Appendix 17 Work Plans

Appendix 17.1 2016/2017 Geotechnical Investigation Work Plan

2016/2017 Geotechnical Investigation Work Plan

NorthMet Project Geotechnical Investigations

Prepared for
Poly Met Mining Inc.

June 2016

2016/2017 Geotechnical Investigation Work Plan

NorthMet Project Geotechnical Investigations

Prepared for
Poly Met Mining Inc.

June 2016

4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435
952.832.2600
www.barr.com

2016/2017 Geotechnical Investigation Work Plan

June 2016

Contents

List of Tables

List of Large Figures

List of Large Tables

1.0 Introduction

This document is the Geotechnical Investigation Work Plan (Work Plan) for the proposed 2016/2017 geotechnical investigations at the NorthMet Project site (Project). The purpose of this Work Plan is to present an overview of the Project geotechnical investigations, consisting of SPT and Rotosonic borings, test pits, and geophysical investigations. This Work Plan was developed to document this phase of the Mine Site and Plant Site Geotechnical Investigations. The purpose of the geotechnical investigations is to collect information on the subsurface (i.e., depth to water, depth to bedrock, stratigraphy of overburden soils). The findings from the geotechnical investigations will be used in final design of Project infrastructure. The results of these investigations will inform the need for and extent of future phases of geotechnical investigation for the Project.

Included in the Work Plan is a brief summary of the Project site infrastructure, description of the geotechnical investigations planned, and proposed material test methods and documentation. This Work Plan was developed to be a companion document to the Geotechnical Investigation Construction Stormwater Pollution Prevention Plan (SWPPPs). Items excluded from this Work Plan that can be found in the Geotechnical Investigation SWPPPs include: approximate access road layout and construction, erosion control plans, and information regarding installation of proposed groundwater monitoring wells.

2.0 Project Summary

The Project consists of the Mine Site, Plant Site, and the Dunka Road Transportation and Utility Corridor. Table 1 summarizes the infrastructure planned for additional investigations as part of this 2016/2017 Work Plan.

Table 1 Summary of 2016/2017 Geotechnical Investigation Locations

Mine Site	Plant Site
Fueling and Maintenance Facility	Flotation Tailings Basin (FTB)
Dikes and Stormwater Ponds	Flotation Tailings Basin Seepage Containment System (FTB SCS)
Rail Transfer Hopper (RTH)	Waste Water Treatment Plant (WWTP)
VSEP Concentrator Track	Plant Stormwater Controls
Stockpiles	Sewage Treatment System
Central Pumping Station	
Rail for RTH	
Category 1 Groundwater Containment System (Cat. 1 GCS)	

Information regarding previous geotechnical investigations and currently available geotechnical data for the Project can be found in:

- Geotechnical Data Package Volume 1 - Flotation Tailings Basin
- Geotechnical Data Package Volume 2 – Hydrometallurgical Residue Facility
- Geotechnical Data Package Volume 3 – Mine Site Stockpiles

3.0 Exploration Methods and Equipment

Geotechnical exploration methods will include Rotosonic drilling, hollow-stem and mud rotary auger borings and possibly other rotary drilling methods with Standard Penetration Testing (SPT), test pits, and potentially seismic surveys.

Rotosonic work will consist of Rotosonic coring, collection of soil and rock samples, installation of standpipe piezometers, and slug testing. All work will be performed in accordance with ASTM D6914, Standard Practice for Sonic Drilling for Site Characterization and Installation of Subsurface Monitoring Devices D5092. Soil samples will be classified based on the Unified Soil Classification System (USCS). Piezometers will consist of a riser with a screened pipe interval at the bottom 5 feet. Sand pack will be placed in the annulus along the screened interval and a bentonite seal will be placed above the sand to isolate the pore water pressure to the screened interval. The piezometers will then be backfilled with bentonite grout to prevent unwanted vertical migration of water. Slug tests may be performed after the piezometers are cleaned and water levels are stabilized.

The SPT geotechnical investigations will consist of SPT soil borings using mud rotary and hollow stem auger drilling methods. Rock cores will be collected to confirm depth to bedrock, typically indicated by SPT results in excess of 50 blows for less than one-half foot of penetration, and to provide qualitative information, including Rock Quality Designation (RQD) values and fracture characteristics. All split spoon sampling and standard penetration testing will be completed in accordance with ASTM D1586, Standard Test Method for SPT and Split-Barrel Sampling of Soils. Soft clay and organic soil samples will be collected with 3-inch thin-wall samplers, when feasible, in accordance with ASTM D1587. Packer testing intervals will be determined in the field with the intent to obtain the most representative data possible and provide hydraulic conductivity values of the bedrock.

Test pits will be performed to determine depth of peat, confirm subsurface conditions, and log stratigraphy. Soil samples will be collected where deemed appropriate. Test pits can be up to 15 feet deep and soil will be removed using a hydraulic excavator. Removed soils will be placed next to one side of the excavation and will be replaced and compacted upon completion of the soil profile evaluation and sample collection.

Groundwater monitoring wells will be installed as part of the individual National Pollutant Discharge Elimination System and State Disposal System (NPDES/SDS) permit application for the Project. Groundwater monitoring wells may be installed during the same timeframe as the geotechnical investigation but are not an integral part of this plan.

Geotechnical investigation phasing will be determined prior to construction. Preference will be given to completing geotechnical investigations located within wetlands when the ground is frozen. This timing will minimize the potential for discharge of sediments and other pollutants. Access routes crossing wetland areas will also be completed when the ground is frozen, when possible, to minimize temporary wetland impacts. In some cases, access to monitoring well locations is not feasible unless there are frozen ground conditions. Where wetland impacts are required during non-frozen ground conditions, construction mats and/or low-pressure equipment will be used to minimize impacts to wetlands.

Equipment required to complete the geotechnical investigation includes all-terrain drill rigs for the SPT and Rotosonic investigations, and an excavator to perform the test pits. Non-invasive seismic equipment will be used to perform any geophysical investigations.

Existing gravel and paved roads will be used to access the geotechnical investigation locations. Existing trails and/or forest roads located throughout the Mine Site will be used where possible to access the geotechnical investigation locations and minimize soil disturbance; however it is assumed that some ground disturbance may be required with use of the existing trails and/or forest roads. Temporary access routes, including existing trails and/or forest roads, will be utilized to reach those geotechnical investigation locations not accessible from the existing gravel and paved roads.

4.0 Construction and Erosion Control

Construction Stormwater Pollution Prevention Plans (SWPPPs) have been prepared to outline pollution prevention requirements and procedures applicable to the geotechnical investigation activities. The SWPPPs are live documents; they are based on current plans for geotechnical investigation and will be updated as needed as on-site reconnaissance is performed to confirm geotechnical investigation locations and vehicle access routes.

Existing gravel and paved roads, trails, and/or forest roads will be used to access the geotechnical investigation locations to the extent possible. Temporary access roads will need to be constructed to allow equipment to reach some of the desired investigation locations. The temporary and proposed access routes, including those in wetland areas, are shown in the Geotechnical Investigation SWPPPs figures. Best Management Practices (BMPs) established by the Minnesota Pollution Control Agency (MPCA) will serve as guidelines for developing access roads and avoiding disturbance to wetland soils. Each geotechnical location and access route will be chosen using the criteria outlined in the Geotechnical Investigation SWPPPs.

Clearing, grubbing, and grinding or chipping of vegetation (trees, snags, logs, brush, stumps, and shrubs) and pushing large rocks from temporary access roads will be performed to facilitate geotechnical investigation activities at the Project site. Trees and other vegetation designated to remain undisturbed in wetland areas will be protected from damage throughout the duration of the construction period. The limits of the area(s) to be cleared and grubbed will be marked by stakes, flags, tree markings, or other suitable methods. Trees to be left standing and uninjured will be designated by special markings that are conducive to preventing injury to the tree and will be placed on the trunk about 6 feet above the ground surface. All trees not marked for preservation and all snags, logs, brush, stumps, shrubs, and similar materials will be cleared from within the limits of the designated investigation areas to the extent needed to conduct the geotechnical investigations.

The Geotechnical Investigation SWPPPs describe the BPMs that will be implemented during the geotechnical investigations to address erosion prevention practices and sediment control practices.

5.0 Work Plan Specifics

There is currently a limited geotechnical data set available for design at each of the Project facilities. The proposed 2016/2017 investigation will provide additional information needed to move forward with final design. Additional investigations for final design will likely be required prior to construction of some features, but future geotechnical evaluations will be informed by the results of this 2016/2017 investigation.

The geotechnical investigation schedule will be determined prior to commencement of road construction. An approximate schedule is summarized in Table 2. This information is presented to provide an idea of the sequencing of each task to be performed from the start of the work to completion of the final geotechnical investigation report.

Table 2 Summary of the Geotechnical Investigation Work

Schedule	Summary of Work in Required	Owner
Fall 2016	Field reconnaissance to stake investigation locations and flag access roads, obtaining coordinates of each	Barr
	Pre-Construction Notification (PCN) to U.S. Army Corps of Engineers	PolyMet
	Obtain permits or access easements	PolyMet
	Create maps/figure based on field reconnaissance to show updated locations and access roads	Barr
	Update the Geotechnical Investigation SWPPPs based on field reconnaissance to show updated investigation locations and access roads	PolyMet/Barr
	Prepare plans and specifications for the subcontractors	PolyMet / Barr
	Coordinate/award investigation contract	PolyMet / Barr
	Install erosion controls and clear and grub along access roads	PolyMet/ Subcontractor
Winter/Spring 2017	Oversee access road construction	PolyMet / Barr
	SWPPP inspections, supervision of installation, maintenance, and repair of BMPs	To be determined prior to construction
	Perform investigations	Subcontractor / Barr
	Seeding, restoration, and final stabilization	Subcontractor
	Geotechnical material testing (in-lab)	Subcontractor / Barr
	Data analysis	Barr
	Final report	Barr

The proposed 2016/2017 geotechnical investigations include SPT borings, test pits, geophysical work and material testing. The purpose, methods, and equipment required for each are summarized below.

5.1 Standard Penetration Test Borings

There are a total of 34 Standard Penetration Test (SPT) borings proposed for the 2016/2017 geotechnical investigations, to be performed at seven future facilities. There are 20 Mine Site SPT borings, shown on Large Figure 1. Six of these have been identified as being located in wetland areas. There are 14 Plant Site SPT borings, shown on Large Figure 2, of which four have been identified as being located in wetland areas. A summary of the proposed SPT borings is provided in Large Table . Preference will be given to completing geotechnical investigations located within wetlands when the ground is frozen, as described in greater detail in the Geotechnical Investigation SWPPPs. This timing will minimize the potential for ground disturbance.

The naming convention for each SPT boring will identify the investigation method and year, followed by the investigation number. For example, BH2017-01 will represent the first (01) SPT location (BH or borehole) performed in 2017. Naming convention is preliminary and will be finalized at the time that the borings are performed.

5.2 Test Pits

The 2016/2017 geotechnical investigation has proposed 88 test pits to be performed at six future facilities. There are 81 Mine Site test pits, shown on Large Figure 1. Twenty-five of these have been identified as being located in wetland areas. There are seven Plant Site test pits, shown on Large Figure 2, all located outside of wetland areas. A summary of the proposed SPT borings is provided in Large Table 1. Ideally the test pits will be performed when the ground is firm but not frozen such as in the fall or spring. This timing will provide adequate ground support for the excavator and minimize the potential for disturbance in wetland areas.

The naming convention for the test pits will identify the investigation method and year followed by the investigation number. For example, TP2017-01 will represent the first (01) test pit (TP) performed in 2017.

5.3 Geophysical Investigations

Geophysical investigations may be performed as part of the geotechnical investigation program. The objective of these investigations will be to provide a potentially more cost effective means to:

1. Estimate the depth to bedrock along the alignment for the cut-off wall planned as part of the Flotation Tailings Basin Seepage Containment System at the Plant Site, and around the Category 1 Stockpile at the Mine Site.

2. Estimate the thickness of peat deposits in the proposed stockpile footprints at the Mine Site.

The ability to collect subsurface data through geophysical explorations from the ground surface can provide a valuable supplement to the more intrusive boreholes in developing models of the subsurface conditions. It is also assumed that the geophysical investigations will be performed in wetland areas.

Seismic refraction will be the most effective technique to map and estimate the bedrock surface beneath the proposed cut-off wall alignment at the Plant Site and Mine Site. Data would be collected simultaneously for both seismic refraction and the multi-channel analysis of surface waves (MASW) technique. This geophysical survey would produce a 2-dimensional cross-section of distance vs. depth with model layer values measured in seismic velocities. Survey results, along with existing borehole data, would be used to adjust the subsurface model cross-section and target additional borings to verify anomalous bedrock depths revealed in the seismic survey results.

Ground penetrating radar (GPR) at the Mine Site will be the most cost-effective means to estimate the thickness and extent of peat deposits in the stockpile areas. Data processing is usually minimal, and real-time images of the resulting data are produced. When coupled with GPR common depth point (CDP) soundings, reasonably accurate depth profiles are possible. Data would be analyzed to determine the depth of investigation, effectiveness of the method, and antenna selection. The desired data density would be satisfied by parallel transects in the wetland areas of each of the stockpile footprints. Lineal footage assumptions are based on an approximation assuming cross lines spaced 200' apart, crossing wetlands of each area:

- Category 1 Stockpile = 110,000 lineal feet [L.F.]
- Category 2/3 Stockpile = 22,000 L.F.
- Ore Surge Pile = 3,800 L.F.
- Central Pit (Category 4 Stockpile) = 7,200 L.F.
- Overburden Storage & Laydown Area = 6,000 L.F.

Total = 149,000 L.F. (28.2 miles)

Geophysical investigations summarized above are at the conceptual planning stages with geophysical exploration sub-contractors. Even with geophysical investigations, site access and vegetation density, as well as subsurface conditions, can interfere with survey implementation, accuracy and efficiency. These factors will be further evaluated as the time nears for Work Plan implementation.

5.4 Material Testing

Material testing will be performed on select soil samples recovered from SPT borings and test pits performed as part of the planned geotechnical exploration. Typical material testing performed in the laboratory may include but not be limited to:

- Water Content – ASTM D4643
- Sieve Analysis – ASTM D6913
- Hydrometer Analysis – ASTM D4211
- Specific Gravity – ASTM D854
- Atterberg Limits – ASTM D4221

- Standard Proctor – ASTM D698
- Permeability – ASTM D5084

In addition to the material tests summarized above, a limited quantity of in-laboratory material shear strength testing may also be performed. The material testing results will be utilized to plan horizontal and vertical extent of excavations, to confirm material type and availability for on-site construction uses, to further evaluate material strength for use in foundations support, and to determine areas of soil requiring excavation and replacement.

5.5 Documentation

Pre- and post- road development and geotechnical investigations will be documented using photographs, field notes, and electronic handheld devices which include Global Positioning Systems (GPS) and digital tablets. Digital tablets have the capability of tracking real-time data that would allow team members to remotely monitor the road construction while it is occurring, documenting the access roads in wetlands, and allowing Geotechnical Investigation SWPPP figures to be updated in a timely manner. Documentation for each geotechnical investigation will include:

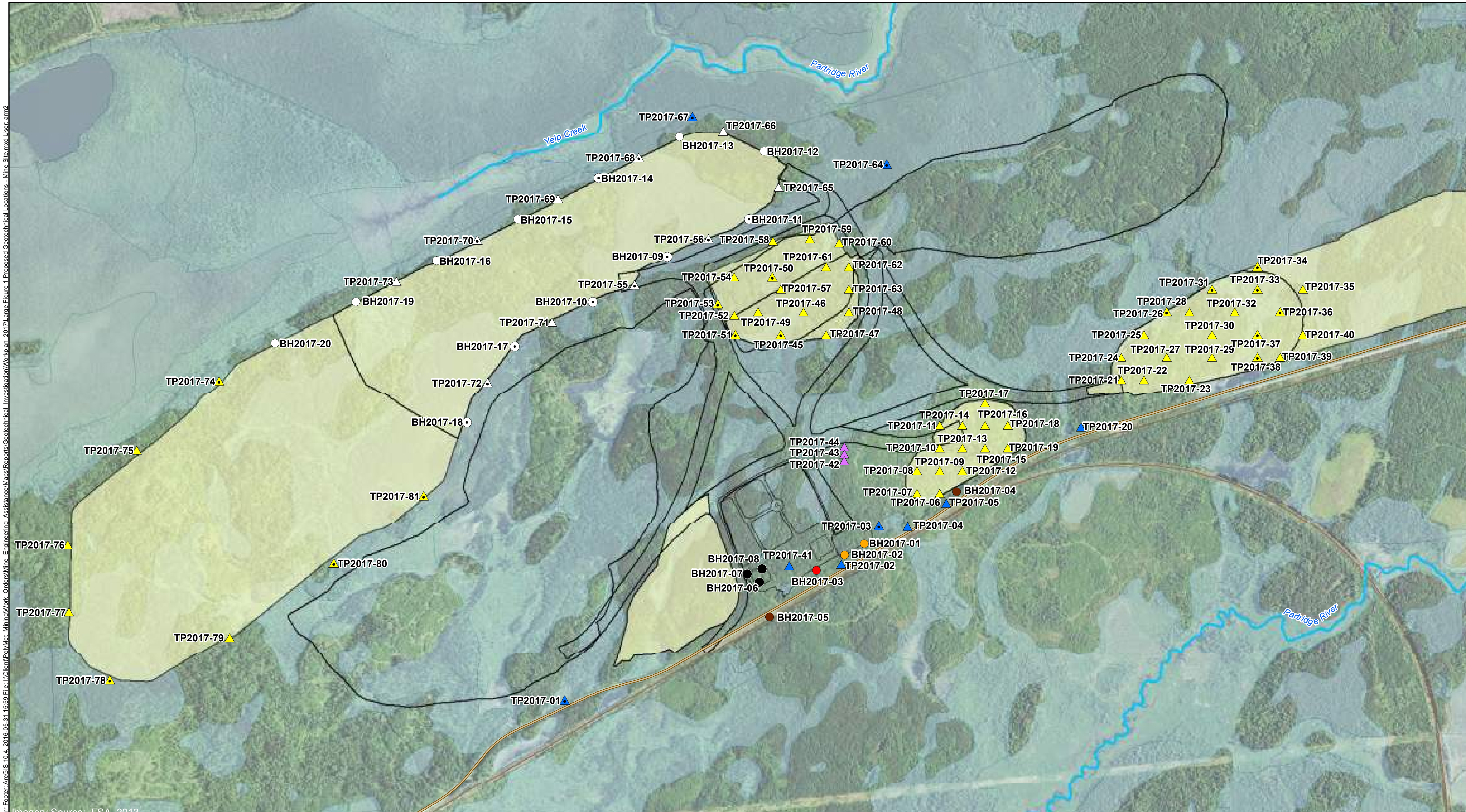
- Coordinates and elevations
- Logs of stratigraphy
- Grouting details for each SPT boring
- Restoration plan and record of abandonment for each test pit

Upon completion of the geotechnical investigations, and when the soils collected from the field have been subjected to visual characterization and laboratory testing, a soil investigation report will be prepared for use in planning and design, summarizing results, and providing soil data (including boring logs). The report will contain typical geotechnical investigation information such as:

- Scope and purpose of investigation
- Geologic conditions of the site
- Summary of field investigations (SPT borings, test pits, and geophysical investigations)
- Groundwater conditions
- Laboratory testing data
- Analysis of subsurface conditions
- Design recommendations
- Anticipated construction challenges

- Maps/figures
    - Site location
    - Location of borings with respect to infrastructure
- Boring logs
- Laboratory test results

Large Figures



Proposed Geotechnical Locations

- Fueling and Maintenance Facility Test Pits Count: 3
- Stockpile Test Pits Count: 44
- Stockpile Test Pits in Wetlands Count: 15
- Dikes and Stormwater Test Pits Count: 5
- Dikes and Stormwater Test Pits in Wetlands Count: 4
- RTH SPT Borings Count: 2
- Rail for RTH SPT Borings Count: 2
- VSEP Concentration Track SPT Borings Count: 1
- CPS SPT Borings Count: 3
- Cat. 1 GCS SPT Borings Count: 6
- Cat. 1 GCS SPT Borings in Wetlands Count: 6
- Cat. 1 GCS Test Pits Count: 5
- Cat. 1 GCS Test Pits in Wetlands Count: 5
- Dunka Road
- Existing Private Railroad
- Proposed Mine Features
- Public Waters Inventory (PWI) Watercourses
- Wetlands

0 600 1,200 2,400
Feet

DRAFT

PROPOSED GEOTECHNICAL LOCATIONS - MINE SITE
NorthMet Project
Poly Met Mining Inc.

Large Figure 1
Geotechnical Investigation Work Plan

Proposed Geotechnical Locations

- FTB SCS SPT Boring Count: 8
- FTB SCS SPT Boring in Wetland Count: 4
- WWTP SPT Boring Count: 2
- Plant Stormwater Test Pit Count: 3
- Sewage Treatment Test Pit Count: 4
- Geophysical Investigation
- Dunka Road
- Existing Private Railroad
- Colby Lake Water Pipeline
- Public Waters Inventory (PWI) Watercourses[1]
- Wetlands

0 1,000 2,000 4,000

Feet

DRAFT

PROPOSED GEOTECHNICAL LOCATIONS - PLANT SITE

NorthMet Project

Poly Met Mining Inc.

Large Figure 2

Geotechnical Investigation Work Plan

Large Tables

Large Table 1 - PolyMet NorthMet Proposed Geotechnical Investigations

6/6/2016 KNA

Totals	Number of Test Pits	*Test Pits in Wetlands*	Number of SPT borings	*SPT borings in Wetlands*	Total Number of Geotechnical Investigations
	88	*25*	34	*10*	**122**

Mine Site	Number of Test Pits	Test Pit ID	Located in a Wetland	Geotechnical SWPPP Figure Number	Number of SPT borings	SPT boring ID	Located in a Wetland	Geotechnical SWPPP Figure Number	Total Number of Mine Site Investigations	Proposed Geophysical Investigation
Fueling and Maintenance Facility	3	TP2017-42	no	3-21	0	--	--	--	3	no
		TP2017-43	no	3-21		--	--	--		
		TP2017-44	no	3-21		--	--	--		
Dikes & Stormwater Ponds	9	TP2017-01	yes	3-1	0	--	--	--	9	no
		TP2017-02	no	3-7		--	--	--		
		TP2017-03	yes	3-8		--	--	--		
		TP2017-04	no	3-8		--	--	--		
		TP2017-05	no	3-8		--	--	--		
		TP2017-20	no	3-10		--	--	--		
		TP2017-41	no	3-19		--	--	--		
		TP2017-64	yes	3-28		--	--	--		
		TP2017-67	yes	3-36		--	--	--		
Rail Transfer Hopper (RTH)	0	--	--	--	2	BH2017-01	no	3-7	2	no
		--	--	--		BH2017-02	no	3-7		
VSEP Concentrate Track	0	--	--	--	1	BH2017-03	no	3-7	1	no
Stockpiles	59	TP2017-06	no	3-8	0	--	--	--	59	TBD
		TP2017-07	no	3-8		--	--	--		
		TP2017-08	no	3-9		--	--	--		
		TP2017-09	no	3-9		--	--	--		
		TP2017-10	no	3-9		--	--	--		
		TP2017-11	no	3-9		--	--	--		
		TP2017-12	no	3-9		--	--	--		
		TP2017-13	no	3-9		--	--	--		
		TP2017-14	no	3-9		--	--	--		
		TP2017-15	no	3-9		--	--	--		
		TP2017-16	no	3-9		--	--	--		
		TP2017-17	no	3-10		--	--	--		
		TP2017-18	no	3-10		--	--	--		
		TP2017-19	no	3-10		--	--	--		
		TP2017-21	no	3-11		--	--	--		
		TP2017-22	no	3-11		--	--	--		
		TP2017-23	no	3-11		--	--	--		
		TP2017-24	no	3-12		--	--	--		
		TP2017-25	no	3-12		--	--	--		
		TP2017-26	yes	3-12		--	--	--		
		TP2017-27	no	3-12		--	--	--		
		TP2017-28	no	3-12		--	--	--		
		TP2017-29	no	3-12		--	--	--		
		TP2017-30	no	3-12		--	--	--		
		TP2017-31	yes	3-13		--	--	--		
		TP2017-32	no	3-13		--	--	--		
		TP2017-33	yes	3-13		--	--	--		
		TP2017-34	yes	3-13		--	--	--		
		TP2017-35	no	3-13		--	--	--		
		TP2017-36	yes	3-13		--	--	--		
		TP2017-37	yes	3-14		--	--	--		
		TP2017-38	yes	3-14		--	--	--		
		TP2017-39	no	3-14		--	--	--		
		TP2017-40	no	3-14		--	--	--		
		TP2017-45	yes	3-23		--	--	--		
		TP2017-46	yes	3-23		--	--	--		
		TP2017-47	no	3-23		--	--	--		
		TP2017-48	no	3-23		--	--	--		
		TP2017-49	no	3-24		--	--	--		
		TP2017-50	yes	3-24		--	--	--		
		TP2017-51	yes	3-24		--	--	--		
		TP2017-52	no	3-24		--	--	--		
		TP2017-53	yes	3-24		--	--	--		
		TP2017-54	no	3-24		--	--	--		
		TP2017-57	yes	3-26		--	--	--		
		TP2017-58	no	3-26		--	--	--		
		TP2017-59	no	3-27		--	--	--		
		TP2017-60	no	3-27		--	--	--		
		TP2017-61	no	3-27		--	--	--		
		TP2017-62	no	3-27		--	--	--		
		TP2017-63	no	3-27		--	--	--		
		TP2017-74	yes	3-44		--	--	--		
		TP2017-75	no	3-46		--	--	--		
		TP2017-76	no	3-47		--	--	--		
		TP2017-77	no	3-48		--	--	--		
		TP2017-78	yes	3-51		--	--	--		
		TP2017-79	no	3-52		--	--	--		
		TP2017-80	yes	3-55		--	--	--		
		TP2017-81	yes	3-56		--	--	--		
Central Pumping Station	0	--	--	--	3	BH2017-06	no	3-19	3	no
		--	--	--		BH2017-07	no	3-19		
		--	--	--		BH2017-08	no	3-19		
Rail for RTH	0	--	--	--	2	BH2017-04	no	3-8	2	no
		--	--	--		BH2017-05	no	3-19		
Category 1 Groundwater Containment System (Cat. 1 GCS)	10	TP2017-55	yes	3-25	12	BH2017-09	yes	3-25	22	TBD
		TP2017-56	yes	3-26		BH2017-10	yes	3-25		
		TP2017-65	no	3-34		BH2017-11	yes	3-34		
		TP2017-66	no	3-35		BH2017-12	no	3-35		
		TP2017-68	yes	3-36		BH2017-13	no	3-36		
		TP2017-69	no	3-37		BH2017-14	yes	3-37		
		TP2017-70	yes	3-38		BH2017-15	no	3-37		
		TP2017-71	no	3-39		BH2017-16	no	3-38		
		TP2017-72	yes	3-41		BH2017-17	yes	3-40		
		TP2017-73	no	3-42		BH2017-18	yes	3-41		
		--	--	--		BH2017-19	no	3-43		
		--	--	--		BH2017-20	no	3-44		

Mine Site Totals	Total Number of Mine Site Test Pits	*Test Pits in Wetlands*	Total Number of Mine Site SPT borings	*SPT borings in Wetlands*	Total Number of Mine Site Geotechnical Investigations
	81	*25*	20	*6*	**101**

Plant Site	Number of Test Pits	Test Pit ID	Located in a Wetland	Geotechnical SWPPP Figure Number	Number of SPT borings	SPT boring ID	Located in a Wetland	Geotechnical SWPPP Figure Number	Total Number of Geotechnical Investigations	Proposed Geophysical Investigation
Flotation Tailings Basin Seepage Containment System (FTB SCS)	0	--	--	--	12	BH2017-23	yes	3-7	12	possibly
		--	--	--		BH2017-24	no	3-8		
		--	--	--		BH2017-25	yes	3-9		
		--	--	--		BH2017-26	yes	3-10		
		--	--	--		BH2017-27	no	3-11		
		--	--	--		BH2017-28	no	3-11		
		--	--	--		BH2017-29	no	3-12		
		--	--	--		BH2017-30	yes	3-14		
		--	--	--		BH2017-31	no	3-15		
		--	--	--		BH2017-32	no	3-16		
		--	--	--		BH2017-33	no	3-18		
		--	--	--		BH2017-34	no	3-18		
Waste Water Treatment Plant (WWTP)	0	--	--	--	2	BH2017-21	no	3-6	2	no
		--	--	--		BH2017-22	no	3-6		
Plant Stormwater Controls	3	TP2017-82	no	3-1	0	--	--	--	3	yes
		TP2017-87	no	3-4		--	--	--		
		TP2017-88	no	3-5		--	--	--		
Sewage Treatment System	4	TP2017-83	no	3-2	0	--	--	--	4	yes
		TP2017-84	no	3-2		--	--	--		
		TP2017-85	no	3-2		--	--	--		
		TP2017-86	no	3-3		--	--	--		

Plant Site Totals	Total Number of Plant Site Test Pits	*Test Pits in Wetlands*	Total Number of Plant Site SPT borings	*SPT borings in Wetlands*	Total Number of Plant Site Geotechnical Investigations
	7	*0*	14	*4*	**21**

Notes:
1) Geophysical data collection locations not identified in Geotechnical Construction SWPPPs.

Appendix 17.2 Monitoring Wells North of the Mine Site: Installation and Hydrogeologic Monitoring Plan

Monitoring Wells North of the Mine Site: Installation and Hydrogeologic Monitoring Plan

NorthMet Project

Prepared for
Poly Met Mining Inc.

October 2016

4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435
952.832.2600
www.barr.com

Monitoring Wells North of the Mine Site: Installation and Hydrogeologic Monitoring Plan

October 2016

Contents

List of Tables

List of Large Figures

1.0 Introduction

This document describes the Monitoring Plan for assessing hydrogeologic conditions in the area between the Poly Met Mining Inc. (PolyMet) NorthMet Project (Project) Mine Site and the Northshore Peter Mitchell Pit (PMP) operated by an affiliate of Cliffs Natural Resources. The PMP is an active mine located approximately 1 to 2 miles north of the Project Mine Site. To facilitate mining, the PMP is dewatered – groundwater levels are drawn down so ore can be accessed.

Current PMP dewatering does not affect water levels in bedrock at the Project Mine Site. PolyMet has monitored water levels in bedrock wells at the Project Mine Site since 2007, and water levels in these bedrock wells do not show a response to dewatering activities at PMP. The lack of response in the observation wells during a period of dewatering at the Peter Mitchell East Pit provides recent, direct evidence to support the conclusion that water levels in the PMP do not have an effect on bedrock water levels at the Project Mine Site.

Concern has been raised that despite this site-specific data, continued dewatering at PMP has the potential to cause water from the backfilled/flooded NorthMet pits to flow via groundwater to the PMP pits (Reference (1). The Co-lead Agencies determined that the potential for this flow is not reasonably foreseeable, but could not be totally excluded, and as such stated in the FEIS that they would require monitoring of bedrock groundwater levels north of the Mine Site to determine the potential for northward flow between the NorthMet and PMP pits (Section 5.2.2 of Reference (2)). This document presents a proposed monitoring plan consistent with what was described in the FEIS.

The purpose of the monitoring proposed in this plan is to further evaluate potential effects of PMP dewatering in the area north of the Project Mine Site and to collect additional data to refine predictions of future water levels in the area north of the Mine Site as mining at PMP progresses. With early implementation of this Monitoring Plan, PolyMet will be able to collect and analyze additional information concerning "pre-Project" hydrogeologic conditions. Continued monitoring during Project operations and reclamation will provide data for ongoing assessment of potential effects of PMP dewatering activities on groundwater levels and flow directions in the area north of the Project Mine Site.

Implementation of this Monitoring Plan will allow ample opportunity to collect the necessary data, and to complete applicable environmental review and/or permitting, engineering and construction prior to the development of a northward flowpath (if one were to form). As stated in the FEIS, conditions potentially supporting development of a northward flowpath would not exist until water levels in the NorthMet pits are higher than at the Northshore pits (Reference (2)).

PolyMet will analyze monitoring information and use adaptive management practices, as needed, including adaptive engineering controls. These tools are industry standard practice, have been used throughout PolyMet's environmental review process, and will continue to be used in permitting, operations, reclamation, and long-term closure (Reference (3)).

The outline of this document is:

Section 2.0	Description of the basis for monitoring locations
Section 3.0	Methods for monitoring well installation, downhole geophysics, and hydrogeologic testing
Section 4.0	Explanation of how the data collected will be synthesized
Section 5.0	Overview of annual reporting associated with this Plan
Section 6.0	Overview of timing for installation and monitoring activities
Section 7.0	Description of the adaptive management strategy
Section 8.0	Overview of permit requirements for monitoring well installation

2.0 Monitoring Well Installation

2.1 Existing Monitoring Wells

There are five existing NorthMet bedrock wells (OB-1 through OB-5) at the Mine Site. Three of these wells (OB-1, OB-4, and OB-5) will become part of the permanent monitoring network, and two (OB-2 and OB-3) will be abandoned during Mine Site construction, as they are within the footprints of mine features (Large Figure 1). The existing wells will continue to be monitored three times a year until they are abandoned or new monitoring requirements are established for the proposed bedrock monitoring wells.

2.2 Proposed Monitoring Wells

PolyMet proposes installing twelve new bedrock wells in the area between the Project Mine Site and the PMP. At nine of the bedrock well locations, a surficial aquifer well will also be installed, if the unconsolidated materials and aquifer thickness are sufficient. Surficial aquifer wells already exist at three of the locations where new bedrock wells are proposed. The proposed installation will result in a total of twelve new surficial/bedrock well "nests".

The proposed bedrock monitoring network will allow for triangulation of water levels near the NorthMet pits to calculate hydraulic gradients. The network will also result in two transects between the NorthMet pits and the PMP: a western transect, that runs from the NorthMet West Pit to the Northshore Area 003 West pit, and an eastern transect, that runs from the NorthMet East Pit to the Northshore Area 003 East pit. Large Figure 1 depicts the location of the proposed monitoring wells. Table 2-1 presents additional information on the location and depth of the proposed wells. Because bedrock permeability decreases with depth, the currently proposed depths are sufficient to provide the necessary information on subsurface conditions. Once operations commence, PolyMet may drill additional deeper monitoring wells or deepen exiting monitoring wells, if necessary to obtain additional information on bedrock characteristics at depth.

Table 2-1 Summary of Proposed Well Locations North of the Mine Site

Well ID	Location	Winter Only Construction?	Surface Ownership	Estimated Depth (feet below ground surface)[1]	Estimated Bottom Elevation (feet MSL)[2]
Bedrock: GW508[2]	S of Cat 1 WR Stockpile	Yes – Wetland Area	Forest Service (Land Exchange)	235	1380
Surficial: GW468				20-30	1585-1595
Bedrock: GW509[2]	N of East Pit	Yes – Wetland Area	Forest Service (Land Exchange)	223	1380
Surficial: GW499				20-30	1573-1583
Bedrock: GW510[2]	East Transect	Yes – Wetland Area	Forest Service (Land Exchange)	221	1380
Surficial: GW470				20-30	1571-1581
Bedrock: GW512[2,4]	N of Central Pit	Yes – Wetland Area	Forest Service (Land Exchange)	221	1380
Bedrock: GW514[2,4]	NW of Cat 1 WR Stockpile	Yes – Wetland Area	Forest Service (Land Exchange)	233	1380
Bedrock: GW515[2,4]	West Transect	Yes – Wetland Area	Forest Service (Land Exchange)	225	1380
Bedrock: GW517[2]	West Transect	Yes – Wetland Area	Forest Service (Land Exchange)	225	1380
Surficial: GW477				20-30	1575-1585
Bedrock: GW518[2]	West Transect	No – Upland Area	Forest Service (Land Exchange)	230	1380
Surficial: GW478				20-30	1580-1590
Bedrock: GW519[2]	West Transect	No – Upland Area	Forest Service (Land Exchange)	246	1380
Surficial: GW479				20-30	1596-1606
Bedrock: GW521[2]	N of East Pit	Yes – Wetland Area	Forest Service (Land Exchange)	219	1380
Surficial: GW471				20-30	1569-1579
Bedrock: GW522[3]	East Transect	No – Upland Area	State of Minnesota	349	1250
Surficial: GW472				20-30	1569-1579
Bedrock: GW523[3]	East Transect	No – Upland Area	Cliffs Erie	366	1250
Surficial: GW473				20-30	1586-1596

(1) Determined based on estimated ground surface elevations from 2010 LiDAR, 2011 LiDAR, or an average of the two
(2) Bedrock wells will be drilled to estimated maximum extent of mining at the PMP west (1380 ft MSL).
(3) Bedrock wells will be drilled to estimated maximum extent of mining at the PMP east (1250 ft MSL)
(4) Surficial aquifer well already in place

2.3 Drilling Methods and Well Installation

Boreholes for the nested surficial aquifer and bedrock monitoring wells will be advanced using traditional drilling methods, such as Rotasonic, air hammer, or diamond core, depending on the geologic materials encountered. Locations of the boreholes are shown on Large Figure 1 and the estimated depths for the bedrock monitoring wells are included in Table 2-1. The monitoring wells will all be installed in accordance with Minnesota Rules, parts 4725.6450-7000 (administered by the Minnesota Department of Health [MDH]) by a licensed well contractor.

2.3.1 Bedrock Wells

The bedrock monitoring wells are anticipated to be open-hole within the bedrock and will be advanced through the overburden using traditional drilling methods with an approximately eight- to ten-inch diameter bit to the top of bedrock. The top of bedrock is estimated to be approximately 30 feet below ground surface (bgs). A steel casing (large enough to accommodate a four- to six-inch diameter drill bit, respectively) will be installed through the overburden thickness to prevent any caving into the hole and will be seated at least 2 feet into the bedrock; additional measures, such as grouting the casing into place, may be taken to ensure a proper seal between the two units. In the bedrock, drilling with a nominal four- to six-inch diameter bit, depending on the type of drilling, will be used to complete the remainder of the boring to the approximate elevations indicated in Table 2-1.

Drill cuttings or intact core will be removed from the borehole, and samples will be examined by a geologist or geologic technician at least every 5 feet. Samples will be collected and stored in either sample trays, plastic sheeting, or containerized and will be covered overnight and between drilling shifts. Formation water will be collected in an onsite sump (upland areas) or containerized (wetland areas), according to the stormwater pollution prevention plan (SWPPP). If the borehole appears likely to produce more water than can be contained in the sump or containers, either the sump will be enlarged, or additional containers will be used, or drilling advancement will be discontinued. Upon reaching the target depth, the bedrock section of each borehole will be developed to remove solids from the borehole and ensure connectivity across the borehole wall. All containerized formation water and drill core/cuttings will be removed from the wetland areas and properly disposed. Boring logs and well construction logs will be prepared for each bedrock monitoring well.

2.3.2 Surficial Aquifer Wells

If a surficial aquifer well is not currently in place at a bedrock monitoring well location, a new surficial aquifer well will be installed in locations where the total thickness of the unconsolidated materials is greater than 10 feet and the saturated thickness is greater than 5 feet. The surficial aquifer well will be installed approximately 5 feet from the corresponding "nested" bedrock well. The surficial aquifer borehole will be advanced through the unconsolidated materials using Rotasonic, or similar, method. The total depth of the surficial aquifer boreholes will be based on subsurface conditions encountered during the advancement of the bedrock boreholes. Samples of unconsolidated materials will be collected and logged by a geologist or geologic technician in the field; location of transition between unsaturated and saturated material will be recorded. Any drill cuttings or samples not retained will be thin spread in the upland areas or containerized and moved off-site in the wetland areas; during drilling activities, cuttings and samples may be stored on plastic sheeting and will be covered overnight and between drilling shifts. Formation water will be treated similarly as with the bedrock borehole drilling.

In general, the surficial aquifer monitoring well screen will be positioned to intersect the water table; however, at locations where the groundwater is close to the ground surface, the well screen may need to be submerged to permit installation of the required surface seal. Upon reaching the target depth, based on the location of the water table, a monitoring well will be installed in the surficial aquifer borehole. The monitoring wells will be constructed in accordance with Minnesota Rules, constructed with a 2-inch diameter Schedule 40 PVC risers, and will be completed above grade with steel protective casing. It is anticipated that the wells will be constructed with 5- to 15-foot long 10-slot screens; however, the depth and screened interval of the well, the size of the screen mesh, and the type of filter pack will be determined in the field based on unconsolidated material observed during drilling and the water level measured in the borehole. Well development will need to be conducted to remove residual drill cuttings from the well and to ensure connectivity across the filter pack. Boring and well construction logs will be prepared for each surficial monitoring well.

2.4 Well Completion

All the wells will be completed in compliance with Minnesota Rules with a bentonite or cement ground surface seal, which will extend at least five feet from the ground surface. A protective locking steel casing will be placed over the borehole and well riser, and will be completed above grade. In the event that flowing conditions are encountered, the wellhead will be capped and an appropriately rated pressure gauge and sampling tap will be installed. Protective posts will be installed around the monitoring well casings when located near future haul roads or at the request of the property owner (if not PolyMet). The elevation of the top of each monitoring well riser and ground surface will be surveyed to the nearest 0.01 foot, and the easting and northing of each well will be determined using a global positioning system (GPS), and recorded.

Permit requirements for the well installations are discussed in Section 8.0.

3.0 Hydrogeologic Investigation

Following completion and development of the new bedrock wells, downhole geophysical and hydrologic testing will be conducted. The purpose of these wells is to gather data regarding the current water table elevation and bedrock characteristics in specific locations north of the Mine Site pits rather than information about water quality. Nonetheless, to the extent that water quality data is necessary and the collection of such water quality data is permissible under the various access authorizations PolyMet will need to secure, the proposed monitoring wells may be useful in collecting this water quality data.

3.1 Geophysical Testing

Downhole geophysical data will be collected from the open-hole section of each of the bedrock wells. The following geophysical tests are proposed for new bedrock well:

- Caliper: the caliper provides an *in-situ* measure of borehole diameter and can be used to identify the presence of fractures;

- Borehole fluid temperature and resistivity: changes in fluid temperature can be an indication of a location where water is entering or leaving the borehole. The fluid resistivity data can be used to assess the relative salinity of water in different parts of the borehole. Changes in fluid temperature and fluid resistivity can be used along with other borehole logging information to identify hydraulically active fractures;

- Single-point resistance: this test provides information on the variations in lithology encountered within the borehole. The location of fractures can be identified from single-point resistance logs. Single-point resistance logs may provide some qualitative information regarding groundwater salinity and porosity of the formation. Single-point resistance logs can be used for correlation between boreholes;

- Spontaneous potential: this log measures the natural electrical potential between rock and borehole fluids. Spontaneous potential logs can be used to identify contacts between dissimilar rock types along the length of the borehole. As such, information on bed thickness can be determined from the log. Spontaneous potential logs can be used for correlation between boreholes. In cases where the lithology does not change, spontaneous potential logs can provide qualitative information on changes in groundwater salinity. In addition, a spontaneous potential log may provide a qualitative indication of permeability of the rock adjacent to the borehole.

- Short and long normal resistivity: provides information on lithology differences along the length of the borehole. Normal resistivity logs are affected by bed thickness. Normal resistivity logs are also used to evaluate water quality (i.e., variations in salinity) and formation porosity. Normal resistivity logs can be used for correlation between boreholes. In addition, normal resistivity logs can be used to evaluate the distance that drilling fluid has penetrated into the formation;

- Acoustic and/or optical borehole imaging: Borehole imaging logs can be used to measure borehole wall textural variability beyond what is obtained with a caliper log. The logs can also be used to identify fracture locations, fracture aperture, and fracture orientation. Acoustic borehole imaging logs can be run in fluid filled boreholes regardless of whether the fluid is clear or not. Optical borehole imaging (OBI) logs require clear fluid. The imaging tools are equipped to provide oriented logs.

The results of geophysical logging will be compiled into downhole logs and will be reviewed to determine target monitoring intervals for discrete interval hydrogeologic testing described in Section 3.3.

3.2 Flow Logging

Flow logging will be conducted to characterize fractures and estimate transmissivity changes with depth (e.g., Reference (4)). Trolling flow logging can be used to obtain qualitative information on flow in the borehole. Conducting stationary flow logging under both ambient and dynamic (i.e., pumping) conditions provides data for estimating the hydraulic properties of aquifers or fractures identified by geophysical logging methods. Flow logging under ambient conditions provides data for determining the direction of vertical hydraulic gradient between hydraulically active zones, cross-communication between geologic units, and identifying fractures that are hydraulically active. In order to estimate hydraulic properties of fractures or zones in an aquifer, flow logging under both ambient and dynamic conditions is required (Reference (5)).

Flow logging can be used to identify hydraulically active features that may not be apparent from geophysical logs alone. Results may also be used to estimate bulk hydraulic parameters (Reference (4)). Flow logging methods applied will be appropriate for the anticipated borehole flow rates and could include mechanical spinner, electromagnetic (EM), heat-pulse flowmeter, and HydroPhysical™ (HpL™) logging technologies. Due to anticipated low flow rates, the EM, heat-pulse flowmeter, and HpL™ logging technologies may be most appropriate. HpL™ logging has been previously utilized at PolyMet and provides the widest range of identifiable flow rates (0.0005-3,000 gpm). This method replaces the borehole water with deionized water and then profiles changes in electrical conductivity, allowing it to identify both horizontal and vertical flow into/out of the borehole. The HpL™ logging will be conducted under both ambient and dynamic conditions. All formation water and deionized water will be containerized during flow logging and disposed of properly.

3.3 Aquifer Testing

Aquifer testing of discrete intervals will be conducted to further characterize the bedrock. Discrete interval testing involves isolating specific intervals of the open borehole, and then conducting pumping tests in which water is withdrawn or displaced only from the isolated interval. On average, three discrete interval tests will be conducted per borehole, targeting the upper zone which is expected to be more fractured (approximately the upper 40 feet), the middle zone, and the lower zone of each borehole. The specific number and cutoffs for the various zones will be based on the results of the borehole logging, downhole geophysical testing, and flow logging. Details on the aquifer testing will be developed in consultation with the State agencies following completion of the geophysical testing and flow logging.

Each discrete interval test will include isolating the interval with inflatable packers, beginning with the zone closest to the bottom of the hole. The packer assembly will include a pressure transducer beneath the lower pack (assuming it is not placed at the bottom of the borehole), a pressure transducer in the interval between the packers, and a pressure transducer above the upper pack (assuming there is a sufficient volume of water above). These transducers will be used to monitor the hydraulic heads above, within, and below the discrete interval. The packer assembly will also include a submersible pump installed between the packers to lift water from the packed interval to the surface.

Once the packers are inflated, the isolated interval will be allowed to equilibrate and then pumping will begin, assuming sufficient bedrock response. Generally speaking, pumping will be conducted for up to two hours, however this may change depending on conditions encountered. The pumping discharge rate will be measured and recorded periodically. At the completion of pumping, the pump will be turned off and the total pumping time recorded. Water level recovery in the pumped interval and in the interval above and below the packed off discrete interval, if any, will be monitored via the pressure transducers and recorded on the datalogger. Recovery will be allowed to continue until the hydraulic head in the pumped interval has returned to at least 95% of the pre-pumping level. If the hydraulic head in the pumped interval does not recover to at least 95% of the pre-pumping level within four hours, then testing of the zone will be terminated. Water level data from the pumping and recovery periods will be analyzed by a Barr hydrogeologist to estimate the hydraulic conductivity of the formation in the tested interval. Additional testing, such as step drawdown pumping tests and slug tests may also be conducted to supplement the results of the single-well pumping tests.

3.4 Long-Term Hydrogeologic Monitoring

PolyMet will begin monitoring water levels in the surficial and bedrock wells within one month following the completion of well/borehole testing, and will continue until the end of mine closure or an alternative period authorized by the Minnesota Department of Natural Resources (MDNR) and the Minnesota Pollution Control Agency (MPCA). Monitoring will be conducted using a combination of continuous data-logging pressure transducers and periodic manual measurements.

Continuous loggers (pressure transducers) will be installed at locations where more frequent water level data are desired for monitoring the water level effects of PMP operations and where access constraints preclude obtaining periodic manual measurements. Pressure transducers will be installed at each of the monitoring network locations, including the twelve monitoring well “nests” and the three OB-series wells, for a total of 27 pressure transducers. The pressure transducers will record water levels at least hourly to provide a continuous log of water levels throughout the period of monitoring. Vented pressure transducers may be utilized as they autocorrect for barometric pressure changes, removing the need for installing barotrolls and manually correcting transducer data for barometric pressure fluctuations. Manual measurements of water levels will be conducted in these wells quarterly using an electronic water level indicator to set level references for the continuous monitoring equipment. Annual maintenance will be conducted on the transducers. Monitoring frequencies may decrease in the future following consultation with the MDNR and MPCA.

Periodic manual measurements will be used at locations where less frequent water level data is required. All pressure transducer data will be verified with manual measurements. Where pressure transducers are not installed, water levels will be recorded manually on a monthly basis using an electronic water level indicator.

4.0 Data Synthesis and Predictive Simulations

Data collected during the installation and testing of the proposed bedrock and surficial aquifer wells will be analyzed in conjunction with other available information on the hydrogeologic conditions in the area between the PMP and NorthMet Mine Site. Results from the geophysical testing, flow logging and aquifer testing will provide useful information on key aspects that will help confirm the lack of hydrologic connection between the two mining areas, and to rule out the potential for northerly flow. Specifically, information on conditions within the Virginia Formation distal from the contact with the Duluth Complex and the Biwabik Iron Formation, including fracture density, presence or absence of flow zones with depth, and changes in horizontal hydraulic conductivity with depth.

This data will be used to help predict how water levels are likely to change under future conditions at NorthMet, and to the extent they are known, at the PMP. Predictions could be made using analytical or numerical techniques, and will address uncertainty in the predictions. Predictive simulations will be conducted for key time periods during PMP and NorthMet operations and closure. The key times that will be simulated will be determined in consultation with the State agencies and will likely include conditions with the PMP and NorthMet pits at maximum depths. Updated predictions of whether adaptive management measures will be necessary will be made; this assessment will be updated annually, as discussed below, as additional data is collected throughout the life of mine. The predictive simulations done for this purpose will be done under the review and approval of the State agencies.

PolyMet anticipates that the State agencies will evaluate potential permit conditions that may be incorporated into the appropriate permit (e.g., NPDES/SDS, permit to mine). These permit conditions could include post-permitting requirements relating to monitoring activities or predictive simulations, as well as thresholds for collecting additional data, and when adaptive management (including contingency mitigation measures) might be needed and initiated.

5.0 Annual Reporting

Annual reports will provide the results of the water level monitoring presented in Section 3.4, which will include the raw data in an electronic form. Information on the water levels and/or mining depths in the NorthMet pits, as well as publicly available data, if there is any, for the water levels and pit depths at PMP, will also be included. The annual report will include an updated assessment of exiting groundwater flow conditions for the area between Project Mine Site and the PMP. The annual assessment will include the following:

- verify that mine plans for NorthMet and if publicly available, PMP have not changed for the current year and following year (information provided in the annual reports of the respective Permits to Mine)
- analyze water levels relative to expected conditions (from previous year's predictive simulations)
- update predictive simulation based on new data if necessary (could include recalibration of existing tools, modification of existing tools, or development of new tools)
- update predictive simulations for the next year of operations, and assess the need for (and effectiveness of) potential engineering controls

6.0 Timing for Installation and Monitoring Activities

The proposed timing of activities included in this plan is summarized in Table 6-1. The specific timing for installation of monitoring wells is dependent on (1) PolyMet obtaining necessary permitting authorizations; (2) PolyMet securing the necessary access authorizations from land owners; and (3) the suitability of field conditions for installation activities.

Table 6-1 Summary of timing of plan activities

Timeframe related to NPDES/SDS permit	Month/year	Tasks to be Completed
Pre-application submittal	May and June 2016	• Submittal/approval of Well Installation, Testing and Monitoring Plan • Develop access agreements for properties not owned by PolyMet to conduct work

Pre-permit issuance	June 2016 - 2017	• Obtain all permit approvals and access authorizations needed for the well installations
		• Install monitoring wells
		  ○ Upland locations –fall, winter (once access authorizations obtained)
		  ○ Wetland locations – winter
		• Hydrogeological investigation and reporting
		• Monitoring of water levels
		• Monitoring for water quality (to extent necessary and authorized under access authorizations)

Post permit issuance	2017 – Life of Mine	• Monitoring of water levels • Monitoring for water quality (to extent necessary and authorized under access authorizations) • Adjust monitoring plan, if needed • Annual reporting

7.0 Adaptive Management

Adaptive management is an important tool that PolyMet will use during construction, operations, reclamation, and long-term closure. There are two key adaptive management components considered here: 1) refinement of plan and/or monitoring network, and 2) implementation of adaptive engineering controls. The need for adaptive management will be assessed annually using the process developed for this purpose, as discussed in Section 5.0.

7.1 Refinement of Monitoring Plan

As additional information is gathered through the implementation of this Monitoring Plan, more will be known about the hydrogeologic conditions in the area between the Project Mine Site and the PMP. PolyMet will use this information to assess whether any changes to the Monitoring Plan are warranted. Changes to the Monitoring Plan could include changing the monitoring network (adding or retiring monitoring wells), the frequency of monitoring or reporting, the process for conducting predictive simulations, or the requirements for the annual report.

7.2 Adaptive Engineering Controls

There are adaptive management actions that could be implemented if monitoring data and predictive simulations suggest that there will be northward flow in the future. In general the steps will be:

1. initiate field studies to gather additional data, if needed, to understand the issue
2. develop the conceptual design for mitigation options
3. collect additional data for the assessment of mitigation options, if needed
4. select of mitigation measures to be implemented
5. develop final design for the selected mitigations measures
6. obtain permits and/or conduct environmental review, if needed
7. implement mitigation

The FEIS presented feasible adaptive engineering controls that could prevent a northward flow of water from the proposed NorthMet pits to the PMP if data and analysis suggests they are necessary. These include:

- NorthMet pit water level suppression
- bedrock water level maintenance via extraction wells or artificial recharge
- pit wall grouting

Additional adaptive management options may also be identified and considered during the adaptive management process.

8.0 Permit Requirements for Well Installations

The temporary workspace areas and temporary access routes required for the installation of the groundwater monitoring wells will, in aggregate, result in greater than one acre of land disturbance and therefore will require coverage under the Minnesota General Permit Authorization to Discharge Stormwater associated with Construction Activity under the National Pollutant Discharge Elimination System / State Disposal System (NPDES/SDS) Program (Permit No. MN R100001). Per the requirements of this permit, an associated Construction SWPPP has been developed and will be implemented.

Additionally, temporary and permanent impacts for certain well pads and access routes will occur within wetlands requiring authorization from the U.S. Army Corps of Engineers (USACE) to complete the work under Regional General Permit 3 (RGP-003-MN) and notification to the MDNR and Northern St. Louis County Soil and Water Conservation District for a Minnesota Wetland Conservation Act (WCA) no loss/exemption. A Pre-Construction Notification (PCN) will be submitted to the USACE, St. Paul District and a letter providing the information to confirm the no-loss and exemption determinations will be submitted to the MDNR. Monitoring well permits will be obtained from the MDH as required by Minnesota Well Code. Monitoring well permit applications will be submitted by a licensed well contractor or registered monitoring well contractor.

Finally, any access arrangements that may be needed for the well installation will be obtained prior to the start of work. To the extent that the access arrangements require any authorizations or other actions from any governmental bodies, PolyMet will complete the applicable regulatory processes in advance of undertaking well installations.

9.0 References

1. **U.S. Army Corps of Engineers; U.S. Forest Service; Minnesota Department of Natural Resources.** NorthMet Environmental Impact Statement Co-lead Agencies' Consideration of Possible Mine Site Bedrock Northward Flowpath. October 12, 2015.

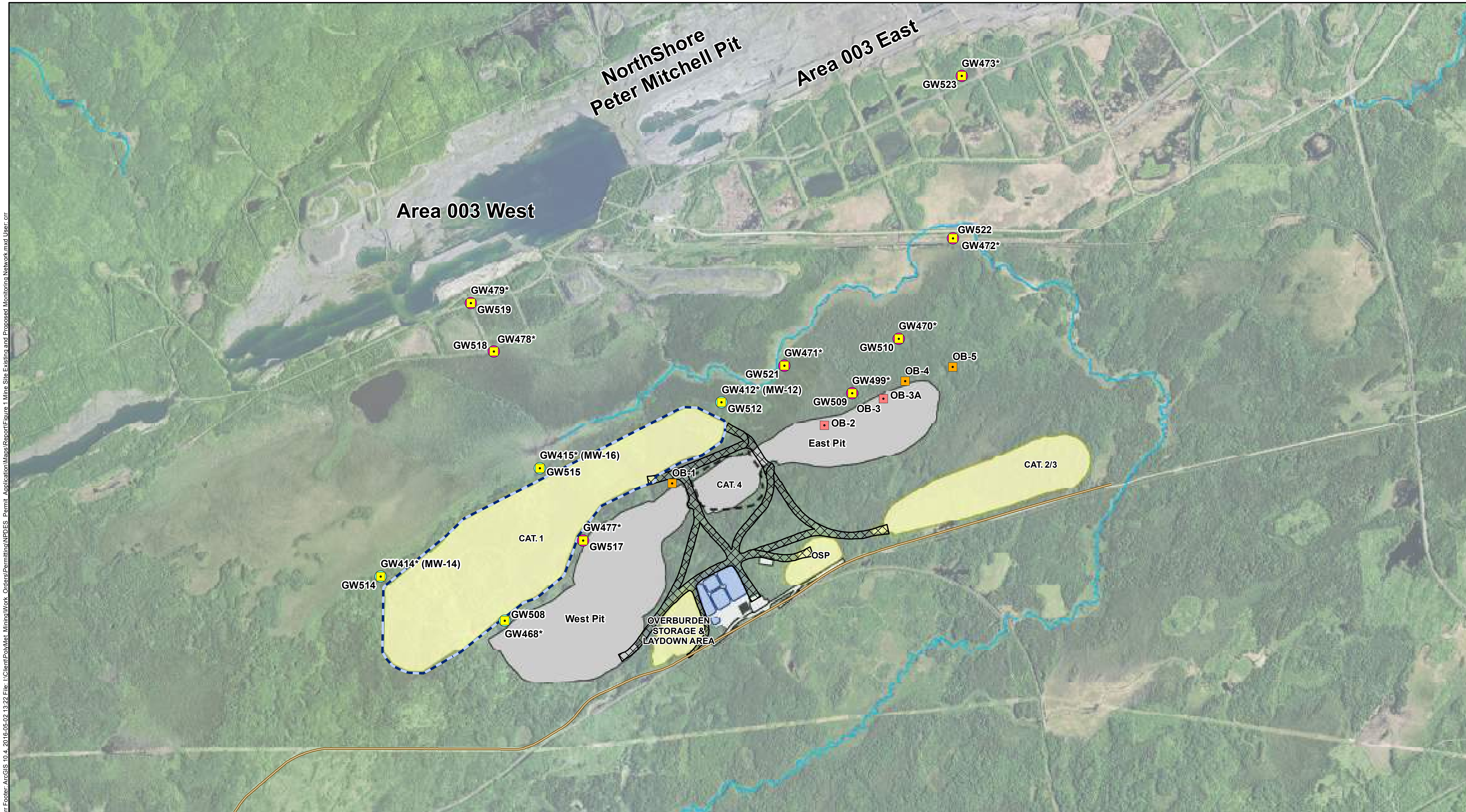
2. **Minnesota Department of Natural Resources, U.S. Army Corps of Engineers and U.S. Forest Service.** Final Environmental Impact Statement: NorthMet Mining Project and Land Exchange. November 2015.

3. **Barr Engineering Co.** Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 4 Technical Memo to Bill Johnson, Minnesota Department of Natural Resources. September 14, 2015.

4. **Day-Lewis, F. D., et al.** A computer program for flow-log analysis of single holes (FLASH): Ground Water. [Online] 2011.

5. **Young, Steven C. and Pearson, Hubert S.** The Electromagnetic Borehole Flowmeter: Description and Application. *Ground Water.* 1995, Vol. 33, pp. 311-318.

Large Figures



Barr Footer: ArcGIS 10.4, 2016-05-02 13:22 File: I:\Client\PolyMet Mining\Work Orders\Permitting\NPDES_Permit_Application\Maps\Report\Figure 1 Mine Site Existing and Proposed Monitoring Network.mxd User: crr

- Existing Surficial Aquifer Monitoring Wells
- Proposed Surficial Monitoring Wells
- Proposed Bedrock Monitoring Wells
- Existing Bedrock Monitoring Wells
- Wells to be Abandoned

Year 11 Features
- Haul Roads
- Active Stockpile
- Removed Stockpile
- Mine Pit

- Public Waters Inventory (PWI) Watercourses
- Groundwater Containment System

GW405* (MW-5) Proposed NPDES/SDS Monitoring Station ID (Current Monitoring Station ID)
* Indicated Surficial Monitoring Well

0 1,250 2,500 5,000
Feet

Large Figure 1
MINE SITE: EXISTING AND PROPOSED MONITORING NETWORK
Monitoring Wells North of the Mine Site: Installation and Monitoring Plan
NorthMet Project
Poly Met Mining Inc.

Appendix 17.3 NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Report

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Project I.D.: 12P778

Poly Met Mining, Inc.
St. Paul, Minnesota

August 2014

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Project ID: 12P778

Prepared for

Poly Met Mining, Inc.

444 Cedar Street, Suite 2060
St. Paul, MN 55101

Prepared by

Foth Infrastructure & Environment, LLC

August 2014

2121 Innovation Court, Ste. 300 • PO Box 5126 • De Pere, WI 54115-5126 • (920) 497-2500 • Fax: (920) 497-8516 • www.foth.com

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Contents

Tables

Figures

List of Abbreviations, Acronyms, and Symbols

cm/s	centimeters per second
EIS	Environmental Impact Statement
gpm	gallons per minute
MDNR	Minnesota Department of Natural Resources
PolyMet	Poly Met Mining, Inc.
the Project	NorthMet Project
RQD	Rock Quality Designations

1 Problem Statement

The Poly Met Mining, Inc. (PolyMet) NorthMet Project (the Project) will involve construction of an open pit mine approximately 3 miles long, 0.5 miles wide and 700 feet deep. The pit will be excavated through up to 60 feet of unconsolidated, variably saturated glacial till underlain by variably-fractured rocks including the igneous Duluth Complex and the sedimentary/ metamorphic Virginia Formation. A plan view and cross section of the proposed open pit are shown in Figures 1 and 2.

Both the Virginia Formation and the Duluth Complex rocks that will be intersected during pit excavation are generally highly indurated and competent, exhibiting Rock Quality Designations (RQD) in excess of 95% in most intervals (Golder, 2006). Fractures are present throughout the full extent of the proposed pit depth. Some drill holes have shown slightly greater fracture prevalence in the uppermost several meters of both the Virginia Formation and the Duluth Complex. Fracture frequencies are typically less than one per foot, with broken intervals that may correspond to fault locations showing frequencies of 20 fractures per foot or greater (Golder, 2006).

Analysis of the groundwater hydrology of the Mine Site was performed as part of the Environmental Impact Statement (EIS) (MDNR et al., 2013). This analysis included a quantitative characterization of bedrock hydrogeology and included pumping tests, water-level measurements, and numerical modeling of groundwater flow under both current conditions and proposed conditions in which the pit is excavated and operating as a groundwater sink. Using field-measured hydraulic conductivity values and water levels to calibrate the model, subsequent simulations indicated moderate groundwater inflow to the pits from surrounding bedrock (MDNR et al., 2013). Given the minimally fractured nature of the majority of bedrock at the Mine Site modest pit inflow rates are the generally expected condition. High rates of pit inflow from bedrock, if they occur, are expected to be limited to localized areas where open fractures or broken/fault zones intersect pit walls. Due to the sparse and discontinuous nature of open fractures and broken or fault zones, predicting if and where these features might intersect pit walls is not possible over the majority of the pit shell.

To estimate the impact of pit inflow on surrounding surface water resources, particularly wetlands, an evaluation of groundwater data from existing open pit operations on the Mesabi Iron Range was performed (MDNR et al., 2013). A review of groundwater elevation data gathered adjacent to the Canisteo and Minntac pits showed minimal correlation between pit lake levels and groundwater in surrounding rock and till deposits. Using the Canisteo and Minntac results as the basis for a conservative analog modeling methodology, MDNR et al. (2013) estimated some potential for measurable drawdown in surficial groundwater within 1,000 feet of the pit perimeter. Between 1,000 and 1,700 feet from the pit, some drawdown is expected but the magnitude is expected to be indistinguishable from natural variations. Outside 1,700 feet, drawdown resulting from pit inflow is expected only under isolated conditions such as the case of a continuous fault extending laterally from the pit wall to a point beyond the 1,700-foot perimeter and simultaneously extending vertically to the base of the surficial aquifer underlying a wetland.

Using the observations and groundwater data gathered from other open pit mines on the Mesabi Iron Range, 866.9 acres of wetlands are estimated as having high likelihood of potential indirect hydrologic impact resulting from drawdown caused by pit inflow (MDNR et al., 2013).

Additionally, the model of groundwater flow was used to evaluate water flow between the pit and the groundwater system following cessation of operations when the pits will refill via groundwater inflow and precipitation capture. This analysis indicated groundwater will flow into the pits along the northern pit perimeter and pit water will flow into the groundwater system along the southern pit perimeter. Outflow from the pit along its southern perimeter may contribute to constituent migration in groundwater following closure.

Based on the preceding summary of pit and bedrock groundwater analysis performed in support of the EIS, the following potential Project impacts are identified:

1. Groundwater inflow from bedrock could be several hundred gpm or higher. Costs will be imposed on the Project to pump, remove, and treat pit water that are directly proportional to the rate of pit inflow.

2. Additional costs may be imposed on the Project to control pit inflow water to protect haul roads and other pit infrastructure, to maintain work areas, and to ensure slope stability.

3. Locally high discharge from productive fractures or fault zones could damage or potentially damage haul roads and pit slopes.

4. Rates of pit groundwater inflow have been estimated for each year of planned operations. Indirect impacts to wetlands within 1,000 feet of the pit may occur as a result of groundwater inflow to the pits. Using the analog model developed from impact data at other vicinity mine sites, the estimated wetlands acreage that might experience indirect impacts resulting from pit inflow is 867 acres. Mitigation, including reconstruction or wetlands banking, could be necessary should such impacts materialize. Pit inflow rates that substantially exceed initial estimates could heighten the potential for indirect wetlands impacts resulting from pit inflow and groundwater drawdown.

5. If open faults or fractured/broken zones create conditions of abundant pit inflow, such features would also contribute to increased outflow from the pit to the bedrock groundwater system during and after pit refilling. Larger outflow rates would translate to larger constituent migration rates from pit water into groundwater.

Items 3, 4, and 5 in the preceding list represent pit inflow/outflow impacts that might exceed those developed in the analysis upon which Project permits are based and could require corrective action or mitigation, should such impacts occur. An attractive mitigation strategy for controlling bedrock groundwater flow to and from the pits is the use of injection grouting to partially seal or close productive fractures, faults, and/or broken zones. Grout curtains are widely used for groundwater control in both unconsolidated deposits and fractured and porous rock. Grout curtains differ from grout or slurry walls in that the latter consists of an excavated trench filled with low-permeability grout, often mixed with native soil or earthen material.

Alternatively, a grout curtain is constructed by drilling a series of purposely spaced and oriented bedrock drill holes and injecting grout designed for site-specific conditions into surrounding rock to fill pore spaces, fractures, and broken or fault zones.

Construction of a grout curtain enclosing the entire pit shell as a preventative measure is not expected to be warranted, given the minimally-fractured nature of the majority of rock surrounding the proposed pit. Accordingly, use of grout curtain(s) at the Mine Site as a mitigation measure will be undertaken in localized reaches and at specific, targeted depths to mitigate problematic pit inflow resulting from localized fractures, fractured zones, and/or fault zones. Problematic pit inflow is defined as that which gives rise or may give rise to impacts identified in items 3 or 4 above.

2 Determination of When and Where Pit Inflow Mitigation is Required

Construction of grout curtains to control groundwater flow is a mature technology and is common in projects such as excavation dewatering, embankment seepage control, dam underflow mitigation, and dam foundation stabilization. In many such projects, grout curtains are constructed prior to the commencement of excavation, dewatering, or structure construction. Such practice simplifies the construction of a grout curtain because hydraulic gradients remain at natural or ambient levels. Ambient or small hydraulic gradients translate to small groundwater flow rates which simplify grout injection and cause less washout of grout during the injection process. Large hydraulic gradients occurring after or during construction require thicker grouts to prevent washout. Thicker grouts possess higher viscosity which reduces the mobility of grouts and the extent of coverage associated with any one grout hole.

Grout curtains have also been installed as remediation or mitigation measures to control groundwater flow after construction has accentuated hydraulic gradients and groundwater flow rates. Examples of such practice include grout curtains constructed in dam foundations and impoundment embankments experiencing stability problems due to excessive groundwater flow or seepage rates.

As noted previously, construction of a grout curtain prior to pit excavation is impractical because the length and depth required to completely encircle the pit would entail prohibitive cost. Additionally, construction of localized curtain segments prior to pit excavation is not practical because identifying the portions of the pit perimeter where pit inflow mitigation might be required is precluded by the inability to predict the location of such zones due to the lack of continuity exhibited by open fractures and fault zones.

Accordingly, bedrock groundwater flow mitigation will be considered during pit excavation and refilling if either of the following conditions is observed:

- Pit inflow occurs from localized features such as fractures, fracture zones, or faults, at sufficient rate to present a hazard such as pit slope instability or a management challenge relative to pit infrastructure such as haul road maintenance.

- Substantive hydrologic impacts are observed at distances exceeding 1,000 feet from the pit perimeter. Substantive hydrologic impacts are declines in water levels in excess of natural fluctuations and lasting greater than six months, or changes in wetlands hydrology that cause a change in wetlands vegetation of sufficient magnitude to change the wetlands' function and classification.

3 Field Investigation to Define Problem Extent and Design Mitigation

If or when one of the prior "mitigation triggers" is observed, the first response will be to review the problem and evaluate whether or not mitigation of pit groundwater inflow/outflow is warranted and feasible. The key element that will determine whether consideration of grouting is warranted is the presence of problematic flow that occurs, at least in part, in localized areas and from identifiable or discrete features or zones. As noted previously, grout curtain mitigation of pit inflow is not envisioned for controlling diffuse pit inflow that is distributed over expansive portions of the pit shell.

When a review of a potential pit groundwater inflow/outflow problem determines that grout curtain mitigation merits consideration, the following sequence of evaluations and analysis will be initiated:

1. Identify, analyze, and survey the zone(s) and feature(s) present in the pit wall that are contributing to excessive inflow. This step will include a careful geologic inspection of the features displayed in the pit wall.

2. Review existing geologic data (inferred fault maps, drill hole logs, loss of circulation occurrences during exploratory and geotechnical drilling, geophysical logs, core photographs, and archived core), in conjunction with the results from step 1, to define the orientation, location, and extent of structures contributing to the problematic inflow.

3. Using the results of steps 1 and 2, determine if conditions appear favorable to grout curtain mitigation of pit inflow/outflow. If conditions are favorable, proceed with the design of a drilling program to refine the location and orientation of the structures and gather structure data (extent, permeability, and aperture) required for design of a grout curtain. If conditions identified by this drilling program appear unfavorable for grout curtain mitigation of pit inflow, evaluate alternative management strategies.

The occurrence of problematic inflow does not mandate the commencement of drilling and grouting; rather, the occurrence of problematic pit inflow will result in an evaluation of the merits of a grouting program or other possible management responses. If, during the course of this preliminary evaluation, an alternative mitigation measure is identified or circumstances are identified that indicate grouting would be ineffective or unnecessary, further pursuit of grout curtain mitigation for the particular location will be suspended and alternative management strategies will be considered.

Step 1 following the identification of a pit groundwater management problem will involve geologic inspection and surveying of fractures and faults by a professional geologist and surveyor to determine a preliminary estimate of the feature orientation and to locate them in three-dimensional space for plotting and analysis relative to existing geologic data.

Step 2 will entail the spatial analysis and plotting of structure data for fractures and faults that can be identified in lithologic logs, circulation logs, core, geophysical logs and core photographs from existing drill holes located adjacent to the pit shell in the vicinity of the features contributing to excessive pit inflow. Steps 1 and 2 will combine to provide an improved projection of the location, orientation, and continuity/extent of the producing fractures/faults. Determining orientation will be a primary goal of steps 1 and 2 because orientation will be the primary determinant in designing investigation drilling that successfully intersects the producing features.

Once the expected location and orientation of producing features have been projected from the pit shell into the adjacent unexcavated rock mass, a series of investigative, angled drill holes will be advanced to intersect the producing fractures and/or fault(s). This work constitutes step 3 of the field investigation. Step 3 entails a limited drilling and field testing program designed to confirm the distribution of producing features beyond the pit shell and quantify their hydraulic properties (aperture and hydraulic conductivity). A summary of existing bedrock hydrogeologic characteristics that will influence pre-grout field investigations and the design of individual grouting programs is provided in Table 1.

Sufficient drill holes will be installed to locate producing features with a high degree of certainty. Drill holes will be angled such that intersection angles with primary producing features are as large as practicable. Drilling will be performed using a rotary down-hole percussion water hammer drilling method (Wassara system or equivalent) to avoid air-entrained cuttings fouling of open features that would subsequently impede grouting efficiency. Field data collection will include optical televiewer logging, caliper logging, and packer testing. Televiewer logging will be used selectively for confirming interception of the producing features, confirming feature orientation, and defining feature aperture which influences the design of grout mixes used for injection and sealing. Field investigation drill holes will be planned to allow integration into the final grout hole layout whenever possible and will be grouted to prevent cross-circulation routes and to enhance the overall grouting program effectiveness.

Packer testing, involving dual- or single-packer testing to allow isolation of discrete features or feature intervals will be performed in each hole to aid in locating target (producing) zones and to calculate permeability. Packer testing will conform to ASTM D4630 and ASTM D4631. The goal of packer testing is to determine interval-specific hydraulic conductivity or permeability to aid in the design of the grout mix, to identify target zones to be grouted, and to estimate projected grout volumes per target zone. Because the typical lower limit of hydraulic conductivity achieved via grouting is 1×10^{-6} centimeters per second (cm/s) and Duluth Complex and Virginia Formation rocks exhibit a range of bulk hydraulic conductivities already encompassing this magnitude, grouting will only be effective in reducing the permeability of zones exhibiting a relatively high frequency of open fractures or the presence of open or broken fault zones. Packer testing will serve to confirm grouting target zones initially identified via three-dimensional mapping of pit wall survey data, lithologic and drilling logs, and televiewer and caliper logs.

Table 1

Bedrock Characteristics and Properties, NorthMet Mine Site

Rock Property	NorthMet Values/Properties
Duluth Complex Rock Type	Precambrian Igneous intrusive mafic rocks; largely troctolite and gabbro
Virginia Complex Rock Type	Precambrian sedimentary and contact metamorphic rocks consisting of argillite, siltstone and greywacke
Strike and Dip of Duluth Complex Intrusion	Strike is approximately N56°E Dip is 15 – 25° to SE
Median Rock Quality Designation-Duluth Complex	Unit 1 = 99.2% Unit 2 = 97.5% Unit 3 = 99.2% Unit 4 = 99.6% Unit 5 = 99.2% Unit 6 = 99.2% Unit 7 = 99.2%
Median Rock Quality Designation-Virginia Formation	90.8%
Primary Rock Porosity	Assumed less than 5% inferred from origin, mineral composition and core inspection.
Faults	Inferred faults predominant strike ENE, NE, and NNE; minor faults strike NW. Drill hole logs show sporadic, discontinuous evidence of faults and broken zones ranging from moderately broken and open to shattered and very open. Broken/open fault zones do not show continuity between drill holes nor alignment with inferred fault mapping.
Median Fracture Frequency-Duluth Complex	Unit 1 = 0.4 fractures/ft Unit 2 = 0.7 fractures/ft Unit 3 = 0.5 fractures/ft Unit 4 = 0.5 fractures/ft Unit 5 = 0.6 fractures/ft Unit 6 = 0.5 fractures/ft Unit 7 = 0.5 fractures/ft
Median Fracture Frequency-Virginia Formation	1.2 fractures/ft
Hydraulic Conductivity-Duluth Complex	10^{-7} - 10^{-5} cm/s
Hydraulic Conductivity-Virginia Formation	10^{-7} – 10^{-4} cm/s

Sources: Golder, 2006; MDNR et al., 2013; Miller et al., 2001.

Prepared by: DRD
Checked by: MJV2

4 Mitigation Design, Construction, Verification

4.1 Grout Hole Layout Design

Once the target zone or feature(s) have been reasonably identified in terms of position, orientation, extent, frequency, and aperture, a grout injection hole network will be designed. The grout hole network is typically designed as a sequence of "split-distance" holes as shown in Figure 3. The first or primary sequence of split-distance holes are spaced relatively far apart (up to 40 feet). Subsequent sequences are commonly termed "secondary holes," "tertiary holes," "quaternary holes," and "verification holes." Most grout curtains involve primary and secondary sequences at a minimum. All grout curtain programs require a verification sequence of holes to provide a quality assurance check on the coverage and permeability reduction of the main sequences. Figure 3 illustrates a program involving three main split distance sequences followed by a verification sequence. Drill holes will be advanced via rotary percussion water hammer (Wassara system or equivalent). Use of air-rotary drilling is prone to fouling of open features with air-entrained cuttings. Cuttings entrapped in features targeted for grouting reduce the mobility and effectiveness of grouting but do not contribute to meaningful reductions in permeability or seepage. Drill hole diameter is typically 95 millimeters. Two and sometimes more parallel rows of grout holes, commonly at offset vertical angles, are often used to add thickness to the grout curtain perpendicular to the flow direction, thereby providing more effective permeability reduction and a factor of safety relative to grout washout prevention. Each completed drill hole will be down-hole surveyed using a system such as Boretrack or equivalent to verify proper hole orientation and intersection with the target zone.

Spacing for the primary sequence of grout holes may be as large as 40 feet. Spacing is a function of the permeability of the rock or feature being grouted and the viscosity of the grout to be injected. As noted previously, the host rock at the Mine Site is of extremely low permeability and will be effectively impervious to any grout mix. As such, the permeability of conductive fractures or broken/open fault zones will be the controlling feature relative to hole spacing. Also affecting hole spacing will be the hydraulic gradients across the target zone. Greater hydraulic gradients require low-viscosity grouts to reduce washout potential. Low-viscosity grouts require smaller hole spacings to promote complete grout infiltration throughout the target features or zones. If large problematic producing zones are encountered in the pit wall, thereby requiring large grout curtains for mitigation, application of numerical modeling of the grout inject process may be applied to optimize the spacing of grout holes, injection pressures, and grout viscosities, such that the number of grout holes and the volume of grout required is minimized.

4.2 Grout Mix Design

Grout mix design is commonly based on an empirical approach using rock or feature permeability, hydraulic gradients, and hole spacing as variables. As noted previously, numerical simulation of different grout mixes may be used in cases where extensive grout curtain lengths are required and control of costs requires optimization of grouting efficiency. Grout mix components commonly include cement, water, and bentonite. Superplasticisers may be added if the target features are relatively small aperture fractures requiring low-viscosity grout for adequate penetration. Conversely, high hydraulic gradients and/or large aperture fractures require high-viscosity grouts to prevent washout. Increased viscosity can be obtained by adding sand or thickening additives such as Rheomac UW-450 cellulose thickener, which is also effective in preventing bleeding of cement content and dilution by formation water.

Suitable grout mix design may be tested and verified by initial injection of multiple grout mixes in distinct grout holes combined with comparison of injection monitoring data and televiewer logging adjacent holes to verify radial migration of grout throughout the target zone.

4.3 Grout Injection

Once the grout mix design has been finalized and verified via preliminary field testing, grout injection proceeds first in all primary holes followed by injection in secondary and then tertiary holes. Grout injection in verification holes is performed after all quality assurance testing and data collection have been completed in the verification holes.

During injection, several parameters are computer monitored to allow the grouting engineer to ensure successful and safe grout delivery to the target features or zone. A computerized software program such as *CAGES* (ECO Grouting Specialists, 1997) or equivalent will be used to ensure rapid data acquisition and interpretation which aids in the management and optimization of the grout injection process. Table 2 summarizes the parameters that will be monitored during injection together with the information provided by each parameter.

Table 2

Grout Parameters Monitored During Injection for Optimization of Grouting Effectiveness

Grout Injection Parameter	Information Provided
Grouting Pressure (range from zero to in excess of 90 bar)	Successful grouting should display steady pressure until grout refusal (setting) occurs as indicated by pressure increase. Steady pressure beyond target refusal time signals runaway grout. Rapid pressure fluctuations indicate potential plastic fracturing.
Grout Flow Rate (gpm)	Grout flow rate should be steady and then decline at target refusal or slowly decline toward zero at refusal. Steady flow rate beyond target refusal time indicates cavity encountered or runaway grout. Spike in flow rate indicates plastic fracturing. Slow increase in flow rate indicates ground heaving.
Grout Volume Injected (Take) (gallons)	Compare with target volume. Overshooting target volume indicates runaway grout, cavity or heaving.
Apparent Grout Lugeon (Lu)	Should decline toward zero for successful grouting. Spikes indicate plastic fracturing. Steady value indicates runaway grout or cavity.
Theoretical Grout Spread (feet)	Reveals if delivery to targeted grout zone is achieved.

Prepared by: DRD
Checked by: MJV2

Each hole will be grouted in stages from the bottom up. Stages are typically 10 feet long. During injection, in addition to monitoring the parameters in Table 2, pH and flow rate at the pit wall will be monitored and observed, respectively. Elevated pH will indicate the grout is intersecting the required target zone, as will observation of declining flow discharging at the pit wall. Failure to observe increasing pH or decreasing flow will necessitate re-evaluation of the projected target zone beyond the pit wall and the location and orientation of the grout holes.

4.4 Quality Control, Assurance, and Testing

Monitoring of the data summarized in Table 2 is one element of the construction-phase quality control. Additional quality control testing performed during grouting includes Marsh-cone testing, bleed testing, and temperature monitoring of grout mix. All three tests are performed a minimum of once per batch per grouting phase/interval. Test results outside the acceptable range specified in the mix design require termination of injection and immediate water washout of that interval of the hole that received out-of-specification grout.

Completion of grout injection in all planned holes (primary, secondary, tertiary, etc.) and lines is then be followed by drilling a series of verification holes. Verification holes will be located and drilled to intersect the same zone or features targeted by the main grouting program but will be located and spaced between the main set of grout holes. If a multi-line, grout-hole program is used, some or all of the verification holes will be located between the main grout-hole lines. Unlike the main grout holes, verification holes will be drilled with a core rig to allow core inspection and photography to provide visual confirmation of grout delivery and sealing throughout the entire target zone. Televiewer logging may also be performed to visually confirm grout propagation throughout the target zone. Additionally the grouting pressure curve, flow rate, and volume delivered will be recorded and compared for each verification hole to the final sequence of split-spacing holes. The objective is to find higher injection pressures and lower flow rates early in the time series recorded for each verification hole and to observe lower overall grout volumes injected relative to the last split-spacing sequence of holes. Higher pressures, lower flow rates, and lower injected volumes all indicate a relative lack of space available for grout invasion, meaning that the prior sequences of grout injection of successfully filled and sealed open fractures, faults, and broken zones.

Additionally, prior to injection of grout in verification holes, packer testing will be conducted to determine residual, post-grouting permeability. Comparison of verification hole packer test hydraulic conductivities with those measured in the main grout holes prior to grouting will provide the final indication that the intended reductions in hydraulic conductivity were achieved throughout the zone. An example of this comparison is presented in Figure 4. A successful grouting program will exhibit a steady decline in permeability within the target zone as primary, secondary, and tertiary holes are successively grouted. Verification holes should show permeabilities lower than all other holes. Failure to achieve this result indicates potential ungrouted or partially grouted zones within the target area. Because the verification holes are themselves grouted, it is possible that an ungrouted zone is remedied by the grouting of the verification hole that identified the ungrouted zone. Additional verification holes are called for in such instances.

Lastly, successful grouting will ultimately be validated by substantial reduction in the flow observed at the pit wall. In instances where the pit inflow problem was excessive indirect impacts to wetlands, successful grouting will ultimately be demonstrated by a reversal or reduction in the dewatering impacts observed in wetlands outside the 1,000-foot radial perimeter surrounding the pit.

5 References

ASTM D4630. *Standard Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test*. 2008.

ASTM D4631. *Standard Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using Pressure Pulse Technique*. 2008.

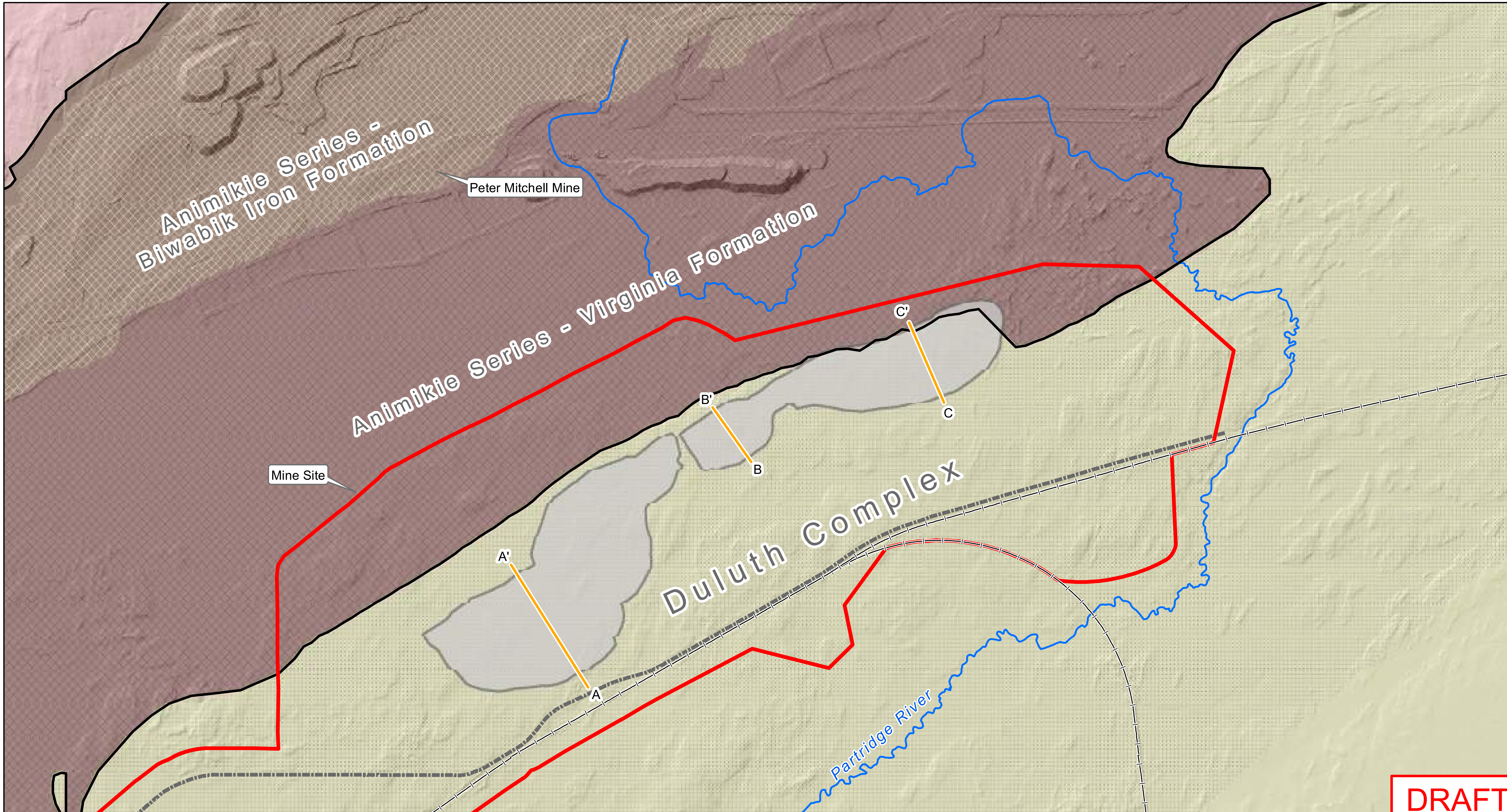
ECO Grouting Specialists, 1997. *CAGES, Computer-Aided Grouting Evaluation System*. ECO Grouting Specialists, Ontario, Canada. 1997.

Golder Associates, 2006. *Recommendation for NorthMet Open Pit Rock Slope Designs, NorthMet Mine Project*. Submitted to PolyMet Mining Corporation, 2350-1177 West Hastings Street, Vancouver, BC. June 2006.

Miller, J.D. Jr., J.C. Green, M.J. Severson, V.W. Chandler, and D.M. Peterson, 2001. *Geologic Map of the Duluth Complex and Related Rocks, Northeastern Minnesota*. University of Minnesota, Minnesota Geological Survey, Map M-119, Sheet one of two. 2001.

Minnesota Department of Natural Resources, United States Army Corp of Engineers, and United States Forest Service, 2013. *Supplemental Environmental Impact Statement, NorthMet Mining Project and Land Exchange*. November 2013.

Figures



Notes

1. Project Features supplied by Barr Engineering.
2. Geology 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.

Legend

- Existing Private Railroad
- Dunka Road
- Proposed Project Area Boundary
- Rivers and Streams
- Mine Pits (Year 20)
- CrossSection Locations Mine Site

Bedrock Geology (Severson and Miller, 1999)

- Animikie Series
- Duluth Complex
- Duluth Complex - Partridge River Intrusion
- Giants Range Crystalline Rocks
- Animikie Series - Virginia Formation
- Animikie Series - Biwabik Iron Formation

POLYMET MINING

Foth

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	JSL	DATE:	JUL. '14
APPROVED BY:	DRD	DATE:	JUL. '14
APPROVED BY:		DATE:	

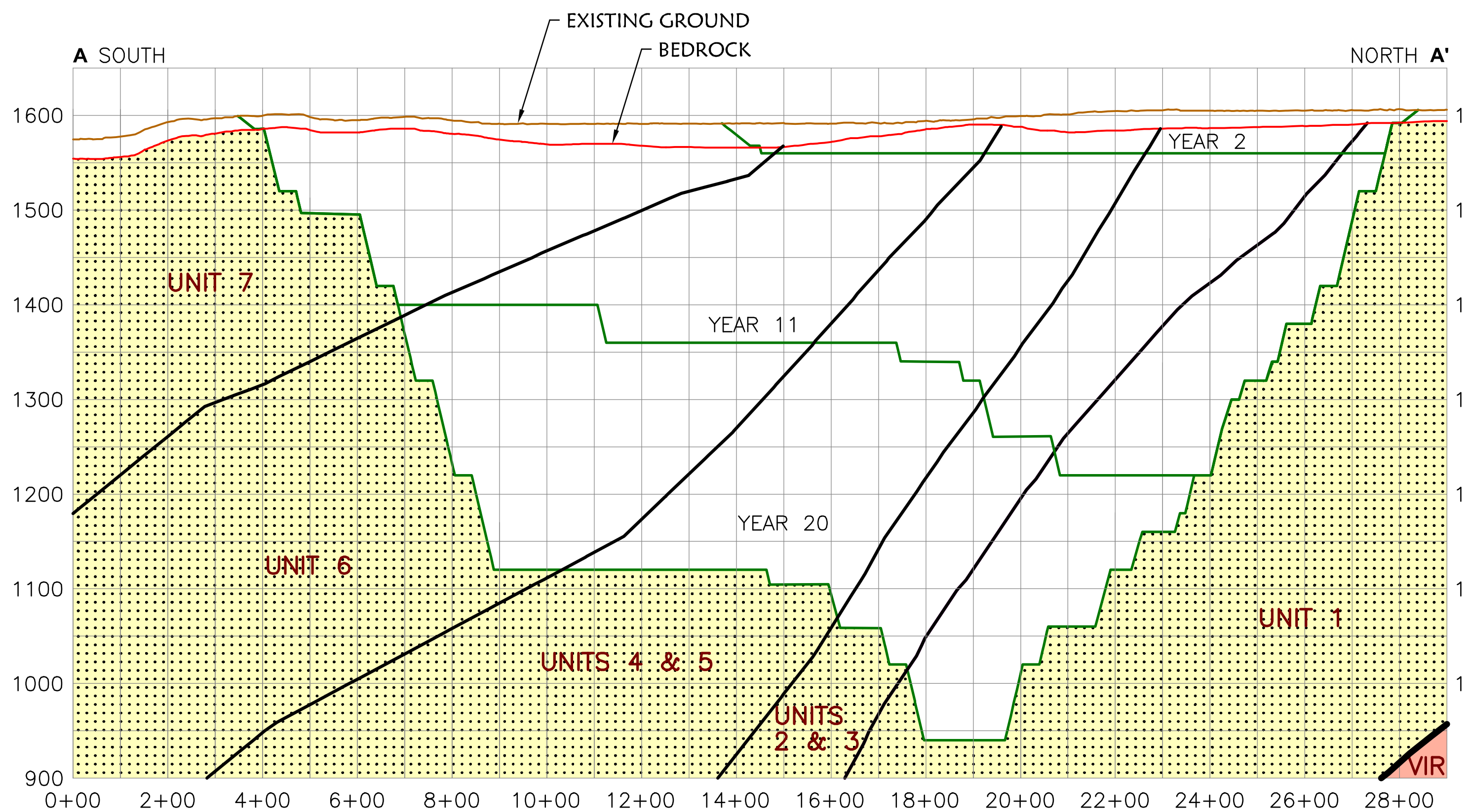
POLYMET MINING

FIGURE 1

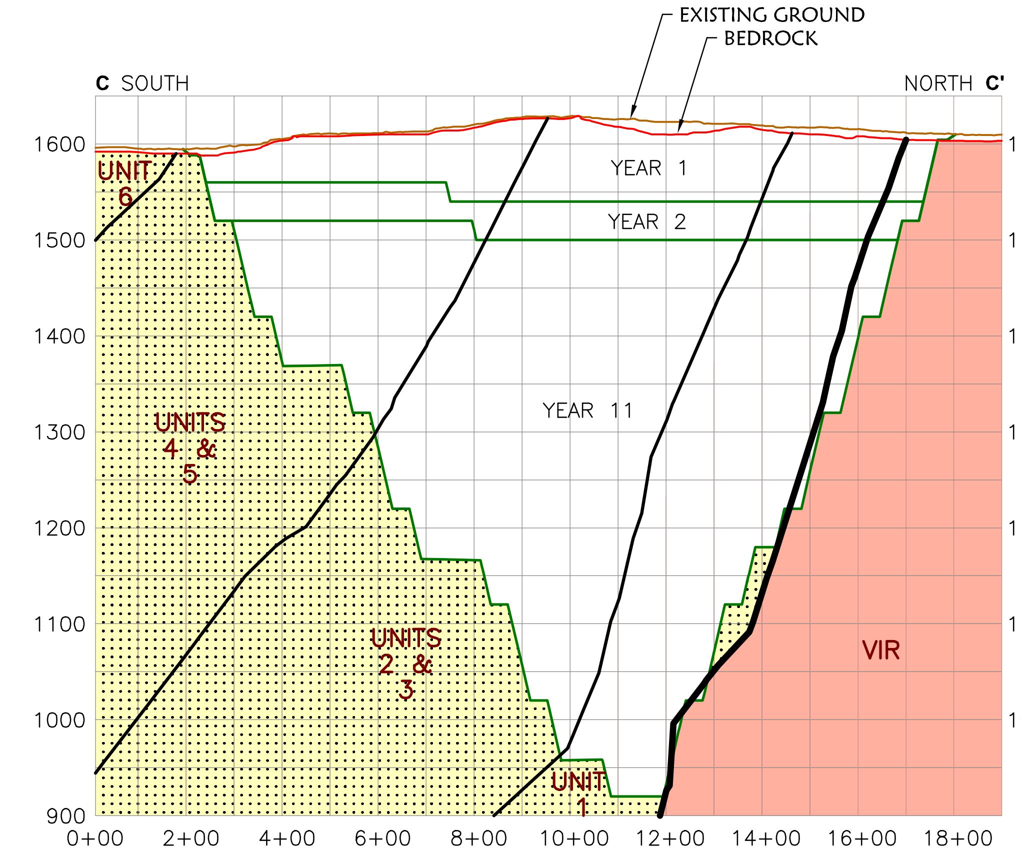
PLAN VIEW OF MINE SITE WITH OPEN PIT FOOTPRINT AND BEDROCK GEOLOGY AS MAPPED AT UPPERMOST BEDROCK SURFACE
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: 0 1,000 2,000 Feet	Date: JULY 2014
Prepared by: DAT	Project No: 12P778

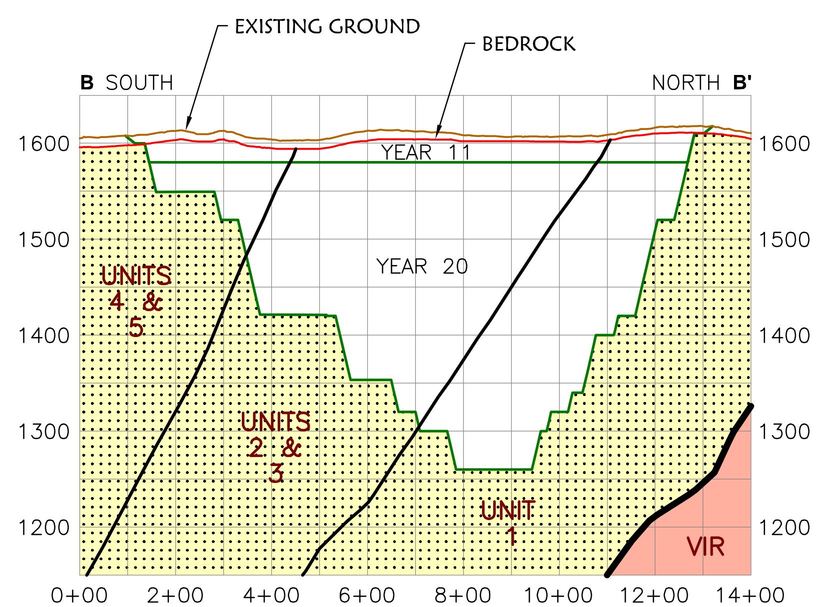
Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 1 Grout Plan Bedrock Geology.mxd Date: 7/23/2014



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 ANIMIKIE SERIES

HORIZONTAL 0 400 800 SCALE IN FEET

VERTICAL 0 200 400 SCALE IN FEET

DRAFT

POLYMET MINING

Foth

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY: JSL DATE: JULY,'14

APPROVED BY: DRD DATE: JULY,'14

APPROVED BY: DATE:

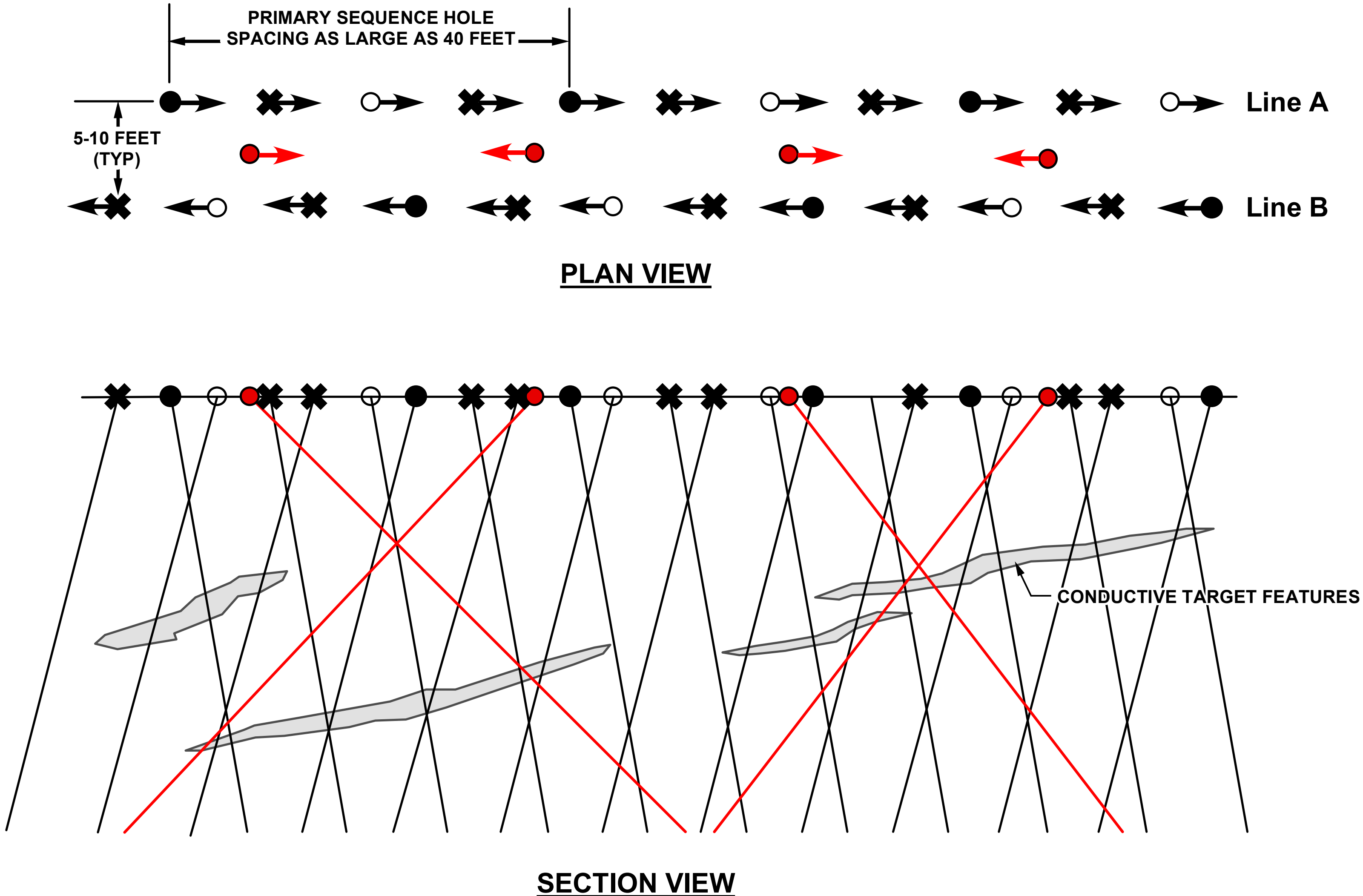
POLYMET MINING

FIGURE 2
CROSS SECTIONS THROUGH PROPOSED MINE PIT SHOWING PRIMARY BEDROCK GEOLOGY
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: NOT TO SCALE | Date: JULY, 2014

Prepared By: JOW | Project No: 12P778

X:\GB\IE\2012\12P778\cad\figures\Mine Site\12P778_ Fig 2 Grout Plan Geo cross sections A–B–C.dgn
7/23/2014 9:17:33 AM jrb2



DRAFT

Legend

- Primary Sequence Grout Hole
- Secondary Sequence Grout Hole
- Tertiary Sequence Grout Hole
- Verification Sequence Hole
- Dip Direction of Hole
- Conductive Target Features

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	MJV2	DATE: JUL. '14
APPROVED BY:	DRD	DATE: JUL. '14
APPROVED BY:		DATE:

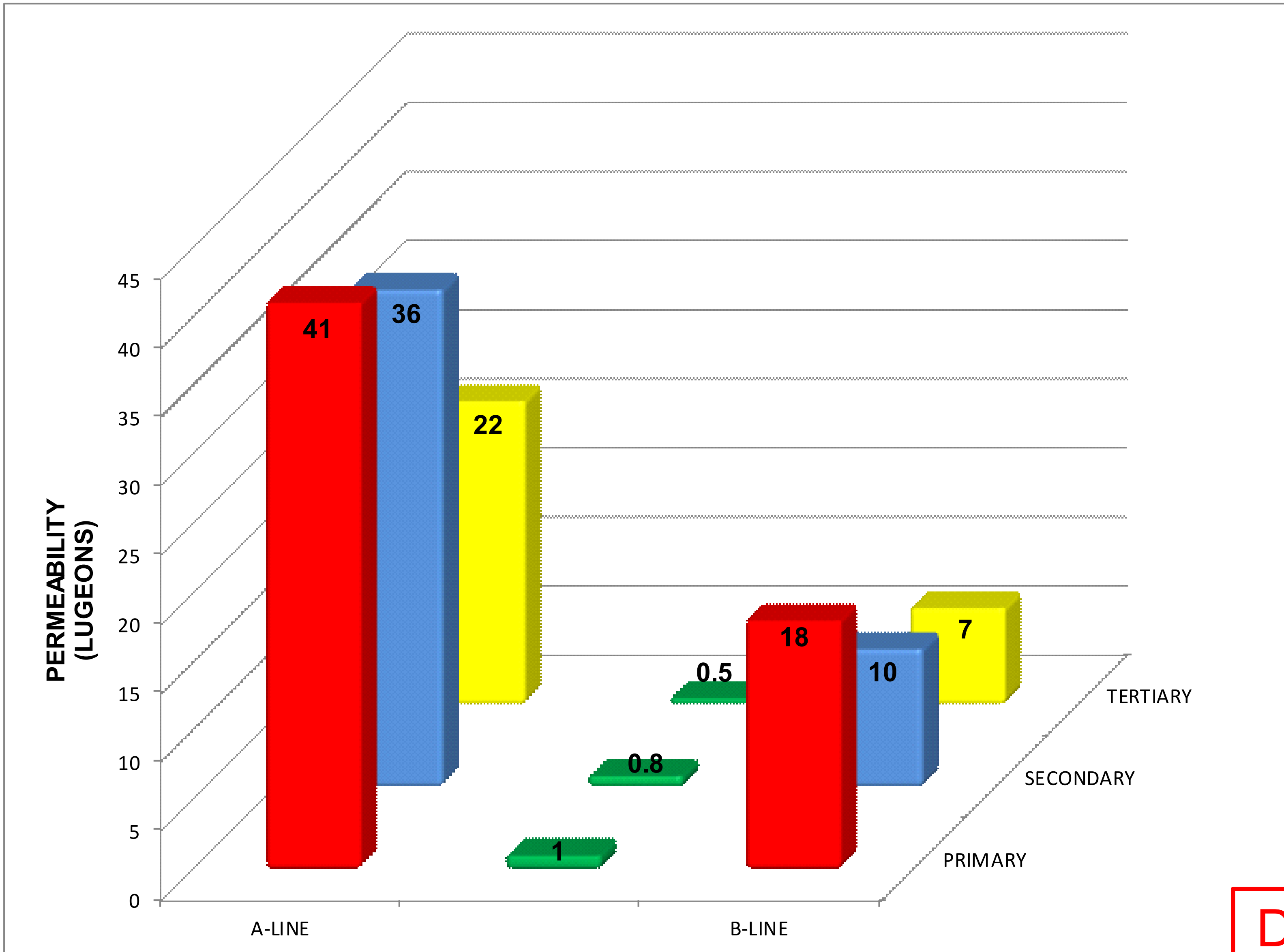
POLYMET MINING

FIGURE 3

EXAMPLE OF GROUT HOLE CONFIGURATION
USING SPLIT SPACING SEQUENCE
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale:	NOT TO SCALE	Date:	JULY 2014
Prepared by:	BJW1	Project No:	12P778

Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 3 Grout Plan Configuration Spacing.mxd Date: 8/27/2014



DRAFT

Legend

- Primary Sequence Holes
- Secondary Sequence Holes
- Tertiary Sequence Holes
- Verification Sequence Holes

POLYMET MINING

Foth

Foth Infrastructure & Environment, LLC			
REVISED	DATE	BY	DESCRIPTION

CHECKED BY: MJV2	DATE: JUL. '14	
APPROVED BY: DRD	DATE: JUL. '14	
APPROVED BY:	DATE:	

POLYMET MINING

FIGURE 4
HYPOTHETICAL PERMEABILITY COMPARISON PLOT FOR MAIN VERSUS VERIFICATION HOLES
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: NOT TO SCALE	Date: JULY 2014
Prepared by: BJW1	Project No: 12P778

Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 4 Grout Plan Permeability Comparison.mxd Date: 8/27/2014

Appendix 17.4 Engineered Wetlands Pilot Scale Testing Work Plan

PolyMet Mining

ENGINEERED WETLANDS

PILOT SCALE TESTING WORKPLAN

DRAFT – Last Updated: October 12, 2016

,

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

This Pilot Test Work Plan (Work Plan) has been prepared to outline the design, construction, and operation of a pilot scale, non-mechanical engineered wetland water treatment system proposed to be located on the former LTV Steel Mining Company (LTVSMC) tailings basin.

Arcadis has drafted this Work Plan on behalf of Poly Met Mining, Inc. (PolyMet) in order to assess the effectiveness of a non-mechanical water treatment system; specifically, an engineered treatment wetland, in conjunction with the proposed NorthMet Project (Project). This document is intended to be a working document that will be updated based on findings of the recent proof-of-concept bench scale testing (described below), findings from similar projects (as applicable), and findings from the proposed bench-scale testing outlined later in this document.

The primary parameter of concern (POC) on the former LTVSMC tailings basin for this evaluation is sulfate. Other identified surface water POCs that may need to be addressed include mercury, total dissolved solids (TDS), specific conductance, alkalinity, and hardness. The focus of the proposed pilot test is to evaluate the potential applicability and effectiveness of an engineered treatment wetland to mitigate the POCs present in the seeps emanating from the LTVSMC tailings basin. Water from LTVSMC tailings basin seeps will be used in the pilot test to evaluate the effectiveness of treatment. As described in further detail below, the system will work primarily by reducing sulfate through biological reduction in a floating, subsurface flow, engineered wetland (i.e., the engineered wetland treatment cell will be installed within existing wetlands, an influent distribution system will be provided to disseminate flow within the media bed, will be hydraulically connected to the wetlands via an engineered outfall structure or structures, and will be equipped with a cover system to facilitate winter operations and prevent cycling of reduced sulfur compounds to sulfate). Reducing sulfate will likely also result in reductions in TDS and specific conductance since sulfate is a significant contributor to those parameters.

The pilot test will provide information on the potential applicability of engineered treatment wetlands in mitigating these POCs as well as any byproducts of the biological reduction process (e.g., alkalinity). In addition, the pilot test will provide valuable information on design and operational considerations that may need to be optimized for full scale application of the technology.

2 BACKGROUND DATA

The former LTVSMC tailings basin has several seeps that currently discharge from the tailings basin. Water flowing through the LTVSMC tailings basin results in the transport of weathered minerals and dissolved ions; the resulting effluent water quality has circumneutral pH but can contain elevated concentrations of sulfate, hardness (dominated by magnesium [Mg^{2+}]), and alkalinity. Together, these elevated salt concentrations contribute to elevated total dissolved solids (TDS) and specific conductance. A seep exists along the southern edge of the tailings basin, approximately ¾ of a mile upstream of permitted surface outfall SD026. This seep is considered representative of water chemistry conditions found along the basin seeps. This seep is currently being collected and pumped back to the tailings basin (SD026 Pumpback). A slip stream of the SD026 pumpback water will be used for pilot testing activities. Existing water quality data has been compiled and summarized for SD026 in an effort to characterize the potential pilot test influent water and is summarized in **Table 1**. SD026 pumpback water is expected to have similar water quality characteristics to SD026.

In 2011, a bench test was conducted by Barr Engineering to test the sulfate reduction potential of a floating wetland. This floating wetland bench test was completed using water from surface discharge SD033, which is an outfall from a former mining area east of the LTVSMC tailings basin. Compared to SD033 water, the water from the SD026 pumpback (from the LTVSMC tailings basin) that will be used as influent flow for pilot scale testing is lower in sulfate, hardness, and specific conductance water, while bicarbonate alkalinity is comparable.

The primary goal of the 2011 bench scale test was to evaluate a floating wetland technology for its ability to facilitate sulfate reduction in site-specific water. The 8-week pilot demonstrated that the floating wetland treatment effectively supported sulfate reduction when the reactors were established and maintained at approximately ideal conditions for microbial growth. Bench testing demonstrated nearly 90% reduction of sulfate at times during the test, with average reductions ranging between 62 – 76%.

The promising results from the 2011 bench scale test merit expansion of the test to a pilot scale. Testing biological sulfate reduction technology on a pilot scale will provide the opportunity to evaluate its treatment capabilities under site-specific conditions at the LTVSMC tailings basin.

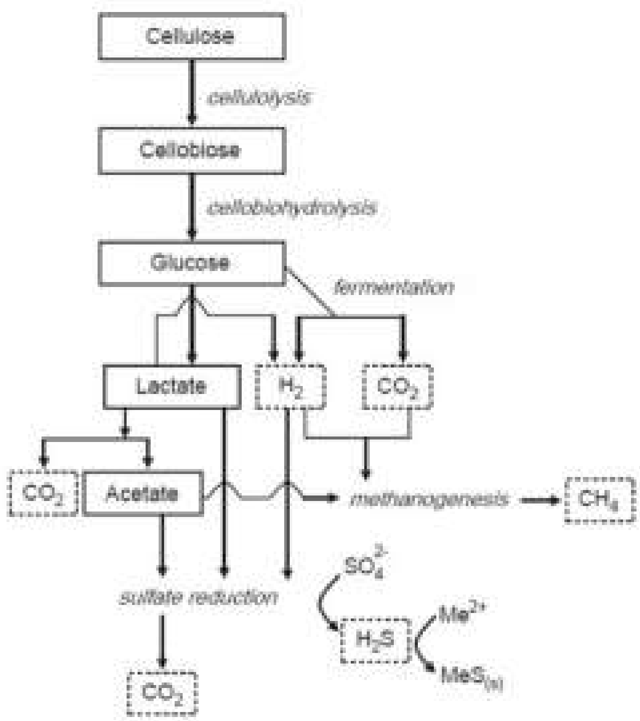
3 CONCEPTUAL TREATMENT TECHNOLOGY

3.1 Biological Sulfate Reduction

Sulfate reduction occurs via dissimilatory sulfate reduction by sulfate reducing bacteria (SRB). In general, this reaction can be summarized as follows:

Equation 1 $1/8\ SO_4^{2-} + 1/8\ CH_3OO^- + 3/16\ H^+ \rightarrow 1/16\ H_2S + 1/16\ HS^- + 1/8\ CO_2 + 2HCO_3^- + 1/8\ H_2O$

Organic matter (a carbon source) and anaerobic conditions are required to facilitate heterotrophic sulfate reduction. The organic matter can be provided by various methods, including naturally growing plant mass or it may be supplemented with either solid organic matter (manure, sawdust, woodchips, straw, peat, etc.) or a liquid feed source, such as methanol or ethanol. Acetate (depicted in Equation 1) is a carbon source utilized by SRB that is derived from various carbon sources (including carbohydrates such as cellulose) through microbial pathways as shown in the schematic below.



To remove the H_2S (hydrogen sulfide) generated by the SRB, dissolved metals can be added to precipitate metal sulfides. Iron, in forms ranging from iron oxide to zero valent iron (ZVI), is commonly used as a metal additive to facilitate this precipitation. A general reaction for the metal sulfide precipitation is:

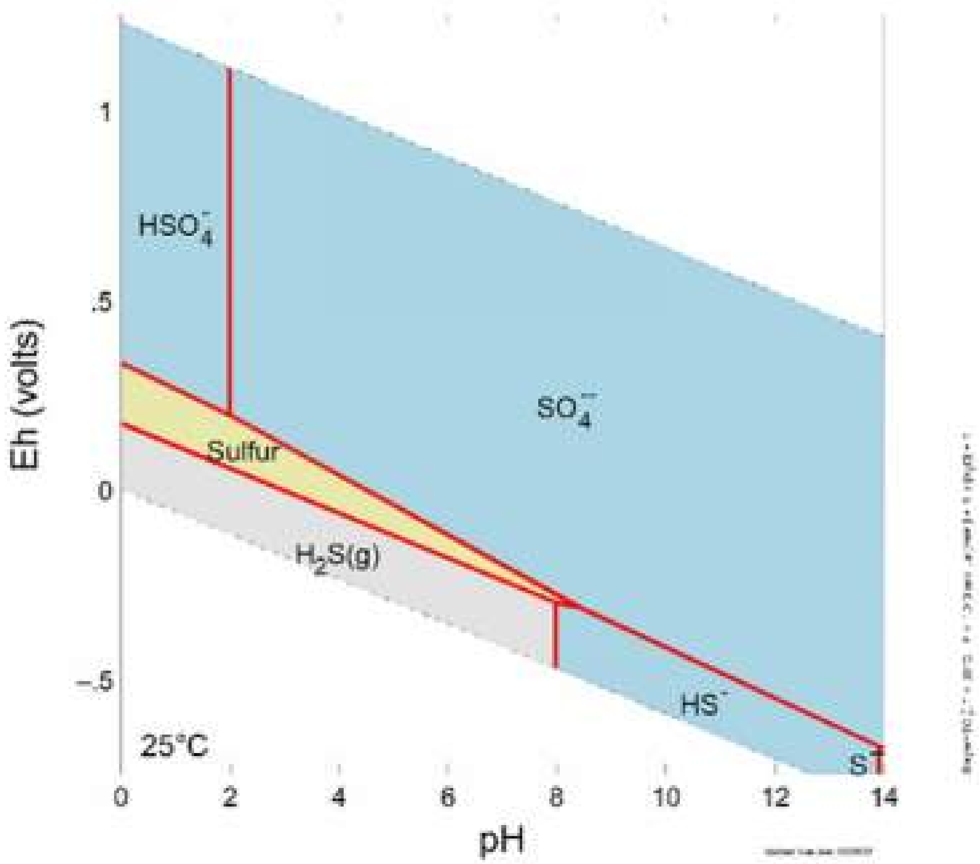
Equation 2 $H_2S + M^{2+} \rightarrow MS + 2H^+$

Therefore, the combined reaction for the reduction of sulfate by SRB and subsequent precipitation of metal sulfide is:

Equation 3 $$SO_4^{2-} + 2CH_2O + M^{2+} \rightarrow MS + 2H_2CO_3$$

The speciation of carbonic acid (H_2CO_3) will be dependent on the pH of the treatment system. For circumneutral or slightly alkaline waters, the bicarbonate ion (HCO_3^-) will dominate. As can be seen from Equation 3, metal ions (primarily iron and manganese) must be present in the same molar concentration as sulfate in order for complete metal sulfide precipitation. In the absence of sufficient concentration of metal ions, the reaction represented in Equation 1 would dominate, and hydrogen sulfide would be the primary sulfur-containing product.

As demonstrated in the Eh/pH diagram below, the fate of hydrogen sulfide (the primary reduced sulfur species generated in the absence of metals) when exposed to oxidants depends on the pH. At a pH greater than 8.0, hydrogen sulfide will be converted to sulfate. At pH less than 8.0, hydrogen sulfide will be converted to elemental sulfur. To avoid re-generation of sulfate as effluent is oxidized, it will be important to control the pH (i.e., maintain circumneutral pH).



3.2 Constructed Wetlands

Constructed treatment wetlands mimic biotic and abiotic processes that occur in natural wetlands and are able to remove pollutants through one or more mechanisms. These include biochemical oxidation and reduction, phytodegradation or immobilization, chemical precipitation, sedimentation, photodegradation, and volatilization. Constructed treatment wetlands have been used to treat mine influenced waters since at least the 1970s. Typical wetland configurations used in mining applications have been aerobic surface flow wetlands, anaerobic subsurface flow wetlands, and vertical flow wetlands. Aerobic wetlands have been effective at removing elevated concentrations of metals through oxidation and precipitation (Tarutis 1999; Watzlaf 2004). Effective metal removal rates in aerobic wetlands have been documented in Minnesota at the Dunka Mine in Babbitt (ITRC 2010) and have been the subject of numerous Minnesota Department of Natural Resources research projects (MDNR undated). Subsurface flow and vertical upflow wetlands are designed to limit atmospheric oxygen transfer and promote anaerobic conditions, limiting sulfate cycling in the wetlands and decreasing the potential for nuisance odor issues created by hydrogen sulfide emissions. These conditions should favor sulfate reducing bacteria and the formation of insoluble metal sulfides, which will be tested by PolyMet. However, the presence of alternate electron acceptors such as ferric iron, nitrate, and especially oxygen, would decrease the sulfate removal efficiency, as other microbial populations capable of utilizing these electron acceptors would out-compete the SRB.

3.3 Conceptual Field-Scale Pilot System

The intent of the field-scale pilot test is to confirm and further refine testing data obtained during previous proof-of-concept bench-scale testing of the anaerobic reduction process and to determine operational requirements for a full scale implementation. A conceptual field-scale pilot system test is shown in **Figure 1**.

Influent water will flow through a covered underflow, engineered wetland at a rate between 1-10 gallons per minute (gpm), with a steady state flow of 2.5 gpm (design flow). We will perform tests to achieve the maximum practical reduction for sulfate, which we expect to be approximately 100 mg/L. The system will be designed to target less than 100 milligrams per liter (mg/L) sulfate in the effluent. Drainage piping and stone will be installed to promote drainage of non-targeted water around the engineered wetlands. The pilot scale system will be lined with a 60-mil high density polyethylene (HDPE) liner (0.060-inch thickness) placed between layers of non-woven geotextile. Organic substrate with potential media amendments (e.g., zero valent iron, iron bearing rock/minerals, etc.) will be placed to a depth of four feet within the engineered wetland. Organic substrate will likely include hay, cow manure, nutshells, chitin, and woodchips, locally sourced as feasible. Additionally, use of fully digested bioreactor sludge as seed will be considered to enhance biological activity at the beginning of the pilot. Distribution laterals will be placed above the substrate to prevent short-circuiting of water through the system. A cover of mulch or woodchips, overlying an HDPE and geotextile liner, will be placed on top of the engineered wetland to provide freeze/thaw protection to the system. Additional benefits of the HDPE/geotextile liner will be to minimize cycling of sulfate by mitigating oxygen migration into the system, and to mitigate the potential for nuisance odors from hydrogen sulfide release. An outlet control structure will regulate water levels and effluent flow rates. It is likely that an aerobic polishing pond will be required to polish the engineered wetland effluent. The polishing pond will allow any residual iron or manganese to be oxidized, as well as to decrease biological oxygen demand (BOD) in the effluent prior to discharge from the treatment system.

3.4 Engineered Wetland Pilot Test

3.4.1 Objectives

The purpose of the engineered wetland pilot test is to determine the efficacy of the treatment approach for achieving sulfate load reduction at the LTVSMC tailings basin seeps.

The primary objectives of the engineered wetland pilot test include the following:

- Complete a supporting bench scale test prior to pilot-scale implementation in order to determine an effective blend of carbon substrate and inorganic media that will be used in subsequent pilot testing and to assess different non-metal reagents that may be used for sulfur capture to enhance long-term stability of the sequestered sulfur.
- Determine the extent of sulfate reduction through a range of flow and loading rates in a field-scale configuration under the operating conditions of climate/temperature and seasonality, as well as conditions that exceed design operating conditions (slug tests) to characterize performance under stress conditions.
- Refine key design parameters, such as contaminant mass loading rate and reduction capacity of the substrate, to refine the full-scale engineered wetland design.
- Assess wetland capacity and sustainability, including expected and potential organics demand, byproducts, life cycle considerations (e.g., carbon substrate depletion, iron media depletion, etc.), maintenance requirements, and generated constituent solid wastes.
- Assess reductions to other POCs, such as elevated TDS and alkalinity, which may be addressed by polishing steps as needed.
- Assess the dynamics of potential byproducts that could impact downstream water quality.
- Identify site-specific construction/implementation concerns and refine field-scale implementation approaches.
- Establish capital and operating costs associated with a full-scale implementation of the subsurface flow, engineered wetlands technology.

Pilot testing will include implementation within the LTVSMC tailings basin. The engineered wetland pilot test will be staged in an area to access a slip stream of water from SD026. The proposed schedule is summarized in **Table 2**.

3.4.2 Bench Testing

Prior to implementation of pilot testing, a supporting bench-scale test will be completed to determine an effective mix of carbon substrate and inorganic media for the engineered wetlands. Non-metal reagents may also be tested to enhance long-term stability of sequestered sulfur. This substrate and media blend will be able to achieve optimal pH and redox conditions within the engineered wetland in order to mitigate the cycling of sulfides back to sulfate.

Bench testing will occur in a controlled setting and should take no more than two months. A 30-day bench test window will allow sufficient time to observe steady state conditions at the bench scale. This testing will provide useful data that should support the optimization of the engineered wetland to achieve precipitation of sulfides with metals such as iron, or as elemental sulfur.

3.4.3 Engineered Wetland Pilot Test Design

The following preliminary design and operation parameters were assumed:

- The wetland will be engineered to target a sulfate removal rate of 0.04 moles per day per square meter of substrate, based on various benchmarks established in the literature for low metals concentration water chemistry (Wildeman 1993, Gusek 2013).
- A volume of approximately 75 feet (ft) by 55 ft by 7 ft depth (not including sloping factors) will be excavated prior to constructing the engineered wetland. Additionally, a vehicle turn-around area and other minor road improvements adjacent to the pilot testing area may be required to promote safe passage during construction, operation, and monitoring.
- The engineered wetland will include a drainage and liner system, a four-foot depth of blended substrate and media, a layer of distribution laterals, and a mulch or woodchip layer with geotextile cover to provide freeze/thaw protection and to minimize cycling of sulfate in the system. Refer to Figure 1 for a conceptual design of this system.
- Flow through the engineered wetland will run in a down-flow configuration, with distribution laterals installed to dispense inflows evenly across the substrate.

3.4.4 Pilot Test Operation

The engineered wetland pilot test operation will include three phases. The first phase will involve initial startup and troubleshooting of the system. During this time, the system flow rate will be brought up to 2.5 gpm in an incremental fashion in order to achieve steady state conditions. This phase is expected to take three months to complete. An Operations and Maintenance (O&M) manual will be developed at the end of phase one operation and will contain the following:

- Influent and Effluent flow control operations
- System maintenance procedures
- Performance monitoring and measurement
- Troubleshooting guidelines
- Final field design review
- Site and logistics review

The second phase will be steady state operations of the pilot system at approximately 2.5 gpm. This phase will determine the sulfate load reduction capacity of the substrate and lifespan of any media amendments used in the system. This phase is expected to take nine to twelve months of system operation, with the option to continue operating the system for another nine to twelve months if the performance of system is sufficiently promising Long term operation of the engineered wetland is required in order to determine seasonal/climatic effects on the system as well as identify any long term performance issues the system may face.

The third and final phase of system operation will be performance testing. This phase will increase the flow and/or sulfate loading rates to the engineered wetland in a series of slug tests. These slug tests will push the limits of system performance, identify key issues with system operation, and identify the flow and loading limits of stable system operation. This phase is expected to take 3 months to complete.

After the three phases of engineered wetland pilot testing are complete, the system will be drained and winterized or decommissioned as necessary. The media will be sampled for visual analyses, as well as measurements including alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.

3.4.5 Performance Monitoring

Performance monitoring will be conducted during each phase of pilot system operation as summarized in the table below for both field parameters and a suite of analytical samples. Field parameters will include: pH, temperature, specific conductance, oxidation-reduction potential, and dissolved oxygen. The analytical samples are described in the table below. Analytical sample collection, packaging, and shipping will follow applicable standard operating procedures. Samples will be shipped to a qualified laboratory following chain-of-custody procedures.

Sample Location	Analytical Suite
Influent	Total/dissolved metals, sulfate, TDS, total suspended solids (TSS), alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Engineered Wetland	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Effluent	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Polishing step effluent (if implemented)	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon

During the various phases of pilot testing, samples will be taken at variable frequency, as detailed below:

- During phase one of pilot testing, analytical samples will be collected weekly and field parameters will be collected twice per week. Additionally, the media will be characterized visually, as well as analyzed for alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.
- During phase two of pilot testing, analytical samples will be collected twice per month and field parameters will be collected weekly.
- During phase three of pilot testing, analytical samples will be collected twice per month and field parameters will be collected weekly. Additional sampling may be required based on the slug testing timelines.
- After the pilot testing is complete, the media will be characterized visually, as well as analyzed for alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.

Additionally, site and system conditions will be documented at the time of sampling. Flow rates will be calculated and recorded during each site visit. Any maintenance or operational challenges will be documented and addressed. Precipitation will be documented throughout testing.

Finally, a data logger will be placed into the effluent sump drain to record conductivity and specific conductance, temperature, and water depth at regular intervals of 60 minutes. Data from the logger will be downloaded monthly during analytical sampling events.

3.4.6 Design Basis Assumptions

The engineered treatment wetland is designed to handle a flow of 2.0 gpm. This represents the nominal consistent flow rate expected to the pilot scale test. The engineered wetland influent will be supplied by a slip stream from the SD026 pumpback system. During later phases of the pilot testing program, influent flow rates will be increased to “push” the system for determination of limits of operation relative to hydraulic and mass loading.

The engineered wetland design is sized based on the average sulfate concentration at SD026 (183 mg/L), and a sulfate reduction rate based on the goal of reducing sulfate concentrations to 100 mg/L or less. The target sulfate reduction rate is 0.04 moles per day per square meter of substrate. Based on flow and loading calculations (Table 3), the dimensions of the pilot scale engineered wetlands are approximately 70 feet in length, 50 feet in width, and 4 feet of substrate depth (total wetland depth of approximately 7 feet). This sizing includes a 10% volume allowance for blending of inorganic amendments such as zero valent iron if bench testing indicates this step is necessary. A detailed basis of design calculation can be found in **Table 3**.

4 SCHEDULE AND REPORTING

A preliminary schedule for the construction, operation, and reporting tasks associated with the engineered wetland pilot test is presented below, with a more detailed schedule presented in Table 2.

Quarterly reports will be prepared and submitted to PolyMet for the periods when the pilot test is operational. Quarterly reports will include summaries of available data, preliminary interpretation of the data, and discussion of operation and maintenance issues or challenges. A final report will be submitted to PolyMet following the conclusion of the pilot test.

Pilot testing and follow-up sampling activities will occur according to the schedules outlined in Table 2 and summarized below:

Engineered Wetland Pilot Test Schedule	
Submittal of Engineered Wetland Pilot Test Work Plan:	Sep 2016
Agency approval of Work Plan:	Oct 2016
Finalize design; procurement of supplies:	Dec 2016 through Feb 2017
Supporting bench testing:	Jan through Feb 2017
Construction/startup of engineered wetland:	Apr through May 2017
Engineered wetland system operation:	Jun 2017 through Oct 2018
Phase One:	Jun through Aug 2017
Phase Two:	Aug 2017 through Aug 2018
Phase Three:	Aug through Oct 2018
Submittal of final engineered wetland pilot test report:	Dec 2018

4.1 Engineered Treatment Wetlands in Mine Planning

PolyMet plans to implement this work plan in the spring of 2017. The test work under this plan will occur in parallel with the permitting process, and potentially also in parallel with construction of the project, which is estimated to last for two years once permits are received. If engineered wetland treatment is demonstrated to be successful one year prior to the commencement of operations, PolyMet will propose a transition from mechanical water treatment to non-mechanical water treatment in its contingency reclamation estimate.

5 REFERENCES

Gusek, J.J., Buchanan, R.J. Jr., and Sorells, D. 2013. Infiltration-Diverting Cap and Full-Scale Biochemical Reactor Operation at the Iron King/Copper Chief Mine, Arizona. *Proceedings, International Mine Water Association Annual Conference*, pg. 581-586.

ITRC (Interstate Technology & Regulatory Council). 2010. *Constructed Treatment Wetland*. Washington, D.C.: Interstate Technology & Regulatory Council, Mining Waste Team. www.itrcweb.org.

Logan, M.V., Reardon, K.F., Figueroa, L.A., McLain, J.E.T., Ahmann, D.M., "Microbial Community Activities During Establishment, Performance and Decline of Bench-Scale Passive Treatment Systems for Mine Drainage." Water Research 39, Vol. 19, 2005, pgs. 4537 -4551.

MNDNR (Minnesota Department of Natural Resources. *Reclamation Publications List: Mitigative Techniques – Passive Treatments – Wetlands*. Hibbing, MN: Minnesota Department of Natural Resources Division of Lands and Minerals. http://files.dnr.state.mn.us/lands_minerals/reclamation/reclamation_publication_list.pdf.

Rose, A.W. 2004. Vertical Flow System - Effects of Time and Acidity Relations. *Proceedings America Society of Mining and Reclamation*, Lexington, KY, pg. 1595-1616.

Tarutis Jr., W.T., Stark, L.R., and Williams, F.M. 1999. Sizing and Performance Estimation of Coal Mine Drainage Wetlands. *Ecological Engineering* 12, pg. 353-372.

Watzlaf, G.R., Schroeder, K.T., Kleinmann, R.L.P, Kairies, C.L., and Nairn, R.W. 2004. The Passive Treatment of Coal Mine Drainage. *U.S. Department of Energy National Energy Technology Laboratory Internal Publication.*

Wildeman, T.R., Brodie, G., Gusek, J.J. 1993. *Wetland Design for Mining Operations*, BiTech Publishers, LTD, Richmond, BC, Canada. ISBN 0 021095 27 9.

TABLES

Table 1 - SD026 Historical Water Quality (2005 - 2011)

	Parameter	Units	# of Samples	Minimum	Maximum	Average
Required Monitoring Parameters	Cis-1,2-Dichloroethylene	ug/L	6	<0.5	<1	<0.83
	Benzene	ug/L	6	<.5	<1	<.83
	Bicarbonates (Alkalinity as CaCO3)	mg/L	58	254	687	454
	Boron	ug/L	26	140	286	238
	Calcium	mg/L	54	53.2	96	81
	Cations, Total	meq/L	7	13.9	16	15
	Chloride	mg/L	48	7.5	16.7	12.6
	Chloroform	ug/L	6	<1	<2	<1.2
	Cobalt	ug/L	26	<.2	2.5	0.18
	Ethyl Benzene	ug/L	6	<1	<1	<1
	Flow	mgd	83	0	1.82	0.64
	Fluoride	mg/L	26	1.28	3.4	2.23
	Hardness, Carbonate (as CaCO3)	mg/L	37	294	537	463
	Magnesium	mg/L	54	55.5	121	100
	Manganese	ug/L	26	161	2190	636
	Mercury, Low Level	ng/L	26	<.05	2.1	0.53
	Molybdenum	ug/L	26	14.2	52.8	26.6
	Organics, Diesel Range	mg/L	78	<0.08	0.4	<.02
	pH	Std Units	83	7.3	8.4	8.0
	Potassium	mg/L	9	6.39	14.8	9.5
	Sodium, % of Total Cations	%	7	16	22.8	18.8
	Sodium	mg/L	7	35.7	52.9	46.9
	Solids, Total Dissolved (TDS)	mg/L	48	483	866	730
	Solids, Total Suspended (TSS)	mg/L	64	<1	16	2.96
	Specific Conductance	umh/cm	83	728	1350	1115
	Sulfate	mg/L	58	115	360	183
	Tetrachloroethylene	ug/L	6	<1	<1	<1
	Toluene	ug/L	6	<1	<1	<1
	Trichloroethylene	ug/L	6	<1	<1	<1
	Xylene, M&P	ug/L	6	<1	<2	<1.6
	Xylene, O	ug/L	6	<1	<1	<1
Non-Required Monitoring Parameters	Arsenic	ug/L	1	<2	<2	<2
	Bromide	mg/L	2	<.5	<.5	<.5
	Copper	ug/L	2	<2	<2	<2
	Hardness, Total, as CaCO3	mg/L	58	361	780	610
	Iron	mg/L	1	0.048	0.048	0.048
	Nickel	ug/L	1	<2	<2	<2
	Nitrogen, Ammonia as N	mg/L	1	0.15	0.15	0.15
	Nitrogen, Nitrate+Nitrite as N	mg/L	1	<.1	<.1	<.1
	Phosphorous, Total as P	mg/L	1	0.014	0.014	0.014
	Salinity	Std Units	10	0.3	0.6	0.5
	Selenium	ug/L	1	<2	<2	<2
	Surrogate 1,2-Dichloroethane-d4	%	4	99.2	109	106
	Surrogate Bromofluorobenzene	%	4	98.9	104	101
	Surrogate Toluene-d8	%	4	97.9	107	101
	Total Organic Carbon	mg/L	2	4.4	4.4	4.4
	Trans-1,2-Dichloroethylene	ug/L	1	<1	<1	<1
	Zinc	ug/L	1	<25	<25	<25

Table 2 - Engineered Wetland Pilot Test Schedule

Engineered Wetland Pilot Test Schedule - 2016 & 2017	2016				2017											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engineered Wetland Pilot Test Work Plan																
Submittal of Engineered Wetland Pilot Test Work Plan																
Agency approval of Work Plan																
Finalize design; procurement of supplies:																
Supporting bench testing:																
Construction/startup of engineered wetland:																
Engineered wetland system operation:																
Phase One:																
Phase Two:																
Phase Three:																
Submittal of final engineered wetland pilot test report:																

Engineered Wetland Pilot Test Schedule - 2018	2018											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engineered wetland system operation:												
Phase Two:												
Phase Three:												
Submittal of final engineered wetland pilot test report:												

Table 3 - Detailed Design Basis Calculations

Preliminary Sulfate Reducing Engineered Wetland (SREW) Sizing
Polymet
Tailings Basin

Prepared By:	L. Weidemann
Checked By:	J. Forbort
Revision No.:	001
Date:	9/25/2016

Piped Seep Flow Rate

Slip stream of tailings basin seep water ranging from 1-10 gpm.

Estimated Flow Rate =	2.5	gpm
	14,000	L/day

Calculate Minimum Volume of Organic Substrate Required

Volume of Organic Substrates Based on the Following Loading Rate (Gusek et. al, 2013)
Ranging from 0.04 to 0.08 moles/day/m^3

Target Metals Loading Rate =	0.04	mol/day/m^3

Volume of Organic Substrates Based on Sulfate Concentration

Sulfate Concentration =	183	mg/L
Sulfate Loading =	2,560,000	mg/day
	2,560	g/day

Sulfate Removal Targets

Sulfate Concentration =	183	mg/L
Sulfate Effluent Target =	90	mg/L
Sulfate Target Removal =	93	mg/L
Sulfate Target Removal =	1,300	g/day
Molecular Weight of Sulfate =	96.06	g/mol
Sulfate Loading Molar Basis =	13.5	mol/day
Volume of Organics =	338	m^3
	11,900	ft^3
Empty Bed	24	days

Calculate Combined Volume of Organic Substrate and Zero Valent Iron

Substrate will be a Mixture of 90% Organic Material and 10% Zero Valent Iron (or similar amendment)

Volume of Iron =	1,322	ft^3
Total Combined Volume =	13,200	ft^3

Calculate Base Area of SRBR Based on Substrate Volume

Min. Substrate Thickness =	4	feet
Total Area (Volume Based) =	3,300	ft^2

SRBR Sizing Summary

Minimum Substrate Volumes

Volume of Organics =	11,900	ft^3
Volume of Limestone =	1,322	ft^3
Minimum Substrate Volume =	13,200	ft^3

Minimum Base Area for SRBR

Total Area (Volume Based) =	3,300	ft^2
Factor of Safety =	1.0	unitless
Total Base Area of SRBR =	3,300	ft^2
Depth Substrate =	4	ft
Length =	70	ft
Width =	47	ft

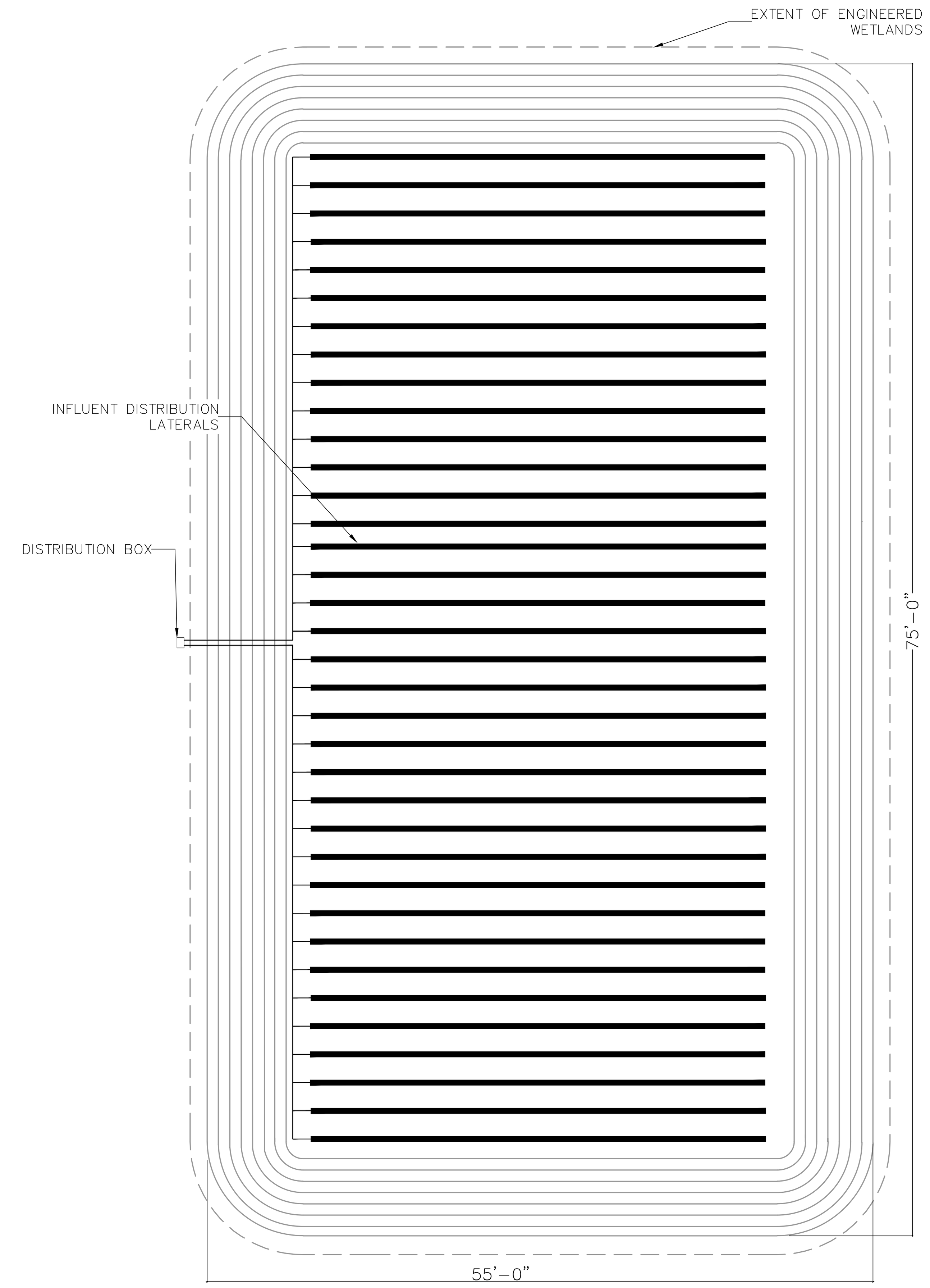
References

Gusek, J.J., Buchanan, R.J. Jr., and Sorells, D. (2013). Infiltration-Diverting Cap and Full-Scale Biochemical Reactor Operation at the Iron King/Copper Chief Mine, Arizona. Proceedings, Internation Mine Water Association Annual Conference, pg. 581-586.

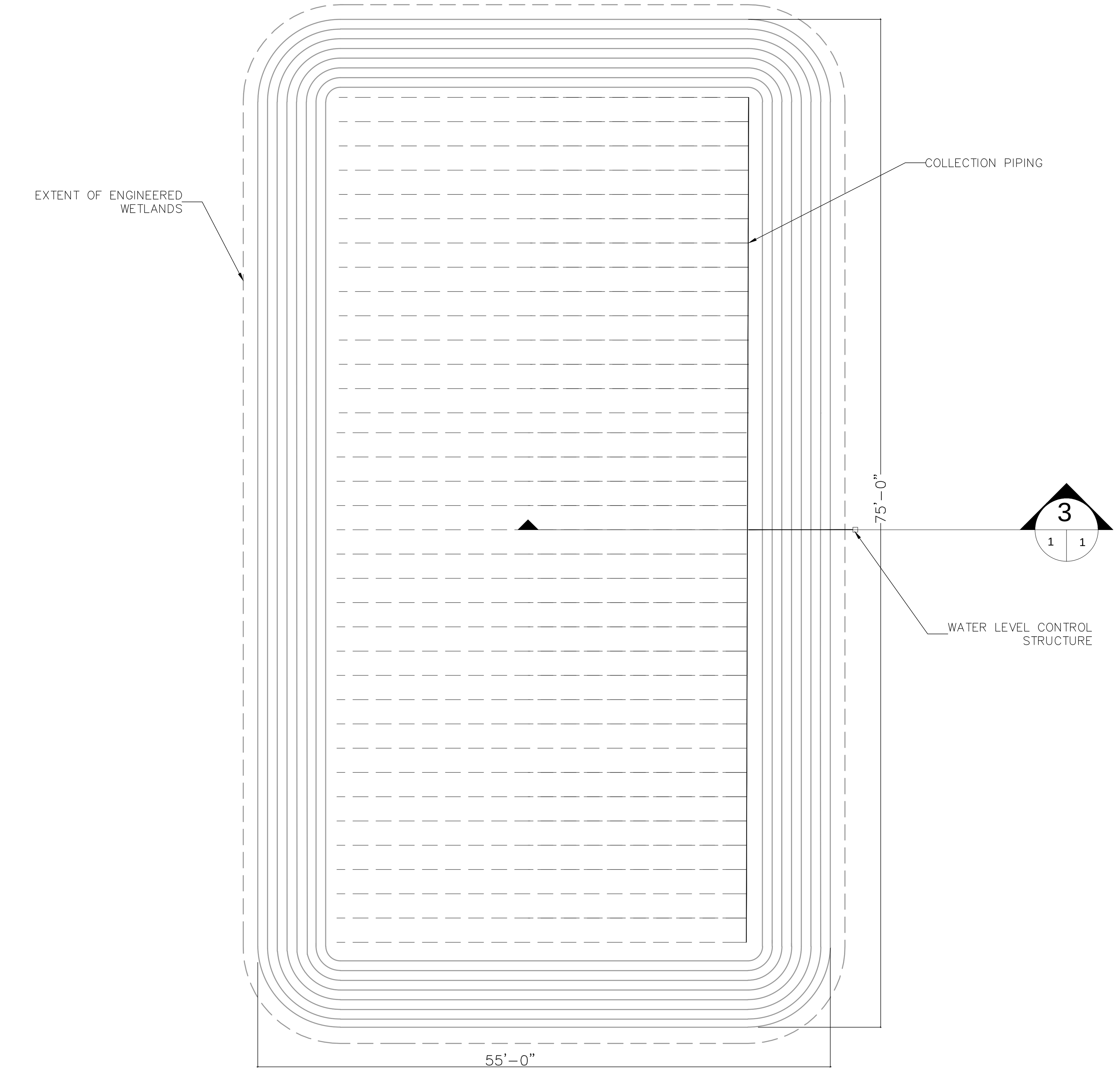
Kirby, C.S., Cravotta, C.A. III (2005). Net Alkalinity and Net Acidity 1: Theoretical Considerations. Applied Geochemistry, vol. 20, pg. 1920-1940.

Rose, A.W. (2004). Vertical Flow System - Effects of Time and Acidity Relations. Proceedings America Society of Mining and Reclamation, Lexington, Ky, pg. 1595-1616.

FIGURES

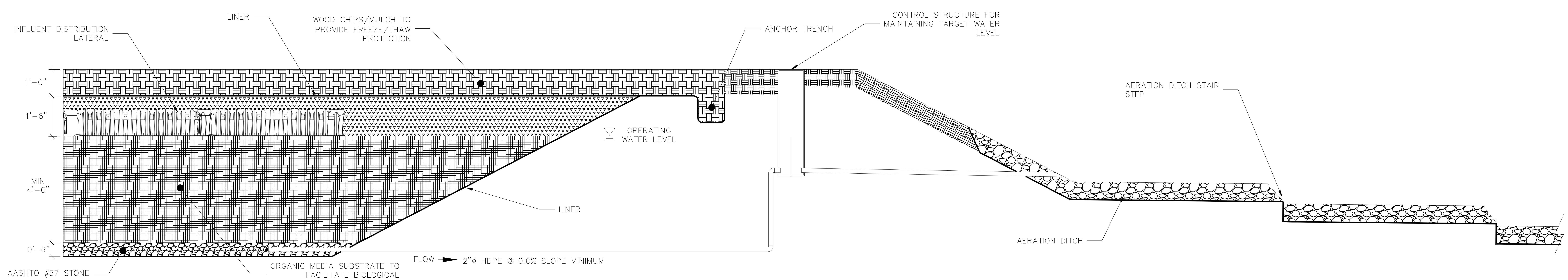


1 | 1 1
ENGINEERED WETLANDS INFILTRATION SYSTEM
NOT TO SCALE



2 | 1 1
ENGINEERED WETLANDS DRAINAGE SYSTEM
NOT TO SCALE

NOTES:
1. FIELD SCALE PILOT DESIGN INTENDED FOR IMPLEMENTATION ON THE TAILINGS IMPOUNDMENT. DESIGN INCLUDES LINERS TO PREVENT SLIP STREAM OF WATER FROM THE EXISTING PUMP BACK SYSTEM FROM PERCOLATING INTO TAILINGS.
2. FULL-SCALE DESIGN WOULD BE INSTALLED TO RECEIVE WATER FROM THE TAILINGS BASIN THROUGH A FUNNEL AND GATE APPROACH WITH THE HYDRAULIC BARRIER.
3. THIS DESIGN IS ONLY INTENDED FOR THE FIELD SCALE PILOT SYSTEM. FULL-SCALE DESIGN WILL BE LARGER AND WILL CONSIST OF MORE ROBUST COMPONENTS.



3 | 1 1
TYPICAL ENGINEERED WETLANDS PROFILE
1/2" = 1'

SCALE(S) AS INDICATED

THIS BAR REPRESENTS ONE INCH ON THE ORIGINAL DRAWING: USE TO VERIFY FIGURE REPRODUCTION SCALE

No.	Date	Revisions	By	Ckd

THIS DRAWING IS THE PROPERTY OF THE ARCADIS ENTITY IDENTIFIED IN THE TITLE BLOCK AND MAY NOT BE REUSED OR ALTERED IN WHOLE OR IN PART WITHOUT THE EXPRESS WRITTEN PERMISSION OF SAME.

Professional Engineer's Name		
Professional Engineer's No.		
State	Date Signed	Project Mgr. JEF
Designed by JEF	Drawn by JVA	Checked by JEF

NOT FOR CONSTRUCTION

ARCADIS Design & Consultancy for natural and built assets

ARCADIS U.S., INC.

POLYMET MINING
NORTHMET MINING PROJECT

FIELD SCALE PILOT SYSTEM

ARCADIS Project No.
MN000643.0001.00002

Date
SEPTEMBER 2016

ARCADIS
430 First Avenue North
Suite 720
Minneapolis, Minnesota 55401
TEL.612.339.9434

1

CITY: SYRACUSE, NY DIV/GROUP: IMDV DB: G.STEINBERGER LD: G.STEINBERGER PIC: A.THATCHER PM: A.LONG/L.KETCHAM TM: K.MOTT LYR: ON=*;OFF=*REF* PLOTSTYLETABLE: ---- PLOTTED: 9/27/2016 1:53 PM BY: ALLEN, JONATHAN V.
G:\COMMON\Jon A\Polymet\NORTHMET SITE\Field Scale Pilot Study\Civil\Civil Design.dwg LAYOUT: 1 SAVED: 9/27/2016 1:45 PM ACADVER: 19.1S (LMS TECH) PAGESETUP: ----

Arcadis U.S., Inc.

630 Plaza Drive

Suite 100

Highlands Ranch, Colorado 80129

Tel 720 344 3500

Fax 720 344 3535

www.arcadis.com