APPENDIX B

MINTO MINE CLOSURE HYDROLOGY REPORT

MINTO MINE PHASE IV CLOSURE HYDROLOGY REPORT

September 2013

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This document presents the methodology and results of hydrological analysis and hydraulic design undertaken in support of Minto Mine's ongoing reclamation and closure planning work. This work builds on the design of water conveyance structures presented in the previous Decommissioning and Reclamation Plan (DRP Revision 3.2), and more recent planning (i.e. for Phase V/VI, including outcomes of a preliminary Failure Modes Effects Assessment conducted in January 2013). In particular, the importance of hydrology and the safe conveyance of site water in the closure condition were recognized, given their influence on the ultimate closure objectives related to site water quality and structural stability in closure. This work is intended to support all closure planning initiatives and documents going forward, but is first and foremost being developed to support the Reclamation and Closure Plan for the Phase IV mine configuration. The development and submission of this plan is required under both of the project's main authorizations – the Quartz Mining Licence and the Water Use Licence. Under both licences it is required for submission by September 16, 2013.

The objective of the current study is to produce a preliminary design for site water conveyance structures, including sizing and erosion protection, to route flow downstream of the mine site. A hydrological analysis was performed to determine design flows.

The design considerations and criteria, methodologies and results of the hydrological analysis and hydraulic design completed for Minto Mine closure are presented in the report.

2 AVAILABLE DATA

Numerous sources of data have been obtained to support the current study. These include previous reports, Minto Mine site topography and end of Phase IV contours, meteorological data gathered on the Minto Mine site and from Environment Canada regional stations, and hydrology data gathered downstream of the Minto Mine and at Environment Yukon hydrometric stations.

2.1 PREVIOUS STUDIES

Several previous studies have focused on the site hydrology and meteorological conditions, water balance and ditch design (operational and for closure) for Minto Mine (Table 2-1). These were reviewed to evaluate past methodologies used and layouts proposed or constructed for water conveyance design on site.

Table 2-1 Available relevant reference studies

Study	Author	Year
Review of Hydrology for Minto Project	Remi J.P. Allard Rescan Environmental Services Ltd.	1997
Minto Copper Project – Site Hydrology Update	Clearwater Consultants Ltd.	2006
Minto Copper Project - Water Balance Model	Clearwater Consultants Ltd.	2008, 2009, 2010
Minto Copper Project – Surface Water Hydrology Conditions	Clearwater Consultants Ltd.	2010
Phase IV Closure Water Balance	Clearwater Consultants Ltd.	2010
Design Drawings of Water Conveyance at Closure	EBA Engineering Consultants Ltd	2011
2012 Water Balance Update for the Minto Mine Site	SRK Consulting	2012
Pipe Design for South Diversion Ditch Realignment	EBA Engineering Consultants Ltd	2012
Precipitation Analysis for the Minto Mine	SRK Consulting	2012
South Diversion Ditch Realignment and Overflow Spillway	SRK Consulting	2013
2013 Water Balance Update for the Minto Mine Site	SRK Consulting	2013
Minto Surface Water Hydrology Baseline Report	Access Consulting Group	2013
Minto Climate Baseline Report	Access Consulting Group	2013

EBA Engineering Consultants Ltd.'s Design Drawings of Water Conveyance at Closure, prepared for the DRP Revision 3.2, were used as the basis to updating channel design. From these designs, channel alignments were altered to accommodate the placement of potential passive treatment elements (i.e. bioreactors, wetlands). Additional changes were made to address concerns raised during review of the DRP Revision 3.2 and during the Preliminary Failure Modes Effects Assessment conducted in January 2013.

Minto Mine sub-catchments were delineated and presented in Clearwater Consultants Ltd.'s Phase IV Closure Water Balance (Clearwater Consultants Ltd, 2010). Given updated end of life footprints for Phase IV, these sub-catchment delineations have been updated.

Recent ditch realignment work for operations (EBA Engineering Consultants Ltd, 2012, SRK Consulting, 2013) was also reviewed in addition to other methods recently used for hydraulic design at the recently constructed Bellekeno Mine near Keno City, Yukon (Interralogic, Inc, 2013) and the Wolverine Mine near Frances Lake, Yukon (Klohn Crippen Berger Ltd and Yukon Zinc Corporation, 2009) mines, such that comparable methodologies might be utilized to achieve a reasonably conservative closure water conveyance design. The intent of this comparison was to evaluate the design methodologies at comparable sites in order to ensure that the current design is consistent with recently developed northern projects and to facilitate the design of reasonably conservative closure water conveyancee systems.

Review of the above noted design work suggested SRK Consulting's most recent hydraulic design completed for the South Diversion Ditch Realignment (SRK Consulting 2013), using a statistical approach developed by USGS (Curran et al., 2003), provided flows that are very high for small catchments like at the Minto Mine Site. The calculated values per km^2 for different flood recurrences are significantly higher than those presented for other mine sites within the Yukon.

Meteorological and hydrology data outlined in the Minto Climate Baseline Report (ACG, 2013a) and the Minto Surface Water Hydrology Baseline Report (ACG, 2013b) were used for the hydrological analysis, as described in sections 2.3 and 2.4.

2.2 TOPOGRAPHY

End of Phase IV contour data (1 metre interval) were provided by Minto Mine. This included the footprints and elevations of proposed covers on waste rock dumps and resurfacing of the dry stack tailings and the Mill Valley Fill. Contour data was also provided for the mine pits. Two sets of contour data were provided for the Mill Valley Fill Extension (MVFE) - representing Stage 1 and a potential maximum limits of Stage 2 MVFE. Only the Stage 1 contours were considered for this analysis, although the addition of Stage 2 MVFE would have s relatively minor effect on the hydraulic design at closure.

The topography data were analysed and treated in ESRI ArcGIS software. Quality topographical data allowed the accurate determination of watershed boundaries within the mine site and to accurately determine optimal profiles for all ditches.

2.3 METEOROLOGICAL DATA

A variety of meteorological data have been utilized to complement the hydrological analysis.

Meteorological data are available for the Minto Mine site from two meteorological stations that have been operational since 2005 and 2010, respectively. They provide a continuous but short record of air temperature, wind velocity and direction, pressure, and precipitation. More information is available in the Minto Climate Baseline Report (ACG, 2013a).

Two Environment Canada stations provide a long-term climate record for the region: Pelly Ranch (Fort Selkirk – Climate ID#2100880), 25 km northeast of the Minto Mine, provides a continuous record of daily air temperatures and precipitation in the form of rainfall and snowfall from 1956 to present (57 years), while Carmacks (Climate ID#2100300) 70 km southeast of the Mine) provides a continuous record of daily air temperatures and precipitation in the form of rainfall and snowfall from 1963 to 2008. For the current analyses the Pelly Ranch data were used given the longer record and the closer proximity of the station to the mine.

Intensity-Duration-Frequency curves (IDF curves), short-duration rainfall intensity statistics, were obtained for both Pelly Ranch and Carmacks climate stations from Environment Canada. Last updated in 2009 for stations across Canada, the Pelly Ranch and Carmacks IDF curves were calculated from 33 and 13 years of record, respectively. The curves provide estimates of the rates and amounts of rainfall for 5, 10, 15, 30 and 60 minute, and 2, 6, 12, and 24 hour durations for return periods of 2, 5, 10, 25, 50 and 100 years. The rainfall amounts and rates for various return periods are calculated by fitting a series of annual maximum rainfall rates for the corresponding durations to the Gumbel extreme value distribution using the method of moments. Estimates of rates and amounts for the 200-year return period were calculated using the same methodology as applied by Environment Canada.

Snow surveys have been conducted at Minto Mine in 1994, 1995, 1998, and annually from 2006 to date, at three locations in the Minto Creek catchment area. Minto#1 is located north of the airstrip with a north-facing aspect. Minto#2 is located near the explosives storage area with an east-facing aspect. Minto#3 is located north of the mill with a south-facing aspect. The locations of snow surveys are shown in Figure 2-1 in the next sub-section. Due to site operations, the snow survey sites were relocated to their present positions in 2007 at the approximate aspects and elevations of the previous sites. Snow surveys have been conducted on the first day of March, April and May, or within 2 days before or after these dates, as conditions allowed. Due to the lack of snow remaining on site by May 1, February snow surveys were begun in 2009 to ensure a consistent annual 3-month record. A snow course at Pelly Ranch provides a long term record for the region, with 27 years of record. However, since Pelly Ranch is located at a much lower altitude (454 m) than Minto this data has only been used for comparison purposes.

2.4 HYDROLOGICAL DATA

Hydrological data collected downstream of the Minto Mine, and data from small streams (<100 km^2) in the same hydrographic region as Minto were utilized to validate design storm flood magnitudes calculated for water conveyance structure design.

Hydrometric data have been collected intermittently on Minto Creek since 1993 at two stations: W1, Minto Creek near the mouth, with a catchment area of 42 km^2 and W3, Minto Creek downstream of water storage pond dam, with a catchment of 10.4 km^2. Data at W3 should be used with caution for the period since 2007, as mining operations have resulted in the storage of a significant amount of water within the mine site.

Environment Yukon has operated a small stream network over the last four decades, collecting mostly seasonal flow records on streams ranging from 4 to 500 km^2. Records from 11 small streams less than 100 km^2 in the interior hydrographic region (Janowicz, 2004) were reviewed to determine peak flows in cubic metres per second per square kilometre, for use in comparisons with the calculated design floods. These streams, with contributing basins not more than 10 times larger than the Minto Mine catchment, were considered useful for comparison purposes, while the Water Survey of Canada station Big Creek Near the Mouth was not used for the analysis given its large size (1800 km^2) resulting in a different hydrological response.

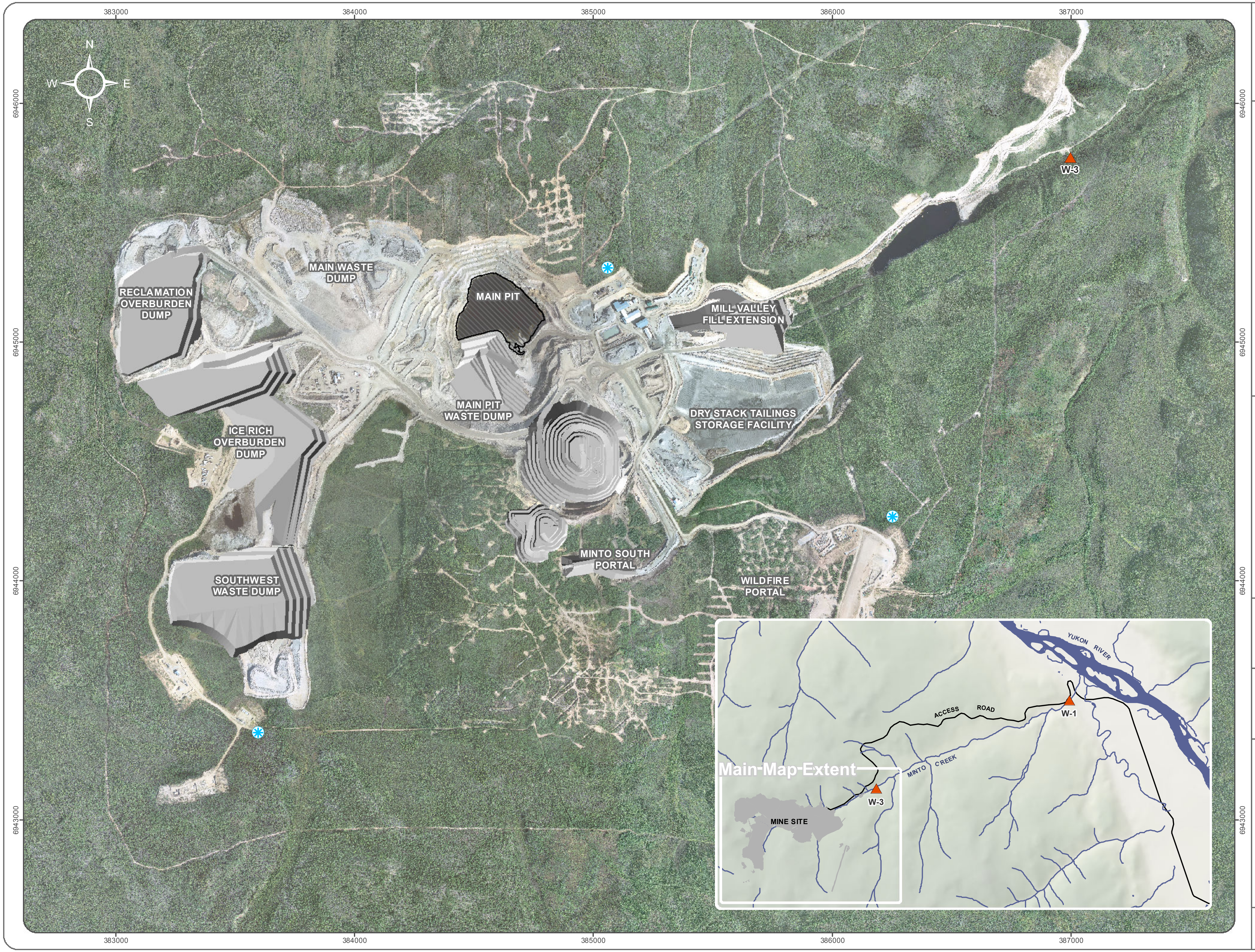

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FIGURE 2-1

HYDROMETRIC AND SNOW SURVEY STATIONS

SEPTEMBER 2013

▲ Hydrometric Station

✱ Snow Monitoring Station

0 100 200 300 400 500 Meters

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Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 14th 2012.
Site contours derived from 2012 aerial imagery obtained from Challenger Geomatics.

Hydrology data provided by Minto Explorations Ltd, May 2009.

Datum: NAD 83 Projection: UTM Zone 8N

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3 SITE CONDITIONS AND LAYOUT

3.1 DESCRIPTION

The Minto Mine is located in central Yukon, approximately 35 km south-west of the community of Pelly Crossing. The area is characterized by rolling hills ranging between 750 and 975 m at the mine site. Minto is located in the extensive discontinuous permafrost zone, thus the areal extent of permafrost ranges from 50-90%, located mostly on north-westerly to north-easterly slopes.

The watershed encompassing the mine site has approximately 50% natural forest cover, with the remaining area having been altered due to mining operations. This includes the excavation of two large pits, having a combined surface area of 0.45 km^2, and several waste rock dumps and a tailings storage facility.

The Minto Mine started operations in 2007. Currently authorized Phase IV mining operations are scheduled to be completed in early 2014, and it is anticipated that Phase V/VI mining operations will commence around the same time – pending authorization. For the purpose of developing the RCP for the Phase IV mine configuration, it is assumed that the site will be decommissioned once Phase IV mining and milling has been completed.

3.2 LOCAL CLIMATE

Minto is located in the subarctic continental climate zone, which is characterized by long, cold winters and short, warm summers. Annual precipitation ranges from 300 to 500 mm. Mean annual temperatures are near –5°C with mean mid-winter temperatures of –23°C to –32°C, in July from +10°C to +15°C and extremes in the lower valleys ranging from –60°C to +35°C.

Extensive analysis of meteorological data available at the Minto Mine site has been conducted, both to determine baseline conditions and to compare site records with the longer data record available at Pelly Ranch. The results show that total annual precipitation is slightly larger at Minto. However, Minto has less rainfall annually than Pelly Ranch, and greater snowfall.

Details of the climate baseline and precipitation analysis are available in the Minto Climate Baseline Report (ACG, 2013a) and the Precipitation Analysis for the Minto Mine Memorandum (SRK Consulting, 2012).

3.3 CHALLENGES

The Minto Mine site presents some key challenges to the design of water conveyance structures. These include:

- Characterizing site hydrology given small catchments with rapid responses to hydrological events, and the compounding influence of discontinuous permafrost at the site, a cold climate, and limited hydrology, meteorological and other climatological data given Minto's remote location;

- Designing water conveyance structures given uncertainty regarding the final topography at closure, especially on and near waste rock dumps. As a result flow direction assumptions are required for sub-catchment delineation in certain areas;

- Addressing topographical/foundation constraints, including steep slopes that occur naturally in the basin and in constructed areas such as the waste rock dumps; and
- Limiting erosion and sedimentation through controlled energy dissipation.

Given these design challenges, a water conveyance layout was established with the primary goal of conveying flows into and throughout the mine footprint, and off of the site in a controlled fashion under a reasonable range of anticipated conditions.

3.4 SITE LAYOUT

The proposed site layout of water conveyance channels has been determined based on the layout proposed in the previous decommissioning and reclamation plan (DRP Revision 3.2), and the mine site topographical constraints at closure. The main objective is to safely convey water downstream of the site, avoiding erosion of waste rock dump covers, tailings and other remaining works at closure.

A combination of primary, secondary and tertiary ditches are proposed (Figure 3-1). Primary water conveyance channels are the main channels that will route the accumulated overland flow through the mine site. They will convey highly variable, intermittent and potentially significant flows. Erosion protection measures will be incorporated to ensure the stability of the channels. Energy dissipation measures will be required to ensure that flow across steep slopes is managed safely and energy is dissipated in controlled locations.

Five primary ditches have been incorporated into the water conveyance design, and are described below.

The South Diversion Ditch (labelled Ditch 100) has been constructed as part of mine operations to intercept flow to protect the Dry Stack Tailings Storage Facility (DSTSF) from run-on flow. This ditch will be upgraded for closure, and will route flows into the Area 2 Pit. The ditch currently has the capacity to carry up to 13.3 m^3/s (SRK, 2013). Currently, during operations, flows are diverted around Area 2 Pit by a pipe which has an estimated capacity of 1.08 m^3/s, while any additional flows enter the pit through a recently constructed spillway.

Flows from the Main Waste Dump and the Reclamation Overburden Dump will be captured in Ditch 300. Ditch 350 will control flow predominantly originating from the Southwest Dump, out of the constructed wetland area. Ditch 300 will discharge its flow into Ditch 350, routing flows into the Main Pit. The alignments of these ditches have been located to minimize flow over erodible buttress soils.

The Main Pit and Area 2 Pit will provide detention for upper catchment flows in the form of pit lakes at closure. The outlets of these pits will direct flow in Ditch 400 and 450, respectively. Ditch 450 will discharge to Ditch 400 in the mill area. Thus, Ditch 400 will convey the majority of on-site flows. The Ditch 400 alignment will stay as far north as possible when crossing the MVFE, hugging the existing hillside, and will be routed down the MVFE NE slope and continuing in the valley bottom (to the north of the W37 collection point) and ultimately terminating up gradient of the water storage pond current location.

Secondary water conveyance channels are ditches that will route runoff water from elevated catchments (i.e. from the top of waste rock dumps and the DSTSF) into the primary ditches and/or energy dissipation and sediment control ponds. These will convey flow from much smaller catchment areas than primary ditches, but will route water down relatively steep slopes (e.g., 2H:1V), which can lead to high flow velocities. The design of secondary ditches will incorporate structures to drop water along the waste rock dump steep faces (i.e spillways, drop structure, baffles) in addition to energy dissipation/sediment control ponds at the base of steep slopes. Their final alignment will be determined at closure.

The Tailings Diversion Ditch being upgraded in fall 2013 as part of operations, has also been retained to assist in preventing run-on flows from entering the DSTSF. It is treated as a secondary ditch, and routes flows to the water storage pond, and will be upgraded as required for closure.

Tertiary water conveyance channels are relatively minor ditches and swales that will direct overland flow on the elevated catchment areas towards secondary ditches, protecting the steep slopes from concentrated surface flow. They will be designed to intercept flow before it can concentrate and potentially erode cover materials. These ditches will route small flows with low flow velocities due to the very small areas of surface runoff being managed.

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FIGURE 3-1
CLOSURE WATER MANAGEMENT LAYOUT

SEPTEMBER 2013

- Proposed Diversion Structure (Primary Ditch)
- Proposed Diversion Structure (Secondary Ditch)
- Proposed Diversion Structure (Tertiary Ditch)
- Existing (Primary) Diversion Ditch (to be consolidated at closure)
- Existing Diversion Ditch
- Pit Lake
- Sediment Pond

THE LAYOUT OF THE DITCHES IS CONCEPTUAL AND WILL BE FINALIZED IN CONJUNCTION WITH THE DETAILED CLOSURE DESIGN. THE MAIN WASTE DUMP DITCHES ARE NOT SHOWN ON THIS FIGURE AND WILL BE DESIGNED AT CLOSURE

0 100 200 300 400 500 Meters

Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 14th 2012.

NAD 83 UTM Zone 8N

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4 HYDROLOGICAL ANALYSIS

4.1 CONTEXT

The Minto Mine footprint is within a small upper catchment of the Minto creek watershed. The total catchment upstream of W3 (located at the downstream end of the mine site) is 10.4 km^2, with monthly average flows at W3 ranging from 0.02 to 0.16 m^3/s for the pre-mining record, with the exception of one spot measurement in May 1997 that reached 0.55 m^3/s. The water conveyance infrastructure designed for closure is intended to control flows into, within and beyond the mine footprint, including controlled energy dissipation to limit erosion and sedimentation. As described above, water conveyance channels can be classified as:

- Primary ditches, with sub-catchments ranging from ~1 km^2 for the primary drainage ditches in the upper catchment to 8 km^2 for ditches 400/450 routing most of the water to the outlet of the mine site;

- Secondary ditches routing flows off the covers (i.e. waste rock dumps and DSTSF) with sub-catchments mainly under 1 km^2; and

- Tertiary ditches directing flows on the covers to the secondary ditches.

The small size of the sub-catchments creates inherent uncertainty in the calculation of design flows, because smaller basins have more rapid responses to hydrological events and are highly influenced by local conditions. In addition, disturbed and reclaimed areas present a challenge to the hydrological design as they require the characterization of non-natural and irregular topography. In particular, the waste rock dumps are characterized by flat covers and steep slopes on downgradient faces. The presence of discontinuous permafrost at the site has been incorporated into the hydrological design where possible through the characterization of groundcover and runoff rates. Where limitations in data quantity and quality were identified, conservative methodologies were applied.

For the larger sub-catchments encompassing the pits (related to ditches 400 and 450) the additional routing of water through the pits provides significant attenuation of flows for design storms. As such, a study was conducted to determine the hydrological inputs that would tend to produce the greatest flows, and resulted in the consideration of constant spring snowmelt flows combined with a 24-hour rainfall event to estimate peak flow events in these sub-catchments. Efforts have been made to validate the methodology using local and regional data.

The 200-year flood (0.5% probability of exceedance in any single year) was selected as the baseline design flood for these closure planning initiatives. The closure planning team feels that this is an appropriate criteria for the design of closure water conveyance structures at the Minto Mine site. Preliminary sizing of water conveyance and diversion channels for closure was conducted to provide minimum dimensions that are required to safely convey the 1:200 year flood. It is recognized that the flow capacity of channels has the potential to be reduced due to possible partial obstructions (e.g., ice damming, sediment accumulation, debris). Adequate freeboard will be applied to all channels to ensure that they have additional hydraulic capacity to convey larger flows if required, or to offset any part of the cross-section that could be obstructed.

4.2 CATCHMENT DELINEATION

Catchment delineation presents a challenge at the Minto Mine site, due to the small size of the catchments and the presence of waste rock dumps and tailings storage that may be modified at closure.

Delineation of the primary ditch sub-catchments was performed using ESRI Spatial Analyst Software in ArcGIS. Raster data were created using a one metre resolution. The end-of-Phase-IV contour data was used to create a one metre resolution digital elevation model (DEM) of the site. This DEM was then used to anticipate how water will flow over the landscape at closure.

The DEM was altered to reflect the proposed diversion structures, "forcing" the water to move into ditches at the desired locations. Using ESRI Spatial Analyst Watershed tools, a fill was applied to the DEM to eliminate artifacts in the DEM. It was determined that a fill of 5 metres was most appropriate, filling artifact sinks and not forcing water around legitimate obstacles. The flow direction and flow accumulation were determined in order to delineate the catchments above each ditch.

General characteristics of each catchment were derived from the contour data, including average channel slope, longest flow path, and forested and disturbed/reclaimed coverage. This data was used in the determination of design flows, as presented in the following section.

The primary ditch sub-catchments are presented in Figures 4-1 and 4-2.

Catchment delineation for secondary ditches was performed using the same methodology. The surface area of each cover contributing to a secondary channel was calculated, and average channel slope and longest flow path were derived.

4.3 DETERMINATION OF DESIGN FLOWS FOR PRIMARY DITCHES

Design flood flows for primary ditches were calculated using the rational method, based on the catchment area. The rational method is widely used for flood estimation in small (<25 km^2) rural and urban drainage basins (MTQ, 2004). Given that extreme rainfall events tend to yield the largest instantaneous flows for small watersheds like the Minto Mine site, the rational method provides a methodology to calculate extreme flows from design rainfall events. For all ditches located upstream of the Main Pit and Area 2 Pit the values calculated using the rational method were used directly for hydraulic design, since flows entering these ditches won't experience any significant routing through water bodies. For ditches 400 and 450 located downstream of the pits, flow routing through the pits was considered given the significant surface area of the pits compared to the calculated flows. Freshet flows resulting from snowmelt were considered for the routing study since this is the hydrological scenario that will produce the highest flows for ditches 400 and 450, maximising the inflow volume. The methodology used and the resulting design flows are presented in the following sections.

4.3.1 Upper primary ditch catchments

Upper primary ditch catchments include all ditches located upstream of the Main Pit and Area 2 Pit. The delineated sub- catchments are shown in Figure 4-1.

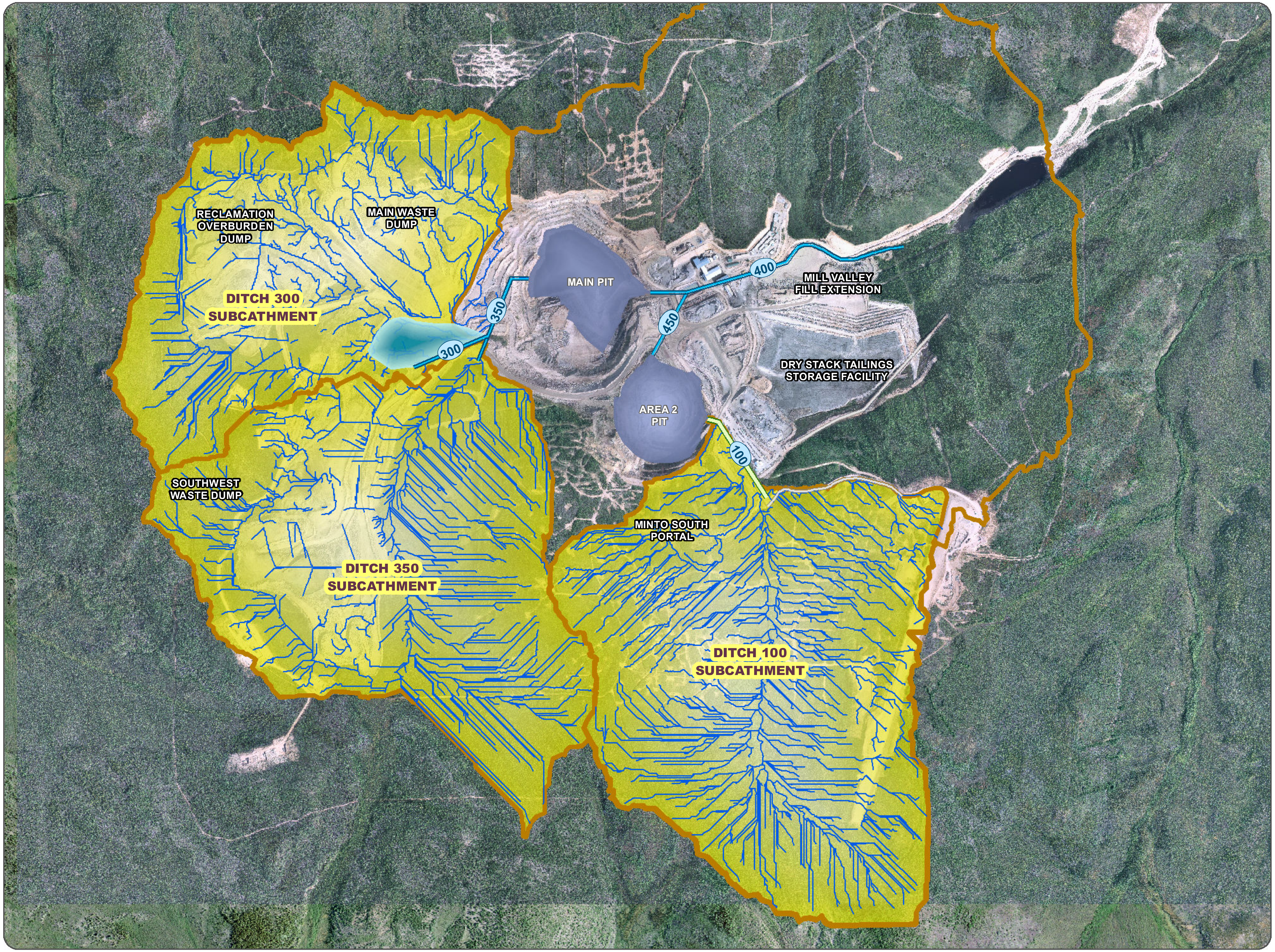

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FIGURE 4-1

UPPER PRIMARY DITCH CATCHMENTS

SEPTEMBER 2013

- Proposed Diversion Structure (Primary Ditch)
- Existing Primary Ditch
- Existing Secondary Ditches
- Modelled Water Flow
- SubCatchment
- Pit Lake
- Sediment Pond

THE LAYOUT OF THE DITCHES IS CONCEPTUAL AND WILL BE FINALIZED IN CONJUNCTION WITH THE DETAILED CLOSURE DESIGN.

0 100 200 300 400 500 Meters

Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 14th 2012.

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Flows for the upper catchment ditches have been calculated using the rational method. Design flows are calculated based on the area of the catchment, a selected rainfall intensity of a given return period, and a runoff coefficient accounting for all factors affecting the relation between peak flow and average rainfall intensity, particularly ground cover and soil type that influence the rate of runoff. The general formula for the rational method is:

$$Q = \frac{AIC}{3.6}$$

Where,

Q is the flow in m^3/s;
A is the catchment area in km^2;
I is the rainfall intensity in mm/h; and
C is the runoff coefficient

Catchment areas delineated for each ditch (primary and secondary), as presented in section 4.2. The catchment area of each ditch located upstream of the pits was used directly to calculate peak flows of different return periods with the rational method.

The rainfall intensity was derived from the Pelly Ranch IDF curve due to the proximity of the weather station to the site. As noted above, Pelly Ranch is situated ~400m lower in elevation than the Minto Mine site, however monthly rainfall at Minto was shown to be 12% less on average than at Pelly Ranch (SRK Consulting, 2012). A preliminary analysis of measured daily rainfall at Pelly Ranch and the Minto Mine site for 2011 and 2012 showed relatively good correlation, although Pelly Ranch typically had higher values for daily precipitation greater than 5 mm. Thus, using Pelly Ranch rainfall intensities could be considered conservative. Table 4-1 presents the IDF curve rainfall intensities derived by Environment Canada for the Pelly Ranch weather station. Rainfall intensities for the 200-year recurrence period were derived using the same methodology.

Table 4-1 Rainfall intensities from Pelly Ranch IDF curve

Duration	Rainfall intensity (mm/h) – Recurrence period					
	2 years	10 years	25 years	50 years	100 years	*200 years*
5min	39	77	96.2	110.4	124.4	*140.3*
10min	27.9	54.3	67.5	77.4	87.1	*96.8*
15min	22.6	45.4	56.9	65.4	73.9	*82.6*
30min	13.7	27.4	34.2	39.3	44.4	*49.0*
1h	8.2	16.5	20.7	23.8	26.9	*30.1*
2h	5.1	9.4	11.6	13.3	14.9	*16.5*
6h	2.2	3.7	4.4	5	5.5	*6.0*
12h	1.4	2.1	2.5	2.8	3.1	*3.3*
24h	0.8	1.2	1.5	1.6	1.8	*1.9*

The length of the rainfall event was adjusted to the time of concentration of each sub-catchment. The time of concentration is defined as the theoretical time it would take for water to travel from the headwaters of the basin to the outlet, or the time it would take for the entire catchment to contribute to flow. Various equations are available in the literature to calculate the time of concentration. Most of them were developed based on site observations and measurements, and are linked to the catchment's main characteristics. The Quebec Ministry of Transport (MTQ, 2004) suggests the following equation for catchments with a runoff coefficient lower than 0.4 which will used in the current analysis:

$$t_c = \frac{3.26\ x\ (1.1 - C)\ x\ L^{0.5}}{{S_c}^{0.33}}$$

Where,

C is the runoff coefficient;
L is the creek length (longest flow path) in m; and
S_c is the 85-10 slope in % (slope of the longest flow path excluding the upper and lower extremities).

The 1 hour rainfall intensity I is then multiplied by a factor F to adjust the value to the time of concentration. The 1 hour rainfall intensity is used because all of the sub-catchments have a time of concentration smaller than 2 hours. The rational method then considers a storm occurring over a duration equal to the time of concentration. The formula for F is:

$$F = 12.25\ x\ {t_c}^{-0.612} \qquad \text{if } t_c < 1 \text{ hour}$$

$$F = 17.07\ x\ {t_c}^{-0.693} \qquad \text{if } t_c > 1 \text{ hour}$$

The last parameter required for the rational method is the runoff coefficient, which is used to account for the speed flows tend to travel through the basin, based on the catchment's physical characteristics. Determination of the runoff coefficient is based on soil type, cover type (natural forest or land disturbed by mine operations, including tailings storage, mine pits, waste rock dumps, etc), average basin slope and anticipated retention time. The runoff coefficient is chosen based on tables extracted from various references (i.e, Pilgrim and Cordery, 1993, Alaska Department of Environmental Conservation 2011, MTQ 2004). It is the parameter within the rational method that has the largest influence on the calculated flows, although there is no specific equation based on empirical values that can be used to determine the runoff coefficient. For reference, a runoff coefficient of 1 would be applied to a soil that is fully impervious and has no friction in a catchment with a steep average slope, while a runoff coefficient close to 0 would be applied to a highly permeable soil capable of absorbing most of the rainfall and located within a flat catchment. Conservative values were chosen for the current study, in particular given the presence of permafrost which can reduce infiltration and increase runoff. The following values were used for the calculations of flows:

- Forested area: C = 0.25 (largest value recommended in the literature for forested areas)
- Disturbed land (by mine operations): C = 0.5 (corresponding to values suggested for graded soils with a slope greater than 6 to 8%)

Finally, the calculated flows from the rational method were multiplied by a routing coefficient to consider the lag effects that wetlands, swampy areas, and depressions would have on floods. This is especially relevant for areas where waste rock dumps and tailings piles are located, given the presence of small localized depressions generating temporary storage. A coefficient of 0.8 was selected, based on the assumption that approximately 5% of catchment area provided temporary water retention (MTQ, 2004).

Table 4-2 presents the characteristics for each primary ditch sub-catchment that were used in the application of the rational method. The weighted runoff coefficient, based on the percent cover of forested area and of disturbed land, varies between 0.27 and 0.40 for all sub-catchments. The time of concentration varied between 48 and 74 minutes for the upper catchment ditches.

Table 4-2 Upper primary ditch catchment characteristics

Parameter	Ditch 100 basin	Ditch 300 basin	Ditch 350 basin
Catchment area (km²)	2.2	1.7	3.9
Average catchment slope (%)	13	18	9
Forest area (%)	95	40	55
Longest flow path length (m)	2400	1500	2500
85% elevation (m)	920	920	925
10% elevation (m)	815	850	840
Longest flow path slope (%)	5.8	6.2	4.5
Weighted runoff coefficient	0.27	0.40	0.36
Time of concentration (min)	74	48	76

Flows of various return periods were calculated for primary ditches located upstream of pits. Table 4-3 presents the calculated flows for the primary ditches upstream of the Main Pit and Area 2 Pit. The 200-year flood flow has been selected as the design flood for the primary ditches.

Table 4-3 Upper primary ditch catchment flows

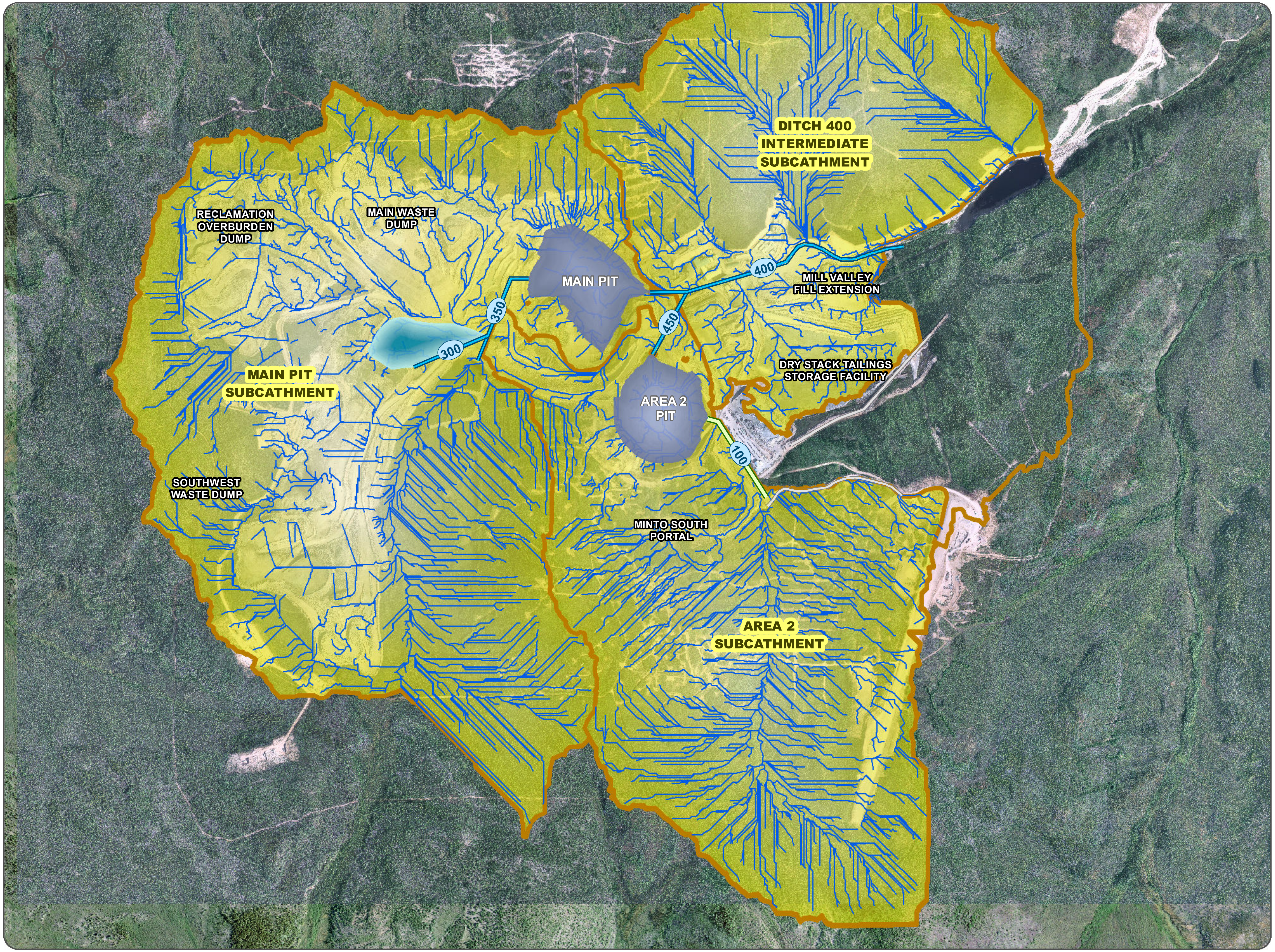
	Catchment area (km²)	Flood flows (m³/s)			
		1:2 years	1:25 years	1:100 years	1:200 years
Ditch 100	2.2	0.9	2.4	**3.1**	3.5
Ditch 300	1.7	1.4	1.4	**4.5**	5.0
Ditch 350	3.9	2.2	5.5	**7.2**	8.0

The above calculated values were verified using the HEC HMS software developed by Hydrologic Engineering Center (HEC) of the United States Army Corps of Engineers (USACE). The software allows users to perform watershed modelling using various methods to simulate precipitation runoff processes. A model of the watershed is first created by entering physical characteristics for each sub-catchment and connecting reaches. The design rainfall event is then entered to provide a basis for the flow calculations. Finally, various methods are available to account for base flows or for reduction in the potential runoff, due to infiltration, friction, storage areas, etc. Routing of inflows was also performed using HEC HMS for the Main and Area 2 pits (see section 4.3.2).

Simplified simulations were run for the Minto Mine site watershed to determine the inflows for each sub-catchment. The SCS Curve Number loss method was used to account for the variation in the runoff coefficient between different catchments (Curve number between 70 and 85), and the SCS Unit Hydrograph transform method to account for the calculated time of concentration. Resulting flows for the upper sub-catchments were generally within 10% of the values presented in Table 4-3, thus confirming the values calculated with the rational method. The rational method in its application considers more of the physical characteristics of catchments (i.e., percent forested area, flow path length and slope, etc) compared to HEC-HMS, which relies more on soil characteristics and infiltration parameters. Since comprehensive data about all site soil characteristics is not available, the rational method provides a better approach by utilizing the available topographical information.

4.3.2 Lower primary ditch catchments

Ditches 400 and 450 are located downstream of the Main Pit and Area 2 Pit. Flows in these ditches will be influenced directly by the routing of upgradient flows through the pits. This routing through the pits is significant due to the large surface area of the pits compared to the inflows. Ditch 450 drains the sub-catchment of the Area 2 Pit, while ditch 400 drains the sub-catchment of the Main Pit and the intermediate watershed below the pit. The delineated sub-catchments of ditches 400 and 450 are presented in Figure 4-2. The main characteristics of each sub-catchment is presented in Table 4-4.



capstone
MINTO MINE

MINTO MINE PHASE IV

CLOSURE HYDROLOGY REPORT

FIGURE 4-2

LOWER PRIMARY DITCH CATCHMENTS

SEPTEMBER 2013

- Proposed Diversion Structure (Primary Ditch)
- Existing Primary Ditch
- Existing Secondary Ditches
- Modelled Water Flow
- Sediment Pond
- Pit Lake
- Subcatchment

THE LAYOUT OF THE DITCHES IS CONCEPTUAL AND WILL BE FINALIZED IN CONJUNCTION WITH THE DETAILED CLOSURE DESIGN.

0 50 100 200 300 400 500 Meters

Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 14th 2012.

NAD 83 UTM Zone 8N

ACCESS

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(*Last edited by: mducharme;13/09/2013/08:54 AM*)

Table 4-4 Lower primary ditch catchment characteristics

Parameter	Ditch 400 basin	Ditch 450 basin
Catchment area (km²)	8.8	2.4
Average catchment slope (%)	20	17
Forest area (%)	65	85
Weighted runoff coefficient	0.34	0.28

As a result of significant routing through the pits, flows calculated for ditches 400 and 450 using the rational method over the total surface area of their respective sub-catchments would be overestimated for an extreme rainfall event. As such, routing of the inflows from the upper sub-catchments was undertaken using HEC HMS, with the addition of intermediate sub-catchment flows to the system. The resulting flows for the 200-year flood are 2.2 and 0.4 m^3/s for ditches 400 and 450, respectively, considerably smaller than the contributing upper catchment ditch flows. This is due to the relatively small overall inflow volume resulting from a short but intense rainfall event, and the extensive storage provided by the pits.

Thus, another approach to estimating design flood flows for these ditches was considered, focusing on the freshet period. Specifically, a constant base flow resulting from snowmelt was estimated and superimposed on a 24-hour rainfall event with a 200-year recurrence. Using this method, it is assumed that the inflows to the pits will be constant over a period of time and lead to a balance between inflows and outflows.

Available snow data from the Minto Mine site was used to estimate an appropriate snowmelt flow. For the purpose of determining an event of approximately 200 years in recurrence, the snowmelt flow was maximized based on the available data and local knowledge of freshet occurrence. Nine years of spring snow data is available at Minto, with measurements taken at three different sites in early March, April and May. Data is available as snow water equivalent (SWE) in mm. The maximum SWE is observed in most years in April, or sometimes in March, while there is generally minimal to no snow left on the ground by early May. Given that snowmelt occurs primarily in April at the site (Clearwater Consultants Limited, 2006), for the purpose of the estimation of a snowmelt base flow, the maximum SWE values observed in April at any of the stations was utilized. The values are presented in Table 4-5.

Table 4-5 Minto Mine site snow data

Year	Maximum April SWE (mm)
1994	112
1995	73
1998	76
2006	101
2007	107
2008	101
2009	170
2010	86
2011	143
Average	108

A frequency analysis was done with the above data to determine SWE values of different return periods. Given only nine years of data available, the estimation of SWE values for return periods of more than 20 years was not considered appropriate. Results of the frequency analysis using various methods (Gumbel, GEV, Log-Pearson III) suggest that the maximum measured SWE value of 170 mm has a recurrence interval greater than 20 years, likely in the 25 to 30-year recurrence interval range. This value was therefore used to determine the resulting snowmelt base flow, assuming complete snowmelt over 7 days, with a 12-hour melting period per day. This hypothesis is based on local knowledge and observations, and is considered conservative to maximise the resulting flow. Table 4-6 summarizes the snowmelt base flow estimation.

Table 4-6 Snowmelt base flow analysis

Parameter	Value
Maximum Snow Water Equivalent– ~25-year return period	170 mm
Snowmelt period (12 hours per day)	7 days and 12 hours per day
Resulting constant snowmelt flow	0.56 m^3/s /km^2

The snowmelt base flow was then calculated for each of the upper sub-catchments that flow into the pits (ditches 100, 300 and 350) using the unit value per km^2 presented above.

A 24-hour rainfall event with 200-year return period was then added to the snowmelt base flow using the data presented in Table 4-1 which yields a total rainfall of 45.6 mm in a 24-hour period. This was added as a constant flow, assuming that the resulting flow from rainfall is constant for a prolonged period of time, leading to the pits reaching a steady state (equal flows entering and exiting the pits). The rational method was again used for this analysis, for a storm duration of 24 hours. The flows calculated in the previous section are larger, for a storm lasting only the time of concentration of each watershed. However, routing those flows through the pits leads to smaller flows downstream in ditches 400 and 450 compared with the constant flow resulting from a 24-hour rainfall event. This is a conservative assumption that increases outflows from the pits given a greater inflow volume.

Finally, a snowmelt base flow and a 24-hour event rainfall flow were also calculated for the intermediate watershed of ditch 400 below the Main Pit, using the same methods outlined previously.

Table 4-7 and 4-8 present the resulting calculated flows for each lower sub-catchment. All values calculated are added together to obtain the resulting maximum flow in ditches 400 and 450.

Table 4-7 Area 2 Pit outlet and ditch 450 design flows

Component	Snowmelt flow (m^3/s)	24 hr rainfall flow (m^3/s)
Sub-catchment 100	1.3	0.3
Area 2 Pit sub-catchment	0.1	0.1
Total at outlet of Area 2 Pit	**1.4**	**0.4**
Ditch 450 – TOTAL ESTIMATED DESIGN FLOW	**1.8**	

Table 4-8 Main Pit outlet and ditch 400 design flows

Component	Freshet flow (m³/s)	24 hr rainfall flow (m³/s)
Sub-catchment 350	2.2	0.8
Main Pit sub-catchment	0.3	0.1
Total at outlet of Main Pit	**2.5**	**0.9**
Outlet of Main Pit – TOTAL ESTIMATED FLOW	**3.4**	
Intermediate sub-catchment of ditch 400 (including the DSTSF)	1.0	0.4
Flow from ditch 450	1.4	0.4
Ditch 400– TOTAL DESIGN FLOW	**6.6**	

4.3.3 Summary of design flows

Design flows were determined for all primary ditches. The 200-year flood was chosen as the design flood, with the most severe hydrological scenario considered for each type of ditch. The ditches will be designed to ensure that the design flows can pass safely and respect all of the selected design criteria. Table 4-9 summarizes the selected design flows for all primary ditches

Table 4-9 Design flows for primary ditches

Component	Design flow (m³/s)
Ditch 100	3.5
Ditch 300	5.0
Ditch 350	8.0
Ditch 400	6.6
Ditch 450	1.8
Main Pit outlet structure	3.4
Area 2 Pit outlet structure	1.8

4.4 DETERMINATION OF DESIGN FLOWS FOR SECONDARY AND TERTIARY DITCHES

We refer to secondary and tertiary ditches as all ditches that will convey water from the various waste rock dumps and the DSTSF to the primary ditches. These ditches will be constructed to prevent surface water from eroding cover materials. Tertiary ditches will be laid out on the waste rock dumps and tailings surface and will connect to a main secondary ditch that will convey water to the bottom of each waste rock dump and of the DSTSF.

The rational method outlined in the previous section was also used to compute flows for all secondary ditches, with a simplified approach to determine catchment characteristics. A runoff coefficient of 0.5 was used for the waste rock dumps and the DSTSF. The small surface area of sub-catchments (less than 1 km^2) combined with a high runoff coefficient yields a small time of concentration of less than 30 minutes for most secondary ditch sub-catchments. Given the small size of the sub-catchments contributing flow to tertiary ditches, conservative design flows were selected in comparison to calculated secondary ditch flows.

Figure 3-1 in section 3.4 presents a potential layout of secondary and tertiary ditches, while Table 4-9 summarizes the design flows. Selected values were based on the 200-year flood. All secondary and tertiary ditches will be sized and protected to resist at a minimum the flows presented below. The final layout of secondary and tertiary ditches will be determined at closure. It will be laid out to accommodate the final topography of the waste rock dumps and DSTSF, and to minimize the risk of erosion.

Table 4-10 Secondary and tertiary ditch design flows

		Design flow (m^3/s)
Secondary ditches	- DSTSF	3.0
	- Main Overburden Dump - Southwest Dump (South section)	2.0
	- Southwest Dump (Middle and North sections) - South Overburden Dump - Main Waste Dump - Tailings Diversion Ditch	1.0
Tertiary ditches		0.5

4.4.1 Validation

As validation for the design flows calculated for the primary and secondary ditches, hydrometric data collected on Minto Creek and for small streams less than 100 km^2 in Yukon's interior hydrographic region collected by Environment Yukon were reviewed. In particular, maximum daily flows were extracted from the hydrometric records to establish the observed range of maximum daily flows per square kilometre.

Table 4-10 lists the characteristics and peak flows of the 11 small streams reviewed for validation of design flows. Ranging from 4.5 to 93 km^2, measurements on these streams have reported peak flows ranging from 0.04 to 0.96 $m^3/s/km^2$. For Minto Creek, hydrometric data have been collected intermittently at two stations, however continuous data logging only began after mining at Minto Mine had begun, and runoff storage in the water storage pond had been initiated (April 2007). From these data a peak flow of 0.02 $m^3/s/km^2$ for W3 and 0.05 $m^3/s/km^2$ for W1 was observed. Prior to 2007 only spot measurements were taken, although a value of 0.55 m^3/s was reported for W3 in May 1997, resulting in a peak flow of 0.05 $m^3/s/km^2$. Thus the Minto Creak measurements are at the lower end of the peak flows reported regionally.

Table 4-11 Small streams

Station ID	Station Name	Watershed Area (km^2)	Years of Record	Max Daily Flow (m^3/s)	Peak Flow ($m^3/s/km^2$)
29AB007	Granger Creek	4.5	8	4.29	0.96
30HA001	Dale Creek at ford on Amax Road	14.2	2	4.91	0.35
29AB006	Wolf Creek - Upper	14.5	6	3.38	0.23
29AC005	Haeckel Creek near Km 1493 Alaska Highway	30.5	3	1.20	0.04
30BE003	Cosh Creek	32.5	6	1.63	0.05
30AD005	Flood Creek at Km 100.3 Nahanni Range Road	42.8	3	8.09	0.19
29AE003	Partridge Creek at Km 1184.9 Alaska Highway	63.7	11	16.0	0.25
29BA002	180 Mile Creek at Km 295.8 North Canol Highway	83.1	7	23.43	0.28
29BB001	Boulder Creek at Km 387.0 North Canol Highway	84.1	6	21.27	0.25
29BC003	Vangorda Creek at Faro Townsite Road	91.2	17	10.60	0.12
30BE002	Contact Creek - Upper	93.0	5	13.30	0.14

In comparison, the peak flows calculated for the design of water conveyance structures for Minto Mine closure range from 1.4 to 2.7 $m^3/s/km^2$ for the upper catchment primary ditches. These peak flows are higher than for all small streams reviewed and well above the Minto Creek values. For the lower catchment primary ditches routing plays a significant role in attenuating peak flows, however relatively high values close to 0.7$m^3/s/km^2$ for ditches 450 and 400 were calculated.

This analysis confirms that the design flows calculated are reasonably conservative and appropriate for the chosen design event.

5 HYDRAULIC DESIGN

This section presents the preliminary design of all water conveyance structures at the Minto Mine. Design was undertaken at a conceptual level to be able to determine a ±30% cost estimate for the construction of the closure works. The selected design criteria, methodology and channel sizes are presented hereafter.

5.1 DESIGN CRITERIA

The design criteria for drainage ditch sizing were selected based on the level of risk associated with failure of the proposed infrastructure and previous experience in mine closure. Several assumptions were chosen as part of the design process and are outlined below. The purpose of the drainage ditches is to safely convey surface water through and downstream of the Minto Mine site at closure. Drainage ditches need to be sized to resist a design flow. Appropriate ditch dimensions to prevent overtopping and adequate means of erosion protection will provide a safe and reliable design. Erosion protection can be provided by adequate channel protection (riprap or other types of liners), and drop structures and energy dissipation works when slopes are too steep.

5.1.1 Channel sizing

The design flows for all ditches (primary, secondary and tertiary) were selected as the 200-year flood. Primary ditches will be designed using the calculated design flows, while secondary and tertiary ditches will be designed using selected values that can safely convey the 200-year flood. The calculation of design flows was not done for tertiary ditches in the current study as these will only require minor swales.

The selected values for the primary ditches were presented in section 4.3.3 (Table 4-9) and the selected values for secondary and tertiary ditches were presented in section 4.4. (Table 4-10).

The selected design criteria for all drainage ditches are outlined below. These design criteria, however, will not apply to additional structures that may be required to convey water down steeper slopes. This includes the steep sections and spillways that need to be constructed as part of the secondary ditches to convey water from the top of the waste rock dumps and the DSTSF to the bottom. These works are discussed in Section 6 of this report.

Flow velocity

- The maximum allowable flow velocity is set at **3.5 m/s** in all primary ditches.

This velocity will limit the required riprap size to a D_{50} of 300 mm or less which is a size that is assumed to be easily available on the Minto Mine site. Other means of erosion protection considered, such as synthetic liners, will work best with velocities equal or less than 3.5 m/s. Channel slopes will be limited such that the flow velocities don't exceed this value. When a ditch slope exceeds the allowable slope (for the design velocity), additional works will be required to safely convey the flow. Two options are envisioned depending on the ditch considered; either conveying water through steeper slopes using drop structures and stilling basins configured to ensure the formation of a hydraulic jump in a controlled location and dissipating energy, or adding fill along the ditch profile to lower the slope and designing a spillway at the channel outlet. Potential additional works are discussed in more detail in Section 6.

- The maximum allowable flow velocity is set at **2.5 m/s** for all secondary ditches, except in their steep sections where spillways will be constructed.

Secondary ditches will flow for the majority of their length on top of covers with mild slopes (lower than 2%). The design velocity chosen for these ditches is lower than for the primary ditches to simplify the construction and ensure the use readily available materials. A riprap size with a D_{50} of 150 mm will resist such velocities. Spillways for waste rock dumps faces are discussed in Section 6.

The maximum allowable slope for each ditch will be based on this maximum allowable velocity criteria. The slope has been determined for each ditch for a given cross-section,.

Channel geometry

All drainage ditches will have a trapezoidal cross-section, with the following characteristics.

- Side slopes of 2.5H:1V;
- A minimum channel slope of 0.5% is selected for all ditches;
- A target ratio of 2 is selected as the maximum ratio of base width over maximum water depth.

These design criteria are assumed to provide the optimal and most economical ratio to minimize cut and fill volumes, and to limit the size of riprap required for erosion protection. When the closure plan is implemented, further optimization studies will be required to determine the optimal channel size and alignments.

Freeboard allowance

The following freeboard allowances were selected to protect the ditches against overtopping and provide a safety margin against potential obstructions (debris, sediment deposition, settlement, etc.). These provide an additional margin of safety for calculated flows that present uncertainty as stated in section 4.

- Primary ditches: 0.5 m
- Secondary ditches: 0.3 m

A larger freeboard allowance is selected for the primary ditches since they will capture most of the flow coming out of the mine, especially for ditches 400 and 450.

5.1.2 Construction methods and available materials

The drainage ditches will be either excavated through earthfill material or constructed with available fill, depending on the location. Construction materials will need to meet licensed requirements for construction grade materials.

In general, any channel that will run over placed fill at the site is unlikely to encounter permafrost. It is however possible that some of the fill already in place is non-engineered fill, such that it may have inconsistent levels of compaction and may contain frozen soils and ice. It could than result in significant differential settlement, thus modification of the constructed ditches profile which could provide to be a mechanism of failure Excavation of the fill already in place may be required in some location, or the placement of additional material, to provide a proper foundation for the ditches in the long term. In the event that permafrost is encountered along the proposed alignments, gravel pads or additional means of protection may have to be put in place to ensure long term stability of the ditches.

Cross-sectional dimensions and optimal slopes will require further optimization when the closure plan is implemented to determine the most economical solutions for each ditch. The ditches will be laid out along the proposed alignments within the calculated range of longitudinal slopes that allow the design criteria to be met. Grading of the alignment will be required in many locations.

Erosion protection will be provided by rip rap or synthetic liners, such as “Geoweb”. Small to medium rip rap should be easily available without any significant blasting and sorting required on site. It is assumed that rip rap with a D_{50} equal to or smaller than 300 mm can be obtained at a reasonable cost. As an alternative, Geoweb could be used where ground conditions can’t provide adequate stability to rip rap. Geoweb can be filled with crushed stone with a diameter equal to or smaller than 100 mm, and provide an equivalent means of protection to rip rap. In areas where larger velocities will be experienced (spillways, energy dissipation basins), grouted Geoweb could provide resistance against larger flow velocities. Concrete may also be used in a few specific locations, but its use will be minimized to limit costs. A geotextile will be installed under all riprap material.

5.2 DRAINAGE DITCH DESIGN

The preliminary design of ditches was completed based on the previously calculated design flows. The longitudinal profiles along the proposed ditch alignment were extracted to determine the optimal profile.

5.2.1 Ditch profiles

The proposed site layout for water conveyance structures and other infrastructure at closure has been discussed in detail in Section 3.4.4. Ditch profiles were then extracted from ArcGIS for each primary ditch to determine the variation in longitudinal slope along the proposed alignment. Table 5-1 summarizes the main characteristics of the current natural ground profile along each proposed primary ditch. The average slope was calculated along the entire path length, excluding steeper slopes at the downstream end of the proposed ditches. Minimum and maximum slopes were estimated over a minimum distance of at least 20 m. If steeper slopes exist in certain location, they are classified as `steeper drops’.

Table 5-1 Primary ditch profile characteristics

Ditch	Average slope (%)	Min Slope (%)	Max slope (%)	Steeper slopes	Outlet
100	1.1	0.5	2.5	No	Flows into Area 2 pit
300	4.8	0.5	6	Yes (26% over 25 m and 21 % over 15 m)	Flows into Ditch 350
350	0.5	0	6.6	No	Flows into Main Pit
400	5.9	0	18	No	Connects with Water Storage Pond
450	8.8	0	11	Yes (up to 40% over 20 m)	Connect with Ditch 400

Secondary ditches collect flow from the tertiary ditches and will span both the relatively flat tops of the WRDs and will also convey surface flows down the steep faces of the WRDs – down slopes as steep as 1.5H:1V and across flat benches. The secondary ditches will be fortified with both rip rap and geosynthetic liner reinforcement. It is anticipated that steep sections may require concrete reinforcement. The secondary ditches will drain into energy dissipation ponds at the base of the WRDs and the DSTSF.

Tertiary ditches will flow entirely on top of covers such that they will be laid out on fairly mild slopes, have relatively minor flows and will require minimal engineering reinforcement. .

5.2.2 Methodology

Ditches dimensions were determined using the Manning's equation for open channel flow, using trapezoidal cross-sections. The design criteria outlined before were used as target values. The equations is:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where,

Q is the flow in m^3/s;
n is the Manning's roughness coefficient;
A is the flow cross-sectional area in m^2;
R is the hydraulic radius in m (defined as A/P, where A is the flow cross-section area and P the wetted perimeter);
S is the channel slope in %

Solving this equation for a given flow requires the determination of the water depth that matches a given slope for a fixed Manning's coefficient. Iterative solving is required to obtain the solution to the depth that influences both the cross-sectional area A, the wetted perimeter P and hence the hydraulic radius R.

A Manning's roughness coefficient of 0.035 was selected as it applies to engineered channels with rockfill elements. If a geosynthetic liner is selected in certain locations, it would lower the roughness and thus lower the Manning's coefficient. The value could then vary between 0.012 and 0.025 depending on the type of fill that is used (ODOT, 2005).

The design process involves solving the above equation for two distinct configurations, i.e. to determine the minimum and maximum allowable slope for each ditch. The objective is to provide channel dimensions that can apply to a range of slopes within the proposed alignments. The two step process is as follows:

1) The minimum channel slope leads to the largest water depth in the channel. The depth of each ditch is sized based on the minimum slope. Subcritical flow is observed in this condition

2) The maximum channel slope leads to the fastest velocities. The maximum channel slope was defined based on the maximum allowable velocity of 3.5 m/s that was selected as the design criteria. Supercritical flow is observed for most primary ditches in these conditions, although the resulting Froude numbers are 2 or less, thus indicating limited turbulence within the channels.

The optimal base width to meet the design criteria and obtain the largest maximum slope was determined based on a trial and error exercise. Various ditch configurations were considered for both primary and secondary ditches.

5.2.3 Channel erosion protection

All ditches will require protection against erosion resulting from flow velocities and shear stresses. Rip rap or synthetic liners will be used, depending on site specific conditions and cost efficiency.

The Isbash equation has been used to determine the appropriate size of rip rap that is required to ensure adequate channel protection to resist flow velocities and resulting shear stresses. The Isbash equation is widely used in engineering applications and relates the mean diameter of rip rap (D_{50} in mm) required to resist a given flow velocity:

$$D_{50} = \frac{V^2}{2g\ C^2 \left(\frac{\gamma_r - \gamma_e}{\gamma_e}\right) \cos \alpha}$$

Where,

V is the flow velocity in m/s;
g is the gravitational constant of 9.81 m^2/s;
C is the Isbash coefficient for turbulence (0.86 for low turbulence, up to 1.20 for high turbulence where hydraulic jumps form);
γ_r is the specific weight of rock, approximately equal to 2.65 x 9810 N/m^3;
γ_e is the specific weight of water, approximately equal to 1 x 9810 N/m^3;
α is the angle of repose of rip rap (based on side slope of channel).

The following graph presents curves for different turbulence coefficients for given velocities. A side slope of 2.5H:1V was used to determine the angle α, which is the side slope proposed for all drainage ditches.

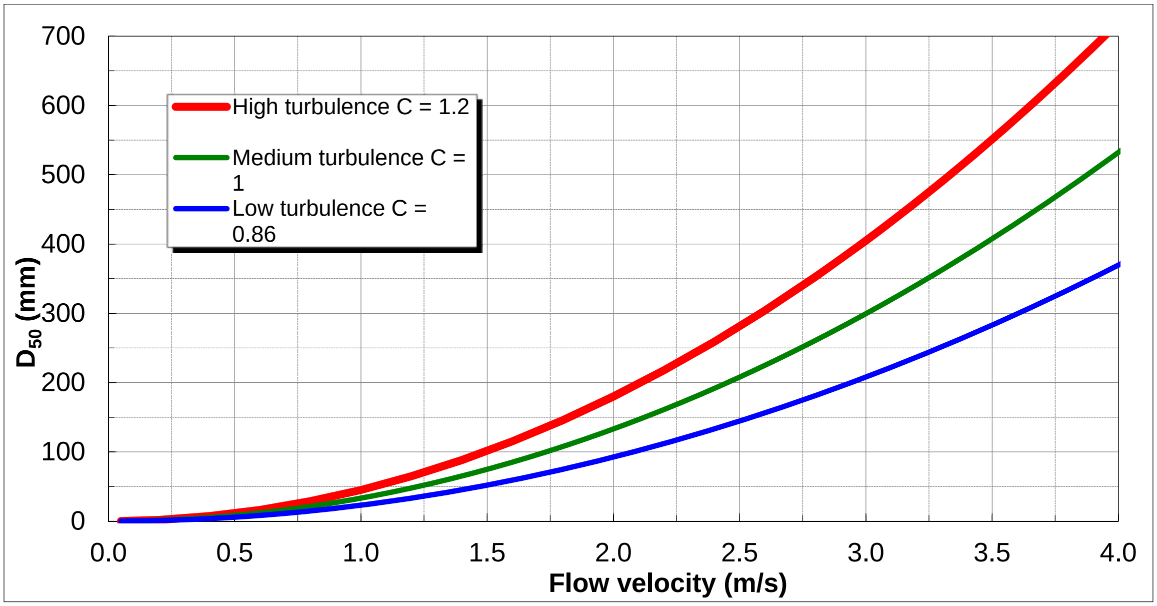

Figure 5-1 Required Rip rap D_{50} to Resist a Given Flow Velocity

It is anticipated that low turbulence will be observed along the ditches (except where spillways or drop structures will be required), as such we adopt a C coefficient equal to 0.86. For the primary ditches, the maximum allowable velocity of 3.5 m/s will require rip rap with a D_{50} of 300 mm. For the secondary ditches, rip rap with a D_{50} of 150 mm will be sufficient to resist a maximum velocity of 2.5 m/s. The required D_{50} for each primary ditch is presented in Table 5-2 in the next section.

5.2.4 Primary ditches

Each primary ditch was analyzed separately, to determine an adequate minimum cross-section and range of longitudinal slopes that would meet the design criteria. Table 5-2 presents the selected base width, slopes and the required rip rap mean diameter (D_{50}) for each primary ditch. The relevant calculated hydraulic parameters are also presented. Those dimensions are the minimum required to ensure an adequate design for the 200-year flood. A 0.5 m freeboard will be applied to all primary ditches to ensure an adequate safety margin against overtopping. The minimum depth of each ditch should then be equal to the maximum flow depth plus 0.5 m.

A short discussion for each ditch is presented below. The constructed profile could vary within the established minimum and maximum slopes at construction to optimize the profile, by minimizing cut and fill. Final ditch alignments, profiles and cross-section should be optimized in the detailed design phase.

Table 5-2 Design parameters for primary ditches

Ditch	Design flow (m^3/s)	Base width (m)	Minimum slope (%)	Maximum slope (%)	Maximum flow depth (m)	Maximum flow velocity (m/s)	Maximum rip rap size – D_{50} (mm)	Steep slopes/stilling basin
100	3.5	1	0.8	1.5	0.8	1.9	100	No*
300	5.0	1.5	2	6.5	0.7	3.5	300	Yes (at outlet)
350	8.0	2	1	4.5	0.9	3.4	300	No*
400	6.6	1.5	1	5	1.0	3.4	300	Yes (MVF)
450	1.8	1	1	10	0.6	3.2	250	No

*Ditches 100 and 350 will required an overflow spillway at their outlet to discharge water into the Main Pit and Area 2 Pit

Ditch 100

Ditch 100 already exists on the Minto site and is known as the South Diversion Ditch. It currently intercepts water from the hills to the south east of the mine site and conveys it towards and around the Area 2 Pit. This ditch will be upgraded and consolidated as needed at closure, but will remain the same dimensions. The current ditch has an estimated total capacity of 13.3 m^3/s (SRK, 2013) which is nearly 4 times the calculated 200-year design flow of 3.5 m^3/s. If the ditch was to be reconstructed, only a 1 m channel base width is required. The ditch can be constructed on a slope between 0.8 and 1.5%, which easily follows the current topography with only grading required and no significant excavation or fill. The minimum required depth of the ditch is 1.3 m (0.8 m maximum flow depth and 0.5 m freeboard allowance). A minimum D_{50} of 100 mm is required for the rip rap. The current ditch has rip rap with a D_{50} of 200 mm, which is sufficient to resist the calculated flow velocities resulting from the design flood.

Ditch 100 empties into the Area 2 Pit through an overflow spillway. Such a spillway is already constructed and should only be consolidated if required at closure.

Ditch 300

Ditch 300 will intercept water from the northwest corner of the mine site, i.e. from the Reclamation Overburden Dump and the Main Waste Dump. It will connect with Ditch 350 which flows into the Main Pit. A minimum base width of 1.5 m is required to convey the 5 m^3/s design flow. The depth of the ditch should be at least 1.2 m (0.7 m maximum flow depth and a 0.5 m freeboard allowance). Such a cross-section can be constructed on a slope varying between 2 and 6.5% to safely convey the flow. A minimum D_{50} of 300 mm is required for the rip rap.

Ditch 300 will require a steeper section at its outlet to join ditch 350. Larger riprap or another means of protection will be required in this location. An energy dissipation basin will also be required at the junction of the two ditches.

Ditch 350

Ditch 350 is the primary ditch with the highest design flow at 8 m^3/s. It will convey water from the western half of the mine site, where the waste rock dumps are located. It captures flow from the Southwest corner of the mine site (Overburden Dump and Southwest Waste Sump), and also intercepts flow coming from Ditch 300. A minimum base width of 2 m is required along with a minimum depth of 1.4 m (0.9 m maximum flow depth and 0.5 m freeboard allowance). Such a cross-section can be constructed on a slope varying between 1 and 4.5 %. A minimum D_{50} of 300 mm is required for the rip rap.

Ditch 350 will empty into Main Pit through an overflow spillway. Such a spillway will be designed and constructed at closure.

Ditch 400

Ditch 400 will convey most of the surface water out of the mine site. It act as the outflow from Main Pit which captures the flow from Ditch 350. It also captures the outflows from Area 2 Pit (through Ditch 450) and flows coming from its intermediate watershed downstream of the Main Pit. It will run adjacent to the main access road downstream from Main Pit, to the north of the Mill Valley Fill Extension (MVFE). It will then drop on the MVF east face to reach the bottom of the main valley that leads to the water storage pond at the downstream end of the mine site.

Ditch 400 has a design flow of 6.4 m^3/s. Flows from the upper catchments will experience significant routing through the two pits, such that the flood peaks are attenuated. A minimum base width of 1.5 m and a minimum depth of 1.5 m (1.0 m flow depth and 0.5 m freeboard allowance) is required for Ditch 400. The longitudinal slope of the constructed ditch can vary between 1 and 5%. A minimum D_{50} of 300 mm is required for the rip rap.

Ditch 400 will require the construction of an intake structure at the outlet of Main Pit. The confluence with ditch 450 will also require another structure to properly merge the flows. If possible, those two structures could be combined in a single larger intake basin. A spillway will also need to be designed along the MVFE east slope. A stilling basin will be constructed at its toe to dissipate energy coming from the spillway.

Ditch 450

Ditch 450 will convey the routed outflows from Area 2 Pit. Area 2 Pit will only receive inflows from Ditch 100, such that the design flow of Ditch 450 is of 1.8 m^3/s. Ditch 450 will connect with Ditch 400 after 300 m. A minimum base width of 1 m and a minimum depth of 1.1 m is required (0.6 m maximum flow depth and 0.5 m freeboard). Such a cross-section is adequate for a longitudinal slope varying between 1 and 10%. A minimum D_{50} of 250 mm is required for the rip rap.

Ditch 450 will require the construction of an intake structure at the outlet of the Area 2 Pit. It will empty into Ditch 400 in an energy dissipation basin. These structure will be designed in detail at closure.

5.2.5 Secondary ditches

Secondary ditches will flow on top of covers and convey water from high flat ground down on the steep faces towards the primary ditches. Their design includes two parts:

- a typical channel cross-section on mild slope (less than 10%)
- a steep section down the waste rock dump and DSTSF faces, with a slope up to 65% (1.5H:1V)

Secondary ditches will be laid out as a single main channel on the top of covers, but will be required in certain locations to be divided into numerous smaller parallel channels to drop from the steep faces to the primary ditches. Smaller channels will allow a reduction in discharge and flow velocities in each channel, and thus reduce the importance of the erosion protection measures required. Stilling basins at the toe of the steep faces will be required to dissipate the energy of the flow coming from higher ground, before it enters the primary ditches.

A single minimal cross-section was developed for all secondary ditches to meet the design criteria and safely convey the 200-year flood at a minimum. This cross-section is applicable to the section of secondary ditches flowing on top of covers, or on mild slopes, but not going down the steep faces of the waste rock dumps and the DSTSF. Since three different design flows were determined for secondary ditches (1, 2 and 3 m^3/s, see section 4.4), the maximum slope limitation varies for each secondary ditch. Table 5-3 presents the calculated values.

Table 5-3 Design parameters for secondary ditches

Ditch	Design flow (m^3/s)	Base width (m)	Minimum slope (%)	Maximum slope (%)	Maximum flow depth (m)	Maximum flow velocity (m/s)	Maximum rip rap size – D_{50} (mm)
Secondary ditches	1	1	0.5	9	0.5	2.5	150
	2	1	0.5	5	0.7	2.5	150
	3	1	0.5	3.5	0.8	2.5	150

A cross-section with a minimum base width of 1 m and a minimum depth of 1.1 m (0.8 m maximum flow depth for 3 m^3/s and 0.3 m freeboard allowance) will work properly for all reaches of secondary ditches within the define slopes. This design will be finalized at closure.

5.2.6 Tertiary ditches

Tertiary ditches will be minor swales that will convey water on top of the covers towards the secondary ditches. All tertiary ditches are designed for a flow of 0.5 m^3/s. They will be laid out over most of the site where needed, to accommodate topography at closure. No preliminary design of tertiary ditches is provided at the current level of study. They will be designed when closure is implemented.

6 ENERGY DISSIPATION STRUCTURES

Section 5 presented the design of ditches and cross-sections that can safely convey water around the site at closure. Additional structures will be required to convey water over steeper slopes and at convergences. The current section outlines the additional structures that are envisioned at the current state of design of closure. It is possible that additional structures may be required at closure depending on the updated site conditions.

6.1 SPILLWAYS AND DROP STRUCTURES

Spillways will be required at every location where a ditch has to be constructed over a slope steeper than its defined maximum allowable slope (see Table 5-2). Spillways allow high velocities and energy levels to be concentrated into confined reaches. All drop structures and spillways will empty into larger water bodies to safely dissipate the energy of the flow (stilling basins or pit lakes).

For the primary ditches, four spillways or drop structures will be designed prior to closure:

1) Ditch 100 spillway into Area 2 Pit (free overflow)

2) Ditch 300 spillway, at its outlet to connect with Ditch 350 (requires stilling basin at toe)

3) Ditch 350 spillway into Main Pit (free overflow)

4) Ditch 400 spillway down the MVFE slope (requires stilling basin at toe)

For secondary ditches, spillways may be required to drop flow from the top of the covers to the primary ditches. Slopes of up to 60% are possible with such a scheme, thus secondary ditches may be divided into additional channels in such location to limit the flow transiting through steep slopes.

Spillways will be design to resist higher flow velocity than the defined maximum allowable velocity criteria. They can be constructed with larger riprap, grouted geosynthetic liners, concrete, or a combination of such materials. If bedrock is found near the surface at the spillway locations, flow will convey straight on profiled bedrock. Spillways will require the construction of energy dissipation ponds at their toe to dissipate the high energy supercritical flow and allow the formation of a hydraulic jump within the basin. The spillway at the end of ditches 100 and 350 will however empty directly into the two pit lakes which will allow to dissipate energy through those large water bodies.

6.2 CHANNEL INTAKES

Two intake structures are required for the Minto Mine Closure at the end of Phase IV: one to convey water from Main Pit into Ditch 400 and one to convey water from Area 2 Pit into Ditch 450.

Main Pit average water elevation = 785 m

Area 2 Pit average water elevation = 802 m

Intakes to Ditch 400 (for Main Pit) and Ditch 450 (for Area 2 Pit) will be designed to flow at water elevations greater than the average values presented above. The invert elevation of both intake structure should be set at those elevations. The intake structures will provide a smooth transition from the deep and slow moving pit lakes flow to the shallow and fast flowing ditches. If required, geotechnical consolidation of the pit edges at the intake structure will be done to ensure adequate long term stability of the structure.

6.3 STILLING BASINS

Stilling basins (or energy dissipation ponds) will be required at the toe of each spillway on site, except for the overflow spillways at the downstream end of ditches 100 and 350 that empty into the pit lakes. This will allow the formation of a hydraulic jump resulting from supercritical flow (with a Froude number larger than 2) in a controlled location. Stilling basins will also be required at the junction of ditches, to properly merge flow and provide an adequate transition to the downstream ditch. They will be required at the following locations:

1) Toe of MVF spillway in ditch 400

2) Ditch 350 – at the confluence with Ditch 300

3) Ditch 400 – at the confluence with Ditch 450

4) At the bottom of most secondary ditches dropping down a steep slope

Stilling basins will be sized independently for each channel and protected with riprap or a synthetic liner to prevent erosion and significant washing of the ground, due to both high velocity and turbulence levels. Stilling basins will de be designed at closure, especially to determine proper foundation conditions and required dimensions.

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