0.00074
Pb	0.11	0.02	0.00013	0.0528	0.0928	<0.00010
Cd	0.0103	0.002	0.00037	0.00605	0.01	0.00003
Zn	1.5	0.5	0.466	1.13	1.45	0.399
Ag	0.00370	0.001	<0.00005	0.0044	0.00917	<0.00005
Se	1.73	0.02	1.16	1.21	1.65	1.07
WAD CN	0.0513	0.025	0.0743	0.0588	0.0619	0.0779

The results shown in Table 6-3 indicate the following:

- The best water quality is achieved when ferric addition is followed by sulphide addition. This type of treatment removes all metals of concern (Ag, Cu, Cd, Pb, and Zn) to levels below their respective discharge limits.
- Ferric addition alone removes only 0.08 mg/L of total selenium. In contrast, ferric addition combined with sulphide addition results in the removal of 0.66 mg/L of total selenium.
- There was no removal of WAD cyanide across the metals removal stage. In fact a slight increase in WAD cyanide concentration appears to result from metals removal. This can either be due to inconsistency with WAD cyanide assays or could be caused by the liberation of cyanide from silver cyanide complex during sulphidization where Ag_2S precipitates and the cyanide originally complexed by silver report to WAD cyanide.

The water treated using ferric iron addition followed by sulphidation was used to test the removal of selenium and cyanide in the next unit process, Selen-IX™. Figure 6-2 shows an image of the water treated using ferric addition followed by sulphidization. As apparent from the image, the water was clear with no suspended solids indicating that all suspended solids were removed as part of the metals removal stage and will not be an issue for the downstream processes.

Figure 6-2 Effluent water from the metals removal stage. Solution is clear with no suspended solids.

Table 6-4 shows the speciation of selenium in the feed and effluent from the metals removal process.

Table 6-4 Selenium speciation in the raw water and effluent from the metals removal process.

Analyte	Unit	Raw Water (Feed to Metals Removal Process)	Metals Removal Process Effluent
Selenium +4	µg/L	174	16.3
Selenium +6	µg/L	494	496
Selenocyanate	µg/L	728	578
Unknown Se Species	µg/L	45.6	64.2

As expected, almost all of selenite was removed by the metals removal process. In addition, partial removal of selenocyanate is observed across the metals removal circuit, but not to the degree that would satisfy the target discharge concentrations.

6.3 Selenium Removal

6.3.1 Selenium Capture by IX Resin and Resin Regeneration

Water that had been treated by sulphidization with ferric addition for metals removal was subsequently fed into a packed bed IX column. Figure 6-3 shows the selenium concentration in the column effluent, i.e. the breakthrough curve. The horizontal axis of Figure 6-3 shows the number of Bed Volumes (BV) calculated by dividing the volume of water treated through the column by the volume of resin contained in the column. The units of BV are commonly used in IX testing to allow comparing results from columns of different sizes.

As can be seen from Figure 6-3, initially all selenium was removed from the feed before breakthrough which occurred at approximately the 35 to 40 BV mark followed by a plateau starting at 60 BV.

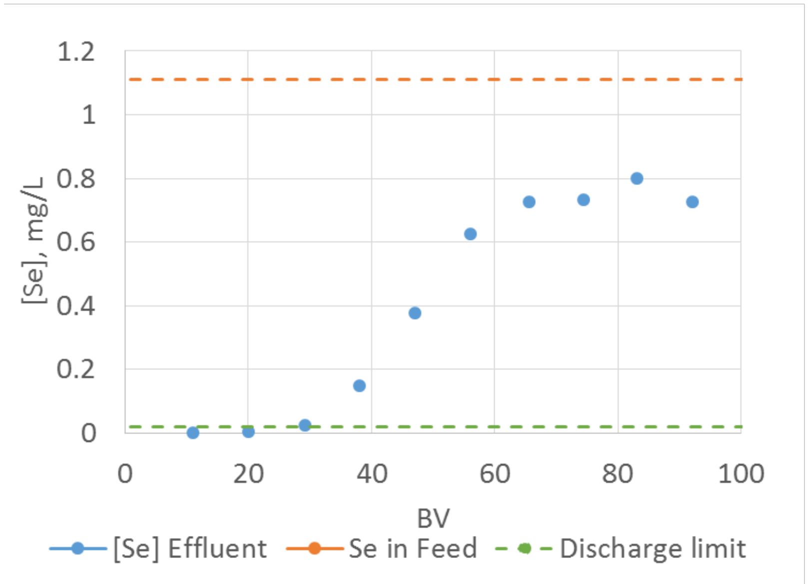

Figure 6-3 Selenium removal by IX in a packed bed column

The results of resin regeneration are shown in Figure 6-4. The figure features the typical bell shaped curve of a chromatographic peak, in this case for selenium being eluted from the column.

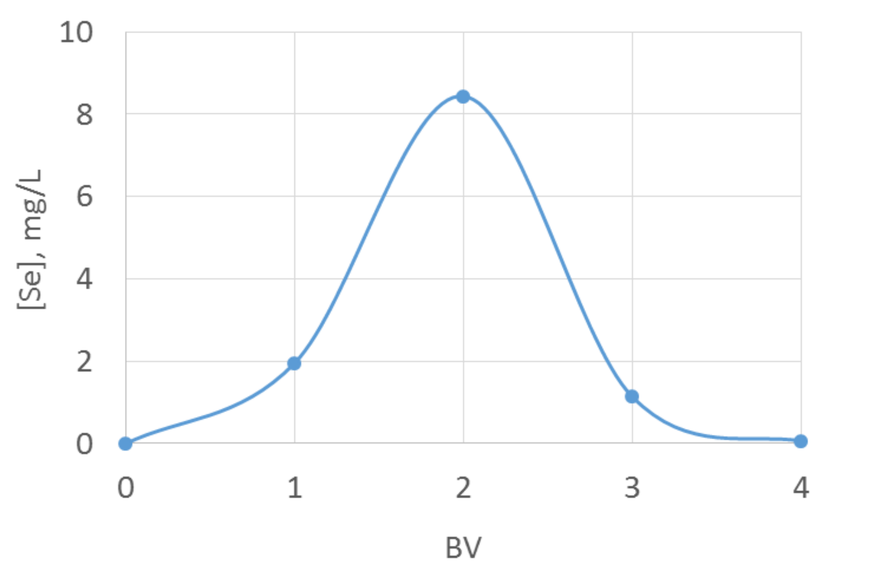

Figure 6-4 Elution of selenium from IX resin during resin regeneration

It is evident from Figure 6-4 that the elution of selenium starts from the moment the regenerant solution came into contact with the resin in the column and was complete after about 4 BV of regenerant had passed through the column. However, when the composite regenerant sample was analyzed, it became clear that the mass of selenium eluted from the resin was only approximately 20%

of the total selenium captured by the IX resin. This is shown in Table 6-5 which presents the selenium balance around the IX column.

Table 6-5 Selenium balance around IX column

Se loaded, mg	3.15
Se regenerated, mg	0.6
% of Se regenerable	19%

The overall results of IX loading and regeneration contrast with BQE Water's previous selenium removal experience. In previous projects involving treatment of water containing Se(VI) (selenate) as the dominant species with only traces of Se(IV) selenite, all selenium loaded onto the resin and the resin could be stripped and reused in many consecutive loading and regeneration cycles. The results obtained in this program show that only the selenate and selenite selenium in the Wolverine water behave as expected, while selenocyanate and possibly unknown organoselenium species load irreversibly on the resin and do not effectively regenerate.

Recognizing that selenocyanate was not amenable to IX regeneration, the use of IX resin as a single use disposal adsorbent removing non selenate species that bind irreversibly was envisaged. The only pre-requisite for this system is that the capacity of the resin for selenocyanate be high enough to make it an economically feasible process. Therefore, one test was carried out with an extended IX loading cycle to establish the full breakthrough curve and determine the capacity of the resin for selenocyanate. The results of this extended loading cycle are shown in Figure 6-5.

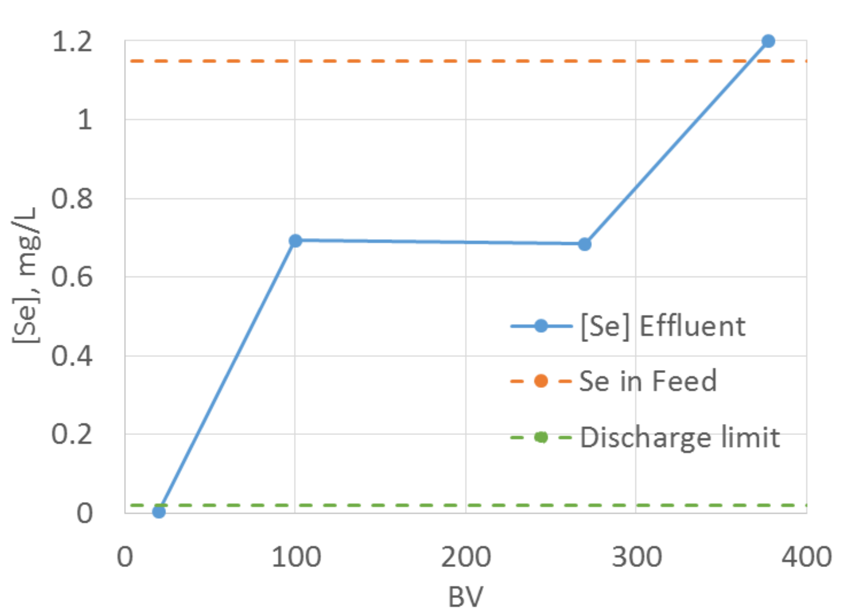

Figure 6-5 Extended IX loading to establish the capacity for non selenate species

As can be seen from this figure, the breakthrough of the non-selenate species occurred between 300 and 400 BV. Unfortunately, the capacity of the resin corresponding to 300 to 400 BV is too low to make use of IX as a single use product economically feasible for Wolverine water treatment. This is discussed further in section 7.

Table 6-6 shows the speciation of selenium in the feed and effluent of the IX process. The effluent sample was a composite collected between the start and end of the test corresponding to the end point on the IX loading breakthrough curve shown in Figure 6-5.

Table 6-6 Speciation of selenium in the feed and effluent of the IX process

Analyte	Unit	Metals Removal Process Effluent (Feed to IX)	IX Effluent Composite
Selenium +4	µg/L	16.3	<5.0
Selenium +6	µg/L	496	484
Selenocyanate	µg/L	578	14.3
Unknown Se Species	µg/L	64.2	<4.0

The speciation results confirm that indeed selenocyanate and organoselenium species were removed by the IX resin with the highest efficiency.

6.3.2 Selenium Removal from IX Regenerant by ERC

Results of selenium removal from IX regenerant subjected to ERC treatment are plotted in Figure 6-6.

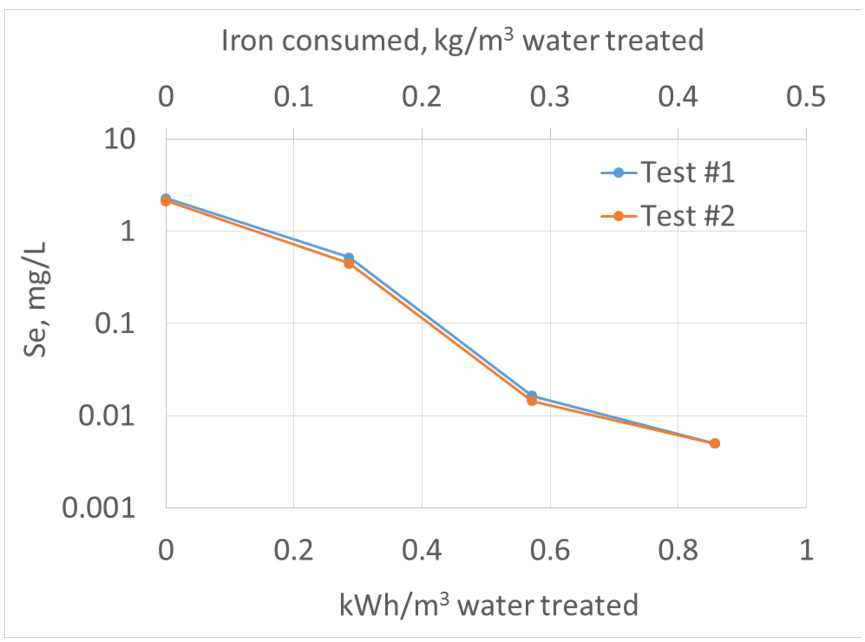

Figure 6-6 Selenium removal from IX regenerant in ERC

As can be seen from this figure, selenium was removed entirely from the spent regenerant down to < 10 µg/L detection limit applicable to brine solutions. Duplicate tests were completed and results show great repeatability.

6.3.3 Selenium Removal by Direct ERC Treatment

As discussed previously in Section 4, ERC treatment can be applied directly, without IX, to the tailings pond water or be combined with RO treatment where it would treat the RO retentate. In order to test the performance of the direct ERC treatment, Wolverine water was fed directly to the bench scale ERC circuit and the removal of selenium was monitored as a function of power consumption and iron consumption by the ERC. The test results are presented in Figure 6-7.

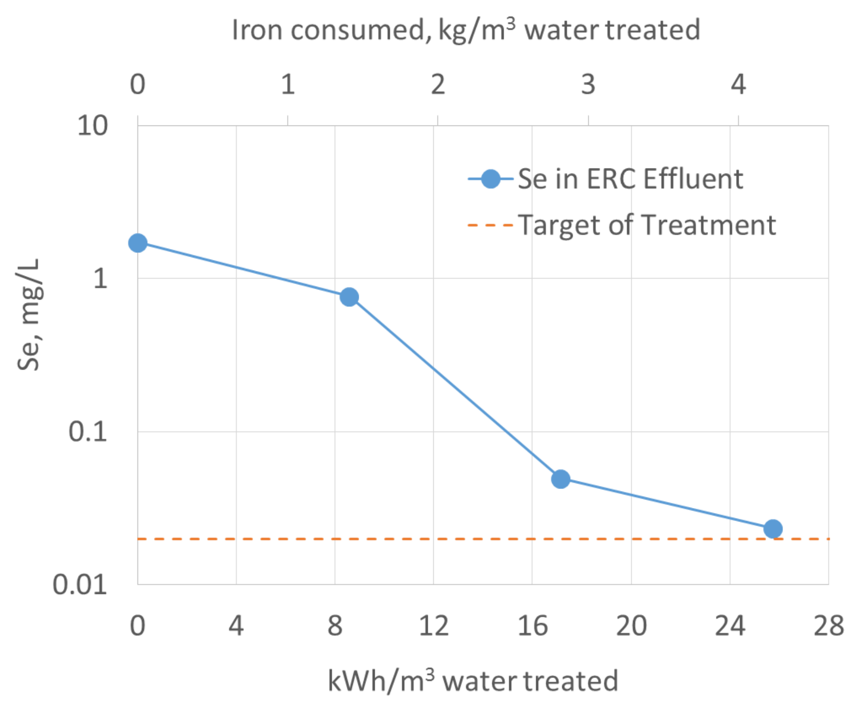

Figure 6-7 Selenium removal from Wolverine water by direct ERC treatment

As apparent from these results, the ERC was able to meet the treatment target. However, the ERC would not have to meet the discharge limit if ERC were combined with RO such that ERC would treat RO reject stream prior to discharge back into the tailings pond. In this scenario, the consumption of power and iron would be significantly reduced for the following reasons:

a) There is no longer a need for the ERC effluent to meet environmental discharge targets. Instead of generating water for discharge, ERC treatment acts as a sink for selenium from the RO reject before returning the reject to the pond. Figure 6-7 shows that the consumption of power and iron by ERC would be reduced significantly if concentration in ERC discharge were 100 µg/L instead of 20 µg/L.

b) Based on results of extensive ERC testing in previous projects, BQE has established that the iron dose and power consumption per mass of selenium removed from water are reduced when the starting concentration of selenium is higher. As the use of RO would concentrate selenium in the tailings pond water, this would improve the efficiency of the ERC.

Based on the test results and preliminary mass balances, the consumption of power and iron in the full scale treatment plant using the combination of RO and ERC at Wolverine would be approximately 26 kWh/m^3 and 4.7 kg/m^3, respectively. These figures are incorporated into the cost estimate described in Section 7.

6.4 WAD Cyanide Removal

6.4.1 Conversion to Thiocyanate and Co-removal with Metals

Results shown in Table 6-3 indicate that the conversion of WAD CN to thiocyanate or its precipitation as iron cyanide did not occur and that no removal of WAD cyanide was achieved across the metals removal treatment step. In fact, the results in Table 6-3 show a net increase in WAD cyanide concentration in the effluent from the metals removal step. Based on BQE's experience, at least a portion of WAD cyanide must be removed during this process. It is expected that the presence of organic species, thiocyanate, and selenocyanate causes interference with WAD cyanide measurements. Therefore, two more tests were conducted to confirm the efficiency of WAD cyanide removal during the metals removal process. These results along with the results from the first metals removal test are shown in Table 6-7.

Table 6-7 WAD cyanide removal across the metals removal circuit.

Metals Removal Test (Sulphidization and Ferric Iron)	WAD Cyanide in Feed, mg/L	WAD Cyanide in Effluent, mg/L
Initial Test (also shown in Table 6-3)	0.0513	0.0779
Duplicate Test	0.0395	0.0302
Triplicate Test	0.0394	<0.0020

It is evident from the results that although the initial test showed an increase in WAD cyanide concentration, the second test showed minor removal and the third test showed complete removal of WAD cyanide across the metals removal circuit. In addition, one of the WAD cyanide measurements in the feed is significantly different than the other two. These observations confirm inconsistency in WAD cyanide measurements. Results also indicate that WAD cyanide removal occurred across the metals removal circuit. Based on BQE's experience, the efficiency of WAD cyanide removal in the metals removal step using sulphidization with ferric addition will increase if WAD cyanide concentration in the pond water increases. In conclusion, the metals removal circuit could potentially act as a sink for WAD cyanide in the tailings pond supernatant.

6.4.2 Cyanide Adsorption

Based on previous project experience, BQE Water identified the possibility of using activated carbon and a Strong Base Anion (SBA) IX resin to capture WAD cyanide from mine impacted water. Understanding that pH may influence WAD cyanide capture, two sets of tests were run with activated carbon and resin at pH 7.5 and 9.5. The results of the tests are shown in Figure 6-8.

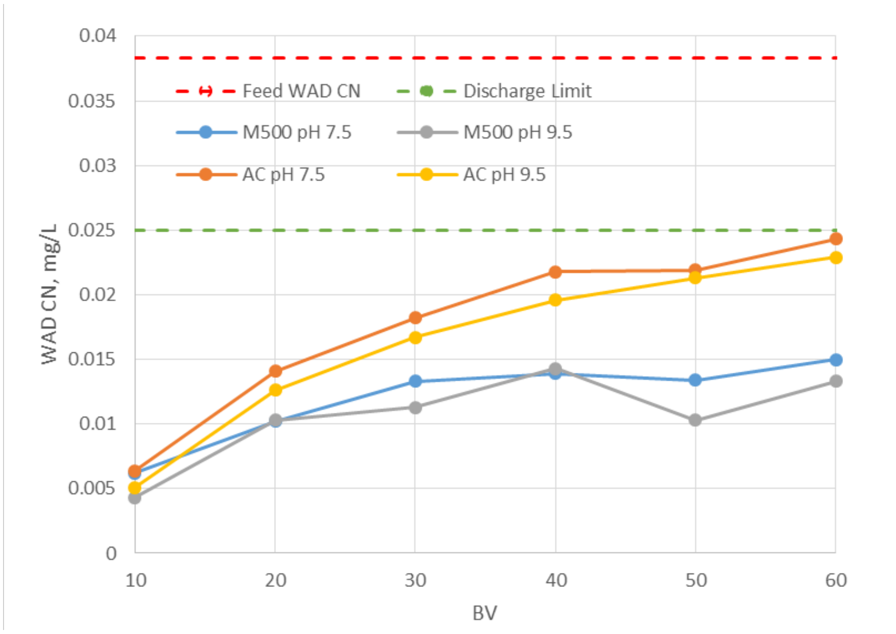

Figure 6-8 High pH adsorption of cyanide by IX resin and activated carbon.

As apparent from these results both activated carbon (AC) and IX resin M500 were successful in removing WAD cyanide to below the treatment target of 25 µg/L. However, the M500 resin's performance was significantly better than activated carbon. Based on BQE Water's experience from similar water chemistries, the anticipated performance of the IX resin for WAD cyanide removal is about 2500 BV of load before cyanide breakthrough is observed.

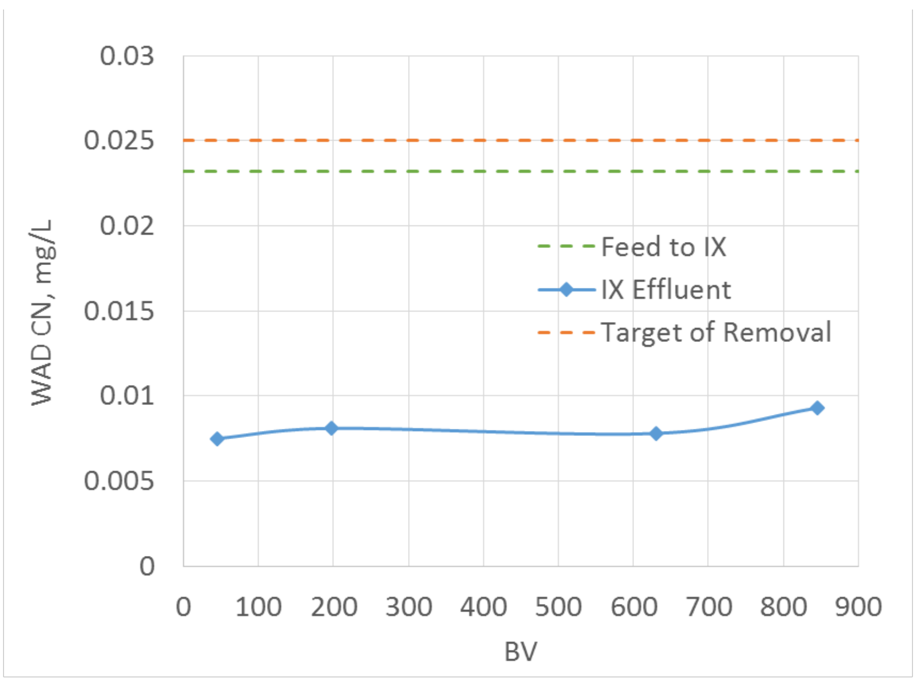

Figure 6-9 High-pH adsorption of cyanide by IX resin – extended loading cycle.

In order to properly assess the length of the loading cycle, additional water was shipped to BQE Water's lab in Vancouver. This water was used to run an extended IX loading cycle and identify the actual resin capacity for WAD cyanide removal and ensure it aligns with the expectations. Figure 6-9 shows the results of this extended loading cycle. It is evident from the graph that the new sample included lower WAD cyanide concentration, 23.2 µg/L. Although the WAD cyanide concentration in the feed to the IX column was below the discharge target of 25 µg/L, results confirm the efficiency of WAD cyanide removal using the IX resin. This is evident since even after 846 BV of load the IX resin was still removing WAD cyanide very efficiently.

7. Proposed Treatment Process and Cost Estimate for Full Scale Implementation

7.1 Treatment Process

Based on the evaluation of different treatment options and results of bench scale testing, BQE Water developed a comprehensive treatment process flowsheet for full scale implementation at Wolverine. This system will allow the dewatering of the pond and deportment of contaminants into stable residues. The system is shown schematically in Figure 7-1.

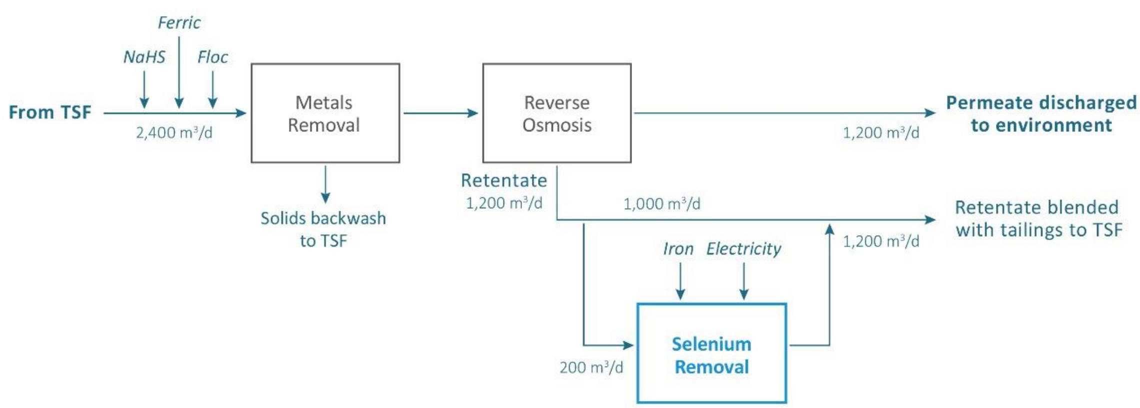

Figure 7-1 Schematic flowsheet for full scale implementation

In this system, influent water is treated to precipitate metals using sodium hydrosulphide and ferric iron as demonstrated by bench scale tests with results summarized in Section 6.2. The metal sulphide solids along with any suspended solids present in the feed are then removed by multimedia filtration, with the filter backwash stream either directed back to the TSF or subject to thickening and subsequent blending into the zinc concentrate filterpress feed in the mill.

The turbidity free stream is then treated using a single pass RO. The purpose of the RO is to reject all selenium species and WAD cyanide and produce effluent for discharge. The RO reject stream is split. A portion of the reject is treated using direct ERC to remove all selenium species from solution into stable solid residue that can be safely co-deposited with tailings in the tailings pond thus providing a sink for selenium in the overall scheme.

The test results of direct ERC treatment were presented in Section 6.3.3. The remainder of the RO reject is mixed with tailings prior to deposition in the tailings pond. The blending of RO reject with tailings prior to deposition of tailings in the pond is important as it helps desaturate the RO reject with respect to gypsum and bring calcium and sulphate levels in the supernatant down to gypsum saturation. RO is used in a similar fashion at Rio Tinto's operation at Kennecott.

The rationale behind the treatment scheme is as follows:

- Although RO can produce discharge water quality, RO alone would simply concentrate in the tailings pond and would not provide a long term solution to the issue

- Metals removal step provides excellent pre-treatment upstream of RO, removes suspended solids from tailings supernatant, and provides a permanent sink for heavy metals, and
- ERC treatment provides a permanent sink for selenium

This system would be sized to treat 2,400 m^3/d of influent water, projecting the RO to generate 1,200 m^3/d of permeate reaching environmental discharge targets. The selenium removal unit would treat a slipstream of 200 m^3/d of RO reject. Assuming a treatment season of 5 months per year, the water treatment system will discharge approximately 180,000 m^3 per season. Assuming a starting pond volume of 800,000 m^3 and average pond influent of 200-300 m^3/d, the TSF could be dewatered and all contained contaminants of concern removed within 6 seasons of operation.

While the chosen flowsheet involves electroreductive treatment of RO reject, another option that was evaluated was the use of sacrificial resin for removal of selenocyanate and other selenium species as explained in Section 6.3.1. The cost effectiveness of this method of treatment depends on the capacity of selenium for resin, as this dictates the rate of sacrificial resin replacement. While the resin was effective at removing all selenium from water the capacity was not high enough and it is estimated that the annual replacement cost would be approximately $2.2M CAD per year. This cost was deemed too high and consequently, the option was discarded in favour of direct electroreductive treatment of the RO reject as shown in Figure 7-1.

7.2 Cost Estimates

The cost of implementing the system described in this section was estimated by developing a high level process mass balance and sizing equipment appropriately. The cost of process equipment was estimated based on equipment quotations from similar size projects. The total installed cost was estimated by applying a cost multiplier factor to the equipment cost which ranged from 2 to 3.5 depending on the level of off-site fabrication possible. Table 7-1 shows a breakdown of the capital cost of the system.

Table 7-1 Breakdown of capital cost of full scale system.

System component	Capital Cost ($CAD)
Metals removal	$400,000
Reverse osmosis	$1,100,000
Selenium removal	$1,600,000
Total installed cost A	$3,100,000
RO retentate desaturation	$400,000
Total installed cost B	$3,500,000

The total installed cost A is for a treatment plant that operates while fresh tailings are deposited in the pond which helps desaturate the RO retentate recycled to the pond. The total installed cost B includes an incremental cost for additional equipment required for RO retentate desaturation in the event that the plant is used for water discharge during closure. It should be noted that while BQE drew on its significant experience with projects of similar size as Wolverine, the level of engineering conducted to develop the scoping level figures in Table 7-1 was limited.

Operating costs were estimated based on bench scale test results and reagent quotations obtained during recent projects. Table 7-2 shows a breakdown of consumable operating costs.

Table 7-2 Breakdown of operating costs of consumables for full scale system.

Operating Consumable	Unit Price	Consumption rate	$CAD/year (150 d/a operating season)
NaHS	1930 $/t	1.8 t/a	$3,500
Ferric iron	3470 $/t	7.2 t/a	$25,000
H_2SO_4	269 $/t	32 t/a	$3,500
RO Reagents	$4250/t	14 t/a	$60,000
RO Membranes	1 set of elements	1 set/season	$30,000
Iron Anodes	1153 $/t	142 t/a	$140,000
Power	$0.06/kWh	575 kW	$125,000
Total Consumables			**$387,000**

The above estimate was developed on the basis of the laboratory program and assessment. A more detailed assessment of how the water treatment plant would integrate with the rest of the Wolverine project infrastructure is required in order to develop a better estimate of costs and realize possible efficiencies in implementation.

8. Conclusions

The outcome of BQE Water's assessment of the treatment options is summarized below:

- A single stage treatment cannot remove all three classes of contaminants that exist in Wolverine water: heavy metals, selenium, and WAD cyanide.
- Treatment processes that were identified to be technically feasible, produce stable residue, and therefore, reduce risks include:
    - Sulphidization with ferric addition for metals and WAD cyanide removal.
    - Activated carbon adsorption and IX for polishing WAD cyanide removal.
    - IX and ERC for selenium removal.
    - Reverse osmosis (RO) for selenium and WAD cyanide removal with the caveat that it would have to be combined with treatment of RO retentate to ensure contaminants do not build up in the tailings pond.

Treatment options that passed the screening criteria (other than RO) proceeded to bench testing. The conclusions from bench testing are summarized below:

- Using sulphidization with ferric iron addition, all metals of concern including Cu, Cd, and Pb were successfully removed to well below their respective removal targets.
- Sulphidization with ferric iron addition also demonstrated removal of WAD cyanide although WAD cyanide assays were subject to inconsistency throughout the test campaign due to interference from organic species.
- Despite the complicated selenium chemistry in Wolverine water (selenite, selenate, selenocyanate, and unknown selenium species) that is atypical of mining impacted waters, all selenium was successfully removed by IX to well below the discharge target of 20 μg/L.
- The capture of selenocyanate and unknown selenium species by IX resin is irreversible and the capacity of the resin used as a single use/disposable adsorbent is too low to make IX treatment for these species economically feasible.
- Using direct treatment in ERC without the use of IX upstream, all selenium species were removed to meet the discharge target of 20 μg/L.
- WAD cyanide can also be removed to well below the required discharge limit using IX. IX could be used as polishing treatment step if needed.

Based on the results of BQE's assessment and bench scale tests, BQE recommends that the full scale treatment be composed of three steps summarized in Table E-1 below.

Table E-1: Recommended treatment for full scale implementation at Wolverine

Treatment Step	Objective	Bench Scale Test Verification
Sulphidization with ferric iron addition	Removal of all heavy metals of concern from water into solid residue suitable for disposal or blending with flotation concentrate produced at site	Verified in this study

	Pre-treatment for suspended solids removal upstream of RO. Removal of WAD cyanide concentrated by RO.	
Reverse Osmosis	Rejection of selenium and WAD cyanide	Bench scale testing not representative of actual performance
ERC treatment	Removal of selenium from RO reject water into stable solid residue suitable for disposal in the tailings pond	Verified in this study

Scoping level capital and operating cost were estimated for a treatment plant that discharges 1,200 m^3/day of the tailings supernatant water into the environment. The total installed capital cost was estimated at $ 3.1M CAD with an operating cost of ~ $460,000/a based on 6 months per year of plant operation and excluding O&M labour. As proper generation of RO scale up information is not practical on a bench scale, conservative figures for RO operating costs were assumed including replacement of RO membrane units every season. In the event that the treatment plant is to be used for closure or discharge of water from the tailings pond when no new tailings are being, an additional capital cost of approximately $400,000 will be needed for desaturation of RO retentate recycled to the pond.

Assuming the starting pond volume of 800,000 m^3 and average pond influent of 200 to 300 m^3/day, preliminary mass balance calculations indicate that the tailing pond could be dewatered and all contaminants removed within 4-5 operating seasons.

9. Recommendations

The performance of the sulphidization with ferric iron addition as well as ERC was demonstrated during this bench testing campaign. Based on the findings of the treatment assessment and the results of bench testing it is BQE's recommendations that before implementation of the proposed treatment system the following actions are completed.

1. Capital and operating cost estimates be verified and the plan for integration of the treatment system into the overall Site Water Management be identified
2. Ensure risks are identified and mitigated

Specifically BQE Water recommends the following:

- Perform basic engineering to validate capital cost estimate and support permitting by providing sufficient design information
- Perform due diligence paper study on RO performance focusing on
    - rejection of selenocyanate and organo-selenium by different RO membranes
    - membrane biofouling in applications with elevated biological content in feed
- Ensure effluent from the metals removal stage meets RO operation requirements by performing SDI tests on water treated by sulphidization with ferric addition. This could be done using the remainder of Wolverine water in a short program at BQE's lab
- Develop a better understanding of the unknown selenium species in the Wolverine water by sending sample to academic experts in this type of analysis
- Evaluate the cost-benefit of increasing the capacity of the metals removal treatment step beyond that required for discharge to improve process water quality during operation, therefore improving mill performance

BQE Water would welcome the opportunity to work with Yukon Zinc on this project going forward.

10. References

[1] Sandy, T. (2016). Presentation to the North American Metals Council Selenium Working Group, November 2016, Orlando, FL.

[2] LeBlanc, K. & Wallschläger, D. (2016). Production and Release of Selenomethionine and Related Organic Selenium Species by Microorganisms in Natural and Industrial Waters. Environmental Science and Technology, 50, 6164-6171.

[3] Wallschlager and LeBlanc, presentation at SWG NAMC meeting, November 2016

Appendix F: Wolverine Mine Dam Safety Review Tailing Storage Facility and Earth Structures, Klohn Crippen Berger, August 2017

Klohn Crippen Berger

Yukon Zinc Corp.

Wolverine Mine

Dam Safety Review

Tailing Storage Facility and Earth Structures

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A05092A01

August 2017

August 10, 2017

Yukon Zinc Corporation
Suite 705 – 1030 West Georgia Street
Vancouver, British Columbia
V6E 2Y3

Peter Mah
Interim Chief Operating Officer

Dear Mr. Mah:

Wolverine Mine - Dam Safety Review
Tailing Storage Facility and Earth Structures

Please find attached the Dam Safety Review (DSR) of the tailings storage facility at the Wolverine Mine. The DSR is a requirement of the Yukon Energy, Mines and Resources, under the Quartz Mining Act per the Quartz Mining License QML-0006 and follows the guidance of the Canadian Dam Association.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Pamela Fines, M.A.Sc., P.Eng.
Associate / Manager

PF:kc

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Yukon Zinc Corp.

Wolverine Mine

Dam Safety Review

Tailing Storage Facility and Earth Structures

EXECUTIVE SUMMARY

This report presents the results of a Dam Safety Review (DSR) that was performed by Klohn Crippen Berger Ltd. (KCB) for the Tailing Storage facility (TSF) and Earth Structures. Yukon Zinc Corporation (YZC), the owner of Wolverine Mine, is currently required to submit a DSR on the TSF every 7 years. The DSR included a site visit by the Dam Safety Review Engineer, Mr. Brett Stephens, P.Eng., and Ms. Pamela Fines, M.A.Sc., P.Eng. The Dam Safety Review report has been carried out using the guidelines provided by the Canadian Dam Association (2007).

The Wolverine Mine is a zinc-silver-copper-lead-gold underground mine, located in the southeast Yukon, within Kaska Traditional Territory, approximately 280 km east of Whitehorse and 170 km northwest of Watson lake. The mine had a production capacity of 1,700 tonnes per a day. YZC placed the mine under temporary closure for care and maintenance January 21, 2015 which has continued to the date of tis DSR. As a result, there has been no mining, milling operation, and tailing discharge in the TSF since January 2015.

The TSF is located south of the mill facility and stores tailing discharged as slurry. The TSF embankment was designed using homogenous earth fill material and constructed as a dam in two stages with a current height of 26 m. In 2009, the first construction stage consisted of a 19 m high dam and the second stage was a 7 m downstream raise in 2012. The TSF continues to accumulate water and has a full water cover on top of the tailings. Water is not being discharged from the TSF as the planned water treatment plant has not been constructed.

The 2013 Canadian Dam Association (CDA) Safety guidelines were adopted to determine the classification of the dam. The consequence classification based on CDA guidelines of the dam is currently reported as “High” to “Very High”. We recommend adopting a classification of “Very High” for the Wolverine Tailings Dam.

The conclusion of the DSR assessment is that the dam is “reasonably safe”. The dam safety review identified deficiencies and non-conformances as summarized in the tables below, which should be addressed to ensure ongoing dam safety.

With a change in classification to Very High, Dam Safety Reviews should now be completed at least every 5 years as per the CDA guidelines. The next DSR for Wolverine Mine should be completed in 2022 or earlier if the dam classification is revised upward in the future.

Table X.1 Recommendations for Dam Safety Aspects

Deficiency or Non-Conformance	No. (Report Section)	Recommended Action	Schedule
Deficient Flood Event Values and Assessment	4.6.1	The hydrology assessment appears to be comprehensive: ▪ However, the specific rainfall total used to calculate the IDF should be presented (not just the design event duration). ▪ PMF volume inflow volume should also be provided.	December 2017.
North End Slump Repair	4.5.3	The slumped section under the liner at the north end should be repaired prior to placement of additional 1 m of water (2020) or additional tailings in the TSF.	Repair by Dec 2019 or prior to restart of mining activities (whichever is first).
Out of date inundation study.	4.2.2	The inundation study was conducted based on published tables and does not meet the current state of practice for inundation studies. This should be updated and used to update the Emergency Preparedness Plan.	C&M – Dec. 2018 Active Mining – Dec. 2018 Closure – part of closure plan development

Table X.2 Recommendations for Surveillance and Maintenance Aspects

Deficiency or Non-Conformance	No. (Report Section)	Recommended Action	Schedule
Lack of consolidated site records	2.1	Site records need to be consolidated into a centralized file, including: ▪ site investigation data and laboratory test data (historic and recent); ▪ as-constructed records, including site visit notes and foundation preparation assessments; and ▪ design basis with assumptions to key design parameters and criteria.	Closure – August 2019 Prior to restart of mining activities (whichever is sooner)
OMS document not updated	4.10.2	The OMS manual should be updated as summarized in Table 4.3 of this document	December 2017
EPP update	4.10.3	Emergency preparedness plan should be updated to reflect current operating staff and communications. The plan should be reviewed/revised again once the new inundation study is available. This can also be used for communication with local stakeholders on potential impacts of a dam safety incident.	December 2017

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1 INTRODUCTION

This report presents the results of a Dam Safety Review (DSR) that was performed by Klohn Crippen Berger Ltd. (KCB) for the Tailing Storage facility (TSF). The Wolverine Mine is located in the southeast Yukon, within Kaska Traditional Territory, approximately 280 km east of Whitehorse and 170 km northwest of Watson lake, as shown on Figure 1.1.

The DSR included a site visit by the Dam Safety Review Engineer, Mr. Brett Stephens, P.Eng., and Ms. Pamela Fines, M.A.Sc., P.Eng.

The CDA Dam Safety Guidelines (CDA, 2013) define a DSR as "a systematic review and evaluation of all aspects of design, construction, maintenance, operation, processes, and systems affecting a dam's safety, including the dam safety management system." The guidelines provide a suggested frequency of DSRs based on consequence classification. The tailings dam at Wolverine is classified as "High to Very High" consequence structures and the agreed DSR frequency was 7 years during operation, consistent with a "High" consequence dam, prior to decommissioning and following closure. This is the first DSR for this facility. The comprehensive review is to provide verification of:

- safety and environmental performance of the facility;
- adequacy of the surveillance program;
- adequacy of delivery of OMS requirements;
- design basis with respect to current standards and possible failure modes; and
- compliance with engineering standards.

The DSR presented herein is classified as a "comprehensive *dam safety review*", which has been carried out by a "*Qualified Professional".* The Qualified Professional is Mr. Brett Stephens, P.Eng., who is a geotechnical engineer with 25 years of experience with tailings dams design, construction and operation worldwide.

Given that the Wolverine Mine is currently under care and maintenance, our recommendations have been provided considering either continued care and maintenance, re-activation of mining or closure of the structure.

Figure 1.1 General Location Plan

2 BACKGROUND INFORMATION AND SITE VISIT

2.1 Document Review

A review of available documentation was carried out and the available references are summarized in Table 2.1.

Table 2.1 Tailing Storage Facility – Permitting, Design and Construction Records

Date	Prepared By	Title	Permitting (P), Inspection (I) Design (D) or Construction (C)	Key Items of Interest
February 2015	Yukon Energy, Mines and Resources	Inspections Direction- Subsection 146(1) Quart Mining Act and Subsection 35(1) Waters Act	P	Inspection Report (Ministry Order-Yukon Government). Direction from the Yukon Government based on mine inspection.
December 2015	Yukon Energy, Mines and Resources	Response to EMR Wolverine Project Reclamation and Closure Plan Approval	P	Terms and Conditions outlined by the Yukon Government to be met in order to approve the reclamation and closure plan.
December 2006	Yukon Energy, Mines and Resources	Yukon Office of the Minister	P	Quartz Mining License outlines development and production with underground mining. Expires December 2021.
October 2007	Yukon Water Board	Yukon Water board	P	Water License outlines conditions for the use and release of site water. Expires December 31, 2027
August 2015	Klohn Crippen Berger	Annual Physical inspection of TSF and on-site earth structures	I	Dam Safety Inspection Report to inspect tailing storage and earth structures
December 2016	Knight Piesold Consulting	Tailings Storage Facility and On-site Earth Structures 2016 Inspection	I	Dam Safety Inspection Report to inspect tailing storage and earth structures
August 2013	Klohn Crippen Berger	Wolverine Mine Tailing Facility 2013 Annual Tailings Facility Physical Inspection	I	Annual Inspection Report to inspect tailing storage and earth structures
2007	Klohn Crippen Berger	Feasibility Study Update	D	Feasibility level design of the tailings storage facility (TSF) and related infrastructure.
March 2009	Klohn Crippen Berger	Tailings and Infrastructure Design and Construction Plan	D	Detailed design of the tailings storage facility (TSF) and related infrastructure.
March 2012	Klohn Crippen Berger	Design Overview for Stage 2 Dam Construction	D	Outlines the design and construction plan for the stage 2 dam raise for Wolverine Mine.
May 2015	Yukon Zinc Corp	Cross-section drawing of the Tailings Pond	D	Bathymetry cross-section of the tailings pond. Volumes and elevations are on the drawing.
May 2011	Klohn Crippen Berger	Addendum to Starter Tailings Storage Facility - 2009 Civil Works	C	Includes information on outstanding construction items following substantial completion of TSF. This includes construction of starter dam spillway, seepage construction dam, install of reclaim pump barge system, and instrumentation install.
November 2012	Klohn Crippen Berger	Wolverine Stage 2 Expansion Construction Record Report	C	Includes information on: construction observation, QA testing, design changes, photos, technical specifications, earthworks QA, liner QA/QC, instrument plan drawing, and design drawings.
May 2010	Klohn Crippen Berger	Starter Tailings Storage Facility - 2009 Civil Works	C	Includes information on: scope of work, construction schedule, weather, material, design changes, construction observations, QA, photos, technical specifications, earthworks QA, liner QA/QC, Instrument plan drawing, and design drawings.
2007-2015		Temperature and Precipitation Data		Temperature-Year-Precipitation Plot.
2009-2016		Ground Water Quality and Water Level Data		Water quality test result and plots and water level reading and plots.
2009-2015		Surface Water Quality and Hydrogeology		Stream discharge, flow rate, surface water quality, water level, precipitation data, precipitation-year-discharge plot.
August 2016	ALS Environmental	Certificate of Analysis		Results for metal detection in surface water.
2015-2016		Wolverine TSF Elevation and Storage Volume		Pond elevation, dam crest elevation, surveyed tailings volume, and plot.
2010-2016		TSF Water Quality Test Results		Water quality test results.
2006-2013		Underground Mine Water Quality Results		Underground dewatering, production development, and mine water quality test results and plot
2011 to 2015	Yukon Zinc Corp	Tailing Facility Monitoring Monthly Impoundment Reports	I	Mill data, site measurements, sketch, photos
2011-2015	Yukon Zinc Corp	Tailing Facility Monitoring Weekly Visual Inspection Report	I	Tailing facility inspection of the dam, discharge, reclaim infrastructure, spillway, and ditches.
2011-2015		Tailing Volume Information		Tailings volume, ditch flow, under drain flow rate, precipitation and temperature, seepage collection flow, and mill tailing solids volume.
2010-2016		Piezometer Data Spreadsheet		Vibrating wire table and plots
2011-2016		Tailing Inclinometer Data Summary		Digital inclinometer data and plots.
July 2010	Yukon Zinc Corp	Operation, Maintenance, Surveillance Manual	C	Project overview, regulatory requirements, tailing facility operation, facility maintenance, surveillance, and emergency response plan.
December 2014	Yukon Zinc Corp	Emergency Response Plan	C	Facility emergency response, preventative measure for dam breach, training and testing.
July 2015	Klohn Crippen Berger	Wolverine Mine Tailings Storage Facility Preliminary Study of TSF Closure Options -Rev 2	C	Mine observations and closure options.
August 2015	Klohn Crippen Berger	Short Term Remediation for Slump along TSF North Wall	I	North wall slump remedial plan
August 2014	Klohn Crippen Berger	2014 Annual Tailings Facility Physical Inspection	I	Annual inspection for tailing storage, earth structures and instrumentation review.

2.2 Organization and Responsibilities

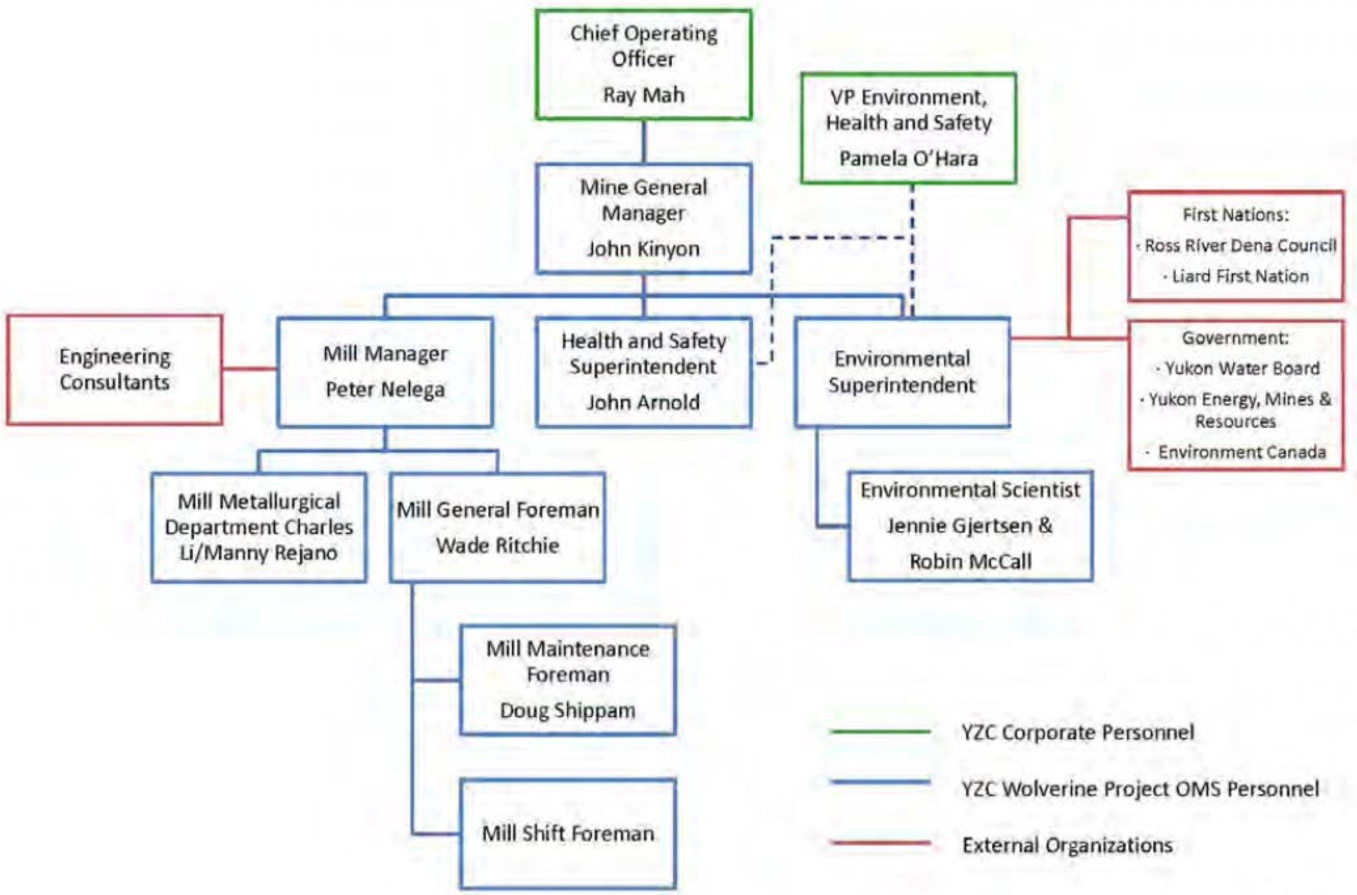
An OMS manual is intended to be a living document that is updated to reflect the changing nature of the life cycle of the facility. The current OMS manual was last updated in 2010 and was not revised when the mine entered care and maintenance. The OMS manual is out of date and needs to be revised to reflect the current roles and responsibilities, surveillance and maintenance activities, and emergency response procedures.

2.2.1 Management

A description of the organization and roles and responsibilities when the mine was in operation is presented in the Operations, Maintenance and Surveillance (OMS) Manual and is summarized in the following sections. The general organization chart shows reporting links are shown on Figure 2.1.

The overall set up and content of the OMS manual is relevant and meets the general requriements of the CDA recommendations. However, the OMS manual is out of date as most of the people referenced in the document no longer work for Yukon Zinc. The mine is currently in care and maintenance and the OMS manual represents how the facility was managed while in operation. The OMS manual needs to be updated to the current status of the facility under care and maintenance. If the mine transitions to to either restart of operations or full closure then the OMS manual should again be revised to represent these new conditions.

Figure 2.1 Wolverine Mine – Operations Organization Chart (outdated) – Main Reporting Links



Currently, the TSF is managed by the care and maintenance crews and they report to Peter Mah who responsible for the site operations. Given the small teams on site and in Vancouver the reporting structure is very lean and should be indicated in the OMS manual.

2.2.2 Management Review and Reporting

Current reporting and review activities are shown below:

- routine surveillance is being conducted by the care and maintenance crew but recording of observations is on paper only in the daily log book;
- engineer inspection report on the condition of the tailing facility; and
- comprehensive dam safety reporting every 7 years.

The OMS manual indicates that more reporting activities should be conducted. Reporting requirements in the OMS were not revised when the mine entered care and maintenance.

Currently there is a small team on site (typically 3 people) and recordings of observations are made and recorded. YZC is also in contact with the Yukon Government regarding their permit requirements.

Formal weekly and monthly observation reports are not being collected at this time. Reporting and management review need to be updated if the mine goes back into production or goes to full closure.

2.2.3 Design

The EoR for the TSF dams is Klohn Crippen Berger Ltd. Mr. Harvey McLeod, P.Eng. has been leading the recent design and associated studies, and construction monitoring works. The EoR is responsible for the design and performance of the mining dam (CDA, 2014). These responsibilities include such items as: 1) dam safety inspections; 2) Construction monitoring; 3) instrumentation planning, design and review; and 4) design modifications.

2.3 Regulatory

The Wolverine Mine falls under The Yukon Territorial Government jurisdiction and the following section present key details of their current permits.

2.3.1 Yukon Energy Mines and Resources

The tailings impoundments at Wolverine are regulated under the Yukon Quartz Mining Act and is to comply with a Quartz Mining License (QML-0006) issued by Yukon Energy Mines and Resources (expires December 31, 2027). The mining license was approved by the territorial minister and stipulates the following:

- process for approval of operations plans and environmental protection plans:
  - the Operation, Maintenance and Surveillance (OMS) manual must be revised regularly during operations; and
  - the Emergency Response Plan (ERP) is required for any dam with a consequence classification of “High” or “Very High”. The ERP will be tested and updated or amendments made as necessary.
- conditions for temporary closure;
- inspection and reporting requirements:
  - annual physical inspection by an engineer to completed before July 1st to review structure, works, and installations to be submitted to Director, Mineral, and Resources (10.1); and
  - annually, on or before March 31st, submit a report that includes information on yearly mining activities (10.5).
- financial security.

There have been communications between the government and YZC regarding the temporary closure plan which was not accepted by the government and the DSR should have been completed in 2016. KCB is not aware of any other contraventions of the conditions of their permits.

2.3.2 Yukon Water Board

The Yukon Water Board issued a water license QZ04-065 to Yukon Zinc Corporation (expires December 31, 2027) per the Waters Act and Regulation to obtain water, divert water, store water, alter the flow of water, deposit a waste, and modify the bed and bank of a Watercourse for quartz mining and milling.

Annual reports are submitted to the Yukon Water Board per the water licence QZ04-065 on or before February 28 of the following year. The annual reports are to include:

- A summary of data generated through the monitoring requirements of this license, including analysis and interpretation by a qualified company and outline variations from baseline conditions; and
- Record of any major maintenance work that may impact water.

Monthly reports were submitted to the Yukon Water Board per the water licence QZ04-065 capturing monthly monitoring results no more than 30 days following the end of the month the data was collected in. It is not clear if the same reporting is being done now that the mine is in care and maintenance.

2.4 Current Operational Status

Operation of the tailing facility commenced in 2009 and increased to an approximate production rate of 1,700 tonnes per day (tpd). The mine entered care and maintenance in January, 2015 but is considering restarting mining activities. The original facility was designed with approximately 8 years of tailings storage with an assumption that 50% of the tailings would be used to produce paste backfill to be placed in the underground workings. The current capacity in the TSF is approximately 1.1 Mt which correlates to approximately 4 years of storage, assuming the original plan of 50% of the tailings being used for paste backfill is achieved at the planned restart tonnage of 1,500 tpd.

The 19 m high starter dam was constructed in 2009 and the 7 m downstream raise was constructed in 2012. The crest elevation is 1,313.5 m and currently stores approximately 853,700 tonnes of tailings and supernant pond volume of 560,000 m^3. Currently no water is being released from the TSF. A detailed bathymetry should be conducted and reconciled with the original liner survey to calculate the volume of tailings and confirm the settled density of the tailings. The bathymetric survey completed in 2016 is suspect due to the very small reported volume occupied by the tailings. A new survey is recommended to confirm the available space remaining in the TSF and what additional dam raise may be required to meet future storage requirements. If the mine goes back into production an annual reconciliation of the tailings density should be completed to compare the tailings rate of rise to the filling plan.

Site activities are currently limited to instrument monitoring and routine maintenance.

2.5 Incident Reporting

There have been no incidents reported for the TSF involving discharge of either water or tailings from the TSF or erosion of the infrastructure.

The only issue is the current temporary closure plan has not been approved by the Yukon Government. YZC are working with the Water Board and the Ministry and Mines to finalize a closure plan. The delay is understood to be associated with the control of water in the underground workings, and unrelated to the TSF.

2.6 Instrumentation

Instrumentation includes survey prisms on the dam crest and four vibrating wire piezometers. Three of the original 7 piezometers installed are no longer functional. Inclinometers were installed but are no longer readable.

The location of instrumentation is shown in plan on Figure 3.4.

The piezometers are attached to data loggers and collect readings twice daily. Survey data is collected annually now that the facility is in care and maintenance.

2.7 Site Visit Dam Inspection

A site visit dam inspection was made over the period of May 5 to May 7, 2010. The site visit was made by Mr. Brett Stephens, P.Eng. and Ms. Pamela Fines, P.Eng.. Mr. Preston Volk provided a tour and inspection of the site and facilitated meetings and information acquisition. Appendix I provides a photographic record from the site visit.

Some of the key observations made during the site visit dam inspection included:

- The weather was sunny with temperatures ranging from 1°C to 10°C, with some brief periods of rain.
- The dam appears stable with no visual evidence of cracking, piping or instability, with the exception of a previously identified slump at the north end of the TSF which is discussed in Section 4.5.3.
- Seepage was noted near the toe of the dam based on the observance presence of wet ground at the toe of the dam near the seepage pond.
- The downstream slope of the dam has presence of minor erosion gullies. This is not a dam safety concern, but rather a reclamation/surveillance/maintenance issue.
- Site contact water is being pumped to the TSF as there is no water treatment plant. The TSF is currently a temporary holding pond for all site surplus water.

2.8 Interviews

Interviews were held with site staff during the DSR site visit of June 24 to 25, 2017 and a brief summary of the interviews are as follows:

Preston Volk

Preston was the prime contact for the site visit and provided a tour of facilities, helped arrange meetings, and provided supporting documentation. Preston is one of seven staff on rotation that maintain the site during the current Care and Maintenance period.

Peter Mah

Peter Mah is the acting Chief Operating Officer and is tasked with the planning for a potential mining restart in 2018. He is responsible for maintenance and management of the TSF. Some of the main observations of the interview included:

- The current site focus is getting permits and activities in line with mining and environmental permits.
- Health and safety is a focus for site activities due to previous incidents on site.
- We discussed several options for restart of mining activities. Restart will also address maintenance and engineering requirements for the TSF, water treatment and potential tailings storage facility expansion.

2.8.1 Engineer of Record

The DSR team has had conversations with KCB design team (Harvey McLeod, P.Eng. and David Willms, P.Eng.) and discussions included clarification of the groundwater assessment and stability review of the slump area. Flows towards the north end of the TSF appear to be affecting the stability of the embankment and the underdrain system was observed to be flowing full during the DSR site visit.

3 FACILITY DESCRIPTION

3.1 General

The tailings facility is an earthfill structure in an elongated natural depression in the Go Creek watershed. The facility has constructed embankment on two sides and ties into rising natural ground on the north and east side of the impoundment. The facility is completely lined with an LLDPE liner to limit seepage from the tailings reaching the environment. The embankment is constructed of a homogeneous glacial till. The embankment was constructed in 2 stages to its current height.
A spillway has been constructed on the western side of the impoundment. A floating reclaim barge which is currently anchored on the south side of the impoundment.

Figure 3.1 shows an aerial photo of the site overlaid with the GPS tracks from the DSR site inspection. Appendix II contains selected design and construction record drawings for the facility.

3.2 Site Conditions

3.2.1 Hydrology and Floods

3.2.1.1 Hydrology and IDF

Average annual precipitation at the site is 570 mm which includes 175 mm equivalent snowpack (KBC, 2009). Monthly rainfall is highest in July. The catchment area of the TSF is approximately 100 ha and during operation most of the catchment is diverted through the surface water ditches. The catchment is largely forested mountainous slopes.

Based on the permits the facility was required to be designed to manage the PMF. The spillway is designed to pass the 1:10,000-year flood and assumes that the clean water diversions are decommissioned or failed. The analysis was based on a peak inflow from a 30-day storm of 9.5 m^3/s. The IDF recommended for “Very High” consequence structures by CDA (2013) is 2/3 between the 1:1000 and the PMF. The inflow from both a 30 minute and a 30-day storm event was assessed. Also, the rational method was used assuming a runoff factor of 1, which will provide a very conservative estimate of inflow. Consideration of rain on snow events was also assessed.

3.2.2 Surficial Geology

The tailings pond is constructed in the Go Creek catchment. Generally, the site is underlain by up to 20 m of interbedded sands, gravels and cobbles, overlying layered volcanoclastic and carbonaceous sediments. These deposits contain springs which were observed during the site investigation and construction. The assessed inflows from these springs were estimated to be of the order of 15 l/s during design of the TSF.

A thin organic layer was removed from the entire foundation area to expose the underlying granular soils (KCB, 2010).

3.2.3 Tailings Properties

A summary of the typical tailings properties (KCB, 2009) is presented in Table 3.1.

Table 3.1 Summary of Typical Tailings Properties

Parameter	Unit	Range
Density	t/m^3	.8 – 1.1
% solids by weight	%	80
Specific Gravity		3.7 – 3.9
Shear Strength	Friction angle	34
Permeability	m/s	7x10^{-8} m/s
% fines[1]	%	83-92

Note: [1] Non plastic fines

3.2.4 Seismicity

CDA Dam Safety Guidelines (2013) state that the 1 in 5000-year event should be used as the design earthquake for a "Very High" consequence dam. However, regulatory requirements state that the facility must be designed to withstand a 1: 10,000 event. A site specific hazard assessment was conducted for the site coordinates of 61.41°N and 130.09°W, giving a peak ground acceleration of 0.22 g for the 1 in 10,000-year event. The acceleration typically used for pseudo-static stability analysis is 50% of the peak ground acceleration.

3.2.5 Hydrogeology

A detailed assessment of the hydrogeology of the site was not conducted. The surficial soils were tested and found to be very permeable. To control seepage, the facility was designed with a liner and a regional groundwater assessment was not necessary. Observations of artesian groundwater levels and seeps during construction were considered when sizing the underdrain system for the liner.

3.3 Tailings Storage Facility Design

3.3.1 General

The dam was constructed along the south and west sides, while the higher topography on the north and east side contain the pond without the need for a dam. Construction of the dam began in 2009 and was raised in 2012. The dam has a maximum height of 16.5 m and is approximately 800 m long, as shown on Figure 3.2. Tailings have not been placed since 2015 as the facility is in care and maintenance.

Figure 3.1 Facility Overview and Site Visit GPS Tracks

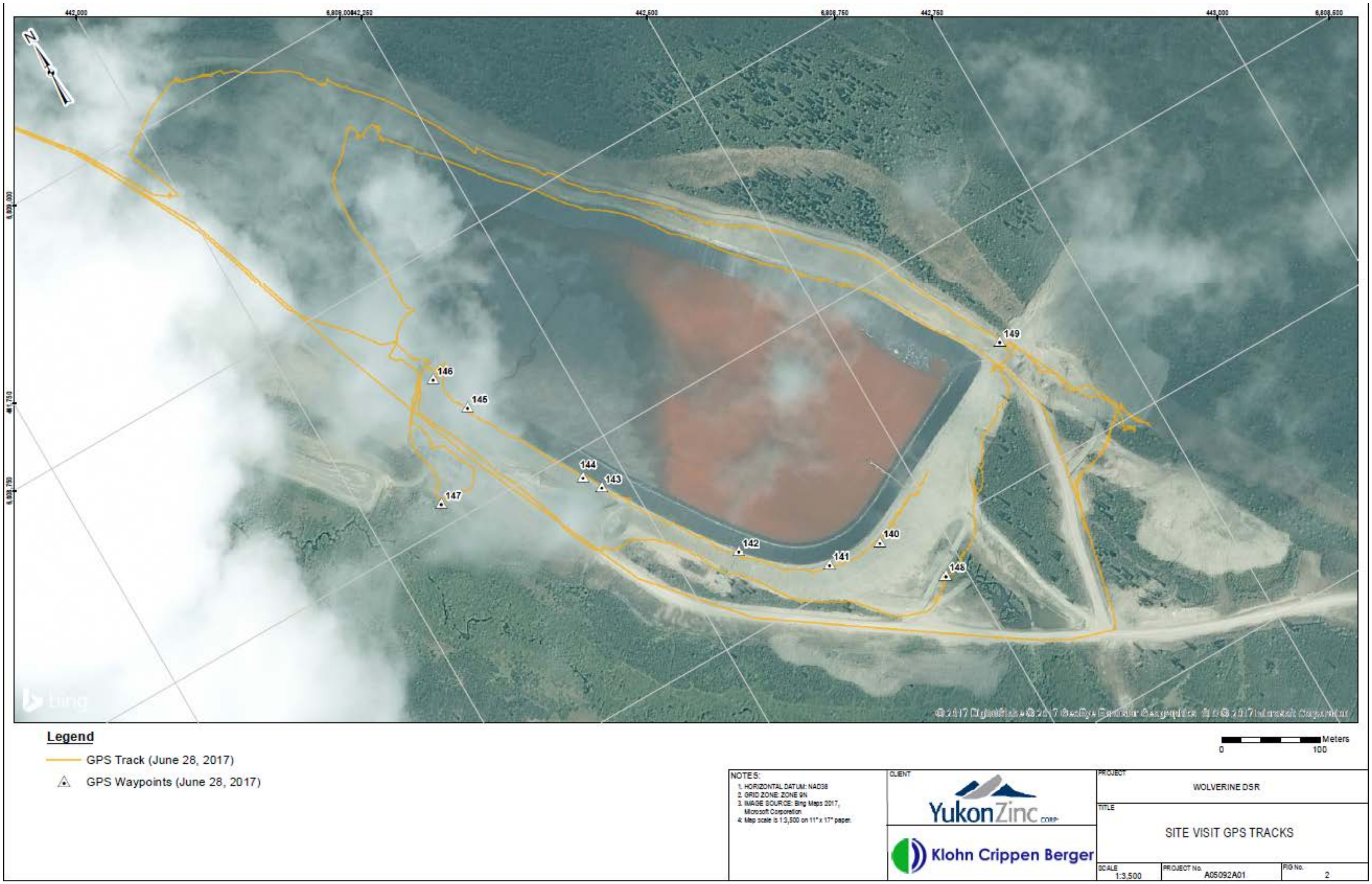
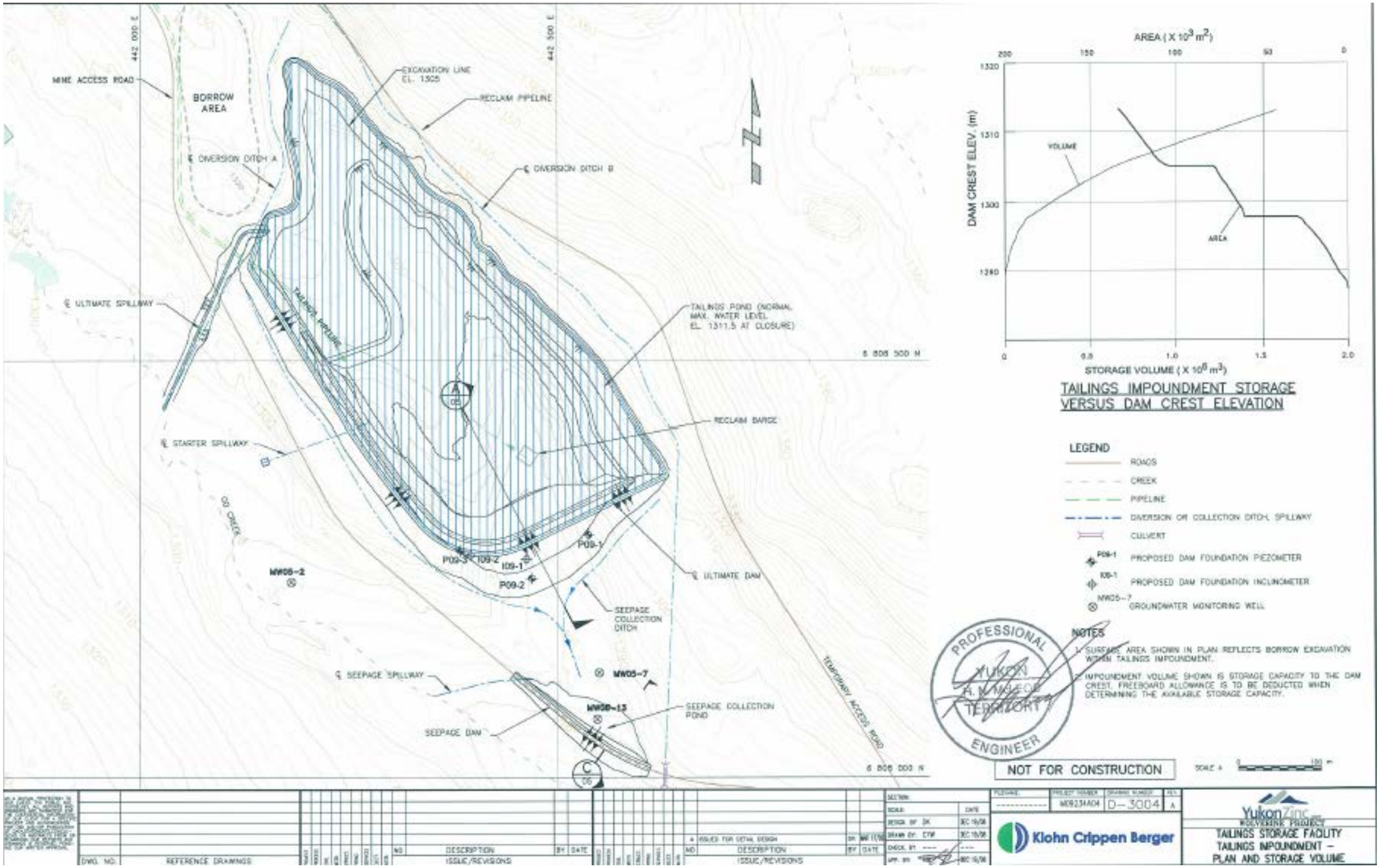


Figure 3.2 Plan View



3.3.2 Dam Design

The dam was constructed as a homogenous earthfill dam using locally borrowed glacial soils for the embankment and screened till for the liner bedding layer. The glacial till was largely borrowed from near the tailings facility or within the footprint. A typical section is shown on Figure 3.3. The dam was raised downstream to allow for the liner to be extended. The upstream and downstream slopes are 2H:1V based on the design slopes and observations on site. The glacial till is a heterogeneous mix of sand, gravel and cobbles. Triaxial tests on the glacial till gave a friction angle of 37° (KCB, 2007). Construction records for the compaction of the glacial till exceeded the specified density of 95% Standard Proctor Density.

The downstream slope of the dam has volunteer grasses that are becoming established but no topsoil or erosion protection has been placed on the slope.

3.3.3 Foundation Conditions

The foundation stratigraphy is up to 20 m of glacial sand, gravel and cobbles over bedrock. The glacial materials were covered with a thin organic layer that was removed prior to construction.

Figure 3.3 Typical Cross Sections

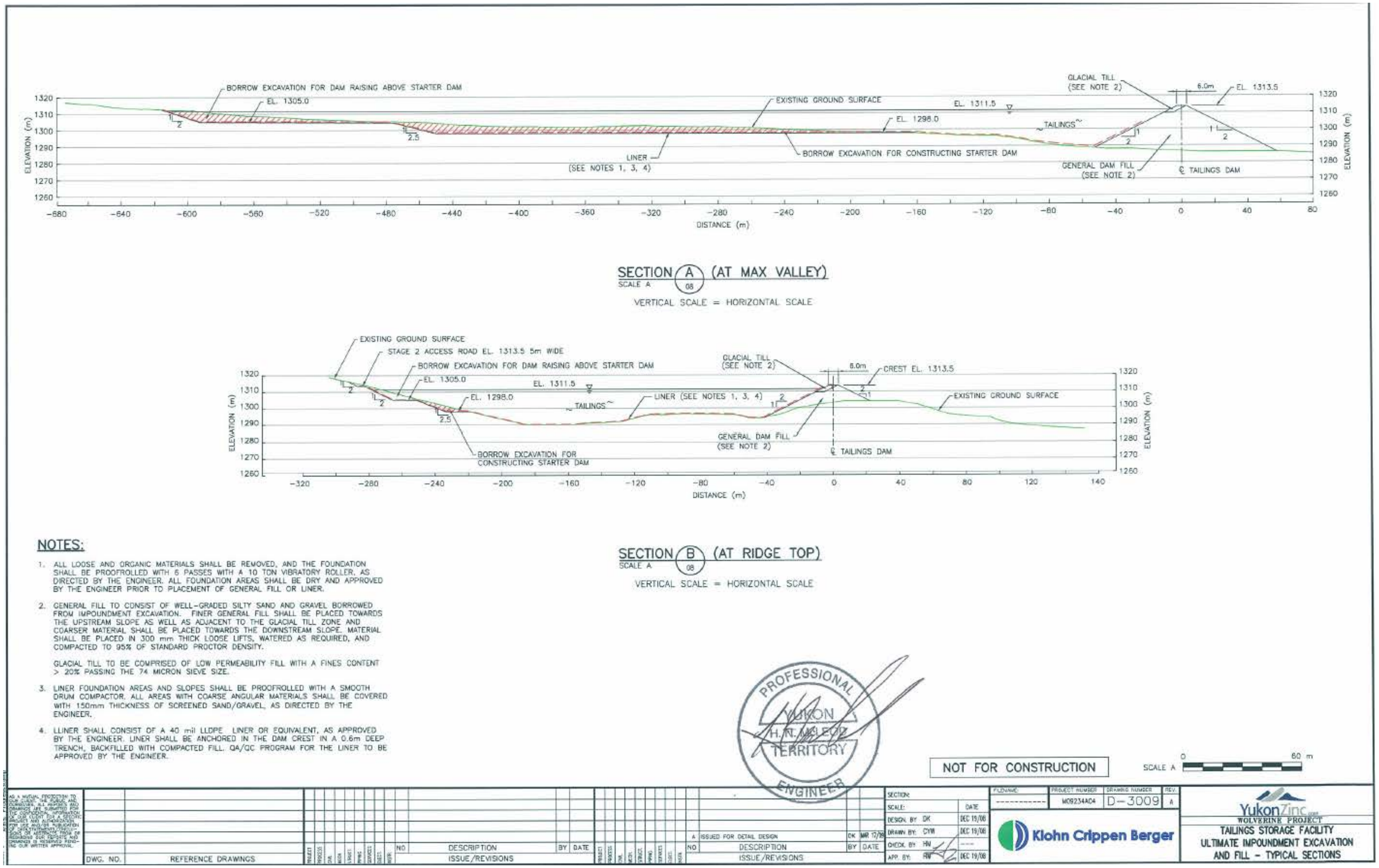
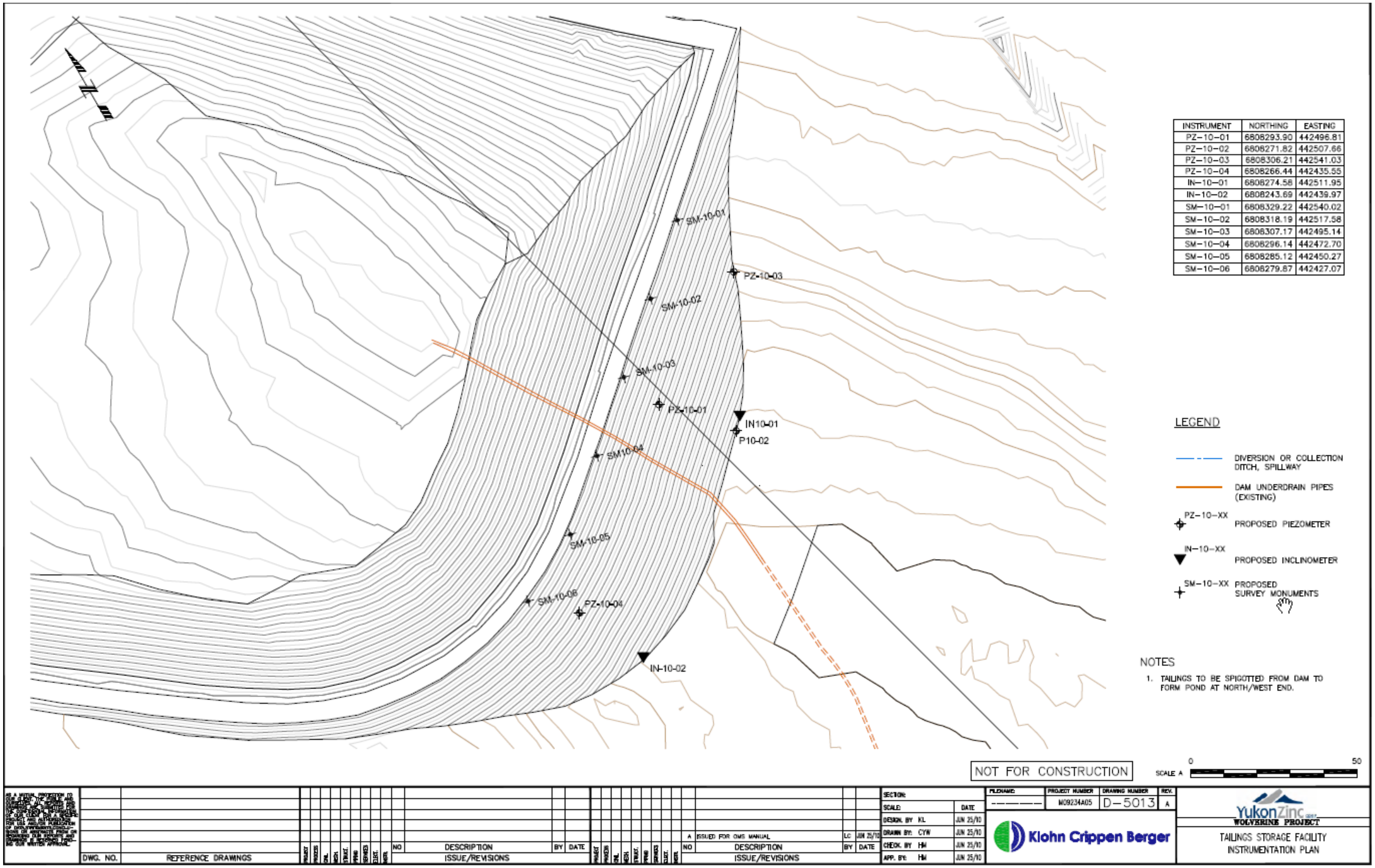


Figure 3.4 Instrumentation Plan



INSTRUMENT	NORTHING	EASTING
PZ–10–01	6808293.90	442496.81
PZ–10–02	6808271.82	442507.66
PZ–10–03	6808306.21	442541.03
PZ–10–04	6808266.44	442435.55
IN–10–01	6808274.58	442511.95
IN–10–02	6808243.69	442439.97
SM–10–01	6808329.22	442540.02
SM–10–02	6808318.19	442517.58
SM–10–03	6808307.17	442495.14
SM–10–04	6808296.14	442472.70
SM–10–05	6808285.12	442450.27
SM–10–06	6808279.87	442427.07

3.4 Water Management and Seepage

3.4.1 Water Management

The tailings pond has two fresh water diversions that direct surface water to the environment before it can flow into the tailings facility. An underdrain has been constructed under the liner to manage groundwater flows under the tailings facility. The underdrains pass under the dam and seepage pond and discharge to the environment.

Currently all contact water is discharged into the TSF. The eventual plan is to construct a water treatment plant so that water can be discharged to the environment.

3.4.2 Water Balance and Seepage

YZC have a water balance for the Wolverine Tailings facility that is maintained along with water quality readings. This has been updated in 2017 and should be reviewed again as part of start-up operations, if the mine goes back into construction.

The facility is lined so there is very low seepage from the tailings expected. The seepage collection dam appears to collect mostly local runoff and foundation seepage. Seepage observed at the toe of the dam is likely natural groundwater seepage.

Visual observations of seepage during the 2017 DSR along the South leg of the toe were observed were limited to damp soil but not actual flowing water.

4 DAM SAFETY ASSESSMENT

4.1 General

4.1.1 Current Dam Classification and Status of Dam Safety Reviews

The reported CDA dam classification for the facility is in the detailed design report is "High to Very High". The dam classification registered with the Yukon Government is "High". We recommend that the TSF be considered a "Very High" consequence structure which could be reduced to "High" if a more detailed environmental assessment is conducted. The change to a Very High consequence structure means that the dam safety reviews should be completed every 5 years, rather than 7 years.

This is the first DSR for the facility however, there have been annual inspections conducted since 2014.

4.1.2 Dam Design and Life of Mine Planning

The dam designs, construction and operations spanned from 2007 through 2017. The facilities the design basis and supporting documentation (e.g. borehole logs, laboratory test data, climate analysis, etc.) is available but has not been compiled either into a single comprehensive document or into a complete design/data base for easy access. As a result, this DSR is based on an assessment of the data and design reports, construction documentation and data that were available. Based on our review we consider that we have reviewed all of the key relevant documents. It is recommended that all records for the TSF be consolidated for the facility.

The potential mine restart may also lead to a desire to increase the tailings storage capacity. If that is the case, consolidated investigation, design and instrumentation details will be valuable.

4.1.3 Credible Failure Modes and Relevant Hazards

The most relevant failure mode is related to geotechnical stability, with respect high phreatic levels in the embankments. The risk of this is considered to be low, but the slump that has occurred at the north end of the impoundment shows that there is some potential for instability in the cut slope under the liner.

The environmental consequence of seepage is low due to the presence of the liner.

The current monitoring program is sufficient for monitoring of the potential for instability due to increased pore pressures however there is no active monitoring for deformations under static loading conditions.

4.2 Consequence Classification Review

4.2.1 Consequence Classification

The Canadian Dam Association Dam Safety Guidelines (2007, revised in 2013) provide a classification of dams based on the consequences of failure, as shown in Table 4.1. The dam consequence classification should be selected based on the criteria shown in each category of incremental losses, and supported by relevant quantitative or qualitative evidence.

The classification was reviewed with respect to these categories as follows, based on review of available information:

- Loss of life: The nearest permanent residents downstream of the dams are more than 40 km away, and are not at risk from a dam breach (KCB 2009). Recreational activities (hunting, fishing, etc.) in the inundation zone are infrequent. The guidelines clarify that the population at risk can be counted as "None" if "There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure" (CDA, 2007). Since people may be present in the inundation zone, it is foreseeable that there is a possibility for loss of life. Therefore, the consequence classification for loss of life should be considered "Significant."
- Environmental and cultural values: Go Creek is a fish-bearing river immediately downstream of the dams, and the flood plain area is inhabited by moose, deer and other wildlife species (KCB 2007). The consequences of a dam breach would most likely include "significant loss or deterioration" of fish habitat, high costs and socioeconomic impacts of a failure suggest a consequence classification of "Very High"
- Infrastructure and economics: The inundation zone includes limited infrastructure and no industry downstream of the dam. The economic costs of a failure could be high, but repair is highly possible which results in a consequence classification of "High".

On the basis of the environmental impacts, the dam consequence classification can be considered either "High" or "Very High" but a detailed environmental assessment would be needed to confirm which classification is appropriate. However, the current design meets criteria for an "Extreme" consequence structure. If the dam is classified as "Very High" then only change required is that Dam Safety Reviews should be conducted every 5 years rather than every 7 which is the current approved DSR interval.

Table 4.1 Dam Classification

Dam class	Population at Risk	Incremental Losses		
		Loss of Life	Environmental and Cultural Values	Infrastructure and Economics
Low	None	0	Minimal short-term No long term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary Only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of important fish or wildlife habitat Restoration or compensation in kind is highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of critical fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities, for dangerous substances)
Extreme	Permanent	More than 100	Major loss of critical fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services, (e.g., hospital, major industrial complex, major storage facilities for dangerous substances

See Table 2-1 in the CDA 2007 Guidelines for notes related to population at risk and implications of loss of life.

4.2.2 Review of Inundation Assessment

The potential downstream influence of a dam breach was assessed by KCB as part of the feasibility study (KCB, 2007) using dam break charts.

Additional observations related to the dam break assessment include:

- The dam breach assumed that only 30% of the tailings would be mobilized and would be deposited near to the dam. Due to the high specific gravity of the tailings this may be the case but this is based on previous case studies and not on site specific assessment of the tailings breach.
- The study does not quantify if it was a “rainy day” or “sunny day” failure mode.
  A water/slimes depth of approximately 5 m was assumed and the maximum instantaneous flow estimate was 1,850 m^3/s.

A more detailed dam break assessment should be completed to meet the new state of practice for dam break assessments. The results of the assessment should be used to quantify the dam classification and to support Emergency Preparedness Plans and Emergency Response Procedures.

4.3 Regulatory Compliance

The Wolverine Mine is regulated under the Quartz Mining Lease and Yukon Water Board. YZC reports annually to meet the regulatory requirements outlined in Section 2.3 of this DSR report.

4.4 Instrumentation Review

Survey has been conducted annually since the mine entered care and maintenance. However, no specific survey monuments have been surveyed. The slope inclinometers that were installed after the Stage 1 construction have all failed. From the data it appears that they were damaged due to construction of Stage 2 rather than significant movement. However, with the loss of these instruments and no specific survey monuments on the dam means there is no way to evaluate potential movements in the subsurface.

The four remaining vibrating wire piezometers are installed in the dam fill and in the foundation. They show seasonal fluctuations but have largely stabilized in a range. The piezometers had been slowly increasing but since 2015 have largely stabilized. The phreatic surface remains low within the dam fill and is currently below the Yellow or Red alert levels. If the dam is raised in the future, then number of piezometers should be reviewed. The piezometer plots are presented in Appendix III.

4.5 Geotechnical Assessment

4.5.1 General

The dam has performed satisfactorily to date based on the instrumentation data and the annual inspections. Localized minor erosion gullies on the dam slopes were noted during the site visit. This superficial erosion does not present an immediate concern to stability, and the risk can be mitigated through regular repairs. In the long term, a plan for erosion protection should be developed. This plan may include re-grading to a shallower slope angle in some locations to improve vegetation growth. Additional berms and erosion protection may be required for closure.

4.5.2 Stability Analysis

The stability of the dams was confirmed by a limit equilibrium stability analysis using the computer program Slope/W. The model geometry, material properties and analysis results are presented in Figure 4.1 and the factors of safety are summarized in Table 4.2. The analysis was carried out to check the stability and to review the sensitivity groundwater elevation.

The analyses were performed for the highest dam section. Only failure geometries that include at least half the width of the dam crest were considered in the analysis. The material properties were taken from the most recent design update report (KCB, 2010). The pore pressures assumed are based on the vibrating wire piezometer data collected in 2017.

The pseudo-static analysis considered the typical PGA reduction of 50% (Hynes-Griffin and Franklin, 1984).

Table 4.2 Results of Limit Equilibrium Stability Analysis

Loading Case	Calculated Factor of Safety	Minimum Required FoS from CDA (2013) Guidelines
Static	1.5	1.5
Pseudo static, 0.12g	1.2	1.0

The results indicate that the static factors of safety meet CDA guidelines. The dam fill is still largely undrained, due to the presence of the liner and under drain system. Even pore pressures 2 m above the base of the dam fill met the required Factor of Safety of 1.5. Given the lack of evidence of seepage on the downstream face of the dam the stability assessment is adequate.

4.5.3 North End Slump

The north end of the impoundment has slumped under the liner. This section of the impoundment is excavated into natural ground and there is no constructed embankment at this location. This area is adjacent to the upstream end of the liner under drain system. The slope failure is likely a combination of high groundwater levels from region sources, seepage from Ditch A before it was lined and potentially high water levels from the liner under drain. This instability does not presently pose a dam safety hazard. But as the liner is damaged there is potential for seepage of contaminated tailings water into the environment if it is not repaired in a timely manner. A short term remediation (recommended by the EOR) of the slump area was implemented but the movement continues and a long term solution is required.

At this time, there is no evidence of a significant rupture in the liner. The pond level is continuing to rise slowly from inflows from other sources on site. If there was a tear in the liner the water would be flowing into the under drain system and unlikely to rise at the rate it has shown. If the mine remains in care and maintenance and there is no water treatment plant available, the pond level will continue to rise. If the mine goes back into operations, then tailings will again be deposited in the tailings facility. If the mine goes to full closure, then the pond will be pumped out and the tailings covered. We recommend that the liner area be repaired before the pond level rises another 1 to 2 meters or additional tailings are placed in the area. However, if the pond level will be managed through water treatment or the move to full closure then there is no reason to repair the area.

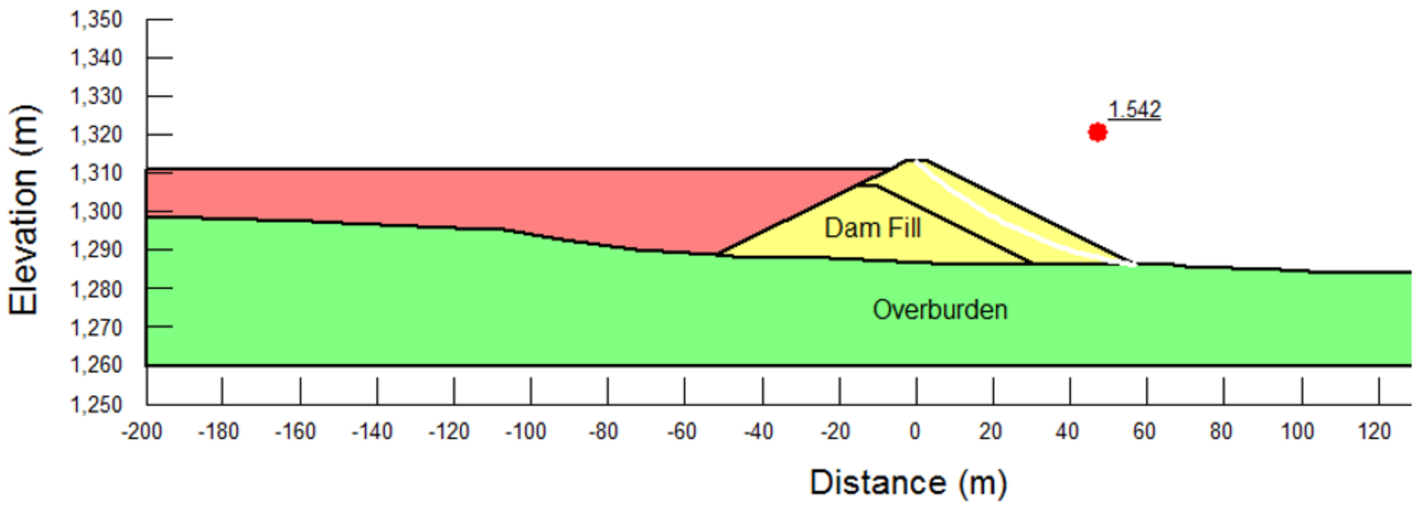
The area can be repaired now fairly easily, as there is less than 1 m of tailings in the area. The area will have to be isolated keep the tailings and water away from the area. An aquadam (inflatable dam) could be used as an isolation structure and water pumped over into the main pond. The liner could then be pulled back and the soft, failed materials removed and replaced with compacted granular fill. A new lined area could be installed and work completed to ensure long term stability of the area.

The repair will also provide an opportunity to inspect the upper section of the underdrains and make sure they are not blocked and adding to ponding at the upstream end of the impoundment.

The repair should be fully documented. This information will be required for future management of the TSF in both operation and closure.

If the tailings facility is expanded this area will be contained within a constructed embankment and consideration will need to be given to foundation conditions and surface water drainage. Ditch A will be constructed over by a tailings dam raise and this will require rerouting of the surface water ditches.

Figure 4.1 Stability Analysis



SUMMARY OF FACTOR OF SAFETY FOR ULTIMATE DAM

FAILURE SURFACE	STATIC FACTOR OF SAFETY (MORGENSTERN-PRICE)	PSEUDO-STATIC FACTOR OF SAFETY (MORGENSTERN-PRICE)(1)
Static	1.59	1.23
Static - Elevated Piezometric Level	1.54	1.20

Consultant:	Client:	Wolverine Dam Safety Review	
Klohn Crippen Berger	YukonZinc CORP	Stability Assessment	
		Project Number: A05092A01.730	Figure: 4.1

4.6 Hydrotechnical Assessment

4.6.1 Inflow Design Flood

The inflow design flood protection is managed by providing storage for the 30 day IDF. This is achieved with a freeboard requirement, which is maintained at all times KCB (2009). The basis for the IDF includes:

- a peak runoff estimate based on a 30-minute storm added to the total runoff volume predicted from a long duration storm event; and
- runoff coefficients of 1.0 for the entire catchment.

The above IDF assessment was used to confirm a minimum freeboard of 1.0 m for the impoundment.

The main KCB observations on the IDF include:

- The specific rainfall event for the design storm is not listed. It would be recommended to have the total rainfall that was the basis for the IDF.
- Wave run-up has not been included in the freeboard assessment and this should be determined.

Based on the above discussion, the IDF documentation should be revised to state a specific rainfall event and wave run-up calculations should be completed to confirm that the freeboard is sufficient to manage waves.

The facility has been designed with a spillway that can safety pass the 1:10,000-year flood event. Currently the spillway not adjacent to the deepest part of the pond but future tailings planning will move the pond closer to the inlet of the spillway.

4.6.2 Water Balance and Seepage

The tailings impoundment is operated on a “no-discharge” basis with water currently being stored in the TSF. Once the water treatment plant is constructed then water will be able to be discharged from the TSF to the environment. If the mine restarts, then water will also be recycled back to the mill via the reclaim barge system. KCB review of the water balance indicates that the loss of water to the tailings voids is included. Routine updates of the water balance are completed by YZC and these should continue and potential updates made as part of the restart plan.

Seepage rates out of the impoundment are very low due to the LLDPE liner. Minor seepage is observed at the toe of the south leg of the dam but this is likely due to regional groundwater and not leakage from the TSF based on the water quality results to date.

4.7 Structural/Hydro-mechanical Assessment

The reclaim system is not operational at this time as the facility is in care and maintenance. Prior to restart of mining operations the reclaim system should be tested and regular maintenance should resume at that time.

From a dam safety perspective, the reclaim system could be shut down for a period of time as long as the dam safety freeboard is maintained. The reclaim system could assist in dewatering the pond during an extreme precipitation event. However, it would not have the capacity, for example, to handle the current IDF volume which flows in at an average rate of approximately 10 m^3/sec.

4.8 Mining Dam Considerations

4.8.1 Closure

The CDA technical bulletin for Mining Dams (2014) introduce requirements for consideration of closure and environmental objectives of the dams. A closure plan for the facility has been developed. The closure plan includes a plan to remove the pond and transition the facility to a dry landform. The CDA technical bulletin for Mining Dams (2014) also recommends higher design criteria for closure-passive care. The design for the facility is suitable for an “Extreme” consequence dam and therefore meets the recommendation for a consequence classification that is higher at passive closure.

4.8.2 Water Quality

The facility is currently operating without direct discharge of surface water to the environment. Seepage from the impoundment is discussed in Section 3.4.2 of this report. Water quality data were available for review up to 2016. The main observations regarding seepage water quality include:

- currently groundwater monitoring outside of the TSF shows minimal change from background readings; and
- surface water sample collection has restarted in 2017 but there have been no reported exceedances of water quality.

We understand that YZC reports water quality data from 4 groundwater wells and a number of surface water sampling points. These reports are issued to the Yukon Government. The only concern at the time of the DSR was that sampling frequency had not been maintained during the care and maintenance period. However, sampling intervals were being re-established in accordance with the permit requirements.

4.9 Public Safety Management

YZC have an Emergency Response Procedure (ERP) in place which is the framework for identifying and responding to emergencies. The ERP is out of date as it references contacts for staff that no longer work of YZC. This document needs to be revised to reflect current site staff and potential responses to an emergency. A test of the emergency response system tested to evaluate the system using the current operations staff.

If the mine goes back into operation or to full closure the plans should also be revised to reflect these new conditions. Similar to the OMS manual the ERP should be a living document that is tested, reviewed and revised to reflect the current stage of the facilities life cycle.

4.10 Dam Safety Management Program Assessment

4.10.1 Organization and Reporting

4.10.1.1 Management and Reporting

The organization structure for management of the tailings facilities is presented on Figure 2.1, but is out of date. This should be updated to reflect the current status of the operation. The OMS manual needs to be revised to reflect the current status of the mine in care and maintenance. It should also be updated again once decisions are made on whether the mine transitions back to operation or to closure.

The framework that is presented in the OMS manual can be used as a basis for future updates to the OMS.

4.10.1.2 Inspections and Engineer of Record Engagement

Current reporting is managed on by care and maintenance site staff and with an environment consultant as needed. Annual reporting to the government is also completed. The dam freeboard requirement is met as the pond level is well below the crest of the dam. The piezometers are on a datalogger so regular readings are collected but the data is only processed annually at this time. reporting processes should be refreshed as part of the OMS review.

The EoR has been actively involved with the tailings facilities and annual inspection reports, construction reports and design update reports have been produced. The reporting quality and documentation of the work is good. The only exception to this is the 2016 annual inspection was conducted by another firm.

4.10.2 Operations, Maintenance and Surveillance (OMS) Manual

The framework of the OMS document is complete and covers the required components. However, there are improvements that should be made to the document to reflect ongoing changes and the results of this DSR. The main observations for improvement are summarized in Table 4.3

Table 4.3 Summary of Review of the OMS Document

Section No.	Description	DSR Observations
2	Roles and Responsibilities	▪ The organization chart and responsibilities of key staff need to be updated to reflect the change in organization and responsibility. ▪ Primary responsibility should rest with an Engineer registered to practice in the Yukon.
3	Facility Description	▪ Site conditions should include 24 hr precipitation rates for various return periods. ▪ Site conditions should show a plan of all drill holes and reference the supporting data (logs, laboratory tests, etc) and their storage location. ▪ Basis of design should document IDF flood volumes for design return period. ▪ Construction history should include current volumes of stored tailings and water.
7	Reporting Responsibilities and Documentation	▪ Update with the new management structure. ▪ Clearly identify Engineer responsible for the TSF. ▪ Report database should be updated to include all reports, with clear reference location for retrieval. Site investigation and laboratory data, etc. should be included. Specify location of Central File.
8	Emergency Planning & Response	▪ Update Emergency Preparedness Plan (EPP) when results of Inundation Study are available. ▪ All contacts should be reviewed and updated as necessary.

4.10.3 Emergency Preparedness Plan

The Emergency Preparedness Plan (EPP) in included in Section 8 of the OMS manual, and as summarized in Table 4.3.

The EPP will need to be updated to reflect the current mine status. This should also include the revised Inundation Study.

The Emergency Response Procedure provides the framework for response to emergencies, with reference to specific emergency response procedures, of with the OMS manual for the tailings facility is referenced.

A specific procedure for evacuation should be developed in the case of a dam breach. The evacuation procedures would require notification of potentially affected communities downstream of Wolverine.

4.11 CDA Principles Assessment

There are 19 CDA Dam Safety Principles presented in the CDA Guidelines (CDA, 2007) and are divided into five categories:

- Principle 1: Dam Safety Management System;
- Principle 2: Operations, Maintenance, and Surveillance;
- Principle 3: Emergency Preparedness;
- Principle 4: Dam Safety Review; and
- Principle 5: Analysis and Assessment.

The results of the CDA Principles Assessment are presented in Appendix IV. A summary of the findings of this assessment are presented as follows:

- 9 Conformance;
- 4 Non-Conformances in Information;
- 2 Non-Conformances in Surveillance; and
- 4 Non-Conformances in Other Procedures.

The majority of the non-conformances relate to the outdated nature of the OMS manual and can be remedied by updating the OMS manual and formalized documentation of existing information. Other non-conformances can be addressed by revising schedules for maintenance and surveillance, commencing these activities, and by documenting the findings.

A full list of recommendations arising from this report is summarized in Section 5.

5 RECOMMENDATIONS

This 2017 Dam Safety Review report has been carried out using the guidelines provided by the Canadian Dam Association (2013).

The conclusion of the assessment is that the dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as summarized in Table 5.1 and Table 5.2.

Table 5.1 Recommendations for Dam Safety Aspects

Deficiency or Non-Conformance	No. (Report Section)	Recommended Action	Schedule
Deficient Flood Event Values and Assessment	4.6.1	The hydrology assessment appears to be comprehensive: ▪ However, the specific rainfall total used to calculate the IDF should be presented (not just the design event duration). ▪ PMF volume inflow volume should also be provided.	December 2017.
North End Slump Repair	4.5.3	The slumped section under the liner at the north end should be repaired prior to placement of additional 1 m of water or additional tailings in the TSF.	Repair by Dec 2019 or prior to restart of mining activities (whichever is first).
Out of date inundation study.	4.2.2	The inundation study was conducted based on published tables and does not meet the current state of practice for inundation studies. This should be updated and used to update the Emergency Preparedness Plan.	C&M – Dec. 2018 Active Mining – Dec. 2018 Closure – part of closure plan development

Table 5.2 Recommendations for Surveillance and Maintenance Aspects

Deficiency or Non-Conformance	No. (Report Section)	Recommended Action	Schedule
Lack of consolidated site records	2.1	Site records need to be consolidated into a centralized file, including: ▪ site investigation data and laboratory test data (historic and recent); ▪ as-constructed records, including site visit notes and foundation preparation assessments; and ▪ design basis with assumptions to key design parameters and criteria.	Closure – August 2019 Prior to restart of mining activities (whichever is sooner)
OMS document not updated	4.10.2	The OMS manual should be updated as summarized in Table 4.3 of this document	December 2017
EPP update	4.10.3	Emergency preparedness plan should be updated to reflect current operating staff and communications. The plan should be reviewed/revised again once the new inundation study is available. This can also be used for communication with local stakeholders on potential impacts of a dam safety incident.	December 2017

6 CLOSING

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Yukon Zinc Corporation. (Client) for the specific application to the Wolverine DSR.

In the preparation of this DSR Report, KCB has endeavored to observe the degree of care and skill generally exercised by other consultants undertaking similar DSRs at the same time, under similar circumstances and conditions, and in the same geographical area. KCB makes no other warranty, expressed or implied.

Use of or reliance upon this instrument of service by the Client is subject to the following conditions:

- The report is intended for the sole and exclusive use of the Client and it may not be used or relied upon in any manner or for any purpose whatsoever by any other party, without the express written permission of KCB.
- The report is based on information provided to KCB by the Client or by others on behalf of the Client. KCB has not verified the accuracy or validity of this information and further, makes no representation regarding its accuracy and validity. KCB shall not be liable for any loss, cost, expense, or damage arising from or as a result of the incorrectness or inaccuracy of such information.
- The report is read as a whole, with sections or parts of the report read or relied upon in the context of and subject to the terms of the Contract Agreement between KCB and the Client.
- The executive summary is a selection of key elements of our instrument of service. It does not include crucial details needed for the proper application of our findings and recommendations, which are best evaluated with the active participation of the professionals who developed them.
- The observations, findings, and conclusions in this report are based on conditions that existed at the time of the work described herein and should not be relied upon to precisely represent conditions at any other time.

KLOHN CRIPPEN BERGER LTD.

Brett Stephens, P.Eng.
Dam Safety Review Engineer

Pamela Fines, P.Eng.
Project Engineer

REFERENCES

Refer to Table 2.1 for a list of references reviewed for this report. The tables also provide a brief summary description of main subjects covered by the reports. Additional references used are as follows:

Canadian Dam Association, 2013. “Dam Safety Guidelines”, January. (with Revised Section 6, issued in 2013)

Canadian Dam Association, 2014. “Technical Bulletin: Application of Dam Safety Guidelines to mining Dams”, not yet issued to public.

Hynes-Griffin, M.E. and Franklin, A.G. 1984. “Rationalizing the Seismic Coefficient Method”. Misc Paper GL-84-13, US Army Corps of Engineers, Washington, DC. Natural Resources Canada (2010). 2010 National Building Code of Canada seismic hazard calculator, http://www.earthquakescanada.nrcan.gc.ca/hazard -alea/interpolat/index_2010-eng.php (accessed on June 23, 2014).

APPENDIX I

Site Visit Photographs

Appendix I
Site Visit Photographs

Photo 1 Overview of Pond Looking South

Photo 2 Overview of Pond looking north

Photo 3 Minor rutting on dam crest near left abutment

Photo 4 Left abutment looking north

Photo 5 Debris and dead animals in pond

Photo 6 Reclaim barge

Photo 7 Overview of seepage pond looking back toward tailings dam

Photo 8 Seepage Pond Embankment Crest – Road

Photo 9 D/S slope, seepage at toe leading into seepage pond

Photo 10 Discharge from under drain pipes downstream of seepage pond

Photo 11 Discharge pipes running near full from recent rains

Photo 12 Upstream end of under drains

Photo 13 D/S Slope looking towards left abutment

Photo 14 Downstream slope looking west

Photo 15 Downstream toe near seepage pond

Photo 16 West Leg of Embankment Looking South

Photo 17 Erosion gully near d/s toe of dam

Photo 18 Minor erosion gullies on downstream slope

Photo 19 Dam crest, anchor post, minor veg on d/s slope

Photo 20 D/s slope looking towards spillway

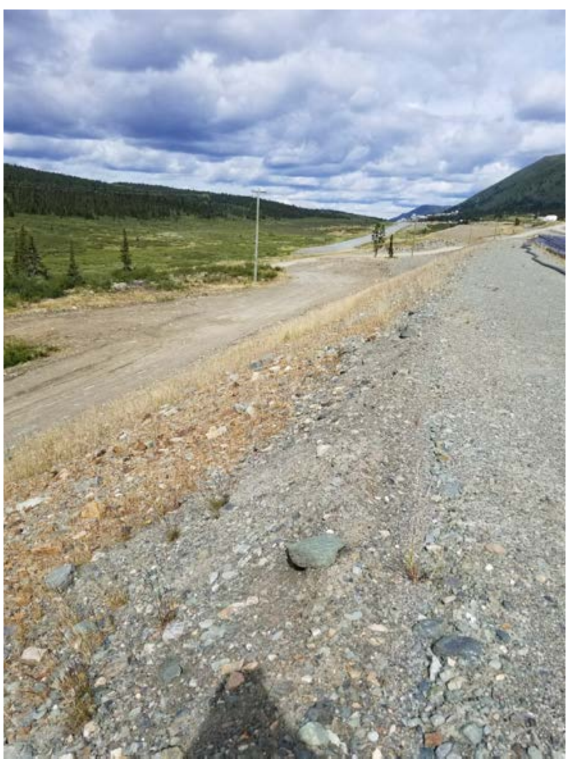


Photo 21 Decommissioned starter spillway]

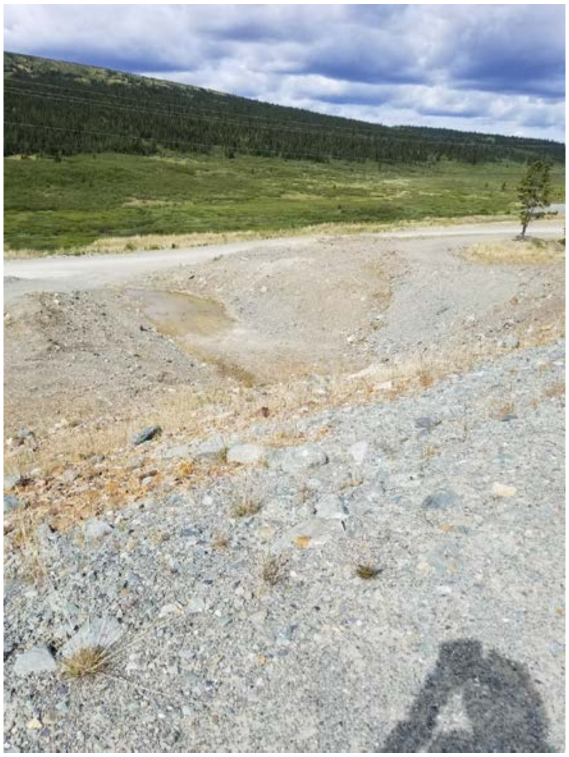


Photo 22 Minor ponded water from recent rainfall

Photo 23 Pipe discharging water from other on site facilities

Photo 24 Cracking in dam crest near north end slump

Photo 25 Temporary cover over slump area

Photo 26 Debris from monitoring set up

Photo 27 Slump at north end

Photo 28 Animal burrow into liner

Photo 29 Ditch B

Photo 30 Ditch B Some Ponding Water

Photo 31 Ditch B Inlet to culvert section pipe to discharge pad

Photo 32 Outlet of Ditch B

Photo 33 Discharge Pad at Bottom of Ditch B

Photo 34 Ditch B Discharge Pad

Photo 35 Reclaim barge anchor – minor damage in tailings pipeline

Photo 36 Spillway channel looking upstream towards pond

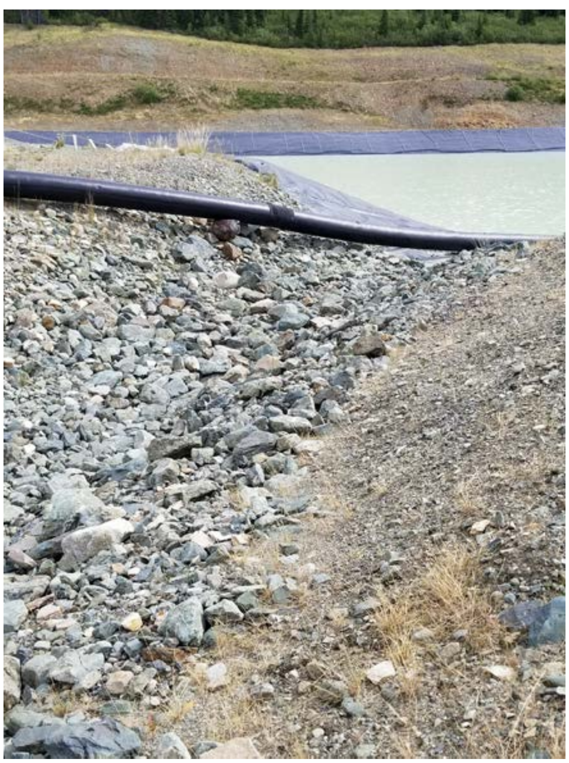


Photo 37 Pipe bridge over spillway channel

Photo 38 Spillway channel looking downstream

Photo 39 Pipe bridge over spillway channel looking downstream

Photo 40 Discharge pad for vacuum trucks

Photo 41 Upstream face and lined section of Ditch A

Photo 42 Ditch A Culvert leading to discharge point

Photo 43 Discharge pad from Ditch A

Photo 44 Lined section of Ditch A

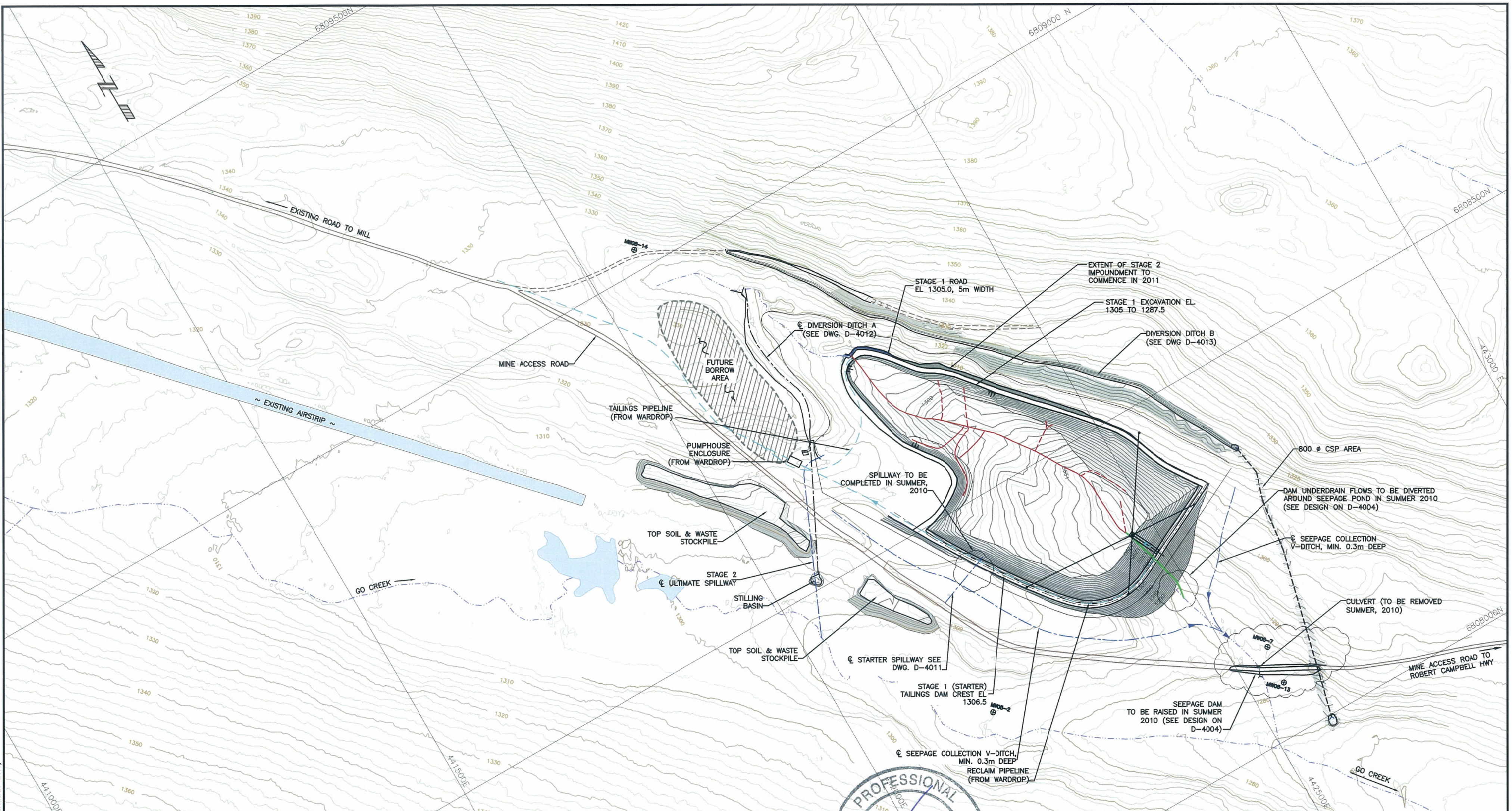
Photo 45 Debris collecting in ditch from surface erosion

Photo 46 North End of Ditch A

Photo 47 Ditch A Adjacent to Biopass

APPENDIX II

Selected Design and Construction Drawings



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Xrefs: CONT_2M_MINE_4Mgrid(Mod7mar25-2010)

NOTES

1. NOT ALL CULVERTS HAVE BEEN SHOWN.
2. ALL ELEVATIONS IN METRES.
3. DRAFT CONSTRUCTION RECORD DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

CONSTRUCTION RECORD

SCALE: 0 — 200 m

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2	DRAFT CONSTRUCTION RECORD	JL	MAR 5/10
1	ISSUED FOR CONSTRUCTION	MD	MAR 13/09
0	ISSUED FOR TENDER	DK	FEB 04/09

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CHECK. BY HM	
APP. BY: HM	MAY 12/10

FILENAME:	PROJECT NUMBER	DRAWING NUMBER	REV.
----------	M09234A05	D-4001	3

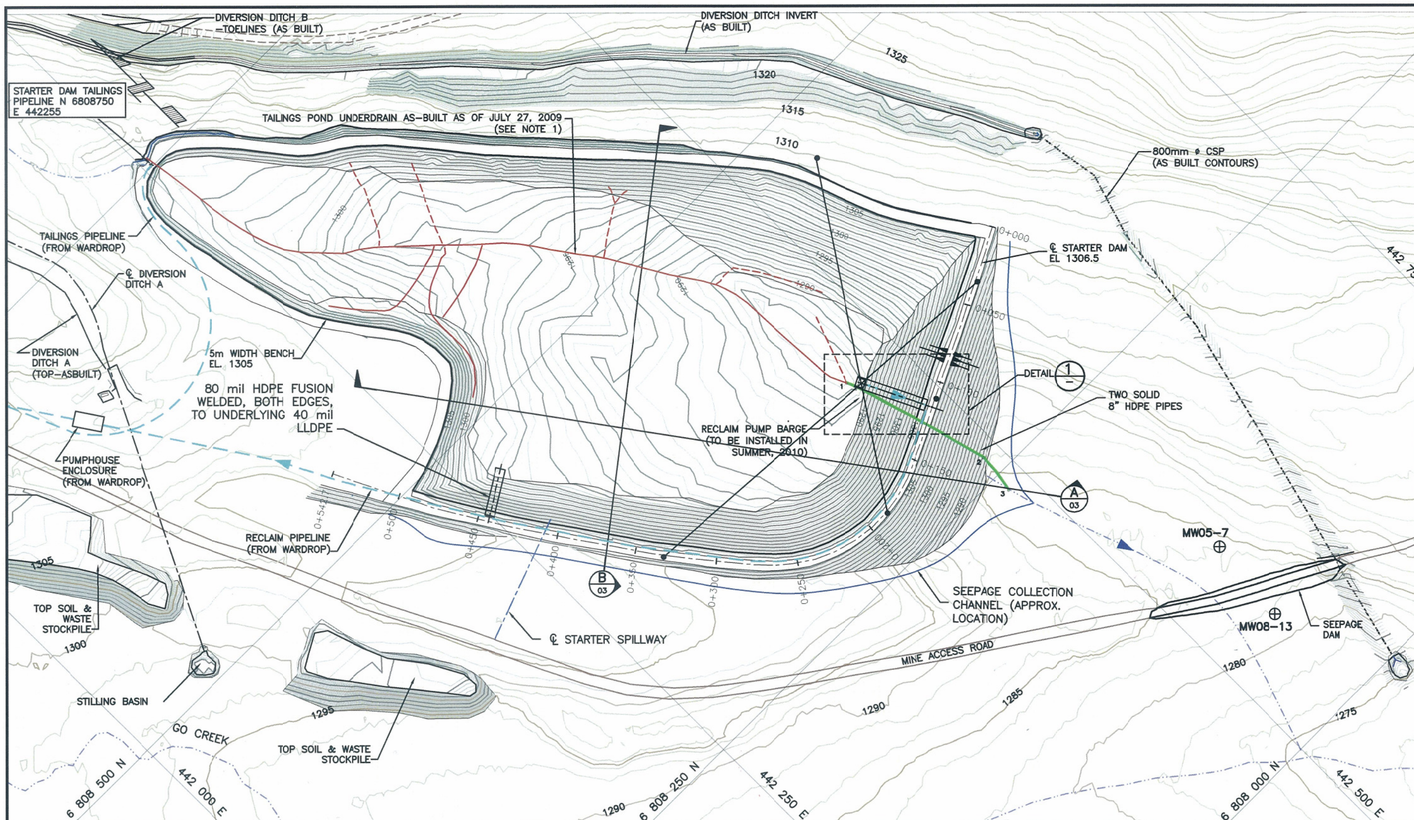
Klohn Crippen Berger

YukonZinc CORP

WOLVERINE PROJECT

TAILINGS STORAGE FACILITY

GENERAL SITE ARRANGEMENT



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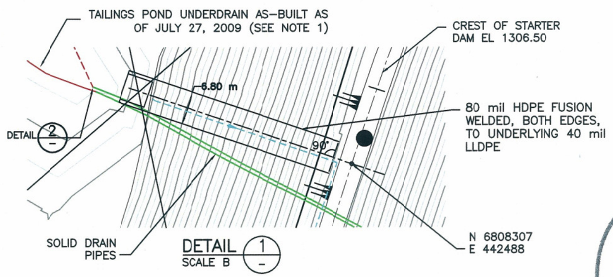

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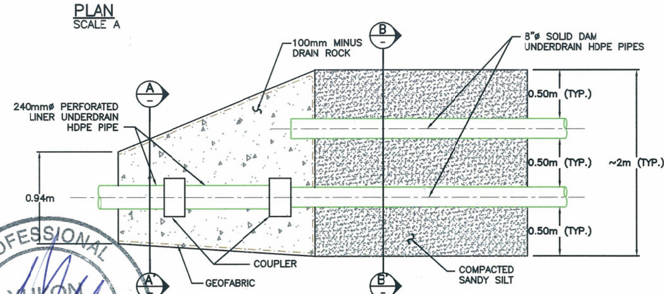

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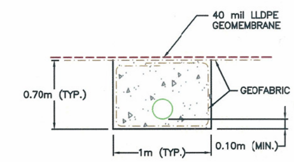
NTS



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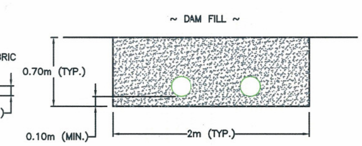
NTS



SECTION B
NTS

DAM – TWO SOLID UNDERDRAIN PIPES

WEST PIPE				EAST PIPE			
SURVEY POINTS	NORTHING (m)	EASTING (m)	ELEVATION (m)	SURVEY POINTS	NORTHING (m)	EASTING (m)	ELEVATION (m)
1	6808355.00	442461.90	0.00	1	6808356.00	442462.20	0.00
2	6808264.06	442488.27	1284.45	2	6808263.98	442489.13	1284.44
3	6808238.83	442485.41	1284.02	3	6808239.14	442486.04	1284.08

LEGEND

- ROADS
- CREEK
- DIVERSION OR COLLECTION DITCH, SPILLWAY
- LINER UNDERDRAIN (240 mm ø PERFORATED PIPE INSTALLED)
- LINER UNDERDRAIN (NO PIPE INSTALLED)
- LINER AREA
- ⊕MW05-7 GROUNDWATER MONITORING WELL
- SOLID DAM UNDERDRAIN PIPE
- ● ANCHOR BLOCKS (FROM WARDROP)

NOTES

1. LOCATION AND EXTENT OF LINER UNDERDRAIN WAS DETERMINED IN THE FIELD BY SITE ENGINEER, FOLLOWING THE LOWEST EXISTING DRAINAGE COURSE. THE UNDERDRAIN REPORTS TO AN OPEN DITCH D/S OF THE DAM VIA 2-SOLID PIPES.
2. LINER FOUNDATION CONTOURS SURVEYED JULY 26, 2009. BY ACL
3. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.
4. BASIN VOLUME BELOW EL. 1304.5 = 665,127 m^3
5. ELEVATIONS ARE GIVEN IN METRES UNLESS OTHERWISE STATED.

SCALE A 0 — 100 m
SCALE B 0 — 50 m

CONSTRUCTION RECORD

PROFESSIONAL ENGINEER
YUKON TERRITORY
H. N. McLEOD

DWG. NO. | REFERENCE DRAWINGS

PROJECT / PROCESS / CIVIL / MECH. / STRUCT. / PIPING / SERVICES / ELECT. / INSTR.

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5	DRAFT CONSTRUCTION RECORD	JL	MAR 5/10

ISSUE/REVISIONS

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3	MODIFY EXCAVATION PLAN, RECLAIM PAD	HM	JUL 17/09
2	ADDED CURVE TABLE	JL	MAY 26/09
1	ISSUED FOR CONSTRUCTION	DK	MAR 13/09
0	ISSUED FOR TENDER	DK	FEB 04/09

ISSUE/REVISIONS

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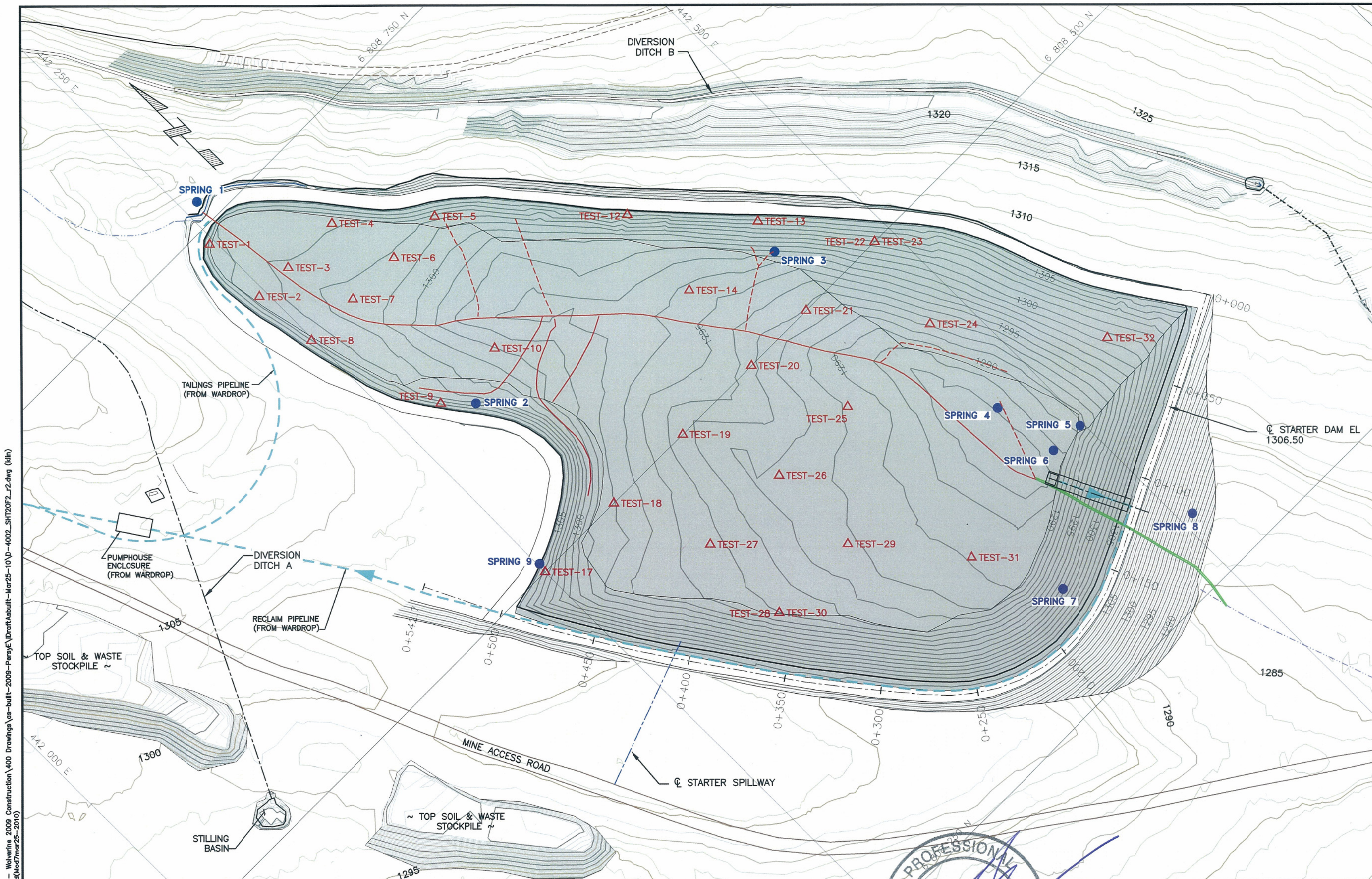
CHECK. BY HM	
APP. BY: HM	MAY 12/10

FILENAME: ---------- | PROJECT NUMBER M09234A05 | DRAWING NUMBER D-4002 | REV. 6

Klohn Crippen Berger

YukonZinc CORP
WOLVERINE PROJECT

TAILINGS STORAGE FACILITY
STARTER IMPOUNDMENT
SHEET 1 OF 2



TEST #	MATERIAL
TEST 1	Silt/Clay and Sand, Gravelly
TEST 2	Gravel and Sand. Silty/Clayey
TEST 3	Silt/Clay and Gravel, Sandy
TEST 4	Sand and Silt/Clay, Gravelly
TEST 5	Sandy Silty/Clayey Gravel
TEST 6	Sandy Silty/Clayey Gravel
TEST 7	Sandy Silty/Clayey Gravel
TEST 8	Gravel and Sand, Silty/Clayey
TEST 9	Gravelly Sandy Silt/Clay
TEST 10	Silty/Clayey Gravelly Sand
TEST 12	Gravel and Sand, Trace Silt/Clay
TEST 13	Sandy Silty/Clayey Gravel
TEST 14	Gravelly Silty/Clayey Sand
TEST 17	Silty/Clayey Gravelly Sand
TEST 18	Silty/Clayey Gravelly Sand
TEST 19	Gravelly Sandy Silt/Clay
TEST 20	Sandy Silt/Clay, trace Gravel
TEST 21	Gravel and Sand, trace Silt/Clay
TEST 22	Gravelly Sand, some Silt/Clay
TEST 23	Silt/Clay and Gravel, Sandy
TEST 24	Gravel and Sand, Silty/Clayey
TEST 25	Silt/Clay and Sand, some Gravel
TEST 26	Sandy Silty/Clayey Gravel
TEST 27	Gravel and Silt/Clay, Sandy
TEST 28	Sandy Silty/Clayey Gravel
TEST 29	Gravelly Silty/Clayey Sand
TEST 30	Sandy Silty/Clayey Gravel
TEST 31	Sandy Silty/Clayey Gravel
TEST 32	Sandy Gravel, some Silt/Clay

SPRING #	FLOW (L/s)
1	1.0 – 1.5
2 – 5	0.5 – 1.0
6 – 9	0.1 – 0.5

LEGEND

- ROADS
- CREEK
- LINER AREA
- LINER UNDERDRAIN (240 mm ø PERFORATED PIPE INSTALLED)
- LINER UNDERDRAIN (NO PIPE INSTALLED)
- SOLID DAM UNDERDRAIN PIPES

NOTES

1. LINER FOUNDATION CONTOURS SURVEYED JULY 26, 2009.
2. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

SCALE: 0 — 100 m

CONSTRUCTION RECORD

PROFESSIONAL ENGINEER — YUKON TERRITORY — H.N. McLEOD

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1	DRAFT CONSTRUCTION RECORD	JL	MAR 5/10

ISSUE/REVISIONS

DWG. NO. | REFERENCE DRAWINGS

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DRAWN BY: KL — MAY 12/10
CHECK. BY: HM
APP. BY: HM — MAY 12/10

PROJECT NUMBER: M09234A05 | DRAWING NUMBER: D-4002 | REV.: 2

Klohn Crippen Berger

YukonZinc CORP
WOLVERINE PROJECT
TAILINGS STORAGE FACILITY
STARTER IMPOUNDMENT
FOUNDATION GEOLOGY
SHEET 2 OF 2

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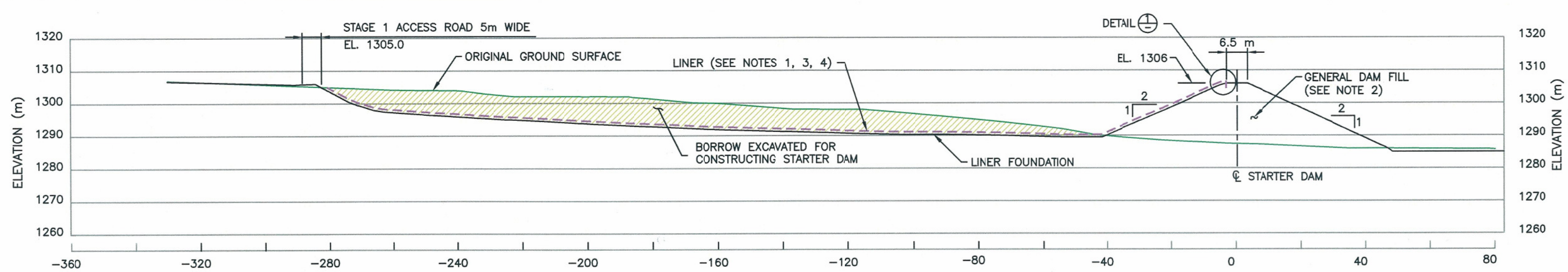
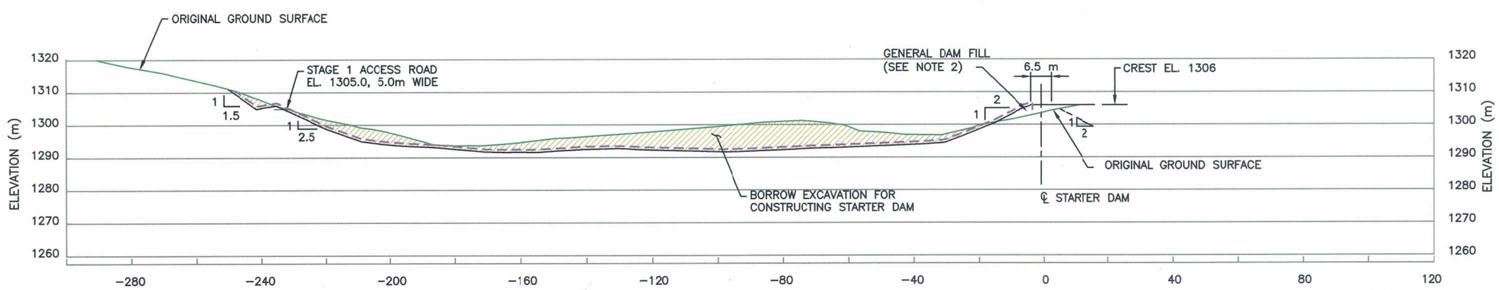


SECTION A
SCALE A 02



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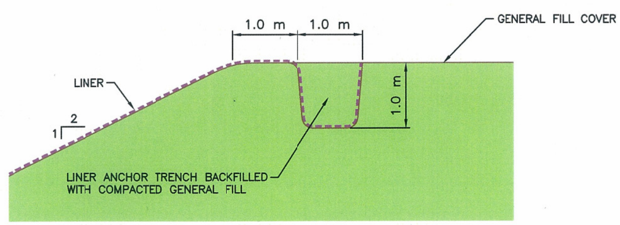
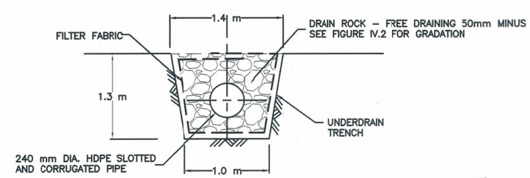
SCALE A 02



DETAIL 1 LINER ANCHOR TRENCH
NTS



DETAIL 2 LINER UNDERDRAIN
NTS 02

NOTES

1. LOOSE AND ORGANIC MATERIALS WERE REMOVED, AND THE FOUNDATION PROOFROLLED WITH 6 PASSES WITH A 10 TON VIBRATORY ROLLER, AS DIRECTED BY THE ENGINEER. FOUNDATION AREAS WERE DRY AND APPROVED BY THE ENGINEER PRIOR TO PLACEMENT OF GENERAL FILL OR LINER.
2. GENERAL FILL CONSISTED OF WELL-GRADED SILTY SAND AND GRAVEL BORROWED FROM IMPOUNDMENT EXCAVATION. FINER GENERAL FILL PLACED TOWARDS THE UPSTREAM SLOPE AS WELL AS ADJACENT TO THE GLACIAL TILL ZONE (STAGE 2 CONSTRUCTION) AND COARSER MATERIAL PLACED TOWARDS THE DOWNSTREAM SLOPE. MATERIAL PLACED IN 300 mm THICK LOOSE LIFTS, WATERED AS REQUIRED, AND COMPACTED TO 95% OF STANDARD PROCTOR DENSITY.
3. LINER FOUNDATION AREAS AND SLOPES WERE PROOFROLLED WITH A SMOOTH DRUM COMPACTOR. AREAS WITH COARSE ANGULAR MATERIALS WERE COVERED WITH LINER BEDDING AS DIRECTED BY THE ENGINEER.
4. A 40 mil LLDPE LINER WAS USED. THE LINER WAS ANCHORED IN THE DAM CREST AND ACCESS ROAD IN A 1.0 m DEEP TRENCH, AND BACKFILLED WITH COMPACTED FILL.
5. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

SCALE A 0 100 m

CONSTRUCTION RECORD

NO	DESCRIPTION	BY	DATE
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2	DRAFT CONSTRUCTION RECORD	JK	MAR 5/10
1	ISSUED FOR CONSTRUCTION	DK	MAR 13/09
0	ISSUED FOR TENDER	DK	FEB 04/09

ISSUE/REVISIONS

DWG. NO. | REFERENCE DRAWINGS

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CHECK. BY HM
APP. BY: HM MAY 12/10

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Klohn Crippen Berger

YukonZinc CORP
WOLVERINE PROJECT
TAILINGS STORAGE FACILITY
STARTER IMPOUNDMENT
EXCAVATION AND FILL TYPICAL SECTIONS

PROFESSIONAL H. N. McLEOD YUKON TERRITORY ENGINEER

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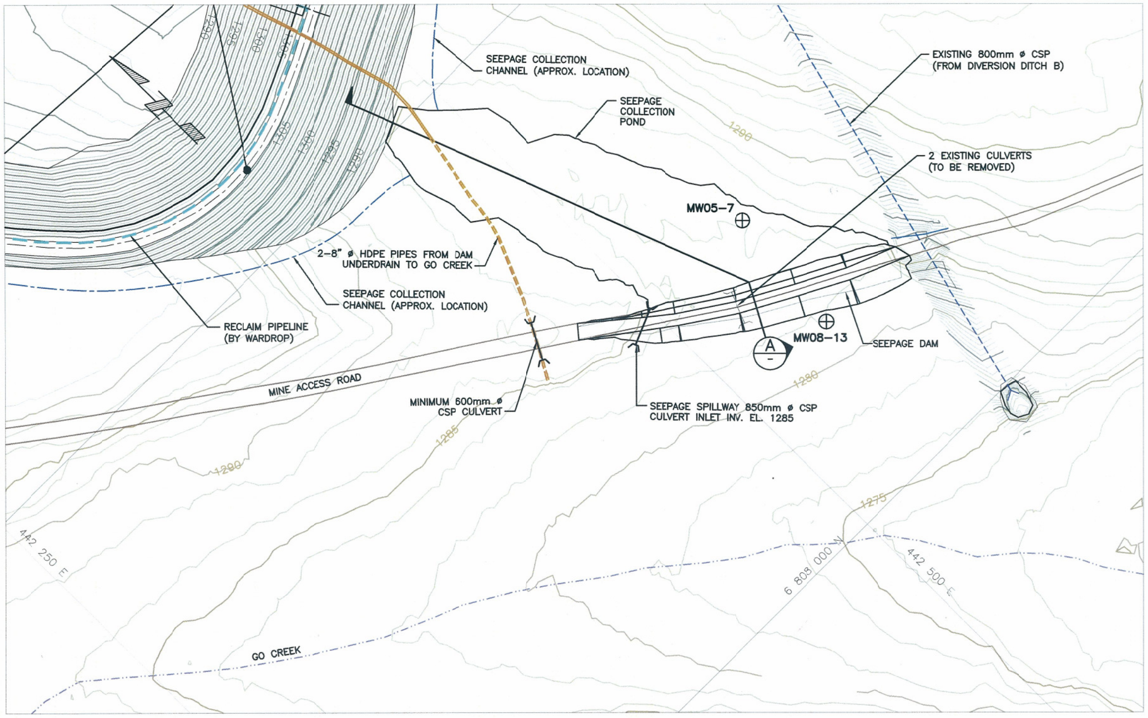

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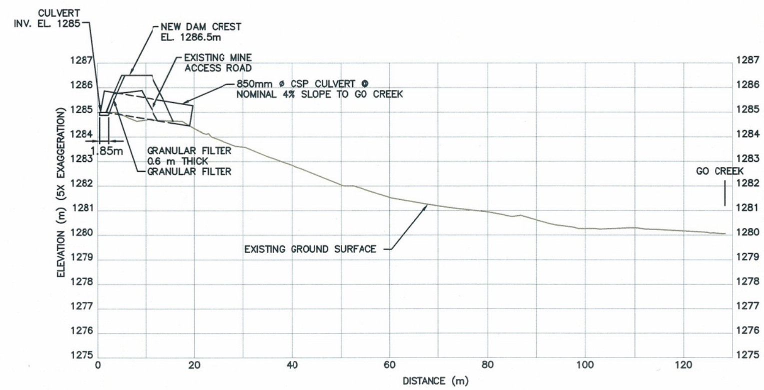
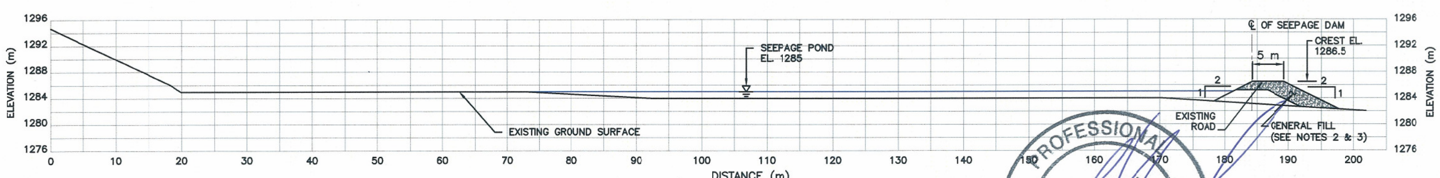
SCALE A



PROFILE OF SEEPAGE SPILLWAY
SCALE: C

LEGEND

- ROADS
- CREEK
- DIVERSION OR COLLECTION DITCH, SPILLWAY
- DAM UNDERDRAIN PIPES (EXISTING)
- MW05-7 ⊕ GROUNDWATER MONITORING WELL (MW08-13) TO BE RELOCATED DOWNSTREAM



SECTION A
SCALE B

NOTES

1. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.
2. ALL LOOSE AND ORGANIC MATERIALS SHALL BE REMOVED, AND THE FOUNDATION SHALL BE PROOFROLLED WITH 6 PASSES WITH A 10 TON VIBRATORY ROLLER, AS DIRECTED BY THE ENGINEER. ALL FOUNDATION AREAS SHALL BE DRY AND APPROVED BY THE ENGINEER PRIOR TO PLACEMENT OF GENERAL FILL OR LINER.
3. GENERAL FILL TO CONSIST OF WELL-GRADED SILTY SAND AND GRAVEL BORROWED FROM IMPOUNDMENT EXCAVATION. FINER GENERAL FILL SHALL BE PLACED TOWARDS THE UPSTREAM SLOPE AS WELL AS ADJACENT TO THE GLACIAL TILL ZONE (STAGE 2 CONSTRUCTION) AND COARSER MATERIAL SHALL BE PLACED TOWARDS THE DOWNSTREAM SLOPE. MATERIAL SHALL BE PLACED IN 300 mm THICK LOOSE LIFTS, WATERED AS REQUIRED, AND COMPACTED TO 95% OF STANDARD PROCTOR DENSITY.

SCALE A 0 — 100 m
SCALE B 0 — 50 m
SCALE C 0 — 50 m

PROFESSIONAL ENGINEER YUKON TERRITORY H.N. McLEOD

ISSUED FOR CONSTRUCTION

DWG. NO. | REFERENCE DRAWINGS

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2	DRAFT CONSTRUCTION RECORD	JL	FEB /10
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0	ISSUED FOR TENDER	DK	FEB 04/09

ISSUE/REVISIONS

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CHECK. BY HM	
APP. BY: HM	MAY 12/10

FILENAME:	PROJECT NUMBER	DRAWING NUMBER	REV.
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Klohn Crippen Berger

YukonZinc CORP
WOLVERINE PROJECT
TAILINGS STORAGE FACILITY
SEEPAGE DAM
PLAN AND SECTION

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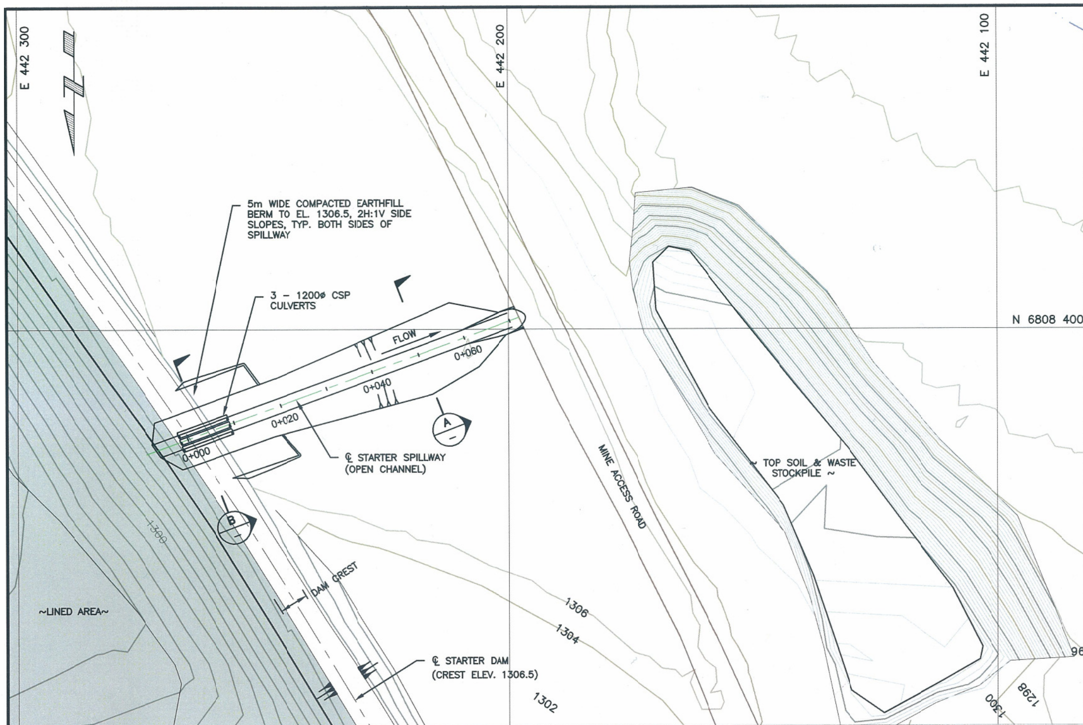
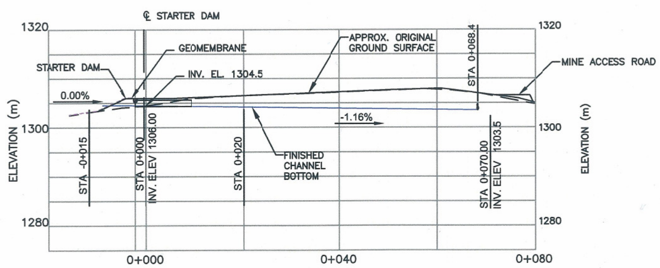
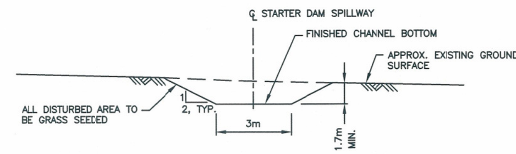


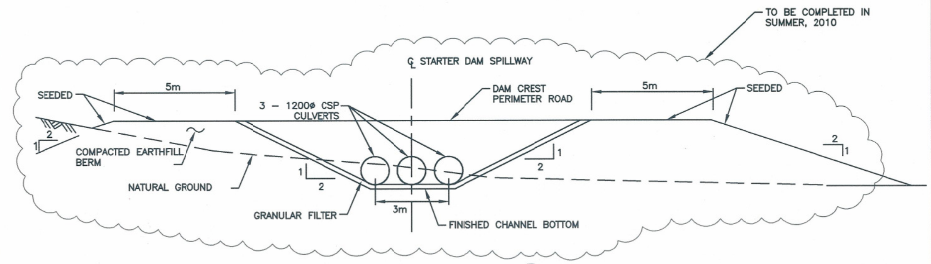
PLAN
SCALE A



PROFILE – STARTER SPILLWAY
SCALE A



TYPICAL GRASS LINED SECTION (A)
NOT TO SCALE



TYPICAL CULVERT SECTION (B)
NOT TO SCALE

NOTES

1. FOR GENERAL SITE ARRANGEMENT, SEE DWG. D-4001.
2. INVERT ELEVATIONS SHOWN ARE TO FINISHED CHANNEL BOTTOM.
3. CULVERT BEDDING/BACKFILL SHALL BE WELL GRADED 100 mm MINUS MATERIAL WITH LESS THAN 20% PASSING THE #200 SIEVE.
4. SPACING BETWEEN CULVERTS WIDTH OF COMPACTOR.
5. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

PROFESSIONAL ENGINEER YUKON TERRITORY H.N. McLEOD

CONSTRUCTION RECORD

SCALE A 0 50 m

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3	CONSTRUCTION RECORD	LC	MAY 12/10
2	DRAFT CONSTRUCTION RECORD	JL	MAR 5/10
1	ISSUED FOR CONSTRUCTON	MD	MAR 13/09
0	ISSUED FOR TENDER	MD	FEB 04/09

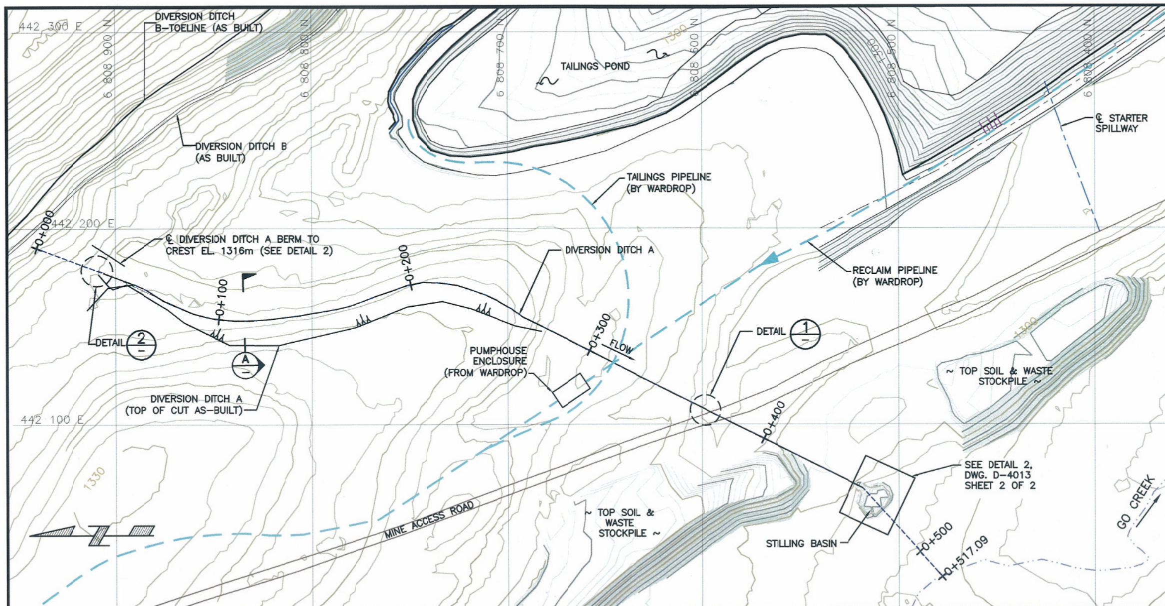
ISSUE/REVISIONS

SECTION:	
SCALE:	DATE
DESIGN. BY LC	MAY 12/10
DRAWN BY: KL	MAY 12/10
CHECK. BY HM	---
APP. BY: HM	MAY 12/10

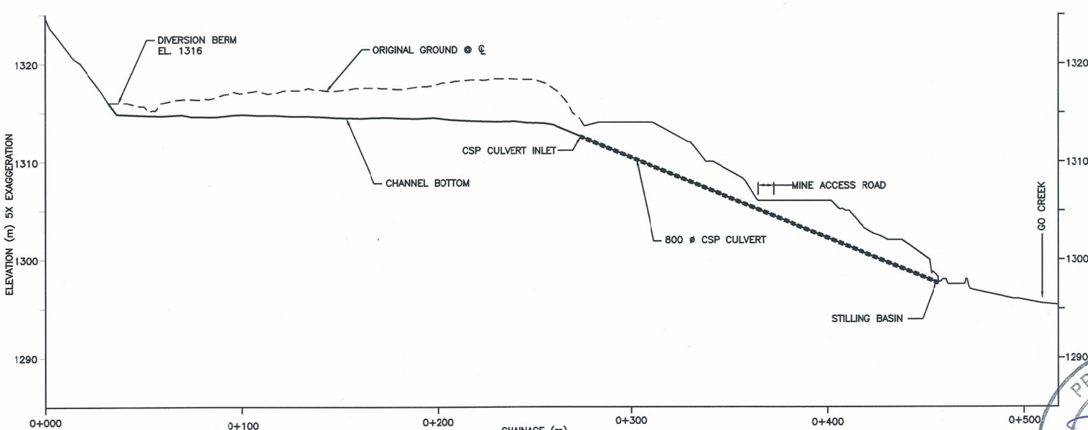
FILENAME:	PROJECT NUMBER	DRAWING NUMBER	REV.
-----------	M09234A05	D-4011	4

Klohn Crippen Berger

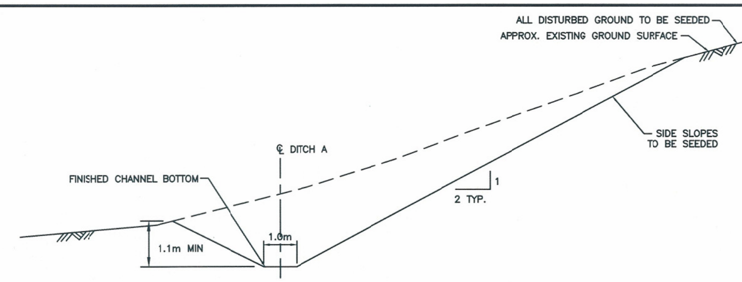
YukonZinc CORP
WOLVERINE PROJECT
TAILINGS STORAGE FACILITY
STARTER SPILLWAY
PLAN, PROFILE AND SECTIONS



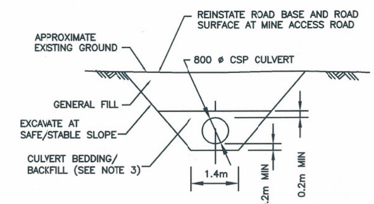
PLAN
SCALE A



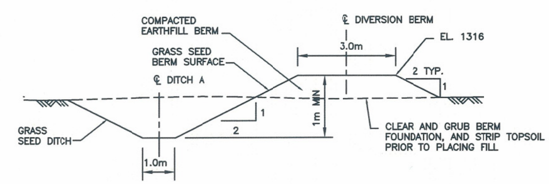
PROFILE DIVERSION DITCH A — VERTICAL SCALE = 5X HORIZONTAL SCALE
SCALE A



SECTION A TYPICAL OPEN CHANNEL SECTION
SCALE B (NO SURVEY DATA)



DETAIL 1 TYPICAL CULVERT SECTION
NTS (NO SURVEY DATA)



DETAIL 2 DIVERSION DITCH A BERM
NTS (NO SURVEY DATA)

NOTES

1. FOR GENERAL SITE ARRANGEMENT SEE DWG. D-4001.
2. INVERT ELEVATIONS SHOWN ARE TO FINISHED CHANNEL BOTTOM.
3. CULVERT BEDDING/BACKFILL WELL GRADED 100 mm MINUS MATERIAL WITH LESS THAN 20% PASSING THE #200 SIEVE.
4. FOR RIPRAP AND GRANULAR FILTER GRADATION AND LAYER THICKNESS, SEE DWG. D-4013 SHEET 2 OF 2.
5. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

SCALE A 0 — 100 m
SCALE B 0 — 6 m

CONSTRUCTION RECORD

PROFESSIONAL ENGINEER — YUKON TERRITORY — H.N. McLEOD

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315476STD.DWG

DWG. NO.	REFERENCE DRAWINGS

NO	DESCRIPTION	BY	DATE
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2	DRAFT CONSTRUCTION RECORD	JL	MAY 5/10
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SECTION:	
SCALE:	DATE
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CHECK. BY HM	
APP. BY: HM	MAY 12/10

FILENAME:	PROJECT NUMBER	DRAWING NUMBER	REV.
----------	M09234A05	D-4012	3

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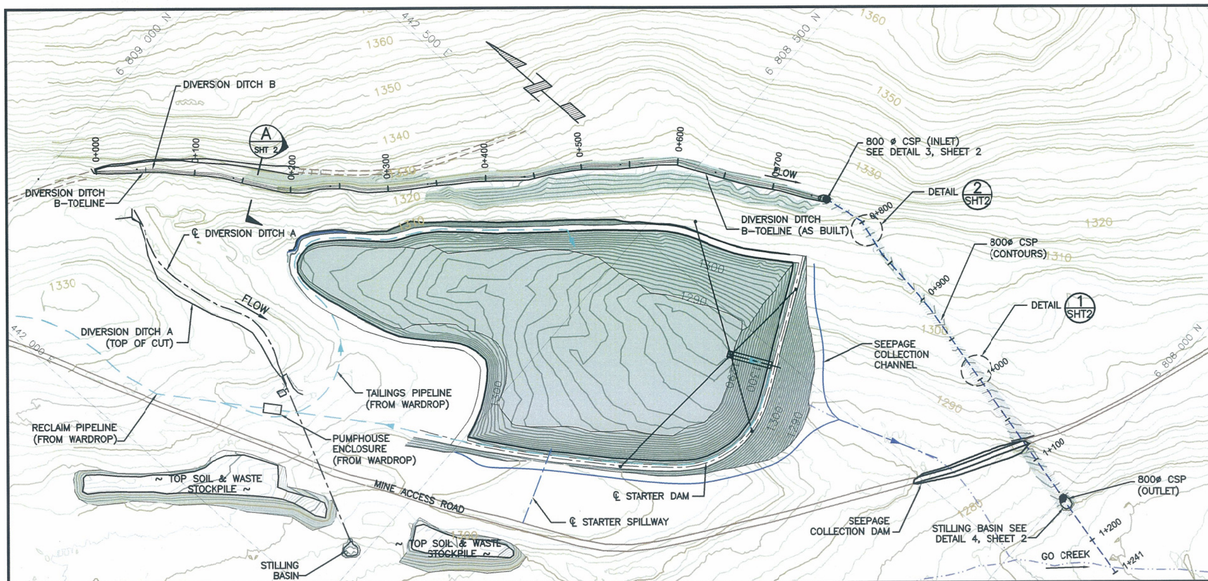
YukonZinc CORP
WOLVERINE PROJECT
TAILINGS STORAGE FACILITY
DIVERSION DITCH A
PLAN AND PROFILE AND SECTIONS



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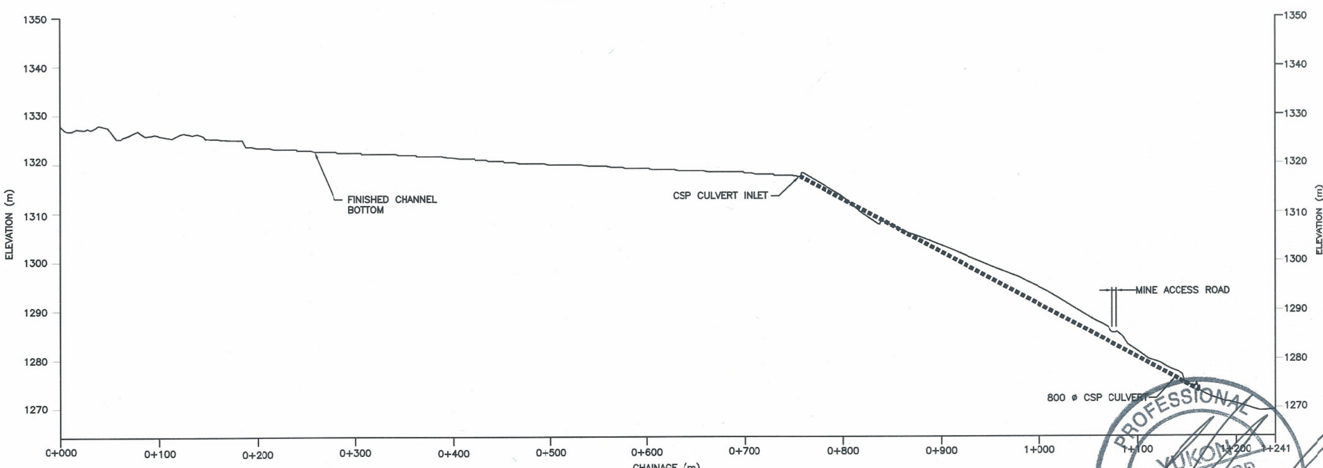

PROFILE DIVERSION DITCH B

VERTICAL SCALE = 5X HORIZONTAL SCALE

LEGEND

– – – – – APPROX. LOCATION OF 800 ø CSP.

NOTES:

1. FOR GENERAL SITE ARRANGEMENT SEE DWG. D-4001.
2. INVERT ELEVATIONS SHOWN ARE TO FINISHED CHANNEL BOTTOM.
3. CULVERT BEDDING/BACKFILL WELL GRADED 100 mm MINUS MATERIAL WITH LESS THAN 20% PASSING THE #200 SIEVE.
4. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC, THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

SCALE 0 250 m

CONSTRUCTION RECORD

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2	DRAFT CONSTRUCTION RECORD	JL	MAR 5/10
1	ISSUED FOR CONSTRUCTION	MD	MAR 13/09
0	ISSUED FOR TENDER	MD	FEB 04/09

DWG. NO.	REFERENCE DRAWINGS

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DRAWN BY:	KL	MAY 12/10
CHECK. BY	HM	
APP. BY:	HM	MAY 12/10

FILENAME: ----------

PROJECT NUMBER: M09234A05 | DRAWING NUMBER: D-4013 | REV. 4

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DIVERSION DITCH B
PLAN AND PROFILE – SHEET 1 OF 2

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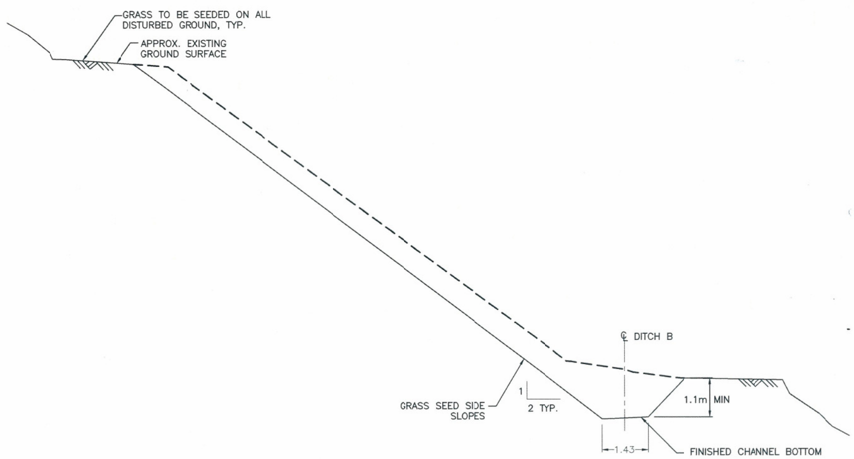
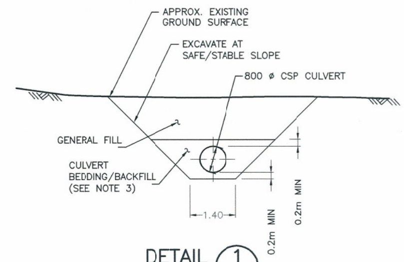


SECTION (A / SHT 1)
SCALE A

TYPICAL OPEN CHANNEL SECTION



DETAIL (1 / SHT 1)
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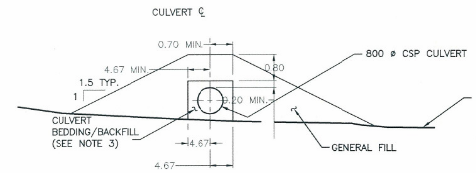
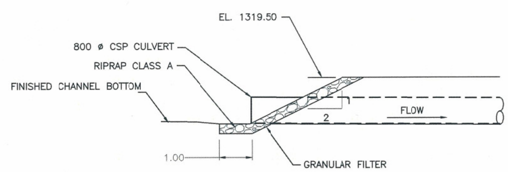


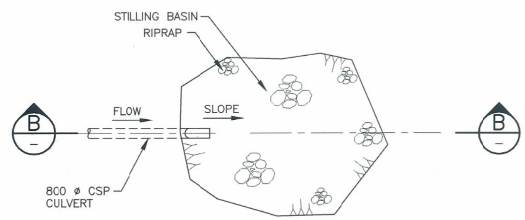
DETAIL (2 / SHT 1)
NTS

CSP CULVERT SECTION IN FILL



DETAIL (3 / SHT 1)
NTS

CSP CULVERT INLET



DETAIL (4 / SHT 1)
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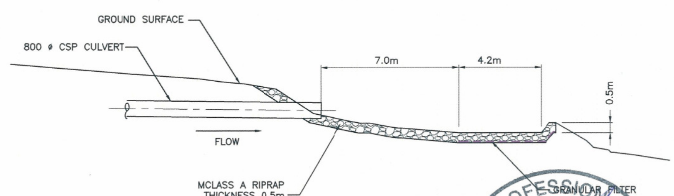
STILLING BASIN PLAN



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SCALE B

RIPRAP AND GRANULAR FILTER GRADATION AND LAYER THICKNESS

(SEE NOTE 4)

Gradation and Layer Thickness

Material	Particle Size (mm)				Layer Thickness (mm)	
	D_{100}	D_{85}	D_{50}	D_{15}	Riprap	Filter
Riprap A	300	260	200	120	400	200 Filter 1
Riprap B	450	390	300	180	600	200 Filter 1
Riprap C	525	455	350	210	700	300 Filter 1
Riprap D	675	585	450	270	900	300 Filter 1
Riprap E	1200	1040	800	480	1600	300 Filter 1 + 400 Filter 2
Riprap F	1500	1300	1,000	600	2000	400 Filter 1 + 400 Filter 2
Filter 1	75	60 to 70	35 to 50	23 to 28	–	–
Filter 2	300	260	200	120	–	–

- Riprap gradation shall be within –5% to +10% of the specified D_{15}, D_{50}, AND D_{85} sizes
- Filter 1 shall be well graded between the 75 mm and 19 mm screen sizes.
- Filter 2 shall be the same gradation as Riprap A.
- Filter 1 grading is based on the subsoil being a silty sand and gravel

NOTES:

1. FOR GENERAL SITE ARRANGEMENT SEE DWG. D–4001.
2. INVERT ELEVATIONS SHOWN ARE TO FINISHED CHANNEL BOTTOM.
3. CULVERT BEDDING/BACKFILL SHALL BE WELL GRADED 100 mm MINUS MATERIAL WITH LESS THAN 20% PASSING THE #200 SIEVE.
4. UNLESS OTHERWISE DIRECTED BY THE ENGINEER, GRANULAR FILTER IS TO BE PLACED UNDER ALL RIPRAP.
5. RECORD ISSUE DRAWING IS BASED ON LIMITED "AS BUILT" DATA PROVIDED BY YZC. THE DRAWING MAY NOT REFLECT ALL FIELD CHANGES.

SCALE A 0 – 6 m
SCALE B 0 – 10 m

PROFESSIONAL ENGINEER – YUKON TERRITORY – H. N. McLEOD

CONSTRUCTION RECORD

NO	DESCRIPTION	BY	DATE
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APP. BY: HM	MAY 12/10

FILENAME:	PROJECT NUMBER	DRAWING NUMBER	REV.
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SECTIONS AND DETAILS – SHEET 2 OF 2

DWG. NO. | REFERENCE DRAWINGS

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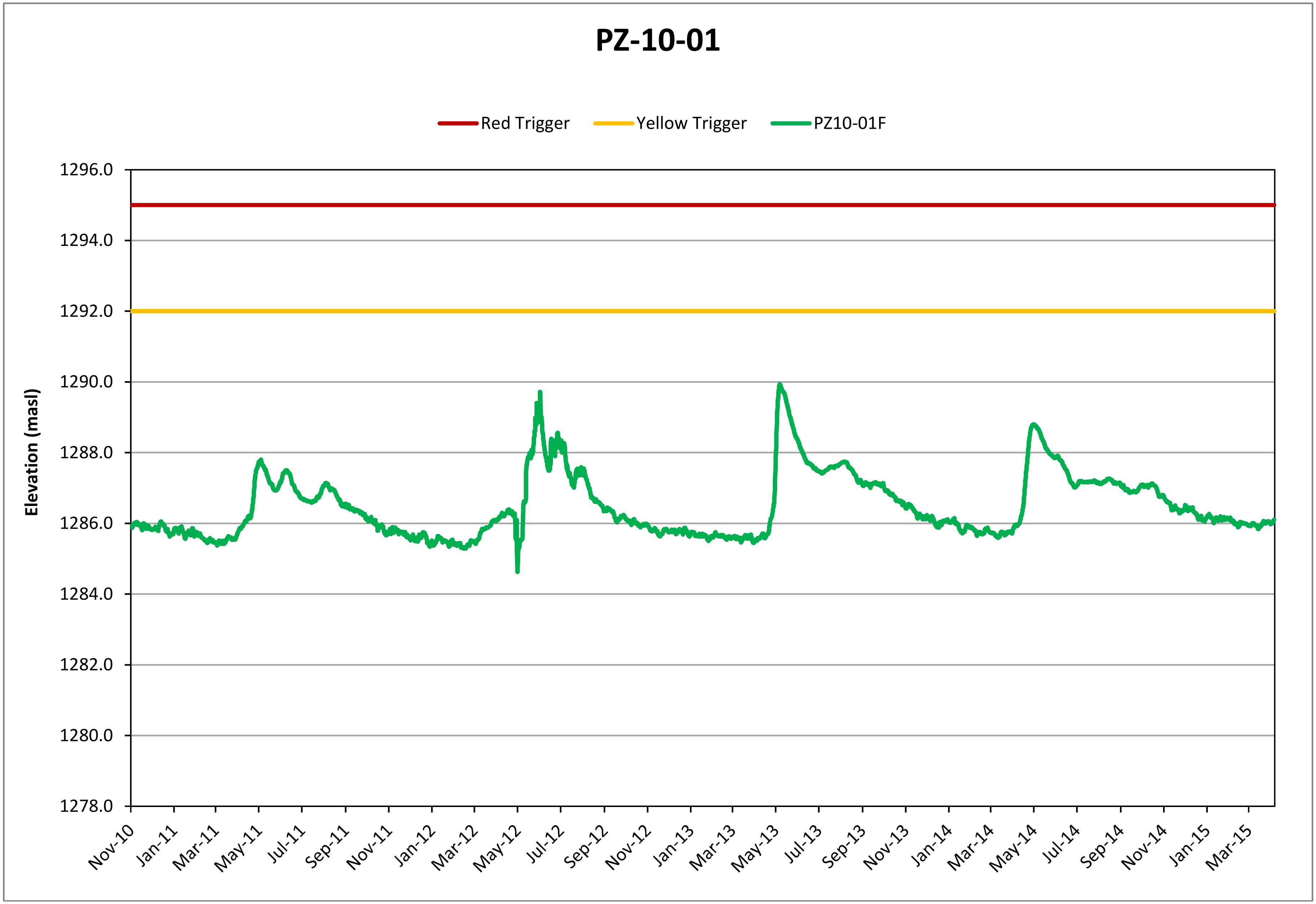
315476STD.DWG

APPENDIX III

Instrumentation Data

Piezometer Data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1284.0
1282.0
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1278.0
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May-11
Jul-11
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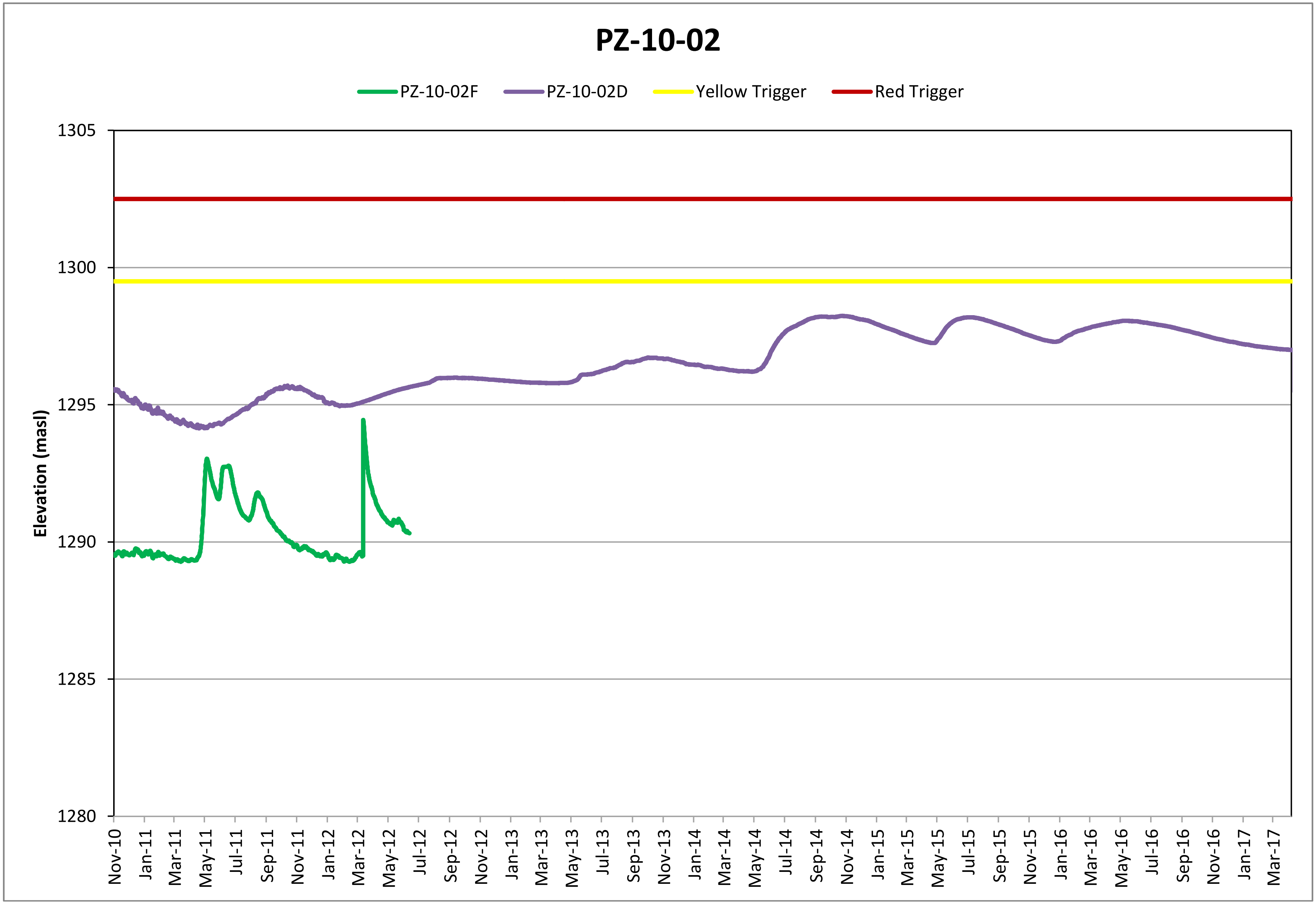
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PZ-10-02D
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Red Trigger
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1280
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May-11
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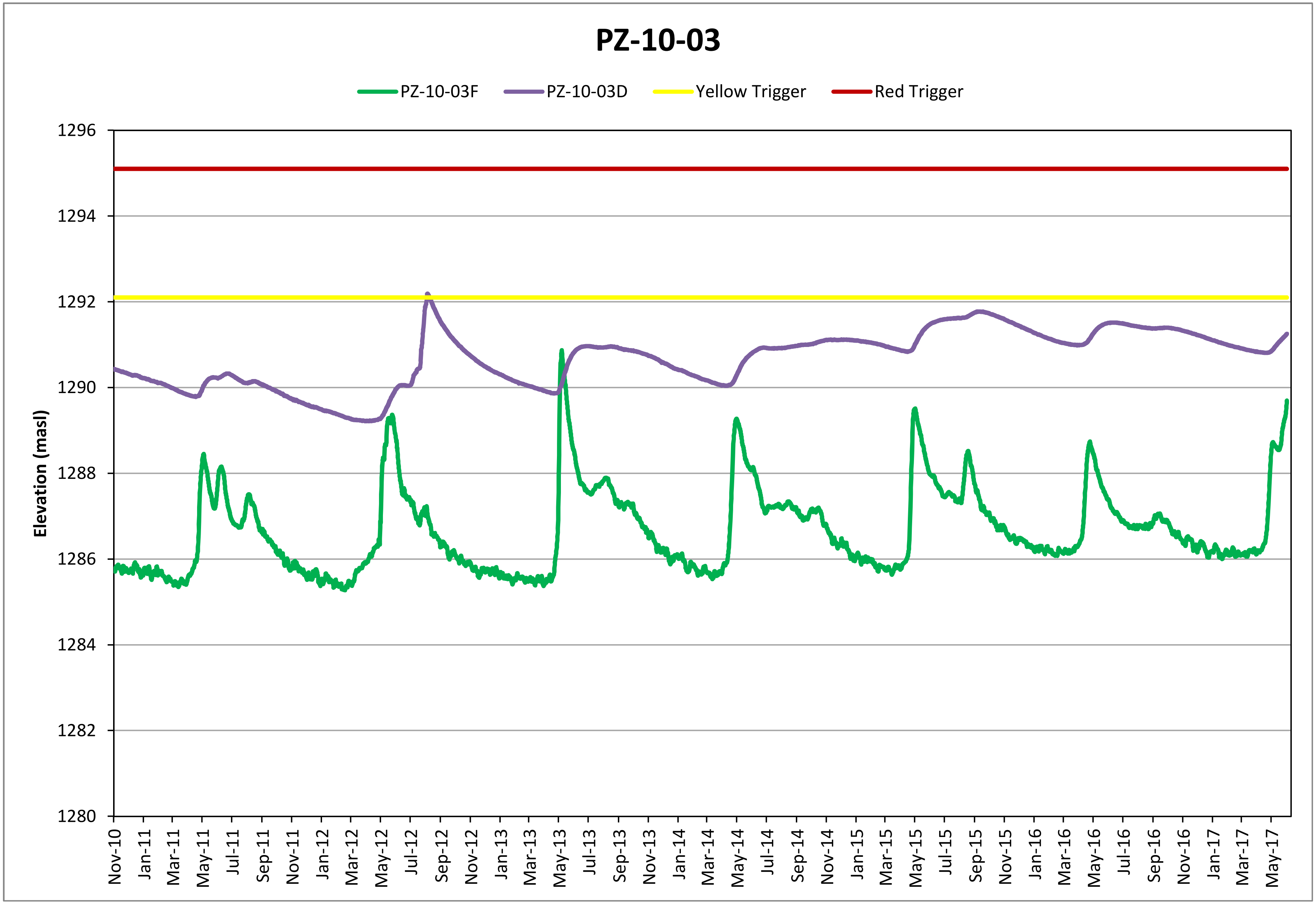
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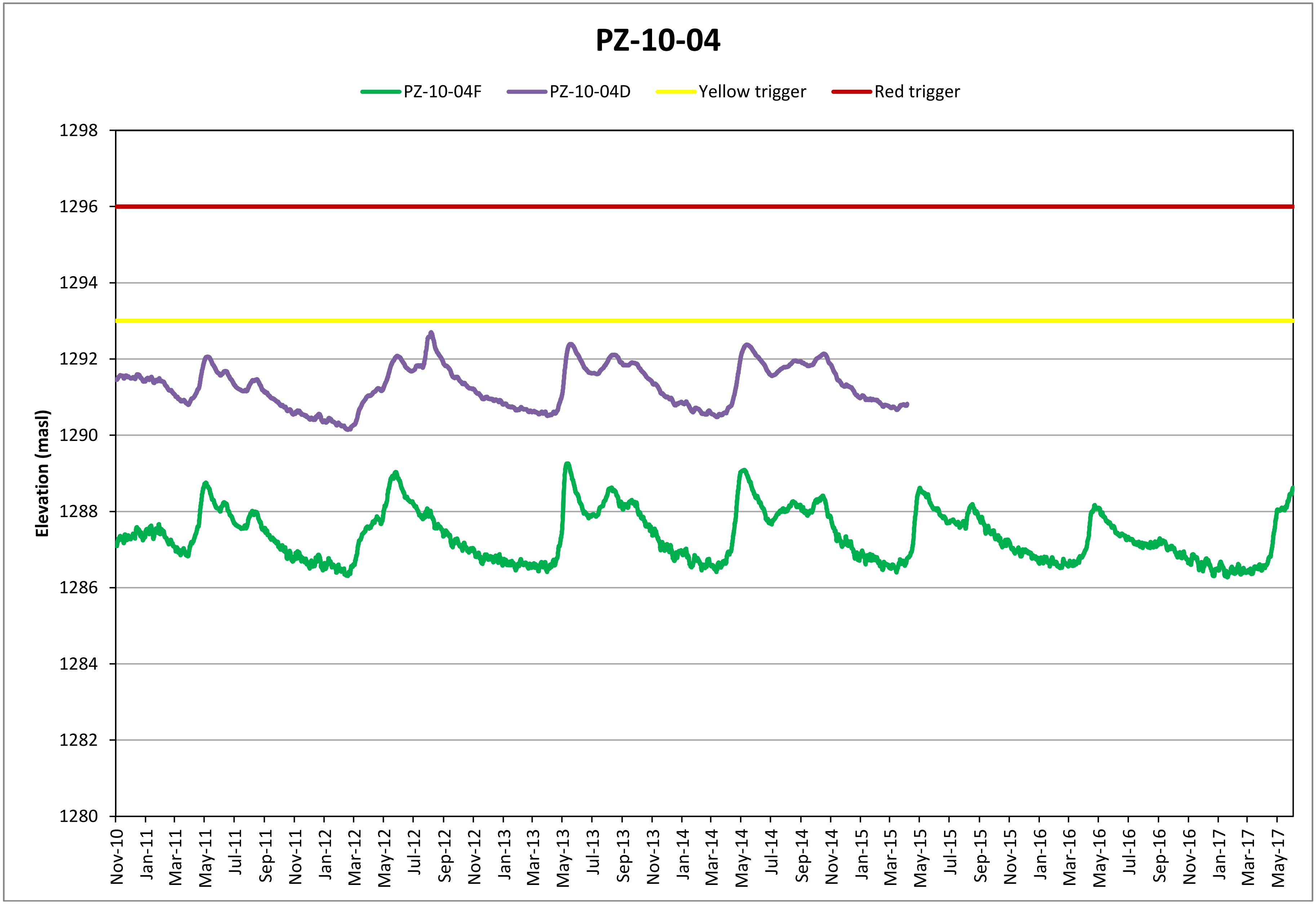
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APPENDIX IV

CDA Principles Assessment

Appendix IV
CDA Principles Assessment

There are 19 CDA Dam Safety Principles presented in the CDA Guidelines (CDA, 2007) and are divided into five categories:

- Principle 1: Dam Safety Management System
- Principle 2: Operations, Maintenance, and Surveillance
- Principle 3: Emergency Preparedness
- Principle 4: Dam Safety Review
- Principle 5: Analysis and Assessment

Conformance / Non-Conformance Types

The types of conformance or non-conformance referred to in each of the CDA sub-principles are listed in the table below.

Label	Type	Description
An	Actual Deficiency	Deficient under normal loads
Au	Actual Deficiency	Deficient under unlikely loads
Cnf	Conformance	Conforms
NCi	Non-Conformance	Information
NCm	Non-Conformance	Maintenance
NCo	Non-Conformance	Operations
NCp	Non-Conformance	Other Procedures
NCs	Non-Conformance	Surveillance
Pq	Potential Deficiency	Expected not to be deficient, quickly demonstrated
Pd	Potential Deficiency	Expected not to be deficient, difficult to demonstrate
Pn	Potential Deficiency	Expected to be deficient under normal loads
Pu	Potential Deficiency	Expected to be deficient under unlikely loads

Principle 1 – Dam Safety Management System

Principle 1A: The public and the environment shall be protected from the effects of dam failure, as well as release of any or all of the retained fluids behind a dam, such that the risks are as low as reasonably practicable (ALARP).

Type:	Conforms (Cnf)
Description:	The design meets or exceeds CDA guidelines for a "Very High" consequence strucutre.
Recommendations:	No recommendation

Principle 1B: The standard of care to be exercised in the management of dam safety shall be commensurate with the consequences of dam failure.

Type:	Conformance (Cnf)
Description:	The dam consequence classification is currently 'Very High' but key design features are desiged to "Extreme" consequence classification based on permit requirements.
Recommendations:	

Principle 1C: Due diligence shall be exercised at all stages of a dam's life cycle.

Type:	Non-Conformance: Other Procedures (NCp)
Description:	OMS requirements for routine inspections are not being documented in accordance with the OMS manual. The OMS manual was never revised to reflect the care and maintenance status of the operation. Inspections are being completed but inspection sheets in the OMS are not being used and the surveillence schedule was never reviewed for care and maintenance.
Recommendations:	Revise OMS surveillance schedule and requirements for mining restart or for closure, depding on decision made on restart of operation..

Principle 1D: A dam safety management system, incorporating policies, responsibilities, plans and procedures, documentation, training, and review and correction of deficiencies and non-conformances, shall be in place.

Type:	Non-Conformance: Information/Other Procedures (NCi/NCp)
Description:	YZC has a dam safety management system for the TSF, which includes annual dam safety inspections, an Operation, Maintenance and Surveillance (OMS) Manual and DSR. In addition to the site based team management system also includes input from experienced individuals within Yukon Zinc. With the potential restart of mining activities an update to the OMS manual is required.. An additional area of improvement for the dam management system is in specifying and documenting training requirements and completion records.
Recommendations:	Refer to recommendations for Principle 1A, 1B and 1C. i. Document staff training in all areas related to dam safety management. Training should include an overview of the TSF facilities and how their work fits into the safe operation of the facilities.

Principle 2 – Operation, Maintenance, and Surveillance

Principle 2A: Requirements for the safe operation, maintenance, and surveillance of the dam shall be developed and documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure.

Type:	Non-Conformance: Information (NCi)
Description:	The OMS document is complete and covers the required components. However, there are improvements that should be made to the document to reflect ongoing changes and the results of this DSR. The main observations for improvement are documented in Table 4.4 in the DSR and include the following: ▪ Revising roles and responsibilities based on new site team ▪ Facility description updated to include design rainfall events and consolidation of site records. ▪ Reporting responsibilities and documentation to be revised based on restart plan ▪ Emergency Planning and Response to be updated based on revised inundation study
Recommendations:	Update the OMS document based on the above recommendations.

Principle 2B: Documented operating procedures for the dam and flow control equipment under normal, unusual, and emergency conditions shall be followed.

Type:	Conformance: (Cfn)
Description:	Operating procedures for components of the tailings facilities are specified in the OMS..
Recommendations:	

Principle 2C: Documented maintenance procedures shall be followed to ensure that the dam remains in a safe and operational condition.

Type:	Conforms (Cnf)
Description:	Maintenance procedures for components of the TSF are docuemented in the OMS
Recommendations:	No recommendation

Principle 2D: Documented surveillance procedures shall be followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.

Type:	Non-Conformance: Surveillance (NCs)
Description:	Surveillance records are maintained in a book on site, but not formally logged using the inspection sheets in the OMS. Where appropriate, reference is made in the OMS to the location of the surveillance records. Threshold values for monitoring equipment (piezometers,) and the appropriate response is included in the OMS.
Recommendations:	Formal inspection records should be developed and saved in a central location on site if the mine goes back into production. If the mine is going to closure then surveillance activities should be revised to reflect the operating condition.

Principle 2E: Flow control equipment shall be tested and be capable of operating as required.

Type:	Non-Conformance: Other Procedures (NCp)
Description:	The barge needs to be tested prior to restart of mining activities. Current operations do not require the barge to be in operating condition but will need to be evaluated for restart.
Recommendations:	Test reclaim system prior to restart and re-establish maintenance protocols for the reclaim barge.

Principle 3 – Emergency Preparedness

According to the CDA (2007), Emergency Response Plans (ERPs) and Emergency Preparedness Plans (EPPs) "should be in place for all dams where lives are at risk or if implementation of emergency procedures could significantly reduce the consequences of failure." These documents should establish a clear emergency response structure that is issued to and understood by all internal and external emergency responders.

Principle 3A: An effective emergency management process shall be in place for the dam.

Type:	Conformance (Cnf):
Description:	There is an ERP in place for the facility. It can be revised once the updated inundation study is complete.
Recommendations:	Refer to Principle 3B.

Principle 3B: The emergency management process shall include emergency response procedures to guide the dam operator and site staff through the process of responding to an emergency at a dam.

Type:	Non-Conformance (NCi)
Description:	The emergency management process is well documented but various site contacts are out of date and government contacts may also be out of date. This should be updated. The inudation study should be revised to provide more detail on potential impacted areas to communicate with external stakeholders.
Recommendations:	Review and update all relevant reporting structures and contact details. The ERP should also be updated once the revised inundation study is available.

Principle 3C: The emergency management process shall ensure that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.

Type:	Non-Conformance: Information (NCi)
Description:	Refer to discussion in Principle 3B regarding innundation maps and off site contacts.
Recommendations:	See Principle 3B

Principle 3D: The emergency management process shall ensure that adequate staff training, plan testing, and plan updating are carried out.

Type:	Non-Conformance: Other Procedures (NCp)
Description:	There is no evidence of training of staff or testing of the ERP. This should be included as part of ongoing training and system improvement and implemented as part of the mining restart process or transition to closure.
Recommendations:	i. Define ERP drills for the tailings facilities in the OMS and confirm that drills include that all members of the dam management team participate.

Principle 4 – Dam Safety Review

Dam Safety Reviews (DSRs) should be conducted regularly to ensure that the dam is safe based on current knowledge and standards, which may have been updated since a previous DSR. A qualified registered professional engineer should conduct the review and should evaluate all aspects that may affect the dam's safety, including design, construction, maintenance, operation, processes, and dam safety management systems.

Principle 4A: A safety review of the dam ("Dam Safety Review") shall be carried out periodically.

Type:	Non-Conformance (NCs)
Description:	The CDA (2007) guidelines call for a Dam Safety Review to be conducted every 7 years for a dam with a "High" consequence rating. The first DSR was conducted in 2017 and should have been conducted in 2016..Dam classification should be revised to "Very High" and DSRs conducted in 5 year intervals
Recommendations:	DSR schedule to be set and observed in future.

Principle 4B: A qualified registered professional engineer shall be responsible for the technical content, findings, and recommendations of the Dam Safety Review and report.

Type:	Conforms (Cnf)
Description:	This review has been conducted by a qualified registered professional engineer.
Recommendations:	No recommendation.

Principle 5 – Analysis and Assessment

According to Principle 5, the purpose of dam safety analysis is to determine the capacity of the dam system to retain the stored volume under all conditions and to pass flows around and through the dam in a safe, controlled manner.

Principle 5A: The dam system and components under analysis shall be defined.

Type:	Conforms (Cnf)
Description:	The Engineer or Record appears to be responsible for all components of the facility. It is important that the OMS manual is revised either for closure or mine restart and that updated roles and responsibilities are identified.
Recommendations:	Update OMS manual

Principle 5B: Hazards external and internal to the dam shall be defined.

Type:	Potential Deficiency: Unlikely to be deficient, difficult to prove (Pd)
Description:	The amount of groundwater that reports to the liner underdrain system has never been comprehensively assessed. The slump at the north end of the TSF may indicate that the liner under drain and French drains constructed to manage water are undersized and more groundwater management is required.
Recommendations:	An assessment of the North Slump area should be conducted to determine what caused the movement and what mitigations are required to prevent further slope movements in the future.

Principle 5C: Failure modes, sequences, and combinations shall be identified for the dam.

Type:	Conforms (Cnf)
Description:	The ERP descirbes various failure modes and consequences of failure and responses that can be implemented to mitigate damage to the facility.
Recommendations:	No recommendation

Principle 5D: The dam shall safely retain the reservoirs and any stored solids, and it shall pass flows as required for all applicable loading conditions.

Type:	Conformance (Cnf)
Description:	The records for the design and construction suggest that the facility was designed and constructed to standards that exceed CDA requirements.
Recommendations:	No recommendation

Appendix G: Detailed Closure Cost Estimates

Table G-1: Temporary Closure Detailed Costs

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost	Notes
Organization, Security and Overhead						
Site Supervisor	Management	month	25	$11,204	$280,100	
Site Caretaker	Management	month	25	$8,853	$221,325	
Camp Costs	per person per day	day	2280	$100	$228,000	Assuming 3 staff on site at all times
Camp Vehicles	light-duty vehicle	day	2280	$125	$285,000	Assume 3 in operation at any given time
Flights	2 flight/month for shift rotations, specialist visits, supplies	flights	50	$3,855	$192,750	Whitehorse-Wolverine + commercial connections
Site maintenance costs Summer	maintenance, fuel (350 L per day), supplies	month	12	$10,500	$126,000	
Site maintenance costs Winter	maintenance, fuel (500 L per day)l, supplies	month	13	$20,000	$260,000	
				Sub Total	**$1,593,175**	
Maintenance						
Repair slump at TSF	Recommended in Dam Safety Review	L.S.		$18,400	$18,400	
Bulkhead installation	Dewatering well installation	L.S.		$122,800	$122,800	
	Underground mine rehab	L.S.		$750,000	$750,000	
	Installation of two hydraulic bulkheads in decline and vent raise	L.S.		$2,270,400	$2,270,400	To be installed in summer 2019
Update Tailings Dam OM&S	Recommended in Dam Safety Review	L.S.		$20,000	$20,000	
				Sub Total	**$3,181,600**	
Monitoring						
Environmental Monitoring Consultants	Sampling and monitoring	month	25	$17,569	$439,231	Monthly surface water and groundwater sampling program
Water Quality Analytical	Surface water quality analysis	each	608	$225	$136,800	See Surface Water Quality Monitoring Table for summary of frequency
	Groundwater quality analysis	each	160	$125	$20,000	See Groundwater Quality Monitoring Table for summary of frequency
	Rainbow Trout LC50	each	24	$200	$4,800	Assume 2/month during discharge May - October
Hydrogeological	Required to improve condition of	L.S.		$120,000	$120,000	

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost	Notes
assessment of groundwater wells	groundwater wells; assume repairs conducted as well					
EEM Sublethal Toxicity Testing (2/year)	Fish species	each	6	$300	$1,800	Required during discharging
	Invertebrate species	each	6	$215	$1,290	Required during discharging
	Plant species	each	6	$200	$1,200	Required during discharging
	Algal species	each	6	$200	$1,200	Required during discharging
Metals in Vegetation analysis	Collection and analysis for metals in lichen, willow and horsetail	each	120	$95	$11,340	Conducted once in 2019 prior to initiation of closure
Geotechnical Inspections	Annual tailings dam inspection	each	2	$20,000	$40,000	Required annually as per QML-0006
	Annual earthen structures inspection	each	2	$5,000	$10,000	Required annually as per QML-0006
				Sub Total	**$787,661**	
Water Treatment						
Design WTP	Design WTP fall 2017	L.S.		$828,000	$828,000	
Capital WTP	Construct and install of WTP in spring 2018	L.S.		$3,500,000	$3,500,000	
Water Treatment Cost	Operation of WTP for 6 months per year in 2018 & 2019	m^3	439200	$2.09	$920,000	
				Sub Total	$5,248,000	
				Sub Total	$10,810,436	
				10% Contingency	*$1,081,044*	
				Total	$11,891,480	
				Inflation	$12,207,971	
				NPV	**$10,382,740**	

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Table G-2: Surface Water Sampling Stations

Station Number	Station Location	Watershed	Sampling Frequency	Notes on access
T1	Tailings Barge	TSF	Monthly	Accessible year round
W82	Upper Wolverine Creek	Wolverine Creek	Monthly	Frozen to ground November - May
W9	Wolverine Creek at Little Wolverine Lake		Monthly	Only accessible when lake is thawed
W1	Wolverine Lake outlet		Monthly	Only accessible when lake is thawed
L1	Little Wolverine Lake		Monthly	Only accessible when lake is thawed
W21	Nougha Creek at Campbell Highway		Monthly	Only accessible when road is open
W8	Campbell Creek		Monthly	Only accessible when lake is thawed
W15	Hawkowl Creek above Go Creek	Go Creek	Monthly	
W16	Go Creek below tailings facility		Monthly	
W81	Go Creek below Hawkowl Creek		Monthly	
W31	Go Creek above TSF		Monthly	Frozen to ground November - May
W80	Go Creek		Monthly	Daily required when discharging May - October
W12	Go Creek above Money Creek		Monthly	Only accessible by ATV in summer
W14	Upper Money Creek	Money Creek	Monthly	Only accessible by ATV in summer
W22	Money Creek above Campbell Highway		Monthly	Only accessible when road is open
W40	Money Creek below Campbell Highway		Monthly	Only accessible when road is open
W71	Pitch Creek below road crossing	Site Access Road	Monthly	Only accessible when road is open
W72	Light Creek		Monthly	Only accessible when road is open
W73	Bunker Creek at road crossing		Monthly	Only accessible when road is open

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Table G-3: Surface Water Sampling Frequencies

	T1	W82	W9	W1	L1	W21	W8	W15	W16	W81	W31	W80*	W12	W14	W22	W40	W71	W72	W73	Total
January	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
February	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
March	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
April	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
May	1	1	0	0	0	1	0	1	1	1	1	4	0	0	1	1	1	1	1	43
June	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	48
July	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	49
August	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	49
September	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	48
October	1	1	0	0	0	1	0	1	1	1	1	4	0	0	1	1	1	1	1	43
November	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
December	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4
Total	**12**	**6**	**4**	**4**	**4**	**6**	**4**	**12**	**12**	**12**	**6**	**184**	**4**	**4**	**6**	**6**	**6**	**6**	**6**	**304**

*Daily sampling when discharging

Table G-4: Groundwater Sampling Stations

Groundwater Station	Location	Watershed	Sampling Frequency	Notes on Status
MW05-1A, 1B	Airstrip North	Go Creek	Quarterly	
MW05-2A, 2B	TSF – Southwest	TSF	Quarterly	
MW05-3A, 3B	Mine	Wolverine Creek	Quarterly	MW05-3A and -3B appear to be hydraulically connected, and are therefore redundant
MW05-4A, 4B	Mine		Quarterly	
MW05-5A, 5B	Mine		Monthly	MW05-5B needs to be re-developed
MW05-6A, 6B	Airstrip East	Go Creek	Quarterly	
MW05-7B	Mine	TSF	Quarterly	Covered with water in the seepage pond
MW06-8S, 8M, 8D	Mine	Wolverine Creek	Quarterly	Tubing has fallen into the well; which prohibits sampling
MW06-9S, 9M	Mine		Quarterly	
MW06-10S, 10M, 10D	Mine		Quarterly	Tubing has fallen into the well; which prohibits sampling
MW06-11S	Mine		Monthly	
MW06-12S	Mine		Quarterly	Needs to be re-developed
MW08-13	TSF - West	TSF	Quarterly	

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Table G-5: Groundwater Sampling Frequencies

	January	February	March	April	May	June	July	August	September	October	November	December	Samples/site
MW05-1A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-1B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-2A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-2B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-3A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-3B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-4A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-4B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-5A	1	1	1	1	1	1	1	1	1	1	1	1	**12**
MW05-5B	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW05-6A	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-6B	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-7B	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW056-8S	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-8M	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-8D	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-9S	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW05-9D	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW06-10S	0	0	1	0	0	1	0	0	1	1	0	0	**4**
MW06-10M	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-10D	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW06-11S	1	1	1	1	1	1	1	1	1	1	1	1	**12**
MW06-12S	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MW08-13	0	0	1	0	0	1	0	0	1	1	0	0	**4**
Monthly Total	**2**	**2**	**16**	**2**	**2**	**16**	**2**	**2**	**16**	**16**	**2**	**2**	**80**

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Table G-6: Bulkhead InstallationDetailed Costs

Phase	Task	Labour	Equipment	Materials & Shipping	Estimated Cost
Underground Rehab	Underground rehab for safe access to bulkhead installation site	$200,000	$50,000	$500,000	$750,000
Underground Construction	Mobilization and Setup	$31,000	$10,000	$44,000	$85,000
	Foundation Preparation	$108,000	$29,000	$0	$137,000
	Formwork Construction	$166,000	$38,000	$180,000	$384,000
	Bulkhead Form Stripping	$21,000	$10,000	$0	$31,000
	Demobilization	$38,000	$10,000	$24,000	$72,000
SCC Installation	Mobilization and setup	$58,000	$3,000	$44,000	$105,000
	SCC Pour	$63,000	$50,000	$94,000	$207,000
	Demobilization	$53,000	$3,000	$44,000	$100,000
Contact and Consolidation Grouting	Mobilization and Setup	$21,000	$3,000	$10,000	$34,000
	Contact grouting	$44,000	$5,000	$4,000	$53,000
	Consolidation Grouting	$54,000	$5,000	$18,000	$77,000
	Demobilization	$16,000	$3,000	$10,000	$29,000
				Subtotal	**$2,064,000**
				Contingency (10%)	***$206,400***
				Total	**2,270,400**

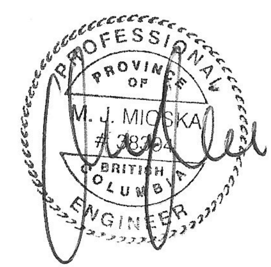

Table G-6: Water Treatment Plant Detailed Costs

Engineering				**Cost**
Pre-design work required for establishing design basis				$22,000
IFC engineering				$430,000
Procurement support				$52,000
Fabrication, construction and implementation				$157,300
Commissioning				$166,700
			Subtotal	**$828,000**
Construction				
Metals removal				$400,000
Reverse osmosis				$1,100,000
Selenium removal				$1,600,000
RO retentate desaturation				$400,000
			Subtotal	**$3,500,000**
Operating Costs	**Unit Price**	**Units**	**Consumption rate (t/a)**	**$CAD/year (150 d/a operating season)**
NaHS	$1,930	$/t	1.8	$3,500
Ferric iron	$3,470	$/t	7.2	$25,000
H2SO4	$269	$/t	32	$8,700
RO Reagents	$4,250	$/t	14	$60,000
RO Membranes	$30,000	set of elements	1	$30,000
Iron Anodes	$1,153	$/t	142	$164,000
Power	$0.06	$/kwh	575	$125,000
			Subtotal	**$416,200**

Table G-7: Tailings Area Detailed Closure Costs

Work Item Description	Description	Equipment	Units	Quantity	Unit Cost	Total Cost
Decommission Diversion Ditches						
Decommission Diversion Ditches A & B	Regrade and contour	Cat D8N Dozer	hrs	60	$350	$21,000
Decommission Diversion Ditch B	Steep slopes	Cat 320CL Excavator	hrs	20	$175	$3,500
Revegetate and Stabilize	Seed and Fertilize area 1.56 km x 5 m	Seed and Fertilizer Application	ha	0.78	$1,500	$1,170
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	Seed and Fertilizer Application	ha	0.39	$1,500	$585
Culvert removal (800 mm)	Uncovering and removal	Culvert Removal (<1200mm)	each	4	$1,500	$6,000
					Sub Total	**$32,255**
Remove Tailings & Reclaim Pipeline						
Remove Pipeline	Cat 320CL Excavator	Cat 320CL Excavator	hrs	150	$175	$26,250
Remove Pipeline	A30D Rock Truck	A30D Rock Truck	hrs	150	$300	$45,000
Remove Pipeline	Labour	Labourer	hrs	300	$36	$10,674
Reclaim area	Seed, fertilize - 3km length x 3 m corridor	Seed and Fertilizer Application	ha	0.9	$1,500	$1,350
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	Seed and Fertilizer Application	ha	0.45	$1,500	$675
					Sub Total	**$83,949**
Water Treatment						
Water Treatment Cost	Operation of WTP for 6 months per year in 2020 - 2023		m^3	878400	$2	$1,840,000
Remove WTP and Pipelines	Remove WTP	Crane	hrs	40	$195	$7,800
Demob WTP	Demob WTP		L.S		$10,000	$10,000
Decommission WTP	Regrade and contour	Cat 320CL Excavator	hrs	40	$175	$7,000
Decommission WTP	General labour	Labourer	hrs	120	$36	$4,270
Revegetate and Stabilize	Seed and Fertilize area	Seed and Fertilizer Application	ha	1	$1,500	$1,500
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	Seed and Fertilizer Application	ha	0.5	$1,500	$750
					Sub Total	**$1,871,320**
Construct Final TSF Landform						
Landform engineering + design	detailed design		L.S			$50,000
Push Stage 2 material to Stage 1	Cat D8N Dozer		hrs	400	$350	$140,000
Remove TSF dam above 1305 level	Cat D8N Dozer		hrs	400	$350	$140,000

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Work Item Description	Description	Equipment	Units	Quantity	Unit Cost	Total Cost
Impermeable cover installation	Use existing liner from TSF area to wrap overtop of TSF landform	Cat 320CL Excavator	hrs	50	$175	$8,750
Spread dam material over TSF landform	Cat D8N Dozer		hrs	300	$350	$105,000
Spread dam material over TSF landform	Compactor			200	$185	$37,000
Load, haul and place topsoil			m^2	16400	$5	$82,000
Seed and fertilize TSF landform and Stage 2 area	Seed and Fertilizer application	Seed and Fertilizer application	ha	16.4	$1,500	$24,600
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	Seed and Fertilizer application	ha	8.2	$1,500	$12,300
Reclaim borrow areas	Seed and Fertilize	Seed and Fertilizer application	ha	2	$1,500	$3,000
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	Seed and Fertilizer application	ha	1	$1,500	$1,500
					Sub Total	**$604,150**
					Total	**$2,591,674**
					10% Contingency	***$259,167***
					Grand TOTAL	**$2,850,841**

Table G-8: Infrastructure Decomissioning Costs

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost
Industrial Complex + Office Buildings					
Remove salvageable equipment	Labourer	hrs	1152	$35.58	$40,988
Remove salvageable equipment	Tradesman	hrs	1128	$49.31	$55,616
Dismantle Building - Manpower	Labourer	hrs	1152	$35.58	$40,988
Dismantle Building - Manpower	Tradesman	hrs	576	$49.31	$28,400
Dismantle Building - Equipment and Loading	Cat 320CL Excavator	hrs	160	$175.00	$28,000
Dismantle Building - Equipment and Loading	Crane	hrs	80	$195.00	$15,600
Concrete Demolition	Cat 320 Excavator + Hammer	hrs	80	$220.00	$17,600
Misc. Supplies & Tools	Misc.	L.S.			$10,000
Scrap haul to landfill	A30D Rock Truck	hrs	208	$300.00	$62,400
Reslope and contour and bury	Cat D8N Dozer	hrs	80	$350.00	$28,000
Load, Haul and place topsoil	Area of 145244 m^2 x 0.25 m depth	m^3	36311	$5.00	$181,555
Reclaim area	Seed and Fertilizer Application	ha	14.5	$1,500.00	$21,750
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	7.25	$1,500.00	$10,875
				Sub Total	**$541,772**
Power Supply - Gensets					
Remove salvageable equipment	Labourer	hrs	180	$35.58	$6,404
Remove salvageable equipment	Tradesman	hrs	108	$49.31	$5,325
Salvage and remove power line and poles		L.S.			$25,000
Dismantle Building - Manpower	Labourer	hrs	96	$35.58	$3,416
Dismantle Building - Manpower	Tradesman	hrs	48	$49.31	$2,367
Dismantle Building - Equipment	Cat 320CL Excavator	hrs	12	$175.00	$2,100
Dismantle Building - Equipment	Crane	hrs	12	$195.00	$2,340
				Sub Total	**$46,952**
Site Diversions					
Decommission 1500 m of diversion ditches	Cat 320CL Excavator	hrs	150	$175.00	$26,250
Remove culverts (<1200 mm)		L.S.	8	$1,500.00	$12,000
Reclaim area	Seed and Fertilizer Application	ha	0.5	$1,500.00	$750
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	0.25	$1,500.00	$375
				Sub Total	**$39,375**
Water Supply Wells					
Remove salvageable equipment - pipeline/pumps and tank	Labourer	hrs	24	$35.58	$854
Remove salvageable equipment - pipeline/pumps and	Tradesman	hrs	24	$49.31	$1,183

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Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost
tank					
Remove pipeline and haul to TSF	A30D Rock Truck	hrs	8	$300.00	$2,400
Remove pipeline and haul to TSF	Cat 320CL Excavator	hrs	8	$175.00	$1,400
Decommission water supply wells	fill with concrete	each	2	$2,000.00	$4,000
Misc. Supplies & Tools	Misc.	L.S.			$500
Reclaim area	Seed and Fertilizer Application	ha	0.1	$1,500.00	$150
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	0.05	$1,500.00	$75
				Sub Total	**$10,562**
Explosive Magazines					
Reclaim area	Seed and Fertilizer Application	ha	0.1	$1,500.00	$150
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	0.05	$1,500.00	$75
				Sub Total	**$225**
Miscellaneous Buildings and Structures					
Remove salvageable equipment	Labourer	hrs	216	$35.58	$7,685
Remove salvageable equipment	Tradesman	hrs	216	$49.31	$10,650
Remove salvageable equipment	Cat 950H loader	hrs	150	$195.00	$29,250
Dismantle Building - Manpower	Labourer	hrs	216	$35.58	$7,685
Dismantle Building - Manpower	Tradesman	hrs	216	$49.31	$10,650
Dismantle Building - Equipment and Loading	Cat 320CL Excavator	hrs	40	$175.00	$7,000
Dismantle Building - Equipment and Loading	Crane	hrs	8	$195.00	$1,560
Concrete Demolition	Cat 320 Excavator + Hammer	hrs	40	$220.00	$8,800
Reslope, contour & bury	Cat D8N Dozer	hrs	60	$350.00	$21,000
Misc. Supplies & Tools	Misc.	L.S.			$2,500
Scrap haul to landfill	A30D Rock Truck	hrs	10	$300.00	$3,000
				Sub Total	**$109,780**
Industrial Reagents Fuels and Waste					
Industrial Reagents - truck to Swan Hills, AB	remove from site	tonnes	50	$100.00	$5,000
Industrial reagents - incineration cost	remove from site	tonnes	50	$3,000.00	$150,000
Remove Glycol from site	remove from site	trips	6	$5,000.00	$30,000
Fuels	remove from site	L.S.			$5,000
Wastes	remove from site	L.S.			$20,000
				Sub Total	**$210,000**
Spill Cleanup					
Concentrate load out area		L.S.			$15,000
Other building site contamination clean up		L.S.			$15,000

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost
				Sub Total	**$30,000**
Waste Rock Pads					
Move WRD #1 to TSF	Load, haul and place tailings cover (CIM)	m^3	34100	$7.00	$238,700
Reclaim WRD #1 footprint	Seed and Fertilizer Application	ha	0.6	$1,500.00	$900
Move WRD #2 to TSF	Load, haul and place tailings cover (CIM)	m^3	91000	$7.00	$637,000
Reclaim WRD #2 footprint	Seed and Fertilizer Application	ha	1.8	$1,500.00	$2,700
Remove liners and deposit in TSF	2 liners	L.S.	2	$8,000.00	$16,000
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	1	$1,500.00	$1,500
				Sub Total	**$896,800**
Stockpiles					
Reclaim temporary stockpile areas	Seed and Fertilizer Application	ha	2.4	$1,500	$3,600
				Sub Total	**$3,600**
Land Treatment Facility					
LTF decommissioning	Labourer	hrs	20	$44.21	$884
Move contents to landfill	A30D Rock Truck	hrs	10	$300.00	$3,000
Move contents to landfill	Cat 320CL Excavator	hrs	20	$175.00	$3,500
Reclaim footprint	Seed and Fertilizer Application	ha	0.4	$1,500.00	$600
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	0.2	$1,500.00	$300
				Sub Total	**$8,284**
Landfill					
Reclaim Landfill area	Seed and Fertilizer Application	ha	2	$1,500.00	$3,000
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	1	$1,500.00	$1,500
				Sub Total	**$4,500**
Mine Site Roads					
Lower road grade	Cat 14G Grader	hrs	60	$185.00	$11,100
Lower road grade	Cat 320CL Excavator	hrs	80	$175.00	$14,000
Lower road grade	A30D Rock Truck	hrs	80	$300.00	$24,000
Stabilize slopes	Cat 320CL Excavator	hrs	40	$175.00	$7,000
Culvert Removal (<1200mm)	uncover, remove and stabilize	each	15	$1,500.00	$22,500
Scarify	Cat D8N Dozer	hrs	70	$350.00	$24,500
Reclaim mine road footprints	Seed and Fertilizer Application	ha	7	$1,500.00	$10,500
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	3.5	$1,500.00	$5,250
				Sub Total	**$118,850**
Demolition Overhead					
Supervision	Site Supervisor	hrs	1000	$59.85	$59,850

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost
Office/Admin Costs	Contracts oversight	year	4	$5,000.00	$20,000
				Sub Total	**$79,850**
				Total	**$2,100,550**
				10% Contingency	**$210,055**
				Grand TOTAL	**$2,310,605**

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Table G-9: Access Road Decomissioning Costs

Work Item Description	Description	Units	Quantity	Unit Cost	Total Cost
Decommission and Reclaim Access Road					
Lower road grade	Cat 14G Grader	hrs	100	$185.00	$18,500
Lower road grade	Cat 320CL Excavator	hrs	140	$175	$24,500
Lower road grade	A30D Rock Truck	hrs	140	$300	$42,000
Stabilize cut/fill slopes	Cat 320CL Excavator	hrs	80	$175	$14,000
Culvert Removal (<1200mm)	Removal to offsite for re-use, resloping banks and armoring wetted section	each	69	$1,500	$103,500
Culvert Removal (>1200mm or multiple/location)	Removal to offsite for re-use, resloping banks and armoring wetted section	each	3	$5,000	$15,000
Culvert Crossing restoration work	Installation of environmental protection measures	L.S.		$20,000	$20,000
Bunker Creek Bridge Removal	Removal of bridge complete with bin-wall, resloping of banks	L.S.		$75,000	$75,000
Bunker Creek habitat restoration	Restoration in riparian zone and re-seeding	L.S.		$2,000	$2,000
Scarify	Cat D8N Dozer (24 km x 13 m)	ha	31.2	$500	$15,600
Permanent barrier at highway	Install trench and barricades	L.S.		$3,500	$3,500
Permanent barrier at Km 14	Install barricade to prevent interior access	L.S.		$1,500	$1,500
Recontour staging and roadside stockpile areas	Cat 320CL Excavator, Cat 14G Grader	L.S.		$20,000	$20,000
Borrow Sources-stabilize slopes	Cat D8N Dozer	hrs	30	$350	$10,500
Borrow Sources- revegetate	Seed and Fertilizer Application	ha	10	$1,500	$15,000
Revegetation of road surface + disturbed areas	Using ATV mounted applicator for seed and fertilizer	ha	37.5	$1,500	$56,250
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	18.75	$1,500	$28,125
Engineering 5%	For major components, particularly removal of bridge			5%	$23,248.75
Surveying 5%	For final as-builts of new contours and stream crossings			5%	$23,248.75
				Sub Total	**$511,473**
Reclaim Seepage Recovery Dam					
Seepage Dam Regrade and Contour	Cat D8N Dozer	hrs	16	$350.00	$5,600
Load, haul and place topsoil	Area of 8000 m^2 with 0.25 m depth	m^3	2000	$5	$10,000
Reclaim area	Seed and Fertilizer Application	ha	0.8	$1,500	$1,200
Reclamation maintenance after 1 year	Assume coverage of 50% with seed & fertilizer	ha	0.4	$1,500	$600
				Sub Total	**$17,400**
				Total	**$528,873**
				10% Contingency	**$52,887**

Grand TOTAL	**$581,760**

Table G-10: Site Management Costs

Work Item Description	Description	Units	Unit Cost	Decommissioning Phase (2020-2023)		Post-closure Phase (2024-2034)		Total Cost
				Quantity	Cost	Quantity	Cost	
Site Manager	Project Manager	month	$11,204	24	$268,896	-	-	$268,896
Camp Costs	per day per person	day	$100	8784	$878,400	-	-	$878,400
Site Caretaker	Security, camp operation, general maintenance (6 months per year for 4 years)	month	$8,853	24	$212,472	-	-	$212,472
Vehicles for security and manager	light-duty vehicle	month	$125	48	$6,000	-	-	$6,000
Site maintenance costs	general maintenance	year	$10,000	4	$40,000	-	-	$40,000
Flights	Whitehorse charter and commercial connections	flights	$3,855	53	$204,315	20	$77,100	$281,415
miscellaneous office/supply/costs	miscellaneous	year	$15,000	4	$60,000	-	-	$60,000
							Sub Total	**$1,747,183**
							Total	**$1,747,183**
							10% Contingency	**$174,718**
							Grand TOTAL	**$1,921,901**

Table G-11: Monitoring Costs

Work Item Description	Description	Unit Cost	Units	Decommissioning Phase (2020-2023)		Post-closure Phase (2024-2034)		Total Cost	Notes
				Quantity	Cost	Quantity	Cost		
Cycle 4 Biological Monitoring Study	Study Design Benthic & fish population sampling and analytical Interpretive report	$90,000	L.S	1	$90,000			$90,000	Required by September 2020. Study Design is required 6 months before study is conducted (i.e., April 2020). Interpretive Report Required to be submitted by December 5, 2020.
Final Biological Monitoring Study prior to Closing Mine	Final Study Design Final Biological Monitoring Studies (benthic and fish population) Final Interpretative Report	$90,000	L.S	1	$90,000			$90,000	Biological monitoring study must be completed during a 3 year period after the operator gives notice to ECCC that the mine is intended to be closed
EEM Sublethal Toxicity Testing	Fish species	$300	each	4	$1,200			$1,200	Once per year during discharge
	Invertebrate species	$215	each	4	$860			$860	Once per year during discharge
	Plant species	$200	each	4	$800			$800	Once per year during discharge
	Algal species	$200	each	4	$800			$800	Once per year during discharge
Surface Water Quality Analysis	Surface water quality sampling required monthly at all sites; and weekly at station W80 when discharging (May -	$225	samples/ year	304	$273,600	18	$40,500	$314,100	

Work Item Description	Description	Unit Cost	Units	Decommissioning Phase (2020-2023)		Post-closure Phase (2024-2034)		Total Cost	Notes
				Quantity	Cost	Quantity	Cost		
	October) during decommissioning. Annual sampling required at all sites post-closure.								
Groundwater Quality Analysis	Quarterly sampling at all sites required during decommissioning. Annual sampling at all sites post-closure.	$125	samples/ year	80	$40,000	13	$16,250	$56,250	
Metals in Vegetation analysis	Collection and analysis for metals in lichen, willow and horsetail		L.S	1	$11,340	1	$11,340	$22,680	If statistical increases in metal concentrations in plants are found, conduct metal analysis in small mammals (see 5.Contingency table)
Environmental Monitoring Consultants	Monthly/quarterly/annual sampling	$17,569	sampling period	48	$843,324	10	$175,693	$1,019,017	Monthly sampling during decommissioning; annual sampling post-closure
Environmental Consultant	Monthly/annual reporting	$130	hour	1920	$249,600	800	$104,000	$353,600	40 hours/month during decommissioning for monthly and annual reporting; 80 hours per year post-closure for annual reporting
Geotechnical Inspections	Annual tailings dam inspection	$20,000	year	4	$80,000	1	$150,000	$230,000	
	Dam Safety Review every 5 years	$80,000	each	1	$80,000	1	$80,000	$160,000	Assume declassification of the dam in post-closure

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Work Item Description	Description	Unit Cost	Units	Decommissioning Phase (2020-2023)		Post-closure Phase (2024-2034)		Total Cost	Notes
				Quantity	Cost	Quantity	Cost		
	Annual earthen structures inspection	$5,000	year	4	$20,000	1	$5,000	$25,000	
							TOTAL DECOMMISSIONING PHASE COSTS	$1,781,524	
							TOTAL POST-CLOSURE PHASE COSTS	$2,364,307	
							TOTAL PERMANENT CLOSURE COSTS	$4,145,831