NorthMet Project

Rock and Overburden Management Plan

Version 10

Issue Date: December 2017

This document was prepared for Poly Met Mining, Inc.
by Barr Engineering Co.

I hereby certify that portions of this report were prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota, specifically the design of the Category 1 Stockpile Groundwater Containment System in Sections 2.1.2.2, 2.1.2.3, 7.2 and 7.3 of this report.

Thomas J. Radue, P.E., Barr Engineering Co. — 12/08/2017 (Date)

PE #20951

I hereby certify that portions of this report were prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota, specifically the design of stockpiles in Sections 2.1.2.1, 2.1.3, 7.1.1 and 7.1.2 of this report.

Brent Bronson, P.E., Golder Associates Inc. — 12/08/2017 (Date)

PE #46492

I hereby certify that portions of this report were prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota, specifically the design of stockpiles in Sections 2.1.2.1, 2.1.3, 7.1.1 and 7.1.2 of this report.

Gordan Gjerapic, P.E., Golder Associates Inc. — 12/08/2017 (Date)

PE #47209

Table of Contents

Acronyms, Abbreviations and Units

Acronym, Abbreviation or Unit	Stands For
%S	Percent sulfur
ARD	Acid Rock Drainage
ASTM	American Society for Testing and Materials
AWMP	Adaptive Water Management Plan
cm/sec	centimeters per second
CQA	Construction Quality Assurance
EIS	Environmental Impact Statement
FTB	Flotation Tailings Basin
gal/acre/day	gallons per acre per day
GCS	groundwater containment system
gpm	gallons per minute
GPS	global positioning system
LOM	life of mine (operations phase)
LLDPE	Linear Low Density Polyethylene
LTVSMC	LTV Steel Mining Company
Max	Maximum
MCY	million cubic yards
DNR	Department of Natural Resources
mil	measurement of liner thickness; a mil is a thousandth of an inch
MPCA	Minnesota Pollution Control Agency
N/A	not applicable
OSLA	Overburden Storage and Laydown Area
OSP	Ore Surge Pile

Acronym, Abbreviation or Unit	Stands For
psi	pounds per square inch
PTM	Permit to Mine
QC	quality control
ROMP	Rock and Overburden Management Plan
RTH	Rail Transfer Hopper
SDS	State Disposal System
SKP	stockpile
TBD	to be determined
UV	ultraviolet
WWTS	Mine Site Waste Water Treatment System

1.0 Introduction

This document describes the Rock and Overburden Management Plan for Poly Met Mining, Inc.'s (PolyMet's) NorthMet Project (Project) and includes the presentation of the Block Model of rock in the mine pits, classification of waste rock and overburden based on the waste characterization study, stockpile design details, construction uses of waste rock and overburden, operating plans, reporting requirements, and adaptive management approaches. Incremental and final reclamation activities associated with stockpiles are also included. Information from this report is included in the Minnesota Department of Natural Resources (DNR) Permit to Mine (PTM) application and Minnesota Pollution Control Agency (MPCA) State Disposal System (SDS) Permit application.

As developed in Section 4.2 of the Waste Characterization Data Package (Reference (1)), the overall plan for management of waste rock at the Mine Site is to classify rock by its potential to produce acidic and/or metalliferous drainage upon weathering and place it in one of three stockpiles based on that classification. Category 1 waste rock, which will produce drainage that is non-acidic but may be elevated in metals, is placed in a permanent stockpile. In addition, a portion of the Category 1 waste rock will be used for select construction applications at the Mine Site or placed directly in the East and Central Pits after mining ceases in each pit. Category 2/3 and Category 4 waste rock, which have potential to produce acidic drainage with elevated metals, are placed in temporary stockpiles. Waste rock from these stockpiles will be relocated to the East and Central Pits for subaqueous disposal after mining ceases in each pit. Management of waste rock is described in Section 2.1, including detailed reclamation plans for the waste rock stockpiles.

Overburden includes all unconsolidated material that overlies the bedrock. Mineral overburden is defined, for this Project, as all non-peat unconsolidated material above bedrock. It includes glacial deposits, alluvial deposits, and topsoil (the top layer of unsaturated mineral overburden, usually the top 2 to 8 inches, with a high concentration of organic matter and microorganisms, which facilitate vegetative growth). Mineral overburden at the Mine Site is classified as either saturated or unsaturated.

- ***Saturated mineral overburden****:* mineral overburden that has remained below the water table and has not been oxidized and can release metals when exposed to air and oxidized.

- ***Unsaturated mineral overburden:*** mineral overburden that has been above the water table including all topsoil. At the Project site, this material has been oxidized and has low potential for metal release.

As developed in Section 3.2 of Reference (1), the overall plan for management of overburden at the Mine Site is to place potentially reactive saturated mineral overburden in one of two temporary stockpiles, the Category 2/3 Waste Rock Stockpile and the Category 4 Waste Rock Stockpile, or to use it in DNR-approved applications, and to use non-reactive unsaturated mineral overburden for construction and reclamation at the Mine Site. Organic overburden, hereinafter called peat, will also be used for reclamation at the Mine Site. Management of Mine Site overburden is described in Section 2.2.

PolyMet has focused waste characterization and management on the overburden materials at the Mine Site due to the underlying Duluth Complex deposits, and the characterization work was designed to assess the degree to which the overburden materials reflect the potential presence of sulfide minerals and/or metal enrichment of this underlying bedrock. As shown on Large Figure 1, the Plant Site overburden materials primarily overlay schist, and granitic geologic materials of the Giants Range Batholith, which have been heavily disturbed as a result of past mining activities without record of environmental or water quality issues as a result of the overburden usage. With regard to the Transportation and Utility Corridors, the overburden materials directly overlay, from west to east, the Giants Range Batholith, the Biwabik Iron Formation, the Virginia Formation, and the Partridge River Intrusion of the Duluth Complex (Large Figure 1). Background information on overburden in the area, compiled as part of the characterization work (Section 2.1 of Reference (2)), indicated that overburden in the region is primarily a result of glacial deposition and associated processes from the Rainy Lobe of the Laurentian Ice Sheet. The Rainy Lobe advanced locally in a direction subparallel to the strike of the contact between the Duluth Complex and the country rocks (Section 2.1.1 of Reference (2)). Therefore, overburden at the Plant Site and the western half of the Transportation and Utility Corridors are unlikely to be impacted by rock from the Duluth Complex. In addition, with the exception of initial construction activities, disturbance of the overburden materials at the Plant Site and along the Transportation and Utility Corridors will be minimal. If disturbance of the saturated mineral overburden in the Transportation and Utility Corridors is necessary, PolyMet will complete waste characterization of the saturated mineral overburden to determine the appropriate handling and disposal of the material.

1.1 Objective and Overview

The objective of the Rock and Overburden Management Plan (ROMP) is to provide stable and safe storage of the Mine Site waste rock and overburden in a manner that results in compliance with safety and environmental regulations.

The Mine Site layouts are presented for Mine Years 1, 2, 11, and 20 as Large Figure 2 through Large Figure 5. Mine Years 1 and 2 are provided because they are the first two years of mining. Mine Year 11 is included because there is a major change in operations – mining in the East Pit is completed, mining in the Central Pit has begun, and the temporary waste rock stockpiles have reached their maximum footprints. Mine Year 20 represents the end of mining, with pits and the permanent waste rock stockpile at their maximum extents and the material in the temporary waste rock stockpiles having been relocated to the East and Central Pits. Cross-sections of the pits are shown on Large Figure 6 and Large Figure 7, and cross-sections of the stockpiles are shown on Large Figure 8 through Large Figure 10.

Some of the information provided in this document will be submitted annually to fulfill the PTM annual reporting requirements, including documentation on the mining and reclamation activities completed during the past year and the mining and reclamation activities planned for the upcoming year.

1.2 Outline

The outline of this document is:

Section 1.0 Introduction, objective and overview, and geology and Block Model

Section 2.0 Description of the design of systems to manage waste rock and overburden including waste characterization, waste classification, and construction uses

Section 3.0 Description of the outcomes of the design

Section 4.0 Description of the operational plans associated with rock and overburden management

Section 5.0 Description of systems to monitor the water quantity and quality from the stockpiles, the amount of material in the stockpiles, and the footprint of the stockpiles

Section 6.0 Description of annual reporting requirements including comparison to plan, waste characterization update, and compliance report

Section 7.0 Description of the reclamation plan for the stockpiles

Because this document has evolved through the environmental review and permitting, a Revision History is included at the end of the document.

1.3 Geology and Block Model

The geology in the Project vicinity and development of the Block Model are summarized in the following sections.

1.3.1 Surficial Geology

Surficial deposits at the Mine Site, the Plant Site, along the Transportation and Utility Corridors, and along the Colby Lake Pipeline Corridor are dominated by the Rainy Lobe till; although outwash, reworked glacial sediments, and peat are also found (these deposits are not laterally continuous). The Rainy Lobe till has been described at a regional scale as an unsorted sandy loam mixture with pebbles, cobbles, and boulders (Reference (3)), which is generally consistent with what has been observed in soil borings collected from within the Mine Site and near the Tailings Basin.

Within the Mining Area, upland areas are commonly underlain by local bedrock highs, which are overlain by relatively thin mantles of glacial deposits. Lowlands are commonly characterized by wetlands with peat accumulations several feet thick. The surficial deposits range in thickness from 0 to 60 feet in the vicinity of the Mine Site and are on the order of 0 to 40 feet near the Tailings Basin at the Plant Site. The Process Plant is on a bedrock high with minimal surficial deposits. North and northwest of the Tailings Basin, surficial deposits thicken to as much as 150 feet (Reference (4)). Along the Transportation and Utility Corridors, bedrock is generally near the surface. The depth to bedrock along the Colby Lake Pipeline Corridor increases to the south; near Colby Lake, the depth to bedrock is over 100 feet.

1.3.2 Bedrock Geology

The bedrock geology in the vicinity of the Project consists of granites and associated lithologies overlain by metamorphosed sedimentary rock that hosts the northeast trending Biwabik Iron Formation and Virginia Formation, and the intruded igneous Duluth Complex, which is the source of the ore to be mined by the Project. Much of the Plant Site is underlain by the Giants Range Batholith.

The Duluth Complex displays a generally layered fabric that dips to the southeast. The mineral constituents that make up the Duluth Complex form an interlocking igneous texture and fabric with no primary porosity or incipient discontinuity in the rock mass. The NorthMet Deposit occurs in troctolitic and gabbroic rocks of the Partridge River Intrusion (PRI).

Geotechnical drilling at the Mine Site by Golder Associates (Golder) indicated core recoveries near 100% and excellent rock quality designation (RQD), typically exceeding 95% (Reference (5)). The higher the number, the less fractured the rock. Golder conducted additional geotechnical testing, including Uniaxial Compressive Strength and Young’s modulus (Reference (5)). In addition, over 14,000 RQD measurements were recorded for more than 217,000 feet of core during the resource drilling within the proposed pits. The RQD data from exploratory drilling indicates that rock quality in the Duluth Complex is generally excellent (>90%), indicating that the bedrock has a low fracture frequency. Average RQD increases from 73% at the top of bedrock to 94% within 40 feet below the top of bedrock (Reference (6)).

1.3.3 Block Model

The Block Model is a mathematical representation of the NorthMet Deposit and is used to develop a mine design and mining schedule. The schedule drives the required capacity for stockpiles. The development of the Block Model is described in Attachment A.

2.0 Mine Waste Management System Design

Mine waste that will be excavated in the process of exposing the ore at the Mine Site includes waste rock and overburden. Management of these mine wastes includes estimating the amount of each type of material to be excavated, evaluating the potential construction uses for each type of material, making use of a portion of these materials in on-site construction activities, and designing and implementing storage areas for the materials that are not used for construction. Waste rock management systems are described in the following subsections of Section 2.0. Procedures used to classify and segregate waste rock during operations are described in Section 4.1, and procedures used to classify and segregate overburden during operations are described in Section 4.2.

2.1 Waste Rock

Waste rock will be excavated and hauled by truck to waste rock stockpiles or to the East and Central Pits for backfilling. Waste rock will be categorized based on the geochemical properties of the waste rock.

2.1.1 Rock Characterization and Classification

Based on work described in Section 4 of Reference (1), waste rock has been divided into four categories according to its sulfur content, in ascending order of reactivity. These waste rock categories are summarized in Table 2-1 and described in more detail below.

Table 2-1 Summary of Waste Rock Properties

Waste Rock Categorization	Sulfur Content (%S)(1)	Approximate % of Waste Rock Mass	Applications(3)
Category 1	%S ≤ 0.12	70%	Construction and East Pit Backfill
Category 2	0.12 < %S ≤ 0.31	24%	East and Central Pit Backfill
Category 3	0.31 < %S ≤ 0.6	3%	East and Central Pit Backfill
Category 4(2)	0.6 < %S	3%	East and Central Pit Backfill

(1) In general, the higher the rock's sulfur content, the higher its potential for generating Acid Rock Drainage (ARD) or leaching heavy metals.
(2) Includes Virginia formation rock.
(3) Applications include uses of the material other than stockpile storage.

The decision on where to haul the waste rock will depend on the rock's waste category, which will be determined through a sampling and analysis program reviewed by the DNR, as discussed in Section 4.0.

As shown in Table 2-2, during Mine Years 1 through 11, Category 2, 3, and 4 waste rock will be placed on the temporary Category 2/3 or Category 4 Waste Rock Stockpiles (Large Figure 2 through Large Figure 4). Beginning in Mine Year 11, after mining of the

East Pit is complete, Category 2, 3, and 4 waste rock will be placed directly in the East Pit. Category 2, 3, and 4 waste rock will also be used to backfill the Central Pit, once mining ceases in that pit. The material in the temporary Category 2/3 and Category 4 Waste Rock Stockpiles will be relocated to the combined East and Central Pit, after mining ceases in each pit. In addition, approximately 49 million tons of Category 1 waste rock mined after Mine Year 11 will be placed in the East and Central Pits. This will result in backfilling the East Pit, which includes the Central Pit, with approximately 45% of the total waste rock mined. See Section 7.3.1 for more details on East Pit backfilling.

Stockpiles will be designed to comply with Minnesota Rules, parts 6132.2200 and 6132.2400. When at their maximum extent, each stockpile is estimated to have the approximate area, height, volume, and elevation shown in Table 2-3. Large Figure 11 also summarizes stockpile capacities.

Table 2-2 Waste Rock Placement

Mine Year	Category 1 Waste Rock – Mine to Stockpile (tons)	Category 2/3 Waste Rock - Mine to Stockpile (tons)	Category 4 Waste Rock - Mine to Stockpile (tons)	Category 1, 2/3, and 4 Waste Rock - Mine to East Pit(1)(3) (tons)	Category 2/3 and 4 Waste Rock - Stockpiles to East Pit(1)(3) (tons)	Total Rock Moved(1) (tons)
1	18,707,500	5,238,800	1,489,200	0	0	25,435,500
2	15,016,700	4,432,900	762,500	0	0	20,212,100
3	16,139,000	4,297,100	1,127,700	0	0	21,563,800
4	12,796,600	3,655,600	827,500	0	0	17,279,700
5	11,741,300	2,415,000	441,900	0	0	14,598,200
6	16,842,200	4,349,000	665,600	0	0	21,856,800
7	10,405,000	2,566,000	549,000	0	0	13,520,000
8	16,939,800	4,332,200	110,600	0	0	21,382,600
9	12,556,200	4,660,200	133,500	0	0	17,349,900
10	12,974,200	4,070,500	76,800	0	0	17,121,500
11	10,180,400	4,003,900	22,400	0	6,206,800	20,413,500
12	10,773,100	0	0	4,834,700	5,739,500	21,347,300
13	2,850,000	0	0	11,032,700	5,739,500	19,622,200
14	0	0	0	12,177,700	5,739,500	17,917,100
15	0	0	0	10,949,900	5,739,500	16,689,400
16	0	0	0	9,099,300	5,739,500	14,838,800
17	0	0	0	6,955,500	5,739,500	12,695,000
18	0	0	0	8,841,600	5,739,500	14,581,100
19	0	0	0	11,944,200	3,844,400	15,788,600

Mine Year	Category 1 Waste Rock – Mine to Stockpile (tons)	Category 2/3 Waste Rock - Mine to Stockpile (tons)	Category 4 Waste Rock - Mine to Stockpile (tons)	Category 1, 2/3, and 4 Waste Rock - Mine to East Pit(1)(3) (tons)	Category 2/3 and 4 Waste Rock - Stockpiles to East Pit(1)(3) (tons)	Total Rock Moved(1) (tons)
20	0	0	0	14,128,000	0	14,128,000
Total	167,922,000(2)	44,021,200	6,206,700	89,963,600	50,227,700	358,341,100(1)
% Total Rock(1)	54.5%	14.3%	2.0%	29.2%	N/A	N/A

(1) The total rock listed includes movement of rock from the temporary Category 2/3 and Category 4 Waste Rock Stockpiles to the East and Central Pits. There will be approximately 311 million tons of waste rock, with about 50 million tons being double-handled for disposal in these pits. At reclamation, waste rock storage will be in either the Category 1 Waste Rock Stockpile or the East and Central Pits. Values reported above exclude saturated mineral overburden. Approximately 3,262,000 cubic yards of saturated mineral overburden will also be backfilled in the East and Central Pits.

(2) A portion of the Category 1 waste rock may be used for DNR-approved on-site construction. The balance will be placed in the Category 1 Waste Rock Stockpile or in the East and Central Pits.

(3) East/Central Pit capacity below closure water elevation 1,592 ft. AMSL is approximately 150,000,000 tons (at assumed waste rock in-place density of 141 pounds per cubic foot). East/Central Pit capacity between closure water elevation 1,592 ft. AMSL and typical pit rim elevation 1,594 ft. AMSL is approximately 1,300,000 tons (at density noted above).

Table 2-3 Maximum Stockpile Dimensions – Approximate

Stockpile	Mine Year of Maximum Footprint	Maximum Footprint (acres)	Capacity (tons)		Height (feet)		Maximum Elevation (feet above sea level)
			Planned(1)	Maximum Capacity	Planned(1)	Height at Maximum Capacity	At Maximum Capacity
Category 1 (Permanent)	6/21(2)	508/526(2)	168M	172M	200	240	1840
Category 2/3 (Temporary)	6	180	44.0M	60.6M	160	200	1770
Category 4 (Temporary)	3	57	6.21M	15.0M	80	180	1790
Ore Surge Pile (Temporary)	N/A(3)	31	2.50M	3.07M	40	40	1645

(1) The planned capacity of the stockpile is the capacity that will be utilized per the current plan described in this document. The maximum capacity reflects the full capacity of the stockpile based on its planned footprint, but filled to maximum achievable height. Maximum capacities of the temporary stockpiles and planned capacity of the permanent stockpile were used for impact evaluations.

(2) The Category 1 Waste Rock Stockpile has a maximum footprint of 508 acres while active. It will reach this size by Mine Year 6. The stockpile will be re-graded as part of reclamation with a final footprint of 526 acres in Mine Year 21.

(3) The OSP is a surge pile that will have ore moving in and out as needed to meet mine and plant conditions.

2.1.2 Permanent Stockpile – Category 1 Waste Rock Stockpile

The majority of the Category 1 waste rock will be placed in the permanent Category 1 Waste Rock Stockpile, which is the only permanent stockpile. Some Category 1 waste rock will be used to backfill the East or Central Pit. Located north and west of the West Pit, the Category 1 Waste Rock Stockpile, at its final configuration (Mine Year 21), will contain approximately 168 million tons of waste rock, cover approximately 526 acres, and be approximately 200 feet high. If filled to its maximum capacity, the Category 1 Waste Rock Stockpile will be 240 feet high.

The Category 1 Waste Rock Stockpile contains rock that is not expected to generate acid rock drainage (ARD), but may leach metals; therefore, it will be constructed differently than the temporary waste rock stockpiles that will contain waste rock with potential to generate ARD. Minnesota Rule, part 6132.2200, subpart 2, item B(2) mandates collection of water that drains from mine waste; therefore a groundwater containment system will be constructed in stages around the stockpile to collect Category 1 Waste Rock Stockpile drainage and convey it to the Waste Water Treatment System (WWTS) for treatment. This groundwater containment system is being developed in lieu of a liner system under the stockpile. Sections 2.1.2.2 and 2.1.2.3 describe the Category 1 Stockpile Groundwater Containment System.

Details on reclamation of the Category 1 Waste Rock Stockpile are discussed in Section 7.1.1 for progressive reclamation, Section 7.2 for closure and postclosure maintenance.

2.1.2.1 Stockpile Design

The Category 1 Waste Rock Stockpile will be the only permanent stockpile and has been designed to comply with Minnesota Rules, part 6132.2400 to minimize hydrologic impacts, be structurally stable, control erosion, promote progressive reclamation, and enhance the survival and propagation of vegetation. In order to meet these requirements, the stockpile has been designed with a maximum lift height of 40 feet, final bench width of 30 feet, initial slopes between benches at the angle of repose of the waste rock, and final reclamation slopes between benches of 3.75 (horizontal) to 1 (vertical).

In preparation for building the stockpile, geotechnically unsuitable soils will be removed from around the perimeter to insure the long-term stability of the stockpile and the adjacent groundwater containment system. For more details on the geotechnical design and modeling to support the design, see Reference (7). Select permit design drawings of the Category 1 Waste Rock Stockpile are included in Attachment B.

Surface water management on active portions of the stockpile has been designed to minimize erosion of the stockpile surface. The benches and top surfaces of the stockpile will be backsloped away from the crests to minimize the potential for breakout of ponded water from eroding the outer slopes. In addition, crest berms (Detail 3, Drawing SPK-032 in

Attachment B) will be constructed along the operational crest perimeters to provide further assurance that surface runoff from active areas will not overflow to the reclaimed areas along the lower slopes. Outslope drainage will be managed in part by using channels constructed on the inboard side of the stockpile ramps, as illustrated on Detail 4 on Drawing SPK-032 of Attachment B. Drainage and any surface runoff from active portions of the stockpile will be collected in the groundwater containment system along the base of the stockpile.

2.1.2.2 Groundwater Containment System Design

A groundwater containment system will be constructed to capture drainage and surface runoff from the Category 1 Waste Rock Stockpile. The Category 1 Stockpile Groundwater Containment System will provide the ability to collect and treat the drainage from the Category 1 Waste Rock Stockpile.

The Category 1 Stockpile Groundwater Containment System will consist of a cutoff wall (a low hydraulic conductivity compacted soil hydraulic barrier) combined with a drainage collection system around the perimeter of the stockpile near the stockpile toe. The final configuration of the groundwater containment system will completely encircle the stockpile as shown on Figure 2-1. Attachment C contains the permit application support drawings for the Category 1 Stockpile Groundwater Containment System for reference in conjunction with the following discussion of the groundwater containment system design. The design will meet the applicable requirements of Minnesota Rules, part 6132.2200, subpart 2, items B and C. During operations, the water collected by the groundwater containment system will be pumped from the Mine Site to the WWTS and treated and then pumped to the FTB or to the East or Central Pits to flood the pits more rapidly. During reclamation, closure, and postclosure maintenance, this water will be treated at the WWTS and pumped to the East or West Pits or discharged to a small watercourse that flows into the Partridge River, as described in Section 7.0.

Groundwater containment systems are commonly used at facilities where there is a need to manage groundwater flow due to existing or potential facility impacts on groundwater quality, such as municipal and industrial solid waste landfills, brownfield sites, and tailings basins. The combined use of a cutoff wall and a groundwater collection system as an effective means of groundwater quality protection is acknowledged by academic, governmental, and industry authorities and by construction markets, as detailed in Attachment D.

The groundwater containment system will collect stockpile drainage and draw down the water table on the stockpile side of the cutoff wall, thereby maintaining an inward gradient along the cutoff wall and eliminating the potential for stockpile drainage passing through the cutoff wall (hydraulic barrier) (i.e., leakage through the cutoff wall will be inward into the groundwater containment system). Figure 2-2 shows a conceptual cross-section of the Category 1 Stockpile Groundwater Containment System. The design of the groundwater containment system is shown in Attachment C, including typical sections during operations on Drawing GCS-010.

A groundwater flow model was developed to assess the ability of the proposed groundwater containment system to collect groundwater from beneath the Category 1 Waste Rock Stockpile and estimate the average groundwater flow rate to the collection system. See Attachment E for a description of this modeling.

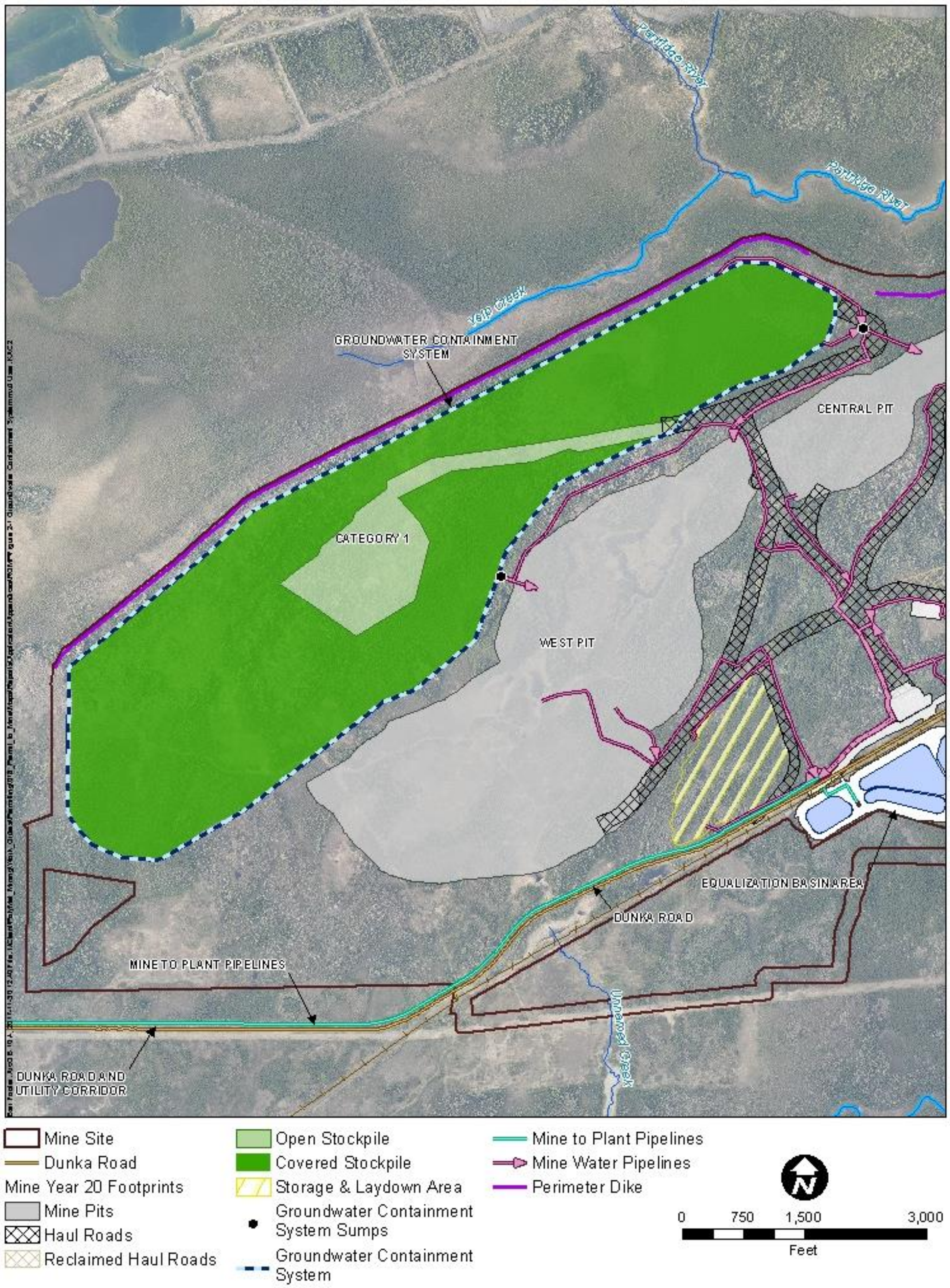


Figure 2-1 Category 1 Stockpile Groundwater Containment System

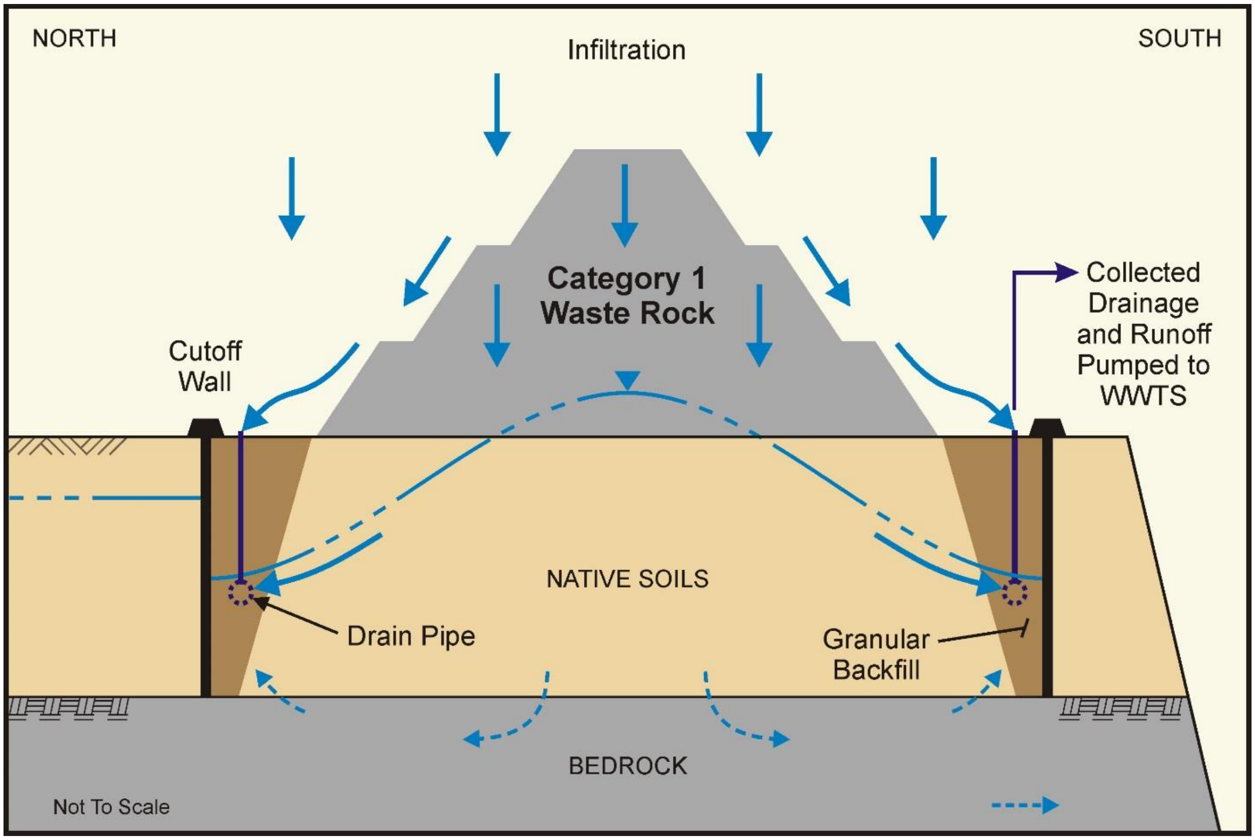


Figure 2-2 Conceptual Representation of Category 1 Stockpile Groundwater Containment System – Operating Conditions Cross-Section

Groundwater flow modeling indicates that stockpile drainage recharging groundwater beneath the Category 1 Waste Rock Stockpile has the potential to flow within the bedrock prior to reaching the groundwater containment system. Groundwater flow within the bedrock is primarily through fractures or other secondary porosity features, as the bedrock has a low primary hydraulic conductivity. At the scale of the model, the fractures are assumed to be sufficiently interconnected that the fractured rock behaves similar to a porous medium. In order for the groundwater containment system to capture groundwater from the bedrock, a hydraulic connection between the drainage collection system and the bedrock must be established, as described in Section 2.1.2.3.

The groundwater containment system will be constructed in stages from the construction phase through Mine Year 5 as shown on Drawings GCS-003 through GCS-007 of Attachment C. The Mine Year 5 configuration of the groundwater containment system will completely contain the stockpile, capturing drainage from the stockpile in its entirety.

2.1.2.3 Groundwater Containment System Configuration and Operation

The groundwater containment system will consist of a cutoff wall and a drainage collection system. The cutoff wall, with a soil hydraulic conductivity of no more than $1x10^{-5}$ cm/sec, will be constructed by excavating a trench near the toe of the stockpile to bedrock and backfilling the trench with a suitable compacted soil material (compacted natural silty clay soil or bentonite amended soil) or by placing a geosynthetic barrier in the trench. Any of these barrier systems will serve the intended function; the type to be installed will be decided based on soil availability, overall cost, and timing/duration of construction at that point in time (i.e., spring, summer, and fall) when construction services are procured and initiated.

The drainage collection system will consist of a combination of pipes and ditches. This includes a slotted or perforated horizontal drain pipe surrounded by aggregate within a trench excavated to bedrock and backfilled with free-draining granular material. In order to establish a hydraulic connection between the collection drain and the bedrock, the elevation of the horizontal drain pipe must be low enough to produce an upward vertical hydraulic gradient between the drain pipe and the bedrock. The existing low hydraulic conductivity soils below the drain pipe will be excavated down to bedrock and backfilled with a high hydraulic conductivity granular material. This should establish the hydraulic connection between the groundwater containment system and bedrock along most of the west, north and east sides of the stockpile where it is estimated that the water level will be above the elevation of the drain pipe. However, along the south side of the stockpile, the water level is likely to be below the drain pipe elevation. Some of the stockpile drainage entering bedrock and flowing south will not be captured by the groundwater containment system but will instead flow into the West Pit.

Along the west, north, and east sides of the stockpile, there may be localized areas where the drain pipe cannot be installed at an elevation low enough to prevent groundwater from flowing beneath the cutoff wall. PolyMet assumed that water collection performance monitoring points will be defined in SDS permitting to confirm (via monitoring differential hydraulic head) whether or not post-construction seepage loss is occurring beneath the cutoff wall. If monitoring confirms that seepage losses are occurring to an extent potentially detrimental to water quality, then groundwater recovery wells can be installed to supplement the groundwater containment system.

Stockpile drainage collected in the horizontal drain pipe will flow by gravity to a low point near the northeast corner of the stockpile. From the northeast corner of the stockpile, a non-perforated pipe will convey the flow to a collection sump where it will be pumped to the WWTS. As the stockpile development progresses to the west, an additional section of the groundwater containment system will collect and convey drainage from the southwest corner of the stockpile by gravity flow to another collection sump where it will be pumped to the WWTS. The two collection sumps will have emergency overflows (by gravity) to the East or West Pits.

In addition to the drainage collection system around the stockpile, a mine water ditch will be incrementally built along the base of the stockpile as the stockpile is built. Stockpile mine water originating from surficial seeps and runoff will be collected and pumped to the

Equalization Basin Area at the Mine Site, and then further sent to the WWTS via the Mine to Plant Pipelines. To accomplish this, the groundwater containment system horizontal drain pipe will have vertical risers extending upward into the mine water ditch. The portion of the risers above ground will be slotted or perforated and encapsulated in aggregate to allow stockpile mine water originating from surficial seeps and runoff collected in the mine water ditch to drain through the risers into the horizontal drain pipe, while excluding soil particles of a size that could clog or otherwise be difficult to clean from the pipe. These risers will also function as access points for cleanout of the horizontal pipe. The correct specification of the aggregate and vertical riser slot size in combination with the ability to access the horizontal pipe to implement periodic preventive cleaning will minimize the risk of clogging the drain pipe.

Shortly after construction and before vegetative cover is fully established, these systems can occasionally fill in with sediments. Multiple cleanout access points will be provided to accommodate equipment needed to prevent and/or remedy clogs if they occur. Periodic maintenance will consist of inspection via video camera of the drain pipe to make sure it is not blocked by sediments or collapsed. If sediments are observed, they will be cleaned out by flushing through the vertical risers. If collapse is observed, the collapsed section will be repaired. The periodic inspections to evaluate the need for maintenance will be every 5 years unless monitoring of the amount of water collected by the groundwater containment system indicates there has been an unusual change in flow not attributed to weather that could be caused by collapse or damage to the groundwater containment system. Over the long-term, once a dense vegetative cover is established, the availability of sand, silt and clay size particles to erode into the system is substantially reduced, as are the potential for clogging and the need for occasional pipe cleaning.

Reclamation of the groundwater containment system, including the mine water ditch, is described in Section 7.3.

As shown in Table 2-4 and Attachment E, the groundwater model simulations indicate that the groundwater containment system is capable of capturing 91% to greater than 99% of the drainage from the Category 1 Waste Rock Stockpile over the life of the mine (LOM) and during the closure and postclosure maintenance phases. The majority of the remaining drainage eventually flows to the mine pits. A small percentage, less than 1% to 2% (<0.01-6 gpm) during operations and less than 1% (<0.01 gpm) during closure and postclosure maintenance, is not captured in the groundwater containment system or the mine pits and is estimated to flow off site.

The groundwater modeling simulations show that the majority of the flow not captured by the Category 1 Stockpile Groundwater Containment System or the pits follow deep and long bedrock flow paths to the south, southeast, and east. These potential uncaptured flows are not significant due to the relatively small volumes of groundwater flow that these flow paths represent and the long travel time along these flow paths (estimated at over 1,500 years travel time to downgradient surface water locations, as described in Attachment E).

However, these potential flows from the Category 1 Waste Rock Stockpile to bedrock south, southeast, and east of the West Pit, along with outflow from the West Pit, are included in the Mine Site water quality model to determine potential impacts from this groundwater to downgradient surface water locations.

Table 2-4 Category 1 Waste Rock Stockpile Drainage Modeling Results

Mine Year	Flow Component	Flow Rate (gpm)	Overall Capture Efficiency
Mine Year 1	Total Drainage	140.7 gpm	>99.9%
	Capture by Containment System	140.2 gpm	
	Capture by West Pit	0 gpm	
	Capture by East Pit	0.5 gpm	
	Uncaptured Flow	<0.1 gpm	
Mine Year 10	Total Drainage	361.2 gpm	98.5%
	Capture by Containment System	328.9 gpm	
	Capture by West Pit	20.6 gpm	
	Capture by East Pit	6.1 gpm	
	Uncaptured Flow	5.5 gpm	
Mine Year 20 (virtually all final cover in place)	Total Drainage	3.7 gpm	99.9%
	Capture by Containment System	3.5 gpm	
	Capture by West Pit	0.2 gpm	
	Capture by East Pit	<0.01 gpm	
	Uncaptured Flow	<0.01 gpm	
Mine Year 30	Total Drainage	3.7 gpm	99.9%
	Capture by Containment System	3.5 gpm	
	Capture by West Pit	0.2 gpm	
	Capture by East Pit	<0.01 gpm	
	Uncaptured Flow	<0.01 gpm	

Mine Year	Flow Component	Flow Rate (gpm)	Overall Capture Efficiency
Mine Year 40	Total Drainage	3.7 gpm	99.9%
	Capture by Containment System	3.5 gpm	
	Capture by West Pit	0.2 gpm	
	Capture by East Pit	0 gpm	
	Uncaptured Flow	<0.01 gpm	
Postclosure Maintenance (Steady State)	Total Drainage	3.7 gpm	99.9%
	Capture by Containment System	3.5 gpm	
	Capture by West Pit	0.2 gpm	
	Capture by East Pit	0 gpm	
	Uncaptured Flow	<0.01 gpm	

Prior to the stockpile being covered, the model is estimating that there is some potential for a very small amount of stockpile drainage (0.2 gpm; a portion of the 5.5 gpm in Mine Year 10) to flow underneath the groundwater containment system and discharge to the adjacent wetlands in areas along the northeast and northwestern sides of the stockpile. These areas will be investigated prior to the construction of the corresponding segment of the groundwater containment system. If field conditions, particularly depth to bedrock, are similar to modeling assumptions, the design of the groundwater containment system may be modified to account for capture at lower elevations or to include groundwater extraction wells that will collect water from a greater depth than the groundwater containment system is currently designed and modeled to collect water.

2.1.2.4 Construction Use of Waste Rock

A significant amount of construction material will be required in the construction phase and the first few years of operation to develop the Mine Site. Construction material requirements change over time, but material continues to be needed throughout the LOM for new and expanded haul roads, stockpile foundations and liners, and ancillary infrastructure. A subset of Category 1 waste rock with sulfur content of 0.05% or less, herein referred to as Duluth Complex construction rock, will be used as a construction material. Procedures for selecting Duluth Complex construction rock that meets environmental criteria are presented in Attachment F.

In addition to Duluth Complex construction rock, construction material may also be sourced from the regionally-available Biwabik Iron Formation (BIF), provided it meets Project-specific criteria indicating minimal potential for acidic and metalliferous drainage, detailed in Attachment F. Sources of BIF for construction include, but are not limited to, a state-owned waste rock stockpile, Stockpile 2012, from LTVSMC Area 3 and/or 2 located approximately 5 miles west of the Mine Site along Dunka Road or from the inactive LTV Steel Mining Company (LTVSMC) Area 5 (Large Figure 12) to the east of the Flotation Tailings Basin.

2.1.3 Temporary Waste Rock Stockpiles (including the Ore Surge Pile)

There are two temporary waste rock stockpiles and one temporary OSP. Although the OSP does not store waste rock, the design of the stockpile is similar to the design of the temporary waste rock stockpiles and is thus included in this section. The locations of the stockpiles, as shown in Large Figure 2 through Large Figure 5, are as follows:

- The temporary Category 2/3 Waste Rock Stockpile is located southeast of the East Pit, near Dunka Road.
- The temporary Category 4 Waste Rock Stockpile is located west of the East Pit, over the Central Pit.
- The OSP, which is a temporary storage pile of ore, is located south of the East Pit, along Dunka Road, east of the Rail Transfer Hopper (RTH).

The temporary waste rock stockpiles will receive material from the East Pit from Mine Year 1 to 11 and from the West Pit from Mine Year 2 through 11. Beginning in Mine Year 11, after mining of the East Pit is complete, Category 2, 3, and 4 waste rock mined from the West and Central Pits will be hauled directly to the East Pit for disposal. Category 2, 3, and 4 waste rock will also be used to backfill the Central Pit, after mining ceases in that pit in Mine Year 16. Starting in Mine Year 11, the temporary waste rock stockpiles will be relocated to the East and Central Pits for ultimate disposal, after mining ceases in each pit.

The OSP will allow for temporary storage of ore until it can be added to the ore delivery schedule or as required due to operating delays. Use of the OSP will allow for delivery of a steady annual flow and assist in providing a uniform grade of ore to the Process Plant. Ore will be added to and removed from the OSP during the LOM as needed to meet mine and plant operating conditions. The OSP footprint is approximately 32 acres with capacity for 2.5 million tons for one 40-foot lift and a maximum capacity of 4.4 million tons in three 40-foot lifts with side slopes at the angle of repose. The OSP will be removed at the completion of mining activities, with the remaining ore processed at the plant or placed in the East or Central Pits for ultimate disposal.

2.1.3.1 Stockpile Design

The temporary stockpiles have been designed to comply with Minnesota Rules, part 6132.2200 to provide for the collection of substantially all water, and Minnesota Rules, part 6132.2400 to minimize hydrologic impacts, be structurally sound, and control erosion on the stockpile surface. Because they are temporary stockpiles, their design does not include progressive reclamation. The stockpiles have been designed with a maximum lift height of 40 feet, bench width of 30 feet, and slopes between benches at the angle of repose of the material, as specified in the Minnesota Rules, part 6132.2400. The stockpile designs include the foundation; underdrain system (when required); liner system; and overliner drainage system. Design of the stockpile sumps and stockpile water management is described in the NorthMet Water Management Plan-Mine (Reference (8)). Details on reclamation of the temporary stockpiles are discussed in Section 7.3 for the Category 2/3 and Category 4 Waste Rock Stockpiles.

In preparation for building the temporary stockpiles, the sites will be cleared, grubbed, and geotechnically unsuitable soils excavated as needed to support a stable foundation. Unsuitable soils are classified as Pt, OH, OL, MH and CH based on the Unified Soil Classification System. Structural fill will then be placed, as needed, to meet the foundation grades designed to provide gravity drainage of water collected on the stockpile liner. In areas for which there is a risk of elevated groundwater levels or excess pore water pressure generation below the liner, the stockpiles will be constructed with a foundation underdrain system. After the underdrain system is installed, the liner system will be constructed.

2.1.3.2 Liner System Design

The stockpile liner is an engineered system comprised of, from the bottom up, a compacted soil liner, a geomembrane liner, and an overliner drainage layer. An underdrain system will be installed beneath the compacted soil liner if deemed necessary, to help manage groundwater to facilitate construction of the liner system and/or to prevent the development of excess foundation pore water pressures during stockpile loading. The determination of need for underdrains will depend on groundwater level and soil types encountered at the time of stockpile liner construction. The composite liner, defined as a compacted soil liner overlain by a geomembrane, has been designed to prevent downward infiltration of water. The high hydraulic conductivity overliner drainage layer minimizes the development of hydraulic head on the liner by collection and gravity conveyance of water collected above the liner to a series of perimeter stockpile sumps. The design components (including the underdrains, composite liner, and overliner drainage layer) function as a system to enhance liner integrity and stockpile stability.

The composite liners are designed to perform commensurate with the level of environmental risk expected by the waste rock classification type. The composite liner system for each temporary stockpile consists of a minimum of one foot of compacted soil overlain by an 80-mil thick Linear Low Density Polyethylene (LLDPE) geomembrane liner and a minimum of two feet of granular drainage material. The temporary stockpile liner systems are described below and are summarized in Table 2-5:

- Category 2/3 Waste Rock Stockpile: A minimum of one foot of compacted soil liner overlain by an 80-mil thick geomembrane liner and a layer of overliner drainage material. The soil liner will consist of local materials that are scarified, moisture-conditioned, and compacted to meet a maximum hydraulic conductivity requirement of $1x10^{-5}$ cm/sec. Based on the available laboratory and site investigation data (Section 4.1 of Reference (7)), it is anticipated that local glacial till soils will meet the hydraulic conductivity requirements specified for the soil liner materials. This data indicates that the hydraulic conductivity of foundation soils is matrix-supported, i.e., the hydraulic conductivity is governed by matrix soils. If necessary, the soil liner materials will be processed to meet the $1x10^{-5}$ cm/sec hydraulic conductivity design criteria.

- Category 4 Waste Rock Stockpile and Ore Surge Pile: A minimum of one foot of compacted soil liner with a maximum hydraulic conductivity of $1x10^{-6}$ cm/sec, overlain by an 80-mil geomembrane liner and a layer of overliner drainage material. Based on the available laboratory and site investigation data (Section 4.1 of Reference (7)), it is anticipated that the compacted soil liner will consist of locally excavated soils. This assumption of using local material is also supported by the long-term hydraulic conductivity values for glacial till reported in the literature (e.g., Reference (9) evaluated the mean field saturated conductivity for glacial till of $3x10^{-6}$ cm/sec when used for cover materials). As the liner soils are subject to much higher confining pressures, are overlain by waste rock, and are therefore protected from freeze, thaw, and desiccation effects, the long-term maximum liner hydraulic conductivity of $1x10^{-6}$ cm/sec for on-site soils is likely achievable. If necessary, the soil liner materials will be processed to meet the $1x10^{-6}$ cm/sec hydraulic conductivity design criteria. The Ore Surge Pile requires a thicker overliner drainage layer than the other temporary stockpiles due to the anticipated mine equipment operating on the overliner drainage layer.

Table 2-5 Temporary Stockpile Liner System Design

Temporary Stockpile	Liner System
Category 2/3 Waste Rock Stockpile	12-inch compacted ($1x10^{-5}$ cm/s) soil liner subgrade overlain by an 80-mil LLDPE geomembrane, covered by a 24-inch overliner drainage layer
Category 4 Waste Rock Stockpile	12-inch compacted ($1x10^{-6}$ cm/s) soil liner subgrade overlain by an 80-mil LLDPE geomembrane, covered by a 24-inch overliner drainage layer
Ore Surge Pile	12-inch compacted ($1x10^{-6}$ cm/s) soil liner subgrade overlain by an 80-mil LLDPE geomembrane, covered by a 6-foot overliner drainage layer

2.1.3.2.1 Liner Leakage Analyses

Each of the selected liner systems was evaluated by conducting liner leakage analyses. The methodology and results of these evaluations are provided in Section 5.2.2 and Section 6.1.1

of Reference (10). Results of leakage analyses conducted on the proposed liner systems assuming long-term steady state conditions are summarized as follows:

- Category 2/3 Waste Rock Stockpile: The proposed liner system for the Category 2/3 Stockpile is estimated to provide an average annual leakage rate based on the 90th percentile of approximately 0.63 gal/acre/day prior to the stockpile being relocated to the East Pit; and

- Category 4 Waste Rock Stockpile and Ore Surge Pile: The proposed liner system for these stockpiles is estimated to provide an average annual leakage rate based on the 90th percentile of approximately 0.18 gal/acre/day prior to the stockpile being relocated to the East Pit or removed.

The calculated liner leakage rates listed above disregard the influence of the waste rock uptake potential. This is likely a conservative assumption that inherently overestimates liner leakage because the stockpile materials will be placed dry of the specific retention moisture content (also referred to as field capacity), which is the minimum moisture content required to overcome the gravimetric surface tension so that gravity drainage of precipitation to the bottom of the stockpile can occur (Reference (11)). The moisture content difference between the specific retention and the moisture content of the originally placed waste rock represents the quantity of water that is permanently lost due to moisture uptake by the waste rock. The quantity of water lost from uptake is not available on a bulk basis for drainage. In addition, uptake by the waste rock is expected to delay the onset of drainage from meteoric water through the waste rock due to the amount of time needed for "break-through" of the wetting front on a bulk basis. Hutchison and Ellison (Reference (12)) note that for waste rock placed at a moisture content below its specific retention value "*… possibly even for several months or years, percolation will go toward raising the moisture content of the waste to levels at which leachate flow can ultimately occur*." It is anticipated that a minor percentage of "short-circuiting" may occur at stockpile boundaries, but the total waste rock uptake is likely to remain significant. For instance, 40 feet of material placed in a single lift with a 5% (by volume) uptake differential will need approximately one year for break-though, assuming no evaporation and runoff losses. Therefore, the overall stockpile will essentially behave as a "sponge" with the majority of the precipitation being permanently lost as uptake until the specific retention moisture content is reached.

No operational water balance quantifying the permanent uptake for the stockpiles was conducted for this permit-level design, as the material characteristics required to define the required parameter have not been developed. In particular, to define the uptake potential, the expected moisture content of the materials placed on the stockpiles and their corresponding specific retention moisture contents are required. Limitations for on-site disturbance currently prohibit the collection of this data. Based on experience on other similar projects, the difference between the initial moisture content of the waste rock and its specific retention value is generally in the range of 1% to 5% by weight, depending on the material's specific properties.

2.1.3.2.2 Foundation Settlement

Compacted waste rock (i.e., Duluth Complex construction rock or BIF) and/or native soils will be used for foundation grading. The foundation soils may exhibit moderate settlement under the high-stress design conditions, as discussed in Section 6.1 of Reference (7). As a result, a LLDPE geomembrane or similar elastic polymer geomembrane will be used for the geomembrane barrier layer component of the liner system for the Category 2/3 and Category 4 Waste Rock Stockpiles and Ore Surge Pile due to its reliability to accommodate high strain deformations. Foundation settlement and liner strain calculations are discussed in Section 6 of Reference (7).

Structural fill will dominantly consist of native till soils compacted to 95% of the maximum dry density as determined by the standard Proctor compaction test (ASTM D 698). When waste rock is used to develop the foundation grades, rock fill will be placed in controlled lifts and compacted in accordance with a specified rock fill compaction method.

2.1.3.2.3 Overliner Drainage Layer Design

The overliner drainage layer material will consist of crushed rock or processed gravel from on-site materials. The use of a crushed rock overliner has been a standard of practice for high stress mine waste applications for decades; e.g., crushed ore has been used extensively in high stress heap leach liner systems for mining applications for over 20 years. The overliner drainage layer provides a buffer to protect the geomembrane from damage during placement of the waste rock, from wildlife, and from the elements (e.g., UV radiation, wind, storm flows).

The overliner drainage layer thickness for the OSP is different from the temporary waste rock stockpiles due to the potential for equipment to be operating on the overliner drainage materials while loading ore onto trains. The OSP requires a minimum overliner thickness of 6 feet, which is based on liner stress computations conducted to accommodate the design criteria of 8 pounds per square inch (psi) maximum vertical stress on the liner from the anticipated mine equipment operating over the liner. The liner system stress calculations are provided in Attachment G.

The overliner drainage layer contains a liquid collection piping network as shown on Details 2 and 3 on Drawing SKP-035 of Attachment B. The preliminary layout of the overliner drainage network of piping are shown on Drawings SKP-017, SKP-023, and SKP-029 in Attachment B. The liquid collection piping design calculations are provided in Attachment H.

2.1.3.2.4 Overliner Drainage and Underdrain Flows Collection

The stockpile subgrades will be constructed to promote positive drainage of future stockpile drainage towards the lined Overliner Collection Sumps (Overliner Sumps). Locations of the Overliner Sumps are shown in Drawings SKP-017, SKP-023, and SKP-029 in Attachment B. Liner grades as shown in Drawings SKP-015, SKP-021, and SKP-027 have been designed to minimize the number of Overliner Sumps at each stockpile. The Overliner Sump design is described in detail in Section 2.1.4 of Reference (8) and is shown on Large Figure 4 through Large Figure 6 of Reference (8).

Underdrain flows will be collected in a series of unlined Underdrain Sumps that will be located directly adjacent to the Overliner Sumps, which are shown in Drawings SKP-015, SKP-021, and SKP-027 in Attachment B. An Underdrain Sump manhole design is shown on Detail 5 on Drawing SKP-035 of Attachment B. The Underdrain Sumps are designed to contain the 24-hour volume of consolidation water expelled from the pores of the underlying soils during the loading process. In addition, the Underdrain Sumps will collect shallow groundwater if intercepted by the underdrain piping network.

Stockpile drainage collected in the Overliner Sumps is considered mine water and will be pumped to the Equalization Basin Area for conveyance to the WWTS (Section 2.1.4 of Reference (13)). Water collected in the Underdrain Sumps will initially be directed to the Overliner Sumps for conveyance to the Equalization Basin Area. It is anticipated that the water quality associated with the Underdrain Sumps will be the same as groundwater quality and will be of sufficient quality to direct off-site through the stormwater system.

2.1.3.3 Stockpile Construction Quality Assurance Plan

A Construction Quality Assurance (CQA) Plan has been developed for the stockpile construction and is provided in Attachment I. This plan outlines CQA procedures for the installation of the foundation and liner components of the temporary stockpile construction. This plan has been developed to assure that the construction of the soil and geosynthetic components are in compliance with the project specifications and to demonstrate that the regulatory requirements for the construction are achieved.

The objective of the CQA Plan is to assure that the Contractor uses the proper materials, construction techniques, and procedures, and that the intent of the design is achieved. This plan also provides the means for resolution of problems that may occur during construction. The CQA Plan is independent of the quality control (QC) programs to be followed by the manufacturers, installers, and the Contractor.

2.2 Overburden

As noted in Section 1.0, overburden (about 4% of the excavated volume for pits and stockpile foundations) includes all unconsolidated material that overlies bedrock. Overburden excavated to access ore and waste rock and to construct stockpile foundations will be classified based on the physical and geochemical properties of the material, and will be used or disposed of based on the classification.

2.2.1 Overburden Characterizations and Classification

Based on work described in Section 4 of Reference (1), the overburden has been classified into three types, based on their physical and chemical characteristics:

1. Peat – this includes all organic soils.
2. Saturated mineral overburden – this includes all mineral overburden (non-peat) that has remained below the water table, has not been oxidized, and can release metals when exposed to air and oxidized (referred to hereafter as saturated mineral overburden in this document).
3. Unsaturated mineral overburden – this includes all mineral overburden (non-peat) located above the water table, including all topsoil. This material has been oxidized and has low potential for metal release (referred to hereafter as unsaturated mineral overburden in this document).

The primary criteria for distinguishing between saturated and unsaturated mineral overburden will be the location of the water table.

2.2.2 Overburden Storage and Laydown Area

The Overburden Storage and Laydown Area (OSLA) will be located south of the West Pit and west of the RTH. This area will be used to screen, sort, and temporarily store peat and unsaturated mineral overburden for future use.

The OSLA will be graded to facilitate drainage around storage and processing areas and to allow for storage and future use of unsaturated mineral overburden and peat. Grading of the site will direct drainage to an unlined mine water pond in the southwest corner. The OSLA will be unlined, but will be compacted sufficiently to support equipment operation in most areas of the site.

2.2.3 Construction Uses of Overburden

A significant amount of construction material will be required in the first few years of operation to develop the Mine Site. Construction material requirements change over time, but material will continue to be needed throughout the LOM for new and expanded haul roads, haul road maintenance, stockpile liners, and ancillary infrastructure. The ability to use overburden as a construction material will be dependent on the application, the expected effect on surface and groundwater quality, and the availability of material relative to when it is needed.

Table 2-6 provides the estimated overburden excavation requirements based on the current design of the stockpiles and pits. This table provides the best available estimate of actual excavation. These quantities were developed based on the depth to groundwater map (Large Figure 13) and depth to bedrock map (Drawing SKP-009 in Attachment B), both of which will be refined throughout the LOM, and have been developed based on drilling records, test pit logs, and monitoring well data collected at the site. The overburden excavation volumes for the pit footprints are based on stripping of overburden down to bedrock. The excavation requirements for the Category 2/3 and Category 4 Waste Rock Stockpile footprints and OSP footprint, however, are based on excavation down to the stockpile liner grades and the estimated removal of geotechnically unsuitable overburden (mainly peat and highly plastic clays) below liner grade, as necessary. The excavation requirements for the Category 1 Waste Rock Stockpile footprint only include removal of geotechnically unsuitable material around the perimeter for long-term stability of the stockpile and the groundwater containment system. While current excavation quantity estimates are based on earthwork activities necessary to implement the design of stockpiles and pits, additional excavation will occur at targeted locations to remove unsaturated mineral overburden that can be used to meet future construction needs. This will be necessary for locations where access will be limited by mining activities in the future (e.g., within the eastern half of the Category 1 Waste Rock Stockpile footprint). Refinements such as this will occur on a real-time basis during construction.

The depth to bedrock map (Drawing SKP-009 in Attachment B) is based on 2010 high resolution topographic mapping of the Mine Site and data collected from drilling, test pits, and geophysical surveys. The depth to groundwater map (Large Figure 13) is also based on this topographic map and data collected from drilling, test pits, and geophysical surveys. Table 2-6 provides the estimated volumes of overburden, by type, based on this information.

Table 2-7 lists the proposed construction uses of saturated mineral overburden, which allows for an estimate of the approximate volume for disposal in the Category 2/3 and 4 Waste Rock Stockpiles or pits. The estimated saturated mineral overburden excavated for the stockpile and pit footprints is approximately 5.6 million cubic yards (MCY). The estimated construction applications listed in Table 2-7 will use approximately 2.3 MCY, assuming these uses are acceptable to the DNR in permitting. This analysis results in a saturated mineral overburden storage need between 3.3 and 5.6 MCY in the Category 2/3 and Category 4 Waste Rock Stockpiles or directly in the East and Central Pits.

Table 2-6 Estimated Overburden Excavation Volumes

Mine Feature	Area (acres)	Estimated Overburden Excavation Volume (bank cubic yards)			
		Saturated Mineral Overburden	Unsaturated Mineral Overburden	Peat	Total
Ore Surge Pile	31	21,000	202,000	4,000	227,000
Category 1 Waste Rock Stockpile(1)	526(1)	0	0	220,500	220,500
Category 2/3 Waste Rock Stockpile	180	27,000	274,000	462,000	763,000
Category 4 Waste Rock Stockpile(2)	57	3,000	53,000	43,000	99,000
West Pit	321	4,491,000	1,193,000	1,498,000	7,182,000
East/Central Pits(2)	207	1,047,000	1,450,000	227,000	2,724,000
TOTAL(2)	1,275(2)	5,589,000	3,172,000	2,454,500	11,215,500

(1) The Category 1 Waste Rock Stockpile overburden excavation volumes include excavation of peat within 100 feet from the outer edge of the stockpile for stockpile stability. The stockpile is 508 acres while active but will be re-graded as part of reclamation, resulting in a final footprint of 526 acres. The 508-acre footprint was used to calculate excavation volumes within the 100-foot buffer for stockpile stability. The groundwater containment system will surround the final 526-acre footprint.

(2) The Category 4 Waste Rock Stockpile footprint overlaps with the Central Pit footprint. The individual areas are greater than the total, which takes into account the overlap. The volumes listed for the East/Central Pits only include the volumes in excess of the Category 4 Waste Rock Stockpile.

Table 2-7 Proposed Construction Applications for Saturated Mineral Overburden

Application	Water Quality Rationale	Estimated Cubic Yards(1)
Stockpile Foundation Material Below the Water Table	Operations: Overburden will remain below the water table. Closure: Overburden will remain below the water table.	823,000
Temporary Stockpile (Category 2/3 and 4 Waste Rock Stockpile and Ore Surge Pile) Drainage Layer	Operations: Water draining through this material will be collected and treated. Closure: This material will be removed prior to removal of the liner during stockpile reclamation.	1,045,000
In-Pit Haul Road Top Dressing	Operations: Water contacting this material will flow into the pit and be collected and treated, or used to flood the East Pit. Closure: Any material remaining above the water table will be moved down below the water table within the pits.	10,000
Mine Water Sumps and Ponds Liner Cover Material	Operations: Most of this material will be submerged; drainage through this material will be collected and treated. Closure: The liner will be removed from these ponds/basins. Mine water ponds may be reclaimed as wetlands, or will be regraded and revegetated; the liner cover material will be placed below the water level in the pits. The equalization basins will be reclaimed by re-grading and vegetating the areas, with liner cover material placed below the water level in the pits.	49,000
Soil Liner Below a Temporary Geomembrane Liner	Operations: Geomembrane liner will prevent water from draining through this material. Closure: This material will be removed with the geomembrane liner during stockpile reclamation.	421,000
TOTAL	N/A	2,348,000

(1) Estimated Cubic Yards are based on current designs; quantities can be expected to increase or decrease due to normal variability in site conditions typically encountered during construction and/or based on incremental adjustments to constructed earthwork infrastructure normally expected during construction.

Due to the geochemical differences between the unsaturated mineral overburden, saturated mineral overburden, and peat, the use of the material will mainly depend on the potential impact to water quality. Based on the geochemical analysis to-date, the unsaturated mineral overburden can be used in most applications across the site as described below. Peat will be used for reclamation activities. Saturated mineral overburden will only be used in specific applications as described in Section 2.2.3.1.

Granite boulders are proposed to be segregated from other non-granitic boulders so they can be crushed and used as needed for haul road cover and railroad ballast. Granite boulders are distinguishable from other non-granitic rock types by their visible crystals of pink feldspar, white or grey quartz, and black mica. There is no horizontal banding in granite as would be visible in some sedimentary and metamorphic rock types, and most other rock types have uniform crystal size and color throughout the rock – very different from the speckled color and larger and variable grain size throughout granite. Granite is a commonly used construction material, so most people can identify it. Even soil-covered boulders, once scraped by a dozer or backhoe or washed clean by rainfall to expose a fresh surface can readily be identified and separated from other types of boulders.

During Mine Site earthwork construction activities, backhoe and dozer operators will preferentially push and stockpile granite boulders for review and acceptance by the on-site construction observer. The operators will push the granite boulders into small discrete piles that will be "audited" by a construction observer with training and experience sufficient to identify granite by visual inspection. Non-granitic boulders will be marked for exclusion from the stockpile during subsequent loading of the boulders into trucks for hauling to the crushing plant. Boulders that are marked for exclusion will be incorporated for uses specified for saturated and unsaturated mineral overburden, independent of rock type, or placed within the appropriate waste rock stockpile based on type. No effort will be made to further characterize the boulder rock types other than for separation of granitic boulders.

A flow diagram of overburden materials and waste rock through the entire LOM is shown in Large Figure 14. This allows for a visual representation of the flow of these materials being removed, stored, and used in construction applications. In addition to overburden movement, the use of Duluth Complex construction rock and borrow material needed for construction purposes, as well as excavated waste rock are also included in the schematic.

As shown on Large Figure 14, borrow material may be required throughout the LOM for multiple applications. This will occur when the material requirements are not available from on-site sources, such as in the first year of the Mine Site development when Duluth Complex construction rock is not yet available or if there are times when there is a greater demand than supply of on-site construction materials. On-site borrow sources of unsaturated mineral overburden will be identified in upland areas or areas planned as future pit or stockpile footprints. In addition to on-site borrow areas, additional borrow sources have been identified for use, including the state-owned waste rock stockpile (Stockpile 2012) located approximately 5 miles west of the Mine Site along Dunka Road and the overburden and waste rock stockpiles from the inactive LTVSMC Area 5 east of the Tailings Basin (Large Figure 12).

2.2.3.1 Saturated Mineral Overburden

Saturated mineral overburden will be used for DNR-approved construction applications. Potential construction uses, as listed below, include applications where it will be placed in a permanently saturated zone, above temporary membrane liners prior to ultimate disposal in a permanently saturated zone, or as the temporary stockpile soil liner immediately below the geomembrane liner. Potential quantities of saturated mineral overburden are shown in Table 2-6, and the proposed construction applications are described in Table 2-7.

2.2.3.1.1 Stockpile Foundation Material Below the Water Table

The foundations for the Category 2/3 and Category 4 Waste Rock Stockpiles and OSP require excavation of geotechnically unsuitable material (mainly peat and high plasticity clays) and replacement with geotechnically suitable material. The Category 1 Waste Rock Stockpile will also require excavation of some unsuitable material (peat and high plasticity clays) around the perimeter of the stockpile for long-term stability. The material used to backfill these excavations could be saturated mineral overburden if the fill will be placed below the water table and if the saturated mineral overburden is geotechnically suitable, or it could be other construction material meeting PolyMet's selection criteria (Attachment F).

2.2.3.1.2 Temporary Stockpile Drainage Layer

The liner systems of the Category 2/3 and Category 4 Waste Rock Stockpiles and OSP include geomembrane liners and require a layer of material above the liner to facilitate drainage and protect the integrity of the liner during construction and decommissioning. Because water passing through these materials above the liner will be collected and subsequently treated, this material can be saturated mineral overburden or other construction material meeting PolyMet's selection criteria (Attachment F).

2.2.3.1.3 In-Pit Haul Road Top Dressing

The primary material used for haul road top cover will be crushed rock; however, in-pit haul roads may have a top cover of select graded overburden (1-inch minus road aggregate). Because water flowing over or through the haul roads in the pits will be collected and treated during operations and submerged in reclamation, closure, or postclosure maintenance, saturated mineral overburden can be used as the top cover material for haul roads within the mine pits if it meets material specifications. If saturated mineral overburden is not used for this application, other construction material meeting PolyMet's selection criteria will be used (Attachment F).

2.2.3.1.4 Mine Water Pond and Equalization Basin Liner Cover Material

Most of the mine water ponds and each of the equalization basins will have a geomembrane liner with a protective layer of material over the top. The protective layer may be constructed using one or both of saturated and unsaturated mineral overburden depending on material types and quantities available at locations near the feature being constructed. Because the liner cover material (protective layer over the liner) will remain perpetually saturated (and water draining off this material during operations will be collected and treated), this layer can be constructed with saturated mineral overburden. During reclamation, mine water ponds will be cleaned out, liners will be removed, and the pond footprints will be reclaimed as wetlands or will be re-graded and vegetated. Material used to construct the mine water ponds will either remain in place as the saturated wetland substrate or be placed into the East or Central Pits for disposal. During reclamation, once the Equalization Basin Area is no longer necessary, the equalization basins will also be cleaned out, liners will be removed, liner cover materials will be placed in the East or Central Pit for subaqueous disposal, and the area will be reclaimed as wetlands or re-graded and vegetated. If saturated mineral overburden is not used in this application, other construction material meeting PolyMet's selection criteria will be used (Attachment F).

2.2.3.1.5 Soil Liner Below a Temporary Geomembrane Liner

As described in Section 2.1.3.2, the Category 2/3 and Category 4 Waste Rock Stockpiles and OSP consist of, from top to bottom, a geomembrane liner over a compacted soil liner over a foundation underdrain system, if required. The purpose of the underdrain system is to prevent the development of excess foundation pore pressure below the liner. If required, the soil liner will be removed with the liner system and the underdrain system during stockpile reclamation. If saturated mineral overburden is not used in this application, other construction material meeting PolyMet's selection criteria will be used (Attachment F).

2.2.3.1.6 Other Potential Uses of Saturated Mineral Overburden

As described earlier, saturated mineral overburden as a construction material will generally be limited to use in a permanently saturated zone, above a temporary membrane liner, or as the temporary stockpile soil liner immediately below the geomembrane liner. No other uses of saturated mineral overburden are proposed at this time.

2.2.3.2 Unsaturated Mineral Overburden

Unsaturated mineral overburden will be used as a general construction material at the Mine Site with some material temporarily stored in the OSLA. Specific uses will not be limited, as it will be used in any application requiring construction material. In order to meet the required specifications for some of the construction materials, unsaturated mineral overburden may be screened and compacted during construction, but cobbles and boulders from this material will not be crushed with the exception of granite boulders, which may be used for haul road cover and railroad ballast. Excess unsaturated mineral overburden could be placed in the mine pits during reclamation to facilitate wetland development in the East and Central Pits or provide improved habitat for the West Pit lake.

In locations where unsaturated mineral overburden depths are very thin, it may not be practical to excavate the unsaturated mineral overburden separately from saturated mineral overburden. In these cases, the excavated mixed soils will be treated as saturated mineral overburden.

2.2.3.3 Peat

Peat will be used for restoration and reclamation activities at the Mine Site or in off-site wetland reclamation activities. This may include the development of wetlands in the East and Central Pits and within the reclaimed temporary stockpile footprints. Peat will also be mixed with unsaturated mineral overburden to increase the organic content for reclamation across the Mine Site, including over the geomembrane cover of the Category 1 Waste Rock Stockpile. Excess peat will be stored in the OSLA until it is able to be used for reclamation.

2.2.4 Disposition of Overburden Not Used for Construction

Maximizing the use of overburden for construction is beneficial; however, not all of the overburden removed can be used for construction. Excess and unusable material will require storage for ultimate use or disposal.

2.2.4.1 Saturated Mineral Overburden

Saturated mineral overburden not used for construction will be commingled with the temporary Category 2/3 or Category 4 Waste Rock Stockpiles. These temporary stockpiles will be relocated to the East and Central Pits after Mine Year 11 and, wherever possible, wetlands will be developed on the space vacated as described in Section 2.2 of Reference (14). Saturated mineral overburden in the stockpile subgrade could be used as wetland substrate within the wetlands if permanently saturated. Otherwise, saturated mineral overburden used in the stockpile subgrade will be placed into the East and Central Pits for disposal.

2.2.4.2 Unsaturated Mineral Overburden

Unsaturated mineral overburden not initially used for construction will be stockpiled in the OSLA or temporarily in areas near its ultimate use. Any temporary stockpiles needed will be built on upland areas or areas planned as future pit or stockpile footprints. Unsaturated mineral overburden may also be placed in the temporary waste rock stockpiles for ultimate disposal in the East and Central Pits.

2.2.4.3 Peat

Peat not initially used for construction will be stockpiled in the OSLA or temporarily in areas near its ultimate reclamation use. Any temporary stockpiles needed will be built on upland areas or areas planned as future pit or stockpile footprints. If permanent stockpiles become necessary in the future, they will be built on upland areas with runoff collection similar to that planned for the OSLA until the area is adequately reclaimed, at which time runoff collection will cease.

2.3 Earthwork Balance

Development of the Project will involve excavating, moving, and stockpiling waste rock and overburden. PolyMet has prepared an earthwork material balance (earthwork balance) for the Project, which is based on current data and will be updated and refined as more data are developed during operations. The earthwork balance includes movement of waste rock, overburden, and construction material. The earthwork balance was performed for both the Mine Site and the Plant Site.

2.3.1 Mine Site Earthwork Balance

Construction activities at the Mine Site will maximize, to the extent practical and permissible, the use of on-site excavated material. Potential on-site construction materials include saturated mineral overburden, unsaturated mineral overburden, Duluth Complex construction rock, and peat. Potential off-site borrow sources are anticipated to include BIF construction rock, and other materials that require specific gradations that are not available from on-site sources (e.g., drain rock). Materials used for construction, whether sourced from on- or off-site, will meet criteria designed to be protective of water quality. Procedures used for selecting material are described in Attachment F.

The construction material types that have been identified associated with rock and overburden management at the Mine Site are identified on the permit application support drawings and include the following specifications, which will be refined in final design:

6-inch Minus (Common Fill 1) – Non-organic overburden with a maximum particle size of 6 inches (8-inch max. particle size when used as structural fill).

Lateral Drainage Layer (3/8-inch Minus Rock, Fine Filter Aggregate) – silty sand or sandy overburden meeting the following requirements:

- Top of Stockpile and Benches – gradation having 100% of particles less than 3/8-inch, rounded to sub-rounded particles and a compacted hydraulic conductivity of less than or equal to 1 x 10^{-3} cm/sec.

- Stockpile Side Slopes – gradation having 100% of particles less than 3/8-inch, rounded to sub-rounded particles and a compacted hydraulic conductivity of less than or equal 1 x 10^{-2} cm/sec.

Overliner Granular Drainage Material – crushed rock or processed gravel with a minimum hydraulic conductivity of $1x10^{-2}$ cm/sec at 190 psi and a gradation with a maximum of 6% by weight of particles passing the No. 200 sieve, 5 to 55% passing the No. 4 sieve, 70 to 100% less than 3/4 inch, and a maximum particle size of 1-1/4 inch.

Riprap – MnDOT current material specifications for Class III, IV and V; D50 size ranging from 9 inch to 18 inch as appropriate to riprap classification and location-specific use.

Soil Liner 1 – on-site fine grained overburden with maximum 1.5-inch particle size, capable of being compacted to achieve an in-place hydraulic conductivity of less than or equal to 1 x 10^{-6} cm/sec, 12 to 100% by weight of particles passing a No. 200 sieve, and 98 to 100% less than 1-1/2 inch particle size.

Soil Liner 2 – on-site fine grained overburden with maximum 1.5-inch particle size, capable of being placed, moisture-conditioned and compacted to achieve an in-place hydraulic conductivity of less than or equal to 1 x 10^{-5} cm/sec, 12 to 100% by weight of particles passing a No. 200 sieve, and 98 to 100% less than 1-1/2 inch particle size.

Underdrain Rock (Granular Drainage Material) – crushed rock or processed gravel with a minimum hydraulic conductivity of 1x10-2 cm/sec at 190 psi and a gradation with a maximum of 6% by weight of particles passing the No. 200 sieve, 5 to 55% passing the No. 4 sieve, 70 to 100% less than 3/4 inch, and a maximum particle size of 1-1/4 inch.

Lateral Drainage Layer (Granular Drainage Material) – granular overburden with Unified Soil Classification System (USCS) classification of SP or SM, capable of being placed to achieve an in-place hydraulic conductivity as specified for stockpile liner and cover.

Vertical Percolation Layer (Unified Soil Classification – ML) – silty overburden, with organic content equal or greater than 3% for reclamation cover zone to be vegetated.

General earthwork material movement for the Mine Site is presented on Large Figure 14. An earthwork balance, prepared to estimate material quantities and evaluate the movement of waste rock and overburden for the Mine Site for each of the material uses on Large Figure 14, was developed using the following process:

1. Delineate boundaries between mineral overburden, peat, and bedrock based on the most up-to-date geological and geotechnical data available.

    a. Delineate the boundary between saturated and unsaturated mineral overburden using the most up-to-date estimate for groundwater levels

    b. Delineate the boundaries between ore and waste rock types using the most up-to-date version of the Block Model

2. Establish Project feature earthwork limits (horizontal and vertical)

3. Perform cut/fill assessment for each Project feature (e.g., Dunka Road, Category 1 Waste Rock Stockpile, Ore Surge Pile)

    a. Determine cut requirements and track quantities, by material type, for each Project feature

    b. Determine fill requirements and track quantities, by material type, for each Project feature

4. Assess and determine movement of each material type based on cut and fill needs

    a. Move cut construction materials to fill areas based on material type needs and availability

    b. Move cut construction materials not needed for fill to appropriate storage or disposal locations (e.g., OSLA, waste rock stockpiles)

    c. Move construction materials from storage or disposal locations to fill areas as needed

    d. Move excavated waste rock to waste rock stockpiles or to the East or Central Pits for in-pit disposal depending on the development stage of the Mine Site

5. Sum quantities for cut and fill by material type and Project feature; track material movements for each Project feature (Large Figure 14)

The steps above will be repeated as new data becomes available based on further geotechnical evaluations, detailed engineering design, and development of the construction schedule. AutoDesk Civil 3D (using the volume calculation module) and ESRI ArcGIS were used to generate the overburden, bedrock, and groundwater surfaces and to compute cut and fill volume estimates necessary to develop quantity estimates and evaluate material movement. Earthwork estimates account for swell and shrink of excavated and installed materials, respectively.

Table 2-8 compares the estimated amount of unsaturated mineral overburden available from earthwork activities with the amount needed for construction during the construction phase (18 to 24 months prior to the start of operations) and during the LOM at the Mine Site. This table demonstrates that the Project contains sufficient overburden at the Mine Site for planned construction uses. As listed on Table 2-8, there are several areas that have been identified as potential borrow areas for unsaturated mineral overburden. Large Figure 15 shows the potential on-site borrow sources included in this evaluation. Use of many of these borrow sources will require further geotechnical evaluation and may require additional permitting prior to their use (e.g., wetland, stormwater).

Table 2-8 Estimated Unsaturated Mineral Overburden Earthwork Balance

Description	Construction Phase (Cubic Yards)	Total Mine Life (Cubic Yards)
Estimated Volume of Unsaturated Mineral Overburden from Feature Footprints	1,643,000	3,676,000(2)
Estimated Volume of Unsaturated Mineral Overburden Needed for Construction	1,436,000	3,885,000
Excess Unsaturated Mineral Overburden	+207,000	-176,000
Additional Volume from Potential On-Site Borrow Sources(1)	5,316,000	

(1) Additional volume from potential on-site borrow sources includes areas within the Mining Area boundary at the Mine Site where excavation is not currently planned for Mine Site feature construction. These areas could be excavated, with permit updates if necessary, for additional construction material.

(2) Includes quantities for planned infrastructure, in addition to Mine features reported on Table 2-6.

2.3.2 Plant Site Earthwork Balance

The earthwork balance for the Plant Site is similar to that described for the Mine Site above. Key differences for the Plant Site earthwork balance are that a large volume of imported borrow material is required for Plant Site construction. Potential construction materials at the Plant Site are anticipated to include overburden, LTVSMC tailings, BIF construction rock, and other off-site materials that require specific gradations that are not available from on-site sources. Procedures used for selecting material are described in Attachment F. General earthwork material movement for the Plant Site is presented on Large Figure 16.

3.0 Geotechnical Modeling Outcomes

To support the permitting-level engineering designs, global stability analyses were completed to evaluate stockpile stability under static and pseudo-static (i.e., earthquake loading) conditions. The geotechnical evaluations completed for the NorthMet stockpile designs are documented in the Geotechnical Data Package Volume 3 (Reference (7)) with stockpile geotechnical modeling methods and results presented in Section 6.0 and Attachment I of Reference (7) and summarized below. The conclusion of the geotechnical evaluation is that the stockpiles with the proposed configurations are expected to meet or exceed the following minimum factors of safety:

- long-term (effective stress) operational static factor of safety for deep-seated failures (waste rock mass thickness in excess of 30 feet): 1.3.
- short-term (total stress) operational static factor of safety for deep-seated failures (waste rock mass thickness in excess of 30 feet): 1.1.
- composite slope (effective stress) pseudo-static factor of safety: 1.0.
- composite slope static factor of safety at closure: 1.5.
- composite slope pseudo-static factor of safety at closure: 1.1.
- design earthquake peak ground acceleration (PGA) (operations and closure): 0.05 g (g being the acceleration due to Earth's gravity) with a return period of approximately 500 years. The PGA for the Mine Site is approximately 0.05 g using the FEMA maps (Reference (15)) for the spectral accelerations with a 10% probability of exceedance in 50 years.

A Phase II geotechnical evaluation will be implemented prior to the initial stockpile construction to verify the geomembrane/soil interface strength parameters, foundation and stockpile material parameters, and to confirm the stockpiles' factors of safety.

4.0 Operating Plan

4.1 Waste Rock

4.1.1 Determining Ore/Waste and Waste Category

Proper identification and separation of the ore from the waste rock, and classification and separation of waste rock are critical to the operation of the mine. Rock sampling will be conducted to continually confirm the location of the ore and waste rock as well as the waste rock category. The Block Model, which estimates the location of ore and different types of waste rock, will be updated as new information is available to further delineate the boundaries between ore and the different waste rock categories. This Block Model will be used by the mining engineers to continually refine mining activities. This process is illustrated in Figure 4-1 and described in more detail in this section. The Block Model will also be used in the GPS Mine Dispatch System to guide excavation and track each truck load of ore and rock. The Block Model is further described in Attachment A.

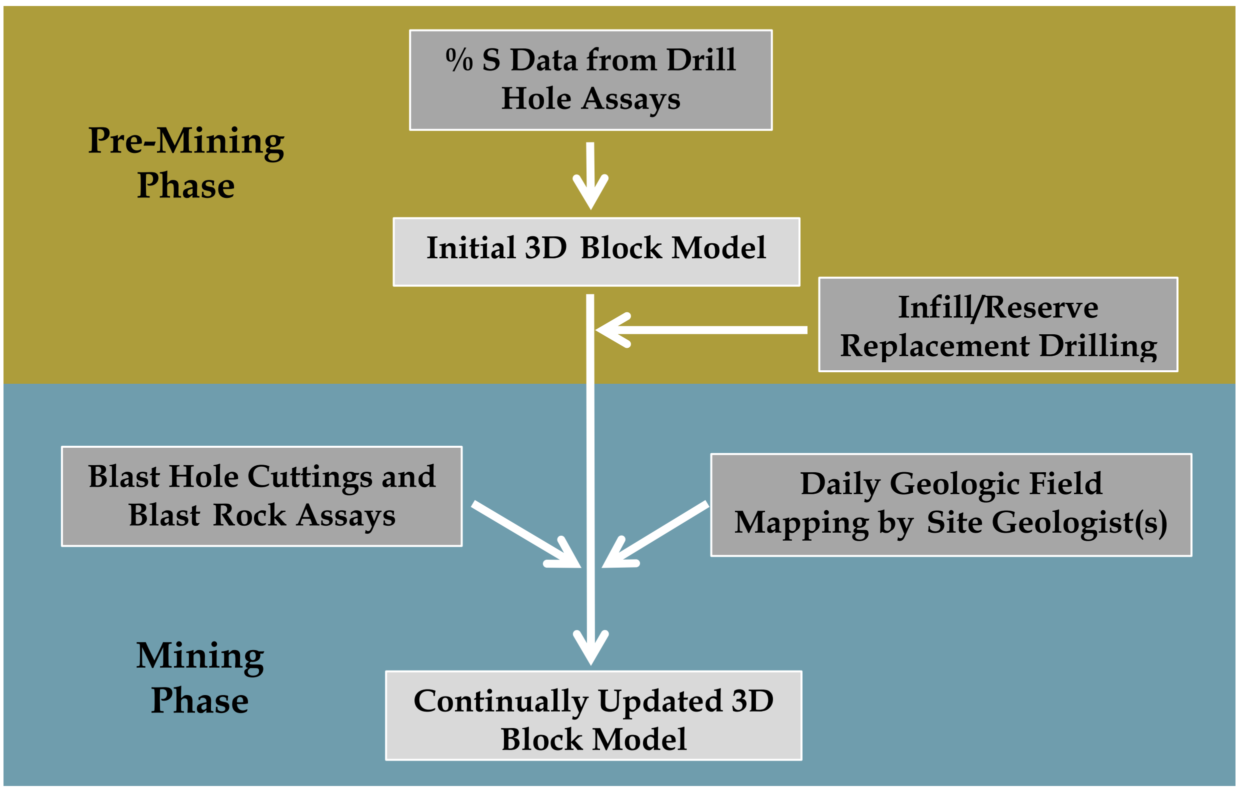


Figure 4-1 Ore and Waste Rock Categorization Sequence

4.1.2 Update Block Model Based on Core Drilling

Additional core drilling will be completed as mining progresses. The information resulting from this drilling will be used to refine the Block Model to continually confirm ore and waste rock contacts and evaluate sulfur grade to classify waste rock into categories. The new drill core information will be incorporated into the Block Model using the process described in Attachment A and summarized below.

The ore body and waste rock are represented as three dimensional (3D) blocks in the Block Model. The Block Model represents the land area as a grid with various layers at depth forming the 3D blocks. Each block is located by a latitude, longitude, and depth. The model is populated with assay data from drill cores, and data are extrapolated to estimate the chemical content of all blocks. Every pit location is covered by a 50 foot long, 50 foot wide, and 20 foot deep block. The blast hole spacing for block model refinement will be less than the 50 foot by 50 foot horizontal dimensions of the Block Model, with preliminary spacing provided in Table 2-1 of the NorthMet Project Mine Site Blasting Plan (Reference (16)). As additional assay data becomes available, the Block Model is updated to improve chemical content estimates.

An example cross-section from the Block Model showing the distribution of waste rock categories around the ore zones with the location of drill cores is shown in Figure 4-2.

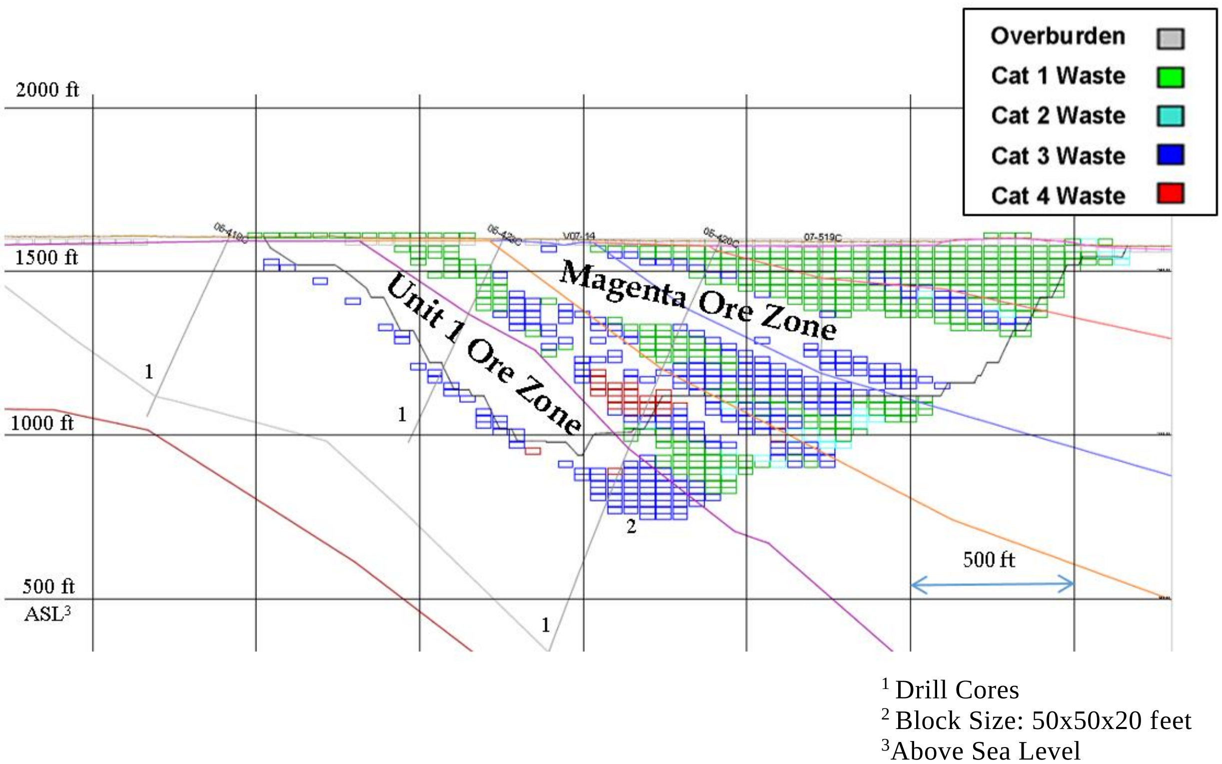


Figure 4-2 Example Distribution of Waste Rock Categories

Currently the Block Model uses data from approximately 38,000 assays. More than 150,000 additional assay results from new, reserve replacement core drilling and blasthole cuttings are anticipated to be added to the Block Model as mining progresses. The exact number of additional assays will be determined using variography analyses to determine appropriate spacing between sample locations. However, as a preliminary estimate, approximately

280,250 blast holes are anticipated to be required for the Project. At the start of operations, every blast hole will be assayed. As mining progresses, assaying will be conducted less frequently. Assuming, for example, that half of the blast holes are assayed, plus an additional 25% for bench grade and boundary definition within individual blocks, that would equate to over 175,156 additional assays.

4.1.3 Blasthole Drill Cuttings Sample

Production blastholes allow for additional data collection to confirm and refine the Block Model. When rock units allow, blast pattern limits can be established such that blasting only occurs in one rock type. Blasthole drill cuttings will be sampled and analyzed for metals and sulfur. Analysis will be done at an on-site or local laboratory to provide the turnaround necessary to be able to use the data for operational mine planning in a timely fashion.

4.1.4 Geologist Observations and Random Sampling

On-shift field geologists will make observations of the mining face, mapping the pit walls and fragmented rock. Geologic mapping efforts during mining may reveal visual field indicators of different waste rock types and improve the field verification methodology. In addition to sampling of blasthole drill cuttings, the field geologists will also randomly sample the mine face as an aid to confirming the geologic mapping. They will provide reports to mine planners and provide direction during mining.

4.1.5 Refined Data at Mining Face

Mine planners will use the updated Block Model, blasthole drill cutting analysis, blast rock sampling data, and geologist's observations to continually refine the mapping of ore, sulfur grades, and boundaries at the mining face. These refined grades and boundaries will be the best available representation of ore and waste rock category and will be used to continually refine the delineation of ore and waste rock categories as mining progresses. These boundaries will be surveyed and monitored for movement during blasting.

4.1.6 Mine Management/Dispatch System

The fleet of mining equipment will be equipped with a mine management system, which is frequently referred to as a Dispatch System. The purpose of the mine management system is to monitor and control mining equipment to achieve quality and production targets, maximize production, efficiently utilize equipment, increase equipment availability, and improve maintenance practices. Mine management systems are computerized systems that utilize technologies such as GPS and wireless communication systems. Mining equipment such as drills, front end loaders, excavators, haul trucks, bulldozers, rubber tired dozers, motor graders, and water trucks are equipped with operator interface panels which enable the equipment operators to communicate with a centralized Mine Management or Dispatch Center. The system tracks production statistics such as cycle times, number of loads or tons, and load origin and destination. The system also utilizes the GPS on equipment to locate loading units in ore and waste rock blasts and to assign destinations for haul trucks based upon the type of material being loaded (additional details are provided in Section 4.1.6.3).

4.1.6.1 GPS Location System

GPS is an integral component of any Mine Management/Dispatch System. High precision GPS is installed on excavators and loaders to establish their position when loading trucks. High precision GPS can also be installed on rotary blasthole drills to establish the location of blastholes. If the drills are not equipped with high precision GPS, blasthole locations can be surveyed using high precision surveying equipment. Haul trucks are equipped with GPS so their movement between the loading unit and the destination can be tracked. Auxiliary equipment such as bulldozers, rubber tired dozers, motor graders and water trucks can also be equipped with GPS so their locations are known and their movements can be tracked. Bulldozers and other equipment used for construction of roads, stockpiles, and ramps utilize GPS for establishing and maintaining proper elevations, grade control, and direction.

4.1.6.2 Linking Excavator Location to Mine Face

As noted in Section 4.1.5, ore and sulfur grades will be continuously refined. This will aid in the continuous confirmation and refinement of boundaries of ore and waste rock categories. The boundaries of the ore and waste rock categories are the excavation limits for each type of material. The digital file of the excavation limits, as extracted from the Block Model, will be loaded onto the interface screen in the equipment (i.e., shovel or front end loader) working the blasted material. The GPS receiver in the equipment will show the location of the loading device on the interface panel relative to the excavation limits. Haul trucks will be loaded with a single rock type (e.g., ore, Category 1 waste rock, Category 4 waste rock). The Mine Management System will then dispatch the haul truck being loaded to the correct location, either the RTH, OSP, or specific waste rock stockpile, based on the location of the loading equipment. The system recognizes the material that is being dug by its location and assigns the haul truck to the correct destination.

4.1.6.3 Tracking Load to Destination

The GPS and radio communication functions of the Mine Management/Dispatch System enable truckloads of ore or waste rock to be tracked from the source, which is a loading unit such as a shovel or front end loader, to the destination, which is typically the RTH, OSP, OSLA, waste rock stockpile, or pit backfill. The system has the capability of establishing a destination for each material type. If the loading unit is located in ore, the destinations for the haul trucks loaded at that location will be the RTH or the OSP. The same applies to a loading unit located in a waste rock blast; the destinations for haul trucks loaded at that location will be the appropriate waste rock stockpile. The system also has the capability to recognize if a haul truck load is not travelling to the proper destination for the material being hauled. If the system recognizes that a load is going to the incorrect destination, an alarm will sound and a message will be sent to the truck driver, mine operations supervisor, and dispatcher alerting them that the load is travelling to the wrong destination.

4.1.6.4 Data Retention

The Mine Management/Dispatch System collects and retains information such as cycle times, delay times, production, productivity, quality, and GPS locations. This information is analyzed to correlate plant performance with ore delivered for analyzing equipment performance and statistical reporting. Historical data from the Mine Management/Dispatch System will be retained for future analysis, review, and reconciliation. The data will be stored or exported in a common format (e.g., ASCII flat file, spreadsheet).

4.1.6.5 Category 1 Waste Rock Stockpile Confirmation Sampling

Because the Category 1 Waste Rock Stockpile is a permanent feature at the Mine Site, a confirmation sampling program will be used to verify that this stockpile is appropriately composed of Category 1 waste rock (%S ≤ 0.12). A confirmation sampling program was developed for the Category 1 Waste Rock Stockpile based on an incremental sampling methodology using a statistical design published by the Interstate Technology & Regulatory Council. ITRC, a public-private coalition, provides guidance on utilizing technology and standards in the environmental decision-making framework. This sampling program was developed based on the size and volume of material in the final planned stockpile, to collect a statistically significant number of samples for the confirmation. During operations, samples will be collected in a grid pattern (i.e., 500 feet x 500 feet x 40 feet grid cells) along each lift of the stockpile. Three composite samples will be collected within each cell, each containing 30 rocks ranging from 0.5 to 6 inch diameter. These three composite samples will be analyzed to generate three average %S values to confirm that the rock within each cell is equal or less than 0.12 %S. This sampling plan will be coordinated with the construction plan, so if test results show that the average sulfur content within any single grid cell exceeds 0.12%, material in that cell can be excavated. A similar grid sampling technique was used by Flambeau Mine in Wisconsin for sampling of their different types of waste rock in reclamation prior to pit backfill (Reference (17)).

4.2 Overburden

4.2.1 Determining Overburden Classification

The key differentiator between saturated mineral overburden and unsaturated mineral overburden is the location of the water table. Secondary criteria, such as visual color differences that have been observed, may be developed in the future based on the results of sampling analyses and construction observation.

Groundwater elevations have been monitored across the Mine Site since 2005 as described in Section 4.3 of Reference (10). The magnitude of temporal groundwater elevation fluctuation varies across the Mine Site, but the overall variation in water levels observed in a single monitoring well is typically less than 4 feet. In general, water levels rise in spring and early summer in response to snowmelt and rainfall, and then decline in late summer and fall with the lowest water levels observed during the winter. Given the limited fluctuation, the water table contour map for the Mine Site is considered to have adequate accuracy throughout most of the year for planning purposes. See Section 4.3 of Reference (10) and Section 4.3 of Reference (14) for more detail on groundwater fluctuation.

Digital maps of the surficial water table will be developed annually for the area planned for overburden removal the following year based on historic water level data (where available), test pits (to verify the depth to the water table in the construction areas), construction observations, and continued water table monitoring. These maps will be uploaded into the GPS system of the excavators prior to removal of overburden so that operators will know the excavation elevation that establishes the interface between saturated and unsaturated overburden. Unsaturated mineral overburden will be removed from a working area first, and then the saturated mineral overburden will be excavated separately for proper storage.

Dewatering of some areas may occur prior to or concurrent with excavation. However, dewatering will not affect the elevation selected as the interface between saturated and unsaturated material will be fixed by any historic water level data available, findings from test pits and any nearby monitoring wells, and other observations made prior to the initiation of dewatering activities.

Visual monitoring during excavation will be performed to confirm actual groundwater elevations at the time of excavation. Real-time visual monitoring will be provided by an engineer, geologist, or other qualified person capable of interpreting the excavation plan and of distinguishing between saturated and unsaturated zones. This qualified person will visually survey the site and excavation activities and will compare observations with excavation designs to confirm whether any adjustments to excavation elevation are warranted. The water table elevation at the time of observation and excavation will be one of several factors that control final delineation of saturated from unsaturated mineral overburden. Historic water level data collected in the immediate vicinity, when available, will carry greater weight in establishing the delineation between saturated and unsaturated mineral overburden.

4.2.2 Tracking Saturated Mineral Overburden Loads to Destination

Saturated mineral overburden loads will be tracked either through paper or electronic tracking, depending on the operator and equipment. When PolyMet-owned equipment is being used for saturated mineral overburden removal, the load tracking will be electronic. As described in Section 4.1.6, mine equipment (shovels, excavators, and haul trucks) will have GPS systems, which will track equipment movements from shovel to destination (construction use, stockpile, pit, etc.). The GPS system in each piece of equipment will be integrated with the Mine Management/Dispatch System.

When the saturated mineral overburden is being removed by contractors, GPS systems may not be available. If a GPS system capable of downloading load tracking is not available in their equipment, truck operators will log analogous data on a daily log sheet. The daily log sheets will be entered into a computer spreadsheet daily.

The combination of these methods will create a computerized record of saturated mineral overburden movement through the LOM.

4.2.3 Data Retention

As described in Section 4.2.2, the daily log spreadsheet and Mine Management/Dispatch System will retain saturated mineral overburden movement tracking information until the Project is closed.

4.2.4 Unsaturated Mineral Overburden Confirmation Sampling

Unsaturated mineral overburden is relatively uniform with respect to chemical make-up, and the geochemistry is well characterized as a result of sampling and testing completed to date. Results indicate that it does not produce acidic drainage and does not present an elevated risk compared to typical local construction materials. Based on discussions with DNR, additional confirmation sampling is not necessary for unsaturated mineral overburden at the Mine Site.

5.0 Monitoring

Proper long-term management of the Mine Site will depend in part on a systematic monitoring program that will be finalized in permitting. As operations proceed, the monitoring program will be updated as required.

5.1 Water Quantity and Quality of Stockpile Drainage and Underdrain Flows

Monitoring will be used to determine Project compliance with permits, improve model accuracy, identify potential causes of changes to water quality or quantity, and identify options, if necessary, to adapt the Project to maintain short-term and long-term compliance. The proposed water quality and quantity monitoring plans that are associated with the various permits and regulations applicable to mining operations are being developed as part of each permit application process. The specifics of monitoring for the Project, including the specific locations, nomenclature, frequency, and parameters, have been outlined in the permit applications, and will be finalized during each applicable permitting process.

5.2 Stockpile Monitoring

The waste rock stockpiles will be monitored as follows:

- Placement verification monitoring – This type of monitoring will be performed daily to verify proper placement and amounts of material into the appropriate stockpile. With the exception of Category 1 Waste Rock Stockpile confirmation sampling, this will be based on the Mine Management/Dispatch System tracking, as described in Sections 4.1.6 and 4.2.2.
- Category 1 Waste Rock Stockpile confirmation sampling – This type of monitoring is described in Section 4.1.6.5 to verify the sulfur content of the material in the stockpile.
- Survey monitoring – This type of monitoring will verify that the stockpile is built to the lines, grades, and slope as designed.
- Stability monitoring – PolyMet will use a combination of visual inspection and surveying to monitor the stockpiles for any irregular or unusual movements, including significant settling.
- Drainage monitoring – Surfaces will be regularly checked for water seeps and erosion; pipes and sumps will be checked for blockage; and outslopes will be checked for presence of seeps and material displacement.

The above information will be developed and/or reviewed by on-site personnel and tracked in Project files.

6.0 Reporting and Adaptive Management

Adaptive management is a system of management practices based on clearly defined outcomes and monitoring requirements to determine if management actions are meeting the desired outcomes; and, if not, implementing changes that will best enable outcomes to be met or re-evaluated. Adaptive management recognizes the uncertainty associated with estimates based on exploration drilling for a 20-year LOM. Adaptive management measures will be developed through the Environmental Review process, permitting, and during construction, operations, reclamation, closure, and postclosure maintenance to define when changes are needed.

A key component of adaptive management for water is the Adaptive Water Management Plan (Reference (13)) that describes adaptive engineering controls that manage water quality and quantity. Fixed engineering controls (liners, groundwater containment systems, etc.) are described in this plan and other management plans. Contingency mitigations that could also be applied, if needed, are also described in the applicable management plans (Rock and Overburden Management Plan, Water Management Plan – Mine (Reference (8)), Water Management Plan – Plant (Reference (18)), Flotation Tailings Management Plan (Reference (19)), and Residue Management Plan (Reference (20)).

6.1 Reporting

The NPDES/SDS permits and the Water Appropriation permits will require and define routine water quality and quantity reporting and annual reports. The content required for those reports will be defined in those permits.

The annual PTM report will compare the annual actual mined tonnages of ore and waste rock by category to the annual tonnages noted in the PTM application and the tonnages planned in the previous years' PTM report. The tonnages planned for the next year will also be reported in the annual PTM report.

The annual PTM report will include cross-sections and maps of actual stockpile footprints as well as those planned for the next year. These will be compared to the cross-sections and footprints noted in the PTM application and the footprints and cross-sections planned in the previous annual PTM report.

6.2 Adaptive Management

The main uncertainty associated with infrastructure outlined in this management plan is the uncertainty in the total volume of waste rock and saturated mineral overburden to be stored in the temporary waste rock stockpiles. Because the temporary Category 2/3 Waste Rock Stockpile and the temporary Category 4 Waste Rock Stockpile will store the Category 2, 3, and 4 waste rock in addition to the saturated mineral overburden, sufficient storage volume is necessary to hold these materials until the East Pit is available for direct disposal. Table 6-1 outlines the total capacity of each temporary stockpile, and Table 6-2 lists the estimated waste rock volumes to be excavated based on Table 2-2 and the estimated volume of saturated mineral overburden to be excavated as shown in Table 2-6.

Table 6-1 Temporary Waste Rock Stockpile Capacity

Mine Feature	Planned Capacity[(1)] (cubic yards)	Maximum Capacity[(2)] (cubic yards)
Category 2/3 Waste Rock Stockpile	23,169,000	31,895,000
Category 4 Waste Rock Stockpile	3,267,000	7,895,000
Total Capacity	26,436,000	39,790,000

(1) The volume of waste rock is based on mass listed in Table 2-2 with a density of 1.9 tons per cubic yard (Reference (7)).
(2) The maximum capacities in this table are the maximum capacities presented on Table 2-3, converted to cubic yards with a density of 1.9 tons per cubic yard.

Table 6-2 Excavation Volumes for Temporary Waste Rock Stockpile Storage

	Category 2/3 Waste Rock[(1)] (cubic yards)	Category 4 Waste Rock[(1)] (cubic yards)	Saturated Mineral Overburden[(2)] (cubic yards)	Total Volume (cubic yards)
Excavation Volumes	23,169,000	3,267,000	5,589,000	32,025,000

(1) The volume of waste rock is based on the mass listed in Table 2-2 with a density of 1.9 tons per cubic yard (Reference (7)).
(2) The volume of saturated mineral overburden is provided in Table 2-6 and assumes, as a worst case scenario, that all saturated mineral overburden will be stored in the temporary stockpiles rather than used for construction uses listed in Section 2.2.3.1.

In addition to the uncertainty associated with the temporary waste rock stockpiles, there is also some uncertainty in the ability of the East and Central Pit to store all the Category 2, 3, and 4 waste rock, some Category 1 waste rock, and the excavated saturated mineral overburden not used in permanent construction applications. Once mined, the East and Central Pits have a combined capacity of approximately 78 million cubic yards. As shown on Table 2-2, there will be approximately 140 million tons of waste rock to be disposed in the East and Central Pits, which equates to approximately 74 million cubic yards of waste rock, yielding an unused pit capacity of 4 million cubic yards. In addition, there will be approximately 5.6 million cubic yards of saturated mineral overburden, as shown in Table 6-2. Approximately 2.3 million cubic yards of saturated mineral overburden has been identified for construction uses, as discussed in Section 2.2.3.1. If at least 1.6 million cubic yards of saturated mineral overburden cannot be used for construction purposes, there may be a shortage of storage capacity in the East and Central Pits.

One potential mitigation for insufficient storage capacity in the East and Central Pits will be to dispose of some of the waste rock or saturated mineral overburden in the West Pit in areas where mining has ceased and potential pit expansion will not be compromised.

6.3 Annual Comparison to Plan

Each year a plan comparison will be completed, as required for the PTM, to keep this document current and to help track changes in the mine plan, rock schedule, and characterization of the material.

6.4 Waste Characterization Update

Updated mine waste characterization data will be included in the annual report required as part of the PTM. In addition, the annual report will include characterization of new rock types or formations encountered during the previous year. This will include:

- description of new rock types or formation encountered
- information on methods utilized for management of the rock (e.g., processed as ore, stockpiled as waste rock)
- general mineralogical description with potential for acid generation and/or release of weathering products
- waste rock characterization, in accordance with Minnesota Rules, part 6132.1000
- potential effects to the approved mining and reclamation plans

6.5 Annual Compliance Report

An annual compliance report will be developed each year for submittal to the DNR to comply with the PTM requirements. Reporting is as described in Section 6.1.

7.0 Stockpile Reclamation

Stockpile reclamation includes progressive reclamation activities that will begin during operations and continue into the reclamation phase.

7.1 Category 1 Waste Rock Stockpile

Reclamation of the permanent Category 1 Waste Rock Stockpile will be progressive starting in Mine Year 14, and the stockpile is expected to be fully reclaimed by the end of Mine Year 21 in order to minimize exposure of the waste rock and the amount of mine water generated from the stockpile. The planned mining schedule has the waste rock and overburden in the temporary waste rock stockpiles being relocated to the East Pit in Mine Years 11 to 19; therefore, no progressive reclamation is required on the temporary stockpiles.

7.1.1 Progressive Reclamation

The Category 1 Waste Rock Stockpile will be reclaimed in increments after material is no longer being placed in those portions of the stockpile. This progressive reclamation will minimize erosion of the outer slopes, promote postclosure maintenance land use, and minimize the need for active site care and maintenance during the postclosure maintenance phase. Prior to construction of the stockpile cover system, the stockpile surfaces will be graded for long-term stability, to promote vegetation growth and erosion control, and to develop a surface drainage network over the stockpile.

7.1.2 Stockpile Cover System

An engineered geomembrane cover system will be constructed over the Category 1 Waste Rock Stockpile to minimize the flow of precipitation into the stockpile, thus reducing the load of constituents to the West Pit during reclamation, closure, and postclosure maintenance. The Category 1 Waste Rock Stockpile Cover System is detailed in Section 3.0 of Reference (13). Construction of the cover system includes stockpile re-grading and construction of surface water controls (surface water channels and downchutes), as described in Section 3.0 of Reference (13). Surface water management details for the stockpile cover and accompanying calculations are included as Attachment J.

7.2 Groundwater Containment System

As the Category 1 Waste Rock Stockpile is progressively reclaimed with the geomembrane cover system, the corresponding sections of the mine water ditch will be filled, and the clean surface water runoff will be routed to the stormwater ditch, as shown on the typical sections on Drawing GCS-011 of Attachment C and portrayed on Figure 7-1. The groundwater containment system vertical pipe risers will be extended to finished cover grade to provide access for pipe cleanout as shown on the typical sections on Drawing GCS-011 of Attachment B. The groundwater containment system will remain fully functional during and after reclamation.

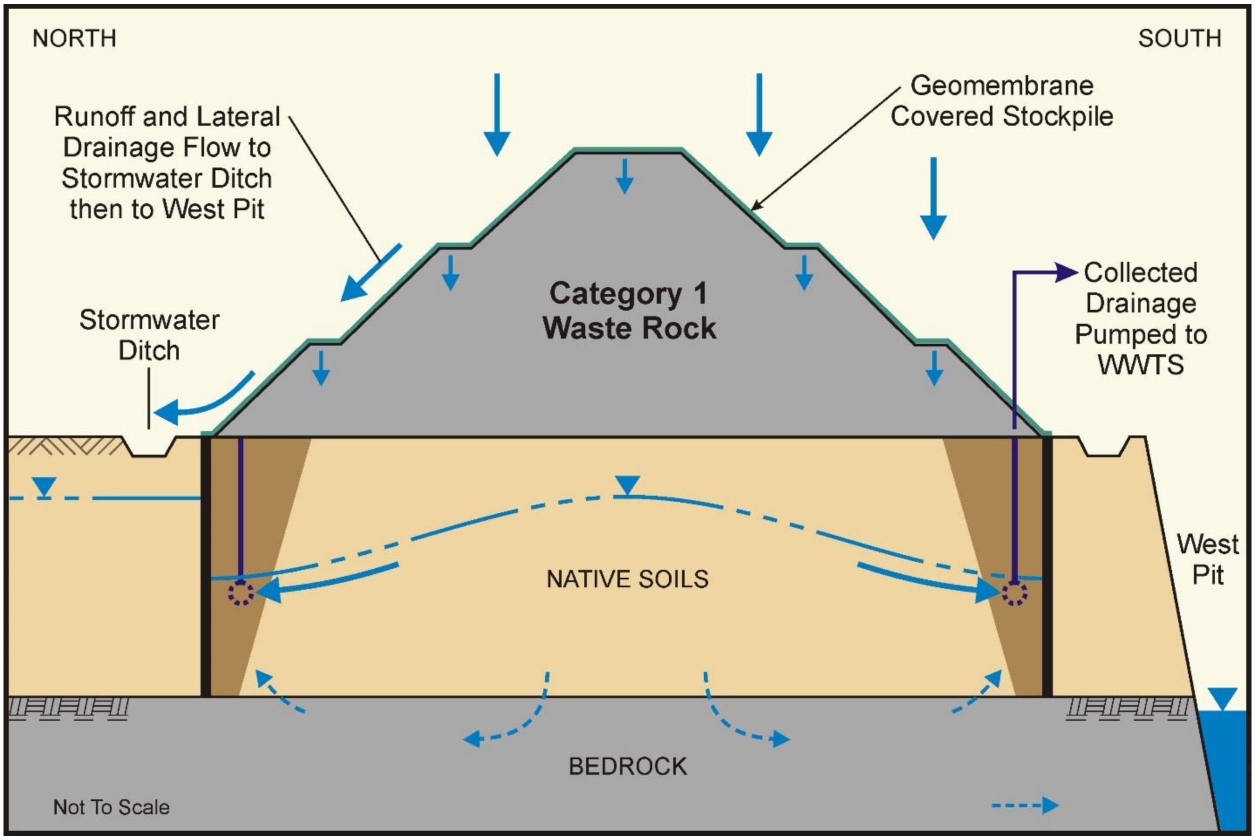


Figure 7-1 Conceptual Representation of Category 1 Stockpile Groundwater Containment System – Reclamation and Long-Term Conditions Cross-Section

7.3 Temporary Category 2/3 and 4 Waste Rock Stockpiles

As discussed in Section 2.1.3, the temporary waste rock stockpiles are the Category 2/3 and Category 4 Waste Rock Stockpiles. The material in these waste rock stockpiles will be relocated to the East and Central Pits, after these pits are each mined out or exhausted, and at that time, the footprint of each of the stockpiles will be reclaimed. After removal of the material from these stockpiles, the stockpile footprints, adjacent access roads and associated disturbed areas around the stockpile perimeters will be reclaimed with a growth medium, if needed, followed by seeding and planting.

7.3.1 Waste Rock Relocation to Pit

Once mining in the East Pit is completed, Category 2, 3, and 4 waste rock mined from the West and Central Pits will be hauled directly to the East Pit for disposal. At that time, the material in the Category 2/3 and Category 4 Waste Rock Stockpiles will also be hauled to the East Pit for final subaqueous storage. The movement of rock from the stockpiles will be timed to allow complete relocation of the material (waste rock and overburden) in the Category 4 Waste Rock Stockpile first, followed by relocation of the material from the Category 2/3 Waste Rock Stockpile. The Category 4 material is expected to be relocated in

Mine Year 11 (approximately 6.2 million tons). The Category 2/3 Waste Rock Stockpile is larger, holding approximately 44 million tons, and is expected to be completely relocated by the end of Mine Year 19.

7.3.2 Reclamation of Temporary Waste Rock Stockpile Footprints

Once the waste rock and overburden are completely relocated from the temporary stockpiles to the East and Central Pits, the stockpile bases, which include the overliner drainage system, liner system, underdrain system, if required, and portions of the foundation, will be disassembled for reclamation of the footprint. Generally, pipes, liners, and pumps will be removed and the footprint of the stockpile will be reclaimed.

For the Category 2/3 Waste Rock Stockpile, wetlands will be restored or created where the hydrology and soil conditions exist to support their development. Approximately 60 acres of wetlands have been identified within the Category 2/3 Waste Rock Stockpile footprint. Wetlands could be developed in areas that were wetlands prior to the start of stockpile development, as well as in additional areas where the stockpile load has depressed the soils enough that wetland hydrology can be established from prior upland areas. The plan for development of wetlands within these areas will likely include grading, the addition of soils as needed, and wetland plant propagation. The ultimate goal in reclamation and development of wetlands within the former stockpile footprint will be to provide drainage and reintegrate the area into the natural watershed. For portions of the footprint that cannot be converted to wetlands, the surface will be scarified or soil will be placed over the reclaimed foundation, if needed, followed by seeding.

Once the liner system from the Category 4 Waste Rock Stockpile is removed, stripping for the Central Pit can begin. The Central Pit stripping area almost entirely encompasses the footprint of the Category 4 Waste Rock Stockpile. The small area outside the Central Pit will be reclaimed by scarifying the surface or by placing a soil layer and seeding.

Revision History

Date	Version	Description
06/16/10	1	Initial release to address overburden with Sections 1.0 and 2.2
08/24/10	2	Refine overburden Section 2.2 and address Category 1 Waste Rock groundwater containment system design in Sections 2.1.2 and 2.1.2.2
12/06/10	3	Change in formatting and organization
11/23/2010	4	Add Sections 1.1 and 1.3, add details to Sections 1.0, 2.1, 2.2, 4.0, 5.0, 6.0, and 7.0, and add Attachment A and Attachment E.
12/28/2012	5	Significant changes to incorporate project changes related to the decisions made in the AWMP Version 4 and 5. These project changes include the extension of the groundwater containment system along the south side of the stockpile, the use of a geomembrane cover on the Category 1 Waste Rock Stockpile, the use of long-term mechanical treatment, and the potential for non-mechanical treatment in long-term closure. Attachments B (partial), C, D, and E were added.

Date	Version	Description
12/5/2014	6	Changes were made to address agency comments and add clarity to the document. There were minor changes throughout for formatting or to clarify text. Other changes include: Remove reference to forecast of annual estimates for contingency closure in Sections 1.2 Update Section 2.1.1 method of rock categorization Update Table 2-3 to include planned and maximum volumes for stockpiles Update Section 2.1.2.3 with remodel results of the Category 1 Stockpile Groundwater Containment System Update Sections 2.1.2.4 and 2.2.3 to describe the state-owned stockpile Update Table 2-5 to include railroad ballast and clarify reclamation of RTH Provide clarity in Section 2.1.3.2 as to the reason the OSP has a thicker overliner drainage layer Update Section 2.1.3.2.1 with remodel results of liner leakage Update Section 2.2.3 for updated overburden volumes and clarity on potential borrow sources Update Section 2.2.3.1 for new use of saturated overburden and updated volumes of overburden Update Section 2.2.3.2 to clarify planned use of cobbles and boulders Update Section 2.2.4.3 for timing of runoff collection Fill in Section 3.0 Update Section 6.0 to describe adaptive water management Update Section 6.1 to clarify content of annual PTM report Update Section 7.1.2 to remove reference to OSP (no incremental reclamation planned for OSP) Update Section 7.1.2.2 and 7.2.2 to remove reference to mitigation wetlands Update Section 7.2.3 to add the area of reclamation for the OSLA Update Section 7.4 to describe location of financial assurance Remove Sections 7.3.4 through 7.3.5
1/20/2015	7	Changes were made to address agency comments on Table 2-2 and 2-4 and in Sections 2.1.2.3, 3.0, and 6.5.
7/11/2016	8	Certification page added; minor changes made to Large Figures to account for changes to the WWTP footprint; permit application support drawings added in Attachments B and C; additional stockpile design calculations were added in Attachments F, G, and I; and the Construction Quality Plan was added as Attachment H.

Date	Version	Description
8/28/2017	9	Changes were made to address agency comments on Version 1 of the Permit to Mine Application and to make the ROMP consistent with other parts of Version 2 of the Permit to Mine Application. Highlighted changes include: • Updated / clarified construction material descriptions (global update) • Added detail for overburden material characterization (global update) • Updates to align with the WWTS changes discussed in the AWMP (global update) • Added language for construction use of Low Sulfur Waste Rock (Section 2.1.2.4, Duluth Complex construction rock and Biwabik Iron Formation (BIF) rock) • Added a subsection to describe the Earthwork Balance (Section 2.3) • Updated / added language to describe confirmation sampling (Section 4) • Clarified / updated language regarding Stockpile Monitoring (Section 5.2) • Updated reclamation descriptions (Section 7) to be consistent with other components of Version 2 of the Permit to Mine Application (e.g., Section 15 - Reclamation, Closure, and Postclosure Maintenance) • Added new attachment, Attachment J – Standard Operating Procedures: Environmental Characterization of Construction Material for the NorthMet Project
12/8/2017	10	Changes were made to address agency comments on Version 2 of the Permit to Mine Application and to make the ROMP consistent with other parts of Version 3 of the Permit to Mine Application.

References

1. **Poly Met Mining Inc.** NorthMet Project Waste Characterization Data Package (v12). February 2015.

2. **Day, Stephen, SRK Consulting Engineers and Scientists; Rich Patelke, PolyMet; Nancy Dent, Barr Engineering Co.** Memo to Stuart Arkley, MDNR re: Overburden Geochemical Characterization Plan in Support of EIS - DRAFT NorthMet Project. February 22, 2008.

3. **Jennings, C.E. and Reynolds, W.K., Minnesota Geological Survey.** Quaternary Geology of the Mesabi Iron Range, Minnesota. Miscellaneous Map M-164. s.l. : Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://purl.umn.edu/58160, 2005.

4. **Olcott, P. G. and Siegel, D. I.** Physiography and Surficial Geology of the Copper-Nickel Study Region, Northeastern Minnesota: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-51. 1978.

5. **Golder Associates.** Recommendations for NorthMet Open Pit Rock Slope Designs - NorthMet Mine Project (RS09). June 2006.

6. **Barr Engineering Co.** Hydrogeology of Fractured Bedrock in the Vicinity of the NorthMet Project (v3). December 2014.

7. **Poly Met Mining Inc.** NorthMet Project Geotechnical Data Package Vol 3 - Mine Site Stockpiles (v5). July 2016.

8. **Poly Met Mining, Inc.** NorthMet Project Water Management Plan - Mine Site (v7). December 2017.

9. *The Integrity of Cover Systems - An Update.* **Wilson, G.W., Williams, D.J. and Rykaart, E.M.** Cairns, North Queensland, Australia : s.n., 2003. Proc. 6-th Int. Conf on Acid Rock Drainage.

10. **Poly Met Mining Inc.** NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v14). February 2015.

11. **Bear, J.** *Dynamics of Fluids in Porous Media.* New York : Dover Publications Inc., 1972. p. 764.

12. **Hutchinson, I.P.G and Ellison, R.D. eds.** Mine waste management: a resource for mining industry professionals, regulators and consulting engineers. s.l. : Lewis Publishers, 1992. p. 672.

13. **Poly Met Mining, Inc.** NorthMet Project Adaptive Water Management Plan (v12).

December 2017.

14. **Poly Met Mining Inc.** NorthMet Project Wetland Management Plan (v7). January 2015.

15. **Federal Emergency Management Agency (FEMA).** *National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures – Part 1: Provisions, FEMA document No. 368 prepared by the Building Seismic Safety Council, Washington D.C.* 2001.

16. **Barr Engineering Co.** NorthMet Project Mine Site Blasting Plan. December 2017.

17. **Foth & Van Dyke and Associates Inc.** Pit Backfill QA/QC: 1997 Summary. Volume I of III. Flambeau Mining Company. Ladysmith, Wisconsin. March 1998.

18. **Poly Met Mining, Inc.** NorthMet Project Water Management Plan - Plant (v7). December 2017.

19. —. NorthMet Project Flotation Tailings Management Plan (v7). May 2017.

20. —. NorthMet Project Residue Management Plan (v6). May 2017.

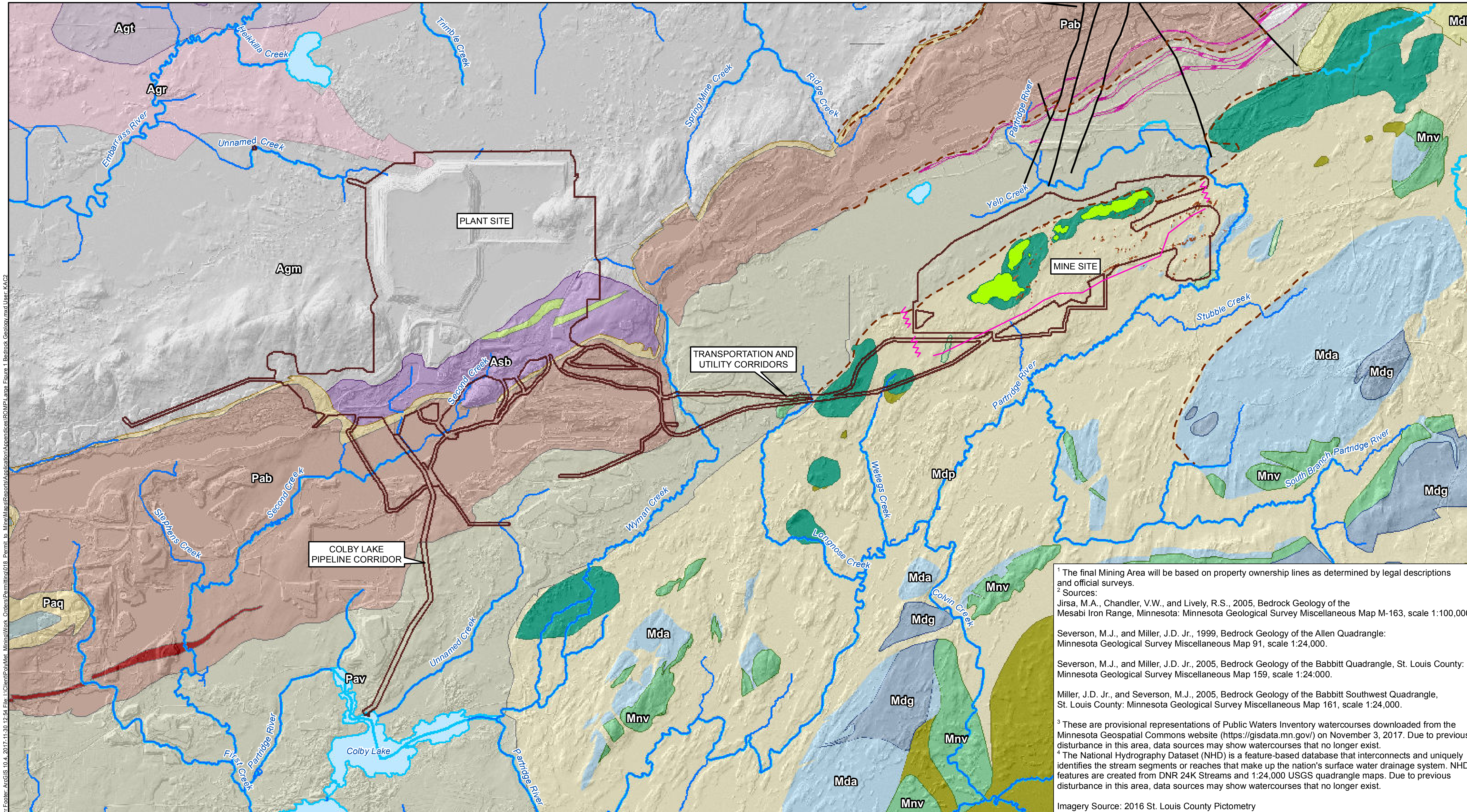
List of Tables

List of Figures

List of Large Figures

List of Attachments

Large Figures



[1] The final Mining Area will be based on property ownership lines as determined by legal descriptions and official surveys.
[2] Sources:
Jirsa, M.A., Chandler, V.W., and Lively, R.S., 2005, Bedrock Geology of the Mesabi Iron Range, Minnesota: Minnesota Geological Survey Miscellaneous Map M-163, scale 1:100,000.

Severson, M.J., and Miller, J.D. Jr., 1999, Bedrock Geology of the Allen Quadrangle: Minnesota Geological Survey Miscellaneous Map 91, scale 1:24,000.

Severson, M.J., and Miller, J.D. Jr., 2005, Bedrock Geology of the Babbitt Quadrangle, St. Louis County: Minnesota Geological Survey Miscellaneous Map 159, scale 1:24:000.

Miller, J.D. Jr., and Severson, M.J., 2005, Bedrock Geology of the Babbitt Southwest Quadrangle, St. Louis County: Minnesota Geological Survey Miscellaneous Map 161, scale 1:24,000.

[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]

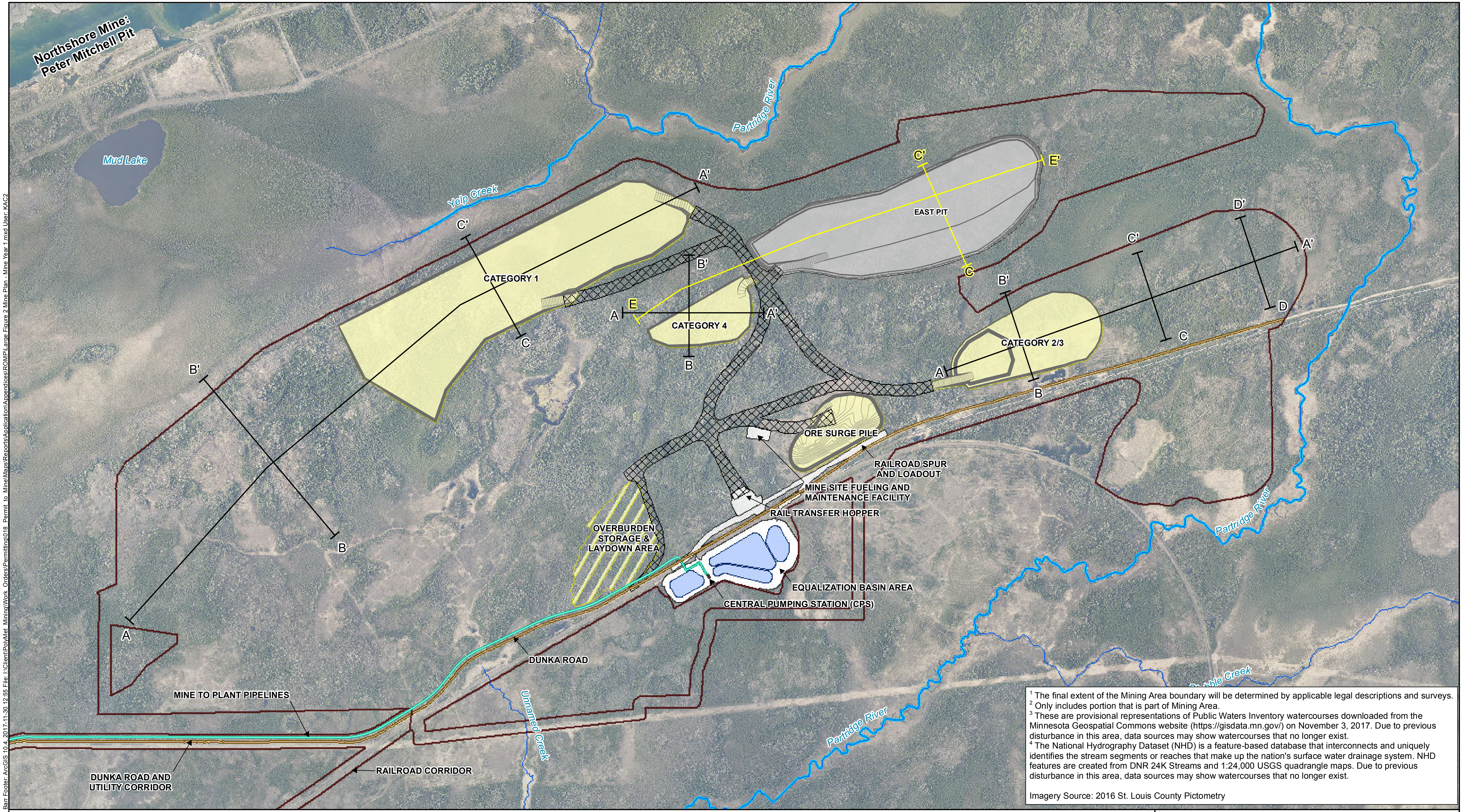
Bedrock Geology[2]

- Agm - Quartz monzonite and monzodiorite
- Agr - Quartz monzonite, monzodiorite, and monzogranite
- Agt - Tonalite to granodiorite
- Amv - Tholeiitic to calc-alkalic volcanic rocks
- Asb - Schist of sedimentary protolith
- Asv - Schist of mafic to intermediate volcanic protlith
- Mda - Anorthositic series subsuite of the Duluth Complex
- Mdg - Gabbro
- Mdk - South Kawishiwi intrusion
- Mdp - Partridge River intrusion
- Mdu - Ultramafic, oxide-rich intrusions
- Mia - Aurora sill
- Mmi - Mafic intrusions
- Mnv - North Shore Volcanic Group
- Pab - Biwabik Iron Formation
- Paq - Pokegama Quartzite
- Pav - Virginia Formation
- Bedrock Outcrop
- Duluth Complex Deposits
- Mine Site Block Model Ore Body
- Geologic Contact (Approximately Located)
- Fault (Approximately Located)
- Limits of Detailed Geologic Model
- Public Waters Inventory (PWI) Basins
- Public Waters Inventory (PWI) Watercourse[3]
- National Hydrography Dataset (NHD) Rivers & Streams[4]

0 0.5 1
Miles

BEDROCK GEOLOGY
NorthMet Project
Poly Met Mining, Inc.

Large Figure 1
Rock and Overburden Management Plan



[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

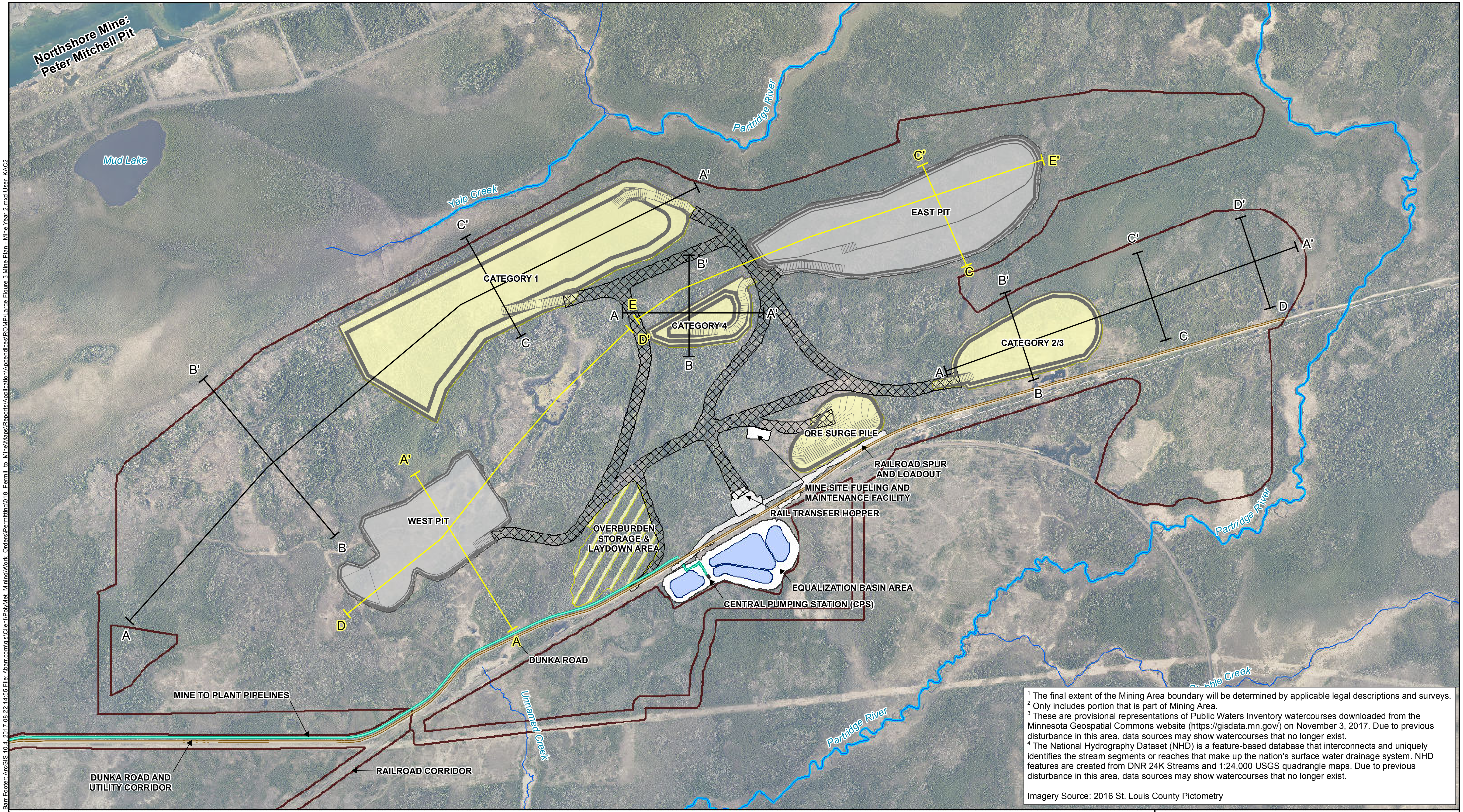
Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Dunka Road[2]
Mine Year 1 Footprints
Mine Pit
Active Stockpile
Storage & Laydown Area
Haul Roads
Mine Pit Cross-Sections
Stockpile Cross-Sections
Mine Pit and Stockpile Contours
Mine to Plant Pipelines
Public Waters Inventory (PWI) Watercourses[3]
National Hydrography Dataset (NHD) Rivers & Streams[4]

0 1,500 3,000
Feet

MINE PLAN - MINE YEAR 1
NorthMet Project
Poly Met Mining, Inc.

Large Figure 2
Rock and Overburden Management Plan



[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

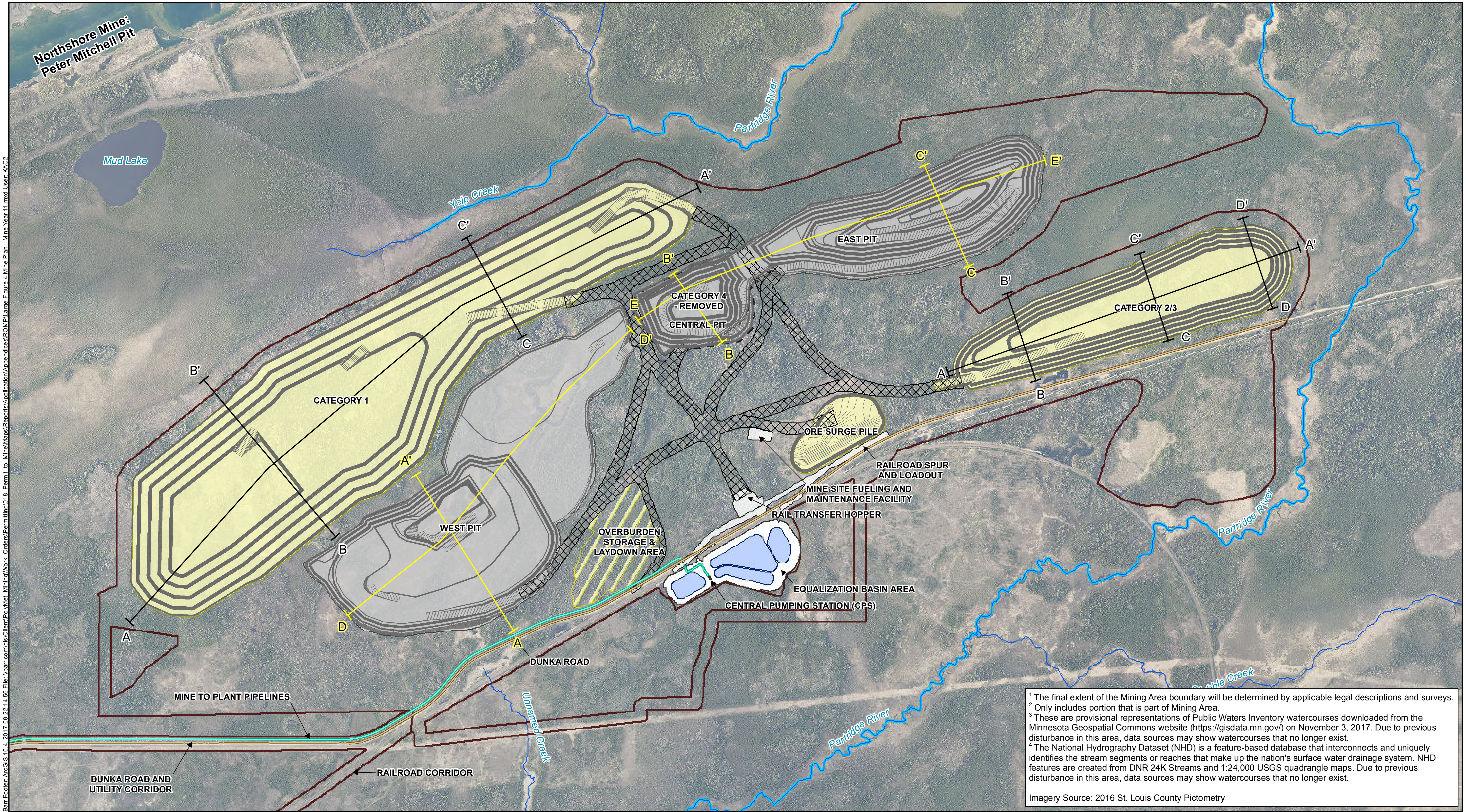
Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Dunka Road[2]
Mine Year 2 Footprints
Mine Pit
Active Stockpile
Storage & Laydown Area
Haul Roads
Mine Pit Cross-Sections
Stockpile Cross-Sections
Mine Pit and Stockpile Contours
Mine to Plant Pipelines
Public Waters Inventory (PWI) Watercourses[3]
National Hydrography Dataset (NHD) Rivers & Streams[4]

0 1,500 3,000
Feet

MINE PLAN - MINE YEAR 2
NorthMet Project
Poly Met Mining, Inc.

Large Figure 3
Rock and Overburden Management Plan



[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

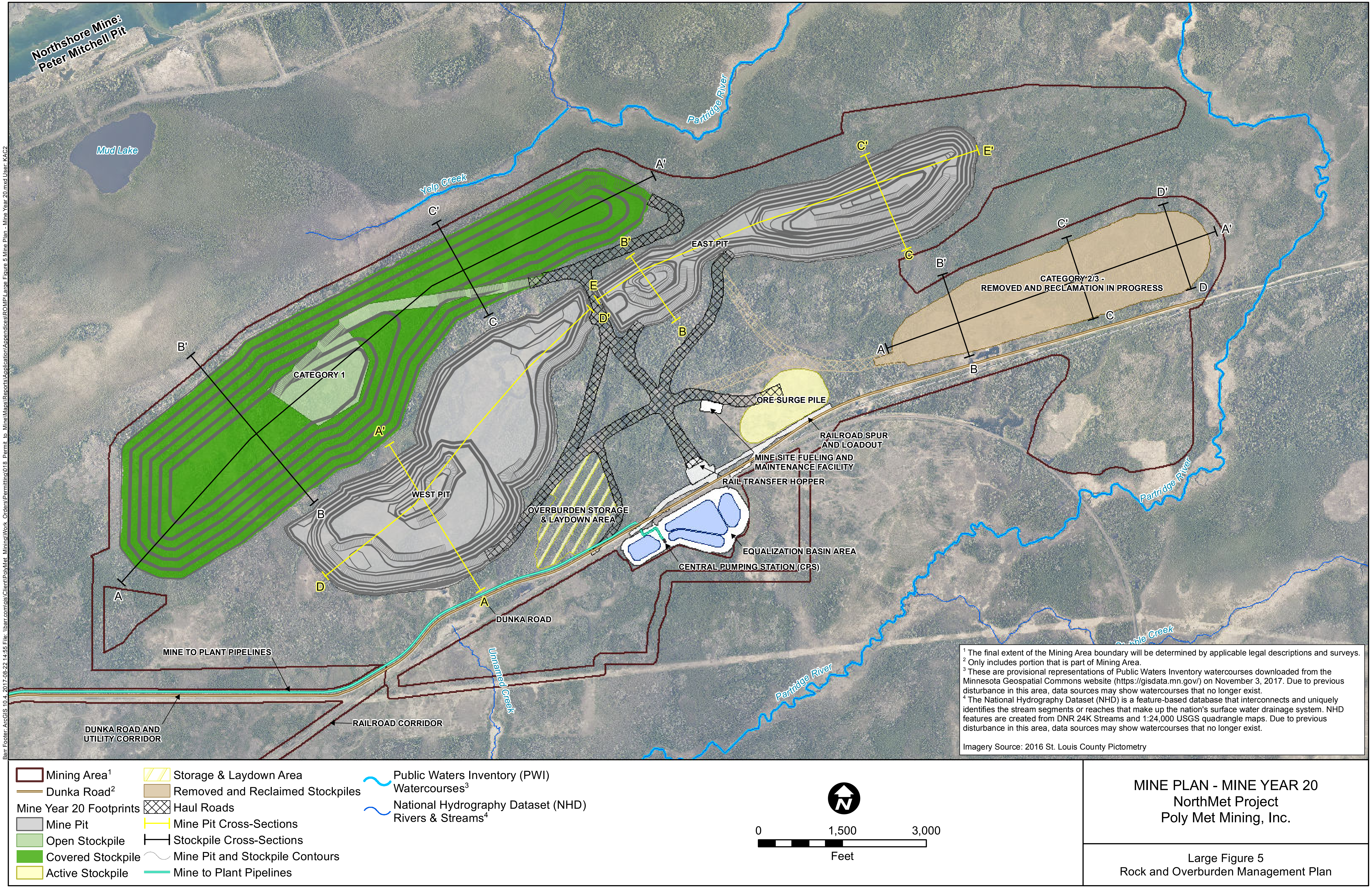
Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Dunka Road[2]
Mine Year 11 Footprints
Mine Pit
Active Stockpile
Storage & Laydown Area
Removed Stockpile
Haul Roads
Mine Pit Cross-Sections
Stockpile Cross-Sections
Mine Pit and Stockpile Contours
Mine to Plant Pipelines
Public Waters Inventory (PWI) Watercourses[3]
National Hydrography Dataset (NHD) Rivers & Streams[4]

0 1,500 3,000
Feet

MINE PLAN - MINE YEAR 11
NorthMet Project
Poly Met Mining, Inc.

Large Figure 4
Rock and Overburden Management Plan

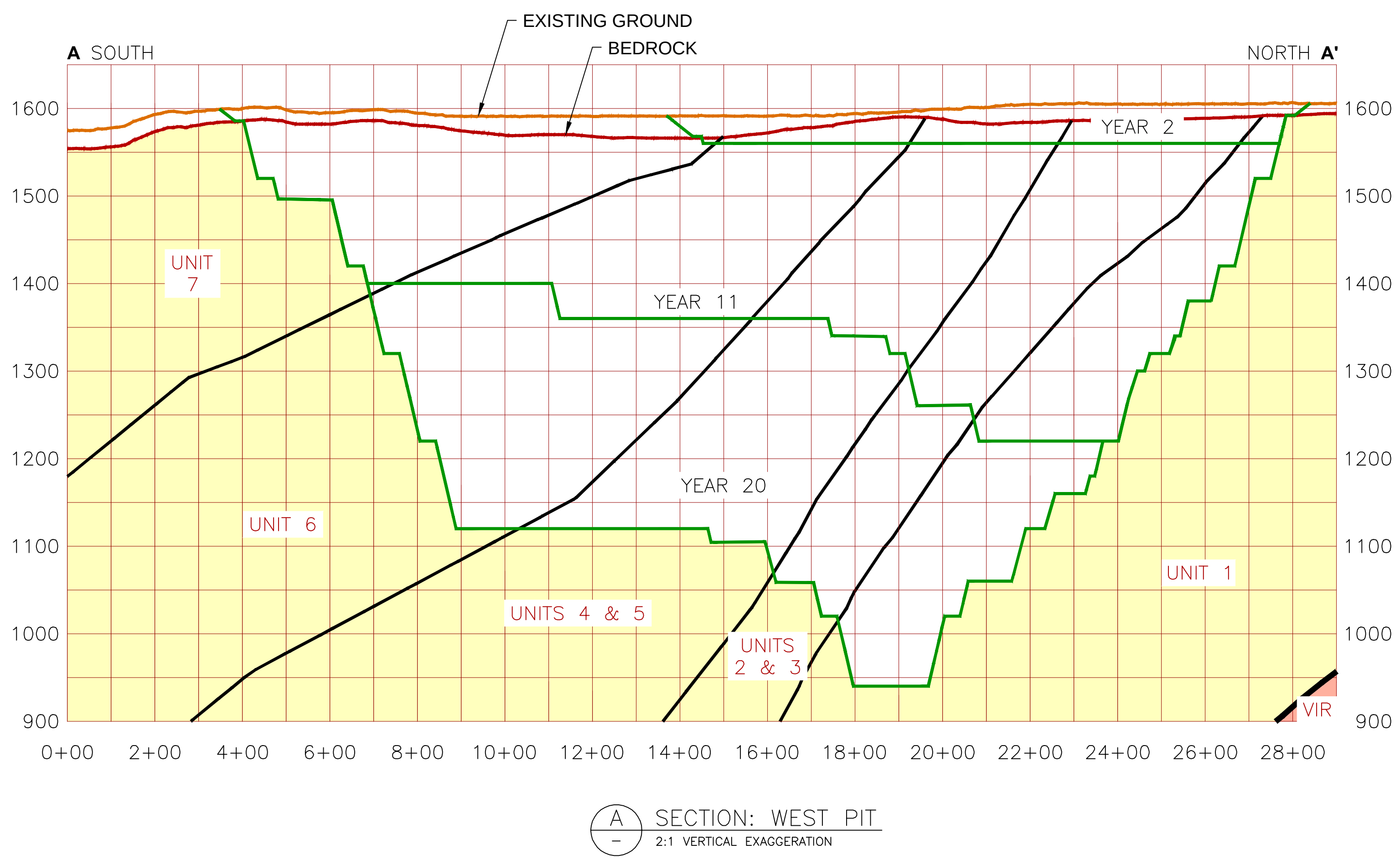


[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

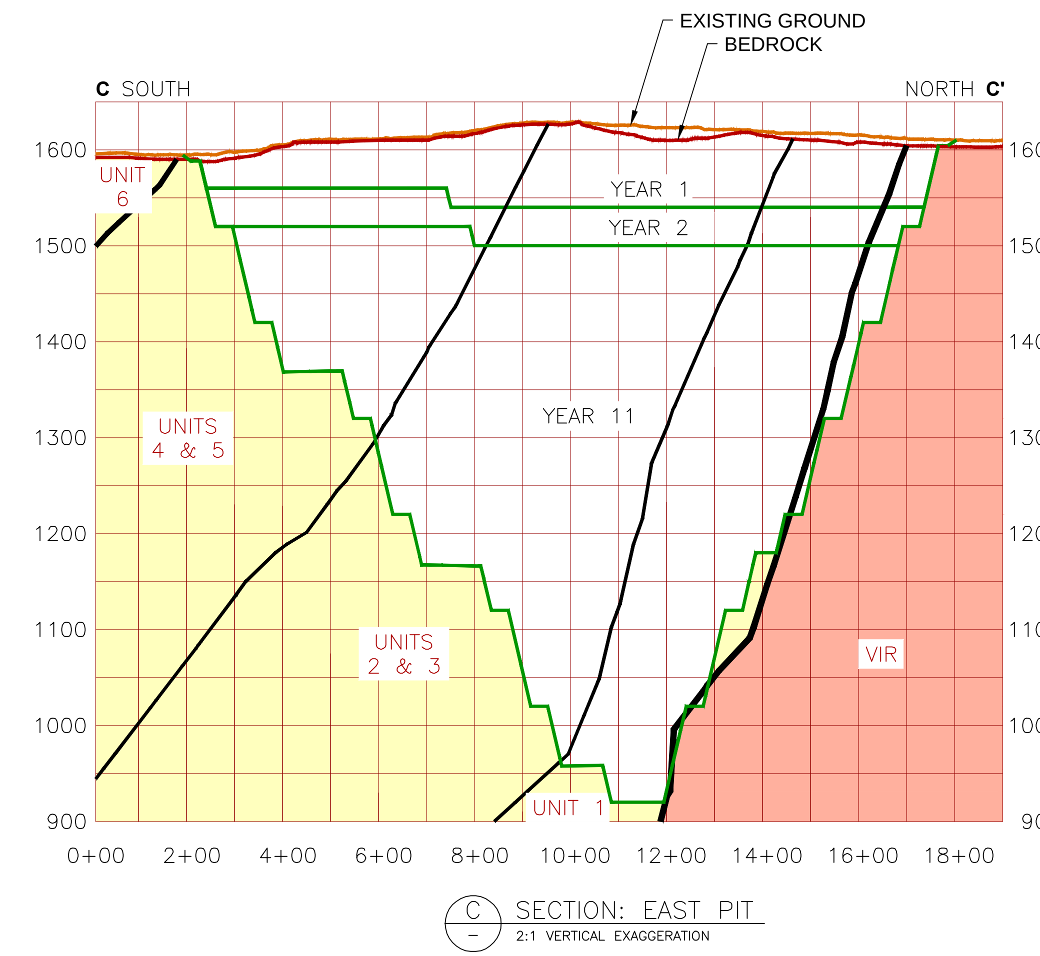
Imagery Source: 2016 St. Louis County Pictometry

MINE PLAN - MINE YEAR 20
NorthMet Project
Poly Met Mining, Inc.

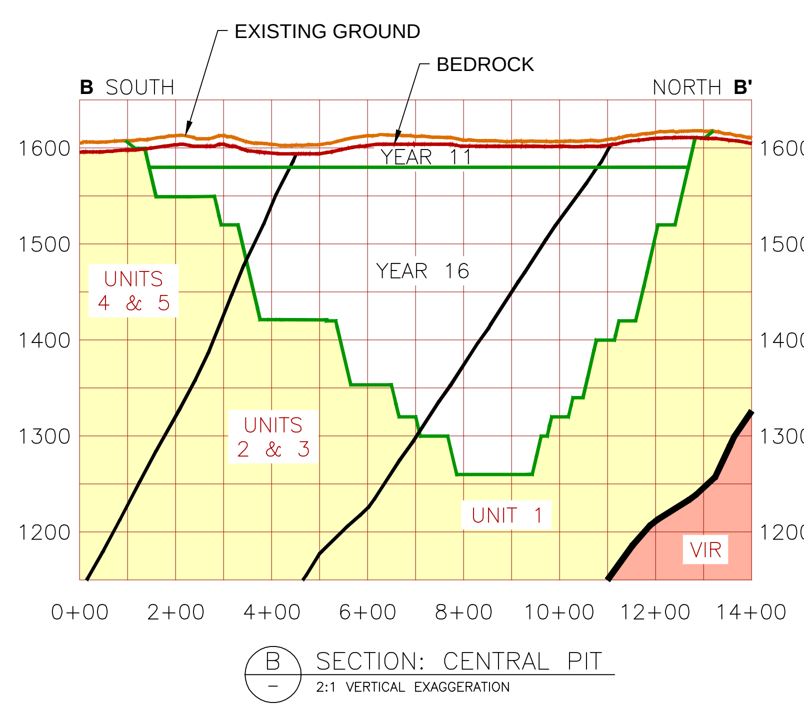
Large Figure 5
Rock and Overburden Management Plan



A SECTION: WEST PIT
2:1 VERTICAL EXAGGERATION



C SECTION: EAST PIT
2:1 VERTICAL EXAGGERATION



B SECTION: CENTRAL PIT
2:1 VERTICAL EXAGGERATION

LEGEND

- UNIT 1–7 — PARTRIDGE RIVER INTRUSION DULUTH COMPLEX
- VIR — VIRGINIA FORMATION
- GEOLOGIC CONTACT

NOTES:

1. CROSS-SECTION LOCATIONS SHOWN ON LARGE FIGURES 2 THRU 5.
2. EAST PIT WILL BE BACKFILLED AS PART OF PROGRESSIVE RECLAMATION BEGINNING IN MINE YEAR 11.
3. CENTRAL PIT MINING WILL BE COMPLETED IN MINE YEAR 16, AT WHICH TIME, BACKFILLING WILL BEGIN.

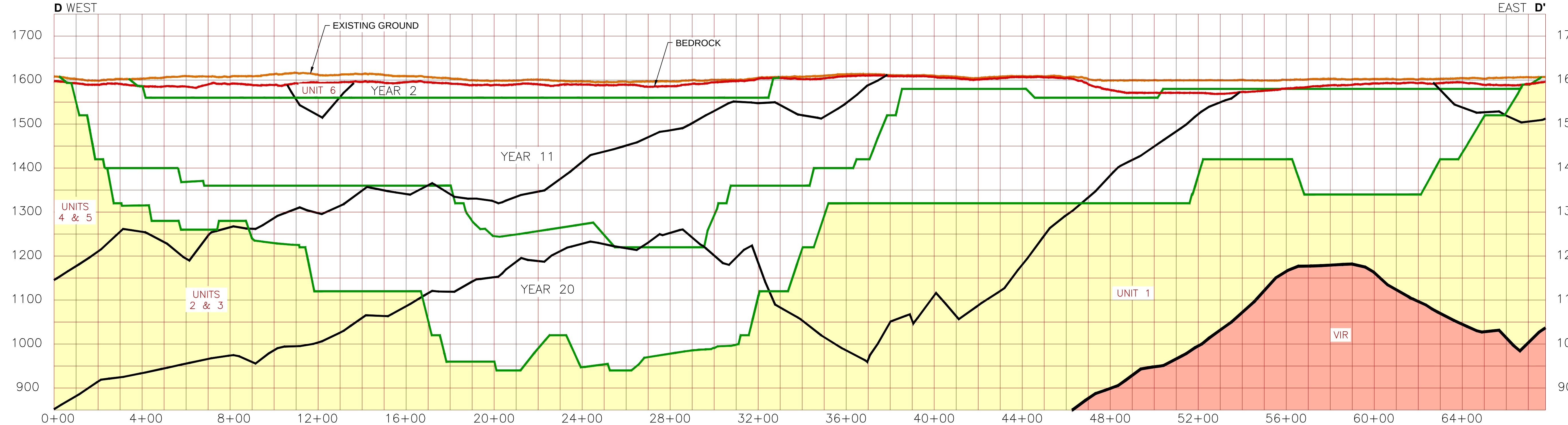
Horizontal 0 200 400 800 Feet

Vertical 0 100 200 400 Feet

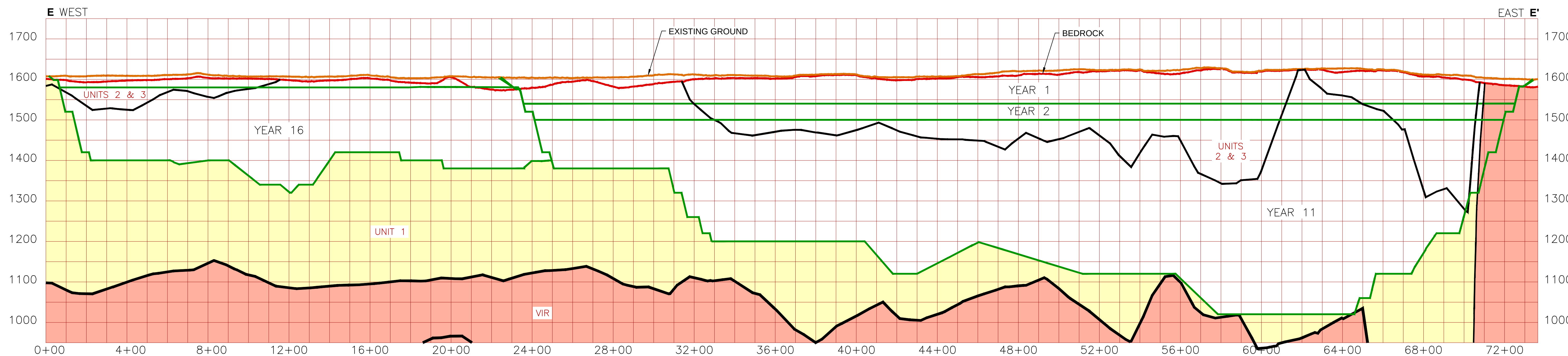
PIT CROSS-SECTIONS A, B, C
NorthMet Project
Poly Met Mining, Inc.

Large Figure 6
Rock and Overburden Management Plan

CADD USER: Veronica Wourms FILE: K:\DESIGN\23690C29.99\PERMIT_ROMP_LARGE FIGURE 6_PIT CROSS SECTIONS A, B, C.DWG PLOT SCALE: 1:2 PLOT DATE: 11/14/2017 1:29 PM
BAR M:\AutoCAD 2011\AutoCAD 2011 Support\enu\Template\Barr_2011_Template.dwt Plot at 1 10/05/2010 14:03:50



D SECTION: WEST PIT
2:1 VERTICAL EXAGGERATION



E SECTION: EAST PIT
2:1 VERTICAL EXAGGERATION

LEGEND

- UNIT 1–7 — PARTRIDGE RIVER INTRUSION DULUTH COMPLEX
- VIR — VIRGINIA FORMATION
- GEOLOGIC CONTACT

NOTES:

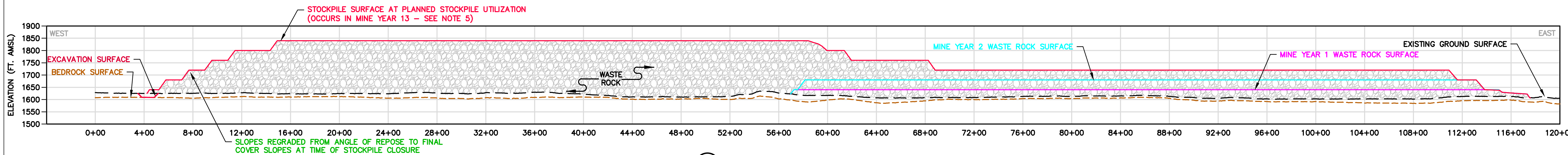
1. CROSS–SECTION LOCATIONS SHOWN ON LARGE FIGURES 2 THRU 5.
2. EAST PIT WILL BE BACKFILLED AS PART OF PROGRESSIVE RECLAMATION BEGINNING IN MINE YEAR 11.
3. CENTRAL PIT MINING WILL BE COMPLETED IN MINE YEAR 16, AT WHICH TIME, BACKFILLING WILL BEGIN.

Horizontal: 0, 250, 500, 1,000 Feet

Vertical: 0, 125, 250, 500 Feet

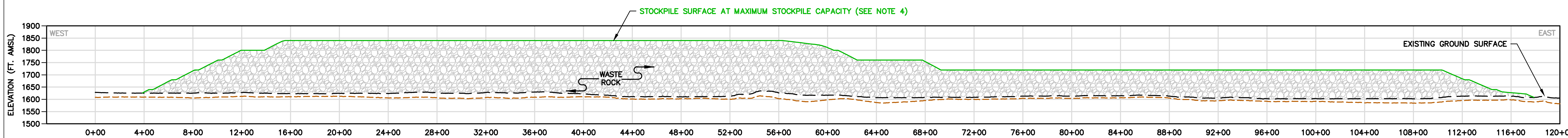
PIT CROSS-SECTIONS D, E
NorthMet Project
Poly Met Mining, Inc.

Large Figure 7
Rock and Overburden Management Plan



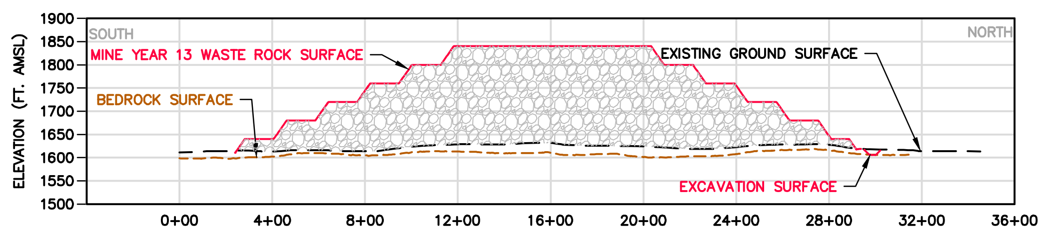
A 013 INTERIM CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



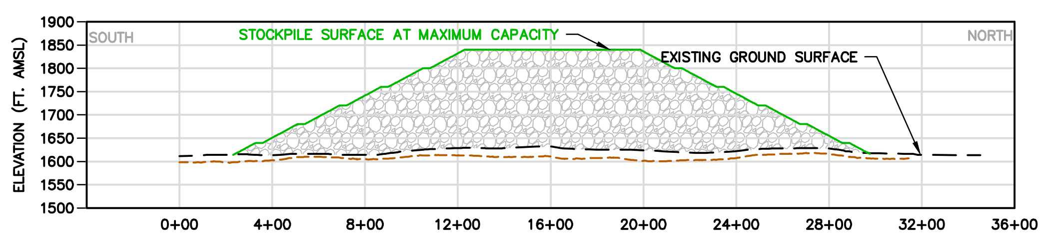
A 013 CLOSURE CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



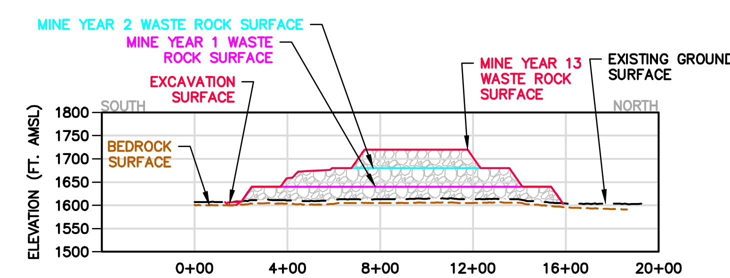
B 013 INTERIM CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



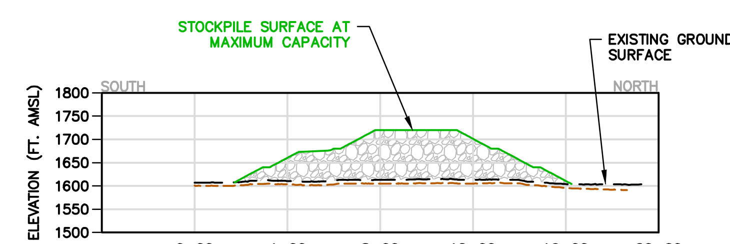
B 013 CLOSURE CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



C 013 INTERIM CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



C 013 CLOSURE CONFIGURATION SECTION

0 400 800
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION

NOTES

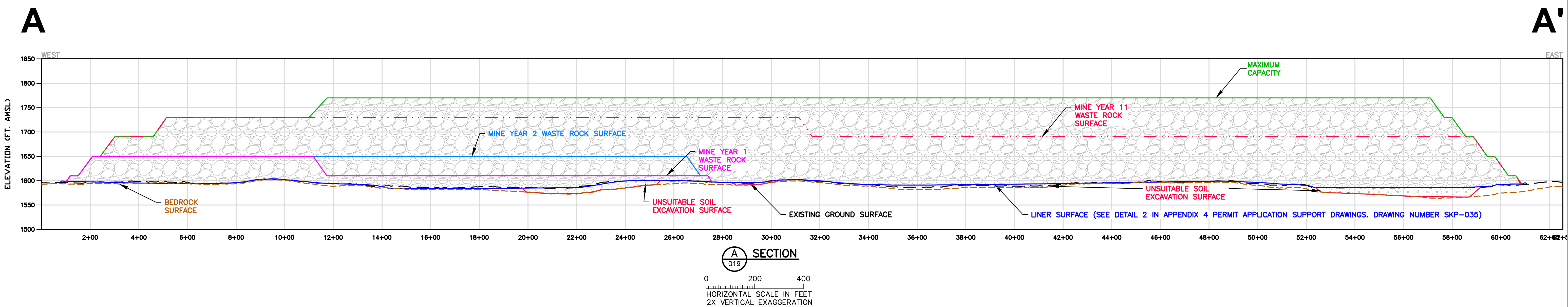
1. UNSUITABLE SOILS TO BE EXCAVATED WITHIN FIRST 100 FEET FROM THE ULTIMATE STOCKPILE BOUNDARIES. GEOTECHNICAL PROPERTIES OF THE FOUNDATION SOILS WILL BE CONFIRMED PRIOR TO CONSTRUCTION.
2. SEE CROSS–SECTION LOCATIONS ON LARGE FIGURES 2 THRU 5.
3. FROM GOLDER ASSOCIATES INC. DRAWING INCLUDED IN APPENDIX 4 PERMIT APPLICATION SUPPORT DRAWINGS: CATEGORIES 1, 2/3, 4 STOCKPILES AND ORE SURGE PILE DESIGN.
4. MAXIMUM STOCKPILE CAPACITY – THE TOTAL CAPACITY OF THE WASTE ROCK STOCKPILE IF FILLED TO THE MAXIMUM ELEVATIONS NOTED.
5. PLANNED STOCKPILE UTILIZATION – THE PORTION OF THE STOCKPILE CAPACITY PLANNED TO BE UTILIZED FOR WASTE ROCK.
6. THESE FIGURES SHOW THE WASTE ROCK SURFACE AT PLANNED STOCKPILE UTILIZATION FOR WASTE ROCK. ADDITIONAL CAPACITY SHOWN UP TO THE MAXIMUM CAPACITY WILL ACCOUNT FOR POTENTIAL VARIATION IN WASTE ROCK QUANTITY AND/OR DENSITY.

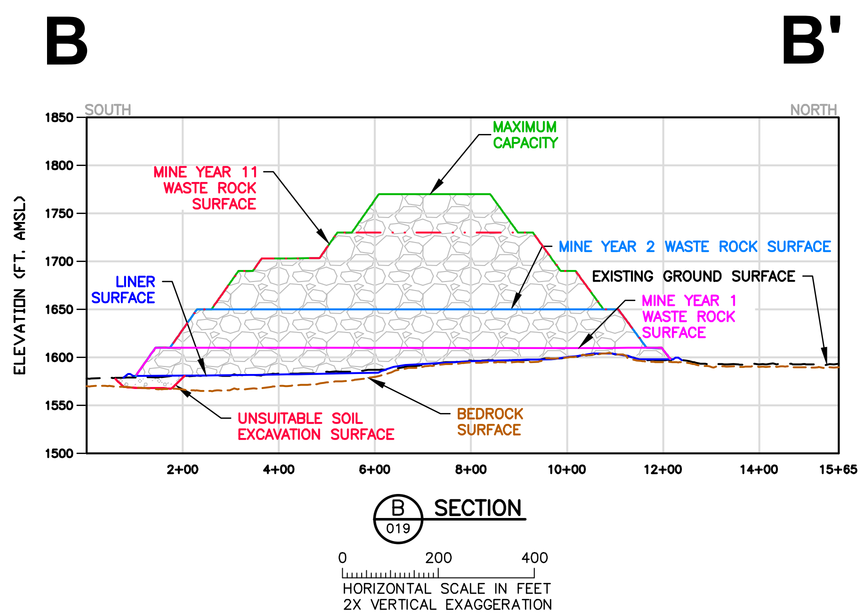
LEGEND

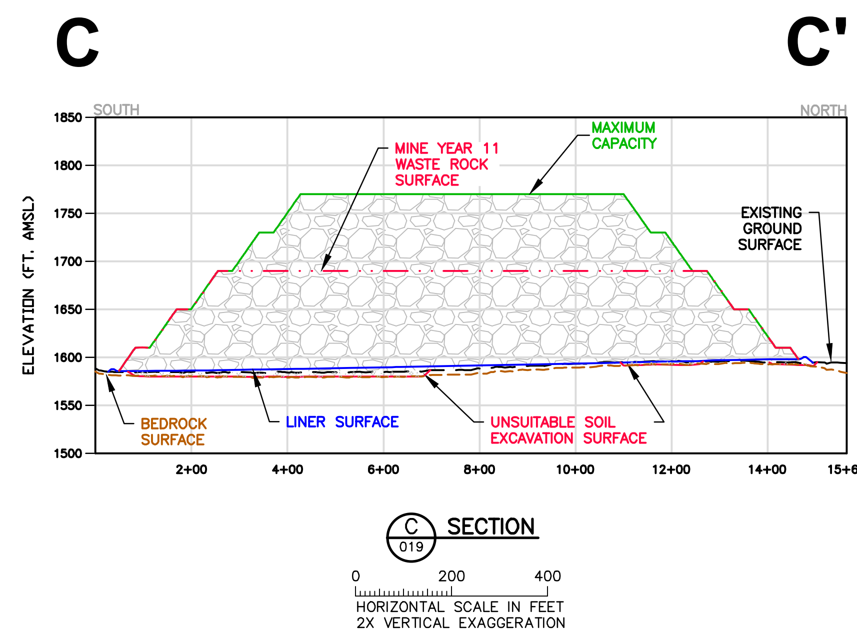
- MINE YEAR 1 LIMITS
- MINE YEAR 2 LIMITS
- MINE YEAR 13 LIMITS
- MINE YEAR 21, ULTIMATE LIMITS
- EXISTING GROUND SURFACE
- BEDROCK SURFACE
- EXCAVATION SURFACE

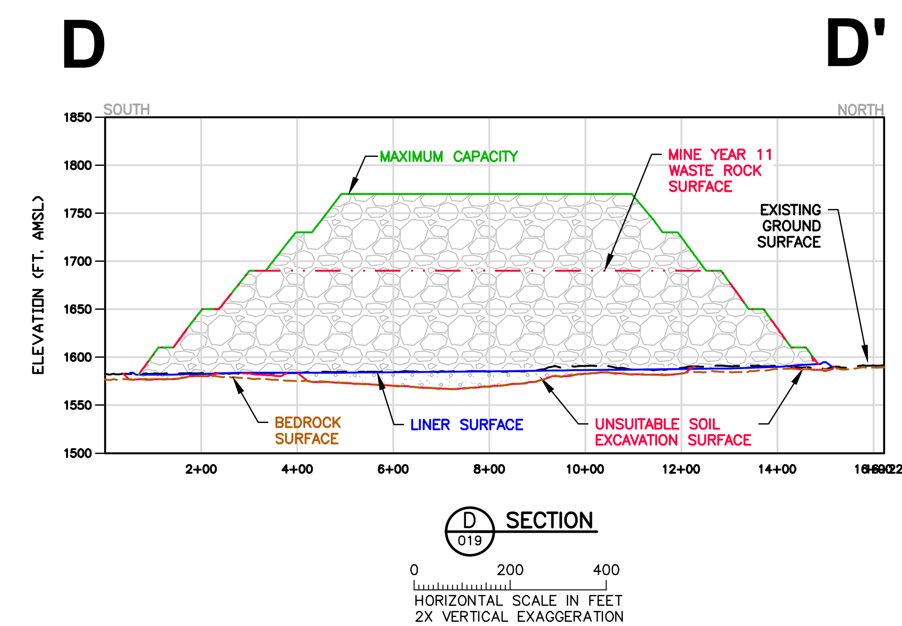
CATEGORY 1 WASTE ROCK STOCKPILE CROSS-SECTIONS
NorthMet Project
Poly Met Mining, Inc.

Large Figure 8
Rock and Overburden Management Plan









NOTES

1. STOCKPILE INTERBENCH SLOPES AT ANGLE OF REPOSE.
2. THIS DESIGN CONSERVATIVELY ASSUMES THAT ALL LOWLAND/WETLAND SOILS ARE GEOTECHNICALLY UNSUITABLE AND WILL REQUIRE EXCAVATION AND REPLACEMENT WITH STRUCTURAL FILL TO THE DESIGN FOUNDATION BASE GRADE. GEOTECHNICAL PROPERTIES OF THE FOUNDATION SOILS WILL BE CONFIRMED PRIOR TO CONSTRUCTION.
3. MAXIMUM DEPTH OF UNSUITABLE MATERIAL SUBGRADE EXCAVATION LIMITED TO 20 FEET FOR THIS DESIGN. THE ACTUAL DEPTH OF UNSUITABLE SOIL EXCAVATION WILL BE CONFIRMED BY PHASE II GEOTECHNICAL INVESTIGATION.
4. SEE CROSS-SECTION LOCATIONS ON LARGE FIGURES 2 THRU 5.
5. FROM GOLDER ASSOCIATES INC. DRAWING INCLUDED IN APPENDIX 4 PERMIT APPLICATION SUPPORT DRAWINGS: CATEGORIES 1, 2/3, 4 STOCKPILES AND ORE SURGE PILE DESIGN.
6. MAXIMUM STOCKPILE CAPACITY – THE TOTAL CAPACITY OF THE WASTE ROCK STOCKPILE IF FILLED TO THE MAXIMUM ELEVATIONS NOTED.
7. PLANNED STOCKPILE UTILIZATION – THE PORTION OF THE TOTAL STOCKPILE CAPACITY PLANNED TO BE UTILIZED FOR WASTE ROCK.
8. THESE FIGURES SHOW THE WASTE ROCK SURFACE AT PLANNED STOCKPILE UTILIZATION FOR WASTE ROCK. ADDITIONAL CAPACITY SHOWN UP TO THE MAXIMUM CAPACITY WILL STORE SATURATED MINERAL OVERBURDEN AS NEEDED AND WILL ALSO ACCOUNT FOR POTENTIAL VARIATION IN WASTE ROCK QUANTITY AND/OR DENSITY.

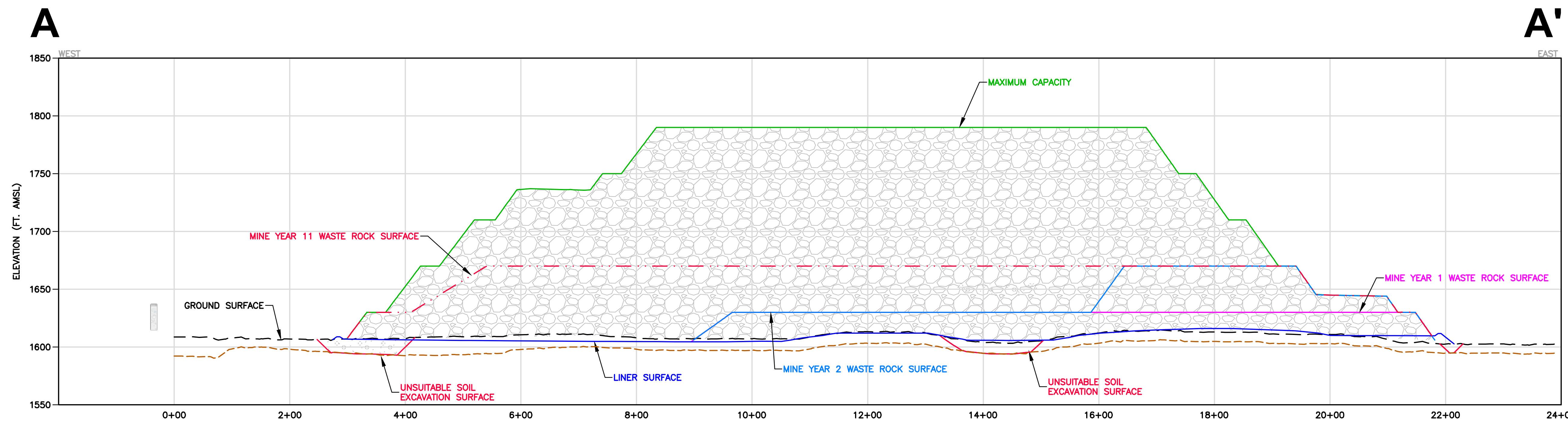
LEGEND

- MINE YEAR 1 LIMITS
- MINE YEAR 2 LIMITS
- MINE YEAR 11 LIMITS
- MAXIMUM CAPACITY
- LINER SURFACE
- EXISTING GROUND SURFACE
- UNSUITABLE SOIL EXCAVATION SURFACE
- BEDROCK SURFACE

CATEGORY 2/3 WASTE ROCK STOCKPILE CROSS-SECTIONS

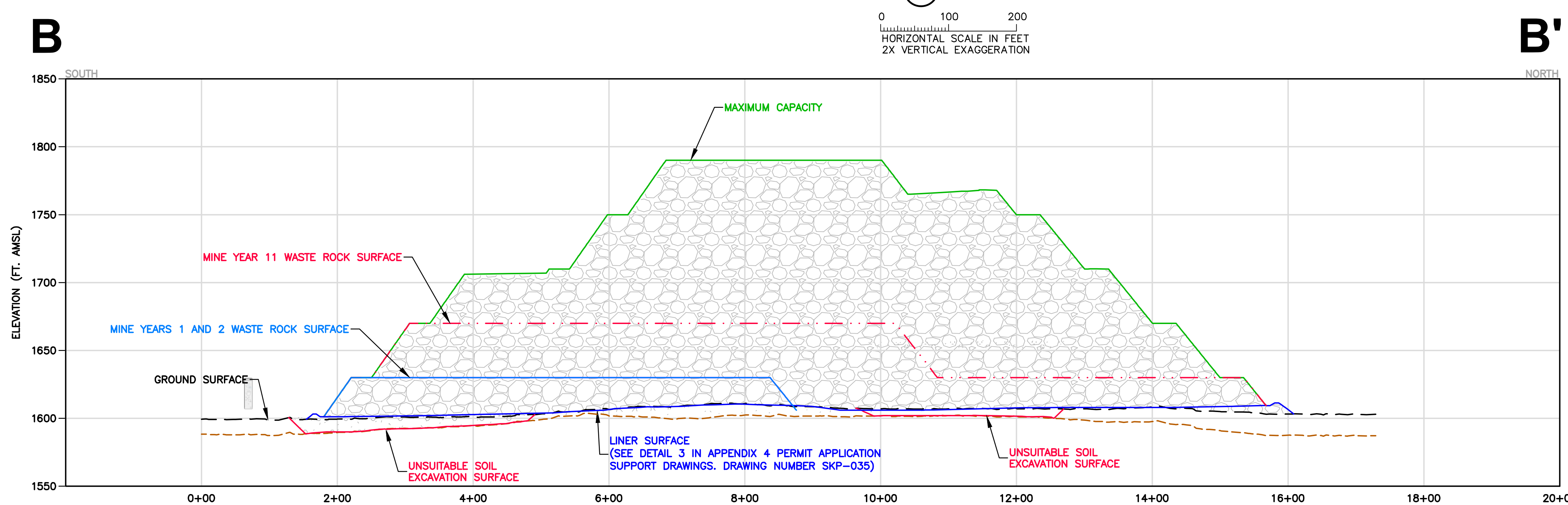
NorthMet Project
Poly Met Mining, Inc.

Large Figure 9
Rock and Overburden Management Plan



A SECTION 025

0 100 200
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION



B SECTION 025

0 100 200
HORIZONTAL SCALE IN FEET
2X VERTICAL EXAGGERATION

NOTES

1. STOCKPILE INTERBENCH SLOPES AT ANGLE OF REPOSE.
2. THIS DESIGN CONSERVATIVELY ASSUMES THAT ALL LOWLAND/WETLAND SOILS ARE GEOTECHNICALLY UNSUITABLE AND WILL REQUIRE EXCAVATION AND REPLACEMENT WITH STRUCTURAL FILL TO THE DESIGN FOUNDATION BASE GRADE. GEOTECHNICAL PROPERTIES OF THE FOUNDATION SOILS WILL BE CONFIRMED PRIOR TO CONSTRUCTION.
3. MAXIMUM DEPTH OF UNSUITABLE MATERIAL SUBGRADE EXCAVATION LIMITED TO 20 FEET FOR THIS DESIGN. THE ACTUAL DEPTH OF UNSUITABLE SOIL EXCAVATION WILL BE CONFIRMED BY PHASE II GEOTECHNICAL INVESTIGATION.
4. SEE CROSS–SECTION LOCATIONS ON LARGE FIGURES 2 THRU 5.
5. FROM GOLDER ASSOCIATES INC. DRAWING INCLUDED IN APPENDIX 4 PERMIT APPLICATION SUPPORT DRAWINGS: CATEGORIES 1, 2/3, 4 STOCKPILES AND ORE SURGE PILE DESIGN.
6. MAXIMUM STOCKPILE CAPACITY – THE TOTAL CAPACITY OF THE WASTE ROCK STOCKPILE IF FILLED TO THE MAXIMUM ELEVATIONS NOTED.
7. PLANNED STOCKPILE UTILIZATION – THE PORTION OF THE TOTAL STOCKPILE CAPACITY PLANNED TO BE UTILIZED FOR WASTE ROCK.
8. THESE FIGURES SHOW THE WASTE ROCK SURFACE AT PLANNED STOCKPILE UTILIZATION FOR WASTE ROCK. ADDITIONAL CAPACITY SHOWN UP TO THE MAXIMUM CAPACITY WILL STORE SATURATED MINERAL OVERBURDEN AS NEEDED AND WILL ALSO ACCOUNT FOR POTENTIAL VARIATION IN WASTE ROCK QUANTITY AND/OR DENSITY.

LEGEND

- MINE YEAR 1 LIMITS
- MINE YEAR 2 LIMITS
- MINE YEAR 11 LIMITS
- MAXIMUM CAPACITY
- LINER SURFACE
- EXISTING GROUND SURFACE
- UNSUITABLE SOIL EXCAVATION SURFACE
- BEDROCK SURFACE

CATEGORY 4 WASTE ROCK STOCKPILE CROSS-SECTIONS

NorthMet Project
Poly Met Mining, Inc.

Large Figure 10
Rock and Overburden Management Plan

Data Source: ROMP v10 Table 2-3

Cat 1 Stockpile (Permanent, tons)

- 168,000,000
- 4,000,000
- 172,000,000

Cat 2/3 Stockpile (Temporary, tons)

- 44,000,000
- 16,600,000
- 60,600,000

Cat 4 Stockpile (Temporary, tons)

- 6,210,000
- 8,790,000
- 15,000,000

Ore Surge Pile (Temporary, tons)

- 2,500,000
- 570,000
- 3,070,000

Cat 2/3 + Cat 4 Excess Capacity (tons)

- 16,600,000
- 8,790,000
- **25,390,000**

Data Source: ROMP v10 Tables 2-6 and 2-7

Overburden (cubic yards)

Peat (Table 2-6)	2,454,500			
Unsaturated Overburden (Table 2-6)	3,172,000		8,761,000	6,413,000
Saturated Overburden	3,241,000	5,589,000 (Table 2-6)		
Saturated Overburden (Table 2-7 Total)	2,348,000			
Total	11,215,500			

Overburden (tons)

Peat (see Note 5)	2,651,000			
Unsaturated Overburden (see Note 1)	6,027,000		**16,646,000**	**12,185,000**
Saturated Overburden (see Note 1)	6,158,000	10,619,000 (Table 2-6)		
Saturated Overburden (see Note 1)	4,461,000			
Total	19,297,000			

<u>Can Planned Stockpiles Accommodate all Overburden if None is Used for Construction (excludes Peat)?</u>

Available Stockpile Capacity in Cat 2/3 Stockpile + Cat 4 Stockpile (tons):	25,390,000		[value is from **Cat 2/3 + Cat 4 Excess Capacity (tons)** portion of this spreadsheet]
<u>Stockpile Capacity Utilized for Overburden</u>	(16,646,000)		[value is from **Overburden (tons)** portion of this spreadsheet]
Remaining Stockpile Capacity if Overburden Use is Zero (tons):	**8,744,000**	**>0**	**therefore Stockpile Capacity is Adequate**

<u>Can Planned Stockpiles Accommodate Overburden not Planned for Use in Construction (excludes Peat)?</u>

Available Stockpile Capacity in Cat 2/3 Stockpile + Cat 4 Stockpile (tons):	25,390,000		[value is from **Cat 2/3 + Cat 4 Excess Capacity (tons)** portion of this spreadsheet]
<u>Stockpile Capacity Utilized for Overburden</u>	(12,185,000)		[value is from **Overburden (tons)** portion of this spreadsheet]
Remaining Stockpile Capacity if Portion of Overburden is Used (tons):	**13,205,000**	**>0**	**therefore Stockpile Capacity is Adequate**

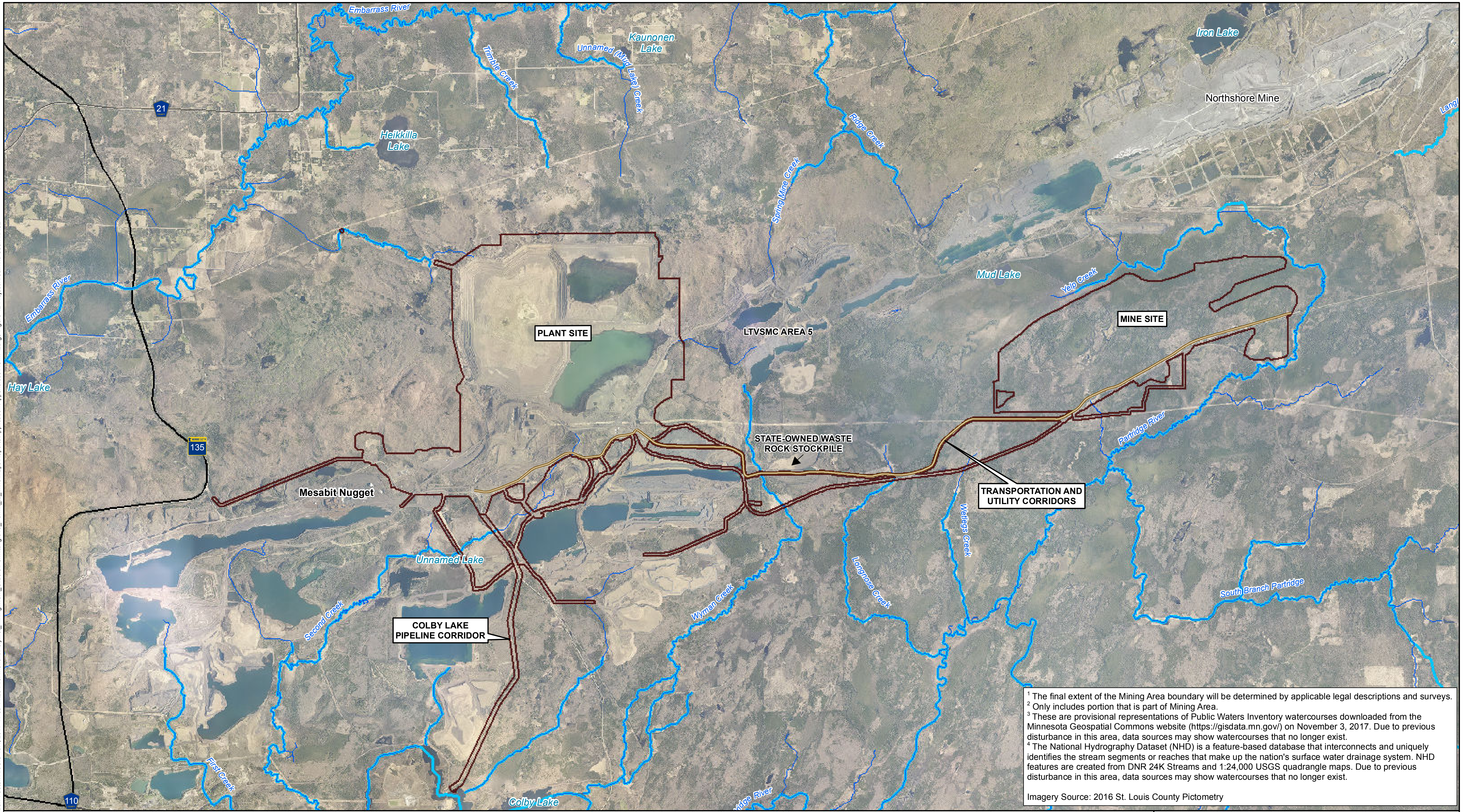
Key:

- Designates Maximum Potential Stockpile Capacity
- Designates Stockpile Capacity Consumed by Waste Rock (excludes Overburden)
- Designates Additional (unused) Stockpile Capacity Available for Overburden
- Designates Additional (unused) Stockpile Capacity Available

Notes and Assumptions:

1) Assumed density of Overburden when stockpiled, in pounds per cubic foot, is: 140.7
2) Assumed voids in stockpiled waste rock are not filled with Overburden. This yields a conservatively high estimate of stockpile capacity required.
3) Peat is used for reclamation and is not placed in the Cat 2/3 or Cat 4 stockpiles.
4) Unused Overburden is placed in Cat 2/3 and/or Cat 4 Stockpile.
5) Assumed density of Peat when stockpiled, in pounds per cubic foot, is: 80.0
6) Assumed Overburden density is same as for waste rock; ref. ROMP v10 Table 6-2 Note 1.
7) Assumed Peat density is from Geotechnical Data Package - Vol. 3, v5 Attachment I Table 1.

STOCKPILE CAPACITIES
NorthMet Project
Poly Met Mining, Inc.



[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

Imagery Source: 2016 St. Louis County Pictometry

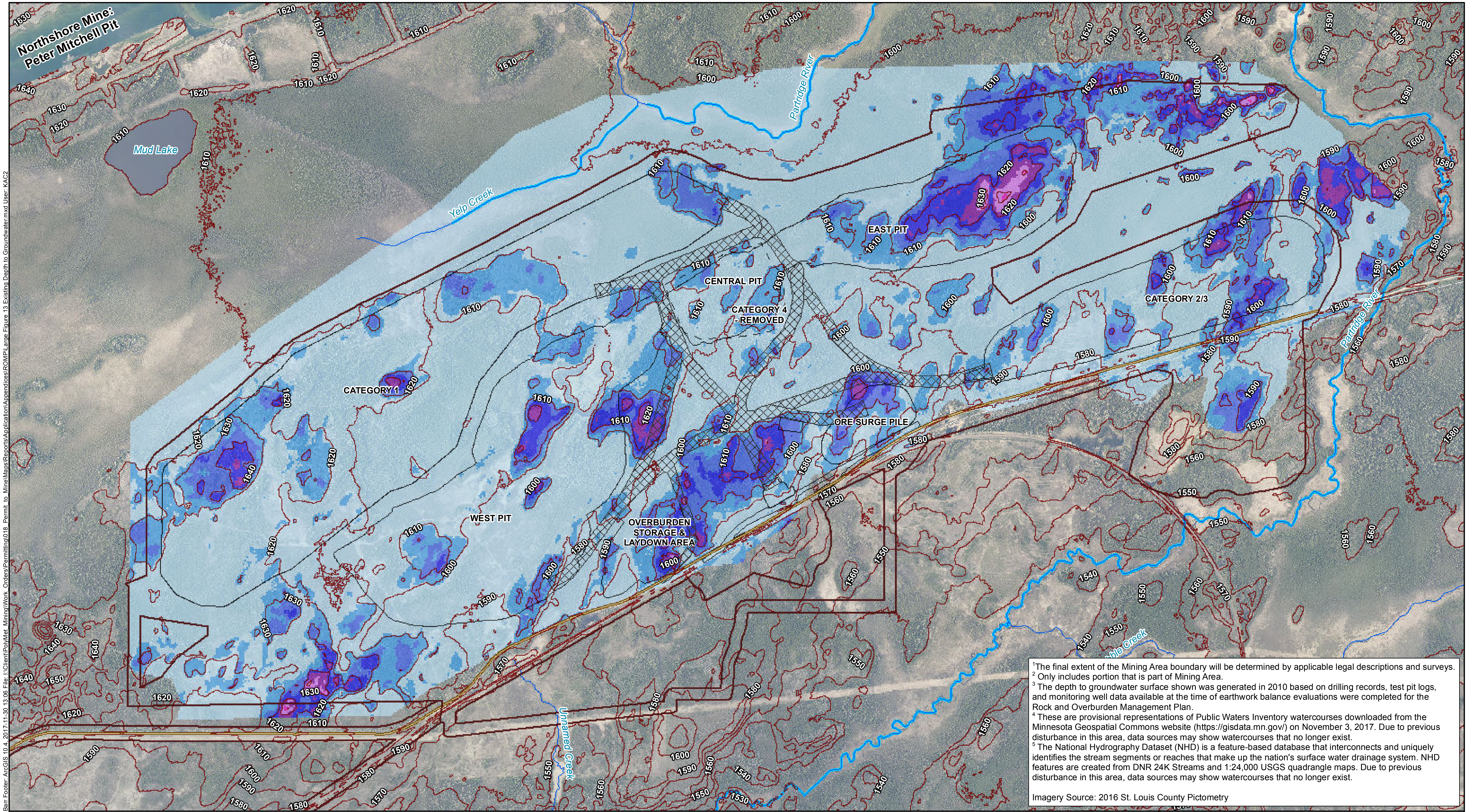
Mining Area[1]
Dunka Road[2]
Public Waters Inventory (PWI) Watercourses[3]
National Hydrography Dataset (NHD) Rivers & Streams[4]

0 0.5 1 2
Miles

PROJECT AREA
NorthMet Project
Poly Met Mining, Inc.

Large Figure 12
Rock and Overburden Management Plan

Barr Footer: ArcGIS 10.4, 2017-11-30 14:28 File: I:\Client\PolyMet_Mining\Work_Orders\Permitting\018_Permit_to_Mine\Maps\Reports\Application\Appendices\ROMP\Large Figure 12 Project Area.mxd User: KAC2



[1] The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2] Only includes portion that is part of Mining Area.
[3] The depth to groundwater surface shown was generated in 2010 based on drilling records, test pit logs, and monitoring well data available at the time of earthwork balance evaluations were completed for the Rock and Overburden Management Plan.
[4] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[5] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Dunka Road[2]
Surface Elevation Contours (10 foot)
Mine Year 11 Footprints
Mine Pit
Active Stockpile
Storage & Laydown Area
Removed Stockpile
Haul Roads

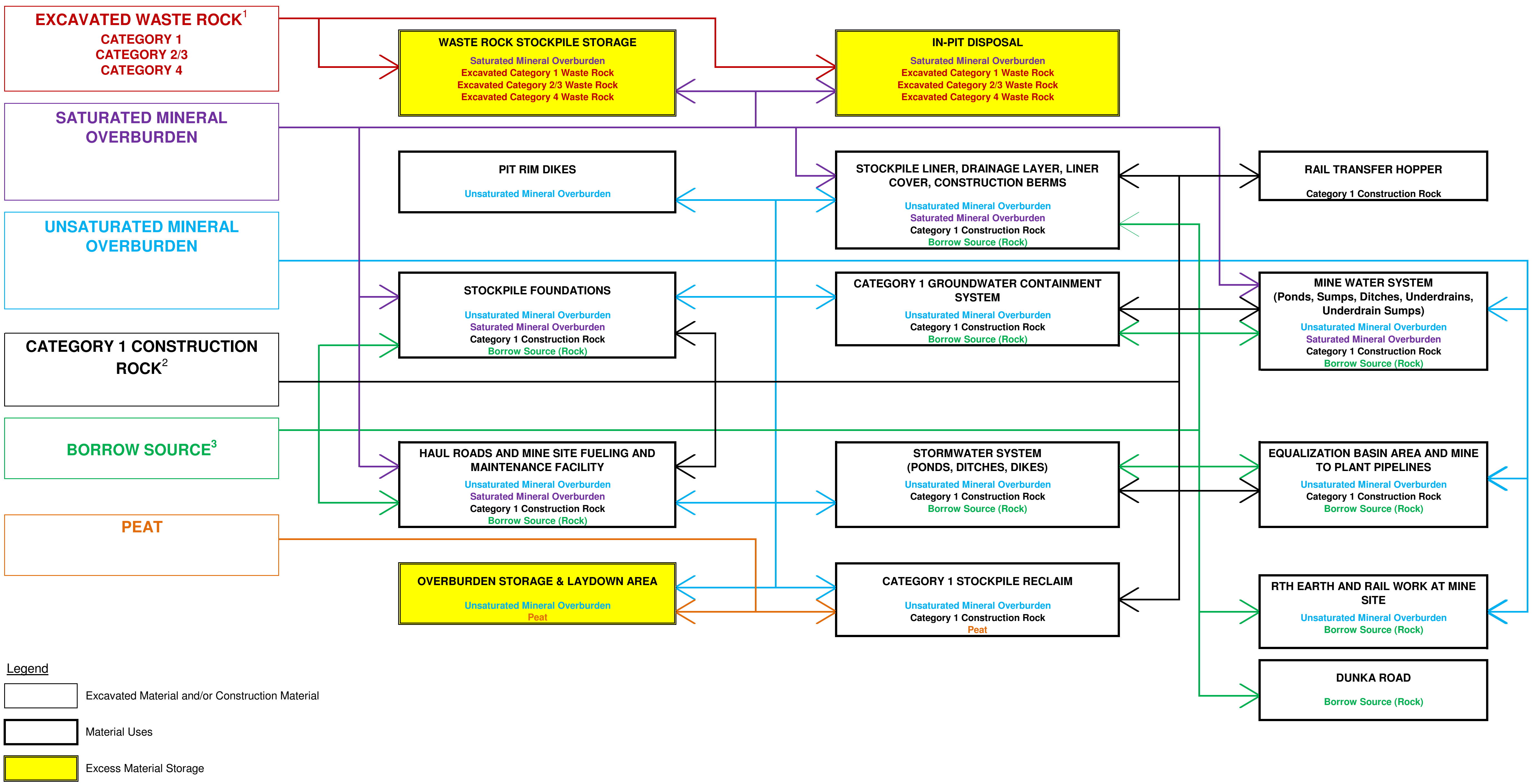
Depth to Groundwater[3]
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
>30

Public Waters Inventory (PWI) Watercourses[4]
National Hydrography Dataset (NHD) Rivers & Streams[5]

0 1,500 3,000
Feet

EXISTING DEPTH TO GROUNDWATER
NorthMet Project
Poly Met Mining, Inc.

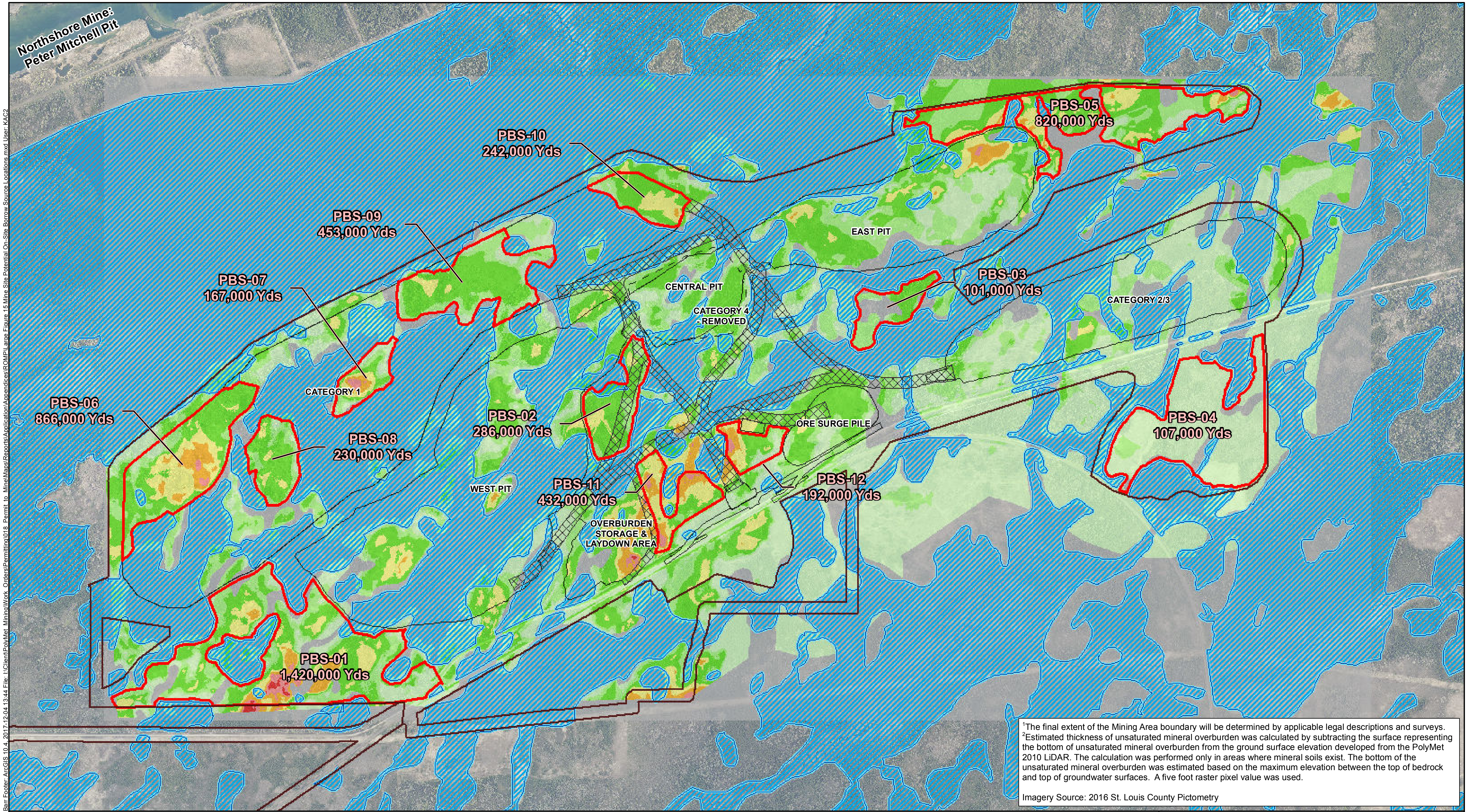
Large Figure 13
Rock and Overburden Management Plan



[1] Waste rock excavated during construction activities only (includes all categories of waste rock)
[2] Category 1 Construction Rock is a subset of the Category 1 waste rock with a sulfur content of 0.05% or less
[3] Borrow sources for the Mine Site will include taconite waste rock meeting the criteria as specified in the Construction Material SOP

MINE SITE OVERBURDEN AND WASTE ROCK USE AND STORAGE DIAGRAM
NorthMet Project
Poly Met Mining, Inc.

Large Figure 14
Rock and Overburden Management Plan



[1]The final extent of the Mining Area boundary will be determined by applicable legal descriptions and surveys.
[2]Estimated thickness of unsaturated mineral overburden was calculated by subtracting the surface representing the bottom of unsaturated mineral overburden from the ground surface elevation developed from the PolyMet 2010 LiDAR. The calculation was performed only in areas where mineral soils exist. The bottom of the unsaturated mineral overburden was estimated based on the maximum elevation between the top of bedrock and top of groundwater surfaces. A five foot raster pixel value was used.

Imagery Source: 2016 St. Louis County Pictometry

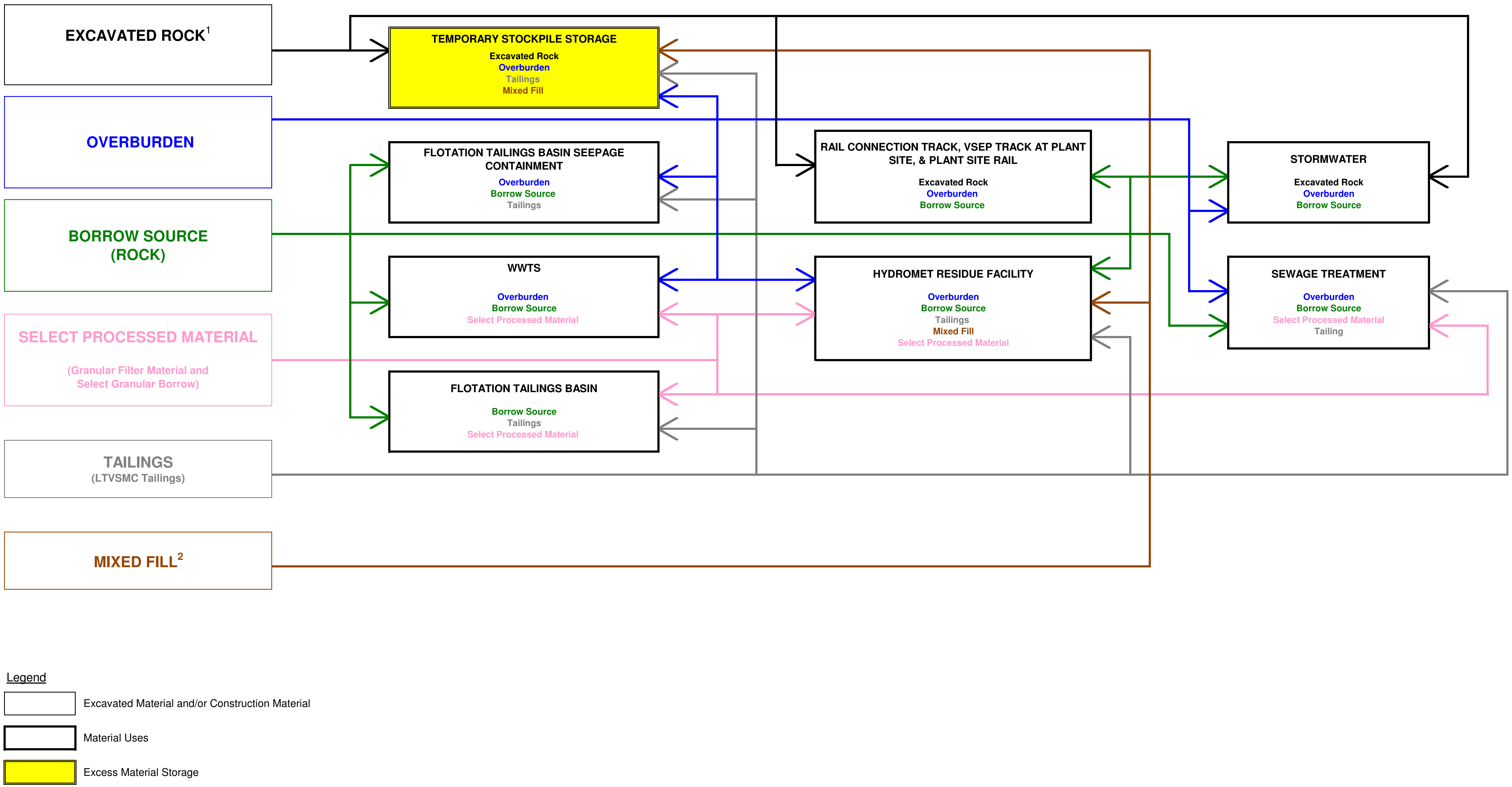
Mining Area[1]
Mine Year 11 Footprints
Mine Pit
Active Stockpile
Storage & Laydown Area
Removed Stockpile

Wetland Areas
Potential Borrow Source (Volume in Cubic Yards)
Unsaturated Soil Thickness (feet)[2]
0.0 - 2.5
2.6 - 5.0
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 34.7

0 1,500 3,000
Feet

MINE SITE POTENTIAL ON-SITE BORROW SOURCE LOCATIONS
NorthMet Project
Poly Met Mining, Inc.

Large Figure 15
Rock and Overburden Management Plan



[1] Rock excavated during construction activities only

[2] Mixed Fill includes material excavated from the HRF area and reused in construction.

PLANT SITE EARTHWORK MATERIAL USE AND STORAGE DIAGRAM
NorthMet Project
Poly Met Mining, Inc.

Large Figure 16
Rock and Overburden Management Plan

Attachments

Attachment A

Block Model

NorthMet Project

Block Model

Version 2

Issue Date: November 7, 2014

Table of Contents

1.0 Block Model

For a mineral deposit to become an ore body, an integral part of the evaluation is the creation of a model (generally digital) which allows the estimation and assessment of grade (quantities of metal or other elements), and therefore value. This model must also quantify the confidence in the estimation of that grade at all locations within the deposit. This confidence categorization is derived from a consideration of a number of factors including geology, continuity of the mineralization, mining method, known grade values (i.e., drill hole samples), and the distances from known samples to the point being estimated. As a measure of predictability, this goes well beyond geologic confidence and is the foundation of the resource and reserve confidence categories needed for project planning and financing.

PolyMet operates under Canadian National Instrument 43-101, which is a standard for reporting on mineral development projects. This standard references the Canadian Institute of Mining (CIM) "Estimation of Minerals Resources and Mineral Reserves, Best Practice Guidelines" (Reference (1)). Under this guidance, deposits (or parts of deposits) can be classified as resource or reserves. A resource is a mineral deposit that has a reasonable expectation of being mined at a profit. A reserve is a resource that has been evaluated to at least a "preliminary feasibility study" stage and is shown to be minable at a profit. The definitions of resources are further broken down to Measured, Indicated, and Inferred, based on their statistical and geologic confidence. PolyMet also uses a fourth category, "in-fill", to insure that the entire model has a value at each block based on available information. Mining companies evaluate the number of "in-fill" blocks and use this information to plan future drilling programs. Reserves may be either Proven or Probable. Measured Resources may be classified as Proven Reserves and Indicated Resources may be classified as Probable Reserves if they meet economic and technical criteria determined by the Feasibility Study, as shown in Table 1-1.

Table 1-1 Relationship between Resource and Reserve

	Higher ← Statistical and Geological Confidence in Grade Values → Lower			
Resources	Measured	Indicated	Inferred	In-fill: Not Reportable
Reserve	Proven	Probable	Not recognized as reserve	Not recognized as reserve or reportable
PolyMet Modeling Confidence Category	1	2	3	4

The amount of material in the resource and reserve categories for a particular deposit are dynamic, changing over time as geologic interpretation or assay data densities change (i.e., using information from additional exploration or development drilling or from changes in the geologic interpretation of the deposit). They are not strictly fixed by the above guidelines, which leave the final decisions up to the "Qualified Person" (or Persons) responsible for the estimation.

Block modeling is the de facto standard method of resource estimation for most metal mines, particularly open-pit mines. This is due in large part to the fact that pit optimization software requires a block model as input. *Pit optimization* is the process of defining a pit shell (i.e., a conceptual hole in the ground without regard to roads and some other design factors) that encompasses the greatest net present value of ore. *Pit design* is the process of establishing roads, sumps, and scheduling of the extraction of the ore in a safe fashion that matches the tonnage and grade required by the plant to produce a final product. This design work is done to best fit the optimized pit shell. Figure 2-1 is a view of an economic pit shell derived from optimization software, and the resulting pit design needed to extract the ore in a safe and efficient manner.

Other less used or older resource estimation methods include polygonal-manual, gridded seam models, and triangulation.

A block model is best described as a three dimensional array of regularly spaced data points. By virtue of the individual cell size each cell represents a specific volume of rock. This volume of rock is the "block" in a block model. Each cell in the model can carry a series of attributes representing the chemistry, or other quantitative properties, of the deposit. The cells are populated with information from drill hole data from several sources such as geologists, geochemists and geophysicists over the course of an exploration program. Because the density of the rock is known, (either averaged or modeled) block tonnage can also be calculated. In simple terms, this modeling is the 3-D version of the 2-D gridding and contouring done in many software programs (e.g., Surfer, ArcView).

2.0 Modeling Process Steps

The entire block modeling process for grade is a method of translating or modeling irregularly spaced drill hole based assay data to a regular 3-D array of data points. However, this is not a purely mathematical process carried out in a vacuum, but must be done in the context of what is known of regional and local geology so that the model is a reasonable representation of the geology and geochemistry of the deposit.

The general process of populating a block model follows a sequence of:

- Collection and verification of drill data. This includes qualitative (primarily lithologic and mineralogic information obtained by geological logging of the drill core); quantitative (assays, density, rock strength, percent of sample recovered and other information); and spatial data such as drill collar location, angle of drill hole, and azimuth. In NorthMet's case, all historical data was re-compiled and verified in 2004 with new data undergoing rigorous quality control prior to inclusion in the database. Figure 2-2 and Figure 2-3 show the top of the Virginia Formation and all drill holes, colored by geologic unit and sampling respectively.

- Use of lithologic and structural geology data to construct a digital geologic model. This can be done directly in the computer or by digitizing hand drawn cross-sections (NorthMet's model was done in the computer with extensive reference to paper sections). To be valid, this digital model needs to honor as much definitive data as possible, such as surface topography, depth to bedrock, outcrop location, and drill hole intercept points to well defined horizons or contacts.

  The geologic model of the deposit is created by generating a series of surfaces representing the tops and bottoms of geologic units. These surfaces include the boundaries between units, and also include the ledge (top of bedrock) surface. These surfaces are based on cross-sections at one-hundred foot spacing across the deposit. Cross-sections are coincident (parallel or perpendicular) to the geometry of the block model. See Figure 2-4 and Figure 2-5 for examples of these 3-D surfaces.

- Compositing of quantitative data. Drill hole data is generally recorded in intervals measured downwards from the top of the hole. Very often different types of data will be measured on different intervals. For instance, rock type changes may be measured in irregular intervals from inches to many feet, or major lithologic units may be intervals hundreds of feet in length (i.e., reflecting the true nature of the geology) whereas assay or geotechnical information may be measured in regular (five or ten foot) intervals. Compositing of drill hole data is the process of applying a weighted average of the numeric data into discrete and regular intervals. Often, the composites at the edge of the geologic units will have their length adjusted so that they do not cross geologic boundaries. Composites are not used (forced to null) if their "support", or amount of actual sample within the interval, does not exceed a certain percentage of the composite length. It is also important to note the difference between a zero value and a null value. Zeros are used in calculation; nulls are treated as if the data point did not exist.

- Variography. This is the geostatistical evaluation of the data to quantify two important variables in the modeling process: 1) spatial continuity-the safe distance that assays can be projected in order to realistically represent a model of the grades in the rock mass, in other words, “what is the meaningful sample spacing?” and 2) isotropy / anisotropy, which determines if the continuity of mineralization is the same in all directions, or whether it is longer in one direction (e.g., along strike) than another (e.g., down dip). These are important variables that have a direct input into evaluating the adequacy of the drilling density and also the next steps of the modeling process.

  The variography compares pairs of samples at larger and larger distances and graphs this variation against distance which will, at some point, define the distance beyond which the grades cannot be accurately projected. These numbers may not be directly used, but are an important consideration in the overall estimation.

  Other statistical testing is done to determine whether or not the chosen boundaries are supported by the numeric data and whether the grade distributions are reasonable.

- Selection of Search Ellipse. The information from the variography is used in determining the optimum size and shape of the “search ellipse”. During the grade estimation process each block is assigned data from the nearby drill hole composites. The search ellipse is the distance along a set of X, Y, and Z axes within which samples can be used in estimation. The center of the ellipse is the centroid of the block being estimated. The distance is directly related to data confidence in that direction. The overall size of the search ellipse is related to the confidence ranking (measured, indicated, inferred, in-fill). The ellipse axis may be tilted to conform with geologic parameters (i.e., dipping rock units or structural zones).

  If the data were fully isotropic, the search ellipse will be a sphere; if the data are anisotropic, the search ellipse may be longer in the direction of the strongest continuity and shorter in the direction of the least continuity. See Figure 2-6 for an image of a search ellipse.

- Creation and Assessment of Domains. As part of the process described above, it is necessary to assess the geologic continuity of mineralization for estimation purposes. In particular, it is important to assess whether or not the mineralization follows clear geologic controls (i.e., unit boundaries or structure), is independent of these controls, or some combination of the above. A number of separate geological / geochemical domains were defined for the purpose of deposit modeling at NorthMet. First, two mineralized domains were defined, Domains 1 and 6. Domain 1 is the main zone of mineralization and occurs mainly in Unit 1, though it may extend into the base of Unit 2. Domain 6, the Magenta Zone, occurs higher in the Duluth Complex in Units 3 – 6 and cross-cuts the upper units in the west half of the deposit. Secondly, the dominantly unmineralized domains were defined. These consist of the Virginia Formation, the unmineralized portions of Units 1 and Units 2 through 7.

- Geologic coding of block model. Geologic unit is assigned to the block model by selecting all blocks between two surfaces. For example, all blocks between the top of Unit 1 and top of the Virginia Formation are coded as Unit 1. At the boundaries the unit coding of the block is assigned based on the percentage of the block lying on one side or the other of the bounding surface. Once all blocks are given a geologic attribute, that attribute can be used to determine which blocks in the model the estimation routines are acting upon. See Figure 2-7 for a cross-section of the geology at NorthMet, and Figure 2-8 for the same image with the block model superimposed on the geology.

- Interpolation of values into model. During the interpolation process, a subset of blocks is chosen for estimation, and then the software sequentially finds the centroid of a block, and using criteria such as number of drill holes and number of composites within the search ellipse distance, assigns a value (essentially a 3-D weighted average) to that block based on surrounding samples. If the criteria cannot be met for number of holes or number of samples within the search radius, the block will be passed over by the first interpolation run. Once all blocks in the model have been done for a set search radius, the radius is expanded and the routine is run again, filling in some, but not all blocks with a value. Blocks assigned a value are ignored in subsequent passes.

  For the NorthMet model, with 5 domains, each domain has a separate interpolation run resulting in 4 confidence categories of confidence that generally correspond to Measured, Indicated, Inferred, and “in-fill”. The “in-fill” category is used to ensure that each block in the model has been assigned a grade value though these grades are not used to report resources. Each domain thus requires four estimation passes for each of the six valuable elements (Cu, Ni, Co, Pt, Pd, & Au) as well as for elements of process and environmental significance (S, Ag, As, Ba, Be, Cd, Cr, Mn, Mo, Pb, Sb, Zn).

  See Figure 2-9 for a cross-section at NorthMet with confidence blocks superimposed on geology, and Figure 2-10 for a section with Net Metals Value superimposed on the geology.

2.1 Use of the Block Model

Once the model is populated with grade and other data, it is generally output to other software for pit optimization and mine design. This requires some assumptions about metals prices, grade or value cut-offs, and mining costs. The blocks are assigned a value based on metals price. The optimization software “virtually” mines the deposit from the top downwards-those blocks above cut-off being classed as ore, those below cut-off as waste. This is done through many iterations and the highest value scenario is then investigated for practicality as a mine design.

Once a pit is designed, the blocks within the pit can be assessed by grade, the measured and indicted resource blocks within the pit may be classified as proven and probable reserves. Data can be output to other programs for assessment. Figure 2-11 shows 3-D Top of Virginia Formation, 20 year pits, Unit 1 blocks above cut-off grade, and the Magenta Zone as a transparent solid.

2.2 NorthMet Block Model Parameters

The 2011 NorthMet block model parallels the deposit geometry, striking N56.06°E, with block size of 50 feet by 50 feet by 20 feet high. There are 399 columns, 122 rows, and 81 levels (3,942,918 blocks). The current model stops at sea level (about 1,600 feet from surface). The overall model limits extend well beyond the expected mining area in all directions.

The 20 year pit shell includes approximately 133,000 ore and waste blocks. Of these, 45.2% are in the measured category, 54.2% are in the indicated category, 0.4% are inferred, and the rest (~0.01%) in-fill. The conversion to reserve can change these percentages a small amount due to economic considerations.

Besides geochemical data, there are attributes stored in the block model for parameters such as geologic unit, density, year expected to be mined, distance to sample, ID of closest drill hole, number of samples used in interpolation, confidence ranking, and net metals value.

Drill hole assay data (mostly five and ten foot samples) were composited to 10 foot samples along the drill hole (length weighted averages). The composited values were used for estimation.

The metals expected to be produced at NorthMet (Cu, Ni, Co, Pt, Pd, and Au) were given values of close to zero where data was absent (based on examination of drill hole data for particular units). Where analyses for Pt, Pd, and Au returned results below detection limit a value of one-half the detection limit was used. This is normal practice to ensure conservatism in the resource evaluation. No copper, nickel, or cobalt values were used below the detection limits and hence no factoring was used in populating the model for these elements.

For the elements with potential effects on water discharge standards (S, Ag, As, Ba, Be, Cd, Cr, Mn, Mo, Pb, Sb, Zn) all values reported as less than detection limit were replaced with the detection limit value, then, all “not sampled” drill core intervals were assigned the average of the data set. This is a conservative method in that it tends to raise the average value for compositing.

Each element was analyzed for spatial relations within each of the domains (variography) using the composited value. From that analysis modeling geometry was established for interpolation of values into the block model.

2.3 Block Model Data and Raw Drilling Data

There are two data sets on rocks within the deposit - drill core and the block model. It is important to recognize that the process of going from irregularly spaced drill hole data to composites, and ultimately to a derived block model, tends to smooth out the grades. The highest values will be lowered and the lowest values will be raised. This makes sense because all samples are smaller than blocks-and block values are representative of the average of many samples-the average block value will always be lower than the highest composited drill core values. Table 2-1 shows how average and highest values for copper decrease in the process of going from raw data, to composites, to the block model.

Table 2-1 Comparison of Raw Data, Composites, and Block Data[1]

	Minimum % Copper	Maximum % Copper	Average % Copper
Raw Drill Hole Data	0.0	4.89	0.161
10-Foot Composites	0.0	2.2	0.155
Block Model Data	0.001	1.15	0.134

Note that this represents raw, composited and block model data within the 20-year "APA" pit. Because the pit is created after the block model, there can be block data with higher values than the in-pit composites.

The NorthMet drill core data set consists of 436 drill holes divided into a total of about 39,000 multi-element assay intervals. Each analyzed interval is also classified by geological unit and rock type. The drill core data set provides information (a measurement) only about the specific points in the pit that were drilled.

The block model was generated from the (composited) drill core data set using accepted geostatistical principles and knowledge of the geology of the deposit. Within the planned 20 year pit there are over 133,000 blocks (or parts of blocks) providing information (an estimate) at any point in the pit. The values in many of these blocks are derived from data points outside the pit. The resolution of the block model is the size of the blocks (50 feet x 50 feet x 20 feet).

Each block has chemistry values (%S, %Cu, %Ni, ppm Co, ppb Pt, ppb Pd, ppb Au, ppm Ag, ppm As, ppm Zn, ppm Cd, ppm Pb, ppm Ba, ppm Be, ppm Cd, ppm Cr, ppm Mn, Pb, ppm Sb), plus values for tons, and year mined. Each block is identified as "ore" or "waste rock" based on metals value. Each waste rock block is assigned to a waste category (Category) based on sulfur content.

2.4 Block Model Data Used for Mine Pit Water Chemistry

Pit water quality modeling requires input data on rocks that make up the surface of the pit wall, organized by elevation and Category. The mine pit walls are divided into 20 foot vertical zones with the tops and bottoms of the zones corresponding to tops and bottoms of blocks. The blocks that contact the pit shell within each zone are identified as edge blocks. Some edge blocks may contact the wall and some may contact the floor; some may only contact the shell across a very small area. The planar (i.e., area looking down) area of each zone is calculated by assuming that the floor blocks are 100% in the edge (i.e. exposed) and the wall blocks are 50% in the edge. This area is calculated for each Category of waste rock in a zone. This is done for the pit shell representing the 20 year pit. Figure 2-12 and Figure 2-13 show the blocks contacting the pit, and those that contact or are above the pit (note that the pit wall intersects the plane of the section at an oblique angle and that blocks that appear to not be contacting the surface are contacting in the third dimension).

2.5 Block Model Data Used for Stockpile Chemistry

Stockpile drainage water quality modeling requires input data on rocks that are placed in each stockpile organized by year. The mining schedule shows what year each block of material will be moved. The Category of the block determines which stockpile each of the waste rock blocks will be placed in.

Chemistry of the rock placed in each stockpile each year will be calculated as the average of the chemistry values of all of the blocks added to that stockpile during that year.

The total tons added to each stockpile each year will be calculated as the sum of the tons all of the blocks added to that stockpile during that year.

2.6 Ore Versus Waste Calculations

Blocks are sorted into ore or waste. Waste may have different handling requirements, depending on the Category. The sorting of the ore and waste Categories is based on the following steps:

- Ore: Based on a particular contained metals value. Because metal prices are set low in the modeling, this may go lower during mining (i.e., waste rock could become ore depending on the cutoff used for metals content).

- Waste rock, Category 4: All of the Virginia Formation, large sedimentary inclusions, and all Duluth Complex waste rock with greater than 0.6% sulfur.

- Waste rock, Category 2/3: Duluth Complex waste rock only, with less than or equal to 0.6% sulfur and greater than 0.12% sulfur.

- Waste rock, Category 1: Duluth Complex waste rock only, with less than or equal to 0.12% sulfur.

2.7 Waste Categorization Sample Comparison

Waste characterization samples were selected from NorthMet drill core in 2005 based on knowledge at that time of the expected categorization of rock. Because sulfur is the main factor in determining rock disposition it is worth comparing these categorizations and their effect.

Table 2-2 below shows the sulfur values for raw drill core from the NorthMet database, values for the samples used in humidity cell tests, and the values for rock stockpiles defined by the results of these tests. Testing focused on the material with the widest range of compositions, hence the lower percentage of testing in the lowest sulfur rocks. It is important to note that the humidity cell test results are used in conjunction with extensive testing from Minnesota Department of Natural Resources and samples chosen are well grounded in the overall geology of the deposit. The match is quite good.

Table 2-2 Sulfur Values in Waste Rock Category Data Sets[1]

		Category 1	Category 2	Category 3	Category 4	Category 4 Virginia Formation
Stockpiles – Block Data	% of Rock	70.33	23.80	3.07	1.00	1.80
	Min % S	0.01	0.13	0.32	0.61	0.33
	Avg % S	0.06	0.18	0.42	0.93	2.43
	Max % S	0.12	0.31	0.60	3.04	4.94
Humidity Cell Tests (2005 on)[2]	Number of Samples	38	16	9	16	3
	Min % S	0.02	0.14	0.32	0.68	2.00
	Avg % S	0.05	0.20	0.44	1.44	3.82
	Max % S	0.12	0.30	0.59	4.46	5.68
Drill Core Database (2011)	Number of Samples	16,127	4,389	1,656	1,429	1,260
	% of Samples	64.9	17.7	6.7	5.7	5.1
	Min % S	0.01	0.13	0.32	0.61	0.01
	Avg % S	0.05	0.2	0.43	1.5	1.67
	Max % S	0.12	0.31	0.60	7.93	8.29

Note that drill data is not composited (i.e., not length-weighted).
Humidity cell tests results shown do not include duplicate samples.

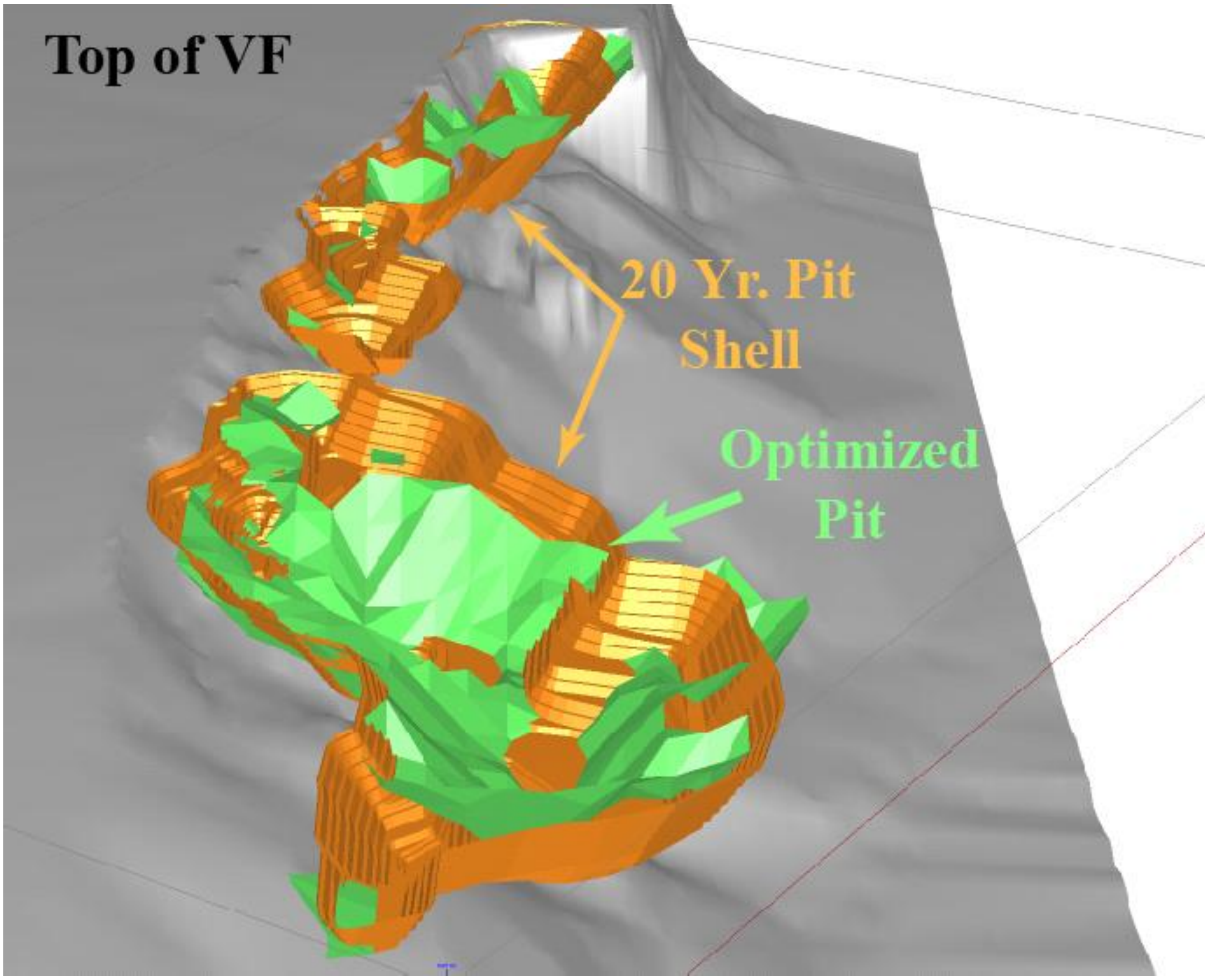


Figure 2-1 Twenty Year Pit Design Built around Optimized Shell
(View looking E-NE, Gray = top of Virginia Formation, Green = Optimized pit shell, Tan / Orange = Pit Design)

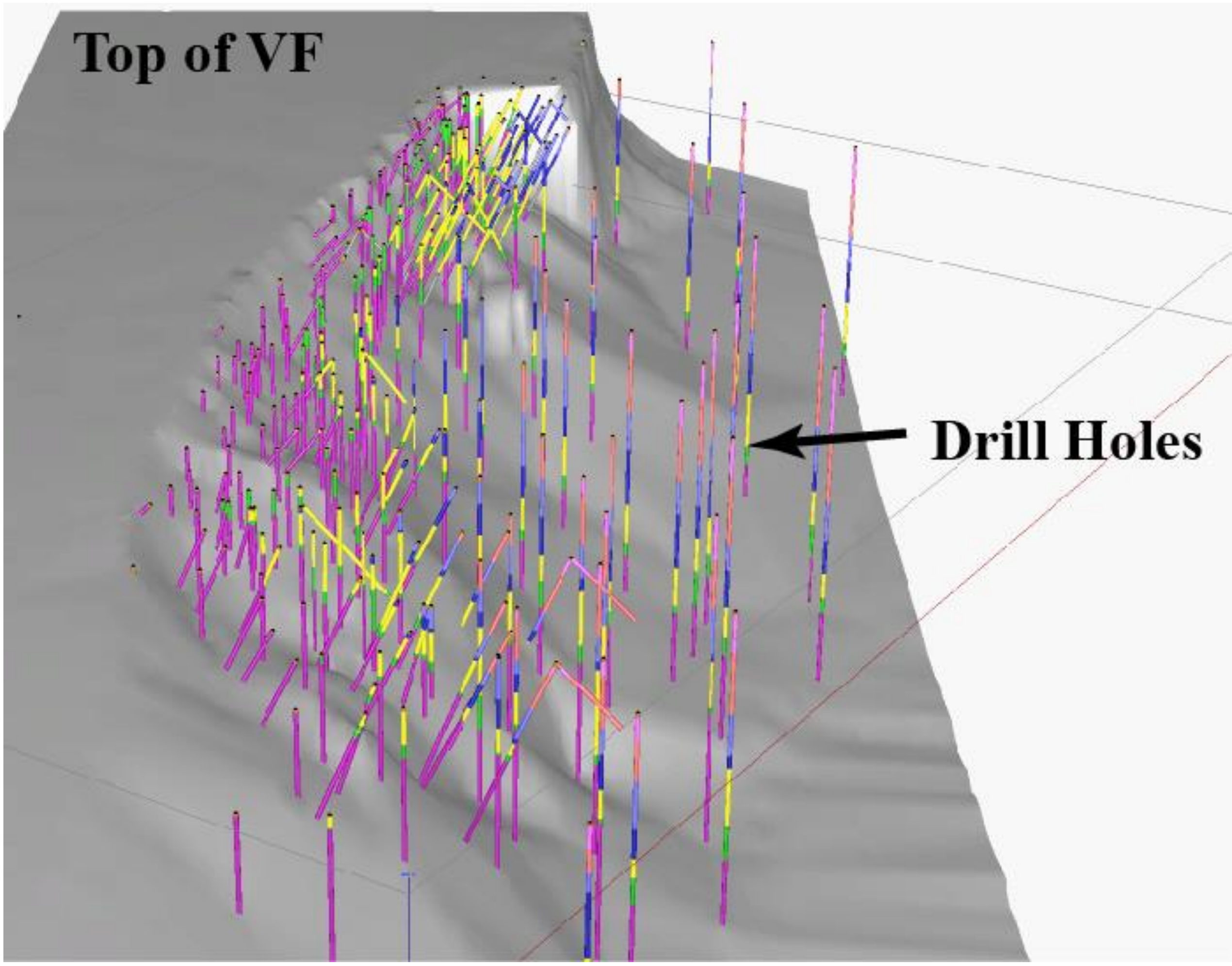


Figure 2-2 Top of Virginia Formation (gray) and Drill Holes Coded by Geologic Unit
(from bottom up, magenta = Unit 1, green = Unit 2, yellow = Unit 3, dark blue = Unit 4, light blue = Unit 5, pinkish-orange = Unit 6, light magenta = Unit 7. View is to ENE.)

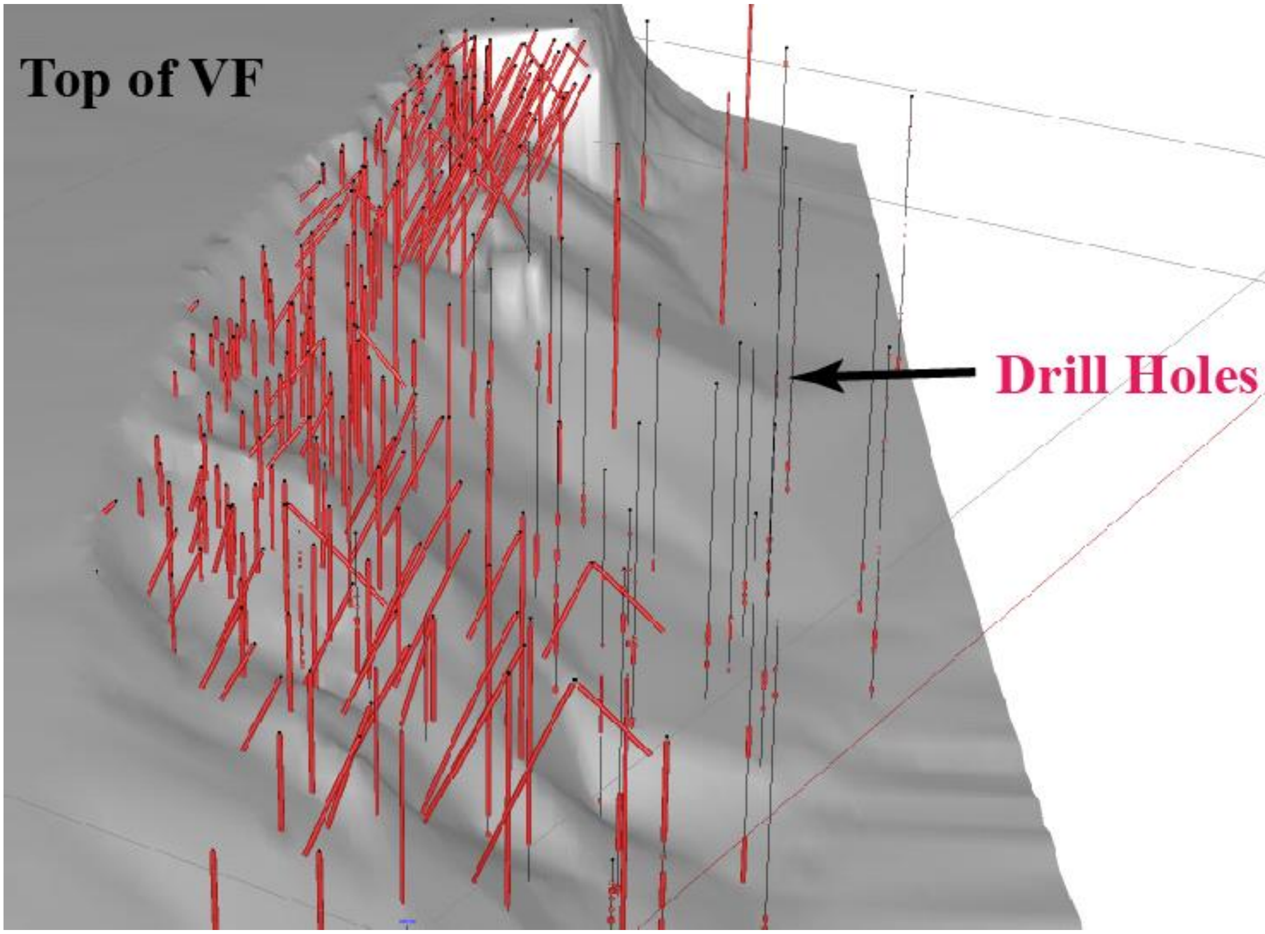


Figure 2-3 Top of Virginia Formation (gray) and Drill Holes Coded by Sampling
(Red drill hole trace = sampled. View is to E-NE.)

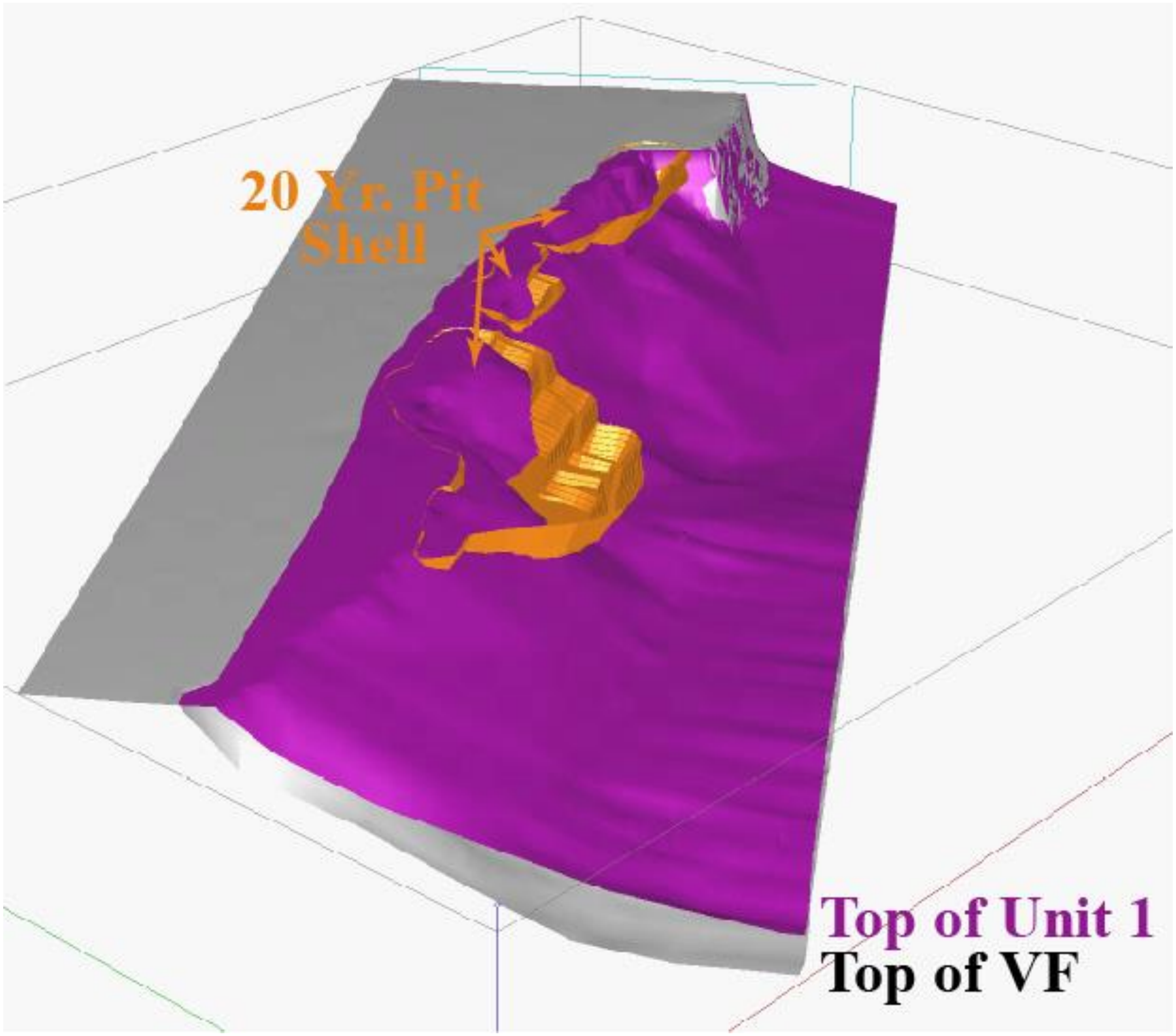


Figure 2-4 Example of Model Surfaces: Virginia Formation, Unit 1, and 20 year pit

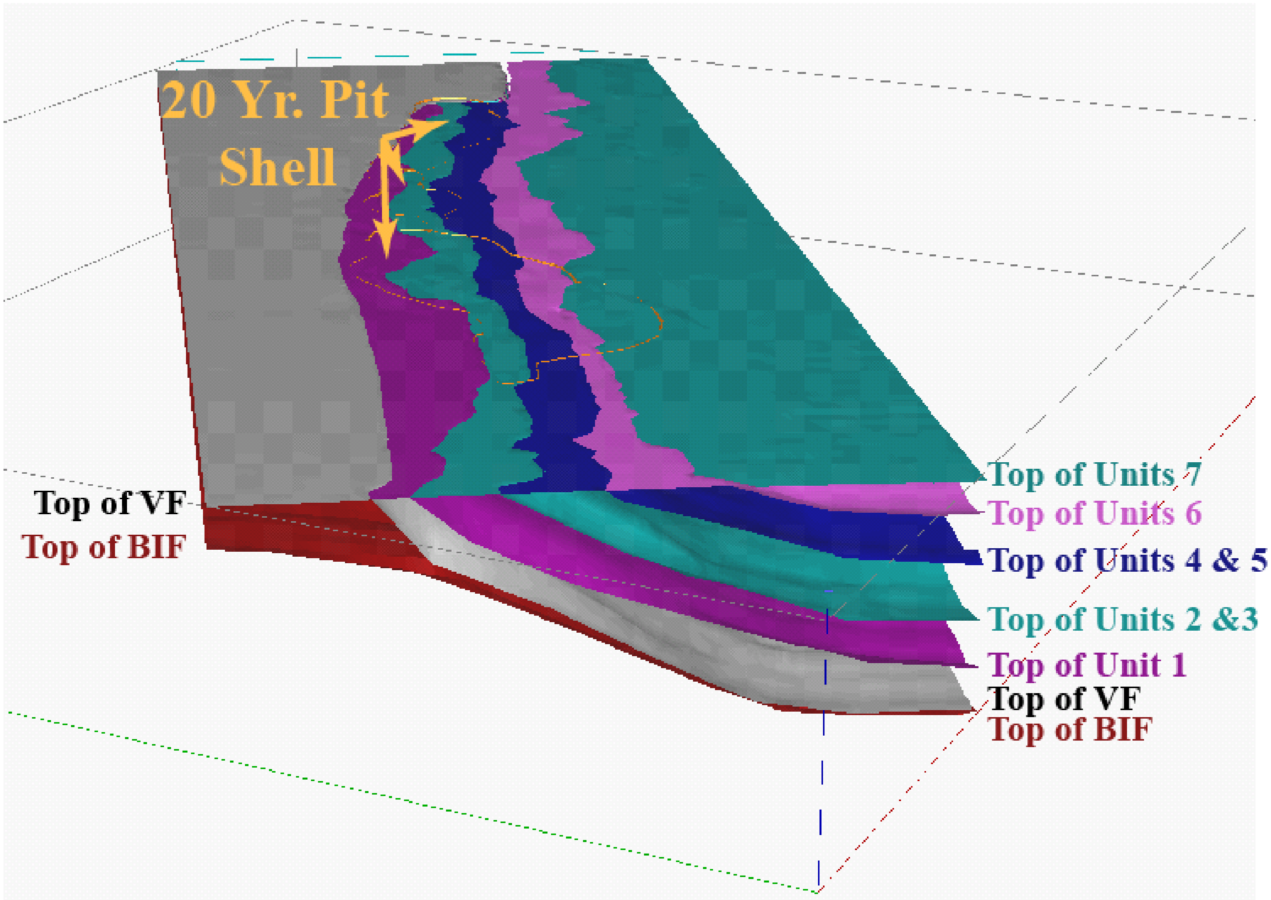


Figure 2-5 Example of Modeled Surfaces: All Geology

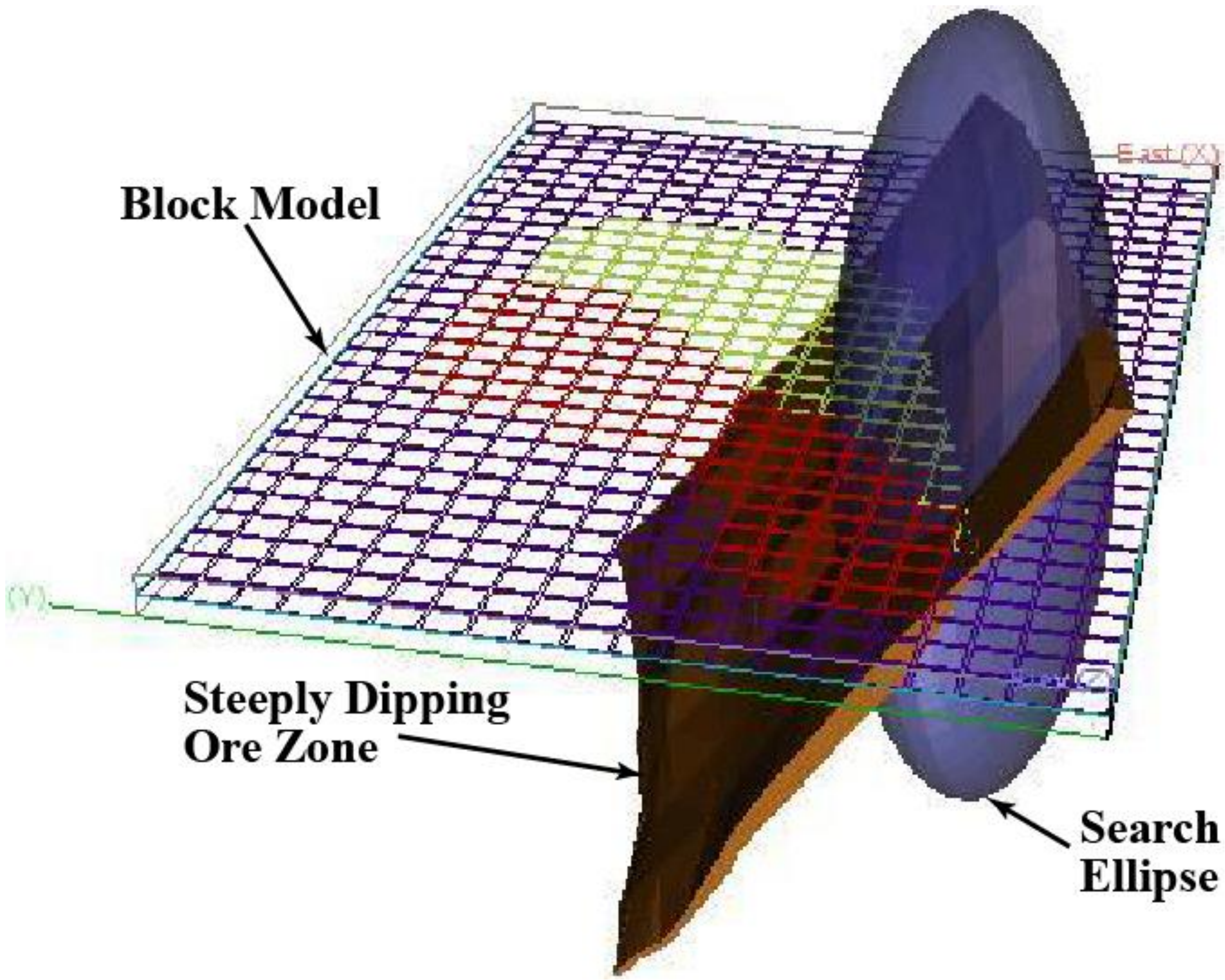


Figure 2-6 Example of Search Ellipse and a Relation to Project Geometry
(not from NorthMet)

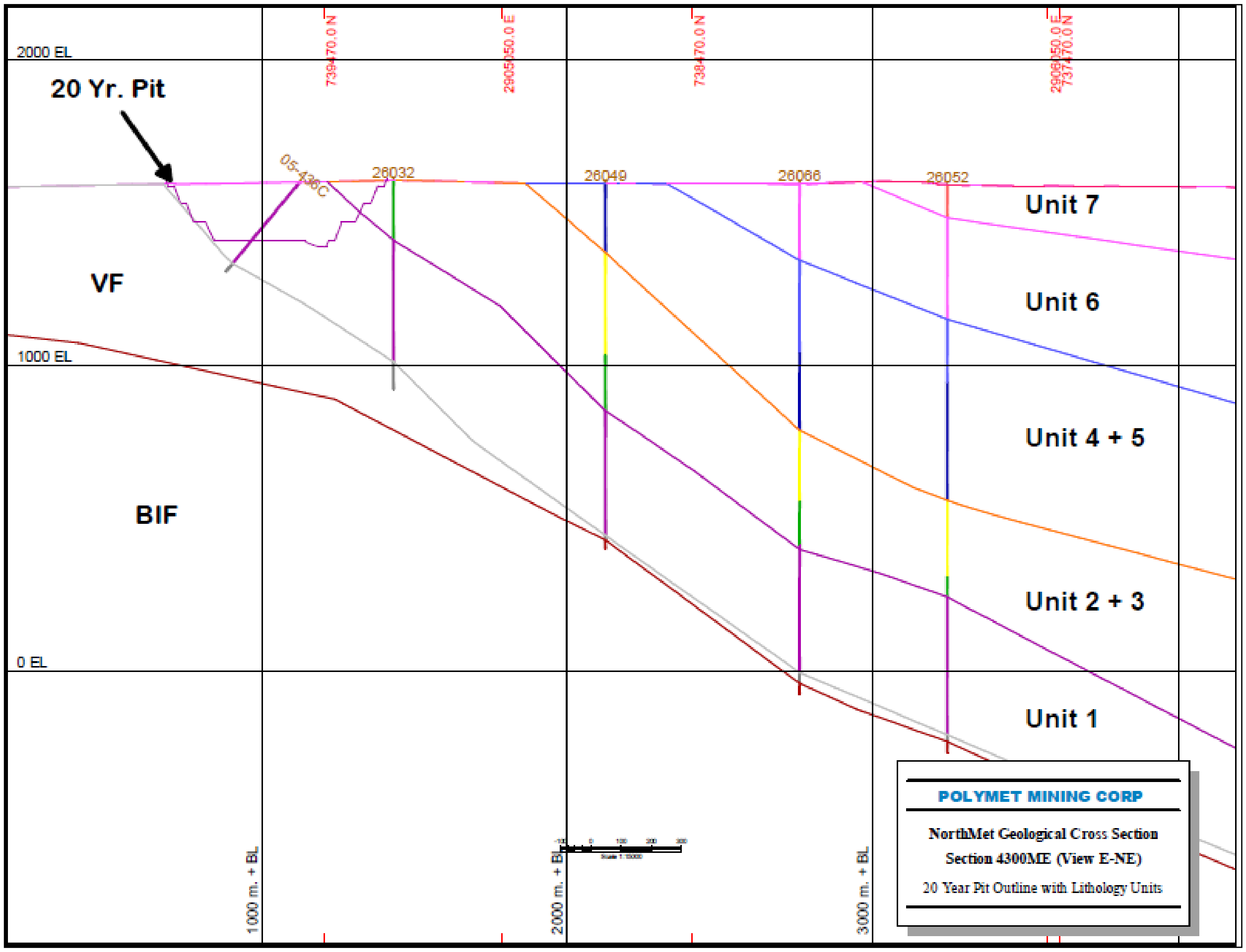


Figure 2-7 NorthMet Geological Cross-Section
(View to E-NE. Note 20 year pit.)

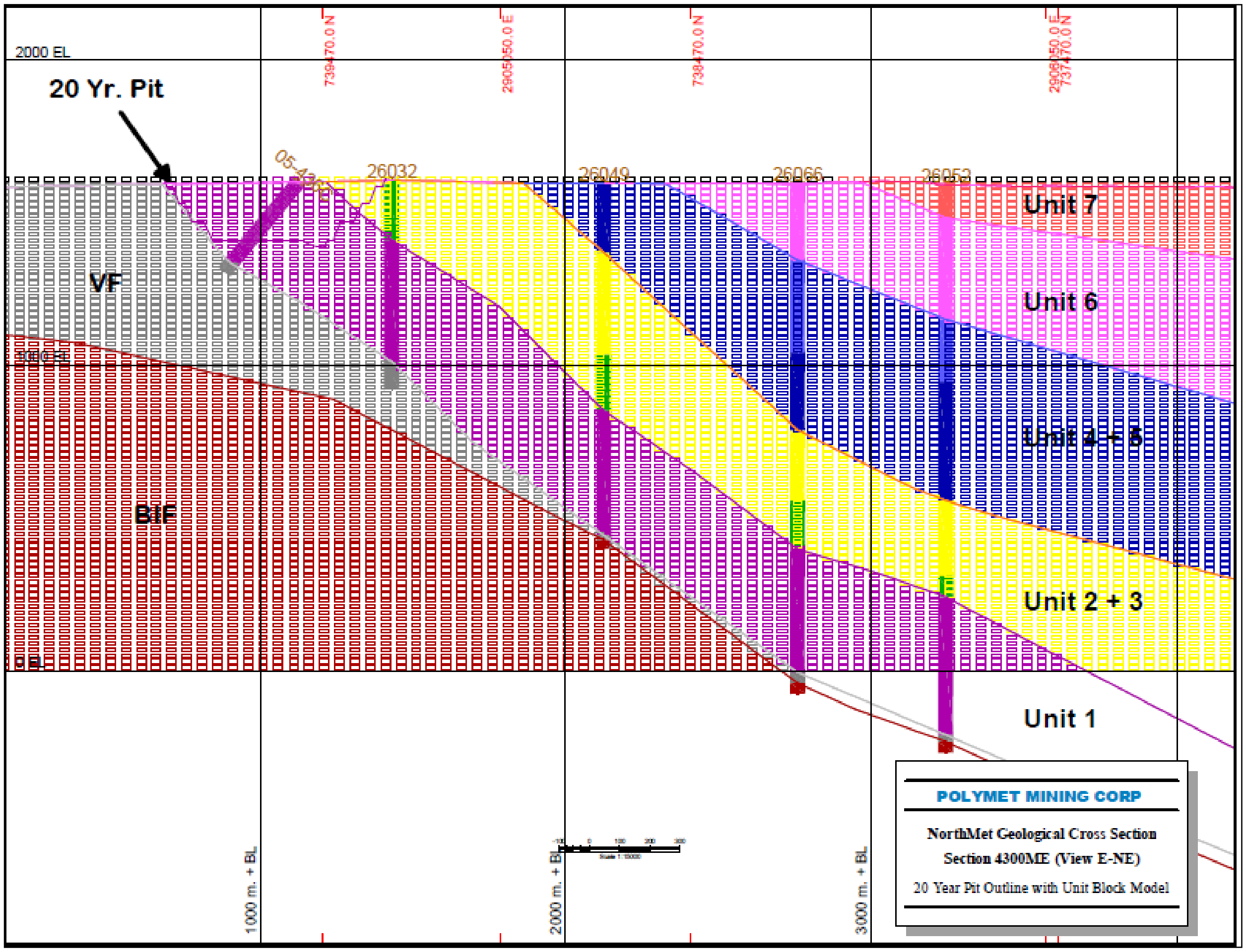


Figure 2-8 NorthMet Geological Cross-Section Showing Unit Block Model
(View to E-NE. Note 20 year pit.)

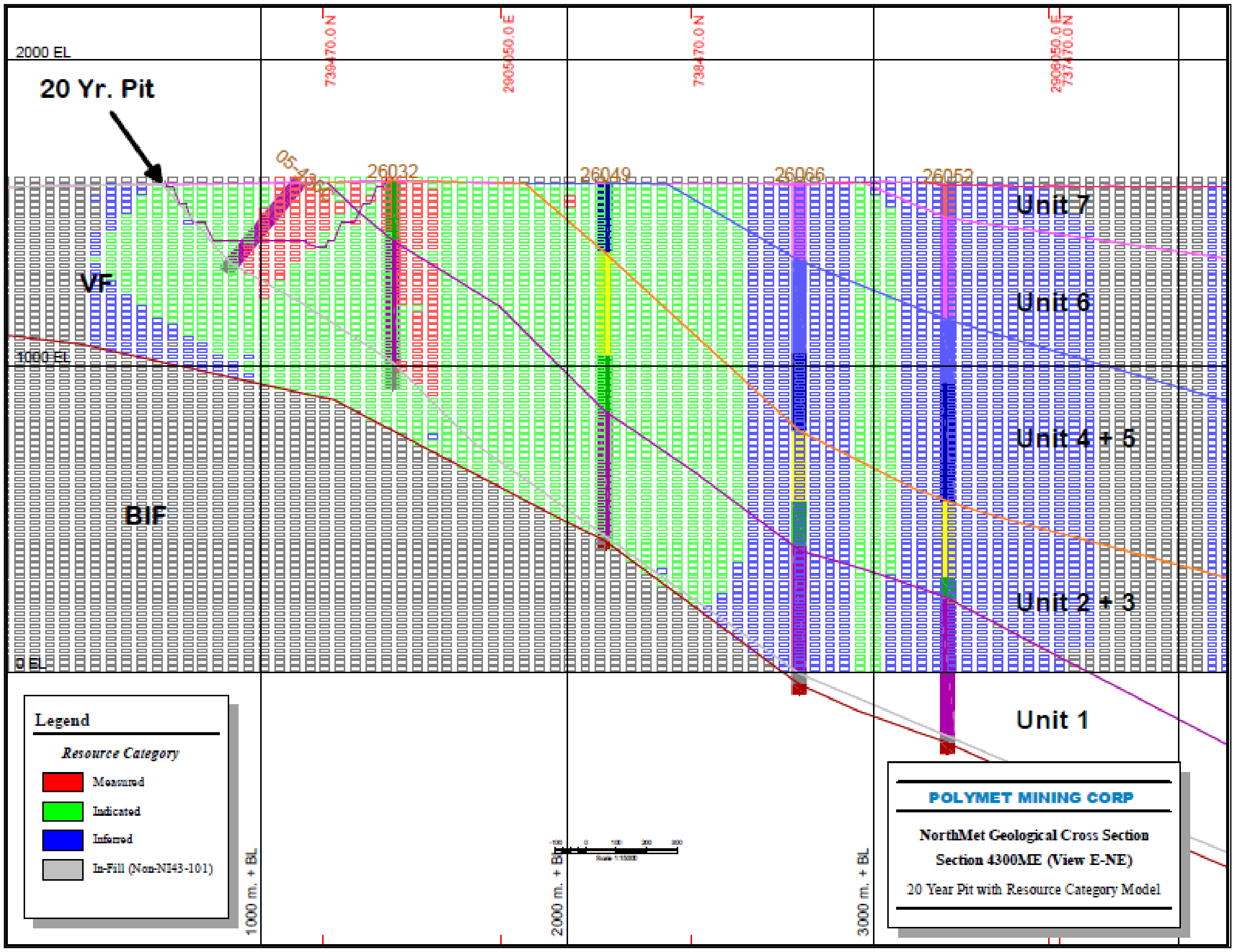


Figure 2-9 NorthMet Block Model Resource Categories Superimposed on Geologic Section
(Magenta = Measured, red = indicated, yellow = inferred, blue = in-fill. Note 20 year pit.)

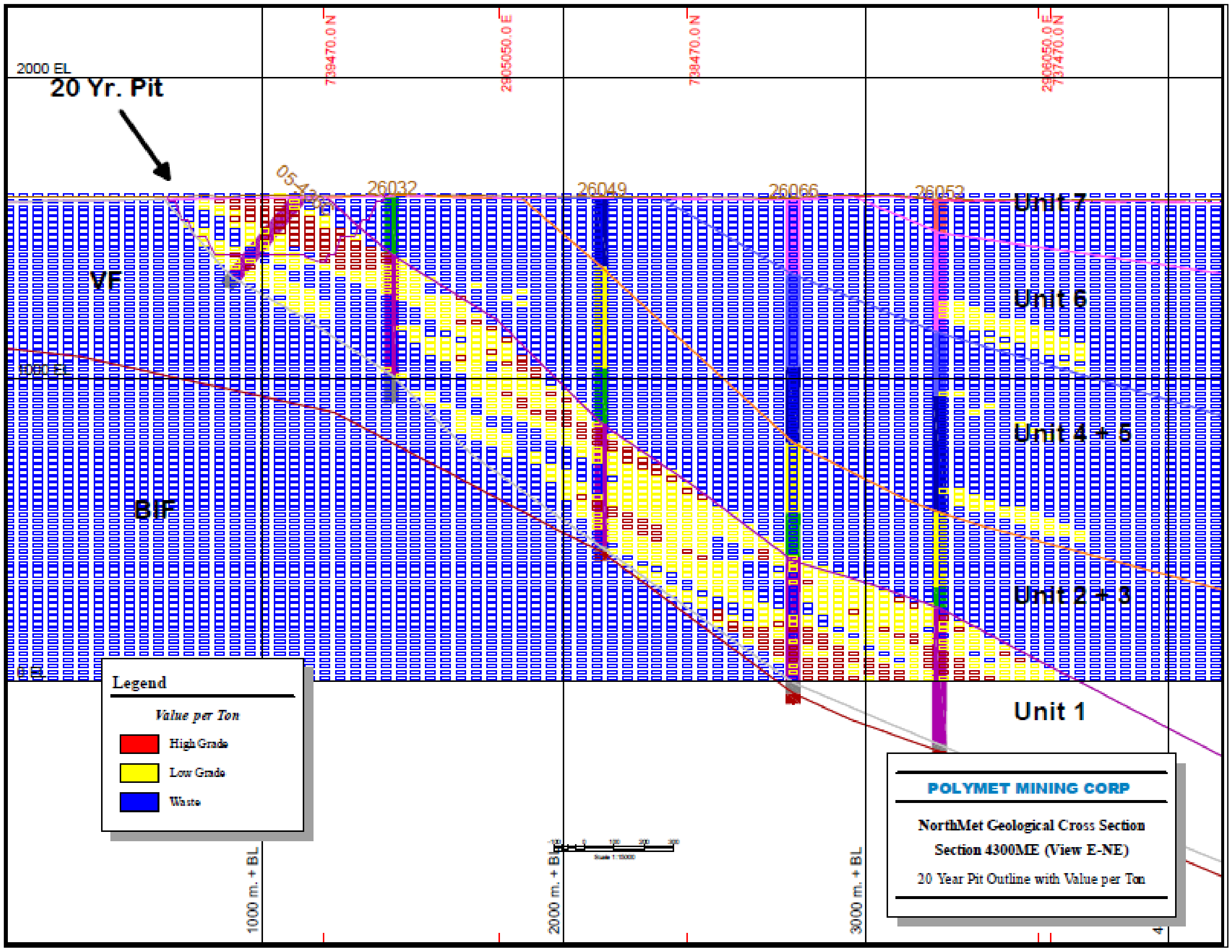


Figure 2-10 NorthMet Grade Categories Superimposed on Geologic Section
(Magenta and red = “ore”, blue = “lean ore”, yellow = “waste rock”. Note 20 year pit.)

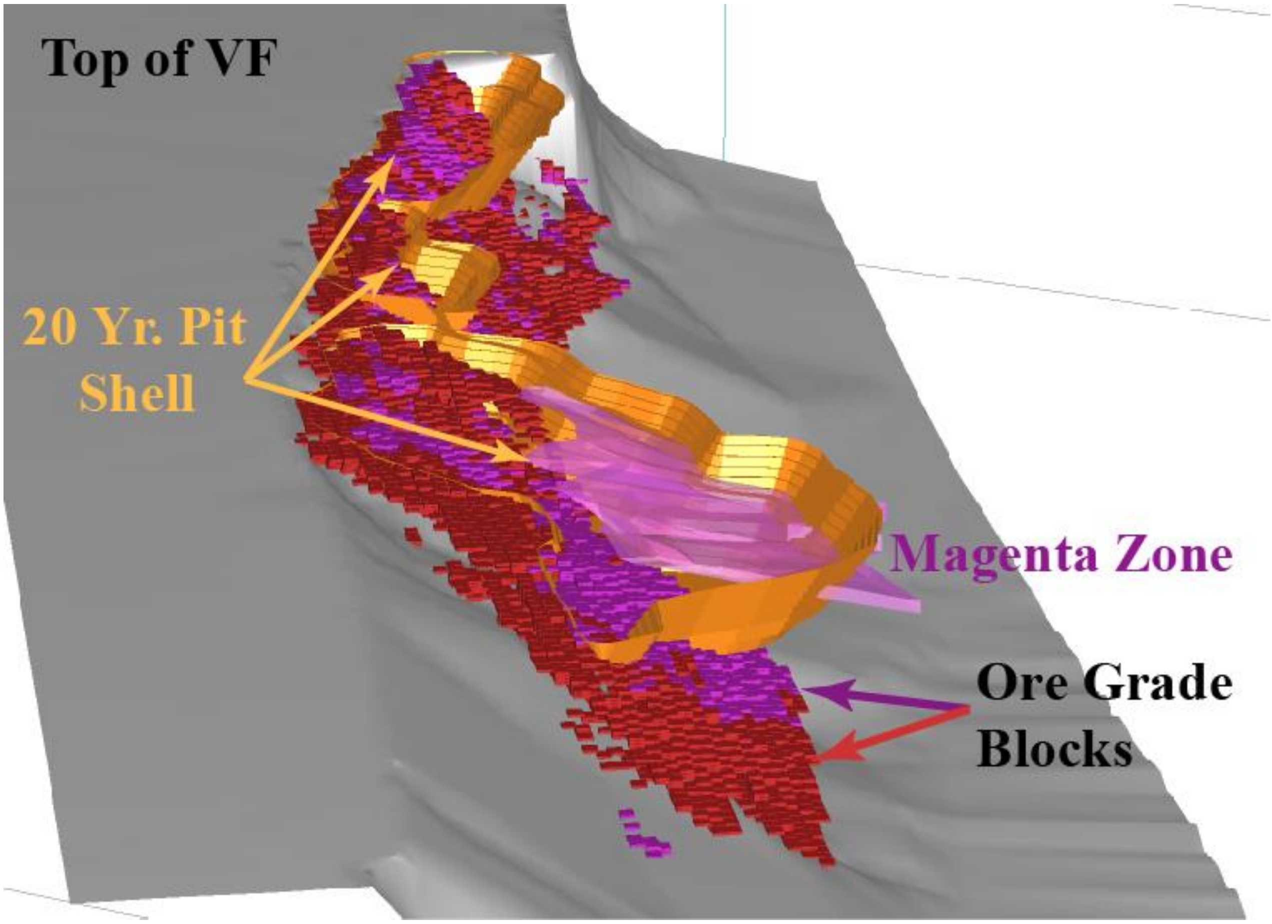


Figure 2-11 Top of Virginia Formation, Unit 1 blocks of "Ore" Grade, 20 Year Pit, and Magenta Zone Geological Solid
(View to E-NE.)

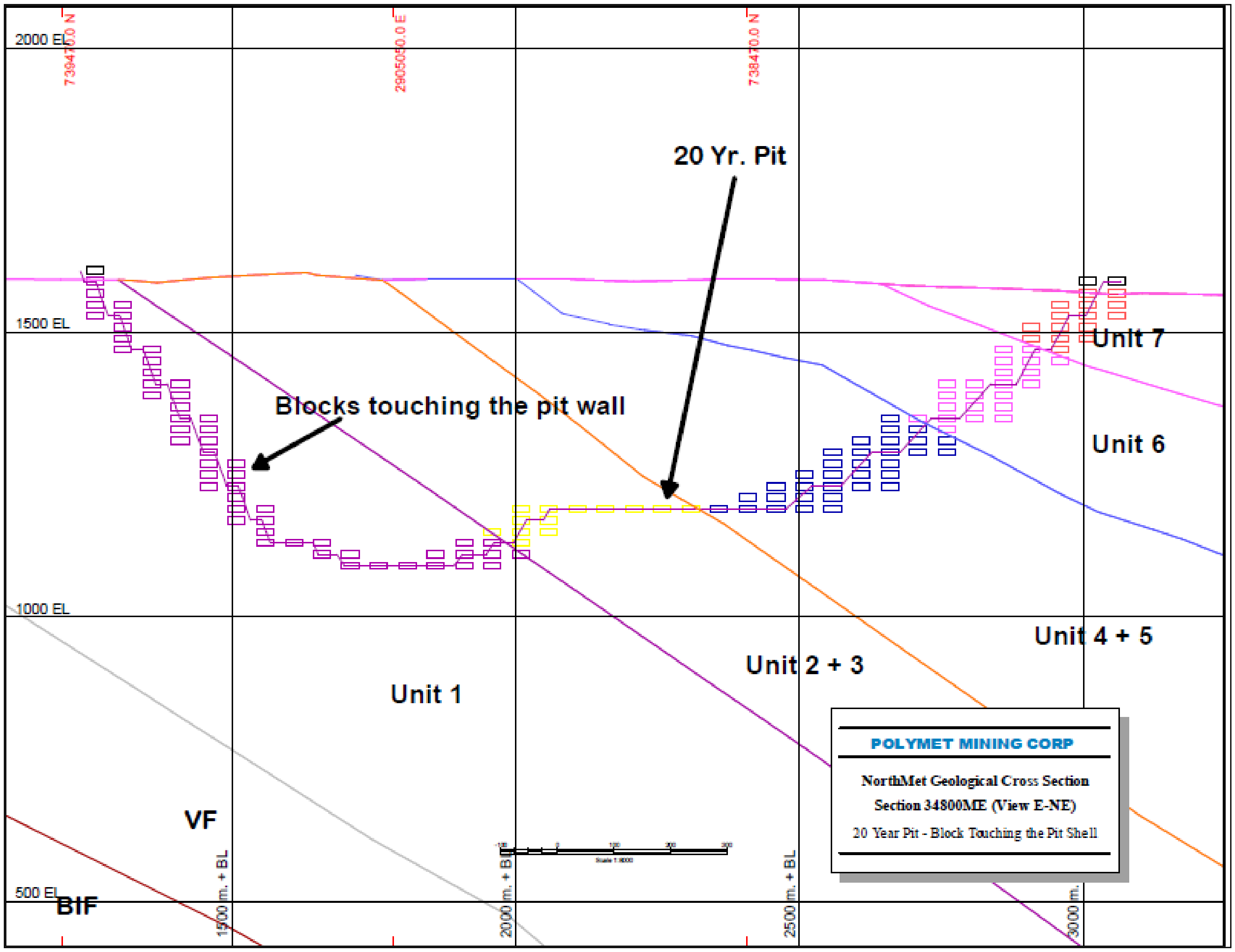


Figure 2-12 Cross-Section Showing Blocks Touching 20 Year Pit
(Note that blocks appearing to not touch pit are touching in the third dimension.)

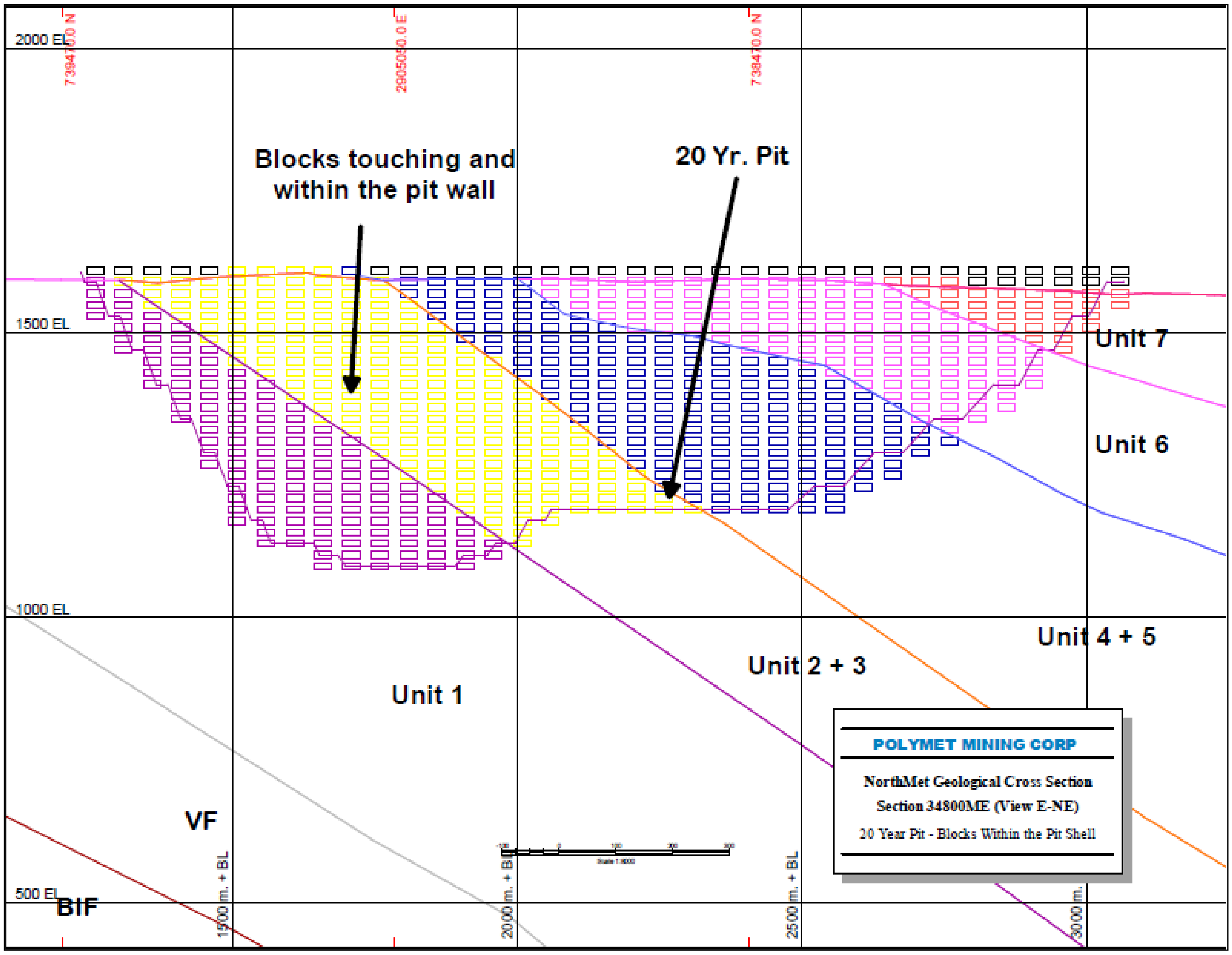


Figure 2-13 Cross-Section Showing Blocks Touching and within 20 Year Pit

Revision History

Date	Version	Description
11/23/11	1	Initial release
11/7/14	2	Update Section 1.0 to clarify the definition of a reserve and to better define pit optimization

References

1. **Canadian Institute of Mining.** Estimation of Minerals Resources and Mineral Reserves, Best Practice Guidelines. 2003.

List of Tables

List of Figures

Attachment B

Stockpile Design Permit Application Support Drawings

Drawings are located in Appendix 4 of the Permit to Mine application and are not duplicated here.

Attachment C

Category 1 Stockpile Groundwater Containment System Design Permit Application Support Drawings

Drawings are located in Appendix 4 of the Permit to Mine application and are not duplicated here.

Attachment D

Groundwater Containment Systems: Degree of Use in Industry

Technical Memorandum

To: Poly Met Mining Inc. (PolyMet)

From: Tom Radue and Christie Kearney

Subject: Groundwater Containment System: Degree of Use in Industry

Date: December 26, 2012

Project: 23/69-0862

A groundwater containment system will be constructed around the Category 1 Waste Rock Stockpile to collect stockpile drainage in lieu of a liner system under the stockpile. This memorandum was developed to document the degree to which groundwater containment systems are used in industry today.

Containment systems such as the Category 1 Stockpile Groundwater Containment System are commonly used at facilities where there is a need to manage groundwater flow, such as landfills, tailings basins, and paper sludge disposal facilities. The combined use of a cutoff wall and a groundwater collection system is acknowledged by academic, governmental and industry authorities, and by construction markets (i.e., MoreTrench [http://www.moretrench.com], Hayward Baker [http://haywardbaker.com] and other cutoff wall construction contractors). By way of example, the United States Department of Labor's Mine Safety and Health Administration has developed design guidance for coal refuse facilities that illustrates various designs for the construction of cutoff wall and groundwater collection systems for the purposes of impoundment stability and water quality management (Reference (1)).

The United States Army Corp of Engineers (Reference (2)) and Department of the Interior's Bureau of Reclamation (Reference (3), Reference (4)) have developed design guidance for dams that illustrates various designs for the construction of cutoff wall and groundwater collection systems for the purposes of impoundment stability and water discharge management. These design guidance documents provide the supporting theory, field data requirements, construction recommendations, and typical post-construction performance monitoring procedures for the installation of cutoff wall and groundwater collection systems.

Large Table 1 provides a list of 15 sites, identified by a data search, having containment systems such as that planned for the Category 1 Waste Rock Stockpile. One such example is the constructed cutoff wall and collection system for water quality management in Taunton, Massachusetts. To control and collect groundwater contamination associated with a former pharmaceutical manufacturing facility, a cutoff wall and groundwater collection trench with perforated drain pipe were installed. The cutoff wall (approximately 50-feet deep and 3-feet wide) was constructed next to the 12-foot wide collection trench. The collection trench was equipped with a 4-inch schedule 40 PVC perforated pipe, wrapped in geotextile and bedded with crushed stone. Another example is the installation of a soil-bentonite cutoff wall around the perimeter of a mine tailings pond located in the province of Alberta, Canada. The cutoff wall is approximately 100-feet deep and 3 feet wide, and has a hydraulic conductivity of less than $1x10^{-7}$ cm/sec. The cutoff wall was used to isolate the tailings pond from downgradient surface water features including wetlands and the Athabasca River. Other such examples are shown on Large Table 1 with references listed for further review of each example.

References

1. **U.S. Department of Labor Mine Safety and Health Administration (MSHA). Mine Waste and Geotechnical Engineering Division.** Engineering and Design Manual Coal Refuse Disposal Facilities. 2nd Pittsburg, PA : s.n., 2009.

2. **U.S. Army Corps of Engineers (USACE).** Engineering and Design – Seepage Analysis and Control for Dams. *EM 1110-2-1901.* Washington, D.C. : U.S. Department of the Army, USACE, 1993.

3. **U.S. Bureau of Reclamation (USBR).** Design Standards No. 13 - Embankment Dams, Chapter 8, Seepage. s.l., Denver, CO : U.S. Department of the Interior, USBR, Technical Services Center, 1989.

4. —. Design of Small Dams, Chapter 6, Earthfill Dams. 3rd Washington, D.C. : U.S. Department of the Interior, USBR, 1987.

5. **Golder Associates Inc.** Trade-off Study, Catch Basin Dike Remediation, Intrepid Potash East Plant, New Mexico, Intrepid Potash-New Mexico LLC. May 2007.

6. **Remedial Construction Services, L.P.** Geotechnical Construction. [Online] http://www.reconservices.com/index.php/services/geotechnical-construction.

7. **Geo-Solutions, Inc.** Slurry Wall Case Studies. [Online] http://www.geo-solutions.com/case-studies/slurry-wall.php.

8. **Envirocon, Inc.** Technical Papers. [Online] http: //www.envirocon.com/techpapers/technical_papers.shtml .

Large Table 1 Examples of Containment Systems at Other Sites

Location	Reference	Project Setting	Barrier Wall	Trench Dimensions	Seepage Collection	Seepage Collection Pipe	Cover
Carlsbad, NM	(5)	Potash Process Disposal	Slurry wall	10 feet deep	Yes	Yes	None
Duncan, OK	(6)	Landfill Remediation	80 mil HDPE panels	35 feet deep	Yes	No	Native soil
Tacoma, WA	(6)	Wood Process Waste Landfill	Bentonite	30 feet deep	Yes	No	GCL
Dallas, TX	(6)	Landfill Remediation	2x40 mil HDPE panels	35 feet deep	Yes	6-inch PVC	None
Bogalusa, LA	(7)	Papermill Landfill	Soil-bentonite	40 feet deep, 2.5 feet wide	Yes	Yes	None
Oak Ridge, TN	(8)	DOE Landfill	Soil-bentonite	22 feet deep	Yes	No	None
San Antonio, TX	(8)	USAF Landfill	Slurry	40 feet deep, 3 feet wide	Permeable Reactive Barrier (PRB)	No	None
Taunton, MA	(6)	Pharmaceutical Mfr Remediation	Bentonite	55 feet deep, 12 feet wide	Yes	4-inch PVC	Multi-composite liner
Toledo, OH	(6)	MGP Mfr Remediation	Bentonite	Yes, dimensions not listed	Yes	No	Native soil
Salt Lake City, UT	(7)	Watkins Dam Restoration	Cement-bentonite	70 feet deep, 2.5 feet wide	18 feet deep, 3 feet wide	No	None
Burbank, CA	(6)	Brownfield Remediation	Soil-bentonite	60 feet deep	No	No	None
Coahoma, TX	(6)	Oil Field Remediation	None	12 feet deep, 3 feet wide	Yes	No	HDPE
Beaumont, TX	(6)	Creosoting Facility Remediation	Soil-bentonite	50 feet deep	Yes	No	None
Greely, CO	(7)	Former Gravel Quarry	Soil-cement-bentonite	65 feet deep, 3 feet wide	No	No	None
Fort McMurray, Alberta, Canada	(7)	Mine Tailings Pond	Soil-bentonite	100 feet deep, 3 feet wide	No	No	None

Attachment E

Category 1 Waste Rock Stockpile Groundwater Containment System Modeling

resourceful. naturally.
engineering and environmental consultants

Technical Memorandum

To: Poly Met Mining Inc.
From: Jonathon Carter and Christie Kearney
Subject: Category 1 Waste Rock Stockpile Groundwater Containment System Modeling
Date: December 12, 2014
Project: 23690862

Background

Barr conducted groundwater flow modeling for the planned Category 1 Waste Rock Stockpile Groundwater Containment System (containment system) to assess the performance of the containment system (Figure 1). This model was most recently documented in the Rock and Overburden Management Plan, Version 6 (Reference (1)). The Mine Site MODFLOW groundwater model that this model was developed upon has been updated and recalibrated and will be documented in Attachment C of Reference (2). Because much of the modeling for the containment system is based on the modeling from the Mine Site MODFLOW model, the containment system modeling has also been updated to reflect the recalibration. This memorandum was developed to provide a summary of the modeling that was completed for the containment system.

Modeling Approach and Set-Up

A conceptual representation of the hydrogeology associated with the containment system is shown in Figure 2 and Figure 3 for conditions during operations and in long-term closure, respectively. Water that infiltrates at the surface of the open stockpile, or percolates through the geomembrane cover system, seeps downward into the native unconsolidated deposits located beneath the stockpile. The unconsolidated deposits are underlain by bedrock having low hydraulic conductivity. A groundwater divide currently exists and is expected to persist, across the stockpile footprint, resulting in groundwater flow to the south toward the West and East Pits and to the north toward the One Hundred Mile Swamp wetland complex.

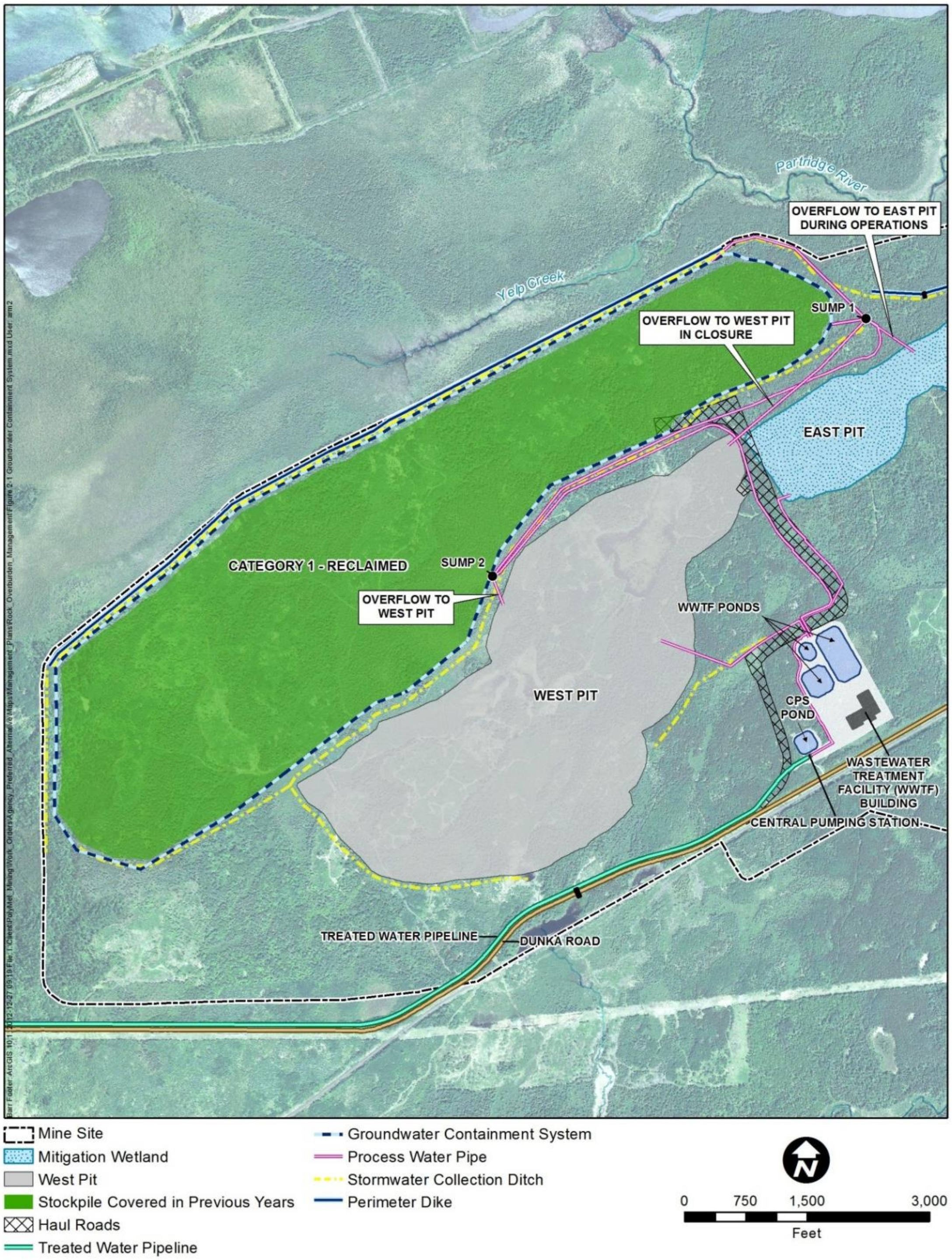


Figure 1 Category 1 Waste Rock Groundwater Containment System

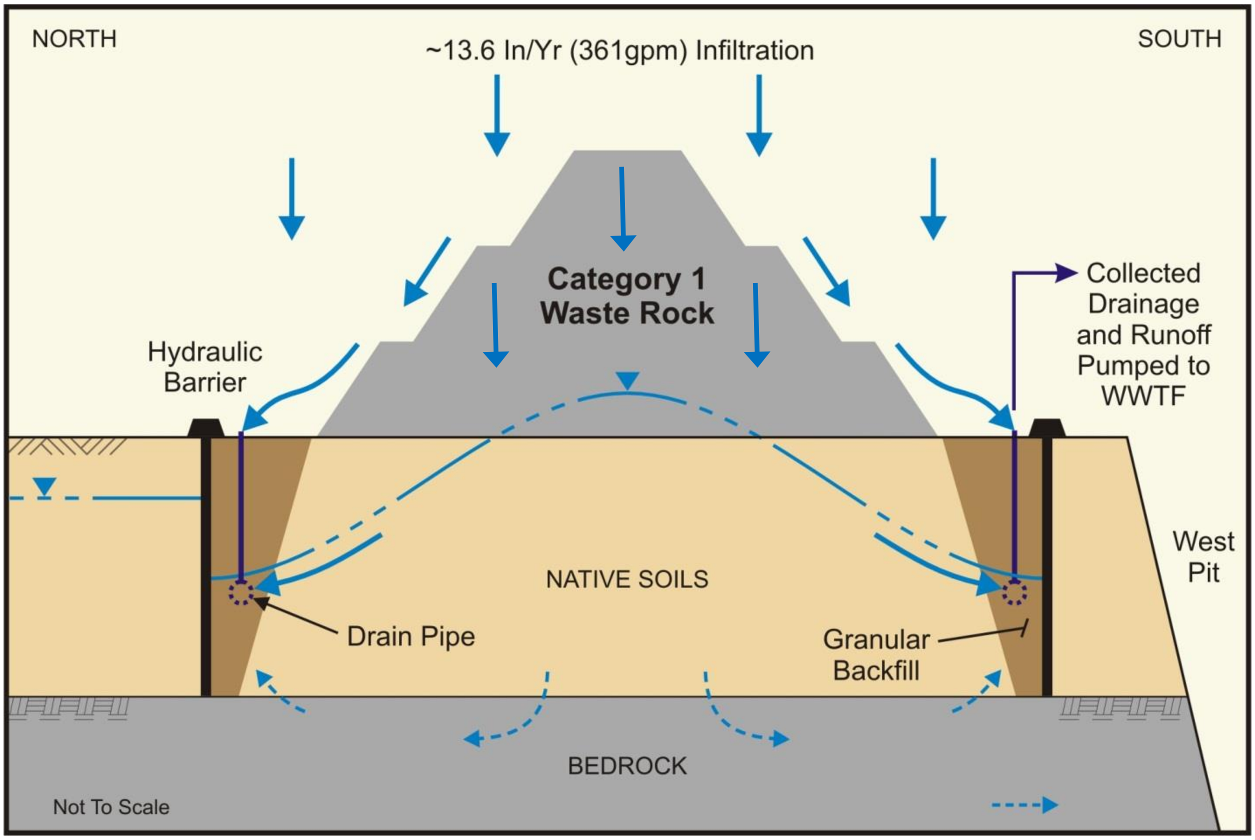


Figure 2 **Conceptual Representation of Category 1 Waste Rock Stockpile Groundwater Containment System – Operating Conditions Cross-Section**

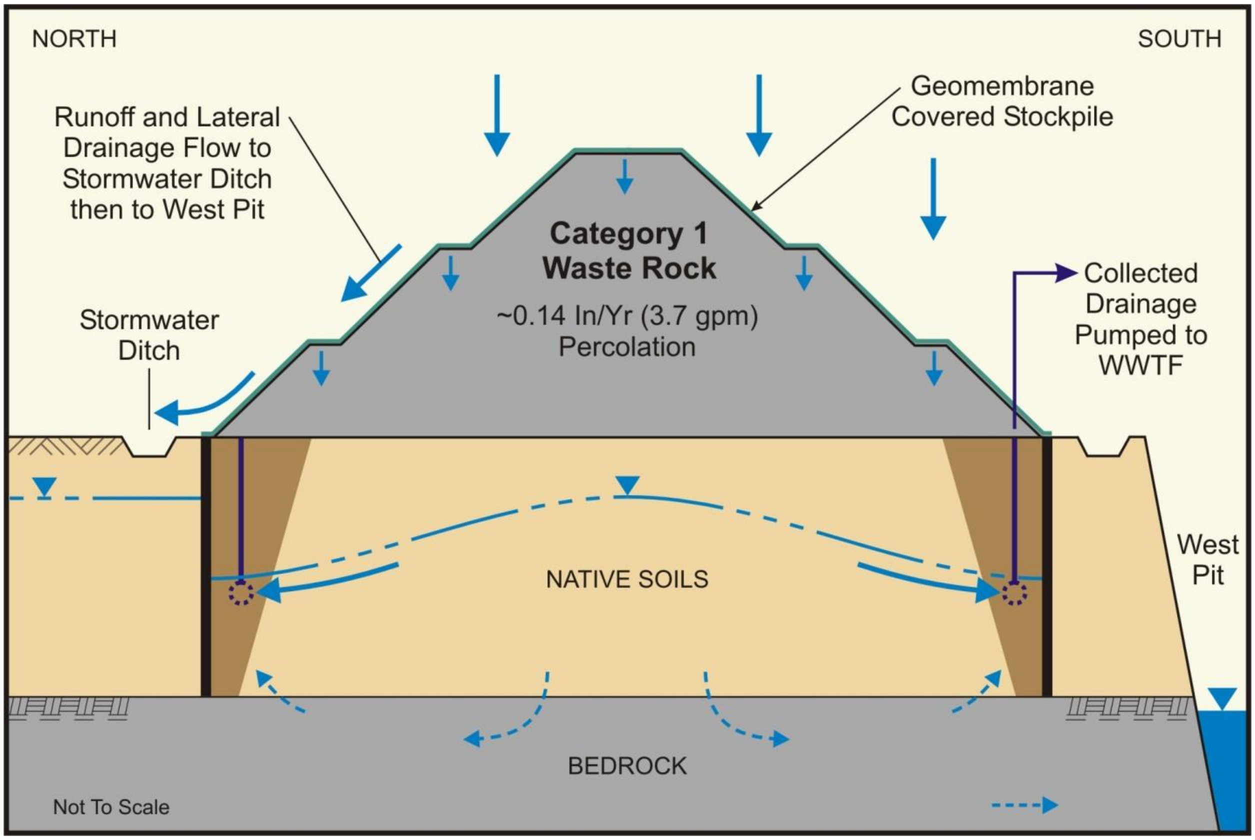


Figure 3 Conceptual Representation of Category 1 Waste Rock Stockpile Groundwater Containment System – Long-Term Closure Conditions Cross-Section

The groundwater flow model used to assess the performance of the containment system is a three-dimensional MODFLOW model (Reference (3)). The model was set up to simulate groundwater flow within the stockpile, the surficial deposits and the bedrock and is used to evaluate how much drainage will be captured by the containment system and how much will pass below the containment system.

The active model grid covers an area of approximately 14 square miles. The largest model cell size is 156 meters by 156 meters near the perimeter of the model, with a much smaller cell size of 10 meters by 10 meters used around the immediate vicinity of the stockpile. The model was vertically discretized into 9 layers; layer 1 represents the Category 1 Waste Rock Stockpile, layer 2 represents the surficial deposits, and layers 3 through 9 represent the bedrock. The top of layer 2 was set the same as the Mine Site MODFLOW model, using project topographic data at the Mine Site and larger scale elevation data outside the Mine Site. The top of layer 3 was based on the project bedrock map at the Mine Site and larger scale bedrock mapping outside the Mine Site. The base elevations of layers 3 through 9 correspond to the base elevations of model layers representing bedrock in the Mine Site MODFLOW model (Attachment C of Reference (2)).

The perimeter boundaries of the model are a simplified derivation of results from the Mine Site model and establish the regional groundwater flow field (Figure 4). The northern boundary of the model is a constant-head boundary set within the One Hundred Mile Swamp wetland complex. The eastern and southern boundaries are constant-head boundaries representing the Partridge River. The southwestern boundary consists of constant-head cells representing Wetlegs Creek. No-flow cells comprise the northwestern boundary of the model, which is positioned approximately perpendicular to the head contours from the Mine Site Model (Attachment C of Reference (2)) in this area. Wetlands within the model domain are represented with river cells with the head elevation equal to the ground surface (Figure 4).

The containment system drain pipe is represented in the model with drain cells. The elevation of the drain cells was set at the design elevations (Drawing GCS-012 to Drawing GCS-014 in Attachment C of Reference (1)). The conductance of the drain cells was calculated based on the length of the drain within the cell and an assumed fill material dimension around the drain of 2.4 meters by 2.4 meters, with a hydraulic conductivity of 50 meters/day. Containment system drain cells were assigned to either model layer 2 or 3 based on the drain elevation.

The cutoff wall was simulated using the Horizontal-Flow Barrier (HFB) Package for MODFLOW (Reference (4)). The cutoff wall conductance was calculated using an assumed thickness of 5 feet and a hydraulic conductivity of $1x10^{-5}$ cm/sec.

Drainage out of the toe of the stockpile was simulated with drain cells. Drain cells were set at an elevation of 0.1 meters above the existing surface elevation along the edge of the stockpile.

All pertinent model parameters are shown in Table 1.

Preliminary modeling was conducted using only steady-state solutions. Results from these models indicated that the vertical component of groundwater flow, influenced by a combination of high recharge over the open Category 1 Waste Rock Stockpile and drawdown from pit dewatering, was overestimated by considering steady state only. These conditions (high recharge and dewatering) are only short-term and are not accurately reflected in a steady-state model. Subsequent modeling described below was done with transient solutions to better reflect changes in the groundwater flow field over the period of mine operations and reclamation. However, for simulations of long-term closure, the model was still run with a steady-state solution, because conditions will approach a steady state over the long-term.

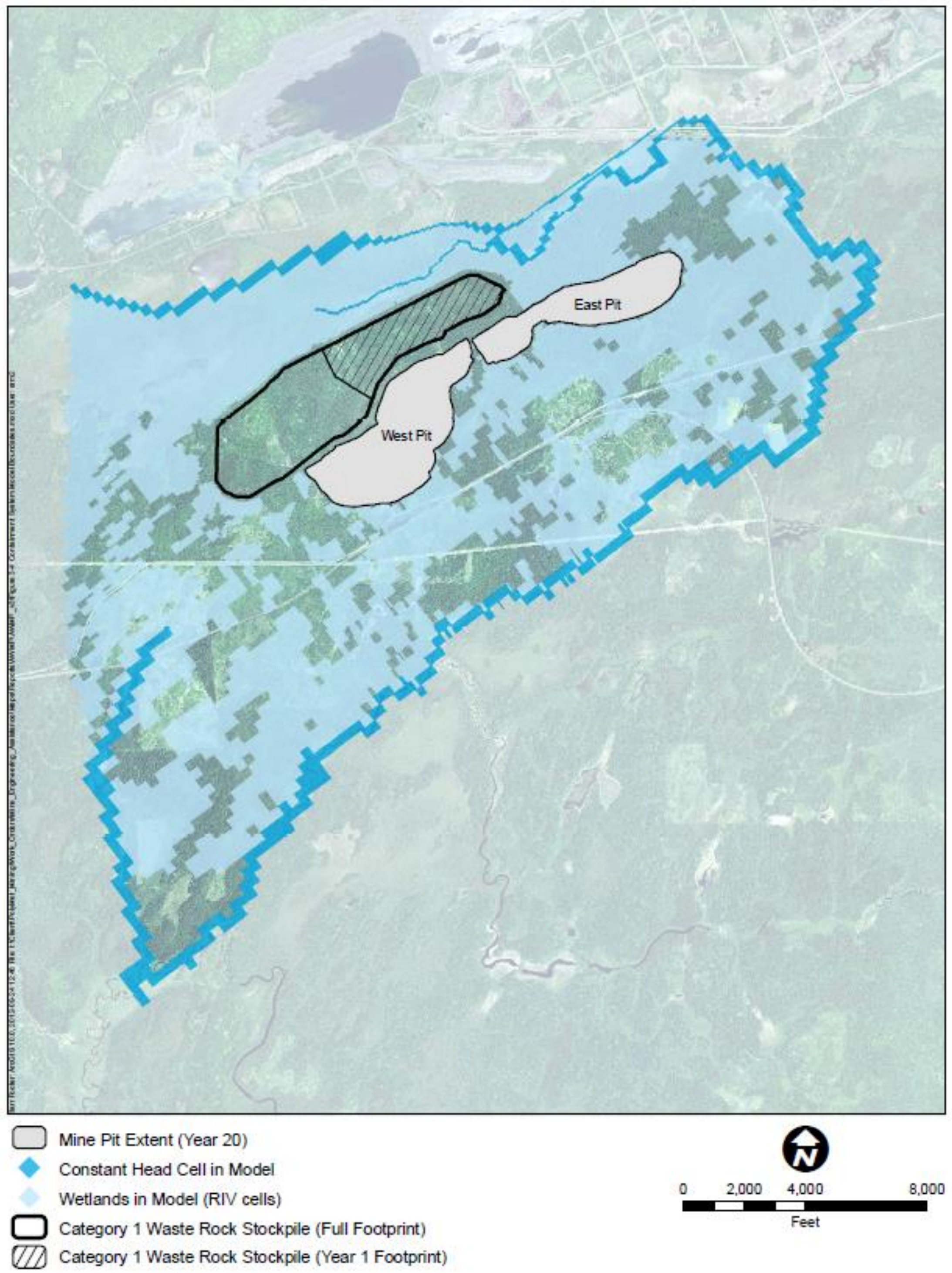


Figure 4 Perimeter Boundaries of Category 1 Waste Rock Stockpile Groundwater Containment System MODFLOW Model

Table 1 Key Category 1 Waste Rock Stockpile Groundwater Containment System MODFLOW Model Parameter Values

Parameter	Value	Units	Data Source
Recharge for wetland deposits	1.8	inches per year (in/yr)	Mine Site MODFLOW Model(1)
Recharge for glacial drift	0.36	in/yr	Mine Site MODFLOW Model(1)
Infiltration over active stockpile area	13.6	in/yr	Value from Section 6.1 of Reference (5)
Drainage though geomembrane stockpile cover	0.14	in/yr	Modeled mean percolation from Figure 3-6 of Reference (6)
Hydraulic Conductivity – Waste Rock	K_x=K_y=K_z = 259	meters per day (m/d)	NorthMet Geotechnical Data Package – Volume 3, v3 (Reference (7))
Horizontal Hydraulic conductivity – Glacial drift	Range: 0.017 - 51.0 Mean: 5.8	m/d	Values and distribution from Mine Site MODFLOW Model(1)
Horizontal Hydraulic Conductivity – Wetland deposits	Range: 0.001 - 68.2 Mean: 7.2	m/d	Values and distribution from Mine Site MODFLOW Model(1)
Vertical hydraulic conductivity – Glacial drift and wetland deposits	0.000864	m/d	Mine Site MODFLOW Model(1)
Hydraulic conductivity – Giants Range Batholith	K_x = K_y = 0.0089 K_z = $8.9\text{x}10^{-4}$	m/d	Mine Site MODFLOW Model(1)
Hydraulic conductivity – Biwabik Iron Formation	K_x = K_y = 0.26 K_z = 0.026	m/d	Mine Site MODFLOW Model(1)
Hydraulic conductivity – Virginia Formation, Upper Portion	K_x = K_y = 0.094 K_z = 0.0094	m/d	Mine Site MODFLOW Model(1)
Hydraulic conductivity – Duluth Complex	K_x = K_y= $1.4\text{x}10^{-4}$ K_z = $1.4\text{x}10^{-5}$	m/d	Mine Site MODFLOW Model(1)
Hydraulic conductivity – Virginia Formation, Lower Portion	K_x = K_y = 0.024 K_z = 0.0024	m/d	Mine Site MODFLOW Model(1)
Specific Storage – Waste Rock	$1\text{x}10^{-5}$	meter^{-1} (m^{-1})	Assumed value
Specific Storage – Bedrock, all units	$1\text{x}10^{-5}$	m^{-1}	Mine Site MODFLOW Model(1)
Specific Storage – Unconsolidated sediments	$1\text{x}10^{-5}$	m^{-1}	Mine Site MODFLOW Model(1)
Specific Yield – Waste Rock	23	Percent	Assumed value equal to porosity
Specific yield – Bedrock, all units	5	Percent	Mine Site MODFLOW Model(1)
Specific yield – Unconsolidated sediments	10	Percent	Assumed value

Parameter	Value	Units	Data Source
Porosity – Waste Rock	23	Percent	Value from Section 4.2 of Reference (7)
Porosity – Bedrock, all units	1	Percent	Assumed value
Porosity – Unconsolidated sediments	25	Percent	Assumed value

(1) Attachment C of Reference (5)

The model was run under a transient condition with yearly stress periods (a stress period is the time period over which model inputs are held constant) for Mine Year 1 to Mine Year 40 and a 15-year stress period from Mine Year 41 to Mine Year 55. These stress periods were developed to capture the dynamic changes in the groundwater flow system as the mine pits are dewatered and filled and the stockpile is either open or reclaimed. A steady-state simulation of current conditions was used to define the initial conditions for the transient simulation. For each stress period, mine pit depths were determined from contours of the pit shell developed for Mine Years 1, 2, 11, and 20; pit elevations between these years were linearly interpolated. The pit-filling sequence was based on the Mine Site water model (Reference (2)). For simplicity and to overcome limitations on how MODFLOW can simulate the building of the waste rock stockpile, it was assumed that the entire footprint of the stockpile was present and open starting in Mine Year 1. The waste rock stockpile was incrementally covered (to simulate the cover system construction sequence described in Section 7.1 of Reference (1)) by specifying different recharge rates in MODFLOW starting at the beginning of Mine Year 14 and ending at the end of Mine Year 21. A final steady-state model run was conducted with the mine pits full of water and the Category 1 Waste Rock Stockpile reclaimed to represent long-term closure.

The combination of the transient simulation and the steady-state, long-term closure simulation allows for assessment of the performance of the containment system under all expected groundwater flow regimes (e.g., drawdown and subsequent filling of the pits, open and reclaimed stockpile and long-term closure). The particle-tracking code MODPATH (Reference (8)) was used to track particles of water originating as drainage from the stockpile. At each model cell within the footprint of the stockpile, a particle was released at the water table at the beginning of Mine Years 1, 10, 20, 30 and 40 of the transient simulation. For Mine Year 1, the particles were released over the stockpile footprint that would exist during Mine Year 1 (Figure 4); particles were released over the full stockpile footprint during all other years. A total of 8,103 particles were released for Year 1; 20,798 particles were released for all other years. All particles were tracked until they reached a groundwater discharge location (e.g., containment system, mine pits, or offsite wetland/stream). Particles that remained active after the 55-year transient simulation (i.e., had not yet exited the groundwater flow system) were tracked through the long-term, steady-state simulation until they reached a groundwater discharge location. An additional complete set of particles were also tracked using the steady-state simulation representing long-term closure.

Modeling Results

The performance of the Category 1 Waste Rock Stockpile Groundwater Containment System was assessed by summarizing the number of particles that exited the groundwater flow system at each groundwater discharge location. Representative volumes of Category 1 Waste Rock Stockpile drainage discharging at each location were determined using the drainage rate through the stockpile at the time the particles were released and the area of the cell where the particle was released. The results of this assessment are shown in Table 2.

As shown in Table 2, the model simulations indicate that the containment system is capable of capturing between 91% and >99% of the drainage from the Category 1 Waste Rock Stockpile over the life of the mine and during long-term closure. The majority of the remaining drainage eventually flows to the mine pits. A small percentage of the stockpile drainage, less than 1% to 2% (<0.01-6 gpm) during operations and less than 1% (<0.01 gpm) during reclamation and long-term closure, is not captured in the containment system or the mine pits and is estimated to flow off site.

The majority of the particles not captured by the Category 1 Waste Rock Stockpile Groundwater Containment System or the pits follow deep and long (over 1,500 years) bedrock flow paths to the south, east, and southeast. These potential uncaptured flows are not significant due to the relatively small volumes of groundwater that these flow paths represent and the extremely long travel time relative to the water quality modeling period of 200 years. However, the potential flows from the Category 1 Waste Rock Stockpile to bedrock south, southeast, and east of the West Pit, along with outflow from the West Pit, are included in the Mine Site water quality model to determine potential impacts from this groundwater to downgradient surface water.

When the stockpile is uncovered, the model is estimating that there is some potential for a very small amount of stockpile drainage (0.2 gpm) to flow underneath the containment system and discharge to the adjacent wetlands in areas along the northeast and northwest sides of the stockpile. These areas will be investigated prior to construction of the corresponding segment of the containment system. If field conditions, particularly depth to bedrock, are similar to modeling assumptions, the design of the containment system may be modified to account for capture at lower elevations or to include groundwater extraction wells that will collect water from a greater depth than the containment system is currently modeled to collect water.

Table 2 Category 1 Waste Rock Stockpile Drainage Modeling Results

Particle Starting Year	Capture Location	% Capture	Representative Flow Rate (gpm)
Mine Year 1	Containment System	>99%	140 gpm
	West Pit	0%	0 gpm
	East Pit	<1%	<1 gpm
	Uncaptured	<1%	<0.1 gpm
Mine Year 10	Containment System	91%	329 gpm
	West Pit	6%	21 gpm
	East Pit	2%	6 gpm
	Uncaptured	2%	6 gpm
Mine Year 20	Containment System	95%	4 gpm
	West Pit	4%	<1 gpm
	East Pit	<1%	<0.01 gpm
	Uncaptured	<1%	<0.01 gpm
Mine Year 30	Containment System	95%	4 gpm
	West Pit	5%	<1 gpm
	East Pit	<1%	<0.01 gpm
	Uncaptured	<1%	<0.01 gpm
Mine Year 40	Containment System	95%	4 gpm
	West Pit	5%	<1 gpm
	East Pit	<1%	<0.01 gpm
	Uncaptured	<1%	<0.01 gpm
Long-Term Closure (Steady State)	Containment System	95%	4 gpm
	West Pit	5%	<1 gpm
	East Pit	<1%	<0.01 gpm
	Uncaptured	<1%	<0.01 gpm

References

1. **Poly Met Mining Inc.** NorthMet Project Rock and Overburden Management Plan (v7). December 2014.

2. —. NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v13). December 2014.

3. **Harbaugh, A.W.** MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16. 2005.

4. **Hsieh, P.A. and J.R. Freckleton.** Documentation of a computer program to simulate horizontal-flow barriers using the U.S. Geological Survey modular three- dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 92-477. p. 32.

5. **Poly Met Mining Inc.** NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v10). January 2013.

6. —. NorthMet Project Adaptive Water Management Plan (v6). January 2015.

7. —. NorthMet Project Geotechnical Data Package Vol 3 - Mine Site Stockpiles (v4). November 2014.

8. **Pollock, D.W.** User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 94-464, 6 ch. 1994.

Attachment F

Standard Operating Procedures: Environmental Characterization of Construction Material for the NorthMet Project

Standard Operating Procedures: Environmental Characterization of Construction Material for the NorthMet Project

December 2017

Prepared for:
Poly Met Mining, Inc.

Prepared by:
MineraLogic LLC

Table of Contents

Abbreviations

ABA	Acid-base accounting
AP	Acid potential
BIF	Biwabik Iron Formation
COIs	Constituents of Interest
DC	Duluth Complex
DNR	Department of Natural Resources
FTB	Flotation Tailings Basin
LTVSMC	LTV Steel Mining Co.
NP	Neutralization potential
NPR	Neutralization potential ratio
SOP	Standard Operating Procedure
USGS	United States Geological Survey

1 Introduction

During construction and operation of the NorthMet Project (Project), there will be a need for construction materials[1]. These materials will be sourced from low sulfur rock from the Duluth Complex (Duluth Complex construction rock or DC construction rock), rock from the Biwabik Iron Formation (BIF construction rock), on-site overburden materials, LTV Steel Mining Company (LTVSMC) tailings, and other off-site materials that require specific gradations that are not available from on-site sources. This document outlines standard operating procedures (SOPs) for usage of Duluth Complex construction rock, BIF construction rock, Mine Site overburden, and overburden from other areas as construction material[2]. These procedures are intended to support selection of materials that, due to their geochemical properties, are suitable for general construction use for the Project. Development and documentation of these SOPs is also intended to preserve flexibility during operations so that selection and use of construction materials can be adjusted based on future conditions (e.g., fuel price fluctuations, contractor construction means and methods, or scheduling logistics). Therefore, the SOPs apply broadly, to both previously identified and potential sources of construction materials on and off the Project site, and will be followed by all parties responsible for sourcing construction material for the Project.

The DC construction rock, BIF construction rock, Mine Site overburden, and overburden from the surrounding area are desirable candidate materials for construction purposes due to:

1. Physical properties that are consistent with material specifications (some applications may require sorting, screening, or crushing);
2. Proximity to the Project site, which minimizes haulage, thereby reducing air quality impacts associated with hauling and related cost/environmental impact of construction;
3. Beneficial reuse opportunities for what would otherwise be a waste material; and
4. Significant regional experience, over more than a century, with using these materials for construction both on and off mine sites.

General environmental objectives for construction material are that rock will be non-potentially acid generating (non-PAG), and will have low potential to leach metals and sulfate to contact water. Specific objectives for construction materials are described in Appendix A, “Technical Support for Construction Material Selection Criteria for the NorthMet Project”. Appendix A also describes the technical basis for selection criteria, based on geochemical characteristics, that have been developed to identify materials likely to meet these environmental objectives. Geochemical characteristics of both DC and BIF are variable and distinct from each other.

[1] “Construction” refers here to any usage that is outside of storage in a waste rock stockpile, as described in (Poly Met Mining Inc. 2017). Construction examples include use in haul roads, liner foundations, and the Rail Transfer Hopper platform.
[2] LTVSMC tailings and Mine Site unsaturated overburden are not further addressed in the current document. LTVSMC tailings are a by-product of taconite processing, and, as such, are relatively uniform in their chemical characteristics. These two materials were characterized as part of the waste characterization and geotechnical evaluation programs for the Project. No further characterization or screening of these two materials is proposed.

Therefore, separate selection criteria have been developed to identify the subsets of each that are suitable to be used as DC construction rock or BIF construction rock.

Overburden around the Project site is largely a product of glacial deposition and, in some cases, post-deposition processes. PolyMet has focused waste characterization and management on the overburden at the Mine Site due to the potential for the underlying Duluth Complex to impact geochemical characteristics of overburden. Plant Site overburden primarily overlays granitic rock of the Giants Range Batholith. Plant Site overburden has been heavily disturbed as a result of past mining activities without record of environmental or other water quality issues as a result of the overburden usage. The Mine Site unsaturated overburden has been shown to universally have minimal potential for acid generation and metal leaching. Based on the waste characterization work that has already occurred and the proposed uses and management of the materials, no further sampling and analysis of the Plant Site overburden or Mine Site overburden is proposed.

This document provides the selection criteria and describes sampling and analysis plans (SAPs) for DC and BIF construction materials that are designed to assess whether materials meet these criteria. This document also includes procedures for separation of Mine Site unsaturated and saturated mineral overburden in the field and guidance for usage of Mine Site overburden.

1.1 Purpose

The purpose of this document is to outline procedures for selecting and characterizing DC construction rock, BIF construction rock, Mine Site unsaturated overburden, and area overburden for use in construction on the Project site.

1.2 Scope

The scope of this document includes:

- Description of procedures for determining the suitability of BIF for use as construction material;
- Description of procedures for determining the suitability of DC for use as construction material;
- Description of procedures used for separation of unsaturated and saturated mineral overburden at the Mine Site, as well as the approved uses of Mine Site overburden; and
- Description of procedures used for testing other sources of overburden for use as construction material.

The technical support used for the development of construction material selection criteria are provided in Appendix A.

1.3 Responsibility

- It is the responsibility of each PolyMet employee and contractor to conduct their work in a manner that achieves the proper use of construction materials on the Project site.

- It is the responsibility of each PolyMet employee and contractor to contact their supervisor or appropriate personnel for information regarding the characterization and use of construction materials.
- It is the responsibility of PolyMet Supervision and Management to provide the PolyMet workforce with appropriate information and training on characterization methods and use of construction materials.
- It is the responsibility of the environmental manager and/or mining operations manager to determine who will characterize potential construction materials, if necessary.

2 Material-Specific SOPs

SOPs for the different types of potential general construction material for the Project are described in this section. A summary of these procedures is provided in Table 2-1.

Table 2-1. Summary of SOPs for General Construction Materials

Material	DC construction rock	BIF construction rock	Overburden (Mine Site)	Overburden (Non-Mining Area)
Selection Criteria	Sulfur content ≤0.05%	1. Sourced from a DNR-approved stockpile (approval provided on the basis of the "stockpile investigation" described herein) 2. NPR ≥ 3	Not applicable	Non-PAG, based on ABA
Selection Procedure	Blocks in the Block Model with average sulfur content of 0.05% or less	Two-stage investigation: 1. Stockpile investigation 2. Construction rock screening during stockpile deconstruction	Separation of overburden at the Mine Site	Minor quantities of off-site materials can be used, as needed; for off-site sources representing greater than 1% of total Mine Site construction material (70,000 cubic yards), characterization required
Sampling and Analysis	Overlaps with ongoing sulfur characterization of waste rock during operations	For construction rock screening: Samples will be collected following a field-prepared grid composite method, and sent to outside lab for sulfur and ABA.	Not applicable	When applicable, substantially the same as previous Project overburden characterization (Day et al. 2008a, b)

2.1 Duluth Complex Construction Rock

Non-ore grade Duluth Complex rock (waste rock) is excavated in the process of exposing ore during operations. A waste rock categorization system has been developed to segregate and manage all waste rock according to its geochemical characteristics. Waste rock categories for the Project are shown in Table 2-2. Based on extensive geochemical characterization, drainage from Category 1 waste rock is expected to remain neutral pH, with no potential to generate acidic drainage. However, there is some potential for drainage from Category 1 waste rock to be elevated in metals. Therefore, a subset of the Category 1 waste rock with especially low potential for metal leaching is planned for use as construction material on the Project.

Table 2-2. Summary of Waste Rock Properties

Waste Rock Categorization	Sulfur Content (%S)[1]	Approximate % of Waste Rock Mass
Category 1	%S ≤ 0.12	70%
Category 2	0.12 < %S ≤ 0.31	24%
Category 3	0.31 < %S ≤ 0.6	3%
Category 4[2]	0.6 < %S	3%

[1] In general, the higher the rock's sulfur content, the higher its potential for generating Acid Rock Drainage (ARD) or leaching heavy metals.
[2] Includes all Virginia Formation rock.

2.1.1 Selection Criteria for DC Construction Rock

Rock from the Duluth Complex will be deemed acceptable for use as construction material if it has a sulfur content of 0.05% or less.

2.1.2 Sampling and Analysis Plan

Sampling and analysis for determination of suitability of Duluth Complex rock for use in construction overlaps with regular waste rock management activities during operations. During operations, the sulfur content of Duluth Complex rock being blasted and excavated will be determined in order to segregate waste rock into the appropriate waste rock category. Volumes of rock with sulfur content of 0.05% or less, as identified through the normal plan of operations would be available to be used in construction. Any rock that is not used in construction, regardless of sulfur content, would be managed as waste rock. Details of the waste rock management plan, including procedures for determination of average sulfur content, are provided in the NorthMet Project Rock and Overburden Management Plan (Poly Met Mining Inc. 2017a). These procedures are summarized below.

Procedures will be conducted to refine and confirm estimates of the sulfur content of DC waste rock throughout operations. These procedures include:

1. Update/refine Block Model based on additional information.

The ore body and waste rock are represented as a 3-dimensional matrix of 50-ft long, 50-ft wide, and 20-ft deep blocks in the Block Model. Each block is georeferenced by a latitude, longitude, and depth. The model is populated with assay data (including bulk sulfur content) from drill cores. These values are interpolated to estimate the average chemical content of each block. As additional assay data becomes available, the Block Model is updated to improve precision of average chemistry estimates.

During operations, additional sulfur data will be added to the Block Model from at least two sources. Core drilling, and assaying of the drill core for sulfur and metals, will continue as mining progresses. In addition, blasthole drill cuttings will be sampled and also analyzed for sulfur and metals. Analytical results from both drill cores and the blasthole drill cuttings will be used to refine the Block Model.

2. Observation by a geologist of the pit face

On-shift field geologists will make observations of the mining face, mapping the pit walls and fragmented rock. They will provide regular reports to mine planners. This information will be compared to outcomes of the Block Model.

3. Sampling at the pit face

In addition to observations and mapping, on-shift geologists will also sample the mine face for the purpose of confirming the geologic mapping.

2.1.3 Selection of DC Construction Rock

Duluth Complex construction rock will be selected as blocks in the Block Model with average sulfur content of 0.05% or less.

2.2 Biwabik Iron Formation Construction Rock

Select units of the Biwabik Iron Formation have been utilized as iron ore for taconite operations on the Mesabi Iron Range over the last fifty years. As part of this process, non-ore grade BIF is routinely blasted, removed, and stockpiled. The BIF that would be used as potential construction material on the Project would be sourced from existing stockpiles.

BIF construction rock is required during the construction phase of the Project (before waste rock from the Project is available) across the entire Project site, and, additionally, at the Plant Site during the operations, reclamation, and closure phases. Approximately 3 million cubic yards (MCY) of BIF construction rock will be required at the Mine Site during the construction phase[3]. Of that, the greatest quantities required are for access and haul roads (1.2 MCY required) and stockpile foundations (1.1 MCY required). At the Plant Site, approximately 3.2 MCY of BIF construction rock is required for the Flotation Tailings Basin (FTB) buttress, which has the greatest need for construction rock at the Plant Site.

The procedures and methods described below could be applied to any stockpiled BIF. It is possible that non-BIF units (for example, rock from the Virginia Formation) may also be stored in

[3] Data on material quantities required is sourced from the spreadsheet “PolyMet Earthwork Construction Materials 5-25-2014”. For comparison, the “5-Mile Haul” stockpile at the LTVSMC property (also referred to as state-owned stockpile 2012/2022/2023) contains approximately 8.4 MCY material.

some stockpiles; if non-BIF materials are identified within existing stockpiles, with identification primarily made on the basis of historical information on stockpile construction, this material will be avoided and not used as construction material.

2.2.1 Selection Criteria for BIF Construction Rock

BIF will be deemed suitable for use in construction if it meets each of the following criteria:

- sourced from a DNR-approved stockpile (approval provided on the basis of a "stockpile investigation", see Section 2.2.3);
- rock has a mean neutralization potential ratio (NPR) ≥ than 3.

2.2.2 Program Implementation

The program to characterize BIF for potential use as construction material is summarized in Table 2-3. Application of the construction selection criteria to BIF will be conducted at two levels of investigation:

1. a preliminary stockpile-scale investigation (stockpile investigation), with the purpose of identifying stockpiles that are likely suitable for use in construction, based on historic information on their waste rock content and the chemistry of their existing drainage; and
2. a geochemical screening program (construction rock screening) to be implemented alongside construction activities, as the stockpile is being deconstructed, to confirm that the portions being used meet construction selection criteria

Table 2-3. Summary of the Program to Screen BIF for Use as Construction Material

Investigation	Location	Material	Minimum Sampling Frequency	Analysis
Stockpile Investigation	Surface water reflecting seepage composition of stockpile	Approximately one liter of water	One sampling campaign per stockpile	Water analyzed for: pH, hardness, Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn, and sulfate
Construction Rock Screening	Grid composite, as per USGS method for stockpile screening	Rock: composite of 30 increments (grab samples)	Approximately 1 composite per 300,000 tonnes rock	Sulfide sulfur, Modified Sobek NP titrated to endpoint pH 8.3; NPR calculation

2.2.3 Stockpile Investigation

Specific design of a stockpile investigation will differ according to details of individual stockpiles. For example, locations for water sample collection will depend on surface water locations specific to each stockpile. However, stockpile investigations will be comprised of three parts:

1. A desktop evaluation of stockpile content based on historic records, as available. Historical records must show that the stockpile was not used for storage of taconite sourced from the Q submember of the BIF, or if it was, that portion of the stockpile must be identified and isolated from use;
2. A sampling campaign to collect and analyze surface water representative of drainage from the stockpile. Water is analyzed for metals from the MPCA's Industrial Stormwater Sector G-2 benchmark monitoring parameters (stormwater benchmarks): Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn; with the addition of pH, hardness, and sulfate;
3. An evaluation that uses the constituent concentrations measured above, scaled to account for a difference in flow path between the stockpile and typical constructed features, to show that:
    a) For parameters with Sector G-2 stormwater benchmarks (Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn), drainage from the stockpile or scaled drainage is consistent with these benchmark values; and
    b) For sulfate (which does not have an applicable stormwater benchmark value), total sulfate loading from constructed features will not result in exceedances of water quality standards downstream.

Results of the stockpile investigation will be provided to the DNR for review and approval.

2.2.4 Construction Rock Screening

Sampling Strategy

Sampling strategy for the stockpile investigation for the construction rock screening is adopted from the USGS method for rapid screening of mine waste material (Hageman and Briggs 2000). This is a statistically-based method that was designed to efficiently characterize average values of large quantities of weathered waste rock. The target population used for USGS method development was the less than 2 mm size fraction of the surficial material of the waste rock dump. The selection of this size fragment was tied to the analytical approach for characterization via a field leach procedure, with the rationale that secondary phases and neutralization depletion would have the most significant effect in this fraction (Smith et al. 2000). Therefore, this sampling method would be protective for evaluating potential water quality impacts with regard to this particular analytical approach. The selection of this size fraction is based on observations from Price and Kwong (1997) that individual minerals are liberated at this particle size. It is supported by test work on size-segregated samples in Smith et al. (2000). However, there is flexibility in the method to modify this size fraction to account for site-specific conditions and objectives.

The samples will be collected following a field-prepared grid composite method. This method has been modified to retain the >2 mm fraction to use for sulfide sulfur and NP measurements. A description of the steps of this method is provided below:

1. Lay out an informal grid across area to be sampled that breaks the area into 30 evenly spaced cells.
2. Collect a sub-sample (increment) at each cell from approximately the upper 15 cm of the surface, using stainless steel trowels, small stainless-steel garden hand shovels, and/or three prong scrapers. During sample collection, all fragments >4 cm are discarded. Increments should be approximately equal in mass, although there is no strict requirement on minimum sample mass.
3. Place increments in a 5-gallon plastic bucket and mix. If the sample is wet, it must be air dried and mixed on a plastic tarp.
4. Sieve composite to pass a 2-mm stainless steel screen, producing a <2 mm and >2 mm fraction.

Samples will be collected at a minimum frequency of one 30-increment composite sample per 300,000 tonnes of rock[4]. This sampling frequency is consistent with industry guidance. Assuming a conversion factor of 1.9 tonnes per cubic yard[5], 1 composite sample would be collected per every 158,000 cubic yards of rock.

Analysis

After sampling, compositing, and sieving, the >2 mm fraction is retained and sent away for ABA testing, described below.

Acid-Base Accounting (ABA)

Standard laboratory ABA techniques are used to characterize NPR and total sulfur. NPR will be calculated by:

NPR= (NP, in kg $CaCO_3$/tonne of material)/(AP, in kg $CaCO_3$/tonne of material) (1)

Where "NP" is the neutralization potential and "AP" is acid potential. AP is calculated from sulfide sulfur, assuming that all sulfide sulfur has the potential to generate acidity consistent with the relationship below:

(AP, in kg $CaCO_3$/tonne of material) = (Total Sulfur, %) x (31.25) (2)

4 Industry guidance indicates that sampling frequency should be selected on a site-specific basis. However, recommendations have been made when site-specific criteria are not available. For example, Price (1997) includes a frequently cited recommendation of 8 samples per 100,000 tonnes of rock. The sampling frequency recommendations made here are consistent with this industry guidance.

5 The conversion factor of 1.9 tonnes per cubic yard is applied throughout Project documents to represent density of rock, accounting for "swell" from inter-clast void spaces.

The factor of 31.25 is used, by convention, to express AP in terms the mass of the $CaCO_3$ that would be required to neutralize the AP, assuming that each mole of $CaCO_3$ can neutralize two moles of H^+. Total sulfur in the sample is determined via combustion-infrared spectrophotometer using a LECO furnace (or similar) following method ASTM-E1915 (ASTM).

NP is determined by titration using the Modified Sobek method, incorporating the modification of Lawrence, as described in Lawrence and Wang (1996). The samples are treated with excess acid, without heating, to a pH endpoint of 2.0-2.5, and subsequently titrated with base back to pH 8.3.

2.2.5 Management Options for BIF Not Meeting Criteria

When deconstructing stockpiles for use as construction material, it is possible that portions of the stockpile may not meet criteria, even if other areas of the stockpile do. It may be desirable to manage the BIF that does not meet criteria in order to access other portions of the stockpile. In this case, the options for management of this rock are:

1. Blend the BIF that does not meet selection criteria with BIF that exceeds criteria, such that the combined material has a mean NPR of greater than 3; or
2. BIF may be blended with a source of alkalinity, such as limestone, so that the combined material has a mean NPR of greater than 3.

It is preferable to use BIF that meets construction criteria without blending. If blending is required, a plan will be submitted to the DNR for review and approval that specifies how this blending will be achieved.

2.3 Overburden

Overburden includes all unconsolidated earth material overlying bedrock. The SOPs target:

- overburden materials at the Mine Site due to the underlying Duluth Complex rock, and, therefore, potential presence of sulfide minerals and/or metal enrichment in the Mine Site overburden[6]; and
- overburden materials from off-site locations, which means outside of the NorthMet Mining Area, due to the potential for underlying Duluth Complex rock.

Subcategories of Mine Site overburden, each with distinct geochemical characteristics, have been defined for the Project, as follows:

Peat: organic matter, excluding coal, formed by the partial decomposition of plant material under saturated conditions (as defined in Minnesota Rules, part 6131.0010, subpart 11).

[6] Overburden at the Plant Site and along the Transportation and Utility Corridor is not, with the exception of the far eastern portion of the Transportation and Utility Corridor, located above the Duluth Complex. Overburden in the area heavily reflects glacial deposits from the Rainy Lobe of the Laurentian Ice Sheet, which advanced locally in a direction subparallel to the contact between the Duluth Complex and the country rock, suggesting little potential for influence from the Duluth Complex rock on geochemistry of overburden on the Plant Site and along the Transportation and Utility Corridor (Day et al. 2008b). There are no SOPs for overburden at the Plant Site or along the Transportation and Utility Corridor specifically related to geochemistry.

Saturated mineral overburden (saturated mineral overburden): mineral overburden (non-peat) that has remained below the water table and has not been oxidized.

Unsaturated mineral overburden (unsaturated overburden): mineral overburden (non-peat) located above the water table, including all topsoil.

It is possible that PolyMet or its contractors will identify additional off-site sources (i.e., outside the Mining Area) of overburden for use as potential construction material on the Project, inclusive of materials from off-site gravel pits in the region. Off-site overburden could be geochemically distinct from on-site overburden sources, so geochemical characterization would be performed.

2.3.1 Procedures for Separation of Mine Site Overburden

Separation of unsaturated and saturated mineral overburden will be made primarily on the basis of location of the water table relative to the overburden, in accordance with the following procedures:

1. Digital maps of the water table will be developed and/or updated on an annual basis for the area planned for overburden removal during the following year. These maps will be uploaded into the GPS system of the excavators prior to removal of overburden, and will be used to identify the excavation elevation that marks the estimated interface between unsaturated and saturated mineral overburden.
2. Visual confirmation of pre-excavation groundwater elevation will be conducted during excavation by an engineer, geologist, or other qualified person. Field observations will be documented and retained. In the event that field observations contradict the mapped pre-construction water table, selection of unsaturated overburden will be made on the basis of field observations. In cases where dewatering has occurred as a result of the construction activities, the pre-construction pre-excavation water table elevation will be used for demarcation between unsaturated and saturated mineral overburden.

2.3.2 Use of Mine Site Overburden

Construction activities will maximize, to the extent practical and permissible, the use of on-site excavated material at the Mine Site. Potential on-site construction materials include saturated mineral overburden, unsaturated mineral overburden, and peat.

Saturated Mineral Overburden

Saturated mineral overburden encompasses all mineral overburden at the Mine Site located below the water table. The location of the water table will be the primary criterion for classification of this material. Due to geochemical characteristics of saturated mineral overburden, PolyMet proposes to use this material in very limited circumstances, including those that meet the following criteria:

- in a permanently saturated zone
- above temporary membrane liners before ultimate disposal in a permanently saturated zone
- in an area where the water that contacts the saturated mineral overburden will be collected and sent to treatment
- as the compacted stockpile soil liner immediately below the temporary membrane liner before being ultimately disposed in a permanently saturated zone

PolyMet has currently identified the following potential construction applications for saturated mineral overburden at the Mine Site:

- stockpile foundation material below the water table (Categories 2/3 and 4 Waste Rock Stockpiles, OSP)
- temporary stockpile drainage layer (Categories 2/3 and 4 Waste Rock Stockpiles, OSP)
- top dressing for ramps and roads in pits
- mine water ponds, sumps, and basins liner cover material
- compacted soil liner below temporary geomembrane liners

Saturated mineral overburden not used for construction will be placed on lined stockpiles, or later in the East or Central Pit.

Unsaturated Mineral Overburden

The mine waste characterization shows that unsaturated mineral overburden has been oxidized and is no longer reactive. PolyMet will use unsaturated mineral overburden as an unrestricted, general construction material. Temporary storage will take place in the OSLA. To meet construction specifications, PolyMet may screen and/or compact unsaturated mineral overburden. While PolyMet will not crush non-granite cobbles and boulders, it will crush granite boulders and use them for haul road cover and railroad ballast.

Peat

Peat includes organic matter that is formed by the partial decomposition of plant material under saturated conditions. PolyMet will excavate peat from construction sites and either use it in construction activities or stockpile it in the OSLA for later use as a soil amendment for reclamation as an unrestricted, general construction material. Peat may be mixed with unsaturated mineral overburden to meet construction specifications for certain materials that are used in construction or reclamation.

2.3.3 Use of Overburden from Off-Site Locations

There may be instances where a contractor will source relatively minor quantities of overburden from an offsite location, for example, to meet material specifications. When the total amount of material supplied from an off-site source is of sufficiently minor quantity (up to 1% of the total construction material used at the Mine Site during the life of mine), it is considered *de minimis* and may be used from any one off-site source before geochemical characterization is required[7]; this *de minimis* quantity of material not requiring further geochemical characterization is 70,000 cubic yards.

If off-site sources of overburden greater than this *de minimis* quantity are going to be used for construction material, they will be first characterized by a program that is substantially similar to the programs conducted on the on-site overburden (Day et al. 2008a, b) or the test pit program described within Day and Kearney (2010). Off-site sources, in this case, are defined as areas outside the NorthMet Mining Area.

3 Exception to General Construction Usage: Buttress Material for the Flotation Tailings Basin

Constituent loading from FTB buttress material was modelled for the FEIS water model using geochemical properties from Category 1 waste rock[8]. Therefore, rock used for construction of this buttress will be evaluated to demonstrate that its use results in:

1. No change required for design of WWTS relative to the FEIS model assumptions;
2. No appreciable increase to sulfate loading to receiving waters relative to the FEIS model assumptions; and
3. No significant negative impact on transition to passive treatment relative to the FEIS model assumptions.

Results of this evaluation will be provided to DNR for review and approval prior to usage of construction rock.

4 Special Handling Instructions

BIF construction rock will not be crushed prior to usage for construction, other than in applications where drainage is captured (same usages as noted for saturated mineral overburden in Section 2.3.2). BIF construction rock may be sorted when necessary to achieved required material gradations.

---

[7] Quality of contact water will reflect geochemical characteristics of the bulk material used for construction. Rock composing up to 1% of constructed features at the Mine Site would have to contain an unrealistically high amount of sulfide mineralization to significantly alter the bulk sulfide content of the total construction material.

[8] This was a decision made for modeling purposes; model documentation in the Water Modeling Data Package for the Plant Site (Version 11, 2015) states that actual rock for this purpose was assumed to be sourced from the BIF waste rock stockpiles from LTVSMC Area 5S.

5 Documentation

Data, analyses, and field observations will be retained by PolyMet. Materials used for construction, along with any additional data generated as a result of the activities described above will be summarized in a yearly report to appropriate PolyMet staff. Documentation may be performed by PolyMet staff or Contractors under Staff supervision, with final responsibility for decision-making and control of documentation held by PolyMet.

6 Process for Updating SOPs

If PolyMet would like to change the SOPs presented here, the proposed revisions will be provided to the DNR for review and approval prior to implementation[9].

[9] Additional details or procedures may be added to the SOPs, as long as the resulting SOPs are inclusive of all of the items presented here (i.e., the additional details or procedures make the SOP more protective), in which case, no additional agency review or approval are required.

7 References

Day S, Kearney C (2010) Results of Analysis from Overburden Drilling Program- Update for March 2010 Test Pit Program NorthMet Project- DRAFT. [Memorandum to PolyMet Mining and DNR]. August 13, 2010.

Day S, Patelke R, Dent N (2008a) Analysis of Samples from Overburden Drilling Program NorthMet Project- DRAFT. [Memorandum to DNR]. March 18, 2008.

Day S, Patelke R, Dent N (2008b) Overburden Geochemical Characterization Plan in Support of EIS-DRAFT. [Memorandum to DNR]. February 22, 2008.

Hageman PL, Briggs PH (2000) A Simple Field Leach Test for Rapid Screening and Qualitative Characterization of Mine Waste Dump Material on Abandoned Mine Lands. 1–13. doi: 10.1016/j.mineng.2005.08.006.

Lawrence RW, Wang Y (1996) Determination of neutralization potential for acid rock drainage prediction. Can Cent Miner Energy Technol Ottawa MEND Repor:11.

Poly Met Mining Inc. (2017) NorthMet Project Rock and Overburden Management Plan, v. 9.

Price WA (1997) DRAFT Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. Smithers, BC.

Price WA, Kwong YT. (1997) Waste rock weathering, sampling and analysis: Observations from the British Columbia Ministry of Employment and Investment database. In: Proceedings of the Fourth International Conference on Acid Rock Drainage. Vancouver, B.C., Canada.

Smith KS, Ramsey CA, Hageman PL (2000) Sampling strategy for the rapid screening of mine-waste dumps on abandoned mine lands. Open-File Rep 1453–1461.

Sobek AA, Schuller WA, Freeman JR, Smith RM (1978) Field and Laboratory Methods Applicable to Overburdens and Minesoils. EPA-600/2-78-054.

USEPA (2001) Data Qualtiy Objectives Decision Error Feasibility Trials Software (DEFT) - User's Guide.

Appendix A

Technical Support for Construction Material Selection Criteria for the NorthMet Project

Technical Support for Construction Material Selection Criteria for the NorthMet Project

December 2017

Prepared for:
Poly Met Mining, Inc.

Prepared by:
MineraLogic LLC

Table of Contents

Abbreviations

ABA	Acid-base accounting
AP	Acid potential
BIF	Biwabik Iron Formation
COIs	Constituents of Interest
DC	Duluth Complex
DLS	Duluth Layered Series
DNR	Department of Natural Resources
GAI	Geochemical Abundance Index
HCT	Humidity Cell Test
LTVSMC	LTV Steel Mining Co.
NP	Neutralization potential
NPR	Neutralization potential ratio
SOP	Standard Operating Procedure
USGS	United States Geological Survey

1 Terms of Reference

During construction and operation of the NorthMet Project (Project), there will be a need for construction materials on the Project site. These materials will be sourced from low sulfur rock from the Duluth Complex (Duluth Complex construction rock, or DC construction rock), Biwabik Iron Formation (BIF construction rock), overburden, LTVSMC tailings, and other off-site materials that require specific gradations that are not available from on-site sources. Standard operating procedures (SOPs) for usage of DC construction rock, BIF construction rock, Mine Site unsaturated overburden, and overburden from other areas as construction material[1] are described in the document "Standard Operating Procedures: Environmental Characterization of Construction Material for the NorthMet Project" (Poly Met 2017b). These procedures are intended to support selection of materials that, due to their geochemical properties, are suitable for general construction use for the Project.

Environmental objectives for general construction material on the Project are that the material will be non-potentially acid generating (non-PAG) and have low potential to leach metals, such that contact water is likely to meet sector-specific stormwater benchmark values. Selection criteria have been identified that will be applied to select suitable general construction material.

The objectives of this report are to:

1. Present environmental objectives for general construction material on the Project; and,
2. Provide technical basis for criteria used to select construction material with geochemically suitable characteristics.

2 Environmental Objectives for Construction Material

Environmental objectives for general construction material for the Project are that it:

1) will be non-PAG; and,
2) will have low potential to leach metals, such that contact water is likely to meet sector-specific benchmark values at stormwater ponds.

Minnesota administrative rules for nonferrous metallic mineral mining (Chapter 6132) indicate that applicability of rules for the handling, disposal, and reclamation of waste rock are dependent on both the geochemical characteristics of the rock and the value of and degree of impact to natural resources[2]. Regardless of the material used for construction, PolyMet maintains the responsibility for meeting applicable water quality standards. Therefore, there is minimal risk of adverse impact to natural resources due to selection of construction material, as long as that material has geochemical properties that will lead to contact water that meets

[1] LTVSMC tailings are not further addressed in the current document. They are a by-product of taconite processing, and, as such, are relatively uniform in their chemical characteristics. These tailings were characterized as part of the waste characterization program for the Project. No further characterization or screening is proposed.

[2] Chapter 6132 outlines rules for handling, disposal, and reclamation for "reactive waste rock", defined in Minnesota Rules, part 6132.0100, subpart 28 as "waste that is shown through characterization studies to release substances that adversely impact natural resources". Where, "adversely impact natural resources' is defined in part 6132.0100, subpart 3 as "an unacceptable level of impact on the natural resources as determined by the commissioner based on an evaluation which considers the value of the resource and the degree of impact".

sector-specific benchmark values, in accordance with MPCA's Industrial Stormwater General Permit. For the Project, the relevant sector is Sector G "Metal Mining (Ore Mining and Dressing", specifically with the Mine Site falling under Sector G-1 "Active Copper Ore Mining, Dressing Facilities" and G-2 "Active Metal Mining Facilities," the Plant Site under Sector G-1, and the Transportation and Utility Corridors under Sector P "Land Transportation and Warehousing". Benchmark values for the metals used for the present evaluation are shown in Table 5-1 and Attachment A. Benchmark values for Sector G1, which covers the Plant Site, only includes the parameters for total suspended solids, nitrite plus nitrate-nitrogen, and chemical oxygen demand.

Geochemical characteristics of the different construction materials considered here are distinct. Therefore, selection criteria are material-specific and discussed separately below.

3 Duluth Complex Construction Rock

Low-sulfur rock from the Duluth Complex is regularly encountered during non-metal mining related development in northeastern Minnesota. These activities have produced road cuts through the Duluth Complex; abandoned Duluth Complex rock quarries; and major usages of Duluth Complex rock for riprap, foundations, road construction, and other construction applications[3]. The Project will, likewise, make use of rock from the Duluth Complex as construction material.

Under the existing waste rock management plan, non-ore grade rock on the Project will be segregated into three types of waste rock, according to its predicted potential to release acidity and metals when exposed to atmospheric conditions (Poly Met 2017a). These waste rock categories are:

Category 1 – sulfur content less than or equal to 0.12% - will not generate acid but may release metals

Category 2/3 – sulfur content greater than 0.12% and less than or equal to 0.60% - will eventually generate acid and consequently release metals at higher rates than Category 1

Category 4 – sulfur content greater than 0.60% - will rapidly generate acid and consequently release metals at higher rates than Category 2/3

With regard to the overall waste rock management plan for the Project, Category 1 waste rock (S<0.12%) is not potentially acid generating. However, depending on the mass of rock being managed and the hydrologic conditions, water contacting Category 1 waste rock does have the potential to contain elevated concentrations of select dissolved metals. A subset of DC rock that meets the selection criteria of having sulfur content of 0.05% or less will be available for use as general construction material on the Project, based on its especially low potential for metal leaching.

[3] For example, the company Coldspring is currently mining Duluth Complex rock from a quarry near Babbitt, MN, which is marketed as "Mesabi Black"; In addition, The Duluth Crushed Stone Company and the City of Duluth quarried Duluth Complex gabbro and/or anorthosite from locations in west Duluth for crushed rock, rip rap, and material for foundations and retaining walls starting by at least 1903 (for example, Bowles (1918)). It is still commonplace during construction around the city of Duluth to blast and manage Duluth Complex rock.

3.1 Evidence for neutral pH Contact Water

Extensive kinetic testing of non-ore grade Duluth Complex rock, from test programs conducted by both PolyMet and Minnesota Department of Natural Resources (DNR), indicate rock with sufficiently low sulfur content will not generate acidic drainage. Tests conducted by the DNR on rock from the South Kawishiwi Intrusion of the DC, have shown that DC rock with 0.22% sulfur will continue to generate circum-neutral drainage over long-term time periods[4] (Kellogg et al. 2014). These results are consistent with humidity cell test results from the Project waste characterization program, which have been running for up to 11 years at the time of this report. Based on an evaluation of data from the HCT program from August-October 2005 through January 2012, representing over six years of data, these long-term test results indicate that DC with at least 0.22% sulfur and less will not generate acidic drainage during weathering (Day 2012). The sulfur content of 0.22% would include all of the Category 1 waste rock (and a portion of the Category 2/3 waste rock). Figure 3-1 shows minimum pH of DC HCTs as a function of total initial sulfur content, illustrating that leachate pH is dependent on total sulfur content, and that all Category 1 waste rock (shown in Figure 3-1 as the blue and yellow symbols) produces neutral pH drainage. Since DC construction rock is a subset of the Category 1 waste rock, all DC construction rock will be non-PAG.

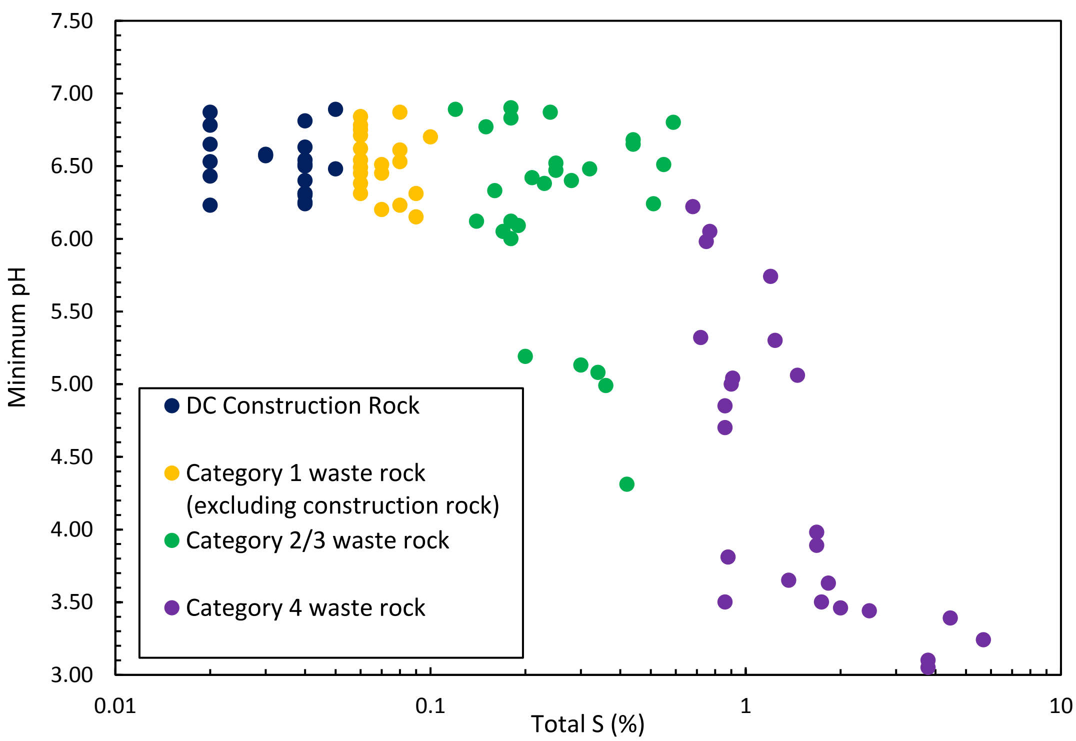


Figure 3-1 Minimum pH as a function of initial sulfur content of Project HCTs. Data used in evaluation from Project HCT program collected up to January 2012. For context, average pH for drainage from two blank cells averaged 5.5 and 6.0. Note, DC construction rock is a subset of Category 1 waste rock.

[4] These tests were conducted for over 25 years, at which point sulfur content had been significantly depleted, suggesting that they would continue to produce neutral pH drainage for the duration of weathering.

Complementary to the direct evaluation of pH, a comparison of sulfate release rates measured from HCT data indicates that the DC construction rock subset of the total HCT samples produces the lowest rate of sulfate release. Figure 3-2 shows time series of sulfate release rates for all Project HCTs. The time series shown in blue are from HCTs on DC construction rock. The time series shown in orange are all non- DC construction rock.

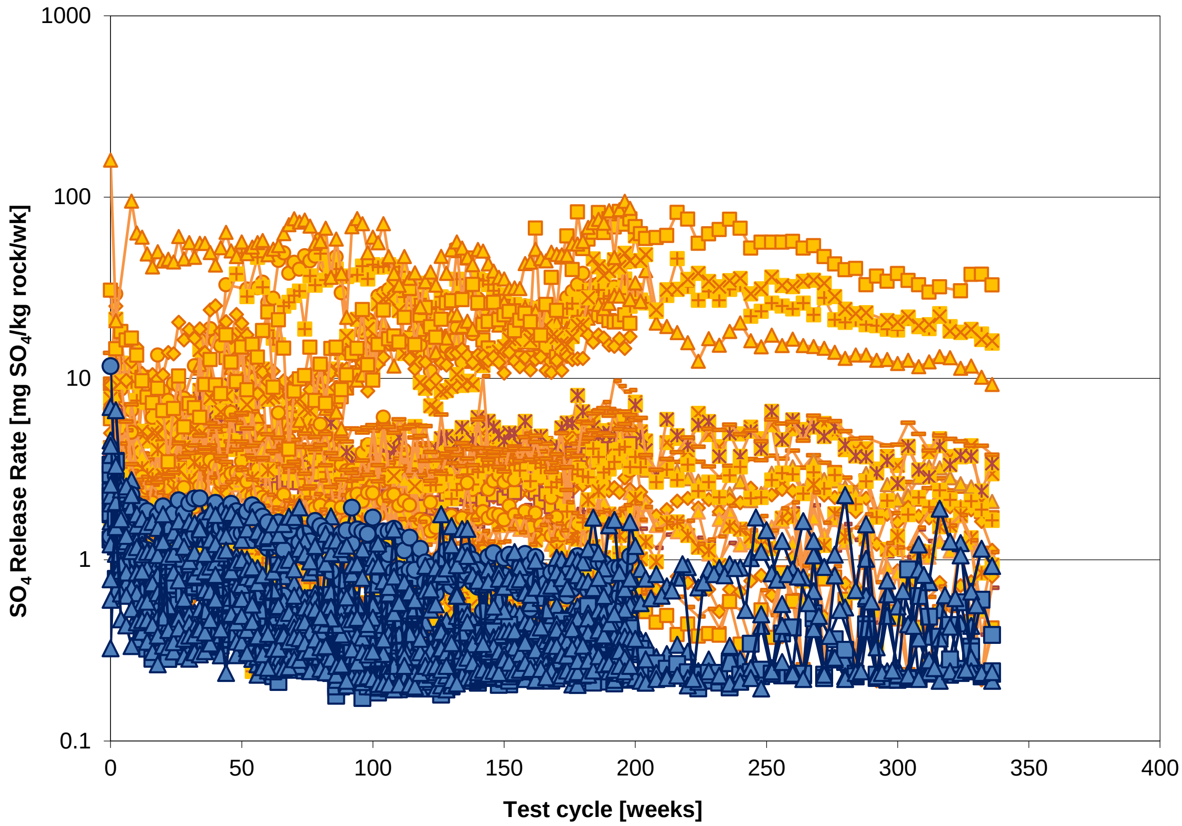


Figure 3-2 Time series showing sulfate release rate throughout test duration (up to January 2012). The time series shown in blue are from HCTs on DC construction rock. The time series shown in orange are all non-DC construction rock (e.g., Category 1 waste rock excluding the DC construction rock, Category 2/3 waste rock, Category 4 waste rock, and ore).

3.2 Assessment of Potential Metal Leaching

Assessment of potential metal leaching for Duluth Complex construction rock is conducted here through evaluations of metal enrichment and water quality observations at analog sites.

3.2.1 Evaluation of Elemental Enrichment

Evidence for lack of potential metal leaching from DC construction rock includes its commensurate lack of elemental enrichment relative to average crustal abundance. An industry standard approach for screening rock for its potential to release dissolved metals is to compare the abundance of chemical constituents in the waste rock with those constituents in a relevant reference class of material, under the premise that potential for metal release is related to elemental enrichment. This approach does not imply that the potential for problematic release is directly correlated to the degree of elemental enrichment. Instead, threshold screening values are generally used to identify constituents that are elevated in the rock; those constituents could then be subject to further investigation. Elemental enrichment does not mean that the element will necessarily be mobile under site conditions; nor does lack of enrichment exclude the possibility that a constituent may be mobile.

The Geochemical Abundance Index (GAI) is one measure used to define threshold screening values. The GAI characterizes the enrichment in individual chemical constituents in the rock according to the relationship:

$GAI=Log_2[C/(1.5*S)]$

where C is the concentration of the chemical constituent in the sample and S is the median concentration of that constituent in the reference class of material.

A GAI equal to or greater than 3 (equating to 12 times the mean crustal abundance) has been used to define "significantly enriched" is consistent with industry guidance (GARD Guide[5]). Values for GAI are typically truncated between 0 (meaning less than 3 times reference value) and 6 (more than 96 times reference value).

For the evaluation of Project construction material, the upper continental crust was chosen as the relevant reference class of material, under the assumption that it represents the average composition of potential alternative sources of construction material. The constituents evaluated are those minor to trace metals for which Sector G stormwater benchmark values exist.

Table 3-1 shows average constituent concentration, as measured by agua regia digestion, for analyses on DC drill core sections that have a sulfur content equal to or less than 0.05% (representing DC construction rock), indicating that all elements have a GAI less than 3, and are, therefore, not significantly enriched.

[5] Additional information is provided at http://www.gardguide.com/index.php?title=Elemental_composition_of_mineralized_rocks, accessed 8/24/2017.

Table 3-1. Comparison of average crustal abundance to Duluth Complex rock with S≤0.05%

Constituent[1]	Duluth Complex Construction Rock (S≤0.05%)[2]	Ave. Upper Continental Crust[3]	Geochemical Abundance Indices[4]
Ag (ppm)	0.12	0.053	0.6
As (ppm)	2.6	4.8	0
Cd (ppm)	0.4	0.09	1.6
Cu (ppm)	160	28	1.9
Ni (ppm)	230	47	1.7
Pb (ppm)	1.9	17	0
Sb (ppm)	1.4	0.4	1.2
Se (ppm)	-	0.09	NA
Zn (ppm)	70.8	67	0

[1] Constituents shown here are included as parameters for which stormwater benchmark values have been established, excluding iron, which is generally a major component of geologic materials and its mobility is more dependent on environmental parameters than bulk composition.
[2] Data from Project drill core database.
[3] From Table 11 in Rudnick and Gao (2004).
[4] As described in Section 3.2.1, GAI=Log2[C/(1.5*S)].

3.2.2 Water Quality Evaluation

Water quality associated with three potential analog sites described below indicates that water contacting DC construction rock will likely meet Sector G-2 stormwater benchmark values.

Miller Hill Mall Area, Duluth, MN

The 50-acre parking lot area at Miller Hill Mall in the City of Duluth is underlain by rock from the Duluth Layered Series (DLS) of the Duluth Complex. This rock had originally been blasted and moved to prepare the site during mall construction in 1973, and the expansion in 1987. Miller Creek, a trout stream, runs near or adjacent to this parking lot. Water was sampled at several locations near the base of the Miller Hill Mall parking lot embankment, which is composed of Duluth Complex rocks. Sampling locations included a swale that directed runoff from the embankment to Miller Creek, a Miller Creek location upstream of the embankment, a Miller Creek location downstream of the embankment, and three additional locations between the toe of the embankment and Miller Creek. Details on this sampling and results are provided in Barr (2016).

Two Abandoned Duluth Complex Quarries, Ely-Isabella Area, MN

As part of a previous DNR investigation, rock from two inactive Duluth Complex quarry sites was sampled and analyzed for bulk chemistry. Samples of quarry pit water were also collected and analyzed for concentrations of dissolved chemical constituents (Lapakko and Oberhelman 1993). Results from that investigation found the pit water to have a pH between 6.5 and 6.8, above that of rainwater, indicating that neutralization potential provided by the weathering of aluminosilicates is more than sufficient to offset acidity produced by oxidation of the sulfides. Sulfate and trace metal concentrations were low and within water quality standards. The low reactivity of the Duluth Complex rock in these abandoned quarries was attributed to the low sulfide content of the rock (equating to low reactivity), the relatively large clast size (implying small reactive surface area) that is typical of a quarry, and the relative small scale of the operations.

Table 3-2 provides a comparison between the contact water chemistry for the Duluth Complex construction rock analog sites and the Sector G-2 stormwater benchmark values. Constituents that are included are those that were analyzed for both the quarry pit lake study and the Miller Creek sampling, and where benchmark values exist. Additional constituents were included in the Miller Creek sampling; the full results of that sampling are included in Barr (2016). At both quarry lakes and the Miller Creek locations, observations of chemical constituent concentrations are below the applicable stormwater benchmark values. Table 3-2 also includes an estimate of average sulfur concentration of the bulk rock at each site. Rock at the two quarries sampled had sulfur concentrations of 0.02 and 0.05%. The estimate of the sulfur content for rock at the Miller Hill Mall area is variable with an average concentration of approximately 0.05%. The apparent lack of metal leaching from rock of this sulfur content, supports the sulfur criterion of 0.05% for Duluth Complex construction rock[6].

[6] Humidity cell test (HCT) results for samples with sulfur ≤0.05% were also qualitatively evaluated to gauge proximity to stormwater benchmarks. Due to differences in weathering conditions, physical characteristics of samples, and hydrology, HCT results are not equal to a prediction of future water quality. However, concentration for stormwater benchmarks constituents (shown in Table 4-1) are far below benchmark values with the exception of one data point for copper from one HCT. Results from analogue sites indicate that copper is unlikely to be elevated in stormwater.

Table 3-2. Comparison of water quality parameters for analogue Duluth Complex construction rock contact water

Site	Average Sulfur in Rock (%)	Cu (mg/L)	Ni (mg/L)	Zn (mg/L)
Sector G-2 stormwater benchmarks		0.028[1]	0.938[1]	0.234[1]
Lake Co. 11[2]	0.05	0.004	0.002	0.013
Lake Co. 11[2]	0.05	0.002	0.002	0.017
Lake Co. 13[2]	0.02	0.002	0.001	0.008
Lake Co. 13[2]	0.02	0.003	0.001	0.01
Miller Creek downstream[3]	0.05	0.003	0.001	0.004
Miller Creek 1A[3]	0.05	0.013	0.002	0.008
Miller Creek 1B[3]	0.05	0.013	0.002	0.007
Miller Creek 2A (base of DC embankment)[3]	0.05	0.008	0.002	0.003
Miller Creek 2C(1)[3]	0.05	0.001	0.002	0.020
Miller Creek 2D[3]	0.05	0.001	0.001	0.020

[1]Hardness-based benchmark values evaluated at 100 mg/L hardness.
[2]Data from (Lapakko and Oberhelman 1993).
[3]Sampling method and results in Attachment A. Data shown for dissolved constituent concentrations.

4 Biwabik Iron Formation

Biwabik Iron Formation (BIF) has been extensively utilized as construction material in northeastern Minnesota. A survey of historic usages by Oreskovich et al. (2007) documented over 400 usages of taconite[7] waste rock for construction off mine sites, and indicated that, by 2006, at least 2.3 million tons of taconite waste rock was being crushed to specification per year and sold for construction use. Minnesota Department of Transportation (MNDOT) has been using crushed taconite waste rock as aggregate, starting in the 1990s (Oreskovich et al., 2007).

BIF construction rock, like all construction rock on the Project, will be non-PAG and have low potential for metal leaching. Selection criteria designed to source such geochemically suitable BIF are:

[7] The term “taconite” refers to the low-grade iron ore found around the Lake Superior region. In the strict sense, it would be synonymous with BIF (in Minnesota); however, some historical usages of the term “taconite waste rock” are unclear as to whether they are including surrounding non-BIF waste rock units. Therefore, the more precise term “BIF” is preferred in the current document, except for instances that are referring to general waste rock from taconite mines.

1. Rock is sourced from a DNR-approved stockpile (approval provided on the basis of a "stockpile investigation", see Section 4.1);
2. Rock has a mean neutralization potential ratio (NPR[8]) of equal or greater than 3.0;

This evaluations presented in this document rely heavily on a geochemical characterization program conducted on BIF waste rock stockpiles and BIF drill core from rock in Area 6 of the former LTVSMC taconite mine (HCItasca 2010), referred to herein as the "Area 6 investigation". Key elements of that investigation are referenced or, in some cases, reproduced below, for convenience. The Area 6 investigation was a comprehensive program that included mineral characterization; leach tests on weathered and fresh rock; acid-base accounting (ABA) on weathered and fresh rock; humidity cell testing (HCT) on weathered and fresh rock; and water chemistry evaluation of pit lakes, groundwater, and surface water located around the site. The investigation site is located directly west of the NorthMet Plant Site. Due to their location on the eastern portion of the Mesabi Iron Range and the extensive scope of the Area 6 investigation, they are used here as sources of proxy data.

4.1 Stockpile Investigation

Specific design of a stockpile investigation will differ according to details of individual stockpiles. For example, locations for water sample collection will depend on surface water locations specific to each stockpile. However, stockpile investigations will be comprised of three parts:

a. A desktop evaluation of stockpile content based on historic records, as available. Historical records must show that the stockpile was not used for storage of taconite sourced from the Q submember of the BIF, or if it was, that portion of the stockpile must be identified and isolated from use. The significance of the Q submember to construction materials is described in Section 4.1.1;
b. A sampling campaign to collect and analyze surface water representative of drainage from the stockpile. Water is analyzed for metals from the MPCA's Industrial Stormwater Sector G-2 benchmark monitoring parameters (stormwater benchmarks): Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn; with the addition of pH, hardness, and sulfate;
c. An evaluation that uses the constituent concentrations measured above, scaled to account for a difference in flow path between the stockpile and typical constructed features, to show that:
    i. For parameters with Sector G-2 stormwater benchmarks (Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn), scaled drainage is consistent with these benchmark values; and
    ii. For sulfate (which does not have an applicable benchmark value), total sulfate loading from constructed features will not result in exceedances of water quality standards downstream.

An example of this evaluation is provided as Attachment A.

[8] Where NPR= (NP, in kg $CaCO_3$/tonne of material)/(AP, in kg $CaCO_3$/tonne of material). This is discussed in Section 4.1.

4.1.1 Significance of the Q Submember to Construction Material

Exclusion from construction material usage of the Q submember of the Biwabik Iron Formation was made on the basis of recognized geochemical heterogeneity between the different BIF submembers. The average sulfur content of the four submembers characterized for the Area 6 investigations are shown in Table 4-1. The Q submember of the Lower Slaty unit contains almost 20 times as much sulfur as the P submember (2.62% compared to 0.14%) and notably more than the R and A submembers. This is consistent with other regional observations that sulfide minerals are concentrated in the Q submember (Severson 2012).

Table 4-1. Sulfur content of the submembers evaluated in the Area 6 investigation

Constituent	Average Composition of Biwabik Members at LTVSMC Site			
	Lower Slaty (P) (n=8)	Lower Slaty (Q) (n=4)	Lower Cherty (R) (n=6)	Upper Slaty (A) (n=1)
S (%)	0.14	2.62	0.17	0.3

In addition, the Q submember stands out as being relatively enriched in trace and minor elements for which Sector G-2 stormwater benchmarks exist. The average composition of BIF, as determined from the drill core samples in the Area 6 investigation, is shown in Table 4-2, along with the GAI for these constituents (described in Section 3.2.1).

The result of this evaluation is that, of the BIF submembers present as potential waste rock at the LTVSMC site, the Q submember is significantly enriched in selenium. While not reaching the GAI threshold of 3, arsenic and cadmium also stand out as being present at greater abundance in the Q and A submembers than average upper continental crust. Elemental enrichment does not mean that the element will necessarily be mobile under site conditions; nor does lack of enrichment exclude the possibility that a constituent may be mobile.

Table 4-2. Average composition of Biwabik Iron Formation compared to average upper continental crust

Constituent[1]	Average Composition of Biwabik Members at LTVSMC Site[2]				Ave. Upper Continental Crust[3]	Geochemical Abundance Indices			
	Lower Slaty (P) (n=8)	Lower Slaty (Q) (n=4)	Lower Cherty (R) (n=6)	Upper Slaty (A) (n=1)		P	Q	R	A
Ag (ppm)	0.0	0.1	0.0	0.2	0.1	0	0.6	0	1.0
As (ppm)	9.4	39.0	20.2	28.1	4.8	0.4	2.4	1.5	2.0
Cd (ppm)	0.2	0.5	0.1	0.7	0.1	0.2	1.9	0	2.5
Cu (ppm)	11.0	67.4	5.4	70.0	28.0	0	0.7	0	0.7
Ni (ppm)	10.0	30.0	2.2	5.0	47.0	0	0	0	0
Pb (ppm)	3.2	13.0	1.6	16.3	17.0	0	0	0	0
Sb (ppm)	0.1	0.1	0.1	0.5	0.4	0	0	0	0
Se (ppm)	0.2	2.8	0.2	0.1	0.1	0.6	4.4	0.8	0
Zn (ppm)	25.5	41.5	14.3	90.0	67.0	0	0	0	0

[1]Does not include iron, the mobility of which will be primarily controlled by pH and redox conditions
[2]Data from Table 10 of HCItasca (2010)
[3]Average upper continental crust abundance from Table 11 of Rudnick and Gao (2004)

A summary of the stratigraphic column for LTVSMC is shown in Table 4-3 (Severson 2012). The Q submember represents a relatively minor portion of the BIF at LTVSMC. It is also located near the bottom of the mined units. Depending on when and where stockpiles were formed at the LTVSMC site, they may or may not contain the Q submember. Therefore, the Stockpile Investigation includes a desktop study component to demonstrate that specific stockpiles used to source BIF construction rock do not contain the Q submember, or if it does contain the Q submember, that portion of the stockpile must be identified and isolated from use.

Table 4-3. Summary of the stratigraphic column for the LTVSMC area, from Figure 6 of Severson (2012)

Member	Submember		Average Thickness (feet)[1] (Blue shading indicates ore units)	Thickness Range (feet)
Upper Slaty	A	Dolomite and Chalcedonic Chert	12	5-17
	B	Thin-bedded w/pale green beds	12	7-16
	C	Magnetic, Thin-bedded	27	20-40
	D	Thin-bedded with chalcedonic chert beds	15	5-23
	E	Alt-bedded with pinkish granular chert, high phosphorous	18	9-31
	F	Alt-bedded with pinkish granular chert, high alumina	32	20-43
Upper Cherty	G	Red/Med-bedded	38	16-56
	H	Alt/Thin bedded	8	5-14
	I	Algal/Conglomerate	5.5	4-9
	J	Reg/Med-bedded with distinct round black chert and magnetite clasts	9	3-11
	K	Striped-bedded (varve-like)	22	11-40
	K'	Wavy-bedded	18	7-33
	L	Wavy-bedded with magnetite clasts	27	10-41
	M	Wavy-bedded w/ "muddy" beds	15	10-22
	Ogr	Wavy/Med-bedded w/granular magnetite	19	8-23
	Oeb	Med/Red-bedded w/Alt-bedding at depth	34	30-50
Lower Slaty	P	Thin/Curved-bedded (Mesabi Select Equivalent" with "slate" to the west)	78	74-102
	Q	Black Carbonacous "Intermediate Slate", pyrrhotite (laminate and disseminated)	28	13-39
Lower Cherty	R	Bold Striped with Mesabi Select zones	15	9-23
	S	Var/Mott-bedded	36	26-50
	T	Wavy-bedded w/local Mottles	28	22-40
	U	Weak Wavy/Reg-bedded	32	21-47
	V	Thin-bedded (Alt- and Med-bdd)	20	15-26
	W	SLTST/Chal/Congl/Algal/(Quartzite)	5	1-12
		Sum of Average Thicknesses	554	
		Sum of Non-ore Submembers' Thicknesses[2]	260	

[1] Blue shading indicates that the unit is considered taconite ore.

[2] Includes all non-ore units above the last ore unit (submembers S, T, and U).

4.1.2 Water Quality Evaluation

Screening for potentially problematic metal leaching from BIF construction rock will be done on a stockpile-specific basis. An example of this evaluation is provided in Attachment A.

4.2 Basis for NPR Criterion

The evaluation of potential acid generation in the Area 6 investigation included measures of acid potential and neutralization potential based on both mineralogy and standard static test methods. It also incorporated an assessment of water chemistry. In addition to the Area 6 investigation, published reports containing information on BIF and mine waste characterization, generally, were also utilized for determination of the NPR criterion.

Rocks from the BIF contain minor to trace quantities of sulfide minerals. The predominant sulfide mineral in the BIF is pyrite, with the exception of on the far eastern extent of the formation, near the DC contact, where the pyrite has been metamorphosed to pyrrhotite (Severson 2012). Acidity can be produced during weathering of BIF by oxidation of pyrite (and/or pyrrhotite) and the subsequent oxidation and precipitation of iron as ferric hydroxide, according to the reactions, shown for pyrite, below:

$FeS_{2(py)} + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$ (1)

$Fe^{2+} + \frac{1}{4} O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2} H_2O$ (2)

$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{(s)} + 3H^+$ (3)

The cumulative effect of reactions 1-3, is that every mole of sulfur present as pyrite can generate 2 moles of proton acidity. Assuming that all sulfide sulfur present may produce acidity with the same efficiency as pyrite, the acid potential (AP) is calculated from sulfide sulfur concentration according to:

(Sulfide Sulfur, %) x (31.25) = (AP, in kg $CaCO_3$/tonne of material) (4)

The factor of 31.25 is used, by convention, to express AP in terms the mass of the $CaCO_3$ that would be required to neutralize the AP, assuming that each mole of $CaCO_3$ can neutralize two moles of acidity.

Rocks from the BIF also contain carbonate minerals. However, the carbonate mineral assemblage tends to be dominated by iron and magnesium-bearing carbonate components (Mcswiggen and Morey 2008). Theoretically, one mole of calcite (or magnesite/siderite) can neutralize up to two moles[9] of proton acidity through the dissolution reaction:

$(Ca,Mg,Fe)CO_3 + 2H^+ \rightarrow H_2CO_3 + (Ca,Mg,Fe)^{2+} \rightarrow CO_2 + H_2O + (Ca,Mg.Fe)^{2+}$ (5)

For siderite (or other iron-bearing carbonate minerals), under oxidizing conditions, the initial dissolution reaction would be followed by oxidation of the iron and the precipitation of an ferric

[9] Actual number of protons neutralized will also depend on equilibria within the H-C-O system.

iron hydroxide (reactions 2 and 3, above), which has the effect of producing two protons, thus, resulting in no net neutralization potential. Therefore, for rocks with an iron-bearing carbonate mineral component, the NP may be overestimated if the measurement method does not allow for complete progress of reactions 2 and 3. The Area 6 investigation included an evaluation of the NP measured using the Sobek method with the modification described in Lawrence and Wang (1996) versus the theoretical NP calculated from mineralogy. The conclusion from this evaluation was that the modified Sobek method (with titration back to a pH of 8.3) resulted in an adequate measurement of NP for this rock type (shown in Figure F-1, Appendix F of HCItasca (2010)).

The potential for acid generation is indicated by the amount of acid potential versus neutralization potential in the rock. There are multiple methods available for comparing these values. The measure used here is the Neutralization Potential Ratio (NPR), defined as:

NPR= (NP, in kg $CaCO_3$/tonne of material)/(AP, in kg $CaCO_3$/tonne of material) (6)

The Area 6 investigation included an evaluation of water quality for taconite-impacted waters to determine a site-specific quantity of NP relative to AP required to maintain neutral pH conditions. According to stoichiometry, the relative rates of reaction 1 and reaction 5 occurring in BIF will be indicated by relative molar quantities of sulfate versus (calcium + magnesium) in drainage (and other water contacting BIF), assuming that these reactions are the predominant sources of these ions. Figure 4-1 shows that for a wide range of waters analyzed for the Area 6 evaluation, the SO_4/(Ca+Mg) ratio trended toward a value of 1.4. Due to this finding, an NPR value of 2 was proposed as a protective screening value for identification of non-PAG rock (Section 3.3.3 of HCItasca (2010)).

The NPR value of 3 is adopted here, at the direction of DNR, as the primary selection criteria for BIF construction rock, where AP is determined by total sulfide sulfur and NP is measured by modified Sobek with titration back to 8.3. This is higher (more protective) than the value of 2 proposed in HCItasca (2010).

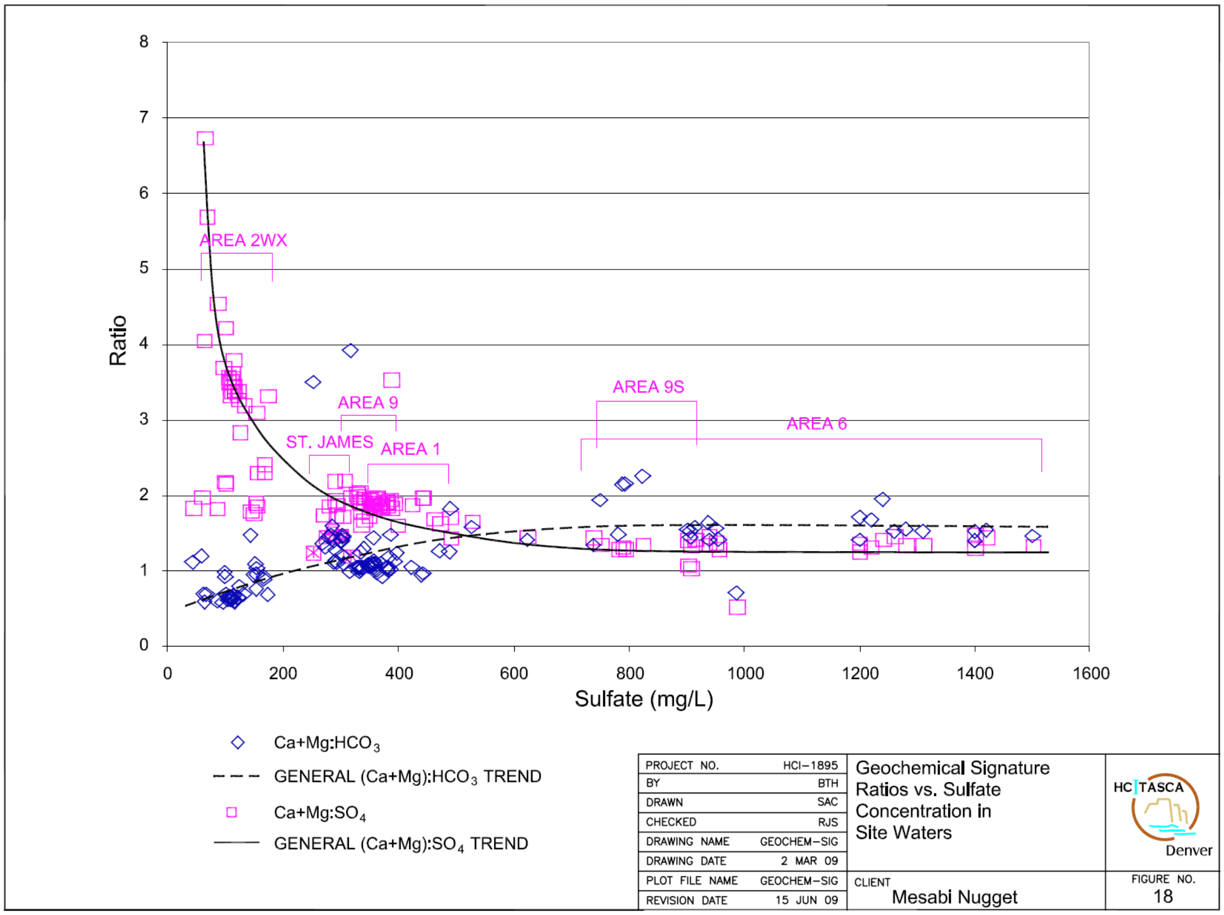


Figure 4-1. Water quality data showing a ratio of 1.4 for (Ca+Mg)/SO_4 for a wide range of BIF-impacted water, reproduced from Figure 18 of (HCItasca 2010).

5 Mine Site Overburden

Usage of unsaturated overburden from the Mine Site for general construction material is supported by conclusions from two complementary geochemical characterization programs. One of these programs focused on the characterization of the overburden drill core samples; for the other program, overburden samples were opportunistically collected during sump development accompanying bedrock drilling at the Mine Site. Results of both of these programs are presented in Day and Kearney (2010). Together, these programs conclude that there is a vertical, rather than a strong lateral, variation in metal and sulfur concentrations in the mineral overburden at the Mine Site. The vertical variation corresponds to the location of the water table surface. The unsaturated mineral overburden contains very low concentration of sulfur and the displays less potential for metal leaching than the saturated mineral overburden.

As part of the overburden characterization work, the Meteoric Water Mobility Procedure (MWMP) was conducted to assess potential metal leaching from overburden samples. Like for all other water quality evaluations conducted here, the MWMP provides analogue data on contact water, not precise water quality predictions. Table 5-1 provides a summary of the MWMP results compared to Sector G-2 stormwater benchmark values. Metal concentrations for both unsaturated and saturated overburden are far below benchmarks.

Table 5-1 Summary of MWMP Leachates results by material type. Data from Table 4 of (Day and Kearney 2010)

	Ag (µg/L)	As (µg/L)	Cd (µg/L)	Cu (µg/L)	Ni (µg/L)	Pb (µg/L)	Sb (µg/L)	Se (µg/L)	Zn (µg/L)
Unsaturated overburden	<0.05	0.5	0.05	5.4	1.4	<0.05	0.3	<0.1	2
Saturated overburden	<0.05	2.3	0.015	13	26	<0.05	0.4	1.9	3
Sector G-2 Stormwater Benchmarks[1]	4.1	680	7.8	28	938	164	180	40	234

There are sporadic samples with elevated sulfur concentration among the saturated overburden samples that appear to be related to chemical-reducing (anoxic) conditions beneath the surface of the water table. Therefore, unsaturated and saturated mineral overburden will be segregated and managed separately on the Project. Unsaturated overburden will be used for general construction material, following SOPs in Poly Met (2017b). Saturated overburden will be used for construction material for limited applications, where the materials remains below the surface of the water table, contact water is collected and treated, or immediately below a geomembrane liner. These usages are listed in Poly Met (2017a).

In general, mineral overburden in the region of the Project was formed as glacial deposits, in some cases, subjected to post-depositional processes, from advances of the Rainy Lobe of the Laurentian ice sheet, Section 2.1 of Day et al. (2008a). PolyMet has focused waste characterization on the overburden at the Mine Site due to potential for geochemical influence from the underlying Duluth Complex rock to the overlying glacial deposits. Plant Site overburden primarily overlays granitic rocks of the Giants Range batholith. Plant Site overburden has been heavily disturbed as a result of past mining activities without record of environmental or other water quality issues observed as a result of the overburden usage. With regard to the Transportation and Utility Corridor, the overburden materials directly overlay, from west to east, the Giants Range batholith, the Biwabik Iron Formation, the Virginia Formation, and a lesser amount of the Partridge River intrusion of the Duluth Complex. The direction of the Rainy Lobe advances has been inferred to be subparallel to the contact between the Duluth Complex and the surrounding country rocks , Section 2.1 of Day et al. (2008a). Therefore, there is minimal potential for relatively high sulfur rocks of the Duluth Complex to significantly impact glacial deposits in the Plant Site and the Transportation and Utility Corridor. In addition, with the exception of initial construction activities, disturbance of the overburden materials at the Plant Site and along the Transportation and Utility Corridors will be minimal. If disturbance of the saturated mineral overburden in the Transportation and Utility Corridors is necessary, PolyMet will complete waste characterization of the saturated mineral overburden to determine the appropriate handling and disposal of the material.

If off-site sources, defined as areas outside the Mining Area, of overburden are going to be used for construction material, they will be first characterized by a program that is substantially similar to the programs conducted on the on-site overburden (Day et al. 2008a, b) or the test pit program described within Day and Kearney (2010). An exception to this requirement for testing off-site sources of construction materials is provided when the total amount of material supplied from an off-site source is relatively minor in quantity and is, therefore, likely inconsequential to potential water quality. For the purposes of this Project, a quantity of up to 1% of the total construction material used at the Mine Site during the life of mine (approximately 70,000 CY) is considered *de minimis* and may be used from any one off-site source before geochemical characterization is required.

6 References

Bowles O (1918) The Structural and Ornamental Stones of Minnesota. The United States Geological Survey Bulletin 663.

Day S (2012) Update on Kinetic Test Data, NorthMet Project - DRAFT. [Memorandum to PolyMet Mining]. October 19, 2012. Reissued January 21, 2015.

Day S, Kearney C (2010) Results of Analysis from Overburden Drilling Program- Update for March 2010 Test Pit Program NorthMet Project- DRAFT. [Memorandum to PolyMet Mining]. August 13, 2010.

Day S, Patelke R, Dent N (2008a) Overburden Geochemical Characterization Plan in Support of EIS- DRAFT.

Day S, Patelke R, Dent N (2008b) Analysis of Samples from Overburden Drilling Program NorthMet Project- DRAFT.

HCItasca Denver I (2010) Geochemical Characterization of Mesabi Nugget Waste Rock, Mesabi Nugget Phase II Project.

Kellogg C, Lapakko K, Olson M, et al (2014) Laboratory Dissolution of Blast Hole Samples of Duluth Complex Rock from the South Kawishiwi Intrusion : Twenty-four year laboratory experiment. MN Dept. of Nat. Resourc., Div. of Lands and Min. St. Paul, MN.

Lapakko K, Oberhelman M (1993) Water quality at potential dimension stone quarry sites in northern Minnesota. MN Dept. of Nat. Resourc., Div. of Lands and Min. Hibbing, MN.

Lawrence RW, Wang Y (1996) Determination of neutralization potential for acid rock drainage prediction. Can Cent Miner Energy Technol Ottawa MEND Repor:11.

McSwiggen PL, Morey GB (2008) Overview of the Mineralogy of the Biwabik Iron Formation , Mesabi Iron Range , Northern Minnesota. Regul Toxicol Pharmacol 52:S11–S25. doi: 10.1016/j.yrtph.2007.09.010

Oreskovich, JA, Patelke, MM, Zanko, LM (2007) Documenting the Historical Use of Taconite Byproducts as Construction Aggregates in Minnesota—A GIS-based Compilation of Applications, Locations, Test Data, and Related Construction Information: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2007/22.

Poly Met Mining Inc. (2017a) NorthMet Project Rock and Overburden Management Plan, v. 9.

Poly Met Mining Inc. (2017b) Standard Operating Procedures: Environmental Characterization of Construction Material for the NorthMet Project. December 2017.

Rudnick RL, Gao S (2004) Composition of the Continental Crust. In: Holland H., Turekian KK (eds) Treatise on Geochemistry. Elsevier, Amsterdam, pp 1–64

Severson MJ (2012) Progress Report Pertaining to Stratigraphy and Metamorphism of the Biwabik Iron Formation (as Delinated by Logging some of the RGGS Holes from the) Eastern End of the Mesabi Iron Range, Minnesota: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2012/48.

Attachment A

Barr Engineering Co., Evaluation of 5-Mile Haul Stockpile for use as Construction Material. December 2017.

Technical Memorandum

To: Christie Kearney, Poly Met Mining Inc. (PolyMet)
From: Peter Hinck, Barr Engineering Co., and Tamara Diedrich, MineraLogic
Subject: Evaluation of 5-Mile Haul Stockpile for use as Construction Material
Date: December 8, 2017
Project: 23690862.14

Usage of Biwabik Iron Formation (BIF) for construction purposes on the NorthMet Mine Site requires that BIF construction rock is sourced from a stockpile that has been approved by Minnesota Department of Natural Resources (DNR) for this use on the basis of a Stockpile Investigation, as laid out in PolyMet's Standard Operating Procedure (SOP) for environmental characterization of construction materials (Attachment F of Reference (1)). The Stockpile Investigation consists of three parts:

1. A desktop evaluation of stockpile content based on historic records, as available. Historical records must show that the stockpile was not used for storage of taconite sourced from the Q submember of the BIF, or if it was, that portion of the stockpile must be identified and isolated from use;
2. A sampling campaign to collect and analyze surface water representative of drainage from the stockpile. Water is analyzed for metals from the MPCA's Industrial Stormwater General Permit (ISW GP) Sector G-2 benchmark monitoring parameters (stormwater benchmarks): Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn; with the addition of pH, hardness, and sulfate; and
3. An evaluation that uses the constituent concentrations measured above, scaled to account for a difference in flow path between the stockpile and typical constructed features, to show that:
    a. For parameters with Sector G-2 stormwater benchmarks (Sb, As, Cd, Cu, Fe, Pb, Ni, Se, Ag, Zn), scaled drainage is consistent with these benchmark values; and
    b. For sulfate (which does not have an applicable benchmark value), total sulfate loading from constructed features will not result in exceedances of water quality standards downstream.

This memo describes the results of a water quality evaluation conducted as a component of the Stockpile Investigation for the combined State-owned BIF Stockpile 2012/2022/2023, located approximately five miles west of the Mine Site along Dunka Road ("5-Mile Haul Stockpile"). The potential impacts of BIF construction rock that would be sourced from this stockpile for use at the NorthMet Mine Site are evaluated with respect to potential future water quality impacts to the Partridge River.

1.0 Constituent Concentrations in BIF-Impacted Water

A water sample was collected from a pond forming at the base of the 5-Mile Haul Stockpile in October 2014. Details of this sampling are provided in Reference (2). Due to the location of the pond relative to the stockpile and local hydrology, water quality of this pond represents water quality of seepage from the 5-Mile Haul Stockpile.

Constituents of interest for this evaluation are metals from the MPCA's ISW GP Sector G-2 stormwater benchmarks, with the addition of sulfate, which does not have an applicable benchmark value. Observed stockpile drainage composition, along with ISW GP stormwater benchmarks are provided in Table 1.

Table 1 Constituent concentrations in BIF-impacted water compared to MN ISW GP benchmark values

Basis	Parameter	Units	Stockpile Drainage(1)	Projected Haul Road Drainage(5)	MN ISW GP Benchmark Value
Sector G-2 parameters	Solids, Total Suspended (TSS)	mg/L	NA	NA	100
	pH	SU	7.33	7.33	6.0-9.0
	Antimony, Total	mg/L	<0.00025	0.000025	0.18
	Arsenic, Total	mg/L	0.0016	0.00016	0.68
	Cadmium, Total(2)	mg/L	<0.00003	0.000003	0.0078
	Copper, Total(2)	mg/L	0.0012(3)	0.00012	0.028
	Iron, Total	mg/L	3.27(4)	0.327	1.0
	Lead, Total(2)	mg/L	0.00022(3)	0.000022	0.164
	Nickel, Total(2)	mg/L	0.0042(3)	0.00042	0.938
	Selenium, Total	mg/L	0.00086(3)	0.000086	0.04
	Silver, Total(2)	mg/L	NA	NA	0.0041
	Zinc, Total(2)	mg/L	0.0095(3)	0.00095	0.234
Other Parameters	Sulfate, Total	mg/L	621	62	NA

(1) Data from Reference (2)
(2) Hardness-based benchmark values evaluated at 100 mg/L hardness
(3) Values flagged by laboratory as estimated concentration above the method detection limit and below the reporting limit
(4) Dissolved iron concentration (0.0393 mg/L) is a small fraction of total iron
(5) Project haul road drainage was estimated by dividing the stockpile drainage by 10 due to the difference in flow length from the haul roads (approximately 5 feet tall) and 5-Mile Haul Stockpile (50-150 feet tall)

Because constituent concentration in drainage from mine features is a function of both release from waste rock and dilution from water flux, constituent concentrations are expected to scale with flow path length; i.e., longer flow path lengths equate to more waste rock per unit water flux and higher resulting constituent concentrations. Therefore, it is anticipated that constituent concentrations in drainage from a large stockpile will be considerably greater than for a haul road that is much shorter in height. On this basis, the constituent concentrations observed at the base of the 5-Mile Haul Stockpile are scaled down to reflect the difference in flow path length between the stockpile and a haul road. The 5-Mile Haul Stockpile is at least 50 feet tall, ranging in height from 50 to 150 feet tall, while the height of a haul road is approximately 5 feet tall. Therefore, projected haul road drainage constituent concentrations were estimated by dividing concentrations observed at the base of a stockpile by a factor of 10. These projected concentrations are shown in Table 1.

A comparison of stockpile drainage and the projected haul road drainage composition to the ISW GP stormwater benchmarks indicates that concentrations for all constituents will be below the stormwater benchmarks for both the existing stockpile drainage and the projected haul road drainage. Therefore the 5-Mile Haul Stockpile meets the water quality criteria for construction rock with respect to metals that have established stormwater benchmark values.

2.0 Construction Rock Sulfate Load

An additional evaluation was conducted to evaluate potential sulfate loading from constructed features. The mine features planned to be constructed from BIF construction rock are shown in Large Figure 1. For the purpose of this evaluation, features which are entirely isolated from infiltration (for example, bases beneath stockpile liners) are not included here. Features not constructed during the construction phase (prior to the production blasting within the pit boundary) are planned for subsequent construction using Duluth Complex construction rock. The specific mine features potentially constructed from BIF construction rock at the Mine Site that are considered for this evaluation include:

- initial build-out of haul roads, excluding subsequent haul road widening and future haul roads
- initial build-out of stockpile liner backslopes, excluding subsequent stockpile liner extensions
- base material for the Railroad Spur

The total estimated plan area for mine features potentially constructed from BIF construction rock is 71.4 acres. This total includes some haul road areas that drain into the mine pits (and have infiltration collected in the mine water system), therefore this plan area is a high-end estimate of mine features that may produce stormwater.

The estimated annual average infiltration rate for bare rock used in the water balance modeling of the NorthMet Mine Site is 13.7 in/yr. This value is based on average annual precipitation of 28.7 in/yr (Section 5.2.1.1 of Reference (3)) and average evaporation estimated from waste rock test piles of 52.4% of precipitation (Section 5.2.2.1.2 of Reference (3)). This infiltration estimate is higher than would be expected for Mine Site haul roads, which have a compacted layer (drive surface) that promotes runoff. Runoff from the haul road drive surface will be collected and treated as part of the mine water system, and will not contribute load to the Partridge River. Therefore, the use of the uncompacted bare rock infiltration rate for this analysis provides a protective (i.e., conservatively high) estimate of the potential volume of water contacting the BIF construction rock.

As shown in Table 1, the projected sulfate concentration in drainage from Mine Site haul roads and similarly-sized features constructed of BIF construction rock is 62 mg/L.

Using the above estimates of the infiltration rate and an assumed constant sulfate concentration, the total potential sulfate loading (annual load = area x annual infiltration x average concentration) from the mine features constructed from BIF construction rock is estimated to be 6,210 kg/yr.

3.0 Partridge River Sulfate Load

The sulfate loading in the Partridge River under existing conditions was assessed at monitoring location SW005, the most upstream location on the Partridge River evaluated with respect to the wild rice sulfate water quality standard of 10 mg/L in the Final Environmental Impact Statement (Reference (4)). The annual average flow at SW005 was estimated from the XP-SWMM model of the Partridge River as 74.77 cfs (Attachment J of Reference (3)). The average sulfate concentration at SW005 has been observed as 9.66 mg/L (Large Table 4 of Reference (5)). The existing average sulfate load at SW005 is therefore 645,000 kg/yr.

4.0 Change in Partridge River Sulfate Concentration

If all of the potential sulfate load from mine features constructed from BIF construction rock of 6,210 kg/yr were to reach the Partridge River, it would represent a 0.96% increase relative to the estimated existing sulfate load at SW005. This potential additional load would result in an increase in the average sulfate concentration at SW005 of 0.09 mg/L, from 9.66 mg/L to 9.75 mg/L. This result is a protective overestimate, because it ignores the portion of precipitation to haul road surfaces that will run off and be routed as mine water and treated, and it assumes that all sulfate that reports to the base of constructed features is wholly transferred to the Partridge River. The typical laboratory detection limit for sulfate is 1 mg/L; therefore, this change in sulfate concentration at SW005 from 9.66 mg/L to 9.75 mg/L would not be measurable or detectable from the natural variability of sulfate at SW005.

References

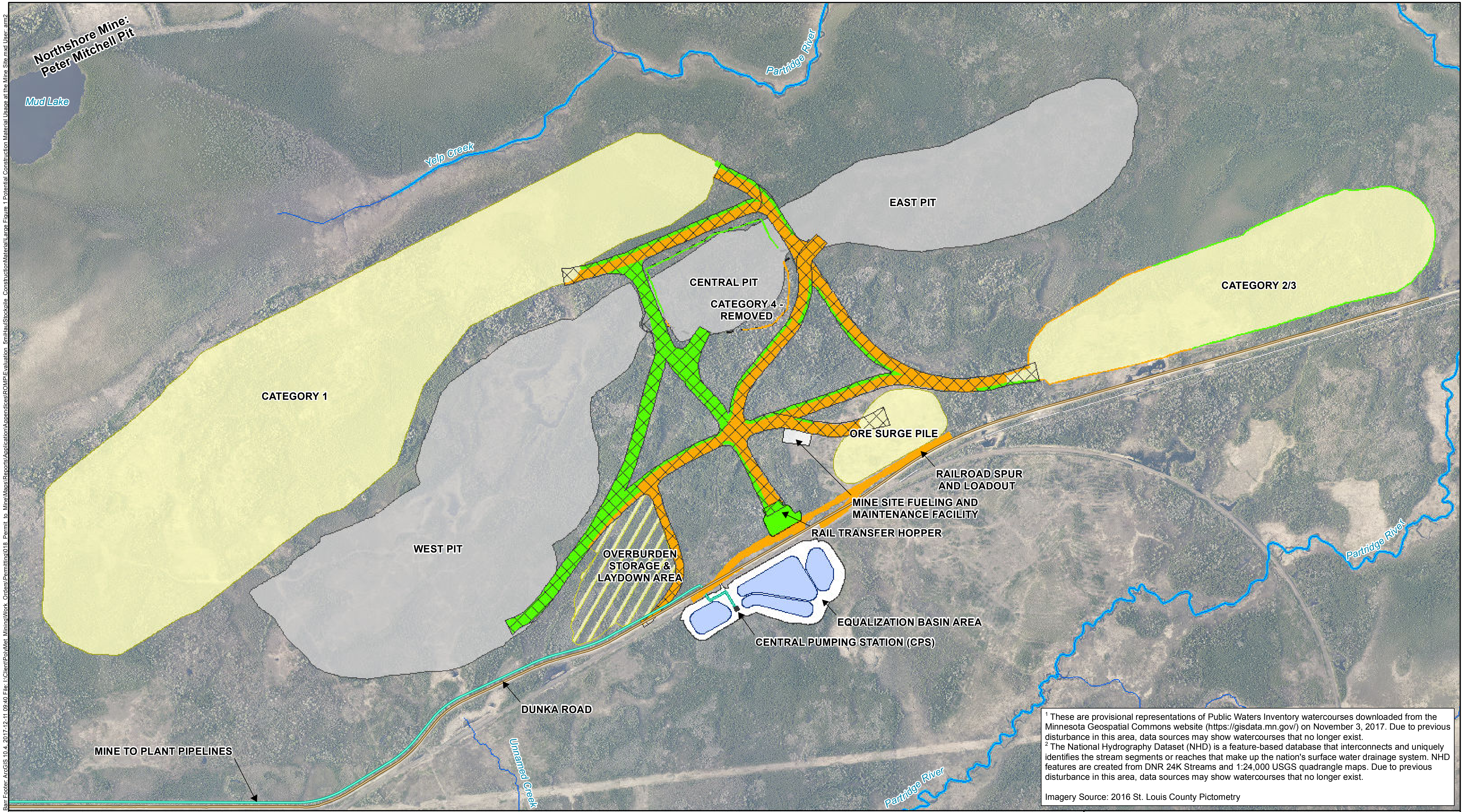
1. **Poly Met Mining, Inc.** NorthMet Project Rock and Overburden Management Plan (v10). December 2017.

2. **Barr Engineering Co.** Proposed BIF Rock Borrow Source Characterization Memo. December 2017.

3. **Poly Met Mining, Inc.** NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v14). February 2015.

4. **Minnesota Department of Natural Resources, U.S. Army Corps of Engineers and U.S. Forest Service.** Final Environmental Impact Statement: NorthMet Mining Project and Land Exchange. November 2015.

5. **Barr Engineering Co.** NPDES/SDS Permit Application Volume II – Mine Site. Prepared for Poly Met Mining, Inc. October 2017.



[1] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

[2] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.

Imagery Source: 2016 St. Louis County Pictometry

Construction Materials
- Duluth Complex
- BIF

Mine Year 11 Footprints
- Mine Pit
- Active Stockpile
- Storage & Laydown Area
- Removed Stockpile
- Haul Roads
- Dunka Road
- Mine to Plant Pipelines
- Public Waters Inventory (PWI) Watercourses[1]
- National Hydrography Dataset (NHD) Rivers & Streams[2]

0 1,250 2,500
Feet

POTENTIAL CONSTRUCTION MATERIAL USAGE AT THE MINE SITE
NorthMet Project
Poly Met Mining, Inc.

Large Figure 1
Evaluation of 5-Mile Haul Stockpile for use as Construction Material

Attachment G

Overliner Stress Calculations

TECHNICAL MEMORANDUM

Date:	September 12, 2012	**Project No.:**	113-2209
To:	Tom Radue and Christie Kearney	**Company:**	Barr Engineering Company
From:	Gordan Gjerapic	**Email:**	ggjerapic@golder.com
cc:	Brent Bronson		
RE:	**OVERLINER STRESS CALCULATIONS**		

1.0 INTRODUCTION

This document summarizes the approach and results of the overliner stress calculations conducted for the proposed waste rock stockpiles at the PolyMet NorthMet Site located near Babbitt, Minnesota. The purpose of the calculation is to evaluate the minimum overliner thickness to protect geomembrane liner from stresses induced by Caterpillar 992 front end loader (CAT 992) operating at the Ore Surge Pile. For comparison, the stresses induced by different haul tracks and dozers were also evaluated.

2.0 METHOD

The conventional Boussinesq equation is used to analyze stresses on the liner due to different types of equipment and varying thickness of overliner material. The stress on the liner is limited to 8 psi per Golder (2009) design criteria.

2.1 Simplified Analysis

Preliminary evaluations were performed to find the loading conditions for various types of equipment (see Attachment 1). The vertical pressure on the liner was calculated by considering the maximum anticipated surface load induced by tires (for wheel equipment) or standard shoe (for track dozers). Specifically, the load was calculated based on the weight and geometry of the equipment and the thickness of overliner material using the Boussinesq equation. These results provide preliminary estimates for the thickness of overliner material required to limit the stress on the liner below 8 psi.

2.2 Detailed Liner Stress Analyses

The largest equipment operating at the Ore Sure Pile is CAT 992 front end loader. Therefore, a more detailed analysis was performed for the CAT 992 accounting for the superposition of vertical loads (i.e., accounting for all four tires). The analysis was performed considering different locations under the Cat 992 footprint: (1) under each tire, (2) at the wheelbase center, and (3) at the midpoints of both the front and rear axles (see Attachment 2).

Factors of safety against frictional failure (see Attachment 2) were calculated as a ratio between the applied shear stress and the shear strength of the overburden material, assuming a friction angle of 25

Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, CO 80228 USA
Tel: (303) 980-0540 Fax: (303) 985-2080 www.golder.com

degrees and zero cohesion. Note that the overburden friction, rather than the geomembrane/overburden interface friction, is used in the analysis since the allowed pressure on the liner (8 psi) and the anticipated contact load widths indicate likely failure surface passing through the overburden material (the contact load width is expected to be smaller than the overburden thickness). This assumption is in agreement with the research by Koerner and Narejo (1995). The analysis conducted for CAT 992 loading indicates factors of safety greater than 1.3 for the overliner thickness of six feet or greater (see Attachement 2).

3.0 RESULTS

Minimum overliner thickness values for different types of equipment are summarized in Table 1:

Table 1: Minimum Overliner Thickness Estimates for Different Types of Equipment

No.	Type of Equipment	Model Name	Operating Weight (lbs)	Overliner Thickness[1] (feet)
1	Rubber tire dozer	CAT 834H	106,844	3.2
2	Front loader	CAT 988	115,101	3.4
3	Front loader	CAT 992	214,948	4.7[2]
4	Haul truck	CAT 777	363,000	6.8
5	Haul truck	CAT 793	846,000	10.4
6	Bulldozer	CAT D8	86,328	2.0
7	Bulldozer	CAT D10	148,277	3.0
8	Bulldozer	CAT D11	248,600	4.4

1) Based on the limiting liner stress of 8 psi and simplified calculations (Attachment 1).
2) Overliner thickness of 6 feet recommended based on detailed calculations (Attachment 2).

4.0 CONCLUSIONS

A minimum overliner thickness of 6 feet is recommended at the Ore Surge Pile assuming that the maximum stresses will be due to Caterpillar 992 front end loader operation.

5.0 REFERENCES

Golder Associates, Inc. 2009. "2nd Draft Waste Rock Stockpile Permitting-Level Design", draft report issued to PolyMet Mining Inc. and Barr Engineering Company on October 1, 2009.

Koerner, G.R., and D. Narejo. 2005. "Bearing Capacity of Hydrated Geosynthetic Clay Liners," Journal of Geotechnical Engineering, Vol. 121, No. 1, pp. 82-85.

ATTACHMENT 1
SIMPLIFIED STRESS ANALYSIS

Table 1 Wheel Equipment

No.	Type of wheel equipment	Brand name	Operating weight (lbs)	Estimated tire type	Estimated max. tire pressure (psi)	Wheelbase (ft)	Estimated centerline front tire width	Approx. axle load as % total load	Contact area (inch^2)	Contact area width	Contact area length
1	Rubber tire dozer	CAT 834H	106,844	35/65R33	62	14.93	12.47	55%	474	35	13.54
2	Front loader	CAT 988	115,101	35/65R33	91	14.93	11.94	55%	348	35	9.94
3	Front loader	CAT 992	214,948	45/65R45	91	19.32	15.46	55%	650	45	14.43
4	Haul track	CAT 777	363,000	27.00R49	95	14.96	13.68	67%	1,280	54	23.70
5	Haul track	CAT 793	846,000	40.00R57	110	19.37	18.42	67%	2,576	80	32.21

Table 2 Track Equipment

No.	Type of track equipment	Brand name	Operating weight (lbs)	Shoe width (inch)	Ground pressure (psi)	Length of track on ground (ft)	Track gage (O.C. distance between tracks) (ft)	Approx. track load as % total load	Contact area (inch^2)	Contact area Width (inch)	Contact area length (inch)
1	Bulldozer	CAT D8	86,328	22	15.54	10.52	6.83	50%	2778	22	126
2	Bulldozer	CAT D10	148,277	24	20.32	12.67	8.33	50%	3648	24	152
3	Bulldozer	CAT D11	248,600	28	25.37	14.58	9.50	50%	4900	28	175

Table 3 Approximate Vertical Pressure on Liner

Depth to Liner (ft)	Equipment							
	CAT 834H	CAT 988	CAT 992	CAT 777	CAT 793	CAT D8	CAT D10	CAT D11
0	62.0	91.0	91.0	95.0	110.0	15.5	20.3	25.4
1	35.3	41.2	55.6	76.2	98.2	12.3	16.6	21.9
2	16.4	18.2	28.4	46.8	71.2	7.9	11.1	15.5
3	8.9	9.7	16.2	29.2	50.2	5.6	7.9	11.3
4	5.4	5.9	10.2	19.3	36.0	4.1	6.0	8.7
5	3.6	3.9	7.0	13.5	26.6	3.2	4.7	7.0
6	2.6	2.8	5.0	9.8	20.2	2.5	3.8	5.7
7	1.9	2.1	3.8	7.5	15.8	2.0	3.1	4.7
8	1.5	1.6	2.9	5.8	12.6	1.7	2.6	4.0
9	1.2	1.3	2.3	4.7	10.3	1.4	2.2	3.4
10	1.0	1.0	1.9	3.8	8.5	1.2	1.9	2.9

Note: Stress imposed by critical equipment (i.e., Cat 992) to be confirmed with detailed stress analysis (see Attachment 2)

ATTACHMENT 2
DETAILED STRESS ANALYSIS

Attachment 2 - Detailed Overliner Depth Calculation

Equipment type:	Cat 992 Front End Loader
Job No:	113-2209
Made By:	JP
Checked By:	GG
Reviewed By:	GG
Date:	6/26/2012

Input parameters:

Overliner material density, γ'	112 pcf
Interface friction angle, ϕ	25 degrees
Lateral reaction coef., K	0.11
Equipment:	CAT 992G
Standard tire:	45/65R45
Tire width:	45.00 inch
Gross machine operating weight	221,073 lbs
Minimum factor of safety	1.3

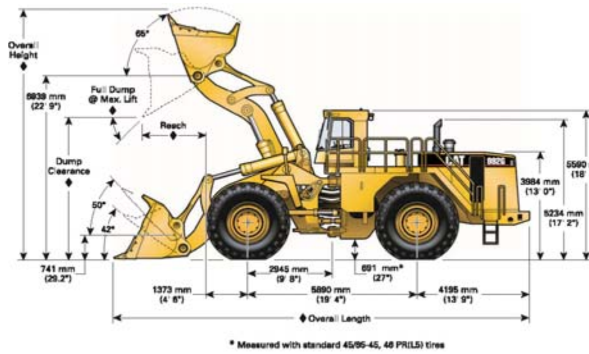


Figure 1. Dimensions

Use integration of the Bousssinesq solution (1885)

1. Define pressure exerted by single tire

Load per tire	60,795	lbs
Tire pressure, q	91	psi
Contact area	668.08	inch^2
Length, a	14.85	inch
Width, b	45.00	inch

2. Define geometry

Wheelbase (3)	19.32	ft
Centerline front tire width (est.)	15.50	ft
Centerline rear tire width (est.)	15.5	ft
Overall tire width (est.)	19.25	ft

Location	Point ID	x (ft)	y(ft)	Surface Load (psi)	a (inch)	b (inch)
Origin (wheelbase center)	A	0.00	0.00	0	0.00	0.00
Mid front axle	B	9.66	0.00	0	0.00	0.00
Front right tire	C	9.66	7.75	91	14.85	45.00
Front left tire	D	9.66	-7.75	91	14.85	45.00
Mid rear axle	E	-9.66	0.00	0	0.00	0.00
Rear rigth tire	F	-9.66	7.75	91	14.85	45.00
Rear left tire	G	-9.66	-7.75	91	14.85	45.00

3. Calculate additional vertical stresses (psi)

Depth \ Point ID	A	B	C	D	E	F	G
1	0.00	0.02	56.65	56.65	0.02	56.65	56.65
2	0.02	0.13	29.06	29.06	0.13	29.06	29.06
3	0.07	0.34	16.69	16.69	0.34	16.69	16.69
4	0.14	0.61	10.54	10.54	0.61	10.54	10.54
5	0.24	0.87	7.19	7.19	0.87	7.19	7.19
6	0.36	1.08	5.19	5.19	1.08	5.19	5.19
7	0.48	1.22	3.94	3.94	1.22	3.94	3.94
8	0.60	1.31	3.10	3.10	1.31	3.10	3.10
9	0.71	1.34	2.52	2.52	1.34	2.52	2.52
10	0.80	1.34	2.11	2.11	1.34	2.11	2.11

4. Calculate activated friction angle

Depth \ Point ID	A	B	C	D	E	F	G
1	0.09	0.60	51.33	51.33	0.60	51.33	51.33
2	0.35	1.99	46.86	46.86	1.99	46.86	46.86
3	0.72	3.45	39.73	39.73	3.45	39.73	39.73
4	1.14	4.51	31.50	31.50	4.51	31.50	31.50
5	1.54	5.08	23.91	23.91	5.08	23.91	23.91
6	1.89	5.23	17.80	17.80	5.23	17.80	17.80
7	2.16	5.09	13.25	13.25	5.09	13.25	13.25
8	2.34	4.79	9.99	9.99	4.79	9.99	9.99
9	2.44	4.41	7.66	7.66	4.41	7.66	7.66
10	2.47	4.00	6.01	6.01	4.00	6.01	6.01

5. Calculate factor of safety

Depth \ Point ID	A	B	C	D	E	F	G
1	288.80	44.89	0.37	0.37	44.89	0.37	0.37
2	76.33	13.43	0.44	0.44	13.43	0.44	0.44
3	37.09	7.74	0.56	0.56	7.74	0.56	0.56
4	23.48	5.91	0.76	0.76	5.91	0.76	0.76
5	17.33	5.25	1.05	1.05	5.25	1.05	1.05
6	14.14	5.10	1.45	1.45	5.10	1.45	1.45
7	12.38	5.23	1.98	1.98	5.23	1.98	1.98
8	11.42	5.56	2.65	2.65	5.56	2.65	2.65
9	10.95	6.04	3.47	3.47	6.04	3.47	3.47
10	10.82	6.66	4.43	4.43	6.66	4.43	4.43

Attachment H

Overliner Piping Design Calculation

TECHNICAL MEMORANDUM

Date:	September 12, 2012	**Project No.:**	113-2209
To:	Tom Radue and Christie Kearney	**Company:**	Barr Engineering Company
From:	Gordan Gjerapic	**Email:**	ggjerapic@golder.com
cc:	Brent Bronson		

RE: **OVERLINER PIPING CALCULATIONS**

1.0 INTRODUCTION

This attachment summarizes the approach and assumptions used to develop the overliner piping design for the lined PolyMet NorthMet stockpiles located near Babbitt, Minnesota. The objective of the design was to minimize drainage time and optimize the system to balance pipe costs and collection efficiency.

2.0 DESIGN PARAMETERS AND ASSUMPTIONS

- 100-year, 24-hr storm event magnitude = 5.2 inches;
- Maximum hydraulic head on liner at mid-point between pipes = 2 feet (per project design criteria), nominal head is 1 foot;
- Waste rock hydraulic conductivity is $k = 1 \times 10^{-2}$ cm/s = 3.3×10^{-4} ft/s;
- Drain cover fill hydraulic conductivity is $k = 0.1$ cm/s = 3.3×10^{-3} ft/s;
- Tertiary collector pipes are PCPE (ADS N-12) pipes with Manning's n = 0.012;
- Secondary collector pipes are PCPE (ADS N-12) pipe with Manning's n = 0.012;
- Assume primary and secondary pipes deform to Figure '8' shape;
- Due to the capacity of the drain cover fill, areas with steeper terrain do not require collection piping; and
- Others, as stated.

3.0 INFLOW RATE

The inflow rate for the overliner pipes is equal to the drainage rate from the stockpiles. Figure 1 shows the maximum daily drainage rate from the stockpiles as a function of stockpile height. The maximum daily drainage rate was modeled using 30-years of climate data from the site location (October 1, 1971 to September 30, 2001) modified to include the 100-year, 24-hour storm event. Figure 2 demonstrates that the primary outlet pipe with the diameter of 12 inches is sufficient to drain stockpile areas of up to forty acres assuming placement of the overliner material with the thickness of 2 feet, i.e. with no uptake provided by the waste rock. Secondary and tertiary pipes are sized for the drainage rate from a single lift of waste rock (i.e., 40 feet) which corresponds to a drainage rate of 0.85 inches/day (Figure 1). For conservatism assume that the maximum daily drainage rate occurs simultaneously over the stockpile

Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, CO 80228 USA
Tel: (303) 980-0540 Fax: (303) 985-2080 www.golder.com

footprint regardless of the height of the waste rock, i.e. neglect the delay of the wetting front caused by the varying height of the stockpile.

4.0 TERTIARY COLLECTION PIPE CALCULATIONS

The following calculations were performed to determine the spacing and maximum lengths of the tertiary collection pipes. The tertiary pipes are 4-inch diameter PCPE pipes.

4.1 Pipe Spacing

The tertiary pipe spacing was calculated using the following equation developed by McWhorter & Sunada (1977):

$$L = \left[(H_{max}^2 - H_o^2) \times \left(4\frac{k}{w}\right)\right]^{0.5}$$

Where: L = pipe spacing (ft);
H_{max} = maximum hydraulic head on liner = 2 ft;
H_o = hydraulic head at pipe = 0 ft;
k = hydraulic conductivity of drain cover fill = 0.1 cm/s; and,
w = inflow rate = 0.85 inch/day = 2.5 $\times 10^{-5}$ cm/s.

A tertiary collection pipe spacing of 250 feet will satisfy the above equation. Conservatively, the spacing between tertiary pipes is limited to **200 feet**.

4.2 Maximum Pipe Length

The minimum liner grade of the stockpiles is approximately 0.5%. The tertiary pipes will be laid skew to the surface contours. Therefore, the minimum grade along the centerline of tertiary piping is assumed to be approximately 0.2%. While some of the flow will be conveyed via the drain cover fill material, tertiary pipes need to provide sufficient capacity to reduce the head on the liner.

From ADS (1995), the flow capacity of a 4-inch pipe is 0.092 ft^3/s. This value assumes the pipe is full and flowing at a slope of 0.2% with a Manning's *n* of 0.012. The ADS pipe capacity table is included as Attachment 1. With a factor of safety of 1.2 to allow for pipe deformation, the design flow rate for the tertiary pipes becomes 0.077 ft^3/s.

The maximum pipe length can be estimated given the inflow rate, design flow rate of the tertiary piping, and calculated pipe spacing.

$$Q = w \times (L \times D)$$

Where: Q = design flow rate (ft^3/s) = 0.077 ft^3/s;
w = inflow rate = 0.85 inch/day = 8.2×10^{-7} $ft^3/s/ft^2$;
L = pipe spacing (ft) = 200 ft; and,
D = maximum pipe length (ft).

Based on this calculation, pipe lengths in excess of **470 feet** may exceed the pipe capacity.

5.0 PRIMARY AND SECONDARY PIPE SIZING

The primary and secondary collection pipes were located in natural swale bottoms within the pad cells and were laid perpendicular to the pad grades to the extent possible. Each pipe was sized for the inflow rate from its contributing area within the pad.

5.1 Flow Capacity

To account for pipe deformation under stockpile loading, assume the primary and secondary pipes deform into a 'Figure 8' shape (i.e., an 8" pipe deforms to two 4" pipes). As a demonstration of how this affects the design flow rate, the flow capacity for various pipe diameters (with and without 'Figure 8' deformation) is presented below based on the ADS table (Attachment 1). Calculations are for pipes at a 0.5% grade (which is representative of the minimum liner grades) with a Manning's n of 0.012.

ADS N-12 Pipe Diameter	Full Flow Capacity (ft^3/s)	Equivalent Figure '8'	Figure '8' Flow Capacity (ft^3/s)
4"	0.15	2 × (2")	0.05
6"	0.43	2 × (3")	0.14
8"	0.93	2 × (4")	0.29
10"	1.68	2 × (5")	0.53
12"	2.73	2 × (6")	0.86
15"	4.95	2 × (7.5")*	1.56
18"	8.05	2 × (9")*	2.54
24"	17.33	2 × (12")	5.46

Note: Manning's equation was used to calculate flow for pipes that are not standard ADS pipe diameters

5.2 Design Calculations

The pipe design calculations are included in Attachment 2.

6.0 PIPE LAYOUT

See design drawings for primary/secondary and tertiary piping (Drawings SKP-020 to SKP-022).

7.0 REFERENCES

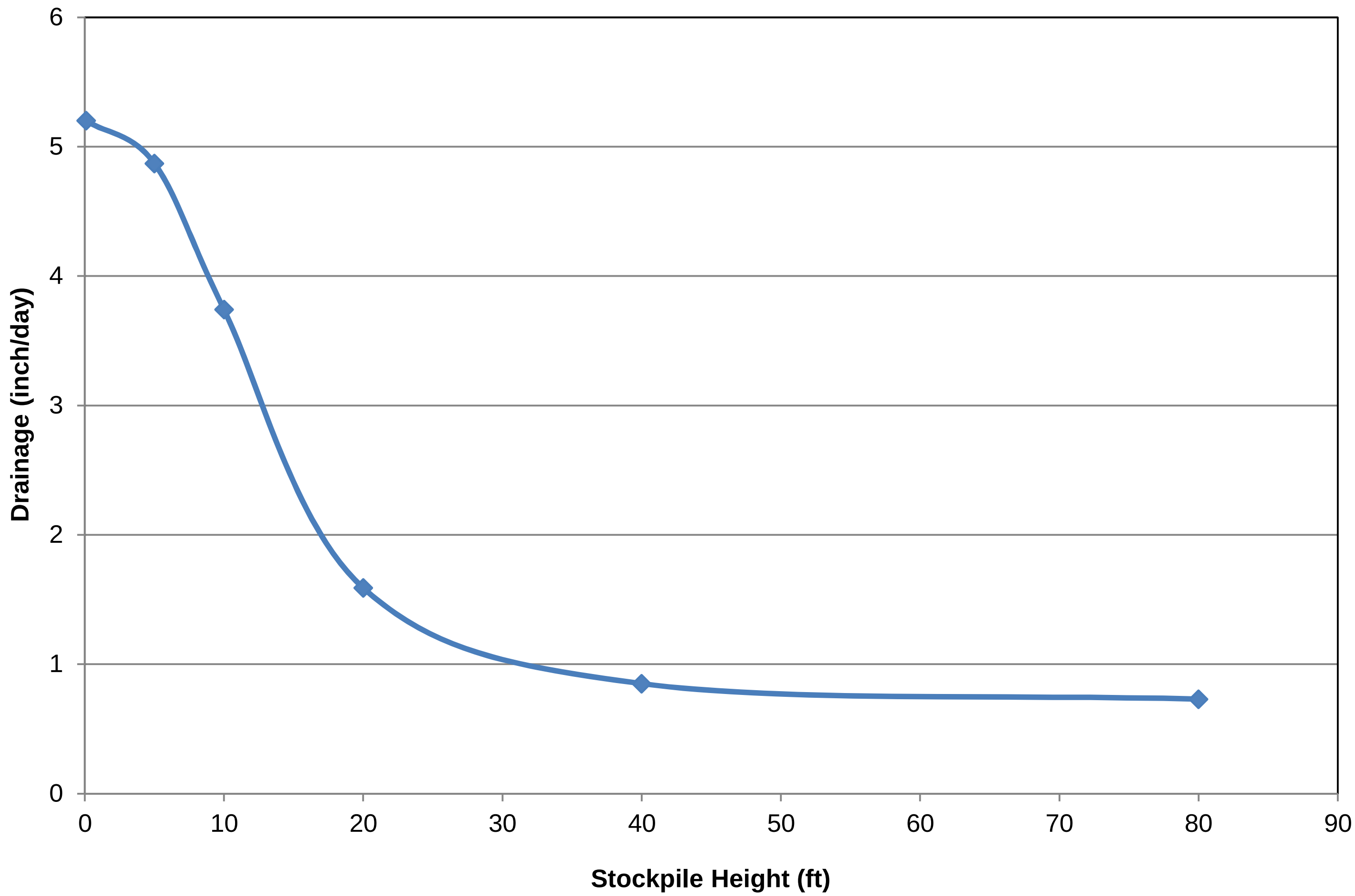
Advanced Drainage Systems Inc (ADS) 1995. Circular Pipe Flow Capacity.

United States Department of Interior, Bureau of Reclamation (USDI), 1978. Drainage Manual. First Edition. A Water Resources Technical Publication. United States Government Printing Office. Washington.

United States Environmental Protection Agency (U.S. EPA), 1989. Technical Guidance Document: The Fabrication of Polyethylene FML Field Seams. U.S. EPA, Washington, D.C. EPA/530-SW-89-069.

McWhorter, D.B. and D.K. Sunada. 1977. Ground-Water Hydrology and Hydraulics. Water Resources Publications, LLC: Fort Collins, Colorado, USA.

FIGURES



Golder Associates

Denver, Colorado

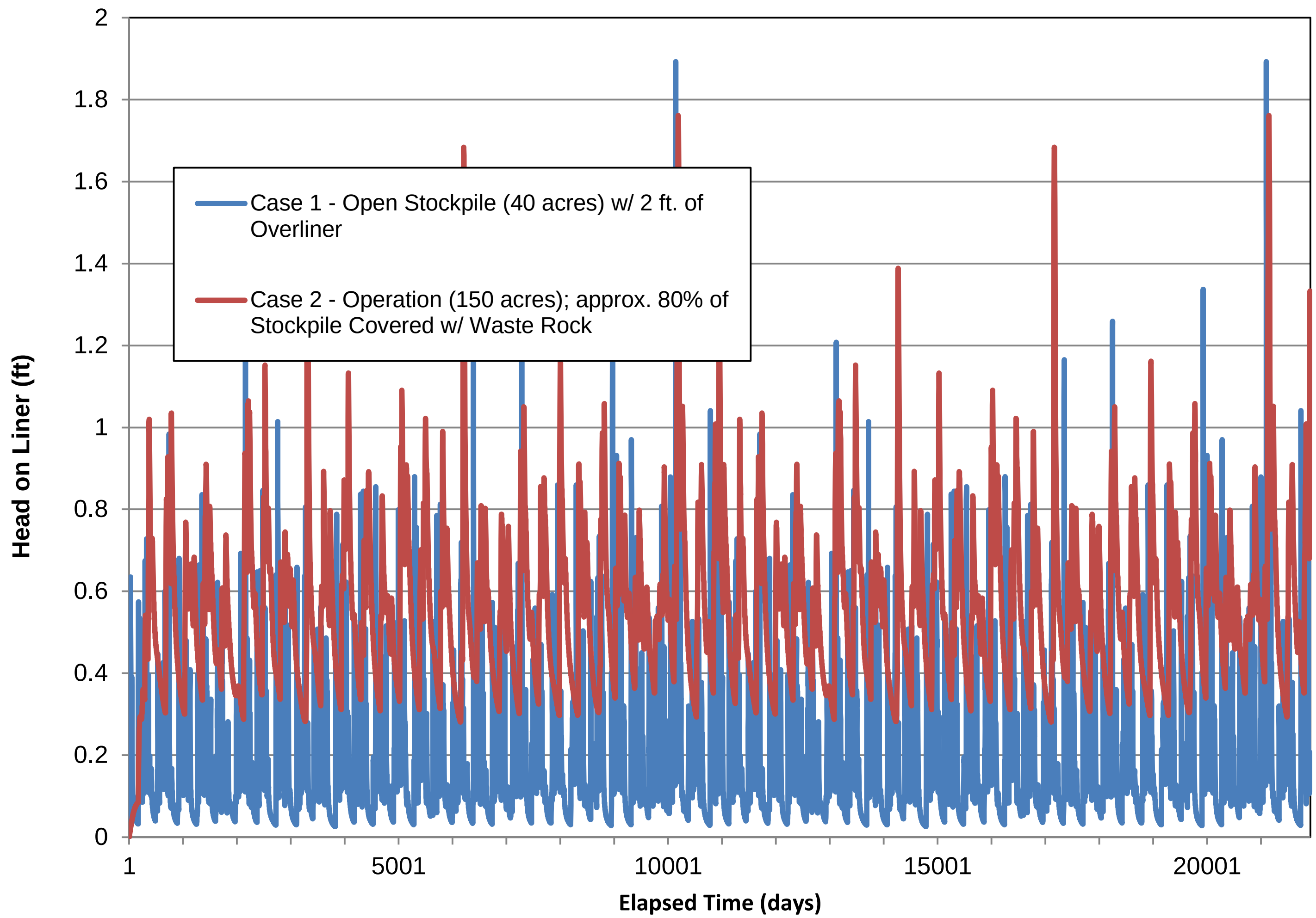
TITLE

Maximum Daily Drainage Rate vs. Stockpile Height

CLIENT/PROJECT

POLYMET MINING CORPORATION
HOYT LAKES, MINNESOTA

DRAWN	GG	DATE	Sep-12	JOB NO.	113-2209
CHECKED	BRB	SCALE	AS SHOWN	DWG. NO.	
REVIEWED	BRB	FILE NO.		FIGURE NO.	FIGURE 1



Golder Associates

Denver, Colorado

TITLE

Maximum Ponding on Liner for 100-Year Storm Event and 12-inch Outlet Pipe

CLIENT/PROJECT

POLYMET MINING CORPORATION
HOYT LAKES, MINNESOTA

DRAWN	GG	DATE	Sep-12	JOB NO.	113-2209
CHECKED	BRB	SCALE	AS SHOWN	DWG. NO.	
REVIEWED	BRB	FILE NO.		FIGURE NO.	FIGURE 2

ATTACHMENT 1
ADS PIPE CAPACITY

ADS(1995)

CIRCULAR PIPE FLOW CAPACITY
Full Flow (cubic feet per second)

Mannings "n"= 0.012

Dia. (in.)	*Conv. Factor	% Slope (feet per 100 feet) 0.02	0.05	0.10	0.20	0.35	0.50	0.75	1.00	1.25	1.50	1.75	2.0	2.5	5.0	10.0	20.0
		(c.f.s.)															
3	0.957	0.014	0.021	0.030	0.043	0.057	0.068	0.083	0.096	0.107	0.12	0.13	0.14	0.15	0.21	0.30	0.43
4	2.062	0.029	0.046	0.065	0.092	0.122	0.146	0.179	0.206	0.231	0.25	0.27	0.29	0.33	0.46	0.65	0.92
5	3.738	0.053	0.084	0.118	0.167	0.221	0.264	0.324	0.374	0.418	0.46	0.49	0.53	0.59	0.84	1.18	1.67
6	6.079	0.086	0.136	0.192	0.272	0.360	0.430	0.526	0.608	0.680	0.74	0.80	0.86	0.96	1.36	1.92	2.72
8	13.091	0.185	0.293	0.414	0.585	0.774	0.926	1.134	1.309	1.464	1.60	1.73	1.85	2.07	2.93	4.14	5.85
10	23.74	0.34	0.53	0.75	1.06	1.40	1.68	2.06	2.37	2.65	2.91	3.14	3.36	3.75	5.31	7.51	10.61
12	38.60	0.55	0.86	1.22	1.73	2.28	2.73	3.34	3.86	4.32	4.73	5.11	5.46	6.10	8.63	12.21	17.26
15	69.98	0.99	1.56	2.21	3.13	4.14	4.95	6.06	7.00	7.82	8.57	9.26	9.90	11.06	15.65	22.13	31.30
18	113.80	1.61	2.54	3.60	5.09	6.73	8.05	9.86	11.38	12.72	13.94	15.05	16.09	17.99	25.45	35.99	50.89
21	171.65	2.43	3.84	5.43	7.68	10.16	12.14	14.87	17.17	19.19	21.02	22.71	24.28	27.14	38.38	54.28	76.77
24	245.08	3.47	5.48	7.75	10.96	14.50	17.33	21.22	24.51	27.40	30.02	32.42	34.66	38.75	54.80	77.50	109.60
27	335.51	4.74	7.50	10.61	15.00	19.85	23.72	29.06	33.55	37.51	41.09	44.38	47.45	53.06	75.0	106.1	150.0
30	444.35	6.28	9.94	14.05	19.87	26.29	31.42	38.48	44.44	49.68	54.42	58.78	62.84	70.26	99.4	140.5	198.7
36	722.57	10.22	16.16	22.85	32.31	42.75	51.09	62.58	72.26	80.79	88.50	95.59	102.19	114.25	161.6	228.5	323.1
42	1089.9	15.41	24.37	34.47	48.74	64.5	77.1	94.4	109.0	121.9	133.5	144.2	154.1	172.3	243.7	344.7	487.4
48	1556.1	22.01	34.80	49.21	69.59	92.1	110.0	134.8	155.6	174.0	190.6	205.9	220.1	246.0	348.0	492.1	695.9

* Conveyance Factor = (1.486 x R2/3 x A) / n

ATTACHMENT 2
PIPE FLOW CALCULATIONS

CLIENT:	Polymet Mining Corporation	PROJECT NO:	113-2209
PROJECT:	Northmet Project	BY:	JP
SUBJECT:	Overliner Pipe Sizing Calcs	REVIEWED BY:	GG
		Date:	June 28, 2012

Design Inflow	
Maximum daily drainage rate (inches/day):	0.85
Overliner pipe inflow per second (ft^3/second/ft^2):	8.2E-07

Notes:

C23-S1 stands for Category 2/3 Secondary Pipe 1

C23-P1 stands for Category 2/3 Primary Pipe 1

See Drawings SKP-020, SKP-021, and SKP-022 for Piping Network Layout

Perforated Corrugated PE Primary and Secondary Pipes Design Calcs - Manning's n = 0.012

Stockpiles and Sub-Areas	Contributing Area (ft^2)	Minimum Slope (%)	Total Flow (ft^3/s)	Required Pipe Diameter* (inch)	Selected Pipe Diameter (inch)	Pipe Length (ft)	Notes
Category 2/3							
C23-P1	77,104	1.0%	0.06	3.96	4	188	
	162,882	0.5%	0.13	5.96	6	138	
	353,972	0.5%	0.29	7.98	8	343	
	612,808	0.5%	0.50	9.80	10	205	Add C23-S1A
	1,036,587	0.5%	0.85	11.94	12	164	Add C23-S1B
	1,289,986	0.5%	1.06	12.96	12	355	Edge of stockpile, assume 20% deformation
C23-S1A	67,592	0.8%	0.06	3.97	4	234	
	164,029	0.5%	0.13	5.98	6	293	
C23-S1B	84,553	1.5%	0.07	3.80	4	255	
	139,659	0.5%	0.11	5.63	6	249	
C23-S2	84,202	2.8%	0.07	3.37	4	227	
	210,453	2.1%	0.17	5.02	6	421	
C23-S3	24,268	0.5%	0.02	2.92	4	107	
	128,020	0.5%	0.10	5.45	6	484	
	310,297	0.5%	0.25	7.59	8	378	
	417,553	0.5%	0.34	8.49	10	852	
C23-S4	55,452	4.0%	0.05	2.70	4	147	
	231,891	1.0%	0.19	5.98	6	287	
	501,316	1.0%	0.41	7.98	8	523	
	912,107	1.0%	0.75	9.99	10	761	
	996,647	1.0%	0.82	10.33	12	355	
C23-S5	234,169	1.0%	0.19	6.00	6	471	
	501,005	1.0%	0.41	7.98	8	230	
	831,620	1.0%	0.68	9.65	10	691	
C23-P2	78,426	1.3%	0.06	3.79	4	344	
	259,288	1.3%	0.21	5.93	6	321	
	503,226	1.0%	0.41	7.99	8	204	Add C23-S6A
	696,150	1.0%	0.57	9.03	10	353	Add C23-S6B
C23-S6A	141,655	3.4%	0.12	3.95	4	141	
C23-S6B	135,859	1.0%	0.11	4.89	6	350	
C23-S7	92,189	1.0%	0.08	4.23	6	1,047	
C23-S8	230,628	1.0%	0.19	5.97	6	848	
C23-S9	231,053	1.0%	0.19	5.97	6	699	
	501,382	1.0%	0.41	7.98	8	258	
	860,728	1.0%	0.71	9.78	10	663	
C23-P3	220,045	1.0%	0.18	5.86	6	461	
	1,474,403	1.0%	1.21	11.96	12	636	Add C23-S9

*Assumes 'Figure 8' shape deformation (i.e., 8” pipe deforms to two 4” pipes)

CLIENT: Polymet Mining Corporation	PROJECT NO: 113-2209		Golder Associates
PROJECT: Northmet Project	BY: JP		
SUBJECT: Overliner Pipe Sizing Calcs	REVIEWED BY: GG	Date: June 28, 2012	

Design Inflow	
Maximum daily drainage rate (inches/day):	0.85
Overliner pipe inflow per second (ft^3/second/ft^2):	8.2E-07

Notes:

C23-S1 stands for Category 2/3 Secondary Pipe 1

C23-P1 stands for Category 2/3 Primary Pipe 1

See Drawings SKP-020, SKP-021, and SKP-022 for Piping Network Layout

Perforated Corrugated PE Primary and Secondary Pipes Design Calcs - Manning's n = 0.012

Stockpiles and Sub-Areas	Contributing Area (ft^2)	Minimum Slope (%)	Total Flow (ft^3/s)	Required Pipe Diameter* (inch)	Selected Pipe Diameter (inch)	Pipe Length (ft)	Notes
C23-S10	119,032	1.0%	0.10	4.66	6	654	
C23-S11	44,694	1.5%	0.04	2.99	4	181	
	223,959	1.0%	0.18	5.90	6	457	
	479,828	1.0%	0.39	7.85	8	470	
C23-P4	86,074	1.3%	0.07	3.92	4	258	
	246,517	1.3%	0.20	5.82	6	424	
	1,038,682	1.3%	0.85	9.99	10	955	Add C23-S11
C23-S12	180,632	1.0%	0.15	5.44	6	1,364	
Category 4							
C4-S1	55,746	0.5%	0.05	3.99	4	265	
	163,604	0.5%	0.13	5.97	6	331	
	355,282	0.5%	0.29	7.99	8	571	
	466,700	0.5%	0.38	8.85	10	536	
C4-S2	164,118	0.5%	0.13	5.98	6	360	
	355,018	0.5%	0.29	7.99	8	301	
	644,607	0.5%	0.53	9.99	10	277	
	688,809	0.5%	0.56	10.24	12	226	
C4-S3	163,484	0.5%	0.13	5.97	6	229	
	355,785	0.5%	0.29	7.99	8	421	
	561,626	0.5%	0.46	9.49	10	737	
C4-S4	76,641	1.0%	0.06	3.95	4	57	
	155,618	4.0%	0.13	3.97	4	167	
	203,519	0.8%	0.17	5.94	6	208	
C4-P1	148,561	1.0%	0.12	5.06	6	473	
	644,298	0.5%	0.53	9.99	10	755	Add C4-S4
OSP							
OSP-S1	56,991	2.0%	0.05	3.10	4	246	
	159,895	1.1%	0.13	5.11	6	449	
	241,976	5.2%	0.20	4.46	6	257	
	277,870	3.8%	0.23	4.98	6	211	
OSP-S2	41,800	1.5%	0.03	2.91	4	167	
	145,466	0.5%	0.12	5.72	6	427	
	204,673	3.6%	0.17	4.49	6	494	
	331,031	1.5%	0.27	6.33	8	559	
OSP-S3	67,121	2.2%	0.06	3.24	4	305	
	211,810	1.6%	0.17	5.29	6	438	
	264,075	0.5%	0.22	7.15	8	253	
OSP-P1	591,134	0.5%	0.48	9.67	10	943	Add OSP-S2
	1,003,881	0.5%	0.82	11.79	12	545	Add OSP-S3

*Assumes 'Figure 8' shape deformation (i.e., 8” pipe deforms to two 4” pipes)

Attachment I

Construction CQA Plan

REPORT

PRELIMINARY CONSTRUCTION QUALITY ASSURANCE PLAN FOR WASTE ROCK STOCKPILE AND ORE SURGE PILE CONSTRUCTION

PolyMet, NorthMet Project, Minnesota

Submitted To:
Barr Engineering

Submitted By:
Golder Associates Inc.
44 Union Blvd., Suite 300
Lakewood, Colorado 80228

Distribution: Barr Engineering - electronic

July 2014

Project No. 113-2209

Table of Contents

List of Tables

1.0 INTRODUCTION

This plan addresses the construction quality assurance (CQA) procedures for the installation of the earthworks (soils) and geosynthetics components required for waste rock stockpile construction at the PolyMet NorthMet Project in Minnesota. This program has been developed to assure that the construction of the soil and geosynthetic components are in compliance with the project SPECIFICATIONS and to demonstrate that the regulatory requirements for the construction are achieved. Construction activities related to procurement, storage, preparation and installation of earthwork and geosynthetic components required for waste rock stockpile construction and construction of related appurtenances are referred hereto as the Work.

The objective of this CQA Plan is to assure that proper materials, construction techniques, and procedures are followed by the **CONTRACTOR** and that the intent of the design is met. The basis of the CQA program for geosynthetics to meet this objective is not to conduct 100 percent CQA coverage of the **INSTALLER**'s work, but rather to provide spot checks of the **INSTALLER**'s means and methods for general conformance with the design requirements. The scope of the geosynthetics CQA program has been established with the goal of 100 percent coverage of deployment and seaming, with 100 percent coverage of the CQC non-destructive testing, and with 75 percent coverage of destructive testing, trial seams and repairs in accordance with industry standards. This CQA Plan also provides the means for resolution of problems that may occur during construction.

This CQA Plan addresses quality assurance, not quality control. This CQA Plan is independent of the quality control (QC) programs conducted by the MANUFACTURERS, **INSTALLERS**, and **CONTRACTORS**. The intent of the earthworks CQA Plan is to provide verification and testing, to demonstrate that the **CONTRACTOR** has met its obligations in the supply and installation of earthwork (soils) materials according to the design, project SPECIFICATIONS, contractual, and regulatory requirements. The intent of the geosynthetics CQA Plan is to provide spot verification and testing of the CQC, to assess whether the **INSTALLER** and **CONTRACTORS** have met their obligations in the supply and installation of geosynthetic materials according to the design, project SPECIFICATIONS, contractual and regulatory requirements. Quality control of earthworks materials is provided by **CONTRACTOR** and refers to those actions taken by the **CONTRACTOR** to ensure that materials and workmanship meet the requirements of the DRAWINGS and SPECIFICATIONS. Quality Control for geosynthetics materials is provided by the MANUFACTURERS, **INSTALLERS**, and **CONTRACTORS** and refers to those actions taken by them to ensure that their materials and workmanship meet the requirements of the plans and project SPECIFICATIONS.

Quality assurance testing, with the exception of the suite of tests completed for Soil Liner 1 and Soil Liner 2 samples associated with permeability, shall be performed at the place of installation. Quality control testing may be performed at the point of processing, from the stockpile, or at the place of installation.

1.1 Description of Parties to Construction Quality Assurance

The following section provides descriptions of the parties to this CQA Plan including their responsibilities and qualifications.

OWNER

In this CQA Plan, the **OWNER** refers specifically to PolyMet Mining, Inc.

MANAGER

In this CQA Plan the **MANAGER** refers specifically to the individual or firm appointed by PolyMet Mining, Inc. as the official representative of the **OWNER,** responsible for coordination of construction activities including oversight and direction of **CONTRACTOR(s)** and **INSTALLER(s)** during construction. The **MANAGER** is also responsible for coordinating construction and CQA activities for the project.

The **MANAGER** shall serve as communications coordinator for the project initiating preconstruction and resolution meetings. As communications coordinator, the **MANAGER** shall serve as a liaison between all parties involved in the project to ensure that ongoing communications are maintained. The **MANAGER** and **ENGINEER OF RECORD** shall also be responsible for the resolution of all CQA issues.

Duties for this position include the following:

- Review and approval of design DRAWINGS and project SPECIFICATIONS for all soil and geosynthetic components of the waste rock stockpile construction and construction of related appurtenances as prepared by the **DESIGN ENGINEER**;
- Preconstruction coordination with the **DESIGN ENGINEER**, **ENGINEER OF RECORD** and CQA Monitor to ensure that the CQA Monitor has performed similar reviews of the design DRAWINGS and project SPECIFICATIONS to ensure that the CQA Plan can be implemented;
- Coordination of all construction activities associated with the various **CONTRACTOR(S)**;
- Scheduling and coordinating construction activities with required CQA testing and activities;
- Overseeing the construction quality control operations performed by the **CONTRACTOR(S)**;
- Approve specific corrective measures to be implemented during construction when deviations from the SPECIFICATIONS occur;

- Ensure that required quality control testing (e.g., execution of the specified test procedures, testing at the required locations, testing at the specified frequency and/or performing specified number of tests) has been performed in accordance with the CQA Plan and to the satisfaction of the CQA Monitor; and
- Ensure that the CQA personnel are provided with all documentation required in the CQA Plan and project SPECIFICATIONS.

DESIGN ENGINEER

DESIGN ENGINEER(s) for the PolyMet NorthMet Stockpiles are Barr Engineering (Barr) and Golder Associates Inc. (Golder). **DESIGN ENGINEER** is the firm responsible for the design and preparation of the DRAWINGS and SPECIFICATIONS. In addition, **DESIGN ENGINEER** is responsible for approving all DESIGN and SPECIFICATION changes, modifications, or clarifications encountered during construction. Barr is the **DESIGN ENGINEER** for the process water collection sumps and all appurtenances downgradient of stockpile liner berms with the exception of underdrain sumps designed by Golder. Golder is responsible for the design of the underdrain sumps and for the design upgradient of the stockpile liner berms i.e., areas within Category 1 Stockpile, Category 2/3 Stockpile, Category 4 Stockpile and Ore Surge Pile footprints. The **DESIGN ENGINEER** shall be a Minnesota registered professional engineer.

ENGINEER OF RECORD

In this CQA Plan, **ENGINEER OF RECORD** for the project refers to: (1) Barr Engineering (Barr) for the process water collection sumps and all appurtenances downgradient of stockpile liner berms except for the underdrain sumps; and (2) Golder Associates Inc. (Golder) for the underdrain sumps and for the areas upgradient of stockpile liner berms i.e., areas within Category 1 Stockpile, Category 2/3 Stockpile, Category 4 Stockpile and Ore Surge Pile footprints. **ENGINEER OF RECORD** is the firm responsible for certifying that the construction was performed in compliance with the DRAWINGS and SPECIFICATIONS. **MANAGER** and **ENGINEER OF RECORD** shall be responsible for the resolution of all quality assurance issues.

CONSTRUCTION QUALITY ASSURANCE MONITOR

The Construction Quality Assurance Monitor, also referred to as the "CQA Monitor," is a representative of the **ENGINEER OF RECORD** and is the individual responsible for performing the CQA tasks outlined in this CQA Plan. The CQA Monitor is the official CQA representative of the **ENGINEER OF RECORD** and has the responsibility of overseeing the CQA aspects of the project. The CQA Monitor has the authority to stop any aspect of the Work that is not in compliance with the CQA Plan and/or in compliance with the SPECIFICATIONS. Work would then be resumed once corrective action has been approved by the **MANAGER** and **ENGINEER OF RECORD**. The specific responsibilities of the CQA Monitor include:

- Review the design DRAWINGS, project SPECIFICATIONS, and related guidance documents;
- Review all **CONTRACTOR** QC submittals and make appropriate recommendations;
- Obtain preconstruction and construction soil samples and perform material evaluation testing as required;
- Obtain and test geosynthetic conformance samples during geosynthetics manufacture;
- Observe geosynthetic material delivery, unloading, and storage;
- Monitor foundation preparation activities and material placement as discussed in articles 2.2.1 and 2.2.2 of this document;
- Monitor the ambient air temperature and fill temperature, as outlined in Section 02300.0 of the SPECIFICATIONS;
- Maintain an on-site soils laboratory and perform regular calibration of soil testing equipment;
- Observe prepared subgrade prior to geosynthetic deployment;
- Monitor and document geosynthetic material placement, trial seam testing, non-destructive testing, seaming and repair operations, and destructive testing;
- Identify seam samples for CQA destructive testing;
- Assure that testing equipment used, and tests performed are conducted according to project SPECIFICATIONS and industry standards;
- Perform or observe, document, and report test results to **MANAGER** as required;
- Report any deficiencies to **MANAGER** that are not corrected to the satisfaction of the CQA Monitor, including design or project SPECIFICATION changes initiated by authorized parties including the **ENGINEER OF RECORD**; and
- Prepare a Construction Quality Assurance Report describing the construction, any deviations from SPECIFICATIONS or DRAWINGS and details, details of all field and laboratory work, subgrade acceptance forms, test data, tests results (both laboratory and field), QC submittals, geomembrane panel layout as-built prepared by the CQA Monitor, photographic record of construction sequencing and construction details, professional certification that construction was completed in compliance with the DRAWINGS and SPECIFICATIONS. The report will be signed and sealed by the **ENGINEER OF RECORD**.

EARTHWORKS CONTRACTOR

The Earthworks Contractor, also referred to as “**CONTRACTOR**”, is responsible for proper processing, delivery, and placement of all components as outlined in the SPECIFICATIONS.

GEOSYNTHETICS MANUFACTURER

The Geosynthetics Manufacturer, also referred to as the "MANUFACTURER," is responsible for production of the geosynthetic components outlined in this CQA Plan. Each MANUFACTURER must verify prior to construction that the MANUFACTURER can produce material that meets the requirements outlined in project SPECIFICATIONS.

GEOSYNTHETICS INSTALLATION CONTRACTOR

The Geosynthetics Installation Contractor, also referred to as the "**CONTRACTOR**" or "**INSTALLER**," is responsible for installation of the geosynthetic components, as outlined in the project SPECIFICATIONS.

The **INSTALLER** will be responsible for storage, handling, deploying, temporary geomembrane anchoring, seaming, repairs and non-destructive testing, in accordance with the project plans, SPECIFICATIONS and the **INSTALLER**'s internal quality control program. It is the **INSTALLER**'s responsibility to see that all submittals are received as outlined in the project SPECIFICATIONS.

1.2 Lines of Communication

The CQA Monitor shall be capable of direct communication with the **MANAGER**, **DESIGN ENGINEER**, **ENGINEER OF RECORD** and **CONTRACTOR** at all times. Deficiencies that can be easily remedied, such as unsatisfactory test results, will be dealt with directly between the CQA Monitor, **INSTALLER**, and/or **CONTRACTORS**.

If there is a disagreement among the **MONITOR, INSTALLER** and/or **CONTRACTORS** that cannot be resolved among themselves, **MANAGER** shall present the matter to the **OWNER** with **MANAGER** related recommendations and the **OWNER** shall decide the matter with such decision being final.

1.3 Deficiencies

When deficiencies (items that do not meet project requirements) are discovered, the CQA Monitor shall immediately determine the nature and extent of the problem and notify the **INSTALLER** or **CONTRACTOR**. If unsatisfactory test results identify a deficiency, additional tests will be performed to define the extent of the deficient area.

The **INSTALLER** or **CONTRACTOR** shall correct the deficiency to the satisfaction of the CQA Monitor. If the **CONTRACTOR** is unable to correct the problem, the CQA Monitor will notify the **MANAGER** and **ENGINEER OF RECORD** who will assist in problem resolution. If the solution involves a design revision, the **DESIGN ENGINEER** must also be contacted.

The corrected deficiency shall be retested and/or approved by the **MANAGER** and **ENGINEER OF RECORD** before any additional related work is performed by the **INSTALLER** or **CONTRACTOR**. All retests and related documentation shall be recorded by the CQA Monitor and included in the final CQA Report.

1.4 Meetings

This section identifies and describes the meetings to be held during the course of the construction. Meetings shall be held in order to clearly define construction activities and goals in order to facilitate construction.

1.4.1 Pre-Construction Meeting

The **MANAGER** will hold a preconstruction meeting at the site prior to the start of construction. The **DESIGN ENGINEER**, **MANAGER**, **ENGINEER OF RECORD**, CQA Monitor, **INSTALLER**, **CONTRACTOR**, and others designated by the **MANAGER** shall attend this meeting. The purpose of this meeting will be to:

- Review the construction DRAWINGS, CQA Plan, and project SPECIFICATIONS;
- Define the responsibilities of each party;
- Define lines of communication and authority;
- Review method of documentation, testing procedures, and reporting inspection data;
- Establish testing protocols and procedures for correcting and documenting construction deficiencies; and
- Discuss any changes that may be needed to ensure that construction will be completed in compliance with the design.

This meeting will be documented by the **MANAGER** or his designee and copies distributed to all parties.

1.4.2 Progress Meeting

The **MANAGER** will hold a daily progress meeting, either before the start of work or at the completion of work. At a minimum, this meeting will be attended by the CQA Monitor, **INSTALLER** and **CONTRACTOR**. The purpose of this meeting will be to:

- Review and discuss safety requirements and protocol;
- Review all the previous day's accomplishments and activities;
- Review scheduled work location and activities for the day; and
- Discuss any problems or potential construction problems.

This meeting will be documented by the CQA Monitor.

1.4.3 Deficiency Meetings

Special meetings will be held, as needed, to discuss potential problems or deficiencies. At a minimum, these meetings will be attended by the CQA Monitor and **INSTALLER** or **CONTRACTOR**. If the problem relates to a design issue, the **MANAGER**, **DESIGN ENGINEER,** and **ENGINEER OF RECORD** should also be present. The meeting will be documented by the CQA Monitor.

1.5 Documentation

Documentation kept by the CQA Monitor shall consist of daily record-keeping, construction problem resolutions, design and SPECIFICATION changes, photographic records of construction, weekly progress reports, chain of custody forms for test sample tracking, and a CQA Report.

1.5.1 Daily Record Keeping

Daily records kept by the CQA Monitor shall consist of field notes, observation and testing data sheets, summary of the daily meeting with **CONTRACTOR**, and reporting of construction problems and resolutions. The CQA Monitor shall submit this information on a daily basis to **MANAGER** for review.

1.5.2 Soils Observation and Testing Forms

The CQA Monitor will document soils observations on forms that generally include the following information:

- Date, project name, location, and weather data, including high and low daily temperatures;
- A site plan or sketch showing work areas and test locations;
- Descriptions of ongoing construction describing work areas and equipment utilized by **CONTRACTOR**;
- Summary of test results and samples obtained, with sample locations and sample elevations and approximate moisture conditions and/or groundwater level observed;
- Resolutions of deficient test results;
- Test equipment calibrations, if necessary;
- Summary of meetings held; and
- Signature or initials of the CQA Monitor.

1.5.3 Geosynthetics Observation and Testing Forms

The CQA Monitor shall work with the CQC personnel to document geosynthetic observations and test results on forms which include the following information:

- Date, project name, location, and weather data;
- Identification of panel or seam numbers;
- Description of ongoing construction, detailing deployment areas;
- Numbering system identifying test or sample number;
- Location and identification of repairs and date of repair;
- Length and/or thickness measurements for geomembrane panels or seams;
- Welding machine temperatures and settings;
- Welding machine and technician identifications;

- Location of tests and test results;
- Identification of testing technicians and time of tests; and
- Signature or initials of the CQA Monitor.

1.5.4 Photo Documentation

The CQA Monitor shall photograph all phases of construction. Photographs shall be identified by location, time, date, and name of the CQA Monitor taking the photograph.

1.5.5 Weekly Progress Reports

The CQA Monitor shall prepare weekly progress reports summarizing all construction and quality assurance activities. This report shall be submitted to **MANAGER** prior the start of the next work week and shall include the following information:

- Date, project name, and location;
- Summary of construction related activities;
- Summary of samples taken and test results;
- Summary of geomembrane deployed (per day);
- Summary of geomembrane areas completed and approved for subsequent Overliner Material placement;
- Summary of deficiencies and/or defects and resolutions; and
- Signature of the CQA Monitor.

1.5.6 Design and Specification Changes

During construction, the need to address design and SPECIFICATION changes, modifications, or clarifications may arise. In such cases the CQA Monitor shall notify **MANAGER**, which shall notify the **DESIGN ENGINEER** and the **ENGINEER OF RECORD**. Design or SPECIFICATION modifications and changes shall only be made with written agreement from **MANAGER** and **DESIGN ENGINEER.**

1.5.7 Construction Quality Assurance Report

At the completion of the project at a schedule mutually agreed with the **MANAGER**, the CQA Monitor shall submit to the **MANAGER** a Construction Quality Assurance (CQA) Report. This report shall certify that the Work has been performed in compliance with the design DRAWINGS and project SPECIFICATIONS and will contain the following information:

- Summary of all construction activities;
- Observation and test data sheets;
- Photographic documentation;
- CQA staff scheduling;
- Copies of weekly reports;

- **CONTRACTOR'S** subgrade acceptance forms;
- CQA test results, including date, test locations and resolutions of deficient test results;
- Copies of surveyors certificate;
- Fill temperature monitoring results;
- Air temperature monitoring results;
- Geosynthetic quality control documents;
- Geosynthetic quality assurance documents;
- Geomembrane installation observations, such as for deployment, trial seams, defect repair, destructive testing and non-destructive testing;
- Sampling, testing locations, and test results;
- Changes to the design DRAWINGS or project SPECIFICATIONS and the justification for these changes;
- Record DRAWINGS; and
- A certification statement that construction was completed in compliance with the DRAWINGS and SPECIFICATIONS, signed, and sealed by the **ENGINEER OF RECORD**.

1.6 Surveying

Record survey documentation will be conducted as part of the **CONTRACTOR**'s QC, with the CQA Monitor conducting periodic spot reviews and/or checks. The use of a Global Positioning System (GPS) receiver calibrated to the local mine site GPS network using mine site coordinates can assist in this documentation. Survey data shall be submitted at the frequency and in a form as mutually agreed with the CQA Monitor, **ENGINEER OF RECORD**, and **MANAGER**.

2.0 EARTHWORKS CONSTRUCTION QUALITY ASSURANCE

Construction of the waste rock stockpile foundations, and other specified earthworks shall be in accordance with the DRAWINGS and SPECIFICATIONS. A CQA monitoring and testing program shall be implemented by the **OWNER** to ensure construction compliance by the **CONTRACTOR**. The CQA testing program shall consist of testing of materials used in Category 1 Stockpile, Category 2/3 Stockpile, Category 4 Stockpile and Ore Surge Pile construction and construction of related appurtenances. Liner systems for the facilities are as follows:

- Unlined: Category 1 Stockpile (construction activities include removal of unsuitable soils within 100 feet from the ultimate stockpile boundaries and replacement of the excavated materials with Structural Fill. Structural Fill materials are expected to consist either of overburden material or Category 1 waste rock approved by the **MANAGER**)
- Soil Liner 1: Category 4 Stockpile and Ore Surge Pile
- Soil Liner 2: Category 2/3 Stockpile

Each of the four facilities (Category 1 Stockpile, Category 2/3 Stockpile, Category 4 Stockpile and Ore Surge Pile) will require earthworks and earthworks construction quality assurance as described in this section (Section 2.0). The types of materials are defined in the SPECIFICATIONS. During construction, the CQA Monitor shall sample and test construction material (soil types) to determine if they meet SPECIFICATIONS. The CQA Monitor shall obtain and test soil samples in accordance with American Society for Testing and Material standards ASTM D75 and ASTM D420. All tests shall be performed by the CQA Monitor on-site or in a geotechnical laboratory approved by **MANAGER**.

2.1 Construction Testing

During construction, the CQA Monitor shall test all earthwork components to verify that the construction is in accordance with the SPECIFICATIONS. Testing shall be performed on all soil used in the construction to confirm the materials meet SPECIFICATIONS. The CQA Monitor shall conduct testing after final placement of the materials with the exception of permeability testing for Soil Liner 1 and Soil Liner 2. Samples of Soil Liner 1 and Soil Liner 2 for permeability testing shall be obtained at a minimum frequency of 1 per 10,000 cubic yards from the stockpiles and forwarded for CQA testing prior to placement. The tests to be performed, and the testing frequency, for each material type are listed in Tables 1 to 4 at the end of this Section. The testing frequencies specified in Tables 1 to 4 shall be increased when the CQA Monitor determines that construction conditions (such as adverse weather, equipment breakdown, improperly ballasted compactor, excessive lift thickness, improper soil type, improper moisture conditioning, and compaction) warrant additional tests. Additional tests will be approved by **MANAGER** and directed by the CQA Monitor.

2.2 Construction Monitoring

The CQA Monitor will monitor and test all earthwork quality assurance components of the construction to verify that the construction is in accordance with the SPECIFICATIONS. The CQA

Monitor shall identify inadequate construction methodologies or materials that may adversely impact the performance of the facility being constructed and existing structures. The CQA Monitor will record visual observations throughout the construction process to ensure that the materials are placed to the minimum dimensions as shown on the DRAWINGS. Quality control testing will be performed by the **CONTRACTOR**.

2.2.1 Foundation Preparation

The CQA Monitor shall observe and document the foundation preparation including:

Stripping and excavation activities are required to remove any material containing organics, high plasticity clays, frozen soil or other geotechnically unsuitable materials from under the lined stockpiles or within 100 feet from the Category 1 stockpile boundaries. The CQA Monitor will document that any unsuitable materials, as determined by the **ENGINEER OF RECORD**, are removed;

- Stripping, excavation and processing activities are required to ensure that **CONTRACTOR** places the material in the appropriate stockpile (e.g. Structural Fill, Soil Liner 1, Soil Liner 2, Common Fill 1, Granular Drainage Material 1, Drain Rock, Geomembrane Bedding Layer and Granular Filter) if stockpiling is necessary;
- Excavations for moisture seeps, unsuitable foundation soil, elevation, and proper drainage;
- Foundation subgrade preparation to confirm that the surface of the subgrade is free of soft, organic, and otherwise deleterious materials (such as peat, debris, branches, vegetation, mud, ice, or frozen materials); and that soil and rock surfaces that contain joints or fractures are adequately filled if required by the SPECIFICATIONS;
- Construction of access roads, underdrains, and erosion control features to verify compliance with the DRAWINGS and SPECIFICATIONS.

2.2.2 Placement of Materials

During placement of Structural Fill, Soil Liner 1, Soil Liner 2, Common Fill 1, Granular Drainage Material 1, Drain Rock, Geomembrane Bedding Layer, Granular Filter, Riprap and Random Fill, the CQA Monitor shall:

- Verify the use of appropriate earthwork materials; and
- Monitor and document material placement, including soil type, particle size, loose lift thickness, moisture conditioning process, compaction equipment and methods used to attain compaction, including number of passes, uniformity of compaction coverage, compacted lift thickness, bonding of lifts and in-place moisture content and dry density is in compliance with the SPECIFICATIONS.
- Monitor Soil Liner 1 and Soil Liner 2 placement and surface preparation to verify that the surface is suitable for geomembrane installation as discussed in Section 02300.0 of the SPECIFICATIONS;
- Monitor the placement of Granular Drainage Material 1 and Drain Rock to ensure that **CONTRACTOR** exercises care in the vicinity of pipes and that the geosynthetic liner and geotextile components of the Work are not damaged;

- Monitor and document **CONTRACTOR** verification of in-place Soil Liner 1 and Soil Liner 2 thickness;
- Monitor equipment being used to place Granular Drainage Material 1 to verify that the **CONTRACTOR** places the material in accordance with the SPECIFICATIONS;
- Monitor that Soil Liner 1, Soil Liner 2, Granular Drainage Material 1 and Drain Rock are pushed uphill for areas in which the slope exceeds 4H:1V and that the dozer does not perform unacceptable pivot turns;
- Monitor and document **CONTRACTOR** verification of in-place Geomembrane Bedding Layer thickness and verify that the material is placed in accordance with the SPECIFICATIONS;
- Monitor equipment being used to place Granular Filter to verify that the **CONTRACTOR** places the material in accordance with the SPECIFICATIONS;
- Monitor the placement of sump materials to lines and grades specified in the DRAWINGS to confirm that they comply with Section 02300.0 of the SPECIFICATIONS; and
- Monitor the fill temperature as identified in Section 02300.0 of the SPECIFICATIONS.

3.0 GEOSYNTHETICS CONSTRUCTION QUALITY ASSURANCE

Construction of the lined stockpiles and related appurtenances must be in compliance with the design DRAWINGS and SPECIFICATIONS. The **OWNER** shall implement a CQA monitoring and testing program to ensure construction compliance by the **CONTRACTOR**. The quality assurance program shall consist of reviewing **CONTRACTOR** quality control submittals, material conformance testing, and construction monitoring and testing.

The types of geosynthetics used in construction include geomembrane and geotextile as specified on the DRAWINGS. These geosynthetics are defined in the project SPECIFICATIONS. Prior to and during construction, these geosynthetics shall be sampled and tested to determine if they meet project SPECIFICATIONS. All tests shall be performed in a geosynthetics laboratory approved by the **MANAGER**.

3.1 Review Quality Control Submittals

Prior to geosynthetics installation, the CQA Monitor shall review the INSTALLER's quality control submittals to evaluate or confirm that these materials meet project requirements. The CQA Monitor shall review the QC submittals that are outlined in Section 02273.0 (Geomembrane) and Section 02272.0 (Geotextile) of the SPECIFICATIONS.

3.2 Geosynthetics Conformance Testing

Prior to installation, the CQA Monitor shall obtain samples of the geosynthetic materials for conformance testing to confirm that these materials meet project requirements. Conformance tests shall be performed in compliance with the project SPECIFICATIONS. The CQA Monitor shall review the test results and shall report any nonconformance to the **MANAGER**, **ENGINEER OF RECORD,** and the **INSTALLER**.

3.2.1 Geomembrane Conformance Testing

The conformance testing frequency shall be at a rate of one (1) test per 150,000 square feet. Samples shall be taken across the entire width of the roll and shall not include the first three (3) feet. The samples shall be three (3) feet wide by the roll width. The CQA Monitor shall mark on the sample the machine direction, roll number, and date the sample was obtained, and forward the sample to a third party geosynthetic laboratory. As a minimum, the following conformance tests shall be conducted:

1. Compound Density (ASTM D1505)
2. Carbon black content (ASTM D1603)
3. Thickness (ASTM D5199/D5994)
4. Tensile strength (ASTM D6693)

Project requirements for geomembrane are outlined in Section 02273.0.

3.2.2 Geotextile Conformance Testing

The conformance testing frequency shall be at a rate of one (1) test per 150,000 square feet. Samples shall be taken across the entire width of the roll and shall not include the first three (3) feet. The samples shall be three (3) feet wide by the roll width. The CQA Monitor shall mark on the sample the machine direction, roll number, and date the sample was obtained, and forward the sample to a third party geosynthetic laboratory. As a minimum, the following conformance tests shall be conducted:

1. Mass Per Unit Area (ASTM D5261)
2. Puncture (ASTM D4833)
3. Apparent Opening Size (ASTM D4751)

Project requirements for geotextile are outlined in Section 02272.0.

3.2.3 Interface Shear Conformance Testing

Prior to geosynthetic procurement, the **CONTRACTOR** shall supply samples of the proposed geosynthetic liner system materials for confirmatory interface shear testing in accordance with ASTM D5321. Testing shall be conducted on the following liner interfaces:

1. Soil Liner 1 with 80 mil LLDPE versus Granular Drainage Material 1.
2. Soil Liner 2 with 80 mil LLDPE versus Granular Drainage Material 1.

If the test set-up restricts placement of the Granular Drainage Material 1, the **ENGINEER OF RECORD** may choose to perform the testing on Soil Liner and LLDPE interface without Granular Drainage Material after reviewing supplied samples and the preliminary test results.

Interface shear testing shall be conducted by a qualified third party geosynthetics testing laboratory with testing methodology confirmed with the **ENGINEER OF RECORD**.

3.3 Geosynthetics Construction Monitoring and Testing

The CQA Monitor shall monitor and test all geosynthetic components of the construction to verify that the construction is in compliance with the project SPECIFICATIONS. The CQA Monitor shall identify inadequate construction methodologies or materials which may adversely impact the performance of the facility being constructed and existing structures. Any deviations from SPECIFICATIONS require pre-approval by **ENGINEER OF RECORD** and **MANAGER** prior to proceeding with the WORK if such is not proposed to be remedied to fully comply with the SPECIFICATIONS. Visual observations throughout the construction process shall be made to ensure that the materials are placed to the lines and grades as shown on the DRAWINGS.

The CQA Monitor shall review the following submittals by the **INSTALLER** during the project:

- Verification that a qualified land surveyor has verified all lines and grades; and
- Subgrade surface acceptance certificates for each area to be covered by the lining system, signed by the **INSTALLER**.

The CQA Monitor shall:

- Inspect all geosynthetic materials delivered to site. The CQA Monitor shall document any damage and notify **MANAGER**;
- Obtain geosynthetic packaging identification slips for verification and generation of an on-site materials inventory;
- Observe subgrade conditions prior to geosynthetics installation and verify that any deficiencies, as defined in Section 02300.0 of the SPECIFICATIONS, are corrected;
- Observe permanent anchoring of geosynthetics to verify that design and project SPECIFICATIONS are met;
- Observe that required overlap distances are met;
- Monitor and record ambient air temperatures;
- Verify that no continuous horizontal seams are placed on slopes unless approved by **ENGINEER OF RECORD**; and
- Observe and document that all soil materials placed on top of the geosynthetics are done in such a manner as to ensure that the geosynthetics are not damaged.

3.3.1 Geomembrane Installation Quality Assurance

During geomembrane installation, the CQA Monitor shall observe and document deployment, trial seams, field seaming, non-destructive and destructive seam testing, and repairs to assess that the installation is in compliance with the SPECIFICATIONS. The scope of the CQA program has been established with the goal of 100 percent coverage of deployment and seaming, with 75 percent coverage of the CQC non-destructive testing, destructive testing, trial seams and repairs.

Deployment - The CQA Monitor shall verify that only approved materials are used, each panel is given a unique panel number, no geomembrane is placed during unsuitable weather conditions as outlined in Section 02273.0 of the SPECIFICATIONS, the geomembrane is not damaged during installation, and anchoring is performed in compliance with the SPECIFICATIONS and design DRAWINGS. The CQA Monitor shall record the deployment on the deployment log form.

Trial Seams - The CQA Monitor shall verify that seaming conditions are performed in compliance with the SPECIFICATIONS, tests are performed at required intervals, specified test procedures are followed, and retests are performed in compliance with the SPECIFICATIONS. If the ambient air temperature measured by the CQA Monitor is above 40°F for the entire day, the CONTRACTOR shall perform trial seams at the beginning of each crew shift, and immediately following any work stoppage (i.e., for lunch, weather conditions, etc.) of 30 minutes or more for each seaming apparatus used that day. If the ambient air temperature measured by the CQA Monitor is below 40°F for the entire day, the CONTRACTOR shall perform four (4) trial seams, at approximately the same time interval throughout the scheduled work day. Each seamer shall make at least one trial seam each day. Seaming operation shall not commence until the CQA Monitor has determined that the seaming process is meeting the SPECIFICATION requirement and is acceptable. The CQA Monitor shall record the trial weld results on the trial seam log form.

Field Seaming - The CQA Monitor shall verify that only approved equipment and personnel perform welding, all welding is performed under suitable conditions as specified in the project SPECIFICATIONS, specified overlaps are achieved, seams are oriented in compliance to project requirements, and that grinding techniques and extrudate meet project requirements for extrusion welding. The CQA Monitor shall record all field seaming on field seaming log forms.

Non-Destructive Seam Continuity Testing - The CQA Monitor shall verify that the seams and repair are non-destructively tested by CQC personnel in compliance with the project SPECIFICATIONS. If a seam cannot be tested, the CQA Monitor shall ensure that CQC monitors observe cap strip operations. The CQA Monitor shall verify that test equipment and gauges are functioning properly and that test procedures are in compliance with the project SPECIFICATIONS. The CQA Monitor shall verify that the seams and repairs with failing test results are repaired and/or re-tested until passing results are achieved. The CQA Monitor shall record observed non-destructive test locations on the vacuum test and pressure test log forms.

Destructive Seam Testing - The **CONTRACTOR** shall obtain samples, at locations selected by the CQA Monitor, of the field seamed geomembrane approximately 2 ft along and 1 ft across the seam and centered over the seam as follows:

- A minimum of one sample per day;
- A minimum of one sample for each geomembrane seamer;
- A minimum of one sample every 500 ft of seaming is required unless, in the opinion of the CQA Monitor, the seamer has demonstrated sufficient quality/experience to increase the seam sample interval. In no event shall the sampling interval exceed 1,000 ft; and
- Seams that appear suspect to the CQA Monitor.

The CQA Monitor shall witness the testing of destructive seam samples by the **INSTALLER**'s CQC personnel. The **INSTALLER** shall mark all samples with their roll and seam number, date, machine number, welding technician identification, extruder and nozzle/wedge temperature, and ambient air temperature. The **INSTALLER** shall test all destructive samples in compliance with the project SPECIFICATIONS.

The **INSTALLER** shall be responsible for patching all areas cut for test samples in accordance with the SPECIFICATIONS and MANUFACTURER's requirements and performing non-destructive testing (i.e., vacuum box) of the seams. The CQA Monitor shall record test locations on the geomembrane defect log forms. Additional testing information will be recorded on the geomembrane seam destructive sample log form. The CQA Monitor shall track failing tests as described in the SPECIFICATIONS.

Repairs - The CQA Monitor shall observe and document that all repair materials, techniques, and procedures used for repairs are approved in advance and meet the requirements of the project SPECIFICATIONS. The CQA Monitor shall verify that all defects and repairs are marked, recorded, repaired, tested, and wrinkles are addressed, prior to being covered by other materials; and that repairs are performed as specified, including proper patch size or dimension. The CQA Monitor shall record defects and repairs on the defect and repair log forms.

3.3.2 Geotextile Installation Quality Assurance

The CQA Monitor shall observe and document that the correct materials, as shown in the DRAWINGS and defined in the SPECIFICATIONS, are delivered to the site and used in construction. During geotextile installation, the CQA Monitor shall observe and document deployment, field seaming, and repairs to assess that the installation is in compliance with the SPECIFICATIONS.

Deployment - The CQA Monitor shall verify that the subgrade is free of deleterious materials prior to deployment, anchoring is achieved as specified, specified methods are used to minimize wrinkles and protect underlying layers during cutting of materials, and deployment procedures are performed in compliance with the project SPECIFICATIONS.

Seams - The CQA Monitor shall verify sufficient overlap and that the specified seam procedures were followed in compliance with the project SPECIFICATIONS.

Repairs - The CQA Monitor shall verify that all repairs are performed in compliance with the SPECIFICATIONS.

Protection - The CQA Monitor shall observe and document that all soil materials placed on top of the geosynthetics are done in such a manner as to ensure that the geosynthetics and underlying materials are not damaged.

4.0 POLYETHYLENE PIPE CONSTRUCTION QUALITY ASSURANCE

Construction of the lined stockpiles and related appurtenances must be in compliance with the design DRAWINGS and SPECIFICATIONS. The **OWNER** shall implement a CQA monitoring and testing program to ensure construction compliance by the **CONTRACTOR**. The quality assurance program shall consist of reviewing **CONTRACTOR** quality control submittals, material conformance testing, and construction monitoring and testing.

The pipe material used for construction is polyethylene as specified on the DRAWINGS. The polyethylene pipe construction requirements are defined in the project SPECIFICATIONS. Prior to installation, pipe materials shall be sampled and tested to determine if they meet project SPECIFICATIONS. All tests shall be performed in a laboratory approved by the **MANAGER**.

4.1 Review Quality Control Submittals

Prior to pipe installation, the CQA Monitor shall review the INSTALLER's quality control submittals to evaluate or confirm that these materials meet project requirements. The CQA Monitor shall review the QC submittals that are outlined in Section 02600 (Piping) of the SPECIFICATIONS.

4.2 Polyethylene Pipe Conformance Testing

Prior to pipe installation, the CQA Monitor shall obtain samples of the pipe materials for conformance testing to confirm that these materials meet project requirements. Conformance tests shall be performed in compliance with the project SPECIFICATIONS. The CQA Monitor shall review the test results and shall report any nonconformance to the **MANAGER**, **ENGINEER OF RECORD,** and the **INSTALLER**.

As a minimum, the following conformance tests shall be conducted:

1. Density (ASTM D1505)
2. Melt Index (ASTM D1238)
3. Slow Crack Growth Resistance (ASTM D1693/F1473 per ASTM D3350)

Project requirements for polyethylene piping are outlined in Section 02600.

4.3 Polyethylene Pipe Construction Monitoring

The CQA Monitor shall monitor the polyethylene pipe installation process to verify that the construction is in compliance with the project SPECIFICATIONS. The CQA Monitor shall identify inadequate construction methodologies or materials which may adversely impact the performance. Any deviations from SPECIFICATIONS require pre-approval by **ENGINEER OF RECORD** and **MANAGER** prior to proceeding with the WORK if such is not proposed to be remedied to fully comply with the SPECIFICATIONS. Visual observations throughout the construction process shall be made to ensure that the pipes are placed to the lines and grades shown on the DRAWINGS.

The CQA Monitor shall review the following submittals by the **INSTALLER** during the project:

- Verification that a qualified land surveyor has verified all lines and grades.

The CQA Monitor shall:

- Inspect all polyethylene pipe delivered to site. The CQA Monitor shall document any damage and notify **MANAGER**;
- Obtain polyethylene pipe packaging identification slips for verification and generation of an on-site materials inventory;
- Observe and document that all soil materials placed on top of the polyethylene pipe are done in such a manner as to ensure that the pipe is not damaged.

4.3.1 Polyethylene Pipe and Fittings Installation Quality Assurance

The CQA Monitor shall observe and document that the correct materials, as shown in the DRAWINGS and defined in the SPECIFICATIONS, are delivered to the site and used in construction. During polyethylene pipe installation, the CQA Monitor shall observe and document that the installation is in compliance with the project SPECIFICATIONS. CQA monitoring of the polyethylene pipe and fittings will include the following:

Placement – Observation that subgrade (pipe bedding) is acceptably prepared according to the SPECIFICATIONS, handling procedures used do not damage the pipe, backfill is placed in compliance with the requirements of the project SPECIFICATIONS so as not to damage the pipe, any foreign material is removed from the interior of the pipe and indentations on the pipe are within the MANUFACTURER's allowable limits.

Joints and Connections - Monitoring of the jointing and connection operations to verify that the **CONTRACTOR** follows the SPECIFICATIONS and the pipe MANUFACTURER's recommendations, verification that the pipes are clean when installed, that perforated sections of pipe are aligned properly prior to connection, and pipe boot connections are made in the field using the specified rings and clamps.

Nondestructive Testing - Observe any required testing of the pipe to verify compliance with the project SPECIFICATIONS.

5.0 CLOSING

Golder sincerely appreciates the opportunity to provide continued engineering support of PolyMet's NorthMet project. Please contact the undersigned with any questions or comments on the information contained within this report.

Sincerely,

GOLDER ASSOCIATES INC.

Brent Bronson, P.E.
Project Director
Principal

Gordan Gjerapic, P.E.
Geotechnical Engineer

TABLES

TABLE 1

CQA TESTING REQUIREMENTS FOR EARTHEN MATERIALS: SOIL LINER 1 AND SOIL LINER 2

TESTING	FREQUENCY
Sieve – Grain Size (ASTM D 422/1140)	One per material type or one per 10,000 cy
Oven Dried Moisture Content (ASTM D 2216)	One per material type or one per 10,000 cy
Standard Proctor Curve (as appropriate) (ASTM D 698)	One per material type or one per 10,000 cy
Density/Moisture – Nuclear Gauge (ASTM D 2922, D 3017)	One per 10,000 compacted cy with minimum of one per lift per day
Nuclear Gauge Calibration Block (ASTM D 2922,D 3017)	One per day
Permeability-Shelby Tube of Compacted Liner (ASTM D 5084)	One per 10,000 cy

Notes:

1. Test frequencies are per cubic yard of placed and compacted material.
2. As a minimum, the following tests should be performed once per day for each day that material is placed:
    a. Nuclear Moisture-Density Test
    b. Oven-Dried Moisture Content
3. All holes made in the soil liner for the purposes of these tests should be backfilled with hydrated bentonite powder, or with hand-compacted clay.
4. When options are allowed in the testing frequency, the option that will result in a greater frequency will apply.

TABLE 2

CQA TESTING REQUIREMENTS FOR EARTHEN MATERIALS: STRUCTURAL FILL

TESTING	FREQUENCY
Density/Moisture – Nuclear Gauge (ASTM D 2922, D 3017)	One per 50,000 compacted cy with minimum of one per lift per day
Nuclear Gauge Calibration Block (ASTM D 2922,D 3017)	One per day
Standard Proctor Curve (as appropriate) (ASTM D 698)	One per material type or one per 50,000 cy

Notes:

1. Test frequencies are per cubic yard of placed and compacted material.
2. As a minimum, the following tests should be performed once per day for each day that material is placed:
    a. Nuclear Moisture-Density Test
    b. Oven-Dried Moisture Content
3. When options are allowed in the testing frequency, the option that will result in a greater frequency will apply.

TABLE 3

CQA TESTING REQUIREMENTS FOR EARTHEN MATERIALS: GRANULAR DRAINAGE MATERIAL 1 AND DRAIN ROCK

TESTING	FREQUENCY
Sieve - Grain Size (ASTM C 117/C 136)	Granular Drainage Material 1: One per material type or one per 30,000 cy. Drain Rock: One per source
Permeability (ASTM D 2434)	Granular Drainage Material 1: One per material type or one per 20,000 cy. Drain Rock: One per source

Notes:

1. Test frequencies are per cubic yard of placed material.
2. When placed over liner, Granular Drainage Material 1 and Drain Rock shall be placed in a single uncompacted lift.

TABLE 4

CQA TESTING REQUIREMENTS FOR EARTHEN MATERIALS: COMMON FILL 1, GEOMEMBRANE BEDDING LAYER, GRANULAR FILTER, RIPRAP AND RANDOM FILL

TESTING	FREQUENCY
Sieve - Grain Size (ASTM C 117/C 136)	Common Fill 1[2]: One per material type or one per 10,000 cy. Geomembrane Bedding Layer[2]: One per material type or one per 10,000 cy. Granular Filter[2]: One per material type or one per 10,000 cy. Riprap: One per source. Random Fill: One per source

Notes:

1. Test frequencies are per cubic yard of placed material.
2. Common Fill 1, Geomembrane Bedding Layer and Granular Filter will be placed in accordance with an approved method specification.

Attachment J

Category 1 Waste Rock Stockpile Cover System Surface Water Calculations

OBJECTIVE:
Estimate the peak flows resulting from the 100-year, 24-hour storm event on the Category 1 Stockpile based on a post closure condition. Design a stormwater conveyance system to control estimated peak flows for benches, downchutes and haul roads for the post closure condition. Perimeter channels are to be designed by others.

METHOD:
Subbasins were delineated on the stockpile based on closure grades. Kinematic wave transform methodology along with SCS curve number (CN) method were used to model the subbasins with the Hydraulic Engineering Center's Hydrologic Modeling System (HEC-HMS) software (USACE, 2010). Basin area, loss parameters, frequency storm rainfall, roughness, slopes, and channel geometry were input into HEC-HMS to calculate the peak flows for each subbasin. A routing schematic is included in the attached HEC-HMS input (**Attachment A**).

Hydraulic calculations were performed using a spreadsheet that solves Manning's equation for normal flow depth using peak flows from the HEC-HMS models. Riprap armoring for the downchutes was designed utilizing the Robinson Method (Robinson, 1998).

Energy dissipation structures at the toe of the downchutes and haul road channels will be constructed using flat hydraulic jump basins armored with riprap. The length and required depth of the flat riprap-lined jump basin was determined by calculating the hydraulic jump length (see **Table 5**).

DATA & ASSUMPTIONS:

- The 100-year, 24-hour storm distribution was obtained from the Rainfall Frequency Atlas of the Midwest (NWS 1992) and input into the HEC-HMS model using the "Frequency Storm" option (See **Attachment B** for precipitation depth vs. duration).
- The minimum intensity duration for the 100-year, 24-hour Frequency Storm is equal to 5 minutes.
- The SCS CN (US SCS, 1986) and overland flow kinematic roughness for the stockpiles under various conditions are as follows:

Surface	CN	Rationale	Roughness
Stockpile (reclaimed)	69	HSG "B" fair cover pasture(Barr 2007, p.38)	0.35

- Manning's roughness coefficient for channel lining:

Channel Lining	Manning's n for HMS Model	Manning's n for Stability	Manning's n for Capacity
Earth	0.022	0.022	0.025
Riprap	0.035	Varies*	0.040

*Manning's number for riprap-lining design was estimated from absolute roughness and hydraulic radius with absolute roughness approximated as one-half the riprap D_{50} (see **Attachment C**).

- Riprap design parameters:
  - Flow concentration factor=1.9 on steep riprap-lined downchutes to accommodate oblique hydraulic jumps caused by inflow from benches;
  - Factor of safety over incipient motion=1.2;

- Maximum allowable velocity for earth-lined channels assumed to be 5 fps (fine gravel, Chow 1959).
- All channels designed with a minimum one foot of freeboard.
- A minimum Froude number of 1.75 was assumed for the haul road channel hydraulic jump basins.

CALCULATIONS:

Subbasin delineations and anticipated downchute locations are shown in **Figure 1**. Subbasin areas, channel and plane information needed for the kinematic wave transform is summarized in **Table 1**. Subbasin area, loss parameters, frequency storm rainfall, roughness, slopes, and channel geometry were entered into HEC-HMS and peak flows were developed for all downchutes. **Table 2** includes summary output from the HEC-HMS model. The "Time of Peak" column in **Table 2** represents a hypothetical future rainfall event. The actual date is arbitrary, and the time is provided for the purpose of comparing the lag between the peaks of the various hydrographs. **Attachment A** contains HEC-HMS input (subbasin areas and kinematic wave transform parameters). **Tables 3 and 4,** provide the hydraulic calculations used to analyze the downchutes and size riprap D_{50} in the downchutes. **Table 5** summarizes hydraulic analyses for hydraulic jump lengths for the riprap-lined energy dissipation basins downstream of the downchutes and haul road channels.

CONCLUSIONS/RESULTS:

Required riprap lining D_{50} for the downchutes and haul road channels range from 9 to 18 inches as shown in **Table 4**. Riprap thickness shall be two times the D_{50} for each downchute and channel.

The calculated length of hydraulic jumps at the toe of the downchutes range in length from 4.5 to 11.2 feet (see **Table 5**). Golder recommends a minimum energy dissipation pad length of 15 feet.

The bench channel capacity calculation verified that even a bench longer than the longest measured bench (approximately 1850 feet) will not violate the stated assumptions for velocity and freeboard. See "Test Bench" reach analysis in **Table 3**.

REFERENCES:

Annandale, G.W. 2006. Scour Technology; Mechanics and Engineering Practice. New York; Mc Graw-Hill.

Barr Engineering. May, 2009. Minneapolis, MN.

Chow, V. T. 1959. Open-channel hydraulics. New York : McGraw Hill.

HEC-HMS Hydrologic Modeling System [computer software] US Army Corps of Engineers Version 3.5

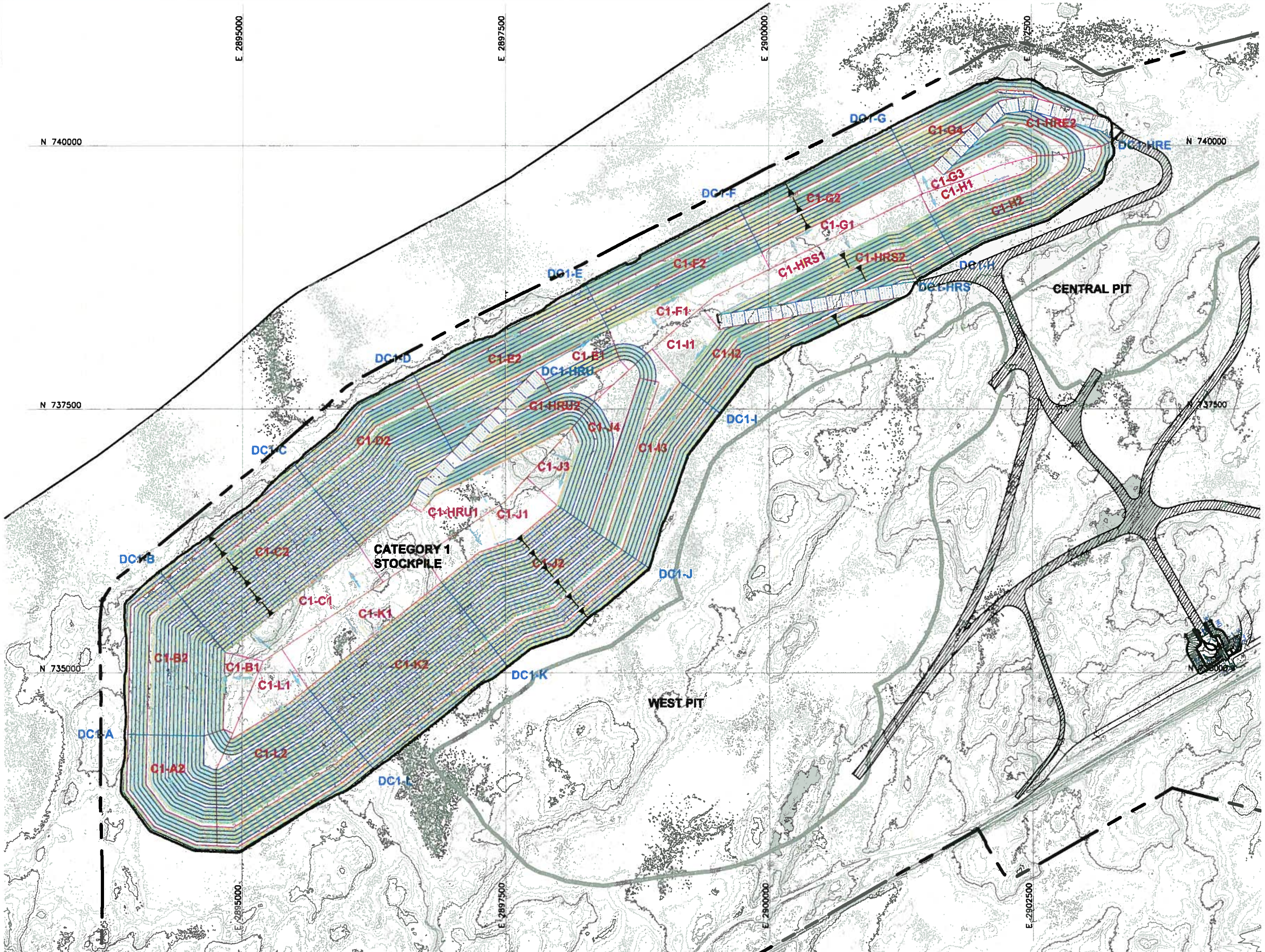
National Weather Service. 1992. Rainfall Frequency Atlas of the Midwest. Bulletin 71Midwestern Climate Center.

Robinson, K.M., K.C. Kadavy, and C.E. Rice. (1998). *Rock Chutes On Slopes Between 2 And 40%,* presented at the 1998 ASAE Annual International Meeting, ASAE Paper No. 982136. St. Joseph, MI: ASAE.

U. S. Soil Conservation Service (US SCS). 1986. Urban Hydrology for Small Watersheds, 2nd edition (USSCS Technical Release Number 55). Washington D.C.: United States Department of Agriculture.

LIST OF TABLES & FIGURES:

LIST OF ATTACHMENTS:



LEGEND

EXISTING GROUND TOPOGRAPHY

PROPOSED FINISHED GRADE

SUBBASIN DELINEATION

C1-H1 SUBBASIN I.D.

DC1-G DOWNCHUTE ID

PROPERTY BOUNDARY

REFERENCES

1. EXISTING GROUND TOPOGRAPHY PROVIDED BY BARR ENGINEERING, AUGUST 2011.
2. COORDINATE SYSTEM REFERENCE IS NAD83 MINNESOTA STATE PLANE NORTH.
3. VERTICAL DATUM REFERENCE IS FEET ABOVE MEAN SEA LEVEL (AMSL).

Golder Associates

SCALE	AS SHOWN
DATE	08/28/12
DESIGN	MBR
CADD	MBR
CHECK	[signature]
REVIEW	[signature]

FILE No. Cat 1-2 srfwtr 8-2012 Rev

PROJECT No. 113-2209 REV. A

TITLE

CATEGORY 1 STOCKPILE SUBBASIN DELINEATION

POLYMET MINING CORPORATION

FIGURE 1

Drawing File: N:\1\1\113-2209\DESIGN\SRFWTR\ Cat 1-2 srfwtr 8-2012 Rev.dwg | Layout: 11x17 Landscape | Modified: Aug 29, 2012 10:16 MRichey | Plotted: 08/30/12 10:53am NRosenthal

Table 1
Kinematic Wave Trasform Parameters

Polymet Mining Company
Stockpile Hydrology
Project No. 113-2209

Date:	8/30/12
By:	MBR
Chkd:	CPA
Apprvd:	[signature]

Kinematic Wave Transform Parameters

				Collector Channel					Plane 1 (Bench)					Plane 2 (Outslope)					Channel			
Subbasin	Area (ft^2)	Area (mi^2)	No. of Benches	Area for Collector Channel (ft^2)	Area for Collector Channel (mi^2)	Length (ft)	Slope (ft/ft)	Manning's n	SCS CN	Length (ft)	Slope (ft/ft)	Roughness	Area (%)	SCS CN	Length (ft)	Slope (ft/ft)	Roughness	Area (%)	Area for Channel (mi^2)	Length (ft)	Slope (ft/ft)	Manning's n
CATEGORY 1/2 STOCKPILE																						
C1-A2	789839.5	0.02833	5	260937.62	0.00936	1250	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02833	745	0.23	0.035
C1-B1	168730.8	0.00605	1		--	--	--	--	69	275	0.01	0.35	100	--	--	--	--	0	0.00605	730	0.01	0.022
C1-B2	1085212	0.03893	5	279098.89	0.01001	1435	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.03893	985	0.23	0.035
C1-C1	519312.9	0.01863	1		--	--	--	--	69	315	0.01	0.35	100	--	--	--	--	0	0.01863	1625	0.01	0.022
C1-C2	1466562	0.05261	5	293400	0.01052	1630	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.05261	990	0.23	0.035
C1-HRU1	740944.7	0.02658	1		--	--	--	--	69	380	0.01	0.35	100	--	--	--	--	0	0.02658	1655	0.01	0.022
C1-D2	1185728	0.04253	5	251053	0.00901	1365	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.04253	825	0.23	0.035
C1-HRU2	815059.9	0.02924	2	267436	0.00959	1200	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02924	1730	0.13	0.035
C1-E1	381519.7	0.01369	1		--	--	--	--	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.01369	1845	0.01	0.022
C1-E2	662065.4	0.02375	2	332222	0.01192	1845	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02375	485	0.23	0.035
C1-F1	417249.0	0.01497	1		--	--	--	--	69	230	0.01	0.35	100	--	--	--	--	0	0.01497	1630	0.01	0.022
C1-F2	584128.8	0.02095	2	293233	0.01052	1630	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02095	495	0.23	0.035
C1-G1	303083.5	0.01087	1		--	--	--	--	69	185	0.01	0.35	100	--	--	--	--	0	0.01087	1630	0.01	0.022
C1-G2	585324.5	0.02100	2	293188	0.01052	1630	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02100	500	0.23	0.035
C1-G3	182475.8	0.00655	1		--	--	--	--	69	150	0.01	0.35	100	--	--	--	--	0	0.00655	1120	0.01	0.022
C1-G4	288371.8	0.01034	2	203734	0.00731	1070	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.01034	500	0.23	0.035
C1-HRE2	630318.6	0.02261	2	149912	0.00538	830	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02261	1960	0.06	0.035
C1-H1	160395.6	0.00575	1		--	--	--	--	69	140	0.01	0.35	100	--	--	--	--	0	0.00575	1120	0.01	0.022
C1-H2	572741.5	0.02054	2	318179	0.01141	1300	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02054	500	0.23	0.035
C1-HRS1	419424.3	0.01504	1		--	--	--	--	69	175	0.01	0.35	100	--	--	--	--	0	0.01504	2245	0.01	0.022
C1-HRS2	889062.3	0.03189	2	242336	0.00869	1775	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.03189	1950	0.06	0.035
C1-I1	213095.7	0.00764	1		--	--	--	--	69	330	0.01	0.35	100	--	--	--	--	0	0.00764	630	0.01	0.022
C1-I2	413468.3	0.01483	2	255514	0.00917	1040	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.01483	490	0.23	0.035
C1-I3	595945.8	0.02138	2	297168	0.01066	1660	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.02138	490	0.23	0.035
C1-J1	408837.7	0.01467	1		--	--	--	--	69	330	0.01	0.35	100	--	--	--	--	0	0.01467	1335	0.01	0.022
C1-J2	1328625	0.04766	5	285827	0.01025	1550	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.04766	1060	0.23	0.035
C1-J3	155152.2	0.00557	1		--	--	--	--	69	245	0.01	0.35	100	--	--	--	--	0	0.00557	625	0.01	0.022
C1-J4	901777.8	0.03235	3	282317	0.01013	1525	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.03235	1060	0.23	0.035
C1-K1	601756.7	0.02159	1		--	--	--	--	69	375	0.01	0.35	100	--	--	--	--	0	0.02159	1620	0.01	0.022
C1-K2	1449236	0.05198	5	283562	0.01017	1610	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.05198	1025	0.23	0.035
C1-L1	256192.4	0.00919	1		--	--	--	--	69	335	0.01	0.35	100	--	--	--	--	0	0.00919	860	0.01	0.022
C1-L2	1207800	0.04332	5	288625	0.01035	1520	0.01	0.030	69	30	0.10	0.35	20	69	150	0.27	0.35	80	0.04332	1000	0.23	0.035

TABLE 2
FLOW RESULTS FROM HEC-HMS

Polymet Mining Company
Stockpile Hydrology
Project No. 113-2209

Date:	8/28/12
By:	MBR
Chkd:	cll
Apprvd:	[illegible]

HEC-HMS Basin Model:	Closure
HEC-HMS Met. Model:	100Yr24Hr
HEC-HMS Control Specs:	5min-36Hr
File Path:	J:\11JOBS\113-2209\Surface Water\HMS\Polymet_Cat1_2_2011_revision\Polymet_Cat1_2_2012_revision.hms

Hydrologic Element	Drainage Area (sq mile)	Peak Discharge (cfs)	Time of Peak	Total Volume (ac-ft)
C1-HRU1	0.0266	17.5	01Jul2020, 13:45	3.0
C1-HRU2	0.0558	54.1	01Jul2020, 13:10	6.2
C1-E1	0.0695	66.2	01Jul2020, 13:15	7.8
C1-E2	0.0238	41.7	01Jul2020, 13:10	2.6
DC1-E	0.0933	101.1	01Jul2020, 13:15	10.4
C1-C2	0.0526	95	01Jul2020, 13:10	5.9
C1-C1	0.0186	13.7	01Jul2020, 13:35	2.1
DC1-C	0.0712	100.2	01Jul2020, 13:10	8.0
C1-G2	0.0210	34.1	01Jul2020, 13:10	2.4
C1-G1	0.0109	10.7	01Jul2020, 13:25	1.2
C1-G4	0.0103	19.4	01Jul2020, 13:10	1.2
C1-G3	0.0066	7.2	01Jul2020, 13:20	0.7
DC1-G	0.0488	63.2	01Jul2020, 13:10	5.5
C1-B2	0.0389	71.8	01Jul2020, 13:10	4.4
C1-B1	0.0061	4.9	01Jul2020, 13:30	0.7
DC1-B	0.0450	74.3	01Jul2020, 13:10	5.0
C1-D2	0.0425	78.8	01Jul2020, 13:10	4.8
DC1-D	0.0425	78.8	01Jul2020, 13:10	4.8
C1-F2	0.0210	38	01Jul2020, 13:10	2.3
C1-F1	0.0150	13.1	01Jul2020, 13:30	1.7
DC1-F	0.0359	43.9	01Jul2020, 13:10	4.0
C1-A2	0.0283	52.9	01Jul2020, 13:10	3.2
DC1-A	0.0283	52.9	01Jul2020, 13:10	3.2
C1-HRE2	0.0226	42.3	01Jul2020, 13:10	2.5
DC1-HRE	0.0226	42.3	01Jul2020, 13:10	2.5
CAT1/2north	0.3876	542.3	01Jul2020, 13:10	43.4
C1-J2	0.0477	86.7	01Jul2020, 13:10	5.3
C1-J4	0.0324	58.9	01Jul2020, 13:10	3.6
C1-J1	0.0147	10.5	01Jul2020, 13:40	1.6
C1-J3	0.0056	4.7	01Jul2020, 13:30	0.6
DC1-J	0.1003	152.6	01Jul2020, 13:10	11.2
C1-K2	0.0520	93.7	01Jul2020, 13:10	5.8
C1-K1	0.0216	14.3	01Jul2020, 13:45	2.4
DC1-K	0.0736	98.7	01Jul2020, 13:10	8.2
C1-L2	0.0433	79.1	01Jul2020, 13:10	4.9
C1-L1	0.0092	6.5	01Jul2020, 13:35	1.0
DC1-L	0.0525	82.2	01Jul2020, 13:10	5.9
C1-HRS2	0.0319	51.7	01Jul2020, 13:15	3.6
C1-HRS1	0.0150	14.9	01Jul2020, 13:25	1.7
DC1-HRS	0.0469	62.4	01Jul2020, 13:15	5.3
C1-I3	0.0214	38.4	01Jul2020, 13:10	2.4
C1-I2	0.0148	27.7	01Jul2020, 13:10	1.7
C1-I1	0.0076	5.5	01Jul2020, 13:35	0.9
DC1-I	0.0439	68.8	01Jul2020, 13:10	4.9
C1-H2	0.0205	38.3	01Jul2020, 13:10	2.3
C1-H1	0.0058	6.5	01Jul2020, 13:20	0.6
DC1-H	0.0263	42.6	01Jul2020, 13:10	2.9
CAT1/2south	0.3434	500.9	01Jul2020, 13:10	38.5
2400 FT	0.0155	25.1	01Jul2020, 13:10	1.7
Test Sink	0.0155	25.1	01Jul2020, 13:10	1.7

Table 3
Channel Hydraulic Analysis

Polymet Mining Company
Stockpile Hydrology
PROJECT NO. 113-2209

Date:	8/28/12
By:	MBR
Chkd:	
Apprvd:	

			Channel Design Geometry						Channel Roughness Parameters				Hydraulic Calculations							
Reach Designation	Q100 from HEC-HMS (cfs)	HEC HMS Element ID for Q	Approximate Channel Length (ft)	Bed Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Bottom Width (ft)	Minimum Channel Depth (ft)	Design Channel Lining		Mannings 'n' for Capacity (Depth Calculation)	Mannings 'n' for Stability (Velocity Calculation)	Flow Velocity (ft/sec)	Normal Flow Depth (ft)	Froude Number	Normal Depth Shear Stress (lb/ft^2)	Stream Power (W/m^2)	Top Width of Flow (ft)	Top Width of Channel (ft)	Available Freeboard (ft)
DC1-A	52.9	DC1-A	745	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	8.6	0.31	2.90	4.51	563.31	22.5	44.0	2.7
DC1-B	74.3	DC1-B	985	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	9.8	0.38	2.99	5.51	781.44	23.1	44.0	2.6
DC1-C	100.2	DC1-C	990	0.23	4.0	4.0	25	3.0	R	Riprap	0.040	0.035	10.1	0.40	3.01	5.73	840.11	28.6	49.4	2.6
DC1-D	78.8	DC1-D	825	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	10.0	0.40	3.00	5.70	826.79	23.2	44.0	2.6
DC1-E	101.1	DC1-E	485	0.23	4.0	4.0	25	3.0	R	Riprap	0.040	0.035	10.2	0.40	3.02	5.81	859.73	28.2	49.0	2.6
DC1-E Bench	66.2	C1-E1	795	0.01	20.0	4.0	0	2.4	E	Earth-lined	0.025	0.022	4.5	1.16	1.08	0.72	47.50	27.8	57.6	1.2
DC1-F	43.9	DC1-F	495	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	8.0	0.28	2.85	4.04	470.23	22.2	44.0	2.7
DC1-G	63.2	DC1-G	500	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	9.2	0.35	2.94	5.01	668.8	22.8	44.0	2.7
DC1-HRE	42.3	DC1-HRE	1960	0.06	4.0	4.0	8	3.0	R	Riprap	0.040	0.035	6.5	0.67	1.62	2.50	236.1	13.3	32.0	2.3
DC1-H	42.6	DC1-H	500	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	7.9	0.28	2.84	3.96	456.7	22.2	44.0	2.7
DC1-HRS	62.4	DC1-HRS	1950	0.06	4.0	4.0	8	3.0	R	Riprap	0.040	0.035	7.4	0.82	1.67	3.09	329.3	14.6	32.0	2.2
DC1-HRU	54.1	C1-HRU2	1730	0.07	4.0	4.0	8	3.0	R	Riprap	0.040	0.035	7.4	0.73	1.78	3.19	344.2	13.9	32.0	2.3
DC1-I	68.8	DC1-I	490	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	9.5	0.37	2.97	5.26	725.8	22.9	44.0	2.6
DC1-J	152.6	DC1-J	1060	0.23	4.0	4.0	20	3.0	R	Riprap	0.040	0.035	12.7	0.59	3.19	8.41	1549.6	24.7	44.0	2.4
DC1-K	98.7	DC1-K	1025	0.23	4.0	4.0	25	3.0	R	Riprap	0.040	0.035	10.1	0.40	3.01	5.68	827.9	28.6	49.4	2.6
DC1-L	82.2	DC1-L	1000	0.23	4.0	4.0	25	3.0	R	Riprap	0.040	0.035	9.4	0.36	2.96	5.14	703.7	27.9	49.0	2.6
Test Bench	25.1	2400 FT	2400	0.01	2.5	10.0	0	2.4	E	Earth-lined	0.025	0.022	4.2	1.03	1.05	0.64	38.8	12.9	30.0	1.4

Table 4
Robinson Method Riprap Size Calculation for Downchutes

Polymet Mining Company
Stockpile Hydrology
PROJECT NO.: 113-2209

Date:	8/28/12
By:	MBR
Chkd:	[signature]
Apprvd:	[signature]

	Robinson Design of Rock Chutes Riprap Calculations for Steep Riprap (Bed Slopes >2% but <40%)							
Reach Designation	**Unit Flow q (1) (cfs/ft)**	**Design Flow Q (cms)**	**Unit Width Flow q (cms/m)**	**Flow Concentration Factor**	**Calculated Particle Size D_{50} (2) (mm)**	**Factor of Safety**	**Calculated Riprap Size D_{50} (inches)**	**Recommended Riprap Size D_{50} (inches)**
DC1-A	2.49	1.498	0.231	1.90	204	1.20	9.6	12
DC1-B	3.45	2.104	0.321	1.90	243	1.20	11.5	12
DC1-C	3.71	2.837	0.345	1.90	252	1.20	11.9	12
DC1-D	3.65	2.231	0.339	1.90	250	1.20	11.8	12
DC1-E	3.75	2.863	0.348	1.90	253	1.20	12.0	12
DC1-F	2.08	1.243	0.193	1.90	186	1.20	8.8	9
DC1-G	2.95	1.790	0.274	1.90	223	1.20	10.6	12
DC1-HRE	4.07	1.198	0.378	1.90	136	1.20	6.4	9
DC1-H	2.02	1.206	0.188	1.90	183	1.20	8.6	9
DC1-HRS	5.69	1.767	0.528	1.90	163	1.20	7.7	9
DC1-HRU	5.09	1.532	0.473	1.90	173	1.20	8.2	9
DC1-I	3.20	1.948	0.298	1.90	233	1.20	11.0	12
DC1-J	6.78	4.321	0.630	1.90	347	1.20	16.4	18
DC1-K	3.71	2.795	0.345	1.90	252	1.20	11.9	12
DC1-L	3.11	2.328	0.289	1.90	230	1.20	10.8	12

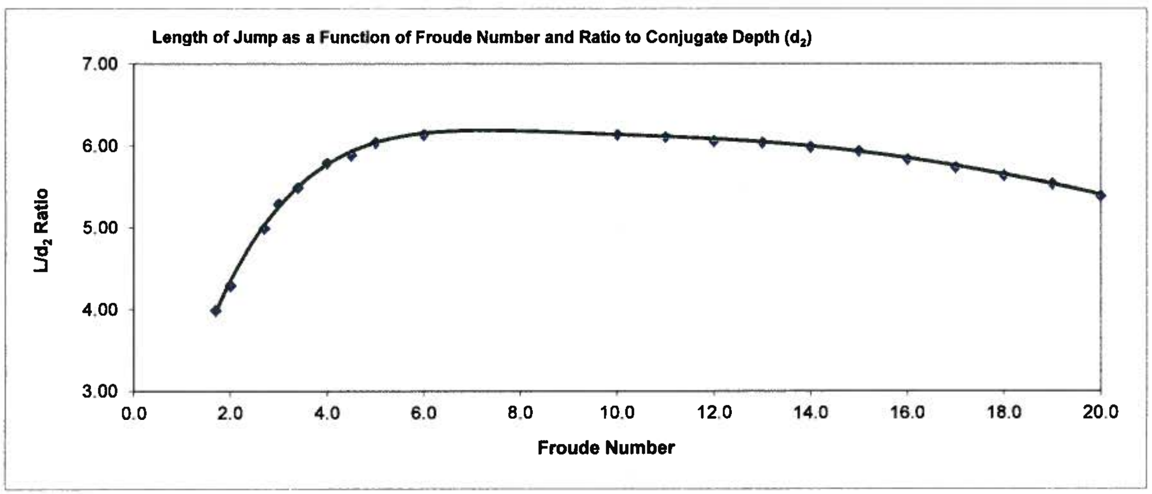
Design of Rock Chutes (ASAE Paper No. 982136 7/98)
Determine unit flow at incipient motion for rock particle size
(1) Unit flow rate is Q/ median width, adjusted by a flow concentration factor
1.9 Flow Concentration Factor (1.25 from USACE steep riprap method)
(2) Bed Slope < 10%, $q = 9.76e\text{-}7\ D_{50}^{1.89}\ S^{-1.50}$
10%<= Bed Slope <= 40%, $q = 8.07e\text{-}6\ D_{50}^{1.89}\ S^{-0.58}$
1.2 Factor of Safety over incipient motion

Table 5
Hydraulic Jump Basin Design

Polymet Mining Company
Stockpile Hydrology
PROJECT NO.: 113-2209

Date:	8/28/12
By:	MBR
Chkd:	[illegible]
Apprvd:	[illegible]

Reach Designation	Q100 from HEC-HMS (cfs)	HEC HMS Element ID for Q	Channel Configuration: Bed Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Bottom Width (ft)	Maximum Channel Depth (ft)	Mannings 'n' for Capacity (Depth Calculation)	Mannings 'n' for Stability (Velocity Calculation)	Hydraulic Calculations: Maximum Velocity (ft/sec)	Maximum Normal Flow Depth (ft)	Normal Depth with Velocity 'n' (ft)	Froude Number	Conjugate Depth (ft)	L/d2 Ratio	Minimum Length of Jump (ft)
DC1-A	52.9	DC1-A	0.23	4.0	4.0	20	3.0	0.040	0.035	8.6	0.31	0.29	2.90	1.02	5.18	5.29
DC1-B	74.3	DC1-B	0.23	4.0	4.0	20	3.0	0.040	0.035	9.8	0.38	0.35	2.99	1.28	5.25	6.74
DC1-C	100.2	DC1-C	0.23	4.0	4.0	25	3.0	0.040	0.035	10.1	0.40	0.37	3.01	1.36	5.26	7.14
DC1-D	78.8	DC1-D	0.23	4.0	4.0	20	3.0	0.040	0.035	10.0	0.40	0.37	3.00	1.34	5.26	7.03
DC1-E	101.1	DC1-E	0.23	4.0	4.0	25	3.0	0.040	0.035	10.2	0.40	0.37	3.02	1.38	5.27	7.26
DC1-F	43.9	DC1-F	0.23	4.0	4.0	20	3.0	0.040	0.035	8.0	0.28	0.26	2.85	0.90	5.14	4.62
DC1-G	63.2	DC1-G	0.23	4.0	4.0	20	3.0	0.040	0.035	9.2	0.35	0.32	2.94	1.15	5.22	6.01
DC1-HRE	42.3	DC1-HRE	0.06	4.0	4.0	8	3.0	0.040	0.035	6.5	0.67	0.62	1.75	1.01	4.03	4.06
DC1-H	42.6	DC1-H	0.23	4.0	4.0	20	3.0	0.040	0.035	7.9	0.28	0.26	2.84	0.88	5.14	4.52
DC1-HRS	62.4	DC1-HRS	0.06	4.0	4.0	8	3.0	0.040	0.035	7.4	0.82	0.77	1.75	1.27	4.03	5.11
DC1-HRU	54.1	C1-HRU2	0.07	4.0	4.0	8	3.0	0.040	0.035	7.4	0.73	0.68	1.78	1.22	4.07	4.98
DC1-I	68.8	DC1-I	0.23	4.0	4.0	20	3.0	0.040	0.035	9.5	0.37	0.34	2.97	1.22	5.23	6.38
DC1-J	152.6	DC1-J	0.23	4.0	4.0	20	3.0	0.040	0.035	12.7	0.59	0.54	3.19	2.08	5.38	11.16
DC1-K	98.7	DC1-K	0.23	4.0	4.0	25	3.0	0.040	0.035	10.1	0.40	0.37	3.01	1.34	5.26	7.07
DC1-L	82.2	DC1-L	0.23	4.0	4.0	25	3.0	0.040	0.035	9.4	0.36	0.33	2.96	1.20	5.23	6.26



$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{2V_1^2 d_1}{g} + \frac{d_1^2}{4}}$$

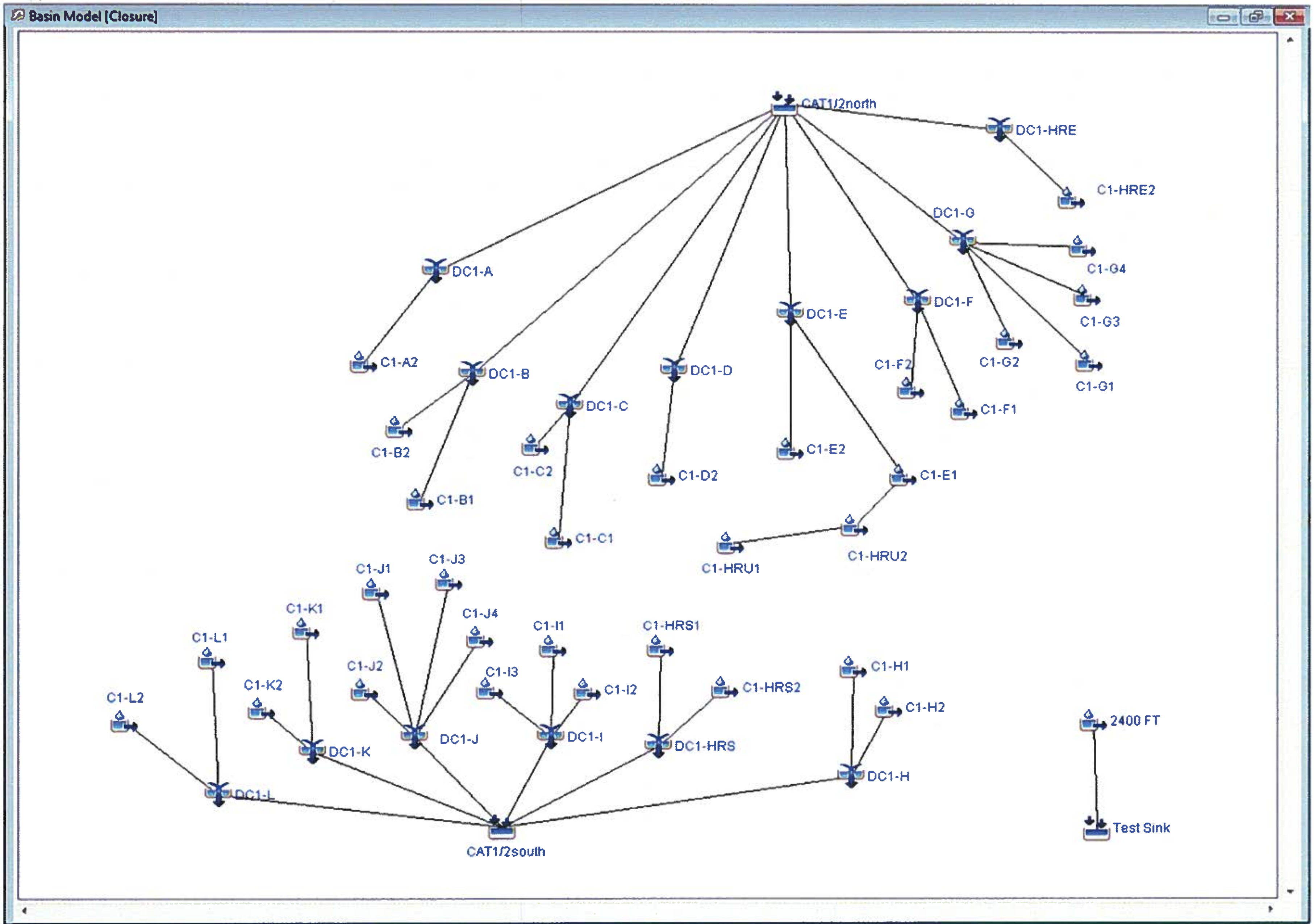
Where:

- d1 = Depth before the jump
- V1 = Velocity before the jump
- d2 = Depth after the jump,
- g = Acceleration of gravity

ATTACHMENT A

HEC-HMS ROUTING SCHEMATIC AND INPUT SUMMARY

Attachment A
HEC-HMS Routing Schematic



ATTACHMENT A
HEC-HMS INPUT

SUBBASIN AREA (Closure)

Subbasin	Area (MI2)
C1-HRU1	0.02658
C1-HRU2	0.02924
C1-E1	0.01369
C1-E2	0.02375
C1-C2	0.05261
C1-C1	0.01863
C1-G2	0.021
C1-G1	0.01087
C1-G4	0.01034
C1-G3	0.00655
C1-B2	0.03893
C1-B1	0.00605
C1-D2	0.04253
C1-F2	0.02095
C1-F1	0.01497
C1-A2	0.02833
C1-HRE2	0.02261
C1-J2	0.04766
C1-J4	0.03235
C1-J1	0.01467
C1-J3	0.00557
C1-K2	0.05198
C1-K1	0.02159
C1-L2	0.04332
C1-L1	0.00919
C1-HRS2	0.03189
C1-HRS1	0.01504
C1-I3	0.02138
C1-I2	0.01483
C1-I1	0.00764
C1-H2	0.02054
C1-H1	0.00575
2400 FT	0.015496

MAIN CHANNEL

Subbasin	Route Upstream	Route Method	Length (FT)	Slope (FT/FT)	Routing Steps	Shape	Manning's n	Diameter (FT)	Width (FT)	Sideslope (xH:1V)	L.B. Manning's n	R.B. Manning's n	Cross Section
C1-HRU1	No	Kinematic Wave	1655	0.01	5	Triangle	0.022			20			
C1-HRU2	Yes	Kinematic Wave	1730	0.07	5	Trapezoid	0.035		8	4			
C1-E1	Yes	Kinematic Wave	1845	0.01	5	Triangle	0.022			20			
C1-E2	No	Kinematic Wave	485	0.23	5	Trapezoid	0.035		25	4			
C1-C2	No	Kinematic Wave	990	0.23	5	Trapezoid	0.035		25	4			
C1-C1	No	Kinematic Wave	1625	0.01	5	Triangle	0.022			20			
C1-G2	No	Kinematic Wave	500	0.23	5	Trapezoid	0.035		20	4			
C1-G1	No	Kinematic Wave	1630	0.01	5	Triangle	0.022			20			
C1-G4	No	Kinematic Wave	500	0.23	5	Trapezoid	0.035		20	4			
C1-G3	No	Kinematic Wave	1120	0.01	5	Triangle	0.022			20			
C1-B2	No	Kinematic Wave	985	0.23	5	Trapezoid	0.035		20	4			
C1-B1	No	Kinematic Wave	730	0.01	5	Triangle	0.022			20			
C1-D2	No	Kinematic Wave	825	0.23	5	Trapezoid	0.035		20	4			
C1-F2	No	Kinematic Wave	495	0.23	5	Trapezoid	0.035		20	4			
C1-F1	No	Kinematic Wave	1630	0.01	5	Triangle	0.022			20			
C1-A2	No	Kinematic Wave	745	0.23	5	Trapezoid	0.035		20	4			
C1-HRE2	No	Kinematic Wave	1960	0.06	5	Trapezoid	0.035		8	4			
C1-J2	No	Kinematic Wave	1060	0.23	5	Trapezoid	0.035		20	4			
C1-J4	No	Kinematic Wave	1060	0.23	5	Trapezoid	0.035		20	4			
C1-J1	No	Kinematic Wave	1335	0.01	5	Triangle	0.022			20			
C1-J3	No	Kinematic Wave	625	0.01	5	Triangle	0.022			20			
C1-K2	No	Kinematic Wave	1025	0.23	5	Trapezoid	0.035		25	4			
C1-K1	No	Kinematic Wave	1620	0.01	5	Triangle	0.022			20			
C1-L2	No	Kinematic Wave	1000	0.23	5	Trapezoid	0.035		25	4			
C1-L1	No	Kinematic Wave	860	0.01	5	Triangle	0.022			20			
C1-HRS2	No	Kinematic Wave	1950	0.06	5	Trapezoid	0.035		8	4			
C1-HRS1	No	Kinematic Wave	2245	0.01	5	Triangle	0.022			20			
C1-I3	No	Kinematic Wave	490	0.23	5	Trapezoid	0.035		20	4			
C1-I2	No	Kinematic Wave	490	0.23	5	Trapezoid	0.035		20	4			
C1-I1	No	Kinematic Wave	630	0.01	5	Triangle	0.022			20			
C1-H2	No	Kinematic Wave	500	0.23	5	Trapezoid	0.035		20	4			
C1-H1	No	Kinematic Wave	1120	0.01	5	Triangle	0.022			20			
2400 FT	No	Kinematic Wave	180	0.23	5	Trapezoid	0.035		20	4			

FLOW PLANES

Subbasin	Initial	Curve	Impervious
C1-HRU1 (Plane 1)		69	0
C1-HRU1 (Plane 2)			
C1-HRU2 (Plane 1)		69	0
C1-HRU2 (Plane 2)		69	0
C1-E1 (Plane 1)		69	0
C1-E1 (Plane 2)		69	0
C1-E2 (Plane 1)		69	0
C1-E2 (Plane 2)		69	0
C1-C2 (Plane 1)		69	0
C1-C2 (Plane 2)		69	0
C1-C1 (Plane 1)		69	0
C1-C1 (Plane 2)			
C1-G2 (Plane 1)		69	0
C1-G2 (Plane 2)		69	0
C1-G1 (Plane 1)		69	0
C1-G1 (Plane 2)			
C1-G4 (Plane 1)		69	0
C1-G4 (Plane 2)		69	0
C1-G3 (Plane 1)		69	0
C1-G3 (Plane 2)			
C1-B2 (Plane 1)		69	0
C1-B2 (Plane 2)		69	0
C1-B1 (Plane 1)		69	0
C1-B1 (Plane 2)			
C1-D2 (Plane 1)		69	0
C1-D2 (Plane 2)		69	0
C1-F2 (Plane 1)		69	0
C1-F2 (Plane 2)		69	0
C1-F1 (Plane 1)		69	0
C1-F1 (Plane 2)			
C1-A2 (Plane 1)		69	0
C1-A2 (Plane 2)		69	0
C1-HRE2 (Plane 1)		69	0
C1-HRE2 (Plane 2)		69	0
C1-J2 (Plane 1)		69	0
C1-J2 (Plane 2)		69	0
C1-J4 (Plane 1)		69	0
C1-J4 (Plane 2)		69	0
C1-J1 (Plane 1)		69	0
C1-J1 (Plane 2)			
C1-J3 (Plane 1)		69	0
C1-J3 (Plane 2)			
C1-K2 (Plane 1)		69	0
C1-K2 (Plane 2)		69	0
C1-K1 (Plane 1)		69	0
C1-K1 (Plane 2)			
C1-L2 (Plane 1)		69	0
C1-L2 (Plane 2)		69	0
C1-L1 (Plane 1)		69	0
C1-L1 (Plane 2)			
C1-HRS2 (Plane 1)		69	0
C1-HRS2 (Plane 2)		69	0
C1-HRS1 (Plane 1)		69	0
C1-HRS1 (Plane 2)			
C1-I3 (Plane 1)		69	0
C1-I3 (Plane 2)		69	0
C1-I2 (Plane 1)		69	0
C1-I2 (Plane 2)		69	0
C1-I1 (Plane 1)		69	0
C1-I1 (Plane 2)			
C1-H2 (Plane 1)		69	0
C1-H2 (Plane 2)		69	0
C1-H1 (Plane 1)		69	0
C1-H1 (Plane 2)			
2400 FT (Plane 1)		69	0
2400 FT (Plane 2)		69	0

Subbasin	Length	Slope (FT/FT)	Roughness	Area (%)	Routing
C1-HRU1(Plane 1)	380	0.01	0.35	100	5
C1-HRU1(Plane 2)					5
C1-HRU2(Plane 1)	30	0.1	0.35	20	5
C1-HRU2(Plane 2)	150	0.27	0.35	80	5
C1-E1(Plane 1)	30	0.1	0.35	20	5
C1-E1(Plane 2)	150	0.27	0.35	80	5
C1-E2(Plane 1)	30	0.1	0.35	20	5
C1-E2(Plane 2)	150	0.27	0.35	80	5
C1-C2(Plane 1)	30	0.1	0.35	20	5
C1-C2(Plane 2)	150	0.27	0.35	80	5
C1-C1(Plane 1)	315	0.01	0.35	100	5
C1-C1(Plane 2)					5
C1-G2(Plane 1)	30	0.1	0.35	20	5
C1-G2(Plane 2)	150	0.27	0.35	80	5
C1-G1(Plane 1)	185	0.01	0.35	100	5
C1-G1(Plane 2)					5
C1-G4(Plane 1)	30	0.1	0.35	20	5
C1-G4(Plane 2)	150	0.27	0.35	80	5
C1-G3(Plane 1)	150	0.01	0.35	100	5
C1-G3(Plane 2)					5
C1-B2(Plane 1)	30	0.1	0.35	20	5
C1-B2(Plane 2)	150	0.27	0.35	80	5
C1-B1(Plane 1)	275	0.01	0.35	100	5
C1-B1(Plane 2)					5
C1-D2(Plane 1)	30	0.1	0.35	20	5
C1-D2(Plane 2)	150	0.27	0.35	80	5
C1-F2(Plane 1)	30	0.1	0.35	20	5
C1-F2(Plane 2)	150	0.27	0.35	80	5
C1-F1(Plane 1)	230	0.01	0.35	100	5
C1-F1(Plane 2)					5
C1-A2(Plane 1)	30	0.1	0.35	20	5
C1-A2(Plane 2)	150	0.27	0.35	80	5
C1-HRE2(Plane 1)	30	0.1	0.35	20	5
C1-HRE2(Plane 2)	150	0.27	0.35	80	5
C1-J2(Plane 1)	30	0.1	0.35	20	5
C1-J2(Plane 2)	150	0.27	0.35	80	5
C1-J4(Plane 1)	30	0.1	0.35	20	5
C1-J4(Plane 2)	150	0.27	0.35	80	5
C1-J1(Plane 1)	330	0.01	0.35	100	5
C1-J1(Plane 2)					5
C1-J3(Plane 1)	245	0.01	0.35	100	5
C1-J3(Plane 2)					5
C1-K2(Plane 1)	30	0.1	0.35	20	5
C1-K2(Plane 2)	150	0.27	0.35	80	5
C1-K1(Plane 1)	375	0.01	0.35	100	5
C1-K1(Plane 2)					5
C1-L2(Plane 1)	30	0.1	0.35	20	5
C1-L2(Plane 2)	150	0.27	0.35	80	5
C1-L1(Plane 1)	335	0.01	0.35	100	5
C1-L1(Plane 2)					5
C1-HRS2(Plane 1)	30	0.1	0.35	20	5
C1-HRS2(Plane 2)	150	0.27	0.35	80	5
C1-HRS1(Plane 1)	175	0.01	0.35	100	5
C1-HRS1(Plane 2)					5
C1-I3(Plane 1)	30	0.1	0.35	20	5
C1-I3(Plane 2)	150	0.27	0.35	80	5
C1-I2(Plane 1)	30	0.1	0.35	20	5
C1-I2(Plane 2)	150	0.27	0.35	80	5
C1-I1(Plane 1)	330	0.01	0.35	100	5
C1-I1(Plane 2)					5
C1-H2(Plane 1)	30	0.1	0.35	20	5
C1-H2(Plane 2)	150	0.27	0.35	80	5
C1-H1(Plane 1)	140	0.01	0.35	100	5
C1-H1(Plane 2)					5
2400 FT(Plane 1)	30	0.1	0.35	20	5
2400 FT(Plane 2)	150	0.27	0.35	80	5

SUBCOLLECTOR & COLLECTOR

Subbasin	Length	Slope	Manning'	Subreaches	Area (MI2)	Shape	Diameter	Width	Sideslope
C1-HRU1(SubCollector)				5		Trapezoid			
C1-HRU1(Collector)				5		Trapezoid			
C1-HRU2(SubCollector)				5		Trapezoid			
C1-HRU2(Collector)	1200	0.01	0.03	5	0.00959	Triangle			20
C1-E1(SubCollector)				5		Trapezoid			
C1-E1(Collector)				5		Trapezoid			
C1-E2(SubCollector)				5		Trapezoid			
C1-E2(Collector)	1845	0.01	0.03	5	0.01192	Triangle			6
C1-C2(SubCollector)				5		Trapezoid			
C1-C2(Collector)	1630	0.01	0.03	5	0.01052	Triangle			6
C1-C1(SubCollector)				5		Trapezoid			
C1-C1(Collector)				5		Trapezoid			
C1-G2(SubCollector)				5		Trapezoid			
C1-G2(Collector)	1630	0.01	0.03	5	0.01052	Triangle			20
C1-G1(SubCollector)				5		Trapezoid			
C1-G1(Collector)				5		Trapezoid			
C1-G4(SubCollector)				5		Trapezoid			
C1-G4(Collector)	1070	0.01	0.03	5	0.00731	Triangle			6
C1-G3(SubCollector)				5		Trapezoid			
C1-G3(Collector)				5		Trapezoid			
C1-B2(SubCollector)				5		Trapezoid			
C1-B2(Collector)	1435	0.01	0.03	5	0.01001	Triangle			6
C1-B1(SubCollector)				5		Trapezoid			
C1-B1(Collector)				5		Trapezoid			
C1-D2(SubCollector)				5		Trapezoid			
C1-D2(Collector)	1365	0.01	0.03	5	0.00901	Triangle			6
C1-F2(SubCollector)				5		Trapezoid			
C1-F2(Collector)	1630	0.01	0.03	5	0.01052	Triangle			6
C1-F1(SubCollector)				5		Trapezoid			
C1-F1(Collector)				5		Trapezoid			
C1-A2(SubCollector)				5		Trapezoid			
C1-A2(Collector)	1250	0.01	0.03	5	0.00936	Triangle			6
C1-HRE2(SubCollector)				5		Trapezoid			
C1-HRE2(Collector)	830	0.01	0.03	5	0.00538	Triangle			6
C1-J2(SubCollector)				5		Trapezoid			
C1-J2(Collector)	1550	0.01	0.03	5	0.01025	Triangle			6
C1-J4(SubCollector)				5		Trapezoid			
C1-J4(Collector)	1525	0.01	0.03	5	0.01013	Triangle			6
C1-J1(SubCollector)				5		Trapezoid			
C1-J1(Collector)				5		Trapezoid			
C1-J3(SubCollector)				5		Trapezoid			
C1-J3(Collector)				5		Trapezoid			
C1-K2(SubCollector)				5		Trapezoid			
C1-K2(Collector)	1610	0.01	0.03	5	0.01017	Triangle			6
C1-K1(SubCollector)				5		Trapezoid			
C1-K1(Collector)				5		Trapezoid			
C1-L2(SubCollector)				5		Trapezoid			
C1-L2(Collector)	1520	0.01	0.03	5	0.01035	Triangle			6
C1-L1(SubCollector)				5		Trapezoid			
C1-L1(Collector)				5		Trapezoid			
C1-HRS2(SubCollector)				5		Trapezoid			
C1-HRS2(Collector)	1775	0.01	0.03	5	0.00869	Triangle			6
C1-HRS1(SubCollector)				5		Trapezoid			
C1-HRS1(Collector)				5		Trapezoid			
C1-I3(SubCollector)				5		Trapezoid			
C1-I3(Collector)	1660	0.01	0.03	5	0.01066	Triangle			6
C1-I2(SubCollector)				5		Trapezoid			
C1-I2(Collector)	1040	0.01	0.03	5	0.00917	Triangle			6
C1-I1(SubCollector)				5		Trapezoid			
C1-I1(Collector)				5		Trapezoid			
C1-H2(SubCollector)				5		Trapezoid			
C1-H2(Collector)	1300	0.01	0.03	5	0.01141	Triangle			6
C1-H1(SubCollector)				5		Trapezoid			
C1-H1(Collector)				5		Trapezoid			
2400 FT(SubCollector)				5		Trapezoid			
2400 FT(Collector)	2400	0.01	0.03	5	0.015496	Triangle			6

ATTACHMENT B

POINT PRECIPITATION DEPTH VS. DURATION

FROM "RAINFALL FREQUENCY ATLAS OF THE MIDWEST"

(MCC) with Stanley Changnon and Peter J. Lamb as the co-principal investigators. The work was continued and completed under the general direction of Kenneth Kunkel, present MCC Director.

Special appreciation goes to Stan Changnon for his foresight, guidance, and encouragement in establishing and accomplishing the program objectives. He and Ken Kunkel reviewed the report and made useful comments and suggestions. Special thanks go to Richard Katz, National Center for Atmospheric Research; Tibor Farago, Hungarian Meteorological Service; and J.R.M. Hosking, IBM Research Division, for providing software for some of the extreme rainfall analyses. Fred Nurnberger, Michigan State Climatologist, provided valuable long-term precipitation data for his state as well as comments on the manuscript. We also thank the following state climatologists for their review and comments on this project: Wayne Wendland, Illinois; Ken Scheeringa, Indiana; Harry Hillaker, Iowa; Glen Conner, Kentucky; Jim Zandlo, Minnesota; Wayne Decker, Missouri; Jeff Rogers, Ohio; and Pam Naber-Knox, Wisconsin.

John Brother and Linda Hascall supervised the extensive drafting work required for the report. Jean Dennison typed and assembled the report, which Eva Kingston edited and formatted.

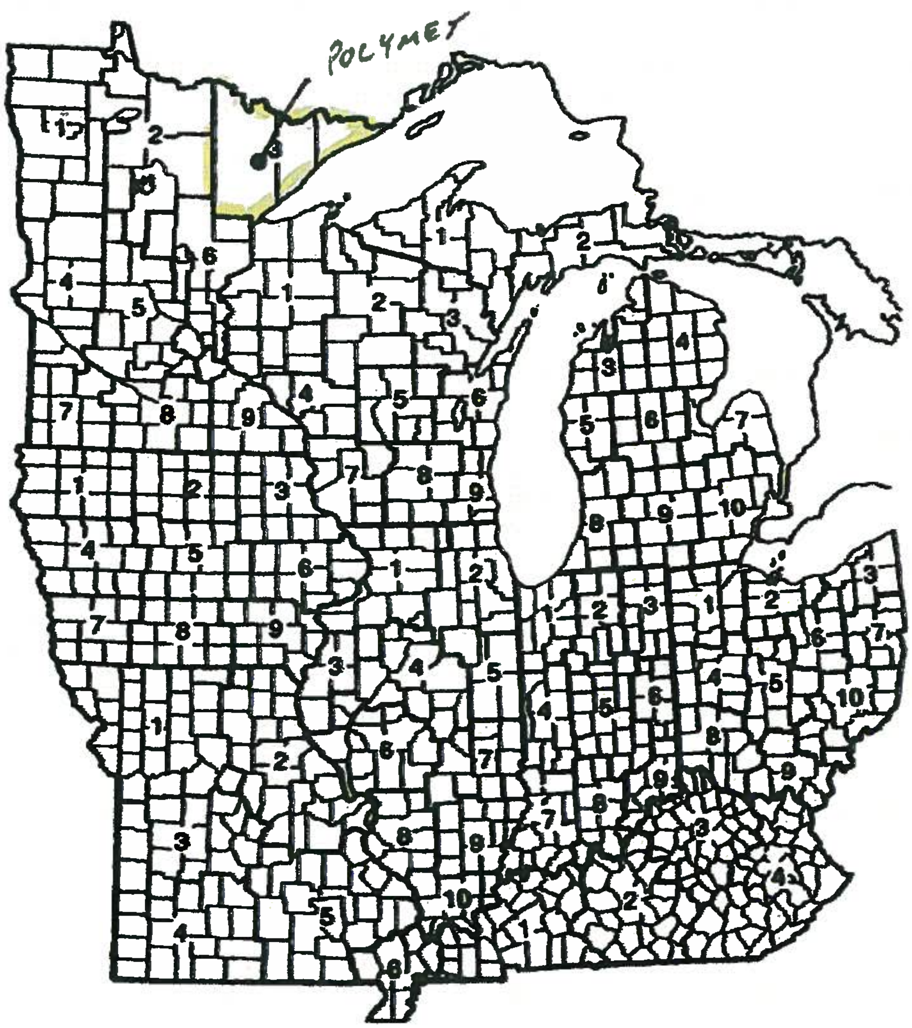


Figure 1 Climatic sections for the Midwest

p. 1/2

Table 6. Sectional Mean Frequency Distributions for Storm Periods of 5 Minutes to 10 Days and Recurrence Intervals of 2 Months to 100 Years in Minnesota

Sectional code (see figure 1 on page 4)

01 - Northwest
02 - North Central
03 - Northeast
04 - West Central
05 - Central
06 - East Central
07 - Southwest
08 - South Central
09 - Southeast

Rainfall (inches) for given recurrence interval

Section	Duration	2-month	3-month	4-month	6-month	9-month	1-year	2-year	5-year	10-year	25-year	50-year	100-year
01	10-day	1.53	1.84	2.12	2.50	2.87	3.12	3.83	4.89	5.80	6.97	7.88	8.75
01	5-day	1.27	1.53	1.73	2.00	2.30	2.50	3.11	4.11	5.01	6.12	7.05	7.94
01	72-hr	1.11	1.30	1.47	1.70	1.96	2.13	2.70	3.61	4.43	5.55	6.41	7.27
01	48-hr	1.03	1.20	1.34	1.55	1.78	1.94	2.42	3.25	4.05	5.13	5.91	6.70
01	24-hr	0.94	1.09	1.20	1.39	1.57	1.71	2.16	2.94	3.69	4.57	5.41	6.11
01	18-hr	0.89	1.03	1.13	1.30	1.48	1.61	2.03	2.76	3.47	4.30	5.09	5.74
01	12-hr	0.82	0.95	1.04	1.21	1.37	1.49	1.88	2.56	3.21	3.98	4.71	5.32
01	6-hr	0.70	0.82	0.90	1.04	1.18	1.28	1.62	2.20	2.77	3.43	4.06	4.58
01	3-hr	0.60	0.70	0.76	0.88	1.00	1.09	1.38	1.88	2.36	2.92	3.46	3.91
01	2-hr	0.54	0.63	0.69	0.80	0.91	0.99	1.25	1.71	2.14	2.65	3.14	3.54
01	1-hr	0.44	0.51	0.56	0.65	0.74	0.80	1.02	1.38	1.73	2.15	2.54	2.87
01	30-min	0.35	0.40	0.44	0.51	0.58	0.63	0.80	1.09	1.37	1.69	2.00	2.26
01	15-min	0.25	0.29	0.32	0.37	0.42	0.46	0.58	0.79	1.00	1.23	1.46	1.65
01	10-min	0.20	0.23	0.25	0.29	0.33	0.36	0.45	0.62	0.77	0.96	1.14	1.28
01	5-min	0.12	0.13	0.15	0.17	0.19	0.21	0.26	0.35	0.44	0.55	0.65	0.73
02	10-day	1.67	2.01	2.32	2.73	3.14	3.41	4.15	5.08	5.81	6.84	7.68	8.52
02	5-day	1.35	1.61	1.82	2.11	2.43	2.64	3.27	4.14	4.84	5.86	6.71	7.57
02	72-hr	1.24	1.45	1.64	1.90	2.19	2.38	2.90	3.64	4.31	5.28	6.10	6.96
02	48-hr	1.14	1.33	1.48	1.72	1.98	2.15	2.68	3.38	3.97	4.86	5.62	6.45
02	24-hr	1.07	1.24	1.36	1.57	1.78	1.94	2.41	3.06	3.58	4.39	5.10	5.88
02	18-hr	1.00	1.16	1.27	1.47	1.67	1.82	2.27	2.88	3.37	4.13	4.79	5.53
02	12-hr	0.93	1.08	1.18	1.37	1.55	1.69	2.10	2.66	3.11	3.82	4.44	5.12
02	6-hr	0.80	0.93	1.02	1.18	1.34	1.46	1.81	2.30	2.68	3.29	3.82	4.41
02	3-hr	0.68	0.79	0.87	1.00	1.14	1.24	1.54	1.96	2.29	2.81	3.26	3.76
02	2-hr	0.62	0.72	0.79	0.92	1.04	1.13	1.40	1.77	2.08	2.55	2.96	3.41
02	1-hr	0.50	0.58	0.64	0.74	0.84	0.91	1.13	1.44	1.68	2.06	2.40	2.76
02	30-min	0.40	0.46	0.50	0.58	0.66	0.72	0.89	1.13	1.32	1.62	1.89	2.18
02	15-min	0.29	0.33	0.36	0.42	0.48	0.52	0.65	0.83	0.97	1.19	1.38	1.59
02	10-min	0.23	0.26	0.29	0.33	0.38	0.41	0.51	0.64	0.75	0.92	1.07	1.23
02	5-min	0.13	0.15	0.16	0.19	0.21	0.23	0.29	0.37	0.43	0.53	0.61	0.71
03	10-day	1.66	1.99	2.30	2.70	3.11	3.38	4.04	4.82	5.41	6.28	6.96	7.58
03	5-day	1.36	1.62	1.84	2.13	2.45	2.66	3.24	4.05	4.69	5.54	6.16	6.57
03	72-hr	1.19	1.39	1.57	1.82	2.10	2.28	2.83	3.57	4.16	4.96	5.53	6.09
03	48-hr	1.09	1.28	1.42	1.65	1.90	2.06	2.54	3.21	3.74	4.49	5.08	5.63
03	24-hr	1.05	1.22	1.34	1.55	1.76	1.91	2.31	2.88	3.36	4.08	4.64	5.20
03	18-hr	0.99	1.15	1.26	1.46	1.66	1.80	2.17	2.71	3.16	3.84	4.36	4.89
03	12-hr	0.91	1.06	1.16	1.34	1.53	1.66	2.01	2.51	2.92	3.55	4.04	4.52
03	6-hr	0.79	0.92	1.00	1.16	1.32	1.43	1.73	2.16	2.52	3.06	3.48	3.90
03	3-hr	0.67	0.78	0.85	0.99	1.12	1.22	1.48	1.84	2.15	2.61	2.97	3.33
03	2-hr	0.61	0.71	0.78	0.90	1.02	1.11	1.34	1.67	1.95	2.37	2.69	3.02
03	1-hr	0.50	0.58	0.63	0.73	0.83	0.90	1.09	1.35	1.58	1.92	2.18	2.44
03	30-min	0.39	0.45	0.50	0.58	0.65	0.71	0.85	1.07	1.24	1.51	1.72	1.92
03	15-min	0.29	0.33	0.36	0.42	0.48	0.52	0.62	0.78	0.91	1.10	1.25	1.40
03	10-min	0.22	0.26	0.28	0.32	0.37	0.40	0.49	0.60	0.71	0.86	0.97	1.09
03	5-min	0.13	0.15	0.16	0.19	0.21	0.23	0.28	0.35	0.40	0.49	0.56	0.62

p. 2/2

ATTACHMENT C

HYDRAULIC ROUGHNESS ESTIMATES FOR OPEN CHANNEL FLOW AS A FUNCTION OF HYDRAULIC RADIUS FOR ROUGH TURBULENT FLOW

MANNING'S N DETERMINATION FOR RIPRAP CHANNELS

Polymet Mining Company
Stockpile Hydrology
Project Number: 113-2209

Reach Designation	Q_{Design} (cfs)	Calculated D_{50} (inches)	First Trial					Second Trial					Third Trial		
			Manning's n	Depth (ft)	Hydraulic Radius (ft)	Hydraulic Radius (m)	Manning's n	Depth (ft)	Hydraulic Radius (ft)	Hydraulic Radius (m)	Manning's n	Depth (ft)	Hydraulic Radius (ft)	Hydraulic Radius (m)	Final Manning's n
DC1-A	52.9	12	0.070	0.44	0.40	0.123	0.039	0.31	0.29	0.089	0.040	0.31	0.30	0.090	0.040
DC1-B	74.3	12	0.070	0.53	0.48	0.148	0.038	0.37	0.35	0.106	0.040	0.38	0.36	0.109	0.039
DC1-C	100.1	12	0.070	0.56	0.51	0.156	0.038	0.39	0.36	0.111	0.040	0.40	0.38	0.114	0.039
DC1-D	78.8	12	0.070	0.55	0.50	0.152	0.038	0.39	0.36	0.109	0.040	0.40	0.37	0.112	0.039
DC1-E	96.1	12	0.070	0.55	0.50	0.154	0.038	0.38	0.36	0.110	0.040	0.39	0.37	0.113	0.039
DC1-E Bench	61.3	6	0.070	1.65	0.80	0.245	0.027	1.16	0.56	0.171	0.028	1.17	0.57	0.173	0.028
DC1-F	43.9	9	0.070	0.39	0.36	0.111	0.037	0.27	0.25	0.078	0.039	0.28	0.26	0.080	0.038
DC1-G	63.2	12	0.070	0.49	0.44	0.135	0.039	0.34	0.32	0.098	0.040	0.35	0.33	0.099	0.040
DC1-HRE	42.3	9	0.070	0.90	0.68	0.207	0.033	0.60	0.48	0.147	0.033	0.60	0.48	0.147	0.033
DC1-H	42.6	9	0.070	0.38	0.36	0.109	0.038	0.27	0.25	0.077	0.038	0.27	0.25	0.077	0.038
DC1-HRS	62.4	9	0.070	1.11	0.81	0.246	0.033	0.74	0.58	0.176	0.033	0.74	0.58	0.176	0.033
DC1-HRU	49.4	9	0.070	0.94	0.70	0.214	0.032	0.62	0.49	0.150	0.033	0.63	0.50	0.152	0.033
DC1-I	68.9	12	0.070	0.51	0.46	0.142	0.038	0.36	0.33	0.101	0.040	0.37	0.34	0.104	0.040
DC1-J	152.6	18	0.070	0.81	0.71	0.215	0.040	0.59	0.53	0.161	0.045	0.63	0.56	0.171	0.045
DC1-K	98.8	12	0.070	0.55	0.51	0.155	0.037	0.38	0.36	0.109	0.038	0.38	0.36	0.110	0.039
DC1-L	82.2	12	0.070	0.50	0.46	0.141	0.038	0.35	0.33	0.100	0.040	0.36	0.34	0.103	0.040

Procedure:

1. Use calculated D_{50} to make first assumption of Manning's n value
2. Determine Hydraulic Radius using assumed Manning's n
3. Use calculated D_{50}, Hydraulic Radius and Figure 5.7 (Scour Technology, page 135) to verify Manning's n value
4. Repeat Steps 2 and 3 until Manning's n values converge

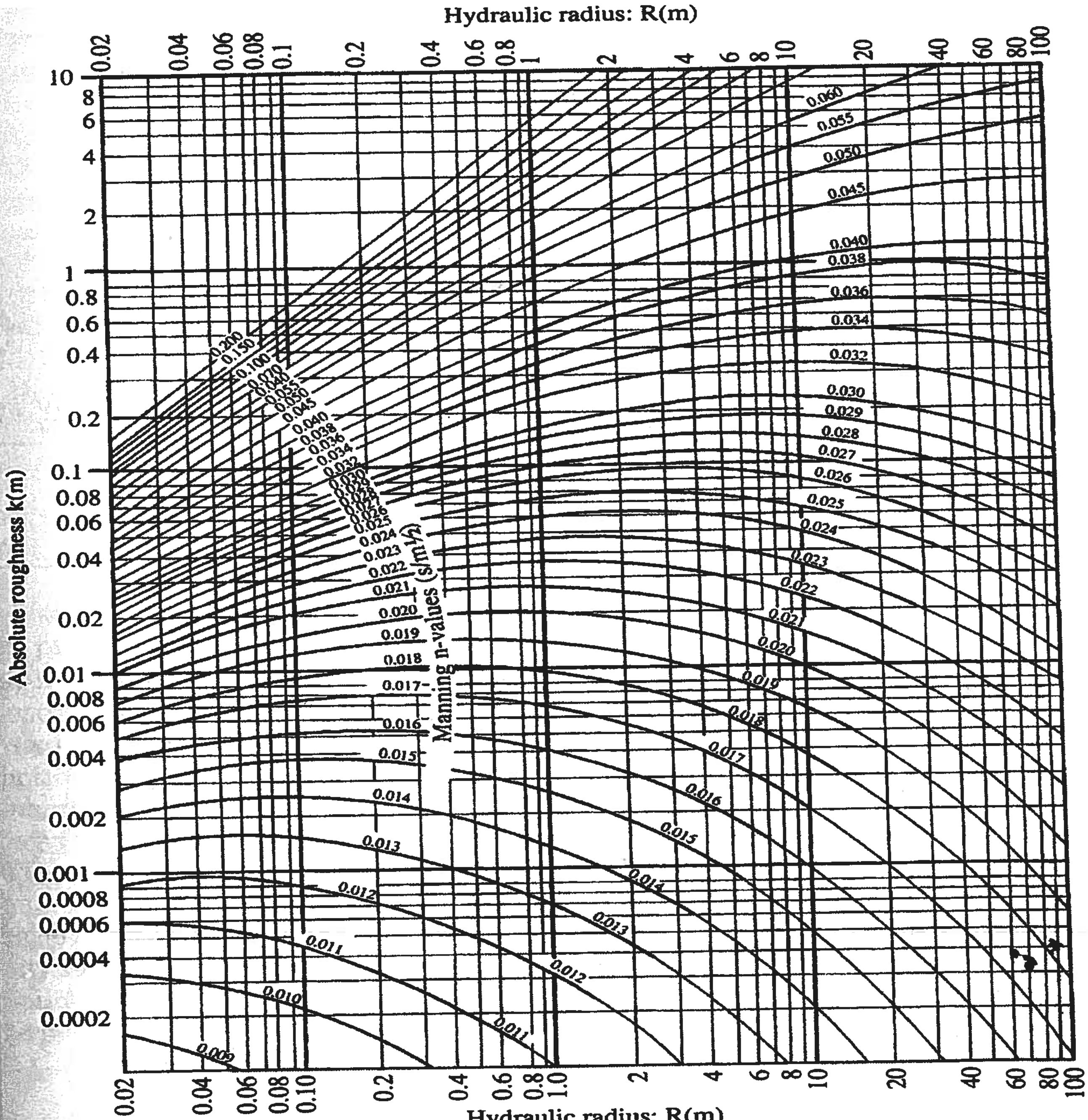


Figure 5.7 Hydraulic roughness estimates for open channel flow as a function of hydraulic radius for rough turbulent flow (Rooseboom et al., 2005).