6 Underground Mine

Table 6-1 provides a summary of the reviewer comments and the location of the response.

Table 6-1 Underground Mine Table of Conformance

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
6.1 Geological Context			
SRK Consulting	Section 2.4	**Geological Figures** A figure showing the location of the samples, the proposed mine workings and the geology would be very helpful in demonstrating whether the geochemistry database is spatially representative.	Section 6.1; Appendix C1-C3
Natural Resources Canada	Section 2.9.6.2 - 2.9.6.5	**Geochemical Modeling Software** What happens when mine is decommissioned with regards to elevated Se levels?	Sections 6.3 and 6.4; Appendix D
6.2 Mine Plan			
Environment Canada	Section 2.5	**Broken Ore on Floor** How quickly will the ore be removed from the floor – has there been consideration of interim ARD/ML leachate from these materials?	Sections 6.2 and 6.4; Appendix D
6.3 Underground Water Quality Model			
Environment Canada	Section 2.4	**Humidity Cell Testwork - Tailings** Provide the testwork data, relevant descriptions and methodology used, and basis for interpretations.	Section 6.3; Appendix D; Section 7; Appendix F2
Environment Canada; Environment Yukon	Section 2.4	**Humidity Cell Testwork & Geological Cross Sections** Data and interpretations from the new humidity cell test program needs to be presented, along with the supporting information to assess whether the information is of reasonable detail and coverage to adequately represent orebody/mine development. Cross-sectional representations indicating the source of sample intervals is one component necessary to support the geochemical information.	Sections 6.1 and 6.3, Appendix C2 - C3
Environment Canada	Section 2.4	**Underground Water Seepage** There appears to be no plan to accommodate metals reporting from underground seepage/flow in the long-term (beyond five years when decommissioning of water treatment facilities is projected). The ability to detect, to collect, and to treat contaminated groundwater for what may be a long time period has not been explored.	Sections 6.4; Appendix D
Environment Canada	Section 2.4	**Oxidization Reaction Rate** No data indicating what the reaction rate of the oxidizing of the underground rock will be.	Section 6.3; Appendix D
SRK Consulting	Section 2.4	**Iron Carbonates** YZC should determine the proportion of iron carbonate in the carbonates present in the samples.	Section 6.3; Appendix D

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
SRK Consulting	Section 2.4	**Humidity Cell Testwork– High Sulphur Sample** It is assumed the samples are composites of each lithology. A high sulphur sample from each lithology should be considered.	Section 6.3; Appendix D
SRK Consulting	Section 2.4	**Underground Flood Water Model with 2005 Humidity Cell Data** The model will have to be updated with revised data.	Sections 6.3; Appendix D
SRK Consulting	Section 2.4	**Flooded Underground Model** The assumptions used in the flooded underground model need to be substantiated. The laboratory data should be scaled to reflect the field conditions. Literature should be cited to support the 10% factor assumed to account for the reduced weathering rate due to cold conditions.	Sections 6.3; Appendix D
Natural Resources Canada	Section 3.4.3.3	**Mine Flooding** Mine flooding and water chemistry after 16 years is not predicted.	Sections 6.3 and 6.4; Appendix D
SRK Consulting	Section 2.4	**Modeling of Paste Backfill** The program will need to provide data on the behavior of the backfill during operations (in other words, determine the degree of oxidation during 14 years of air exposure) and closure (flooded conditions). The laboratory data will then need to be scaled to the field conditions in order to estimate the potential metal release.	Section 6.3; Appendix D
Environment Canada; Natural Resources Canada	Sections 2.4.6.2 and 2.5	**Paste Backfill Testwork** The use of alkaline materials in paste backfill will not necessarily reduce the potential for leaching trace elements.	Appendix D
SRK Consulting	Section 2.4	**Humidity Cell Data** Data from the 2005 program needs to be used in the revised modeling.	Section 6.3; Appendix D
Natural Resources Canada	Section 2.4; Section 2.9; Section 7.6	**Mine Water Quality** Mine water quality analysis is too preliminary. Consult relevant chemistry data for effluent from the 10-Level portal of Myra Mine.	Section 6.3; Appendix D
Natural Resources Canada	Section 2.9; Section 7.6	**Lack of Selenium Data in Humidity Cells** Humidity cells data presently do not include Se.	Section 6.3; Appendix D
Natural Resources Canada	Section 2.4; Section 2.9; Section 7.6	**Groundwater Quality at Closure** A comprehensive analysis of mine water quality is required to effectively determine the impact of the release of metal-laden waters on Wolverine Lake and /or Little Wolverine Lake. Associated mitigation plans are also needed for review. It is unknown if similar effects will be seen in the surface waters quality in Wolverine Creek	Sections 6.3 and 6.4
Natural Resources Canada	Section 2.4	**Sulphate-S Content** This data needs to be complemented with more detailed mineralogical information	Section 6.3; Appendix D

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
		on the two types of waste and an explanation for this occurrence.	
Natural Resources Canada	Section 2.9.4	**Thiosalts, Total Cyanide, Cyanate, and Thiocyanate** Detailed data should be provided to substantiate the claim that the concentrations of thiosalts, total cyanide, cyanate, and thiocyanate in the mill discharge or process water would decrease rapidly with time under field conditions.	Section 7.3; Appendix F2
Environment Canada	Section 2.4	**Kinetic Testing Program** Thirty-seven rock samples - it would be instructive to provide the reviewer with geologic cross-section representations of the spatial distribution of these rock samples in relation to the major lithologies discussed in the document.	Section 6.1; Appendix C1-C3
Natural Resources Canada	Section 2.9.6.2 - 2.9.6.5	**Geochemical Modeling Software** What happens when mine is decommissioned with regards to elevated Se levels?	Section 6.3; Appendix D
6.4 Hydrogeology			
Natural Resources Canada	Section 2.9; Section 7.6	**Portal Discharge During Post Closure** Impacted groundwater will discharge from the portal at a significant rate during the post closure period, once the mine has fully flooded.	Section 6.4.9
SRK Consulting	Section 7.6.2 – 7.6.3; Figure 7.6-4	**Portal Discharge During Post Closure – Hydraulic Plugs** Given the possibility of discharge, it is recommended that the portal(s) be fitted at closure with engineered hydraulically sealed hydraulic plugs.	Section 6.4.9
Environment Canada	Section 7.6.2 – 7.6.3	**Portal Discharge During Post Closure** The EAR suggests that the adit would not discharge post-closure. Were water levels taken prior to the advancement of the adit to determine baseline groundwater elevations?	Section 6.4.9
YTG - Environment Yukon	Section 7.6	**Portal Closure** A discussion of the environmental impact of surface versus ground water discharge on the Wolverine Creek watershed should be provided. The mitigation alternative(s) for a possible surface discharge is required.	Section 6.4.9
Natural Resources Canada	Section 2.9; Section 7.6	**Groundwater Inflow into the Mine & Sensitivity Testing** Proponent estimate of groundwater inflow to the mine may be understated, possibly by a factor of 2. The estimate of groundwater inflow should be provided with more complete supporting documentation, including analysis of its sensitivity to key parameters such as recharge rate and the host rock conductivities.	Section 6.4.8; Appendix E

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
SRK Consulting	Section 2.8.5; Section 7.6.2; Figures 7.6-5; 6; 2.7-2; and 7.6-1	**Groundwater Discharge Area** No potentiometric data were provided in the report for the numerous test holes and monitoring wells. A plot of the potentiometric data needs to be provided in the report with which to evaluate the amount of groundwater that is discharged to the local valley.	Sections 6.4.6 and 6.4.7; Appendices E1 and E7
SRK Consulting	Section 7.6; Table 7.6-3	**Identification of Flow Pathways** The geologic logs of the tested holes as well as logs from selected exploration drill holes should be provided and summarized in the report. Structures considered important barriers or conduits to flow should be identified.	Section 6.4.4 and 6.4.8; Appendix E1
SRK Consulting	Section 2.8.5. - 2.8.6	**Groundwater Discharge to the Tailings Basin.** The potentiometic data from the wells and test holes need to be evaluated.	Section 7.2
Environment Canada	Section 2.8	**Groundwater Gradients in the Tailings Impoundment** It is possible that the loadings from the tailings (considering a water cover as well) can lead to a reversal of the hydraulic gradients, with the resultant being the area becoming a local recharge zone and vulnerable to impacts from tailings porewater.	Section 7.6.4
SRK Consulting	Section 7.6.4.2	**Hydraulic Significance of Mine Openings After Closure** Controls at closure, such as bulkheads, hydraulic plugs, and strategically placed paste backfill should be considered to lessen the risk that acid waters will be generated and/or discharged.	Section 6.4.9
Environment Canada	Section 7.6	**Lack of Data and Detailed Methodology** There is no data presented to show how the bedrock hydraulic conductivities were achieved. The borehole logs and well completion details should be provided.	Section 6.4.6; Appendix E1
YTG - Environment Yukon	Section 7.6.2; Figure 7.6-4	**Conceptual Hydrogeology Model Development** Figure 7.6-4 illustrates the effect of summer rainfall on groundwater level trends. The effects of spring snowmelt should also be assessed.	Section 6.4.6
Environment Canada	Section 7.6	**Bedrock Hydraulic Conductivity** What method was used to determine the hydraulic conductivity i.e. were rising and falling head tests performed or was the value based on one single test?	Section 6.4.4
Environment Canada	Section 7.6	**Hydrostratigraphic Units** There is a need to show where the hydrostratigraphic units are in comparison to the test depth intervals to show the relation between the units and the measured hydraulic conductivity values and the assigned values of each unit.	Section 6.4.4

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
Environment Canada	Section 7.6	**Methodology and Calibration** The cross-sections and flownets shown are drawn based on very little data - where is the calibration data for the piezometers? Were they calibrated in the field or by the manufacturer?	Sections 6.4.3 and 6.3.4; Appendix E4
Environment Canada	Section 7.6	**Vibrating Wire Piezometers** What geological units were the vibrating wire piezometers installed in? What are the details of the installations? No information on the core logs are given, no rock quality descriptions are provided, no fracture assessment or fracture trace analysis is provided.	Sections 6.4.3 and 6.3.4
Environment Canada	Section 7.6	**Groundwater Levels** What other known groundwater levels were used in the conceptual model?	Section 6.4.4
Environment Canada	Section 7.6	**Wolverine Creek Groundwater Discharge** What was the depth of installation of piezometers that were artesian? Does all groundwater discharge to Wolverine Creek?	Section 6.4.4
Environment Canada	Section 7.6	**Core Logs** Were the cores logged to provide a visual inspection of any breaks or fractures such as open fractures or closed fractures or fractures that have been sealed or any chemically altered fractures evident by FeOHx or MnOHx staining? Were the fractures mainly structural or bedding plane fractures?	Section 6.4.4
Environment Canada	Section 7.6	**Ammonia in PZ-A** Why would PZ-A have ammonia concentrations similar to the portal faces where one would expect there to be some interference from blasting?	Section 6.4.5
Environment Canada	Section 7.6	**Goodman Equation** All limitations of this equation should be provided.	Section 6.4.8
Environment Canada	Section 7.6	**Fracture Flow** There would need to be an estimate on fracture aperture and quality.	Section 6.4.4
Fisheries and Oceans Canada	Section 7.6, 7.7, 7.8	**Mine Dewatering Activities and Flow Monitoring** The productive habitat of Wolverine Creek may be reduced during low flow periods and in the winter. A contingency plan needs to be identified.	Section 6.4.9

6.1 Geological Sampling Methodology

The 2005 program required that the major lithologies of the Wolverine deposit be tested for Acid Rock Drainage (ARD), Acid Base Accounting (ABA) and metals. Humidity cells were established to determine the long range effects on the deposit lithologies. Four suites of samples of the six major lithologies were submitted for analysis during 2005. The sampling of drill core for environmental purposes is outlined in detail, including pictures, sample intervals, drill hole information and rock descriptions in Appendix C1. To supplement the ARD sampling report there is a map of the sampled drill holes and eleven geological sections across the deposit in the map pocket of Appendix C2 and C3, respectively.

1. The first sampling program occurred in March and consisted of 31 core samples that represented an equal selection of the six major lithologies and one additional lithology. This additional lithology represents a minor percentage of the Wolverine deposit and is commented on below. The core was sampled from 30 drill holes that were chosen to have a representative distribution across the deposit (Appendix C2), and was used for ARD and metals testing.
2. The second program in August was used for ABA and metals testing. Six samples of unoxidized material were collected. Five of the samples were obtained from recently advanced drill holes and one sample comprised of underground material was taken from an underground muckpile. The EXCP (rock type 3) muckpile was undisturbed after blasting and located within the main decline. A map of the underground workings showing the occurrence of the EXCP unit is found in the map pocket of Appendix C2.
3. In October, 25 core samples were obtained from two drill holes. Only five of the six lithologies were sampled as there was not any interbedded argillite/ rhyolite (type 2) in the drilled holes. The rock material from this core had undergone minimal oxidization as they were drilled earlier in October 2005.
4. A sample program for the humidity cell test work was undertaken during late October and early November, 2005. A total of 19 discrete samples were acquired from the underground mine and one of the recent drill holes for test work. Four of the six major lithologies were collected from the underground workings during the final phase of the 2005 test mine program. Eighteen samples were collected from thirteen sample locations as shown on the map of the underground workings in Appendix C2. Although, the sample locations cannot be directly referenced with the samples, the samples were representative of the lithologies accessible in the test mine workings. The magnetite iron formation (type 4) was sampled from a drill hole in early November. The drill hole data and all the iron formation intercepts for this hole are available in Appendix C1. The sample interval is not specifically known; but is from one of the two thick magnetite iron formation intersections within this drill hole. The type 5 lithology, interbedded argillite/ rhyolite did not show in the test mine and was not available to be sampled from drill core. Although, this lithology was not tested, it is comparable to the argillites (non-carbonaceous, type 1).

As described in the EAR, the Wolverine deposit was established to have six main lithologies as shown in Table 6.1-1. An andesite grouping was originally included with the six lithologies. The andesite lithology describes the Campbell Range greenstones that occur in the upper stratigraphy of the deposit. Later, this lithology was removed from the list of majors as it occurs high enough in stratigraphy that it would not be encountered within the underground workings. However, the first ARD sampling suite from March 2005 analyzed three samples of the andesite lithology before this lithology was removed from the list. These samples can be ignored for purpose of this assessment. The sample tags of the andesite lithology samples are A083506, A083521 and A083527.

It should also be noted that the original listing had the andesite lithology as rock type 6 and the rhyolite lithology as rock type 7 as shown in Table 6.1-2. All results for analyses presented in the EAR and subsequent responses to reviewer comments use rock type 6 for the rhyolite lithology.

Table 6.1-1 Major Lithology Types for Wolverine Deposit with Rock Type Numbering

Rock Type	Lithology	Description
1	**Argillites (non-carbonaceous)**	Aphanitic, hard, siliceous (cherty) black argillite. Often with minor tuffaceous component.
2	**Carbonaceous argillites**	Aphanitic, massive, carbonaceous to strongly graphitic black argillite. May or may not contain significant amounts of carbonate.
3	**Calcite-pyrite exhalite**	Distinctive unit containing up to 30% fine grained pyrite within a matrix of white calcite, both occurring as swirly cm scale bands. Always occurs in the proximal hanging wall to the sulphide zone in the Wolverine stratigraphy, and is also common in the Fisher Zone.
4	**Magnetite iron formations and Silica-pyrite exhalite**	Magnetite iron formation, commonly ranges from 10 to 80 % disseminated to banded magnetite within a fine grained siliceous matrix. Silica dominated exhalite or chert with or without pyrite and/or calcite. Often chloritic and usually well banded. Addition of small amounts of fine carbonaceous sediments form a dark grey to black variety of this unit.
5	**Interbedded rhyolite/argillites**	Intimately interbedded black argillite (carbonaceous, siliceous, tuffaceous) and massive to tuffaceous rhyolite. Ranges from cm scale interbeds to mm scale argillite bands within massive rhyolite.
6	**Rhyolite and rhyolite fragmentals**	Grey rhyolite with distinctive fragmental texture defined by wispy sub mm dark green to black anastasmosing sericitc bands separating cm size felsic "fragments". Fragments are typically sub angular and irregularly shaped with jagged boundaries.

Table 6.1-2 Original Listing of Major Lithology Types for Wolverine Deposit

Rock Type	Lithology	Description
1	**Argillites (non-carbonaceous)**	Aphanitic, hard, siliceous (cherty) black argillite. Often with minor tuffaceous component.
2	**Carbonaceous argillites**	Aphanitic, massive, carbonaceous to strongly graphitic black argillite. May or may not contain significant amounts of carbonate.
3	**Calcite-pyrite exhalite**	Distinctive unit containing up to 30% fine grained pyrite within a matrix of white calcite, both occurring as swirly cm scale bands. Always occurs in the proximal hanging wall to the sulphide zone in the Wolverine stratigraphy, and is also common in the Fisher Zone.
4	**Magnetite iron formations and Silica-pyrite exhalite**	Magnetite iron formation, commonly ranges from 10 to 80 % disseminated to banded magnetite within a fine grained siliceous matrix. Silica dominated exhalite or chert with or without pyrite and/or calcite. Often chloritic and usually well banded. Addition of small amounts of fine carbonaceous sediments form a dark grey to black variety of this unit.

Table 6.1-2 Original Listing of Major Lithology Types for Wolverine Deposit (cont'd)

Rock Type	Lithology	Description
5	**Interbedded rhyolite/argillites**	Intimately interbedded black argillite (carbonaceous, siliceous, tuffaceous) and massive to tuffaceous rhyolite. Ranges from cm scale interbeds to mm scale argillite bands within massive rhyolite.
6	**Andesites**	Medium green massive, fine grained andesite. Interpreted as flows where massive and volcaniclastic where laminated.
7	**Rhyolite and rhyolite fragmentals**	Grey rhyolite with distinctive fragmental texture defined by wispy sub mm dark green to black anastasmosing sericitc bands separating cm size felsic "fragments". Fragments are typically sub angular and irregularly shaped with jagged boundaries.

6.2 Mine Plan

The sections below describe the updated mine plan and mining method. Based on the revised methodology and configuration, the material balance has been updated and is presented in Figure 6.2-1. Quantities are provided in million tonnes (Mt).

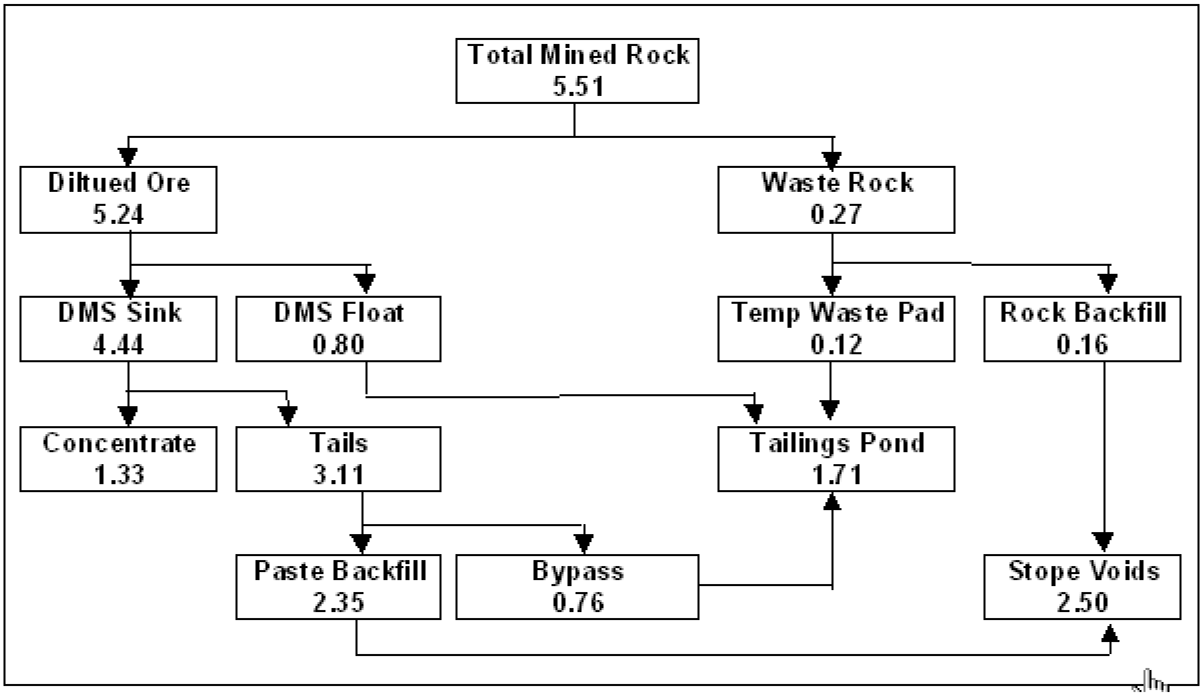

Figure 6.2-1 Revised Mine Material Balance (Mt)

6.2.1 Mining Method

The revised mine plan is shown in Figure 6.2-2 and Figure 6.2-3 in plan and section views, respectively. The main ramp is located between the Lynx and Wolverine deposits (shown as the Barrier Pillar zone) and is primarily located in ore (development in ore is in pink). The stopes are also located within the ore, while the pre-production development ramp (in light blue), portal entrances, diamond drill drifts (green) and ventilation raises (dark blue) are located in hanging wall. The test mine development completed in 2005 is shown in green and the pre-production ramp is light blue. The fresh air raise is shown in red and the return air raises are shown in dark blue.

The stope access crosscut will be located at the center between the orebodies in the barrier pillar zone. A stope drift will be driven in ore along the footwall contact from the stope access crosscut parallel to the strike in both directions through the two ore bodies to the economic extremities of the two ore zones. The sequencing of mine development at the end of 2010, 2015, 2018 and at the end of mining are presented in Figure 6.2-4 to Figure 6.2-7.

For a typical stope lift, the footwall stope drifts will start in the thinner ore of the barrier pillar zone centrally located between the two orebodies. This ore will be left as a barrier pillar to protect the main ramp until the ramp is no longer needed. Ultimately, it will be recovered, or partially recovered using drift and fill with side slash (DFSS).

Figure 6.2-2 Wolverine Mine Development Plan (Figures Section)

Figure 6.2-3 Life of Mine, Elevation Looking Northwest (Figures Section)

Figure 6.2-4 Status of Mine End of 2010 (Figures Section)

Figure 6.2-5 Status of Mine End of 2015 (Figures Section)

Figure 6.2-6 Status of Mine End of 2018 (Figures Section)

Figure 6.2-7 Status of Mine End of Mining (Figures Section)

The ore will thicken as the stope drift advances toward the centers of either orebody then taper again toward the extremity of each stoping lift, ultimately to a non-economic thickness. As such, regular transitions will be made between the stoping methods along a stoping lift in response to changes in ore thickness.

The stopes will be mined in 4 m high horizontal lifts from footwall to hangingwall, and backfilled with paste backfill and loose waste from the development program. The mining direction will be up-dip. When one lift is mined and filled, the next will be mined at an elevation 4 m higher and the backfill of the previous lift will form the floor of the stope. Each stope will be comprised of 5 x 4 m lifts (Figure 6.2-2 and 6.2-9).

A simplistic plan view of each lift can be represented by an elongated barbell, bulging out for both the Lynx and Wolverine orebodies, with a thinner portion of ore connecting them (the barrier pillar zone.) The extremities of both orebodies appear to taper in ore width. The mine will operate numerous 4 m high stoping lifts simultaneously. As many as four lifts will be active simultaneously. A system of raises and crosscuts will be excavated in the hangingwall of the deposit between stoping levels. These will be used for ventilation and emergency egress.

Drift and fill is the mining method selected for the project. Three distinct variants of the drift and fill mining will be employed: Drift and Fill with a Side Slash (DFSS), Drift and Fill with Retreat Panels (DFRP), and Drift and Fill with Primary and Secondary Panels

(DFPS). Mining method selection will be determined by horizontal ore thickness, as shown in Table 6.2-1.

Table 6.2-1 Selection of Mining Method by Ore Thickness

Horizontal Ore Thickness (m)	Mining Method
>7	Drift and Fill with Side Slash (DFSS)
4 to 7	Drift and Fill with Retreat Panels (DFRP)
<4	Drift and Fill with Primary and Secondary Panels (DFPS)

Figure 6.2-8 shows the three mining methods on cross-sectional view and Figure 6.2-9 shows the sequencing of the three methods for a typical stope lift.

The primary reasons for selecting these mining methods are as follows:

- A high percentage extraction of the deposit can be achieved as no permanent pillars are required and thinner zones are mineable.
- Most of the mining backs will be in ore, providing a competent back for most stope headings.
- The poor ground of the hangingwall will have minimal exposure, controlling external dilution and enhancing safety for the workers.
- High productivity can be maintained due to multiple working faces.

Figure 6.2-8 Typical Stoping Level Sequence (Figures Section)

Figure 6.2-9 Typical Stoping Level Detail (Figures Section)

6.2.2 Drift and Fill with Primary and Secondary Panels (DFPS)

For wider zones of ore (> 7 m horizontal thickness), the footwall stope drift will be driven 4 m wide in ore along the footwall contact of the ore. Stoping panels will then be excavated at 4 m widths from the footwall stope drift in a “herringbone” fashion at an angle of approximately 45º to the footwall stope drift. These panels will be driven into and expose the argillitic hangingwall contact.

The panels will be extracted using a primary and secondary sequence. The primary panels will be mined first with solid ore backs and walls. These will then be tight-filled with waste rock and paste backfill. The fill bulkheads will be placed as close to the footwall stope drift as possible to minimize the unsupported span. The secondary panels will then be mined between the backfilled primary stopes, with ore in the back and the exposed backfill of the two adjacent primary panels as walls. The secondary panels will then also be filled as tightly as possible. This will be done in a retreat fashion, filling the footwall drift simultaneously.

The hangingwall is primarily composed of very poor graphitic argillite and excessive dilution is anticipated at the ends of the herringbone panels once it is exposed. It is possible that the last round will be drilled and blasted to double length with extension steel such that the ore is completely blasted without having to control the back. The drift end will be mucked as completely as possible, using a remote controlled scooptram if required. Continuous unravelling of the hangingwall is anticipated. Mucking will continue until dilution is excessive, rendering the muckpile uneconomic, at which point the panel will be closed for filling.

Panels will be paste backfilled individually, which has the potential to be a finicky and tasking exercise due to the numerous bulkheads required and the small size of each individual pour. This will be mitigated by using pre-fabricated mechanical bulkheads designed such that they can be placed and sealed rapidly and recovered after the pour for later use. This process will also allow more complete backfilling of each individual panel than a muckberm and fill fence system, enhancing the stability of the stope by minimizing the open span.

6.2.3 Drift and Fill with Retreat Panels (DFRP)

For ore 4 to 7 m horizontally thick, the method will be modified by extracting the panels one at a time in a retreat fashion rather than using a primary and secondary sequence.

The first panel will be mined at the furthest extent from the access then it and that portion of footwall drift will be backfilled. After curing for a period of 3 to 7 days, the next adjacent panel will be mined, exposing the backfill of the previous panel along the floor. In this fashion, the stope will incrementally retreat towards the stope access.

The backfill bulkhead for each stope pour will be placed in the footwall drift and both the panel and a portion of the footwall drift will be filled.

6.2.4 Drift and Fill with Side Slash (DFSS)

For ore less than 4 m horizontally thick, the ore will be mined in two separate passes. The first will include drifting along the footwall to the extent of mineable ore. Upon reaching the economic extent of the stope, the mineralized wall will then be slashed using horizontal drill jumbo holes starting at the end of the stope and incrementally retreating toward the stope access. The hangingwall exposed by the slashing will not be bolted. As such, the broken ore will be mucked remotely and no access will be allowed in the slashed area.

The maximum width of DFSS stopes will be determined by the reach of the jumbo drill. A 4 m drill steel is assumed, limiting this mining method to a maximum horizontal ore thickness of 4 m at the average dip of 34º.

The individual blasts will range in strike length exposure; 6 to 8 m is assumed. When the exposed hangingwall inside the stope becomes unstable, which will be primarily dependent on the length of exposure, a bulkhead will be placed in the footwall drift and the stope void will be filled as tightly as possible with paste backfill.

The mining method will be determined on the basis of ore thickness, as shown in Table 6.2-1. During operations, testholes will be drilled regularly in the backs and walls of the footwall stope drifts as they are driven to locate the hangingwall contact and determine the ore thickness. This will assure stope back competence and help set the transition points from one stoping method to another. Assaying the cuttings from the testholes will not be required, as the ore/waste hangingwall contact will be defined by the cuttings colour and penetration rate.

6.3 Underground Water Quality Model

The objective of this section is to summarize analytical findings to date on the static and kinetic geochemical testing of mine rock types, and to present the prediction of the mine water quality expected at closure of the mine. The complete report that presents all findings and aspects of the water quality model is contained in Appendix D.

Six major rock types were identified in the deposit, consisting of varieties of argillites, exhalites and rhyolites as described in Section 6.1. All analyses discussed herein were conducted during two programs in 1996-97 and 2005-06. Static test analyses included acid-base accounting, ICP metal scans on the sample solids, shake flask extraction tests and mineralogy using XRD. Kinetic testing included four humidity cells operated in 1997, and the ongoing operation of 19 humidity cells initiated between December 2005 and February 2006 (Appendix D).

Based on the analytical results, the major findings of the ARD/ML assessment work are as follows:

- Sobek-NP exceeded carbonate-NP for all rock types except type 4 (iron formation and silica-pyrite exhalite) suggesting that type 4 samples contain some iron-rich carbonates (e.g. siderite and/or ankerite) that do not contribute to alkalinity.
- Average NP:AP ratios ranged from 0.13 to 2.37 indicating that the mine rock at the site is acid generating to possibly acid generating.
- The average total concentrations of Ag, Sb, As, Cd, Cu, Mo, Pb, Zn and Se in the rock samples were higher by at least one order of magnitude, compared to average crustal abundances.
- The average concentration of Al, Fe, Ca, Mg, Na, K, P and Ti were less than average crustal abundances.
- The concentrations of S in all rock types exceeded background concentrations.
- All measured concentrations for As, Cu, Pb, Ni and Zn in shake flask extracts were much lower than the Metal Mining Effluent Regulation (MMER) concentrations.
- The concentrations of As, Zn, Mo, Cr, Ni and Hg in the shake flask extracts were below CCME guidelines for the protection of aquatic life
- The concentrations of Cd, Cu, Pb and Se in extracts from most samples exceeded CCME guidelines for the protection of aquatic life
- The concentration of Se did not exceed effluent discharge objectives of 0.5 mg/L for the Province of British Colombia (Price, 1997).

A water quality model was developed to predict the expected metal concentrations of the flooded mine at closure. The model utilized the current mine plan and available geochemical data to predict the loads of metals that may be released into the mine once it floods. The model used conservative assumptions regarding the geochemistry of the mine in order to provide a ‘worst-case’ estimate of the mine water quality. The unequilibrated ‘Mass-Loading’ estimate was assessed using the MINTEQA2 program to estimate equilibrium concentrations in the mine water following flooding.

Based on the findings of the water quality prediction, elevated concentrations of metals are predicted to occur in the mine water following flooding of the mine. The predicted Mass-Loading and Base Case concentrations were used to represent the potential range of concentrations expected in the mine following closure, and are summarized in Table 6.3-1 below:

Table 6.3-1 Predicted Mass-Loading and Base Case Concentrations at Closure

Parameter	Mass-Loading Model (mg/L)	Base Case Model (mg/L)
Sulphate	776	852
Aluminum	1.16	0.001
Arsenic	0.275	0.277
Cadmium	0.0537	0.0560
Copper	0.358	0.020
Iron	5.10	0.00001
Lead	0.459	0.045
Molybdenum	0.099	0.096
Nickel	0.635	0.632
Selenium	0.509	0.505
Silver	0.161	0.161
Zinc	6.06	1.50

The predicted concentrations are similar to those observed at existing mine sites with a similar geological and mineralogical setting. Equilibrium modeling of the predicted (mass-loading) concentrations suggests that expected metals concentrations will be reduced due to solubility constraints on several of the metals, namely Al, Cu, Fe, Pb and Zn. However, this reduction is pH dependent and will occur only at circum-neutral pH values.

The model utilizes worst-case assumptions and is therefore highly conservative. As a result, concentrations at closure may be significantly lower than predicted by the model. Conversely, some geochemical factors not accounted for in the model could result in increased metal loads to the mine water at closure.

Ongoing laboratory and field monitoring will be used to further refine the water quality estimate. Laboratory testing of humidity cells containing representative samples of mine rock, ore, float rock and backfill will be used to determine the metal release and oxidation rates for the mine materials. As detailed in Appendix D, on-site monitoring and studies will be utilized to refine the geochemical rates and estimates of mine water quality at closure. Section 6.4.9 describes the groundwater and surface water interaction and proposed monitoring with respect to Wolverine Creek.

6.4 Hydrogeology

6.4.1 Introduction

This section provides an update to EAR Section 7.6 and presents the details of the mine area hydrogeology field program and subsequent data interpretation. The study was designed to determine baseline hydrogeological conditions in the area of the mine footprint, estimate mine inflows using analytical methods and predict potential environmental impacts. The mine groundwater study area is shown in Figure 6.4-1.

Figure 6.4-1 Groundwater Study Plan (Figures Section)

6.4.2 Study Objectives

The primary goal of the hydrogeology field program was to provide site-specific information relating to deep groundwater pressures (elevations) and bedrock hydraulic conductivity (permeability). This data is required to estimate potential groundwater flow into the proposed underground mine.

The primary objectives of the hydrogeological characterization program were as follows:

- Determine the hydraulic conductivity of the bedrock surrounding the Wolverine and Lynx ore bodies using packer tests during the advancement of two exploration boreholes.
- Determine the pre-mining groundwater pressures/elevations and vertical gradients in bedrock surrounding the proposed underground mine by installing vibrating wire piezometers equipped with dataloggers in two exploration boreholes.
- Develop an estimate of mine inflows using analytical methods to support the development of the water balance.
- Identify groundwater recharge and discharge areas and use meteorological data to estimate recharge rates that may be anticipated at the site.
- Collect preliminary groundwater samples from two exploration boreholes to help quantify baseline deep groundwater quality.

6.4.3 Field Methodology

6.4.3.1 Borehole Packer Testing Procedure

Borehole drilling was observed at two exploration boreholes drilled during April 2005. The borehole locations were selected to provide continuous geologic and hydrogeologic information about the bedrock surrounding the proposed Wolverine underground mine. Drill core was inspected for features that may have an impact on groundwater flow including fault gouge and zones of low Rock Quality Designation (RQD). Gartner Lee staff reviewed exploration borehole logs and photographs of the rock core, focusing on features that may have the potential to impact on mine inflows. YZC’s drillhole logs for WV05-156 (PZ-A) and WV05-155 (PZ-B) are included in Appendix E1.

Packer testing was carried out using nitrogen-inflated bladder packers and apparatus supplied by RST Instruments Ltd. of Coquitlam, BC. A description of the packer testing equipment and standard procedure for packer testing is presented in the RST Instruments Borehole Packers Instruction Manual, included in Appendix E2. Site-specific packer testing methodology is described below:

a) A single-packer system (consisting of one packer inside and one packer outside of the drill rods) capable of testing an interval from approximately the depth of the drill bit to the bottom of the open borehole was used to carry out all but one of the packer tests. One packer test was conducted at PZ-B using a double-packer system; however, ground conditions and the consequent uncertainty surrounding seal integrity led to the adoption of single-packer tests for all subsequent testing. The system included instrumentation that measured injection pressure and flow into the bedrock test interval sealed off by the packer assembly. Nitrogen-inflated, NQ-sized (2-63/64"; 75.7 mm) bladder packers were used to seal off borehole intervals for testing.

b) After an interval of borehole had been drilled, the drill rods were partially withdrawn so that the drill bit was at the top of the desired test interval. Upon arrival of Gartner Lee staff at the Site, drilling of WV05-155 (PZ-B) was nearly complete. A double-packer test was conducted in an attempt to generate a hydraulic conductivity profile of the borehole; however, the inclination of the borehole and bedrock conditions did not permit the efficient use of a double-packer assembly. As a result, single-packer tests were used for the remainder of the packer testing program. Packer testing intervals were selected based on a review of geologic units, rock core and fracture zones. Packer testing fairly large intervals was necessary because of the borehole depth (to ensure coverage with limited time for testing) and difficulty encountered in sealing discrete intervals above the bottom of the borehole (inclined boreholes are better suited for single packer tests sealed from below the drill bit to the bottom of borehole).

c) Prior to each test, fresh surface water was circulated for approximately 45 minutes to flush drilling fluids and cuttings from the borehole. A stuffing box was installed on top of the drill rods so that the drill rods could be used to convey water to the test interval. The packer assembly and nitrogen line were lowered into the borehole using the drill wireline. A cable counter and knowledge of bit depth was used to record the location of the packer assembly and verify that the assembly was seated on the drill bit and a packer extended below the drill bit prior to beginning packer inflation. The drill rods were filled with clean water before sealing the stuffing box.

d) Minimum required inflation pressures were calculated based on the packer depth, static water level and recommended packer operating pressures. The packers were inflated slowly in 100-200 kPa increments, allowing time for pressures to equilibrate. The drill rods were then refilled with water and the stuffing box was tightened. It was determined that that packers were properly inflated and sealed after approximately five minutes of injecting water with no return flow up the casing. This confirmed that the packer outside the bottom of the borehole had fully inflated and isolated the bedrock test interval below the bottom packer.

e) Generally, three to five constant head tests were conducted at up to three different pressures, with the first and the fifth tests and the second and the fourth tests being conducted at the same pressures. This allowed for the evaluation of hysteresis in the relationship between injection pressure (head) and flow (take). Prior to each test, the bypass valve was adjusted to achieve the target injection pressure. Pressure was monitored throughout the test and adjusted as required to maintain a constant injection pressure (head). Using an analog flow meter and pressure gauge, flow was monitored at each pressure for between five and 15 minutes, or until flow readings stabilized.

f) When all tests at a specific interval were completed, the packer assembly was deflated and the packer assembly and nitrogen line were removed from the borehole, followed by the stuffing box. Each test took approximately five hours including borehole flushing, drill rod preparation, lowering and inflating the packer assembly, deflation and removal.

g) Field data was tabulated and subsequently analyzed using the Thiem equation to obtain estimates of hydraulic conductivity for each test interval.

6.4.3.2 Vibrating Wire Piezometer Installation

The following is a summary of the vibrating wire (VW) piezometer installation technique:

1. Each VW piezometer and datalogger was verified to be in working order prior to installation. In addition, calibration factors input into the datalogger were confirmed with the calibration documents supplied by the manufacturer for accurate readings. The datalogger instruction manual is provided in Appendix E3.
2. Upon completion of borehole drilling and packer testing, the fluid within the borehole was replaced with fresh water and the drill rods were removed.
3. The VW piezometers were pre-saturated with water and taped to the HDPE tubing upside down to ensure no air was entrapped in the porous membrane. The VW piezometer and cable were attached to 1” diameter HDPE tubing and lowered into the borehole. All wiring was measured as it was lowered down the borehole to enable determination of the installation depth. To verify the installation depth, the piezometer readings and knowledge of the static water level were compared to the calculated vertical depth based on measurements of the length of cable inserted into the borehole.
4. When the installation depth was reached, the VW piezometer was again verified to be functioning. The piezometers were grouted in place using a cement/bentonite grout mixture (Mikkelson and Green 2003). Grouting occurred over two-stages in order to ensure that the pressure tolerances specified by RST Instruments were not exceeded. Throughout the grouting procedure, pressures were monitored using either a vibrating wire readout box or a laptop computer. After each grouting event, the grout was allowed to cure for 12-24 hours prior to adding more grout to the borehole. The HDPE tubing was secured at surface to support the VW piezometer during grout curing. The stabilized piezometer pressure measurements (after grout curing) are considered to be representative of in-situ groundwater pressure at the installation depth.
5. The piezometer leads were secured at surface in the protective stickup casing and connected to dataloggers. Each datalogger was then downloaded and correct logging parameters were confirmed according to the VW piezometer calibration documents supplied by RST Instruments, (included in Appendix E4). The dataloggers recorded measurements of groundwater pressure as groundwater levels responded to test mining activities (e.g., dewatering) and as groundwater levels rebound following cessation of test mine dewatering. Downloaded piezometer data will be available to calibrate drawdown and inflow predictions.

6.4.4 Data Interpretation

6.4.4.1 Geological and Hydrogeological Observations

Location and physical characteristics of boreholes WV05-156 (PZ-A) and WV05-155 (PZ-B) that were targeted for permeability testing and instrumentation are summarized in Table 6.4-1-1 and shown on Figure 6.4-2. Ground surface elevations were measured using a global positioning system (GPS) and verified using mapping and 5 m contour intervals based on known UTM coordinates for the borehole collars. Based on UTM coordinates, PZ-A and PZ-B are located approximately 360 m apart.

Table 6.4-1 Summary of Borehole Information

Borehole Name	UTM Coordinates (NAD 27)		Surface Elevation	Borehole Length	Borehole Azimuth at Collar	Borehole Dip at Collar
	Northing (m)	Easting (m)	(m ASL)	(m)	(degrees)	(degrees)
WV05-156 (PZ-A)	6811111	439851	1393	194.2	90	-75
WV05-155 (PZ-B)	6810835	440085	1389	198.4	215	-85

Figure 6.4-2 Conceptual Hydrogeologic Model Plan (Figures Section)

YZC's borehole logs for WV05-156 and WV05-155 were reviewed for indications of geologic features that could contribute to increased groundwater flow. A summary table including depths and descriptions of notable hydrogeologic features is presented in Table 6.4-2.

Bedrock Fracture and Fault Gouge Occurrence

The presence of faults could increase mine inflow as a result of preferential groundwater flow. All indications of fracturing and fault gouge noted in borehole logs for WV05-156 (PZ-A) and WV05-155 (PZ-B) were inspected. Geotechnical logs for both boreholes showed that RQD values were most commonly 0%, and generally did not exceed 30%; however, occasional zones of higher RQD (70 – 100%) were noted. RQD values higher than 30% were rarely observed. Based on core from WV05-156 and WV05-155, fractures, faults and shear zones are wide (up to 18.3 m thick) and predominantly infilled with thick clay-sized gouge. On average, zones noted as fault zones or fault gouge were less than 4 m in thickness in borehole logs for WV05-156 (PZ-A) and WV05-155 (PZ-B). Bedrock is highly fractured with low competency and bedrock often crumbles in hand specimen. Discrete fractures capable of conducting large volumes of groundwater were not observed/preserved in core samples, nor were there any signs of oxygenated groundwater flow at depth. No significant faults or fractures capable of conducting large quantities of water were intersected by either of the boreholes that were tested.

Table 6.4-2 Summary of Notable Features from Core Log Descriptions

Borehole Name	Depth From (m)	Depth To (m)	Description of Notable Features Taken From Core Logs
WV05-156 (PZ-A)	17.4	18.9	Poor recovery, concave fracture.
	19.0	25.0	Minor thread-like rusty fractures, very broken and blocky.
	30.0	31.68	Fault gouge.
	31.68	32.7	Highly fractured. Fractures have a preferred orientation from 70-80° but go to 45° near 32.5 m.
	32.9	38.7	Fault gouge at end and among any fragments of this unit.
	47.6	50.2	Large angular pieces of chert in fault gouge.
	69.2	72.0	Very poor recovery.
	75.3	76.0	Very poor recovery.
	76.0	76.25	Very broken and blocky.
	76.25	76.5	Clay-rich fault gouge of the unit below.
	76.55	81.3	Very rubbly core.
	86.3	88.9	Very broken with poor core recovery.
	92.6	95.7	Very broken and blocky; very little recovery.
	95.7	97.8	Broken and blocky, especially at the end.
	97.8	101.0	Poor recovery and clay fault gouge throughout.
	108.1	108.6	Broken and blocky, fault gouge in part.
	111.3	111.6	Fault gouge.
	111.6	114.35	Very poor recovery.
	116.1	116.4	Crushed core and fault gouge.
	130.75	130.8	Broken, graphitic, minor fault zone.
	145.4	163.7	Virtually no recovery.
	165.55	166.1	Clay-rich adjacent to fault zone.
	166.1	166.5	Graphite clay matrix. Fault zone.
	169.2	169.4	Small fault zone.
	171.4	171.6	Poor recovery, partly fault gouge.
	191.1	194.2	Very little recovery.
WV05-155 (PZ-B)	29.6	44.8	Intensely broken, very poor core recovery.
	44.8	51.4	Very blocky and broken.
	65.4	68.6	Localized zones intensely fractured.
	72.2	87.2	Broken, pebbly, poor core recovery, blocky.
	90.1	97.5	Rock is competent but intensely broken in local intervals due to lineations perpendicular to bedding.
	97.5	105.3	Moderate fracturing, all breaks along smooth foliation planes into discs.
	105.3	114.0	Blocky and broken core with poor core recovery.
	118.3	125.0	Weakly to moderately fractured (20%).
	151.9	156.1	Concoidal fractures/breaks parallel and perpendicular to foliation.
	156.4	159.8	Concoidal breaks and broken rock.
	162.2	162.7	Moderate fracturing with discs.
	168.5	170.3	Intensely fissile and broken.
	187.1	187.3	Fault gouge, granular and flaky.
	195.3	196.5	Fault gouge, granular and flaky.

6.4.4.2 In-Situ Bedrock Permeability Test Results

A total of nine borehole packer tests were conducted to provide information on the hydraulic conductivity of the various bedrock units. The results of the borehole packer testing are presented in Table 6.4-3 and raw data is presented in Appendix E5. The transmissivity and hydraulic conductivity was calculated using the Thiem (1906) equation as follows:

$$T = \frac{Q \ln\left(\frac{R}{r_b}\right)}{2\pi P_i},$$

where:

T = transmissivity (m^2/day);
Q = injection rate (m^3/day);
R = radius of influence (m);
r_b = borehole radius (m); and
P_i = net injection pressure (m).

Net injection pressure was calculated using the formula:

$$P_i = P_g + h_g + h_s - h_f,$$

where:

P_i = net injection pressure (m);
P_g = gauge pressure (m);
h_g = height of the pressure gauge above ground surface (m);
h_s = depth to static groundwater level (m); and
h_f = assumed losses due to friction (m).

Hydraulic conductivity was calculated from transmissivity (T) by dividing by the length of the test interval. Hydraulic conductivity measurements with depth in each borehole are presented in Figure 6.4-3. Hydraulic conductivity values indicate the bedrock encountered in each of the two boreholes tested had a relatively low to moderate hydraulic conductivity, ranging from 1.72×10^{-7} cm/s to 1.81×10^{-4} cm/s. According to Domenico and Schwartz (1998), these values are within the range of expected values for fractured igneous and metamorphic rocks.

Figure 6.4-3 Hydraulic Conductivity versus Depth (Figures Section)

Table 6.4-3 Summary of Deep Borehole Permeability Testing

Location	Test Number	Packer Test Interval (along borehole axis)		Description of Bedrock Unit Tested	Calculated Hydraulic Conductivity (K)	Qualitative Description of K_s Relative to Other Test Intervals
		Top (m)	Bottom (m)		(cm/s)	
WV05-156 (PZ-A)	1	33.5	125.0	Hanging Wall, Upper/Lower Iron Formation	2.62×10^{-6}	Average
	2	67.1	115.8	Hanging Wall, Lower Iron Formation	6.59×10^{-7}	Less permeable
	3	118.0	194.2	Hanging Wall, Ore Body and Footwall	2.18×10^{-6}	Average
	4	128.0	145.4	Hanging Wall	6.84×10^{-5}	More permeable

Table 6.4-3 Summary of Deep Borehole Permeability Testing (cont'd)

Location	Test Number	Packer Test Interval (along borehole axis)		Description of Bedrock Unit Tested	Calculated Hydraulic Conductivity (K)	Qualitative Description of K_s Relative to Other Test Intervals
		Top (m)	Bottom (m)		(cm/s)	
WV05-155 (PZ-B)	1	73.8	156.1	Hanging Wall, Lower Iron Formation	7.51×10^{-6}	Average
	2	117.3	156.1	Hanging Wall	1.30×10^{-5}	Average
	3	135.0	156.1	Hanging Wall	3.94×10^{-5}	Average
	4	150.3	156.1	Permafrost, Hanging Wall, Footwall	1.72×10^{-7}	Less permeable
	5	74.7	83.8	Lower Iron Formation-Quartz Vein Contact	1.81×10^{-4}	More permeable

Hysteresis/Gouge Characteristics

A number of fluid injection pressures were employed during permeability testing to assess the change in flow with increasing and subsequent decreasing pressures. Similar injection pressures were used during both the increasing and decreasing phases (i.e., pressures were stepped up and subsequently stepped down) to allow for an assessment of flow differences and hysteresis in the pressure-flow relationship. After fractures and gouge were subjected to elevated injection pressures and pressures are subsequently reduced, flow was generally lower than measured during the earlier test at the same pressure. This behaviour is known as fracture hydrosealing and usually results from increased compaction of materials infilling fracture conduits within the bedrock units.

6.4.4.3 Baseline Groundwater Conditions

Four vibrating wire (VW) piezometers capable of measuring porewater pressure and temperature were installed at WV05-156 (PZ-A) and WV05-155 (PZ-B) and began collecting data in April 2005. Details of the VW piezometer installations are presented in Table 6.4-4. Groundwater elevations are represented graphically up to November 7, 2005 on Figure 6.4-4 and Figure 6.2-5 with precipitation and sump flow data, respectively. Evidence of decline dewatering can be seen at PZ-B (Deep) beginning in late June.

Table 6.4-4 Summary of Piezometer Installations and Initial Groundwater Elevations

Borehole I.D. (Piezometer Name/ Mineralized Zone)	Ground Surface Elevation (m ASL)	VW Piezometer Installation Elevation (m ASL)		Initial Groundwater Elevation (07/01/05) (m ASL)	
		Shallow	Deep	Shallow	Deep
WV05-156 (PZ-A/ Lynx)	1393	1362.5	1243.0	1376.9	1373.6
WV05-155 (PZ-B/ Wolverine)	1389	1329.2	1280.7	1370.0	1370.8

Figure 6.4-4 Measured Potentiometric Groundwater Elevations in Mine Area Piezometers – Precipitation (Figures Section)

Figure 6.4-5 Measured Potentiometric Groundwater Elevations in Mine Area Piezometers – Sump Flow (Figures Section)

6.4.5 Groundwater Quality Sampling

Baseline groundwater samples were obtained from two deep exploration boreholes (PZ-A and PZ-B) and from the underground test mine face. Drill rods were pulled back 6 m prior to purging and sampling PZ-B and about 15 m prior to purging and sampling PZ-A. Best efforts were made to purge the borehole of standing water prior to collection of groundwater quality samples, however surface water had been introduced to the borehole during drilling and drill water likely entered the surrounding bedrock fractures. Boreholes were purged using the drill wireline and core barrel as a modified bailer repeatedly until no more water could be lifted. Approximately 150 L of water was purged from PZ-B and 210 L of water was purged from PZ-A prior to sampling, which was estimated to be about one saturated borehole volume based on measured water levels and an NQ-sized borehole (70 mm outside diameter). The groundwater samples collected from PZ-A and PZ-B are considered composite samples of groundwater from the bottom of the borehole and drilling surface water.

Field measurements of pH, conductivity, temperature, total dissolved solids, dissolved oxygen and redox potential were taken in the field prior to laboratory sample collection of pump water (i.e., drilling water from surface) and deep groundwater. Field measurements of these parameters are summarized in Table 6.4-5.

Table 6.4-5 Summary of Field Groundwater Quality Measurements

Sample ID	Description	Conductivity	Temperature	Total Dissolved Solids	pH	Dissolved Oxygen	Redox Potential
		(μ S/cm)	(°C)	(ppm)	(-)	(mg/L)	(mV)
PZ-A Pump	Pump water	136	11.5	68	7.05	5.8	211.7
PZ-A GW1	Deep groundwater	142	6.8	70	7.17	7.6	243.2
PZ-B Pump	Pump water	121	11.9	60	7.37	9.5	261
PZ-B GW1	Deep groundwater	157	6.4	80	7.97	7.5	189

Groundwater samples from the underground test mine were collected carefully from mine face seepage to minimize contamination from test mining processes (i.e., drilling and blasting) and are considered more representative of baseline groundwater quality.

A summary of groundwater quality results from both boreholes and the portal face, that exceeded Canadian Council for Ministers of the Environment (CCME) Canadian Water Quality Guidelines for the protection of aquatic life are presented in Table 6.4-6. Appendix E6 provides a summary of all baseline groundwater quality results. The results indicate that baseline concentrations of mineral ions and dissolved metals are relatively low in groundwater in the proposed underground mine area, with conductivity values of 145 to 389 μS/cm and neutral pH values of 7.7 to 8.2.

Based on an evaluation of water quality parameters including total and dissolved organic carbon, it is believed that the samples may be slightly affected by surface water used during drilling. Elevated total organic carbon concentrations were present in the samples, which are more characteristic of surface water and shallow groundwater and are not expected to be present in deep groundwater samples. Groundwater quality samples collected from PZ-A and PZ-B likely represent a blend of deep bedrock groundwater influenced by surface water introduced during drilling. Groundwater samples collected from underground during test mining (i.e., from the portal face) may be more representative of baseline groundwater quality. Samples collected from upper underground seeps likely represent shallow baseline groundwater quality. Water quality samples collected from the test mining decline at depth represent the average chemistry of the mine groundwater quality discharging to the test mine working face in August and September.

Major ion chemistry indicates that calcium dominates over sodium, magnesium and potassium which is consistent with the presence of carbonate bedrock. Magnesium concentrations are fairly low and indicate some dilution by surface water used for underground drilling. Elevated concentrations of boron at Wolverine (PZ-B) were two orders of magnitude higher than concentrations observed at Lynx (PZ-A). The differences in water quality between samples collected at PZ-A, PZ-B and underground portal face are likely attributable to variations in geology and the spatial variability of minerals in the vicinity of the two boreholes and the decline ramp.

Table 6.4-6 Summary of Select Mine Groundwater Quality Parameters from Boreholes and Underground

	Baseline Groundwater Quality Sampling											**Applicable Criteria**
Sample ID	**Lynx**	**Wolverine**	**Wolverine**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**UG Portal Face**	**CCME – Aquatic Life**
	PZ-A	**PZ-B**	**PZ-B**									
	GW1	**GW1**	**GW2 (Duplicate)**									
Date Sampled	**4/25/2005**	**4/21/2005**	**4/21/2005**	**6/16/2005**	**7/7/2005**	**7/11/2005**	**8/6/2005**	**8/11/2005**	**8/17/2005**	**8/27/2005**	**8/29/2005**	
Sample Origin	**Borehole**	**Borehole**	**Borehole**	**Decline at ~1343 m ASL**	**Decline at ~1340 m ASL**	**Decline at ~1338 m ASL**	**Decline at ~1327 m ASL**	**Decline at ~1325 m ASL**	**Decline at ~1322 m ASL**	**Decline at ~1316 m ASL**	**Decline at ~1314 m ASL**	
Approximate Depth (mbgs)	**150**	**108**	**108**	**4**	**7**	**9**	**20**	**22**	**25**	**31**	**33**	
Fluoride F	*0.162*	0.094	0.105	*0.342*	*0.202*	-	*0.168*	*0.183*	*0.181*	*0.180*	-	0.120 [1]
Cadmium D-Cd	*0.00118*	<0.000050	<0.000050	<0.000050	<0.000050	*0.000076*	<0.000017	<0.000017	*0.000079*	<0.010	<0.010	0.000017
Copper D-Cu	*0.0165*	*0.0024*	*0.0029*	0.0011	<0.0010	<0.0010	<0.0010	<0.0010	0.0011	<0.010	<0.010	0.002 – 0.004
Iron D-Fe	*1.5*	*0.656*	*0.836*	0.142	<0.030	0.032	*0.433*	<0.030	*0.937*	0.142	0.076	0.3
Lead D-Pb	*0.00136*	*0.0108*	*0.0233*	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	*0.00112*	<0.050	<0.050	0.001 – 0.007
Selenium D-Se	*0.0107*	<0.0010	<0.0010	*0.0017*	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.20	<0.20	0.001
Zinc D-Zn	*0.211*	0.0227	0.0176	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0193	0.0214	<0.0050	0.03

Notes: "mbgs" refers to metres below ground surface.
"<" indicates result is less than the detection limit.
"italics" Exceeds CCME guidelines for the protection of aquatic life.
All results are expressed as milligrams per litre except where noted.
PZ-B GW2 is a blind duplicate of PZ-B GW1.
1 Guideline for inorganic fluoride

6.4.6 Conceptual Hydrogeological Model Development

The following data were compiled and reviewed to support the development of the hydrogeological conceptual model:

- Exploration borehole logs for all boreholes presented on cross-sections
- Regional climate data
- Topographic mapping
- Proposed mine workings
- Hydrological data
- Groundwater elevations and temperatures (measured at WV05-155 and WV05-156) from April to November 7, 2005. Elevations were observed before and during active development of the test mine
- Klohn Crippen field investigation data in Appendix E7
- Yukon Zinc test mine sump flow measurements in Appendix E8
- Yukon Zinc test mine development data in Appendix E9

Geological information for several boreholes was interpreted to form the basis of the conceptual model of the Wolverine Creek Basin/Mine Area. The sources of geological information included exploration borehole logs, monitoring well logs, borehole packer testing data, groundwater elevation data, pumping test analysis and topographic and geological mapping. Based on the geological logs and packer testing data, hydrostratigraphic units were identified and assigned hydraulic conductivity values as shown in Table 6.4-7.

Table 6.4-7 Summary of Inferred Hydrostratigraphic Units - Mine Area

Hydrostratigraphic Unit (from surface to depth)	Composition	Assigned Hydraulic Conductivity (cm/s)
Overburden	Soil and Talus	1×10^{-4}
Weathered Bedrock	Rhyolite / Argillite Sedimentary and Volcanoclastic Rocks	5×10^{-4}
Host Bedrock	Rhyolite / Argillite Sedimentary and Volcanoclastic Rocks	1×10^{-5}
Upper Iron Formation	Exhalites	1×10^{-6}
Host Bedrock	Rhyolite/Argillite Sedimentary and Volcanoclastic Rocks	1×10^{-5}
Lower Iron Formation	Exhalites	1×10^{-6}
Host Bedrock	Rhyolite / Argillite Sedimentary and Volcanoclastic Rocks	1×10^{-5}
Mineralized Zone	Massive Sulphides	1×10^{-6}
Host Bedrock	Rhyolite / Argillite Sedimentary and Volcanoclastic Rocks	1×10^{-5}

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. Based on hydraulic conductivity data and groundwater elevations recorded during the advancement of the decline during the test mining program, the upper and lower iron formation as well as the mineralized zone behave as aquitards and may slow the flow of groundwater. Groundwater elevations collected during the initial stages of test mining were analyzed using a leaky confined aquifer solution for 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 as shown in plan on Figure 6.4-2.

A total of four vibrating wire piezometers were installed in two exploration boreholes (PZ-A and PZ-B) during April 2005 to monitor groundwater elevations on an ongoing basis. The vibrating wire piezometers were grouted in place using a cement/bentonite grout mixture so that the piezometers measured groundwater pressure at a discrete point. Vibrating wire piezometer data was used to develop the conceptual model and will be monitored during mine dewatering to validate and refine the hydrogeological conceptual model.

Table 6.4-4 summarizes the piezometer installation details and potentiometric elevations measured at PZ-A (Lynx mineralized zone) and PZ-B (Wolverine mineralized zone). The piezometers were located to monitor groundwater conditions in the Lynx and Wolverine mineralized zones at the proposed depth of mining. The piezometer installations were intentionally located just outside of the proposed mine excavation areas between the Lynx and Wolverine zones (PZ-A) and southeast of the Wolverine Zone (PZ-B) so that they will not be disturbed during mining operations and monitoring of these piezometers can continue during mine development. Static, pre-mining groundwater levels range from about 15 to 20 m below ground surface at instrumented borehole locations PZ-A and PZ-B. A graph of measured potentiometric elevations is presented in Figure 6.4-4. A significant downward gradient was observed at PZ-A in the Lynx Zone and a near neutral gradient was observed at PZ-B in the Wolverine Zone indicating that the mine is located primarily in a groundwater recharge area. PZ-B appears to be located near the groundwater recharge/discharge divide.

Precipitation measurements from the on-site climate station (in mm) and qualitative observations of rain (from July 31, 2005 to September 1, 2005 and from September 27, 2005 to November 7, 2005 when the climate station datalogger was not functioning properly) are included on Figure 6.4-4. Precipitation data was reviewed in conjunction with the groundwater elevation data to assess the short and long-term response of groundwater levels to precipitation events. Groundwater recharge occurs both within the mine area and upslope of the proposed mine footprint (i.e., northeast of the mine). Groundwater is inferred to discharge to Wolverine Creek downgradient (i.e., southwest) of the proposed mine area along the upper 1 km reach of the creek. Precipitation and piezometer data indicates that groundwater levels (and resultant inflow rates into the mine workings) may vary in response to seasonal fluctuations in precipitation and infiltration. The piezometer measurements indicate that groundwater elevations at these depths do not fluctuate on a short-term basis in response to infiltration or rainfall events; however a response to seasonal trends in precipitation and infiltration was observed. Although small fluctuations in water pressure could be a result of variations in barometric pressure, the significant depth of the piezometers probably dampens and/or removes any barometric pressure effects. Temporary increases in porewater pressure and then recovery to initial levels may have been caused by underground blasting or construction activities during test mining.

There appears to be a seasonal decline in water levels (i.e., not mining related) at all piezometer locations and depths between June and November 2005 indicating that groundwater levels naturally drop during the summer season and that summer is not a period of significant groundwater recharge. Some evidence of groundwater recharge is apparent between September and November. The deep piezometer at PZ-B appears to have responded to dewatering activity during test mine decline development being carried out approximately 160 m from the piezometer (Figure 6.4-5). However, the shallow piezometer at this location had not yet responded to the dewatering. During the months of September and October 2005, the test mine decline was closer to the location of PZ-A (approximately 100 m away), and groundwater elevations recorded at PZ-A (Deep) dropped approximately 10 m over the course of two months due to the decline dewatering. Again, the shallow piezometer at PZ-A did not respond to pumping over the two month time period. This indicates that the upper and lower aquifers are separated by a semi-confining or confining layer (i.e., the iron formation). Artesian groundwater conditions (i.e., groundwater elevations above ground surface) were measured in a standpipe piezometer screened in bedrock adjacent to Wolverine Creek (MW05-3A installed by Klohn Crippen) confirming that the area between the proposed mine and Wolverine Creek is a groundwater discharge area for at least a portion of the year. This is further supported by observations of year round flow in Wolverine Creek. Klohn Crippen’s monitoring well logs and groundwater levels are included in Appendix E7. Ongoing monitoring of the mine area piezometers will assist in quantifying the seasonal fluctuations of the water table and confirm the seasonal and mine dewatering related effects on groundwater elevations. The recovery of groundwater levels over the winter months following the cessation of pumping from the test mine decline may provide further insight into the hydrogeological regime through a modified recovery test.

Inferred pre-mining groundwater flow conditions are presented in cross-section on Figure 6.4-6 and Figure 6.4-7. 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 and beyond.

Figure 6.4-6 Conceptual Hydrogeologic Model Cross-Section A-A (Pre-Mining) (Figures Section)

Figure 6.4-7 Conceptual Hydrogeologic Model Cross-Section B-B (Pre-Mining) (Figures Section)

Review of rock core and exploration drillhole logs from PZ-A and PZ-B indicate that the host bedrock is relatively fractured and therefore expected to behave similar to a porous media; however, it is acknowledged that the predominant orientation of fractures will influence groundwater movement in fractured bedrock. Exploration rock core was not oriented during drilling/logging (i.e., orientation of fractures cannot be interpreted from rock core); however, the predominant orientation of fractures is expected to be parallel to the dip of the iron formations and mineralized zone. This would result in higher bedrock hydraulic conductivity in the axis parallel to these zones and lower hydraulic conductivity in the axis perpendicular to these zones. Accordingly, these iron formations are expected to act as hydraulic barriers in the conceptual model resulting in increased gradients across the iron formations and reduced flow of water into the mine workings.

6.4.7 Flownet Construction

The potentiometric surface was inferred beyond measured locations (i.e., at PZ-A and PZ-B). The depth of groundwater at the top of the hill was inferred to be about 100 m below ground surface. The hill shown on Figure 6.4-6 and 6.4-7 has a very small crown/catchment area (see plan view of hill on Figure 6.4-2) and very steep side slopes likely resulting in a deeper water table at the crest of the hill. Mine inflow will be mainly influenced by groundwater pressures in the mine area, which are being measured by vibrating wire piezometers installed at PZ-A and PZ-B.

The illustrated two-dimensional flownets are a network of representative flow lines (direction of movement of a particle of water) and perpendicular equipotential lines (pressure head or energy of flow). The barrier influence of the iron formations was considered when drawing the flownet (i.e., flow lines were deflected at contacts with barrier materials), however it is acknowledged that a flownet is typically used to assess flow in an isotropic and homogeneous media. A flownet is a graphical solution of Laplace's equation in two-dimensions and can be used to estimate flow quantity by multiplying the gradient (the number of equipotential drops over the number of flow channels drawn in the flownet), total head loss (in m), hydraulic conductivity (K in m/s) and depth/length in the z dimension (in m). A flownet-based estimate of mine inflow was calculated to verify inflow rates estimated by empirical calculations. During workplan development, completed in conjunction with the EAR Technical Committee, it was agreed that a numerical groundwater model would not be developed.

Overall the host rock (with the exception of the iron formations and ore) is very fractured with low core recoveries. This indicates a fairly conductive formation where individual fault/fracture zones are not significantly more conductive than adjacent fractured rock (i.e. bulk conditions). For this reason, the use of a flownet (which assumes porous and homogeneous media) is considered valid as one of several analytical methods to estimate inflow and predict groundwater response to mining.

6.4.8 Mine Inflow Prediction

Groundwater extraction to dewater the mine workings will result in a lowered groundwater table in the vicinity of the mine and may result in reduced groundwater discharge to adjacent surface water systems. Baseline conditions representing pre-mining groundwater levels were quantified and groundwater levels during mine operation were predicted based on typical groundwater response, bedrock hydraulic conductivity, site geology, topography and available groundwater monitoring data.

Based on an understanding of the mine area hydrogeology, the response of groundwater to mine dewatering was predicted by developing a conceptual groundwater flow net and other analytical techniques. The conceptual hydrogeologic flow net representing pre-mining conditions (Figure 6.4-6 and 6.4-7) was modified to represent inferred groundwater levels when the mine is fully developed and the rock above the mine is dewatered. Full mine development and drainage of the overlying bedrock is considered the worst-case scenario for potential interception and diversion of groundwater flows from the Wolverine Creek watershed. Figure 6.4-8 and Figure 6.4-9 illustrate the expected groundwater level, equipotential lines and inferred groundwater flow pathways when the underground mine is operational and developed to its maximum depth, at sections intersecting PZ-A and PZ-B respectively.

Figure 6.4-8 Conceptual Hydrogeologic Model Cross-Section A-A' (Operating) (Figures Section)

Figure 6.4-9 Conceptual Hydrogeologic Model Cross-Section B-B' (Operating) (Figures Section)

An estimate of groundwater seepage into the mine was carried out using an analytical equation developed by Goodman *et al.,* (1965) that relates inflow rate to length of mine drift advanced (Figure 6.4-10). The equation proposed by Goodman *et al.,* (1965) for calculation of groundwater inflow during tunnel driving as follows:

$Q = 0.707L\ (KH^3S_y/t)^{1/2}$ where: Q = inflow in m3/day
L = length of drift in m
K = hydraulic conductivity in m/day
H = depth of drift below initial water table in m
S_y = specific yield of aquifer (dimensionless)
t = time since water level reached top of drift (days)

Dewatering data collected during initial advancement of a test mining decline was interpreted as a pumping test to:

- provide a semi-quantitative assessment of aquifer properties;
- calculate the expected radius of influence; and
- support estimates of potential mine inflows.

Appendix E8 includes a summary of pumping rates and mine dewatering volumes during test mining decline advancement as provided by Yukon Zinc Corporation staff. Appendix E9 includes the test mine underground workings following completion of 2005 test mining as provided by Yukon Zinc Corporation.

A flow net analysis was carried out to assess potential impact on groundwater discharge to Wolverine Creek from dewatering of the upgradient mine area. This assessment took into account groundwater conditions during both the pre-mining and operational phases as well as creek elevations inferred from topography.

A mine inflow rate of 7 L/s (25.2 m^3/hr) was calculated based on infiltration of 40% of annual precipitation during a normal year over a drawdown cone catchment area of about 1 km^2. This is considered a minimum inflow rate for fully dewatered conditions at full mine development. The EAR chose to use this minimum mine inflow rate to represent long-term mine inflow rates. For the water balance, a low inflow rate is considered conservative so that the site water balance does not rely on groundwater pumped from the mine for mineral processing requirements, etc. Inflow rates could be higher than this, as a result of a higher infiltration rate or other factors discussed below.

Estimates of mine inflow were carried out using the Goodman equation, a flownet-based calculation and a recharge-based minimum inflow calculation with results of the same order-of-magnitude (10 L/s). Therefore we are confident in reporting 10 L/s as an order-of-magnitude estimate of mine inflow. It should be noted that for the sizing of mine dewatering capacity, a high mine inflow rate is considered conservative. A sensitivity analysis of mine inflow to host rock hydraulic conductivity was carried out using the Goodman equation for a range of drift lengths (Figure 6.4-10), which indicated that a more permeable host rock and drift length of 1,000 m could theoretically produce a mine inflow rate of 35 L/s.

There is a very low likelihood of an inflow rate of 100 L/s, however such a high inflow rate would decrease with time since full drawdown shown on Figure 6.4-8and Figure 6.4-9 would theoretically take only 1 year at a rate of 100 L/s (see Figure 6.4-11). If highly conductive geologic formations (e.g., faults or fracture zones) are encountered during mining they could be grouted, which would reduce flow into the mine. The conceptual model allows for the worst-case scenario of full drainage above the mine. If a highly conductive fault or fracture zone is encountered during mining, drainage of the overlying rock is the worst outcome (as illustrated in section on Figure 6.4-8 and Figure 6.4-9). There are no infinitely large sources of water, such as a lake, above the mine. Accordingly, the only long-term source of water is infiltration of precipitation (e.g. recharge-based inflow calculated to be 7 L/s). Should a water-bearing geologic formation (i.e. fault zone) be encountered, an increased inflow rate is expected to decrease substantially over a short period of time. This was observed in the test mine dewatering when a fault was encountered on October 27, 2005 that increased flows by a factor of 2 for a period of one day. Flows subsequently declined to less than 1 L/s (or <100 m^3/d) as shown on Figure 6.4-5.

Following cessation of test mine dewatering on November 9, 2005, the test mine was allowed to flood. A site visit on February 16, 2006 indicated that the excavated test mine volume of approximately 9,650 m^3 had flooded with groundwater. An inflow rate of about 1.1 L/s was calculated for the 100 day period. This provides further confirmation of observed inflow rates during test mine dewatering (daily sump inflow rates on average stabilized at less than 1 L/s with a peak rate of 1.75 L/s).

Figure 6.4-10 Mine Inflow Estimate versus Drift Length (after Goodman *et al.*, 1965) (Figures Section)

Figure 6.4-11 Days to Drain Pore Water Above Mine versus Inflow Rate (Figures Section)

6.4.9 Potential Impacts from Dewatering and Groundwater Recharge

6.4.9.1 Dewatering during Operations

An analytical equation developed by Goodman *et al.,* (1965) predicted a mine inflow rate of about 10 L/s following development of 300 m of mine drift (i.e., after first year of mining) where the pre-mining groundwater elevation is about 175 m above the average mine elevation (Figure 6.4-10). Development of conceptual hydrogeologic flow net models and interpretation of dewatering data collected during initial advancement of the decline confirmed that a groundwater inflow rate of at least 10 L/s could be expected at full mine development. Inflow rates may be higher immediately following excavation and should decrease with time as the saturated rock above the mine is drained. Figure 6.4-11 illustrates the relationship between inflow rate in L/s and the time to dewater the porewater within the drawdown cone above the mine (calculated to be about 3,000,000 m^3). An inflow rate of 10 L/s corresponds to a period of 10 years to drain the porewater above the mine.

Figure 6.4-12 presents a plan view of the potential area of groundwater depression and approximate contours of groundwater levels for the fully dewatered condition (corresponding to groundwater levels illustrated in section on Figure 6.4-8 and Figure 6.4-9). The potential surface area affected by a lowered groundwater table is approximately 0.9 km^2. This represents about 50% of the Wolverine Creek watershed area (1.7 km^2).

Figure 6.4-12 Potential Groundwater Depression Plan (Figures Section)

After the rock above the mine is drained and a cone of depression (i.e., lowered groundwater table) has developed around the dewatered mine area, infiltration from precipitation will continue to provide inflow to the mine workings. The rate of mine water inflow from precipitation infiltration is estimated to be about 7 L/s.

Based on the results of a flow net analysis, the rate of groundwater flow through the proposed mine excavation area is estimated to be about 8 to 10 L/s. During operations, groundwater will be pumped to the surface for subsequent discharge to the tailings pond and treatment. A corresponding reduction in groundwater discharge to Wolverine Creek may occur as a result of mine dewatering. Water quality in Wolverine Creek is not anticipated to be adversely affected during operations as discharges to that drainage are not proposed.

Baseline flows in Wolverine Creek at W9 are low (see Section 5.1 Hydrology), and the steeper gradient reaches have been observed to flow subsurface. Summer average flows and winter low flows are 12 L/s and 2 L/s, respectively. During operations, Wolverine Creek flows are anticipated to be reduced by approximately 0.5 L/s, or at most by 25% during low winter flows (January to March), and 4% during summer (May to August). Based on the fact that there is a high probability of substrate-to-surface freeze-up during the winter months, there are low fish habitat values with limited productive capacity during the winter period. During summer 2005, all lake-accessible fish habitat in Wolverine Creek was sampled for fish presence (electrofished) and only one juvenile lake trout was captured near the Little Wolverine Lake confluence. This single capture is indicative of very limited fish habitat capacity and likely represents opportunistic feeding forage in lower Wolverine Creek as opposed to sustained use. The impact to summer flows (4% reduction) is within the natural range of flow variability and, therefore, dewatering effects will be negligible.

However, since winter low flow at the outlet of Wolverine Creek was measured to be 3 L/s (March 1996), and not as high as 7 L/s, this may indicate that not all of the groundwater flowing through the mine area discharges to Wolverine Creek; therefore, flow reductions may no occur as currently predicted.

Dewatering of the mine is not expected to affect water levels in the adjacent Little Wolverine and Wolverine Lakes. Based on the elevation of water in Wolverine Creek adjacent to the mine (~1337 m), and the elevation of Little Wolverine and Wolverine Lakes (~1124 m), dewatering of the mine workings (ranging in elevation from 1050 to 1360 m) is not expected to generate gradients that could result in drainage of the lakes into the mine.

In addition, since Wolverine Creek is a small watercourse (0.3 m channel width) that represents only 0.8% of the total watershed area of Little Wolverine Lake, any effect on Wolverine Creek would not affect Little Wolverine Lake.

The benthic invertebrate and periphyton species present in lower Wolverine Creek are adapted to the slow flow associated with low gradient, so it expected that the anticipated minor (4%) changes to water flow**,** within the range of natural variation, will not have an adverse effect on benthic productivity during the summer growing season, nor should it have an effect on fish habitat. Accordingly, effects of mine operations on flow, water quality, benthic invertebrates, periphyton and fish habitat in Wolverine Creek are predicted to be low magnitude, site specific, long-term, moderate frequency, and reversible (as per criteria definitions provided in EAR Table 7.5-12).

6.4.9.2 Closure Considerations

At closure, cemented waste rock and paste tailings backfill will be placed in the mine excavations to provide hydraulic head loss (i.e., hydraulic conductivity) similar to the pre-mining bedrock conditions. Rock to be excavated during mining has measured hydraulic conductivity in the order of 10^{-4} to 10^{-5} cm/s. Cemented paste tailings, if placed in continuous lifts/layers designed to act as hydraulic barriers throughout the mine, will provide sufficient hydraulic head loss to prevent portal discharge. Additional engineered hydraulic barriers will be incorporated into the mine backfill. Prior to closure all openings to surface, including portals and ventilation raises, will be hydraulically sealed to prevent discharge of groundwater to surface. To achieve this objective the upper lengths of decline ramps and both ventilation raises will be filled with low-permeability cemented backfill and/or engineered hydraulic barriers.

Acknowledging the importance of mine backfill and hydraulic barriers to prevent discharge of groundwater from the portal, the mine is expected to slowly flood to pre-mining levels following closure, saturating the backfilled mine. Based on a total volume of 130,000 m^3 of mine and backfill void space and an additional 2,800,000 m^3 of drained bedrock voids above the mine, it could take approximately 13.3 years for groundwater levels around the mine to return to pre-mining conditions (2019 to 2032).

Post-mining groundwater levels are not expected to rise above pre-mining levels. The hydrogeology of the mine area will continue to be influenced significantly by the iron formations. This is supported by a lack of groundwater elevation response in shallow piezometers to test mine dewatering during the fall of 2005.

Given that flows will gradually return to baseline levels following mine closure, and that the difference between baseline and operational flows is small, potential effects of changes in groundwater discharge to surface flows in Wolverine Creek, and related effects on benthic communities and fish habitat, are expected to be of low magnitude and site specific.

6.4.9.3 Groundwater and Surface Water Quality Following Closure

After the groundwater table returns to pre-mining conditions and groundwater gradients are restored, groundwater within the mine voids will then migrate downgradient toward Wolverine Creek and beyond. Groundwater travel times from the mine to surface at Wolverine Creek were estimated to range from 5-25 years at shallow depth (i.e., shorter groundwater flow path distance) and from 10-50 years for the lowest mine elevation (i.e., longest groundwater flow path distance) following flooding of the mine. Travel time estimates were calculated assuming a bedrock hydraulic conductivity of 1 x 10^{-5} cm/s, porosity values of 1% and 5% and flow path lengths of 400 and 760 m. Based on these flow path lengths and the predicted mine water quality at the closure, potential impacts on Wolverine Creek water quality were evaluated and are discussed below.

Baseline water chemistry for Site W9, near the mouth of Wolverine Creek, continues to indicate levels of three metals substantially higher than CCME guidelines. These include zinc (mean levels 4 times higher), selenium (mean levels 3 times higher) and cadmium (mean levels 16 times higher). The EAR Addendum Reports provides levels of these and other relevant parameters on a map of the assessment area. Other parameters (arsenic, chromium, copper, lead, aluminum, iron, molybdenum, nickel, silver, thallium, nitrate, ammonia, pH, total suspended solids) are well within CCME guidelines, with few small exceptions (see Addendum Report for data).

Approximately 0.5 L/s of groundwater flow from the mine area is expected to contribute to Wolverine Creek flows. This groundwater may have elevated concentrations of some constituents (e.g., dissolved metals). Based on conservative equilibrated mine water quality estimates provided in Section 6.3, contributions of groundwater to baseline water quality in Wolverine Creek were estimated for winter low flow (2 L/s) and average summer flow (12 L/s), assuming no attenuation of metals between the mine workings and Wolverine Creek. Using a mass balance approach for dilution, resulting summer and winter concentrations in Wolverine Creek are presented in Table 6.4-8. Information used to define average baseline chemistry is provided in the Addendum Report. Stream concentrations in bold exceed CCME guidelines.

Table 6.4-8 Predicted Water Quality in Wolverine Creek at Closure During Summer and Winter

	Units	Average Baseline Stream Chemistry	Equilibrated Mine Water Quality	Predicted Summer Stream Concentration	Predicted Winter Stream Concentration	CCME Guidelines
Average Flow	L/s		-	12	2	-
Groundwater Discharge	L/s	-	-	0.5	0.5	-
Parameter						
Aluminum	mg/L	0.005	0.001	0.005	0.004	0.1
Arsenic	mg/L	0.0005	0.277	**0.012**	**0.070**	0.005
Cadmium	mg/L	**0.0013**	0.056	**0.004**	**0.015**	0.000081
Copper	mg/L	0.001	0.02	0.0018	**0.006**	0.002
Iron	mg/L	0.03	0.00001	0.03	0.023	0.3
Lead	mg/L	0.0005	0.045	**0.0024**	**0.012**	0.002
Molybdenum	mg/L	0.001	0.096	0.005	0.025	0.073
Nickel	mg/L	0.003	0.632	0.029	**0.160**	0.065
Selenium	mg/L	**0.003**	0.505	**0.024**	**0.129**	0.001
Silver	mg/L	0.00002	0.162	**0.0068**	**0.041**	0.0001
Zinc	mg/L	**0.14**	1.50	**0.20**	**0.48**	0.03

Considering only dilution mechanisms in calculating the effects of groundwater discharge on concentration of constituents in Wolverine Creek, Table 6.4-8 indicates that during the summer, arsenic, cadmium, lead, selenium, silver and zinc will exceed CCME guidelines (baseline concentrations of Cd, Se, and Zn in Wolverine Creek already exceed CCME guidelines). During winter, concentrations of several metals will be notably higher than summer; copper and nickel, in addition to the metals listed above will exceed CCME guidelines. Given the slowly increasing rate of groundwater discharge to Wolverine Creek post-closure, these peak concentrations are expected to take on the order of 20 years to manifest, after which they are expected to decrease with dilution effects of groundwater recharge.

There is considerable uncertainty about these predicted values, given that they do not account for any attenuation processes that are likely to occur within the host bedrock between the mine workings and Wolverine Creek. Processes such as oxidation-reduction and hydrolysis reactions, complexation, adsorption onto clay and organic matter, diffusion, dispersion and ion exchange are likely to reduce the concentrations in Wolverine Creek to below those described in Table 6.4-8. In addition, mitigation measures incorporated into mine operations and at closure to limit oxidation of sulphides and metal release in mine water are proposed. They include:

- placing low-permeability paste backfill in mine stopes and ramps;
- minimizing exposure times of mine floor, wall and back surfaces prior to paste placement; and,
- flooding of the mine following closure (consideration will be given to “accelerated” flooding of the mine with treated water).

The equilibrated mine water quality values are conservative values that will be refined through additional testwork and underground monitoring during the operating period.

An adaptive management approach will be taken to reduce the level of uncertainty about post-closure conditions in Wolverine Creek. This will consist of further testing and modeling throughout mine operation period (2007 to 2019) to better predict the water quality of Wolverine Creek post-closure, monitoring effectiveness of mitigation measures during operations, and groundwater well and stream monitoring post closure to confirm the predictions. Additional contingency measures, such as pumping and treating groundwater, will be developed as new information confirms water quality and flow predictions.

Wolverine Creek currently supports populations of algae, chironomids, blackflies, mayflies and stoneflies (Section 9.1.3), indicating that the benthic community appears adapted to the naturally high levels of zinc, selenium and cadmium. Low numbers of juvenile fish have been reported in the lower reaches of the creek, suggesting opportunistic feeding in the area. The predicted worst-case levels of arsenic, cadmium, lead, selenium, silver and zinc (Table 6.4-8) would likely result in significant long-term effects on benthic invertebrate and periphyton communities in lower Wolverine Creek, given the extent to which the metals exceed baseline conditions. Possible effects include chronic or acute toxicity and increased tissue concentrations.

The lower section of the creek, while accessible to fish from Little Wolverine Lake, is expected to sustain limited use due to habitat limitations (Section 6.4.9.1). The potential for bioaccumulation of metals in fish that consume benthic invertebrates would be considered low. As a result of opportunistic (seasonal) forages into the lowermost reach of Wolverine Creek, by a very small population or individual juvenile lake trout, it seems unlikely that benthic food organisms with (or without) elevated metals concentrations would have a measurable effect on the health or sustainability of individual fish or the whole population in Little Wolverine Lake. Nevertheless, Yukon Zinc Corporation is committed to ongoing predictive testing and effects monitoring to minimize the uncertainty associated with predicted metals levels and to ensure protection of this watershed from adverse effects of the project.

6.4.10 Proposed Monitoring during Operation and Closure Periods

Ongoing monitoring of the mine area piezometers (PZ-A and PZ-B) will be carried out during operations and following closure to assess the affects of mine dewatering on groundwater levels. As the test mine is advanced and as full mine development progresses, ongoing review of groundwater seepage into the mine and pumping rates will be carried out to refine mine inflow estimates, improve the hydrogeologic model and better assess potential impacts to Wolverine Creek. In addition, the collection of climate data such as precipitation and temperature will continue during operations to assist with groundwater recharge estimates.

Monitoring of flow and water quality in Wolverine Creek will be carried out upstream (W82) and downstream (W9) of the mine area during the operation phase to assess effects of mine dewatering on surface water hydrology and aquatic habitat. Water quality will also be monitored in Little Wolverine Lake. Automated flow stations will continue to monitor flow rates in the creek during dewatering of the mine to confirm whether mine dewatering has an impact on flow in Wolverine Creek.

Installation of multi-level monitoring wells (in overburden, shallow bedrock and deep bedrock) at two locations between the mine and Wolverine Creek will be installed in spring 2006. The monitoring wells will be standpipe-type installations suitable for monitoring water level (with transducers equipped with dataloggers) and for collection of groundwater quality samples. The proposed monitoring wells will be located near Wolverine Creek to determine the connectivity and degree of connectivity between the creek and groundwater systems (shallow and deep). These monitoring wells will provide advance notice of the potential for reduced flow during operations, as well as determine the potential for groundwater discharge to Wolverine Creek after closure.

Groundwater quality will be monitored in the proposed monitoring wells during operations and following closure for a period of at least 20 years (note that the travel time for the shallow groundwater flow path was estimated to be 5 years after the mine is flooded). If it is determined that during the operation monitoring period there is connection between the creek and the deep groundwater system, or if water quality in the overburden or shallow bedrock monitoring wells deteriorate during the initial post-closure period then extension of the monitoring program and/or contingency measures will be evaluated. Options such as pumping from recovery wells and subsequent water treatment will be considered. A portable water treatment plant will remain onsite during this period and Yukon Zinc is committed to ongoing monitoring and treatment to ensure that Wolverine Creek is protected.