ACCESS

MINTO MINE PHASE V/VI CLOSURE HYDROLOGY REPORT

June 2014

Prepared for:

CAPSTONE MINING

ACCESS CONSULTING GROUP SIGNATURES

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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 updates the Minto Mine Phase IV Closure Hydrology Report prepared as an appendix to the Minto Mine Phase IV Reclamation and Closure Plan (Revision 4.0) submitted to the Yukon Water Board and Yukon Government Minerals Branch in September 2013. This Phase V/VI Hydrology Report, and the previous Phase IV report build 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 V/VI 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.

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 V/VI 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
Preliminary Design of the Tailings Diversion Ditch Upgrade	SRK Consulting	2013
Main Dam Conceptual Design Report	SRK Consulting	2013
Minto Surface Water Hydrology Baseline Report	Access Consulting Group	2013
Minto Climate Baseline Report	Access Consulting Group	2013
Minto Mine Phase IV Closure Hydrology Report	Access Consulting Group	2013
Regional Peak Flow Analysis at Minto Mine	SRK Consulting	2014

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 during the elaboration of the Phase IV DRP. Additional changes were made to address concerns raised during review of this DRP by the Water Board and

EMR, and in response to the Phase V/VI mine plan as submitted to YESAB in July 2013 (Project number 2013-0100).

Minto Mine sub-catchments were delineated and presented in Clearwater Consultants Ltd.'s Phase IV Closure Water Balance (Clearwater Consultants Ltd, 2010), and in the Minto Mine Phase IV Closure Hydrology Report. Given updated end of life footprints for Phase V/VI, these sub-catchment delineations have been updated and ditches alignment slightly modified where relevant

Ditch realignment work for operations (EBA Engineering Consultants Ltd, 2012, SRK Consulting, 2013a) was also reviewed in addition to other methods recently used for hydraulic design at the 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), 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 conveyance systems.

Following the completion of the Phase IV Closure Hydrology Report, additional ditch realignment work for operations was undertaken by SRK Consulting (SRK Consulting, 2013b), and discussions were initiated between ACG and SRK to determine a hydrological approach that would be applicable to both operations and closure. As a result, a regional analysis was undertaken to develop a unit flow curve that could be used as a comparison tool to determine the accuracy of flows calculated with various methods (SRK Consulting, 2014a). Expected flows for floods of different return periods for catchments 1.5 and 5 km^2 were produced, including a 95% confidence envelope, which was used to validate the peak flows presented in this report for closure water conveyance at the Minto Mine site.

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 V/VI 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. The Stage 2 contours were considered for this analysis. The new Main Pit Dump was also incorporated into the terrain model.

Digital elevation model (DEM) were created (1 meter resolution) from the elevation data provided by Capstone. The resulting DEMs were modified to reflect the placement of tailings in the main and area 2 pits. These DEMS were then used to determine the optimal profiles and location for each ditch and also to delineate the sub-catchment boundaries for each ditch. Catchment boundaries and individual catchment statistics were derived using ArcGIS Spatial Analyst tools.

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 the Pelly Ranch climate station from Environment Canada. Last updated in 2009 for stations across Canada, the Pelly Ranch IDF curves were calculated from 33 years of record. 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 (Figure 2-1), 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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CLOSURE HYDROLOGY REPORT
REVISION 5.0

FIGURE 2 - 1

HYDROMETRIC AND SNOW SURVEY STATION

JUNE 2014

- Hydrometric Station
- Snow Monitoring Station
- Phase IV and V/VI Features

1:100,000 *when printed on 11 x 17 inch paper*

0 125 250 500 Meters

Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 11 th 2013.
Site contours derived from 2012 aerial imagery obtained from Challenger Geomatics.

Inset map: Canvec compiled by Natural Resources Canada at a scale of 1:10,000 - 1:50,000. Reproduced under license from Her Majesty the Queen in Right of Canada, as represented by the Minister of Natural Resources Canada. All rights reserved.

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 later 2014, and it is anticipated that Phase V/VI mining operations will commence around the same time – pending authorization.

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, July temperatures 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 updated based on the layout proposed in the Minto Mine Phase IV Closure Hydrology Report prepared as an appendix to the Minto Mine Phase IV Reclamation and Closure Plan (Revision 4.0), the previous decommissioning and reclamation plan (DRP Revision 3.2), and the mine site topographical constraints at closure after Phase V/VI. 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. Primary ditches layout are shown on 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.

Four primary ditches have been incorporated into the water conveyance design, and are described below:

- The South Diversion Ditch, called Ditch 100 in closure, has been constructed as part of mine operations to intercept flow to protect the Dry Stack Tailings Storage Facility (DSTSF) from run-on flow. The ditch currently has the capacity to carry up to 13.3 m^3/s (SRK, 2013a). In Phase V/VI of Minto Mine, this ditch will be altered to accommodate the Area 2 Stage 3 Pit, redirecting flows toward the Water Storage Pond along the upgraded Tailings Diversion Ditch (discussed below), and the existing spillway will be upgraded to convey the overflow from the Tailings Diversion Ditch into the Area 2 Pit. At closure Ditch 100 will flow into the existing spillway into Area 2 Pit. The spillway will be upgraded so that it can convey all upgradient flows into the Area 2 Pit.
- Ditch 200 will control flow predominantly originating from the Southwest Dump, out of the constructed wetland area (W15), while flows from the Main Waste Dump and part of the Reclamation Overburden Dump will be captured in Ditch 300. Ditch 200 will discharge into Ditch 300, running along the face of the Main Pit Dump towards the Main Pit spillway, which will be constructed in operations to direct flows toward the Area 2 Pit. The spillway is detailed in SRK's Main Dam Conceptual Design Report (2013c).
- The Area 2 Pit will provide detention for upper catchment flows in the form of a pit lake at closure. The outlet of the Area 2 Pit will direct flow into Ditch 400. 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, continuing to the valley bottom (to the north of the W37 collection point) and ultimately terminating up gradient of the current water storage pond 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 primary ditches. The design of secondary ditches will incorporate structures, where necessary, to drop water along the steep faces of waste rock dumps, in addition to energy dissipation ponds at the base of steep slopes. Catchment areas contributing to flows that will be routed down steep slopes will be limited to 5 ha in order to minimize flows, velocities and erosion resulting from the concentration of high energy flows. Secondary ditches will be laid out to follow the natural topography and low points when possible. The Tailings Diversion Ditch, to be upgraded in summer 2014 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. The final alignment of other secondary ditches (for example over and around the Main Waste Dump, Reclamation Overburden Dump) will be determined at 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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CLOSURE HYDROLOGY REPORT

FIGURE 3 - 1

CLOSURE WATER MANAGEMENT LAYOUT

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- Outlet Structure
- Primary Ditch
- Spillway
- Transition Reach
- Energy Dissipation Basin
- Water over Tailings
- Wetland
- Dumps
- Pits
- Pit Tailings
- Tailings Diversion Ditch

1:12,000 *when printed on 11 x 17 inch paper*

0 50 100 200 300 400 500 Meters

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Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 11th 2013.
Site contours derived from 2013 aerial imagery and edited by Capstone to show the Phase V/VI feature and their coutours.

Hydrology data provided by Minto Explorations Ltd, May 2009 and edited by ACG.

Datum: NAD 83 Projection: 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 ~2 km^2 for the primary drainage ditches in the upper catchment to 9.8 km^2 for Ditch 400, which routes 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 and lack of long term monitoring record creates inherent uncertainty in the calculation of design flows. Smaller basins have more rapid responses to hydrological events and are highly influenced by local conditions such that data coming from other catchments may not be representative of the Minto mine site. In addition, disturbed and reclaimed areas present a challenge to the hydrological design as they require the characterization of non-natural and irregular topography, which may or may not accelerate the travel time of floods depending on the surface materials. 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 conservative runoff coefficients.

For the larger sub-catchment encompassing the Area 2 Pit (related to Ditch 400) the additional routing of water through the pits provides significant attenuation of flows for design storms. As such, hydrological inputs that would tend to produce the greatest flows were determined, 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 design flood for these closure planning initiatives. Preliminary sizing of water conveyance and diversion channels for closure was conducted to provide minimum dimensions that are required to safely convey the 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-V/VI 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.

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 primary ditches located upstream of the Area 2 Pit the flow 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 (pit lakes being the main routing feature). For Ditch 400, located downstream of the Area 2 Pit, flow routing through the pit lake was considered given the significant surface area of the pit 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 Ditch 400, 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 Area 2 Pit. The delineated sub-catchments are shown in Figure 4-1.

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FIGURE 4 - 1

UPPER PRIMARY DITCH CATCHMENTS

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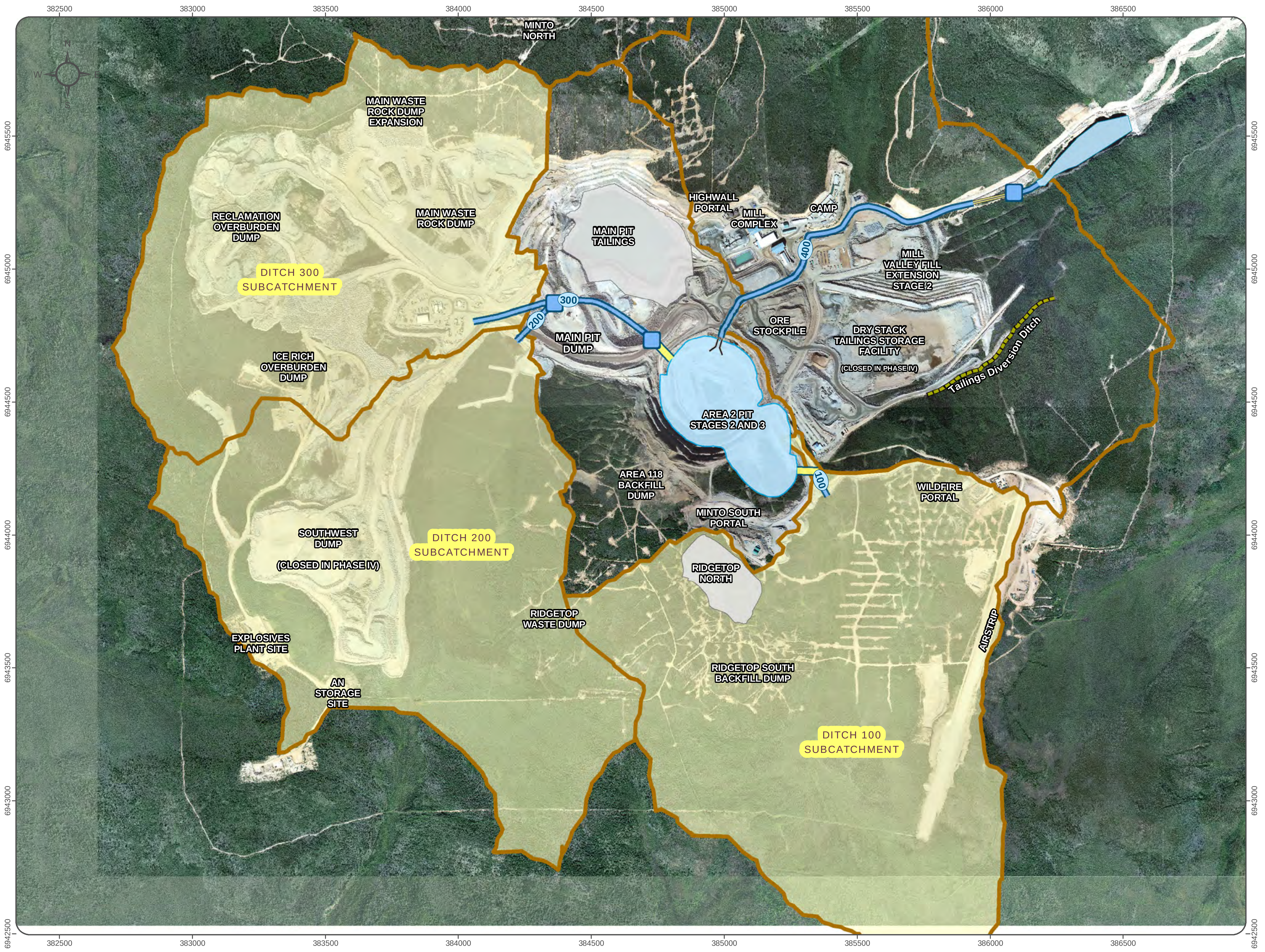

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Outlet Structure
Primary Ditch
Spillway
Transition Reach
Energy Dissipation Basin
SubCatchments
Tailings Diversion Ditch

1:13,669 *when printed on 11 x 17 inch paper*

0 50 100 200 300 400 500 Meters

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Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 11 th 2013.
Site contours derived from 2013 aerial imagery and edited by Capstone to show the Phase V/VI feature and their coutours.

Hydrology data provided by Minto Explorations Ltd, May 2009 and edited by ACG.

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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 primary ditch, are 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 ~400 m 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*
5 min	39	77	96.2	110.4	124.4	*140.3*
10 min	27.9	54.3	67.5	77.4	87.1	*96.8*
15 min	22.6	45.4	56.9	65.4	73.9	*82.6*
30 min	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 = 0.20 (average value recommended in the literature for forested areas)

- Disturbed land (by mine operations): C = 0.35 (corresponding to values suggested for graded soils with a slope greater than 5 to 8% with varying degrees of compaction)

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 also relevant for areas where waste rock dumps and tailings piles are located, given the presence of small localized depressions generating temporary storage. Larger rockfill elements on waste rock dumps also provide routing of flows, providing obstruction in the main flow paths. A coefficient of 0.6 (majority of non-forested area) or 0.7 (majority of forested area) was selected, based on the assumption that approximately 5 to 10% of catchment area provided temporary water retention, and is generally evenly distributed through the basin (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 0.22 and 0.30 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 200 basin	Ditch 300 (upper) basin
Catchment area (km²)	2.1	2.0	1.7
Average catchment slope (%)	14	16	20
Forest area (%)	85	62	35
Longest flow path length (m)	2470	2420	2530
85% elevation (m)	900	900	940
10% elevation (m)	815	840	855
Longest flow path slope (%)	4.6	3.4	4.5
Weighted runoff coefficient	0.22	0.26	0.30
Time of concentration (min)	86	90	80

Flows of various return periods were calculated for primary ditches located upstream of the Area 2 Pit (Table 4-3). Ditch 300 will collect flows from Ditch 200 near the halfway point in its length, such that the resulting maximum flow in the lower reach of the ditch is taken as the sum of the incoming flow from both Ditches 200 and 300 presented above. No lag time between both flood peaks is considered due to only a 6 minute difference between the times of concentration of both catchments.

The 200-year flood flow has been selected as the design flood for the primary ditches, as stated previously.

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	2.1	0.6	1.4	1.9	**2.1**
Ditch 200	2.0	0.6	1.5	2.0	**2.2**
Ditch 300 (upper)	1.7	0.7	1.7	2.2	**2.4**
Ditch 300 (lower)	3.7	1.3	3.2	4.2	**4.7**

The HEC HMS software developed by Hydrologic Engineering Center (HEC) of the United States Army Corps of Engineers (USACE) was previously used during the development of the Phase 4 RCP as a comparison tool to the rational method. 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 Area 2 Pit (see section 4.3.2).

Simplified simulations were run for the Minto Mine site watershed to determine the inflows for each sub-catchment of the Phase 4 RCP. The sub-catchments remain largely similar for the current closure plan compared to Phase 4, such that this previous comparison exercise is still valid for the current purpose. 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 catchment – Ditch 400

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

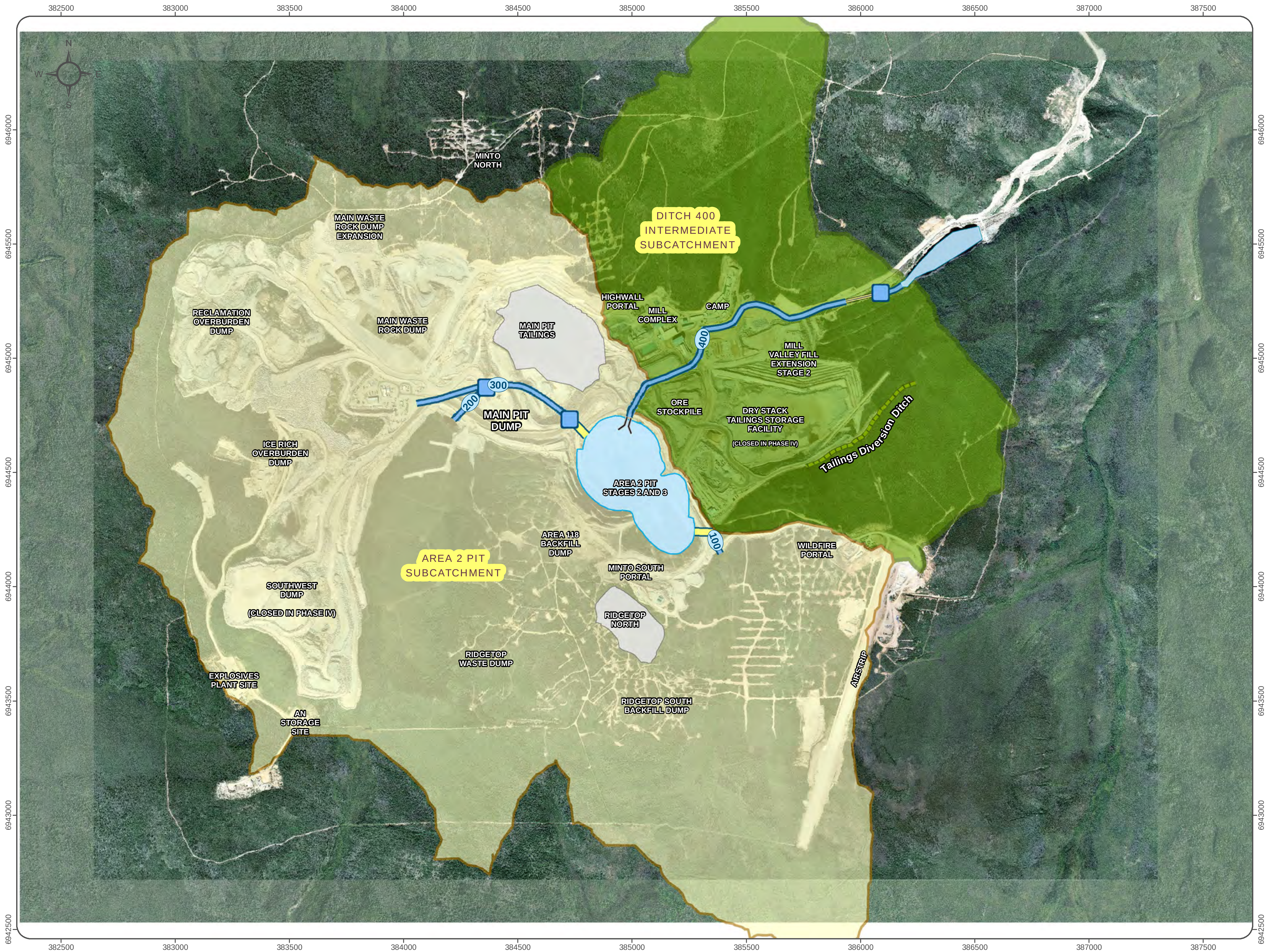
MINTO MINE
PHASE V/VI EXPANSION

CLOSURE HYDROLOGY REPORT

FIGURE 4 - 2

LOWER PRIMARY DITCH CATCHMENTS

JUNE 2014



capstone MINTO MINE

- Outlet Structure
- Primary Ditch
- Spillway
- Transition Reach
- Energy Dissipation Basin
- Ditch 400 Intermediate Subcatchment
- Area 2 Pit Subcatchment
- Tailings Diversion Ditch

1:16,000 *when printed on 11 x 17 inch paper*

0 50 100 200 300 400 500
Meters

ACCESS

Aerial imagery obtained from Challenger Geomatics. Imagery acquired August 11[th] 2013.
Site contours derived from 2013 aerial imagery and edited by Capstone to show the Phase V/VI feature and their coutours.

Hydrology data provided by Minto Explorations Ltd, May 2009 and edited by ACG.

Datum: NAD 83 Projection: UTM Zone 8N

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Table 4-4 Lower primary ditch catchment characteristics

Parameter	Ditch 400 basin
Catchment area (km²)	9.8
Average catchment slope (%)	19
Forest area (%)	59
Weighted runoff coefficient	0.26

As a result of significant routing through Area 2 Pit, flows calculated for Ditch 400 using the rational method over the total surface area of its sub-catchment would be overestimated for an extreme rainfall event (estimated 1:200 years flood of 10.2 m^3/s with the rational method). Alternatively, routing the flows calculated with the rational method for a storm over the time of concentration of each sub-catchment produces a flow less than 2 m^3/s at the outlet of Area 2 Pit into Ditch 400. This is due to the small inflow volumes resulting from the very short but intense precipitation events. Thus, the rational method applied over a given catchment area is believed to produce reliable results for the smaller catchments upstream of Area 2 Pit, but not for the main Ditch 400.

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 Area 2 Pit 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, 200 and 300) 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 46.5 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 Area 2 Pit 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 flow through the pit leads to smaller flow downstream in Ditch 400 compared with the constant flow resulting from a 24-hour rainfall event. This is a conservative assumption that increases pit outflows given a greater inflow volume.

Finally, a snowmelt base flow and a 24-hour event rainfall flow were also calculated for the intermediate watersheds of Ditch 400, using the same methods outlined previously. Table 4-7 presents the resulting calculated flows for Ditch 400. All values calculated are added together to obtain the resulting maximum flow.

Table 4-7 Area 2 Pit outlet and Ditch 400 design flows

Component	Snowmelt flow (m^3/s)	24 hr rainfall flow (m^3/s)
Sub-catchment 100	1.2	0.2
Sub-catchment 200	1.1	0.3
Sub-catchment 300	1.0	0.3
Area 2 Pit sub-catchment	0.7	0.2
Total at outlet of Area 2 Pit	**4.0**	**1.0**
Outlet of Area 2 Pit – TOTAL ESTIMATED FLOW	**5.0**	
Intermediate sub-catchment of ditch 400 (including the DSTSF)	1.5	0.4
Ditch 400– TOTAL DESIGN FLOW	**6.9**	

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 4-8 summarizes the selected design flows for all primary ditches.

Table 4-8 Design flows for primary ditches

Component	Design flow (m^3/s)
Ditch 100	2.1
Ditch 200	2.2
Ditch 300 (upper reach)	2.4
Ditch 300 (lower reach)	4.7
Ditch 400	6.9
Area 2 Pit outlet structure	5.0

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 one or several secondary ditches that will convey water to the bottom of each waste rock dump and off the DSTSF along flow paths that minimize ditch slope, associated construction costs, and ultimately reduce the risk of failure.

The rational method outlined in the previous section was used to compute flows for a standardized secondary ditch design for mild slopes of less than 10%, with a simplified approach to determine catchment characteristics. An average runoff coefficient of 0.3 was used. The small surface area of sub-catchments (i.e. the waste rock dump and DSTSF surfaces which are less than 1 km^2) combined with a fairly high runoff coefficient yields a small time of concentration of less than 40 minutes.

For the secondary ditches that will route flows down the steep faces of the waste rock dumps (greater than 10% slope), catchment areas will be limited to 5 ha in order to minimize flows, velocities and erosion resulting from the concentration of high energy flows. Given this small catchment size, the time of concentration for these ditches is less than 20 minutes.

Given the small size of the sub-catchments contributing flow to tertiary ditches, conservative design flows were selected in comparison to the calculated secondary ditch flows.

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. These will be laid out to accommodate the final topography of the waste rock dumps and DSTSF, and to minimize the risk of erosion.

Table 4-9 Secondary and tertiary ditch design flows

Component	Design flow (m^3/s)
Secondary ditches (<10% slope)	1.5
Secondary ditches (>10% slope)	0.3
Tertiary ditches	0.5

4.5 VALIDATION

Validation of the flows previously calculated was done by analysing available regional flow data. 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 first 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 4-10 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 1.0 to 1.4 $m^3/s/km^2$ (Table 4-11) 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 ditch (400) routing plays a significant role in attenuating peak flows, however a relatively high value of 0.7 $m^3/s/km^2$ was calculated. The design flows calculated are reasonably conservative and appropriate for the chosen design event, when compared to the regional data obtained from Environment Yukon stations.

Table 4-11 Unit flow per km² for primary ditch catchments

Component	Catchment area (km²)	Design flow (m³/s)	Unit flow per km² (m³/s/km²)
Ditch 100	2.1	2.1	1.0
Ditch 200	2.0	2.2	1.1
Ditch 300 (upper reach)	1.7	2.4	1.4
Ditch 300 (lower reach)	3.7	4.7	1.3
Ditch 400	9.8	6.9	0.7

Following discussions between ACG and SRK Consulting (currently performing design work for operations of the Minto Mine), a more complete regional analysis was undertaken by the later (SRK Consulting, 2014a). The objective was to develop a unit flow curve that could be used as a comparison tool to determine the accuracy of flows calculated with various methods. Numerous stations from both Yukon and Eastern Alaska were selected for the analysis, from Water Survey of Canada and the United States Geological Survey. Catchment areas, however, ranged from as little as 2.6 km² to larger catchments like Big Creek near the Minto Mine site, with a catchment area of 1800 km². Approximately one third of the selected stations had a catchment area of less than 100 km². Stations that were selected had a minimum record of 20 years of continuous data. Annual instantaneous peak flows from each year were extracted for each stations and flood frequency analyses were conducted to determine floods of different return periods. A regression line was then developed from the results of this regional analysis to determine the expected flows for floods of different return periods, for catchment of 1.5 and 5 km², respectively. The results from this analysis are presented on Figures 4-3 and 4-4 hereafter, as prepared by SRK Consulting (2014a). A 95% confidence envelope was also calculated (maximum and minimum envelope). Other existing regional equations were also retrieved and included in the analysis for comparison purposes.

It was agreed with SRK Consulting that the 95% confidence limit (Max. Env. Curve) around the SRK (2014a) regression equation be used to validate peak flows estimated with the rational method for the Minto Mine site.

The unit flows presented in Figures 4-3 and 4-4 from the regional analysis match fairly well the values calculated for the catchments within Minto Mine, as presented in Table 4-11. Values for Ditches 100 and 200 are within 10% of those calculated from the regional analysis. Larger unit flows were calculated for Ditch 300, but this is mainly due to steep slopes and higher runoff coefficient (waste rock dumps) within the catchment. As for Ditch 400, a lower value was calculated than the one resulting from the regional analysis, close to the lower limit of the 95% confidence interval, since significant routing of inflows occurs through Area 2 Pit lake. Overall, unit flows for Minto Mine are expected to be high compared to other systems, due to the steep slopes within the catchment, and a highly disturbed area from mining operations, increasing the rate of runoff and response time to precipitation events. The regional analysis has proven that the flows estimated with the rational method are within a similar order of magnitude than what is observed in the surrounding region, and are conservative for mine closure purposes.

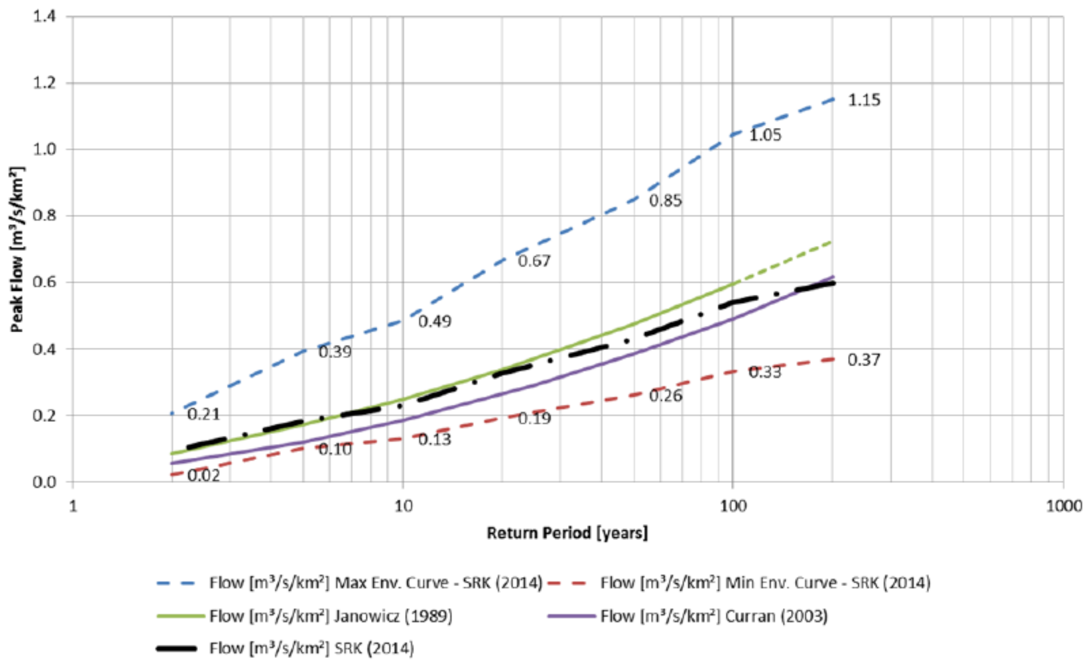

Figure 4-3 Unit peak flow for a 1.5 km² catchment based on regional analysis (SRK Consulting, 2014a)

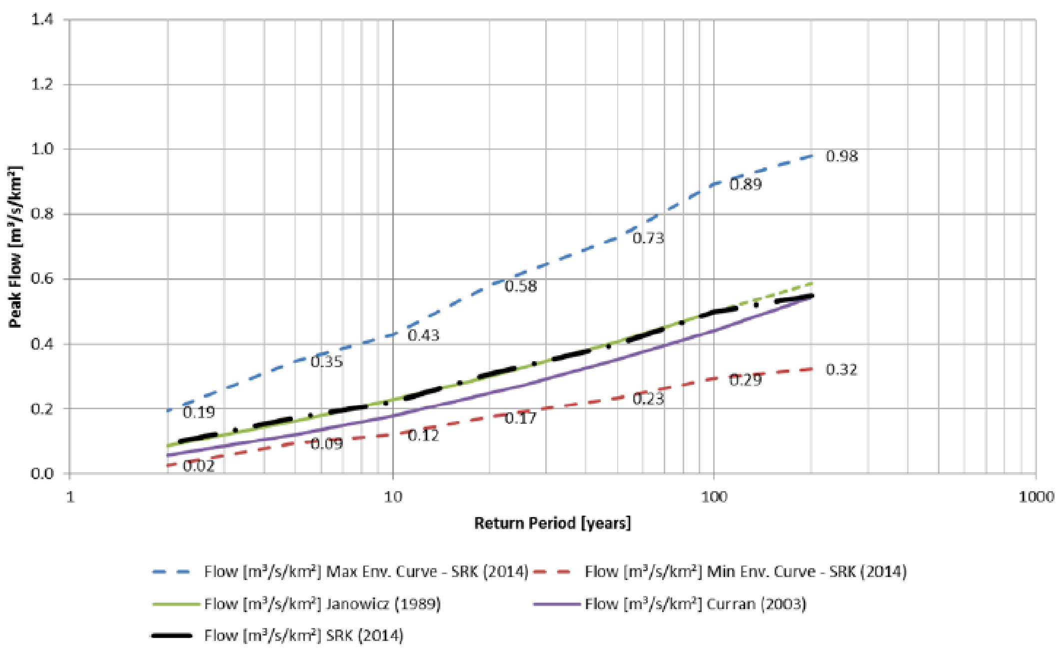

Figure 4-4 Unit peak flow for a 5 km² catchment based on regional analysis (SRK Consulting, 2014a)

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 sizing of water management structures are presented hereafter. Primary ditches were sized based on a set of design criteria and dimensions are provided for each of them. Two designs are suggested for secondary ditches, based on slope steepness (i.e. ditches on relatively flat ground vs ditches routing water down the steep faces of the waste rock dumps) and on minimum dimensions required to convey the flow criteria that was set previously. Energy dissipation structures are proposed to reduce the risk of erosion and control the potential for the formation of hydraulic jumps in steeper reaches.

5.1 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria for water management works 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, drop structures, energy dissipation basins, inlet and outlets structures, and spillways is to safely convey surface water through and downstream of the Minto Mine site at closure.

Drainage ditches need to be sized to resist the design flow. Appropriate ditch dimensions to prevent overtopping and adequate means of erosion protection will provide a safe and reliable design under varying ground conditions. Erosion protection can be provided by adequate channel protection (rip rap or other types of liners), and drop structures and energy dissipation basins when slopes are too steep.

Drop structures are small dams placed across a waterway to provide for changes in gradient, to slow water velocities and to reduce erosion. Drop structures may be used for drainage ditches with larger grades, to minimize flow velocities. In the case of the Minto Mine closure, drop structures may only be required for secondary ditches when flow is conveyed down the steep faces of waste rock dumps. No drop structures are included in the propose layout of the primary ditches.

Energy dissipation basins are boulder fields, rock check dams or stilling basins used to dissipate energy from concentrated flows. These will be placed at the bottom of steep slopes and at channel junctions.

Outlets are structures at the outlet of pits and energy dissipation basins that convey flow from a large body of water to a ditch through a progressive constriction. The invert elevation of the outlet structure will determine the minimum and maximum water levels that are observed in the water bodies. Inlet structures convey flow from a ditch to a larger basin.

Two spillways on the Minto Mine site are associated with each dam: the Main Dam spillway, conveying water from the Main Pit to the Area 2 Pit, and the Water Storage Pond spillway, conveying water off the site. In addition, a spillway will convey flow from Ditch 100 into the Area 2 Pit. Both spillways into the Area 2 Pit need to convey flow ensuring that the geotechnical stability of the pit walls is maintained.

5.1.1 Channel sizing

The design flows for primary and secondary ditches were selected as the 200-year flood. Primary ditches were designed using the calculated design flows, while secondary ditches were designed using selected values that can safely convey the 200-year flood over relatively flat ground, and down steeper slopes. 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 4-8) and the selected values for secondary and tertiary ditches were presented in section 4.4. (Table 4-9).

The selected design criteria for all drainage ditches are outlined below. These design criteria, however, do not apply to structures that are required to convey water down steeper slopes (>10% slopes), which are discussed below. This includes the bottom of Ditch 400 and spillways. The design criteria for these works are discussed in Sections 5.1.2 of this report.

5.1.1.1 Flow conditions

The maximum allowable flow velocity is set at 3.5 m/s in all primary ditches. This velocity will limit the required rip rap 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.

A maximum Froude number of 2 is targeted in all primary ditches. Supercritical flow is allowed in steeper reaches, but the Froude number should not exceed 2 under any condition. This will prevent the formation of strong and well-defined hydraulic jumps, which could be detrimental to the stability of the surface materials (rip rap or synthetic liner). Only small oscillating and partially submerged hydraulic jumps could form under such flow conditions. The formation of hydraulic jumps in ditches could occur in reaches with steep slopes, given a sharp change in slope or raise in the channel bed. This could be the result of an obstruction from debris, or settlement/erosion being observed at a given location.

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 the use of larger rockfill elements in the channel to further slow the flow with additional resistance or the conveyance of water through steeper slopes using drop structures and energy dissipation basins configured to ensure the formation of a hydraulic jump in a controlled location and dissipate energy. In such reaches, the Froude number of the flow could exceed 2, as any potential hydraulic jump would be occurring in a controlled location designed to resist higher velocities and shear stresses. Additional works are discussed in more detail in Sections 5.1.2 and 5.3.

Secondary ditches will flow for the majority of their length on top of covers or around waste dumps with mild slopes (lower than 2%). The design velocity chosen for these ditches should be lower than for the primary ditches to simplify the construction and enable the use of readily available materials. A maximum flow velocity of 2.5 m/s is recommended. A rip rap size with a D_{50} of 150 mm will resist such velocities.

Secondary ditches that convey water down steep slopes (>10%) will be limited to 5 ha in order to limit peak flows and erosion potential. A maximum flow of 0.5 m^3/s is recommended, and will be achievable given the small size of contributing basins, which have an estimated design flow of 0.3 m^3/s for the 200-year event. A rip rap size with a D_{50} of 300 mm will resist such flows on steep slopes (USDI, 1982). D_{max} of the rip-rap on steep slopes will be limited to 1.25 D_{50} in order to further enhance stability.

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.

5.1.1.2 Channel geometry

Guidelines and criteria were set to adequately size ditches based on common practice. Optimal dimensions to minimize the cut and fill volume should be targeted to avoid oversizing a ditch if not required. The following guidelines are selected and will serve for the basis of sizing ditches, when possible.

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

- Minimum base width of 2 m to facilitate construction;
- Side slopes of 2H:1V;
- A minimum channel slope of 0.5% is selected for all ditches;
- A maximum ratio of 2 is selected as the 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 rip rap required for erosion protection. When the closure plan is implemented, further optimization studies will be required to determine the optimal channel size and alignments.

5.1.1.3 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, glaciation, 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 Ditch 400.

5.1.2 Other Conveyance Structures

The design flows for all additional conveyance structures (energy dissipation basins, spillways, outlet and inlet structures) were selected as the 200-year flood, as was selected for all primary and secondary ditches. The selected values for the ditches presented in sections 4.3.3 (Table 4-8) and 4.4. (Table 4-9) were utilized for the additional works.

The selected design criteria and assumptions for additional conveyance structures are outlined below.

5.1.2.1 Energy Dissipation Basins

Energy dissipation basins will be placed at the bottom of steep slopes (>10%) to allow the formation of a hydraulic jump resulting from supercritical flow along a steeper reach (with a Froude number larger than 2) in a controlled location. Energy dissipation basins will also be required at the junction of ditches, to properly merge flow and provide adequate transition to the downstream ditch.

Energy dissipation basins have been incorporated into the water management design at the following locations:

- At the junction of Ditch 200 and Ditch 300;
- At the bottom of Ditch 300;
- At the bottom of Ditch 400;
- At the base of secondary ditches down waste rock dump faces;
- At the junction where secondary ditches convey flow into primary ditches.

These basins will be lined depressions along the flowpath of the ditches, with the invert and outlet elevations on grade with the rest of the ditch. The following design criteria have been established for energy dissipation basins.

Basin geometry:

- Basins will have a square base, with width and length at a minimum 2 times the width of the upstream ditch;
- Minimum water depth of 1 m (thus the bottom elevation of the basin will be at least 1 m below the invert elevation of the connecting ditch);
- Side slopes 2H:1V;
- Basin will be lined with an impervious liner.

These basins will be protected with rip rap to prevent erosion and significant washing of the ground, due to both high velocity and turbulence levels. Rip rap will also provide additional energy dissipation and allow the formation of small not well defined hydraulic jumps. The required rip rap will have a D_{50} of 600 mm.

5.1.2.2 Inlet Structures

Inlet structures convey flow from primary and secondary ditches to energy dissipation basins through a progressive expansion. The following design criteria have been established for inlet structures.

Flow conditions:

The maximum allowable velocity of approach is set at 1.5 m/s for inlet structures. This velocity will limit the required rip rap size to a D_{50} of 150 mm. The geometry of inlet structures was designed based on the following criteria and guidelines.

Progressive expansion:

- Final width: minimum 2 times the base width of the ditch;
- Longitudinal length (expansion): minimum 5 times the base width of the ditch;
- Side slope 2H:1V;

Overflow section:

- Rip rap size with a D_{50} of 600 mm will be required.

5.1.2.3 Outlet Structures

Outlet structures convey flow from a large body of water to a ditch through a progressive constriction. The main outlet structure required is the outlet from the Area 2 Pit to Ditch 400. Outlets from energy dissipation basins are also required. The following design criteria have been established for outlet structures.

Flow conditions:

The maximum allowable velocity is set at 2.5 m/s for outlet structures. This velocity will limit the required rip rap size to a D_{50} of 150 mm. The geometry of outlet structures was designed based on the following criteria and guidelines.

Progressive constriction:

- Initial width: minimum 3 times the base width of the ditch;
- Longitudinal length (constriction): minimum 5 times the base width of the ditch;
- Side slope 2H:1V;

Invert sill:

- Elevation set at the normal operating level of the water body;

- Maximum flow depth 1 m over sill;
- Long broad crested weir: minimum 2 m longitudinal length;
- Upstream longitudinal slope: 2H:1V;
- Downstream longitudinal slope: 0.5%;

5.1.2.4 Spillways

Channelized surface flows diverted into open pits and down spillways - associated both with dams and steep reaches - require more robust designs due to erosion control and constructability challenges.

Two spillways will convey flow into the Area 2 Pit: the Main Dam spillway, conveying flows from the Main Pit in addition to flows from Ditch 300, and the upgraded Tailings Diversion Ditch spillway. In addition, the Water Storage Pond Dam has a spillway, although this dam and spillway will be decommissioned during closure.

SRK Consulting is responsible for the design of the Main Dam and the Tailings Diversion Ditch spillways, although the Tailings Diversion Ditch spillway will be upgraded for closure.

Reaches that have slopes greater than 10% also require designs that ensure erosion protection. Rip rap with a D_{50} of 600 mm will be used to protect these slopes, in addition to the possible incorporation of synthetic products as discussed in the sections below.

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 Civil3D 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 locations, 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	0.5	2	No	Flows into Area 2 pit
200	2	0.5	6	No	Flows into Ditch 300
300	9	0.5	10	No	Flows into Area 2 Pit (spillway)
400	4	1	5	Yes – transition reach 40%	Flows into Water Storage Pond

Secondary ditches collect flow from the tertiary ditches and will convey flow both on the relatively flat tops of the waste rock dumps and down the steep faces of the dumps as well (grade of up to 40%). The secondary ditches will be fortified with rip rap and filter compatible bedding to both dissipate energy and mitigate against erosion. The secondary ditches will drain into energy dissipation ponds at the base of the waste rock dumps and low points in the topography where water is currently collected.

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. Surface erosion will be mitigated by a combination of vegetative cover and maintaining low energy flow.

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 above were used as target values. The Manning's equation 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 cross-sectional area of flow 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); and
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 for primary ditches with mild slopes (Ditch 200 and the upper portion of Ditch 400) as it applies to engineered channels with rockfill elements. For steeper sections (Ditch 300 and Ditch 400 transition reach) with larger rip rap protection, a Manning's roughness coefficient of 0.06 was chosen, since flows will tend to flow through rather than over the larger rip rap, thus increasing the resistance experienced by the flow. Empirical equations available in the literature suggest even larger Manning's coefficients for shallow flow depths like the ones calculated for the steep reaches of ditches. Thus, the selected coefficient is conservative and rip rap size is adequate for long term erosion protection. For locations where synthetic liners may be used as an upper layer, a lower roughness and thus lower Manning's coefficient can be used. 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 a 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; and
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 in shallow gradient channels. A side slope of 2H:1V was used to determine the angle α, which is the side slope proposed for all drainage ditches.

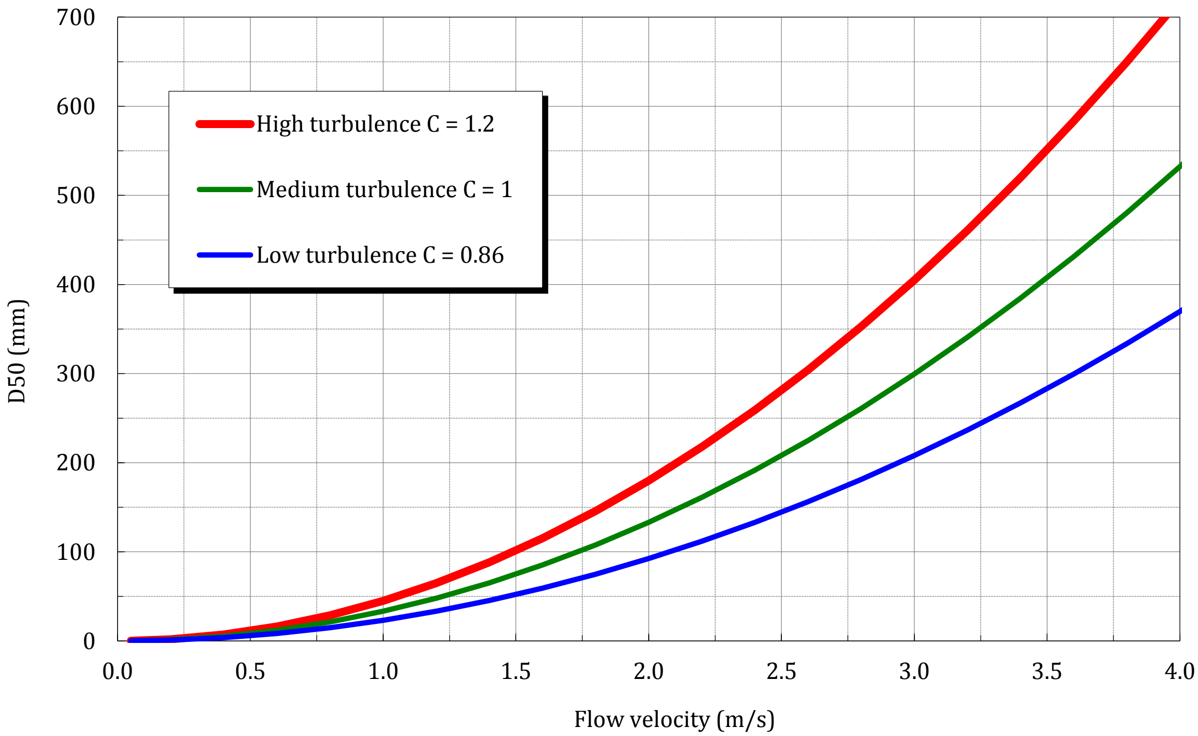

Figure 5-1 Required Rip rap D_{50} to Resist a Given Flow Velocity

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 low gradient secondary ditches, rip rap with a D_{50} of 150 mm will be sufficient to resist a maximum velocity of 2.5 m/s.

For the secondary ditches conveying flow down the steep faces of the waste rock dumps, catchments will be limited to 5 ha in order to limit peak flow to below 0.5 m^3/s, which, combined with a minimum channel base width of 2 m, will require rip rap with a D_{50} of 300 mm to resist flows (USDI, 1982). To further enhance stability, D_{max} of the rip rap will be limited to 1.25 D_{50} on steep slopes.

The required D_{50} for primary and secondary ditches is presented in the following sections.

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/energy dissipation basin
100	2.1	2	0.5	2	0.6	1.8	150	No
200	2.2	2	0.5	2	0.6	1.8	150	No
300 (upper)	2.4	2	0.5	10	0.8	2.6	300	Yes – energy dissipation basin
300 (lower)	4.7	3	0.5	10	0.9	3.0	300	Yes – energy dissipation basin
400	6.9	3	1	5	1.1	2.6	300	Yes - transition reach

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. At closure this ditch will be raised to the level of the overflow spillway invert, but will remain the same dimensions. The current ditch has an estimated total capacity of 13.3 m^3/s (SRK, 2013a) which is nearly 6 times the calculated 200-year design flow of 2.2 m^3/s. If the ditch was to be reconstructed, only a 2 m channel base width is selected as the minimum constructible base width. The ditch can be constructed on a slope between 0.5 and 2%, which easily follows the current topography with only grading required and no significant excavation or fill. The minimum required depth of the ditch is 1.1 m (0.6 m maximum flow depth and 0.5 m freeboard allowance). A minimum D_{50} of 150 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, which is discussed in section 5.3.4. This spillway is already constructed, but requires enhanced erosion protection for long term stability at closure.

Ditch 200

Ditch 200 will convey water from the western half of the mine site, where the waste rock dumps are located. In particular, it captures flow from the Southwest Dump in the southwest corner of the mine site and out of the W15 wetland area, and also intercepts flow coming from the Ridgetop area to the south. A minimum base width of 2 m is required to convey the 2.2 m^3/s design flow, along with a minimum depth of 1.1 m (0.6 m maximum flow depth and 0.5 m freeboard allowance). This given cross-section can be constructed on a slope varying between 1 and 2%. A minimum D_{50} of 150 mm is required for the rip rap.

Ditch 200 will connect with Ditch 300, which flows into the Area 2 Pit. Ditch 200 will empty into an energy dissipation basin at its junction with Ditch 300. The energy dissipation basin is described in Section 5.3.1.

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. Approximately halfway along its length, Ditch 300 is joined by Ditch 200, and thus a separate design has been developed for the upper and lower sections of Ditch 300. A minimum base width of 2 m is required to convey the 2.4 m^3/s design flow in the upper portion of Ditch 300. The depth of the ditch should be at least 1.3 m (0.8 m maximum flow depth and 0.5 m freeboard allowance). This cross-section can be constructed on a slope varying between 0.5 and 10% to safely convey the flow. Expected slopes along the ditch are in the upper end of the design range (8 to 10%). After the junction with Ditch 200, the design flow is 4.7 m^3/s in the lower portion of Ditch 300. A minimum base width of 3 m is required and the depth of the ditch should be at least 1.4 m (0.9 m maximum flow depth and 0.5 m freeboard allowance). This cross-section can be constructed on a slope varying between 0.5 and 10% to safely convey the flow. Again slopes between 8 and 10% are expected along this reach. A minimum D_{50} of 300 mm is required for the rip rap for both the upper and lower portions of the ditch.

Ditch 300 will connect to the Main Dam spillway, which will be constructed in operations to direct flows toward the Area 2 Pit (SRK Consulting, 2013c). Two energy dissipation basins will be required to dissipate energy in Ditch 300 - at the junction where Ditches 200 and 300 meet, and at the end of Ditch 300, upgradient of the Main Dam spillway. Energy dissipation basin design is described in Section 5.3.1.

Ditch 400

Ditch 400 will convey most of the surface water out of the mine site. It will convey the routed outflows from the Area 2 Pit, which will receive inflows from Ditch 300 and Ditch 100, and also capture flows from its intermediate watershed downstream of the Main Pit. Ditch 400 will run adjacent to the main access road downstream from Area 2 Pit, to the north of the Mill Valley Fill Extension (MVFE). It will then drop on the MVF east face, called the Ditch 400 transition reach, 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 6.9 m^3/s. Flows from the upper catchments will experience significant routing through the Area 2 Pit, such that the flood peaks are attenuated. A minimum base width of 3 m and a minimum depth of 1.6 m (1.1 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 outlet structure at the outlet of the Area 2 Pit, discussed in section 5.3.3. A steep transition reach, channel/spillway, with a slope of up to 40%, will also need to be constructed along the MVFE east slope to convey surface flow from the top of the MVFE to the valley below. This is discussed further in section 5.3.4. An energy dissipation basin will be constructed at its toe to dissipate energy coming from the transition reach, as discussed in section 5.3.1.

5.2.5 Secondary ditches

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

- a typical channel cross-section on mild slopes (less than 10%);
- a steep section down the waste rock dump faces, with a slope up to 40%.

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, each with a contributing basin of less than 5 ha, 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. Energy dissipation 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 cross-section was developed for all secondary ditches with mild slopes 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.

A single cross-section for the steeper secondary ditches was also developed, designed to have adequate erosion protection for the small flows (less than 0.5 m^3/s) on steep slopes (USDI, 1982).

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 velocity (m/s)	Maximum rip rap size – D_{50} (mm)
Secondary ditches	1.5	2	0.5	7	0.5	2.5	150
	0.3	2	10	40	0.1	n/a	300

A cross-section with a minimum base width of 2 m and a minimum depth of 0.8 m (0.5 m maximum flow depth and 0.3 m freeboard allowance) will work properly for all reaches of secondary ditches with a slope less than 7%. For secondary ditches with a slope between 10 and 40%, a 2 m base width and a minimum depth of 0.5 (0.1 m maximum flow depth and 0.4 m freeboard allowance) has been chosen.

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.

5.2.7 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 then result in significant differential settlement, thus modification of the constructed ditch profiles, which could prove to be a mechanism of failure. Excavation of the fill already in place may be required in some locations, or the placement of additional material may be needed, 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. Small to medium rip rap should be easily available without any significant blasting and sorting required on site. Rip rap with a D_{50} equal to or smaller than 300 mm can also be obtained at a reasonable cost. In areas where larger velocities will be experienced (spillways, energy dissipation basins), a bituminous geomembrane liner can provide resistance against such high flow velocities. Concrete may also be used in a few specific locations, but its use will be minimized to limit costs. A geotextile filter layer or filter compatible granular base should be installed under all rip rap material to mitigate the risk of erosion of foundation soils.

The size of rip-rap was grouped into three categories. Discussions were undertaken with Minto Mine staff to determine the availabilities of such materials and the ease of production at closure. Preliminary quantities were also estimated and provided to Minto Mine for planning purposes. Those quantities include a 25% additional allowance. The selected rip rap categories were deemed achievable and can be retained as construction materials to design ditches at closure. They are presented in Table 5-4 below.

Table 5-4 Rip-rap categories

Category	D_{50} (mm)	Range (mm)	Estimated volume (m³)
Bedding/filter material	Coarse sand and gravel - 25	0 – 100	10,000
Rip-rap 1	150	100-300	5,000
Rip-rap 2	300	200-500	14,000
Rip-rap 3	600	500-800	2,000

5.3 OTHER CONVEYANCE STRUCTURES

Section 5.2 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. However, it is possible that additional structures may be required at closure depending on the updated site conditions.

Given the potential for erosion and the formation of hydraulic jumps in steeper reaches, preliminary modelling of flow through the additional conveyance structures was undertaken using the HEC RAS software developed by HEC of the USACE (as above with HEC HMS). The software allows users to model the hydraulics of water flow through natural rivers and other channels. A model of the drainage ditch is first created by entering geometric drainage data and cross-sectional profiles along the reach. Steady or unsteady flow data are entered, along with reach boundary conditions, and then the model can be run to determine the flow characteristics at various points along the reach. The results of HEC RAS modelling completed for additional conveyance structures is included in the following sections.

5.3.1 Energy dissipation basins

Energy dissipation basins will be required at the bottom of channels conveying flow down steep slopes (greater than 10%), and at channel junctions in order to control the location of hydraulic jumps resulting from supercritical flow.

Three energy dissipation basins have been incorporated into the design of primary ditches. Two basins are included in the design of Ditch 300: at the bottom of the upper and lower reach, respectively. One basin is included at the toe of the transition reach in Ditch 400. Hydraulic modelling of both ditches was undertaken with the HEC-RAS software. HEC-RAS is a one-dimensional software that can model steady and unsteady flow, in both subcritical and supercritical conditions. The formation of hydraulic jumps can be accurately predicted and this was the main purpose of the modelling exercise. Validation of the previously presented flow depth and velocities was also possible, to account for any backwater effects that may occur. It is not, however, a significant factor to consider in the case of the ditches at the Minto Mine that are generally not influenced by high tailwater levels, for example.

The upper energy dissipation basin on Ditch 300 will be sized according to the design criteria to have minimum base dimensions of 6 m by 6 m by 1 m deep with 2H:1V side slopes. The basin will be inline with both ditches. The second basin at the bottom of Ditch 300 will also be sized to have minimum dimensions of 6 m by 6 m by 1 m deep and 2H:1V side slopes. The energy dissipation basins will be lined with bituminous geomembrane, and covered with rip rap with a D_{50} of 600 mm. HEC RAS modelling shows that the basins along Ditch 300 adequately dissipate energy by forming small hydraulic jumps in the basins themselves. Flow velocities along the steeper reaches of the ditch were calculated between 3 and 4 m/s, which matches the values previously presented in the ditch sizing section.

The energy dissipation basin at the base of the Ditch 400 transition reach, with a slope of 40%, has been placed so it will ensure the formation of a hydraulic jump (weak or oscillating) before discharging flow to the downgradient flow path toward the Water Storage Pond. The minimum dimensions are 10 m by 10 m by 1 m deep, with 2H:1V side slopes. The basin will be lined with bituminous geomembrane. Rip rap with a D_{50} of 600 mm is selected to further dissipate energy and protect against erosion. The channel exiting the energy dissipation basin will be set 1 m above the base of the basin (which will be about 1 m below original ground), the same width as the inflow channel (5 m wide and 2H:1V side slopes), and the perimeter containment will be raised to the full height of peak flow depth plus 0.3 m freeboard. HEC RAS modelling of the Ditch 400 shows that flow velocities along the transition reach could reach values as high as 6 m/s. A hydraulic jump forms in the energy dissipation basin at the toe of the reach, thus adequately dissipating energy at this location.

Basins are also required at the bottom of most secondary ditches dropping down a steep slope and at the junction where secondary ditches convey flow into primary ditches. Secondary ditches are not shown on the water management map.

These energy dissipation basins for secondary ditches will be sized independently for each channel and protected with rip rap or a synthetic liner to prevent erosion and significant washing of the ground, due to both high velocity and turbulence levels.

5.3.2 Inlet Structures

Inlet structures convey flow from primary and secondary ditches to energy dissipation basins. The inlet structures for the two basins at the bottom of Ditch 300 and the Ditch 400 transition reach will be 15 m in length, expanding from 3 m to 6 m in width, with 2H:1V sides slopes. Rip rap with a D_{50} of 600 mm will be used. The inlet structures upgradient of the energy dissipation basin at the junction of Ditches 200 and 300 will each be 10 m in length, expanding from 2 m to 6 m, with 2H:1V sides slopes. 600 mm rip rap will also be required.

Inlet structures for secondary ditches will be designed at closure. These will follow the design criteria outlined above for progressive expansion.

5.3.3 Outlet Structures

An outlet structure is required to convey water from the Area 2 Pit into Ditch 400 at closure. This intake to Ditch 400 will be designed with an invert elevation of 799 m, which is the minimum water level expected in the pit when it is full. The outlet structure will provide a smooth transition from the deep and slow moving pit lake flow to the shallow and fast flowing ditch. It will start with a width of 9 m and contract to 3 m over 15 m in length with a 0.5 % grade. A long broad crested weir, 2 m in longitudinal length will span the start of the outlet structure, with a 2H:1V upstream longitudinal slope upgradient of the weir. Geotechnical consolidation of the pit edges at the outlet structure will be done, using bituminous geomembrane, to ensure adequate long term stability of the structure.

Outlet structures for energy dissipation basins will follow the same design, at a smaller scale. The outlet of the 3 energy dissipation basins along primary ditches will constrict from 6 m to 3 m over 15 m in length.

5.3.4 Spillways

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), and down the steep faces of the waste rock dumps. Spillways allow high velocities and energy levels to be concentrated into confined reaches. All spillways will empty into larger water bodies to safely dissipate the energy of the flow (energy dissipation basins or pit lakes).

The two spillways conveying flow into the Area 2 Pit, the Main Dam spillway and the Tailings Diversion Ditch spillway, have been designed and upgraded by SRK Consulting. No changes will be made to the Main dam spillway for closure. The Tailings Diversion Ditch spillway will be upgraded in Phase V/VI (SRK Consulting, 2014b). At closure, this spillway will be modified for long term stability. These modification will include:

1) The installation of a thick residuum plug to block off the drainage pipes;

2) Partially backfilling the portion of Ditch 100 adjacent to the overflow spillway to the level of the spillway invert and incorporating the existing configuration of the overflow spillway to direct all channel flow towards the Area 2 Pit;

3) Continuing the spillway outlet downgradient of the existing rip rapped area all the way to the upper bench of the Area 2 Pit, over the upper steep overburden slope. This will protect the steep overburden slope against erosion from surface flows from Ditch 100 and minimize infiltration into the overburden (thereby enhancing geotechnical stability of the overburden slope). The infiltration barrier will be extended to well below flooded elevation of the Area 2 Pit. The overburden is to be regraded to a uniform slope that is suitable for placement of a bituminous geomembrane liner directly over the prepared foundation. One metre high berms will be added along the sides of the bituminous geomembrane lined channel to constrain flow and facilitate the anchoring of the liner in anchor trenches. Bituminous geomembrane is recommended due to the combination of its long life when left exposed to the elements and its puncture resistance which minimizes/eliminates the requirement for the addition of protective bedding layers beneath the liner.

For secondary ditches, a spillway type design will be required to channel concentrated flow (collected in tertiary ditches) for all ditches that drop flow from the top of the waste rock dumps to lower elevations. Slopes of up to 40% are possible with such a scheme, thus secondary ditches will be divided into additional channels, with a maximum contributing area of 5 ha, in such locations to limit the flow transiting through steep slopes. The size of rip rap required to control erosion on steep slopes increases substantially with both increased slope and increased flows. The design peak flow is directly related to the size of the catchment area feeding into the water conveyance channel – hence the desire to limit sub-catchment areas feeding into secondary ditches to less than 5 ha. Limiting sub-catchment areas to under 5 ha will enable conventional rip rap and granular filter design to be used as both erosion protection and energy dissipation. It is anticipated that D_{50} of 300mm (and D_{max} of 1.25 D_{50}) will provide robust water conveyance for typical 3H:1V closure slopes of waste rock dumps for channels with 2 m base width. These steep secondary channels 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 a controlled area to mitigate erosion.

A final spillway is required for closure along the Ditch 400 transition reach. This spillway must be able to convey a peak flow of 6.9 m^3/s from the top of the MVFE to the valley bottom. The current configuration of the eastern extent of the MVFE around of the transition reach includes a uniform 40% slope from the top of the MVFE to the valley bottom. The discharge area is constrained by limited space downgradient of the MVFE and the requirement for additional infrastructure such as a seepage collection/pump back station (relocated W37) and space for passive treatment trials and application.

Incorporating a conventional rip rap design to convey 6.9 m^3/s down a 40% slope would require the use of very large rip rap, on the order of a D_{50} of 750 mm for a slope of this steepness, assuming a channel base width of 5 m (USDI, 1982). It is recognized that suitable rip rap of this size may be challenging to source. The size of required rip rap could be reduced by either reducing the slope of the transition reach or widening the channel base. Alternatively, the channel design could incorporate geosynthetic reinforcement or concrete to reduce the reliance on large rip rap. The transition reach at the bottom of Ditch 400 will be designed at closure, following finalization of the space required for closure measures to be implemented within the valley bottom (e.g. passive treatment areas).

The Water Storage Pond Dam spillway, designed by EBA Engineering, will be decommissioned during closure. The closure plan calls for the complete removal of the structure once the Minto Mine site is able to consistently meet discharge water quality requirements.

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