POLYMET
MINING

NorthMet Project

Flotation Tailings Management Plan

Version 7

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

Certifications

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota.

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Acronyms, Abbreviations and Units

Acronym	Stands For
AMSL	Above mean sea level
CAP	Contingency Action Plan
DSI	Dam Safety Inspections
DSR	Dam Safety Reviews
ESSA	Effective Stress Stability Analysis
fps	feet per second
FTB	Flotation Tailings Basin
LTVSMC	LTV Steel Mining Company
DNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
PMP	Probable Maximum Precipitation
SAFL	St. Anthony Falls Laboratory
USSA	Undrained Strength Stability Analysis
WWTS	Waste Water Treatment System

1.0 Introduction

This document describes the Flotation Tailings Management Plan for the Poly Met Mining Inc. (PolyMet) NorthMet Project (Project). The Project is described in the Final Environmental Impact Statement (Reference (1)).The Project will produce Flotation Tailings throughout 20 years of ore processing. Flotation Tailings will be deposited in the Flotation Tailings Basin, which will be placed on Cells 1E and 2E of the existing former LTV Steel Mining Company (LTVSMC) tailings basin.

In this document, the Flotation Tailings Basin (FTB) refers to the newly constructed NorthMet Flotation Tailings impoundment, and the Tailings Basin is the existing LTVSMC tailings basin as well as the combined LTVSMC tailings basin and the FTB. Coarse tailings are LTVSMC coarse tailings, fine tailings are LTVSMC fine tailings, slimes are LTVSMC slimes, and Flotation Tailings are the NorthMet bulk flotation tailings.

The Project will generate approximately 11.27 million short tons of Flotation Tailings annually (approximately 10,000,000 in-place cubic yards annually). Stage-volume calculations demonstrate that Cells 1E and 2E have sufficient capacity available to store tailings for over 20 years of operation. Tailings deposition will begin in Cell 2E. After approximately seven years the Cell 2E elevation will reach the elevation of Cell 1E and the two cells will merge. From Mine Year 7 through the remainder of operations, tailings will be deposited in the merged cell, Cell 1/2E. Over the 20 years of operation Cells 1E and 2E will receive tailings until their elevation approximately matches the existing elevation of Cell 2W. The layout and design of the FTB are shown in the FTB Permit Application Support Drawings FTB-001 to FTB-024 in Attachment A. Template Construction Specifications are provided in Attachment G. Construction Specifications will be updated and detail added as needed prior each major construction event at the FTB.

Personnel who will be responsible for FTB management are:

- *Operations Contact* - Beneficiation Division Manager or designee – Responsible for overall FTB design, planning, operations, maintenance, and monitoring.
- *Design Engineer* (an independent consultant retained specially for dam safety expertise and a Minnesota-registered engineer) – Responsible for performance monitoring data analysis and interpretation, dam safety inspection and reporting assistance, tailings dam planning and design assistance, and permitting assistance.

1.1 Outline

The outline of this document is:

Section 1.0 Introduction and description of existing conditions at the Tailings Basin.

Section 2.0 Description of FTB design including tailings geochemical characterization, dam design and construction, Flotation Tailings transport, return water system and stormwater management. Note that surface and groundwater seepage capture systems are described in Sections 2.1.3 and 2.1.4 respectively of Reference (2).

Section 3.0 Description of outcomes of dam stability, dam break analysis, and tailings deposition modeling.

Section 4.0 Description of operational plans including Flotation Tailings transport and deposition, return water system, pond water level control, and general maintenance.

Section 5.0 Description of monitoring program and Dam Safety Inspections.

Section 6.0 Description of reporting requirements including compliance to plan and waste characterization update, and description of adaptive management practices.

Section 7.0 Description of the reclamation plan for the FTB.

This document is intended to evolve through the environmental review, permitting [Minnesota Pollution Control Agency (MPCA) State Disposal System, Minnesota Department of Natural Resources (DNR) Dam Safety, and DNR Permit to Mine], operating, reclamation, and postclosure maintenance phases of the project. It will be reviewed and updated as necessary in conjunction with changes that occur in facility operating and maintenance methods or requirements. A Revision History is included at the end of the document.

1.2 Existing Conditions

The Tailings Basin was previously used by LTVSMC (and its predecessor Erie Mining Company) for disposal of taconite tailings. The facility is unlined and was constructed in stages beginning in the 1950's. Taconite tailings were deposited from 1957 to January of 2001, when the Tailings Basin was shut down. It has been inactive since then except for reclamation activities consistent with a DNR approved reclamation plan. The Tailings Basin is configured as a combination of three adjacent cells identified as Cell 1E, Cell 2E, and Cell 2W (Drawing FTB-003). Cells 1E and 2E of the Tailing Basin will be used for disposal of

Flotation Tailings. Additional details on existing conditions are in Section 3 of Appendix B of this application.

The existing cells and dams do not have a core or cutoff other than the fine tailings and slimes that deposited upstream (on the pond side) of the coarse tailings dams. While in operation, LTVSMC used ditches, pumps, and pipelines at select locations to capture toe-of-slope seepage water and return it to the pond. When LTVSMC shut down, the ponds started to dry up and the toe-of-slope seepage flow reduced. Many of the seeps are no longer flowing and the pumps are no longer active. The seep located on the south side of Cell 1E (SD026) remains active and its discharge is being collected and pumped back into Cell 1E as part of a consent decree between Cliffs Erie and the MPCA. A seep located near the northwest corner of Cell 2W (SD004) also remains active and its discharge is being collected and pumped to a surface water discharge location (SD006) which has its discharge collected and pumped back into Cell 1E. Piezometers and weirs were established in the Tailings Basin area during operation to monitor piezometric conditions and seepage flows. Most of this instrumentation remains and can be used for annual dam safety evaluations. The piezometers provide information on piezometric heads (groundwater levels) within the Tailings Basin area. The weirs are in seepage collection ditches around the Tailings Basin perimeter and can be monitored for flow rate and water quality. However, flow in the seepage collection ditches is now negligible to non-existent so data from these weirs is no longer routinely collected. Inclinometers are located around the Tailings Basin to monitor movement within the slopes. Some individual seeps are also monitored for flow rate and water quality.

There is no water ponded in Cell 2W and current groundwater elevations in Cell 2W are below the Tailings Basin surface. Ponds of water remain in Cells 1E and 2E. As part of the Consent Decree, some tailings basin seepage is being captured and pumped into Cell 1E. From Cell 1E portions of the water are discharged to nearby Pit 2W via permitted discharge, and other portions of the water are treated and discharged to Second Creek in accordance with facility permit requirements.

2.0 FTB Design

The FTB will contain Flotation Tailings from the flotation process at the Beneficiation Plant. Treated water from the Mine Site will also be pumped to the FTB, enabling the FTB to serve as the primary source of process water at the Plant Site.

2.1 Flotation Tailings Characterization

Flotation Tailings were produced during the pilot-plant processing of Project ore samples. The pilot-plant Flotation Tailings samples are representative of the tailings expected from the beneficiation plant. Samples of the Flotation Tailings were collected for laboratory testing to determine geochemical and geotechnical parameters for use in water quality estimates, FTB planning, slope stability analyses, and staged-construction evaluations. The current ore processing plan utilizes a SAG mill (semi-autogenous grinding) that will not significantly change the characteristics of the tailings relative to those derived from the pilot-plant processing.

Once operations start, Flotation Tailings samples will periodically be collected and analyzed to confirm that data used in water quality estimates and FTB design remain consistent with full-scale operations. Consistent with the Observational Method used at all DNR-permitted tailings basins, tailings characteristics and dam performance monitoring data will routinely be collected and reviewed, with dam design modified as needed based on operational experience (Section 6.0).

2.1.1 Geochemical Characterization

Flotation Tailings samples were collected from pilot-tests run in 2005, 2006, 2008, and 2009. Results from the 2005 pilot-test represented the beneficiation process flowsheet used in the Draft Environmental Impact Statement. The 2006 pilot-test included flotation process optimization tests, and additional tailings samples were collected for environmental purposes (e.g., waste characterization, air quality, water balance, etc.). The 2008 pilot-test represented a refinement that increased the amount of regrinding in the flotation area. The 2009 pilot-test represented a refinement that increased the amount of regrinding in the flotation area and had a cleaner flotation process for the scavenger flotation step. Waste characterization testing has been conducted on a total of thirty-three tailings samples from the three pilot-plant runs. Various samples have been under kinetic testing for 310 to 570 weeks and are ongoing. A detailed analysis of the geochemical properties of the Flotation Tailings and geochemical aspects of water quality modeling are provided in the Waste Characterization Data Package (Reference (4)).

Estimates of water quality in the FTB Ponds, seepage, and at surface water and potential groundwater compliance points are provided in Section 3 of the Water Management Plan – Plant Site (Reference (2)).

2.1.2 Geotechnical Characterization

The geotechnical aspects of the FTB design are detailed in Appendix B of this application.

2.2 FTB Dams

The design of the FTB is based on a number of factors including State of Minnesota Rule requirements (Section 2 of Appendix B of this application), FTB capacity requirements, in-basin hydrology, seepage water quality, and FTB operating plans. The following paragraphs provide an overview of the FTB design requirements and overall design plans.

2.2.1 Dam Design Basis

Based on a review of historical data, a geotechnical evaluation, a study of the Flotation Tailings properties, and an evaluation of stability, it was determined that it is feasible to construct the FTB within Cells 1E and 2E of the Tailings Basin. Geotechnical design of the FTB dams is based on the field and laboratory testing done to date, and is described in Appendix B of this application. The conclusion of the geotechnical evaluation is that the proposed dams can be constructed on the Tailings Basin and necessary factors of safety for slope stability can be achieved and maintained (Section 7 of Appendix B of this application).

The FTB is designed as a closed system not allowing for release of untreated water through overflow or outlet structures during routine operations. The precipitation that falls within the FTB perimeter will be contained by freeboard. Overflow will be prevented by pumping excess pond water to the Waste Water Treatment System (WWTS) as needed. The operation of the WWTS is described in Reference (5). Overflow structures, included in the design as a matter of standard engineering practice, are described in Sections 2.5 and 7.4.

The FTB design process evaluated different dam construction and tailing-disposal methods. The selected construction method is to construct the dams by the upstream method using existing LTVSMC coarse tailings to form the exterior shell. Of the methods evaluated, this method uses the least amount of dam construction material. However, it requires that the deposited Flotation Tailings drain easily, are of suitable strength as a foundation for subsequent dam raises, and are sufficiently permeable to minimize increased phreatic water levels within the dams. The Flotation Tailings will have a small and fairly uniform grind size such that when deposited a fairly consistent particle size distribution will be achieved thereby minimizing segregation of coarse and fine portions (Section 3.2). The Flotation Tailings have nearly 70% fines (material passing the No. 200 sieve). The characteristics of the Flotation Tailings are reported in Appendix B of this application.

The dam design can be modified, if necessary, based on results of performance and stability monitoring and consistent with the Observational Method procedures for dam performance monitoring (Section 6.3). The Observational Method employs sequences of data gathering, detailed calculations and performance predictions, additional data gathering and observations, and design modifications as needed to maintain required operating conditions at the Tailings Basin. First, the engineer uses available information to prepare an initial concept and design that will predict the behavior of the basin. As the stages of construction progress, the engineer monitors and tests the site to obtain more detailed information. The predicted behavior is compared with the measured behavior, enabling the engineer to revise the original predictions. Repeating this process leads to successive refinements in tailings basin dam design and construction. Tailing basin dams are typically built in stages, thus the Observational Method to design is well suited for minimizing risk. The FTB monitoring program is described in Section 5.0.

2.2.2 FTB Staging and Sequencing

Construction of the FTB dams will occur in increments over its 20-year operating life. Drawings FTB-004 through FTB-014 depict the sequential development of the FTB. Large Table 1 shows the staged construction design elevations along with the constructed dam material volumes and FTB capacity. In Large Table 1 and in Attachment A drawings, the FTB dams are shown as being constructed in 20-foot increments. This is for ease of presentation and analysis. Dams may be constructed in smaller increments, always maintaining sufficient Flotation Tailings deposition capacity and freeboard. However, overall dam dimensions will be retained, as the specified dimensions will be needed to maintain dam slope stability safety factors.

The existing Coal Ash Landfill located in the southeastern portion of Cell 1E is a factor in FTB staging and sequencing. The contents of the Coal Ash Landfill will be removed prior to Mine Year 7, when deposition of Flotation Tailings in Cell 1E will begin. The contents of the Coal Ash Landfill will be disposed of in the Hydrometallurgical Residue Facility (HRF) if the materials meet all of the required physical and chemical criteria for placement in that facility. If the criteria are not met, the contents of the Coal Ash Landfill will be transported off-site to a suitable disposal facility. The landfill relocation will be completed prior to Mine Year 7, when deposition of Flotation Tailings in Cell 1E will begin. Drawing FTB-003 shows the location of the Coal Ash Landfill.

2.2.3 FTB Freeboard Requirements

FTB design determined the freeboard required for the pond to safely accommodate precipitation events without overtopping the dams. A hydrology study was conducted to determine the water level (pond) bounce in the cell ponds during the Probable Maximum Precipitation (PMP), 1/3 PMP, and 2/3 PMP events (Attachment C). The bounce in the cells is dependent on the length of exposed beach at the time of the precipitation event. The bounce ranges from 1.5’ to 17.5’ when considering 1/3 PMP, 2/3 PMP and full PMP occurring on beach lengths of 625 feet and 1,250 feet. The elevation difference between the maximum pond bounce and planned dam elevation yields freeboard in the range of 5.25’ (for full PMP) to 26.5’ (for 1/3 PMP) on the basis of the assumed starting water level elevations. From the assumed starting water level elevations, the freeboard remaining after pond bounce is large enough that wave run-up has not been added to the pond bounce computations. Water level will be managed so that minimum freeboard is not exceeded, as described in Section 4.2.

2.2.4 Dam Construction

The dam will be constructed in eight lifts, with an approximate final crest elevation of 1732 feet above Mean Sea Level (AMSL). Each lift of the FTB dam will consist of a 200-foot wide base with 4.5H:1V slopes on the outside of the FTB and 2H:1V slopes on the inside. The dam will be constructed of individual lifts 20 feet high (although each lift may be subdivided into several smaller lifts), with the exception of the last lift, Lift 8, which will be only 10 feet high. Each lift will have a 60-foot bench from the outside edge of the previous lift to the toe of the new lift, with the exception of Lift 5, which requires an offset of 260 feet (Drawings FTB-009, FTB-010, FTB-012, and FTB-014). A layer of LTVSMC coarse tailings will be placed to provide a construction base and underdrain layer beneath Lift 1 and Lift 5.

Based on the difference in the starting Flotation Tailings elevation from current elevation of 1570'to final elevation 1724' in Mine Year 20, the average annual rate of rise is approximately 7.7 feet. Although the dams have been modeled for slope stability at a 20-foot lift height (as shown in the Attachment A Drawings), the actual rate of rise of the dams will be matched to the need to maintain Flotation Tailings containment capacity and by the need to maintain sufficient freeboard. As a result, the rate of dam rise will range from 12 to 13 feet per year early in the life of the FTB, to 4 to 5 feet per year as development of the FTB transitions from Cell 2E to Cell 1/2E (Drawing FTB-009).

The FTB dams will be constructed using LTVSMC coarse tailings. Approximately 18,000,000 cubic yards of construction material will be required to construct the dams to the crest elevations required to store Flotation Tailings for 20 years of operation using the upstream method. Stage-volume calculations demonstrate that the volume of LTVSMC coarse tailings readily available can meet this demand: there are roughly 20,000,000 cubic yards of LTVSMC coarse tailings available. The location of the LTVSMC coarse tailings borrow material is presented in Drawing FTB-003. The tailings borrow material will be mechanically placed and compacted to specifications. During construction of FTB dams, the exterior face of the dams will be amended with a bentonite layer (Section 7.1). The bentonite layer will limit oxygen infiltration into the Flotation Tailings. The amendment will also reduce rainwater infiltration into the dams, which has a small benefit in terms of an increased slope stability safety factor. Additional information on FTB construction methods and preliminary specifications can be found in Attachment G.

Two design features are incorporated to maintain slope stability factors of safety for the FTB dams: (1) buttresses to support existing Tailings Basin dams, and (2) internal shear walls within the existing LTVSMC slimes and fine tailings previously deposited in Cell 2E.

The design includes two buttresses, the north buttress and the south buttress. Construction of the north buttress, at the toe of the existing Cell 2E dam, will begin after filling of Lift 1 (approximately after Mine Year 1). Buttress construction may need to be initiated sooner to accommodate FTB Containment System construction. Final construction of the buttress is required before the Lift 2 dam is in service (approximately in Mine Year 3). The second buttress will be constructed at the south end of Cell 1E near the railroad fill. Construction of the south buttress is required for Lift 5 (first lift at Cell 1E).

Table 2-1 shows the staged construction and proposed heights for buttress construction along with the estimated quantity of material needed. The proposed buttresses will be constructed with DNR approved material from former LTVSMC waste rock stockpiles located in Area 5 (east of the Plant Site, as shown on Figure 3.2-1 of Reference (1)), or other former LTVSMC waste rock stockpiles. Depending on Area 5 material gradation, some mixing may be required to achieve a material gradation suitable for placement in contact with the existing LTVSMC coarse tailings dams. Drawings FTB-004 to FTB-014 show dam layouts and cross-sections including the sizes of the buttresses.

Table 2-1 Flotation Tailings Basin Buttress Development

Mine Year	Dam Lift	Average Flotation Tailings Elevation (FT)	Dam Crest Elevation (FT)	Buttress Height – Cell 2E North Dam (West Segment) (FT)(1) (2)	Buttress Height – Cell 2E North Dam (East Segment) (FT)(1) (2)	Buttress Height – Cell 1E South Dam (FT)	Approximate Buttresses Total Material (CY)
Cell 2E (incl. North Buttress)							
--	Lift 1	1570.0	1602	0.0	0.0	0.0	0
1		1585.0					0
2	Lift 2	1597.0	1622	29.0	19.0	0.0	1,060,000
3		1609.0		41.0	27.0		1,494,000
4	Lift 3	1622.0	1642	53.0	35.0	0.0	1,928,000
5		1633.0		64.0	42.0		2,362,000
6	Lift 4	1646.0	1662	76.0	50.0	0.0	2,796,000
7		1658.0		88.0	58.0		3,230,000

Mine Year	Dam Lift	Average Flotation Tailings Elevation (FT)	Dam Crest Elevation (FT)	Buttress Height – Cell 2E North Dam (West Segment) (FT)(1) (2)	Buttress Height – Cell 2E North Dam (East Segment) (FT)(1) (2)	Buttress Height – Cell 1E South Dam (FT)	Approximate Buttresses Total Material (CY)
Cell 1/2E (merged 1E and 2E; adding South Buttress)							
7	Lift 5	1658.0	1682	88.0	58.0	20.0	3,560,000
8		1666.0					
9		1674.0					
10		1678.5					
11	Lift 6	1683.5	1702	88.0	58.0	20.0	3,560,000
12		1688.5					
13		1693.0					
14		1697.5					
15	Lift 7	1702.5	1722	88.0	58.0	20.0	3,560,000
16		1707.0					
17		1712.0					
18		1716.5					
19	Lift 8	1720.0	1732	88.0	58.0	20.0	3,560,000
20		1724.0					3,560,000

(1) Mine Year for initiation of Cell 2E North Dam Buttress will be adjusted if beneficial for integration of buttress construction and seepage containment construction activities.
(2) Buttress heights shown are total height typical at cross-section location noted. Buttress height elsewhere varies as ground surface elevation varies.

2.3 Flotation Tailings Transport and Deposition

Flotation Tailings will be pumped to the FTB in slurry form through a system of pumps and pipes. The slurry will have in the range of 28 to 32% solids by weight. Tailings will move through pipes from Scavenger Flotation Sump Pumps to the Booster Pumphouse to the discharge point. Portable booster pumphouses can be added as needed. Ultimately, the design of this system must be integrated with FTB dam design to define discharge locations and system head. Pipeline alignment and diffuser details are presented in Drawings FTB-019 through FTB-023. The pumping system design will determine pipe diameter and Booster Pump locations.

Movable pipelines will facilitate effective placement of tailings. The system can be configured to deposit tailings by gravity flow over beaches or subaqueously in the pond. Tailings deposition in the pond will be from the Tailings Disposal Diffuser Raft through a submerged diffuser. Drawing FTB-023 shows plans for the diffuser raft system. The diffuser is designed to spread slurry across the bottom of the ponds without mixing with the pond water. The diffuser provides a decreased slurry discharge velocity and reduced turbulence at the point of discharge to minimize particle size segregation during deposition.

Spigot points will be chosen to uniformly distribute and effectively deposit the Flotation Tailings in all parts of the cell, minimize pond volumes, and minimize active beach areas while maintaining adequate beach for slope stability of the dams. The minimum beach width to maintain dam stability is 625 feet. Roughly 30% of the tailings will be deposited on the beaches and 70% will be deposited subaqueously in the FTB Pond. This percentage split will vary over time as the proper balance is maintained between beach deposition to build foundation for future dam raises, and subaqueous deposition to fully utilize tailings disposal capacity in the pond area of the FTB. Spigot points will also be adjusted as needed to accommodate winter conditions (Section 4.2).

For approximately the first seven years of operation, the Flotation Tailings will be spigotted into Cell 2E. Drawing FTB-019 shows the preliminary tailings transport pipe alignment for Cell 2E. The spigot location will be established as necessary to uniformly deposit tailings along the dams and within the cell to facilitate tailings disposal and develop the tailings beaches. Once the tailings in Cell 2E reach Elevation 1658 AMSL, which is approximately the same elevation as Cell 1E, then Cells 1E and 2E will be merged to form a single cell (Cell 1/2E). Drawing FTB-020 shows the preliminary discharge pipe alignment for Cell 1/2E. After Mine Year 7, tailings will be placed alternately along the dams in Cells 1E and 2E.

A Return Water System will be constructed to recycle water from the FTB for use as process water (Drawings FTB-019, FTB-020, and FTB-022). The Return Water System consists of a Return Water Barge in Cell 1E, the associated piping from the Return Water Barge to the Beneficiation Plant, the Transfer Pump Raft in Cell 2E, and the associated piping for water transfer from the Transfer Pump Raft into Cell 1E. The Transfer Pump Raft and associated piping will not be needed once the cells merge to form Cell 1/2E. The Return Water Barge will remain at its location in Cell 1E, which will ultimately become the merged Cell 1/2E. As the dams are raised, the process-water return pipeline will be moved to maintain the pipeline at or near the surface of the dam. Return water pipes will be fitted with a relief drain valve to allow for water to be drained back to ponds in case of shutdown during winter operations to avoid any damage to the pipes due to freezing or suction. Pumps will be fitted with deicing mechanisms to avoid freezing.

2.4 Seepage Capture Systems

The FTB design includes seepage capture systems (the FTB Containment System and the FTB South Seepage Management System) as described in Sections 2.1.3 and 2.1.4 of Reference (2).

2.5 Stormwater Management and Emergency Overflow Provisions

The tributary area to the FTB is well understood and relatively small. The tributary area is bounded by the system of FTB dams, the high ground area to the east of Cell 2E, the high ground area to the southeast of Cell 1E, and the perimeter dams of Cell 2W. Stormwater falling on Cell 2W infiltrates and is collected by the FTB Containment System.

Precipitation falling inside the FTB dams will flow to the FTB Pond and form part of the make-up water for the Beneficiation Plant. Precipitation falling on the dams will mainly infiltrate through the tailings material that forms the dams and/or runoff as clean surface water runoff. Based on past experience at the facility, stormwater runoff is not expected to cause significant erosion of the dams. Vegetation will be established on dams during construction to minimize erosion and fugitive dust. Areas where erosion of the dams does occur will be corrected and re-vegetated. If areas of excess or repetitive erosion emerge, more robust erosion control measures such as riprap, channels, and/or outfall structures can be designed for those locations

As Flotation Tailings are deposited in Cell 1E and the perimeter dams are raised, current stormwater runoff from lands east of Cell 1E will be blocked. A drainage swale has been designed as part of FTB development to redirect these waters around the FTB as shown in Drawings FTB-004, FTB-011, and FTB-012. This drainage swale will be constructed in Pre-Operation Construction Phase.

FTB overflow will be prevented by pumping any excess FTB pond water to the WWTS (Section 4.2 of Reference (5)). The WWTS will be maintained operable through reclamation and postclosure maintenance until it is demonstrated that water in the FTP Pond is stormwater and that it complies with applicable standards (i.e., pond water could be allowed to overflow) or DNR releases PolyMet from mechanical water treatment requirements under the Permit to Mine (Section 6.5 of Reference (5)) (i.e., non-mechanical treatment can successfully treat excess FTB pond water). Operation of the WWTS during postclosure maintenance is discussed in Section 4.2 of Reference (5).

An emergency overflow for the FTB during operations is provided for protection of the dams in the rare event that freeboard within the FTB is not sufficient to contain all stormwater. Such instances have the potential to occur in the event of a PMP rainfall event or some fraction thereof. However, as described in Section 2.2.3, PMP rainfall events are rare and such an event has a low likelihood of being experienced during the life of the basin. None-the-less, it is standard practice in dam design to accommodate overflows in a manner that protects the integrity of the dams. The location of the operations-phase emergency overflow is presented on Drawing FTB-008 and the incremental development of the operations-phase emergency overflow is presented on Drawings FTB-015 through FTB-018.

During reclamation, the FTB Closure Overflow (Drawing FTB-024) will be constructed (Section 2.5). It is expected that this structure will be modified to serve as a stormwater overflow or non-mechanical treatment system discharge as discussed above. Because there is a net positive water balance in the region, it is anticipated that in postclosure maintenance there will be occasional overflow (stormwater or non-mechanical treatment discharge) via the Closure Overflow outlet to the adjacent wetlands if operation of the WWTS is discontinued.

3.0 Dam Design Outcomes

3.1 Stability of FTB Dams

The design of the FTB dams is based on seepage and slope stability analyses of:

- the Tailings Basin
- FTB dams at maximum height
- FTB dams during construction
- FTB dams subject to various potential liquefaction triggering events
- a flow liquefaction worst case scenario
- FTB dams during postclosure maintenance

Data used in these analyses, the methods used for seepage and stability modeling, the approach for selection of material strength design parameters, and modeling outcomes for the design cross-sections F, G, and N, located through the west-central and east segments of the North Dam of Cell 2E and the west-central segment of the Cell 1E South Dam, respectively, are presented in Appendix B of this application. In summary, development of the proposed FTB design involved an iterative approach whereby various combinations of slope angle, lift height, bench width, high permeability underdrains (foundation layers), and buttresses were modeled to determine the preliminary FTB dam design.

Of particular importance for FTB dam design is the stability of the dam under undrained conditions. The stability models evaluated a range of potential operating conditions. Circular and wedge failure conditions were analyzed. The results of the analysis indicate that for undrained conditions the wedge failure condition presents the critical $USSA_{yield}$ failure surface.

For the effective shear strength analysis (ESSA) case the stability models again analyzed circular and wedge failure conditions. The results of the analysis indicate that the circular failure condition presents the critical ESSA failure surface.

The proposed dam at Cross-Section F has been configured to have a factor of safety equal to or greater than 1.3 for $USSA_{yield}$ conditions and equal to or greater than 1.5 for ESSA conditions. The FTB dams have also been designed to have an overall factor of safety equal to or greater than 1.1 against liquefaction triggering and equal to or greater than 1.1 for the worst-case fully liquefied ($USSA_{liq}$) baseline case (at end of operations). Except for the normal bench requirements, the design does not require an initial setback from the crest of the existing dam. To achieve stability required for the $USSA_{yield}$ condition, a toe-of-dam buttress, underdrain, and mid-slope setback were all incorporated into the dam design; all common design features used for modifying dam stability.

Factor of safety values for Cross-Sections F, G, and N are presented in Appendix B of this application for the ultimate height of the dam (Mine Year 20) and summarized in Table 3-1. The factor of safety for the critical failure surface for Cross-Section F, identified by the wedge and circular failure analysis, is greater than the minimum factor of safety required by the DNR. Factor of safety values for the ESSA and $USSA_{yield}$ conditions are both well above the recommended minimums.

The stability analysis also considered the effects of the Probable Maximum Precipitation (PMP) event. The seepage modeling utilized PMP conditions, Lift 8 dam height, and a pre-PMP beach width of 625 feet, whereby the pond level bounced 4 feet in elevation and remained high long enough for steady-state conditions to apply. Slope stability safety factors for the ESSA and $USSA_{yield}$ strength conditions for normal pool elevation and PMP conditions are compared in Table 3-1.

Table 3-1 Modeled Factors of Safety for Proposed Final Lift Conditions with and without PMP (Cross-Sections F, G, and N)

Case	Slip Surface	$USSA_{yield}$			ESSA		
Required Factor of Safety		$\geq$ 1.3			$\geq$ 1.5		
Cross-Sections Analyzed		F	G	N	F	G	N
Lift 8 at Normal Pool	Circular	1.98	2.42	2.02	3.76	3.30	4.60
	Wedge	1.84	1.86	2.00	3.72	3.29	4.58
Lift 8 w/PMP Event	Circular	1.97	2.43	1.92	3.76	3.29	4.38
	Wedge	1.82	1.86	1.91	3.67	3.29	4.34

FTB dam design includes analysis of the stability of the dam during construction and operation when undrained conditions may develop. Modeling of several of the interim lifts of Cross-Sections F, G, and N was performed for both drained and undrained conditions to assess the change in slope stability over time. Table 3-2 presents the results for Lifts 2, 4, and 6 for ESSA and $USSA_{yield}$ conditions.

Table 3-2 Modeled Factors of Safety for Interim Lifts (Cross-Sections F, G, and N)

Case	Pond Elevation (feet AMSL)	Slip Surface	$USSA_{yield}$			ESSA		
Required Factor of Safety			$\geq$ 1.3			$\geq$ 1.5		
Cross-Sections Analyzed			F	G	N	F	G	N
Lift 2	1620	Circular	2.60	3.26	N/A	3.82	3.30	N/A
		Wedge	2.26	2.29	N/A	3.72	3.30	N/A
Lift 4	1660	Circular	2.22	2.85	N/A	3.75	3.30	N/A
		Wedge	1.96	1.98	N/A	3.72	3.29	N/A
Lift 6	1700	Circular	2.05	2.53	2.21	3.76	3.29	4.48
		Wedge	1.97	1.96	1.88	3.73	3.29	4.43

The factors of safety reported for Lifts 2, 4, and 6 in Table 3-2 are similar to those computed for the final lift conditions (Table 3-1). This is because the interim lift models assume that a portion or the entirety of the buttress has been constructed.

Stability against static and seismic liquefaction triggering was evaluated. Liquefaction was not triggered statically in any of the five cases specified by the work plan, as detailed in Section 7.2.4 of Appendix B of this application and summarized in Table 3-3. Factors of safety for all scenarios are above the required value of 1.1. Results of the seismic liquefaction screening evaluation (Section 6.5.3 of Appendix B of this application) indicate that seismic triggering will not occur.

Table 3-3 Modeled Factors of Safety for Liquefaction Triggering Analyses (Cross-Section F)

Liquefaction Triggering Scenario	Slope Stability $FOS_{overall}$	Slope Stability Average $FOS_{triggering}$ for Liquefaction Susceptible Slices
Required Factor of Safety	**$\geq$ 1.1**	**$\geq$ 1.1**
Baseline	2.13	2.13
Rapid Loading - fast construction of Lift 1	1.78	1.90
Erosion - Local erosion/pipe scour	1.07	--
Plugged Drain Lift 1	1.91	1.91
Plugged Drain Lift 8	2.12	2.12

(1) Simplified analysis approach used in Geotechnical Data Package – Vol. 1 – Ver. 8; detailed analysis approach yields FOS >1.10 (nearly 2.0).

Stability analysis for a worst-case flow liquefaction event based on an unknown trigger was also evaluated. The DNR has requested that the safety factor for this condition be equal to or greater than 1.1. The results for this worst-case condition show that estimated slope stability safety factors are equal to or above the required value (Table 3-4). The modeled value for Cross-Section F is equal to 1.1 because the dams are configured on the basis of this worst-case scenario. Other slope stability conditions are much more likely; hence the dams typically have a relatively high safety factor in comparison to safety factor requirements.

Table 3-4 Modeled Factors of Safety for Worst-Case Flow Liquefaction ($USSA_{liq}$) Conditions (Cross-Section F)

Case	Slip Surface	Slope Stability $FOS_{overall}$		
Required Factor of Safety		**$\geq$ 1.1**		
Cross-Sections Analyzed		**Section F**	**Section G**	**Section N**
All Saturated Contractive Materials Liquefied to $USSA_{liq}$	Circular	1.26	1.36	1.16
	Wedge	1.10	1.10	1.16

Stability analysis of the FTB during postclosure maintenance conditions shows that estimated slope stability safety factors are well above the required values (Table 3-5).

Table 3-5 Modeled Factors of Safety for Long-Term (ESSA) Closure Conditions (Cross-Section F)

Case		Section F $FOS_{Overall}$
	Required Factor of Safety	**$\geq$ 1.5**
Postclosure Maintenance Conditions	End-of-Operations	3.72
	20 years after end of operations	3.86
	200 years after end of operations	3.86
	2,000 years after end of operations–	3.87

Worst-case flow liquefaction was also evaluated for conditions at 20, 200, and 2,000 years after the end of operations. The results of the fully liquefied long-term scenarios are detailed in Section 7.3 of Appendix B of this application, and summarized in Table 3-6.

Table 3-6 Modeled Factors of Safety for Long-Term Fully Liquefied ($USSA_{liq}$) Closure Conditions (Cross-Section F)

Case		Section F $FOS_{overall}$
	Required Factor of Safety	**$\geq$ 1.10**
Long-Term Fully Liquefied Conditions	End-of-Operations	1.10
	20 years after end of operations	1.35
	200 years after end of operations	1.45
	2,000 years after end of operations	1.53

As additional data are gathered in future design- and operations-phase geotechnical investigations and material testing programs, the design strength and hydraulic conductivity parameters used in modeling may be altered to reflect the additional information. As most values selected for these seepage and slope stability analyses were chosen to be reasonably conservative, it is possible that future evaluation of the FTB may lead to an increase in factor of safety values and/or design optimization, reducing the need for buttresses, underdrains, and/or offsets.

3.2 Flotation Tailings Deposition Testing

The University of Minnesota's St. Anthony Falls Laboratory (SAFL) was contracted to perform a series of physical laboratory model studies related to Flotation Tailings delta formation (Attachment B). PolyMet supplied Flotation Tailings produced during the pilot-plant processing of Project ore samples for use in the SAFL models. These studies provided information to the FTB dam design process on likely depositional processes, beach slope, and grain size sorting within the FTB.

Phase I of the project involved 1D flume experiments, at field scales, to evaluate the potential for debris flow behavior and channelization and to develop an initial beach slope estimation matrix. Phase II of the project produced a laboratory scale delta in SAFL's delta basin. The delta experiments were designed such that the laboratory scale delta would have a similar degree of channelization as the field scale delta. Phase II also looked at the range of fines (<74 micron) retention in experiments designed to generate tailings deposits that yield the lower limit of fines concentration within the tailings deposit as a means of better understanding likely saturation conditions of the deposited tailings.

Phase I experiments indicated that the delta will be produced from fluvial-braid processes and channelized rather than from debris flow-type behavior. Phase I also indicated that, within the expected range of slurry discharges, the beach slope will likely range from 0.5% and 2%.

Phase II of the project focused on 2D basin experiments to evaluate grain size sorting, heterogeneity, and hydraulic conductivity in the deposit. A 5 meter by 5 meter by 0.4 meter deep research basin located at SAFL was used for the tests. The degree of fines retention within the delta was measured from surface scrape samples taken from the beach at various times during basin operation. Scrape samples were analyzed for coarse/fine fraction by washing the samples through a 74 micron sieve. The degree of channel-lens formation in the deposit was investigated on two cross-sectional freeze slices taken from the deposit. The Phase II results showed clear visual indication of sorting. Grain size sorting was present in the form of downstream fining (particle size segregation toward smaller grain size along the flow) and coarse/fine lenses (internal structures formed by filling abandoned flow channels with sediment). However, the results of Phase II demonstrate that the field scale deltas will likely exhibit significant heterogeneity related to channelization and that the field delta should have a minimum of 30% (by weight) fines retention throughout. Hydraulic conductivity measurements made on the laboratory deposits showed a decrease in conductivity with distance from the slurry source, suggesting that water transport through the delta will likely be greater at the upstream end than at the downstream end.

The degree of water retention in the field scale deposit could not be estimated conclusively. The estimated deposit thickness and the Soil-Water Characteristic Curve for the tailings (Reference (2)) suggests that suction (the tailings ability to wick water) will not be great enough to keep the deposit saturated; however, internal structures such as lenses, grain size discontinuities, or micropore structure developed from natural deposition may increase the suction pressure of the material and decrease hydraulic conductivity.

3.3 Dam Break Analysis

The FTB dams have been designed to achieve necessary factors of safety (Section 3.1), so a dam break is unlikely. The purpose of dam break analysis is to provide information to facilitate effective response in the unlikely event that a dam break occurred. A dam break analysis consists of hydraulic and hydrologic modeling to determine the area potentially impacted by a hypothetical dam break coinciding with a 72-hour PMP event. A dam break analysis was performed for the FTB and results are presented in Attachment H. Results of the dam break analysis are used in the Contingency Action Plan (Section 5.9 of Attachment F).

The scenario selected for the FTB dam break analysis was a piping-initiated dam failure on the North Dam of Cell 2E. Hydraulic modeling considered the runoff from a 72-hour PMP storm event, with and without a dam break to evaluate the potential flood impacts downstream of the assumed dam break location. The complexity of dam break analysis requires many simplifications, so modeling inputs are chosen to be conservative by setting each parameter in the range that could cause more severe impacts.

The analysis shows that, relative to flood elevations predicted to result from a 72-hour PMP storm event, a dam break increases flood elevations approximately 15 feet at the upstream end of Trimble Creek (near the FTB) and approximately 9 feet at the downstream end of Trimble Creek (at the Embarrass River). Average flood flow velocities range from 10 feet-per-second (fps) to 25 fps in the main channel, but are reduced to 2 fps to 10 fps along the overbanks.

Figure 3 of Attachment H shows the estimated inundation areas and breakout paths along Trimble Creek for the 72-hour PMP event, with and without a Cell 2E dam break. There are 34 homes that could be affected by an FTB dam break. Due to the conservative assumptions made about the percentage of Flotation Tailings that would be released from the FTB, the assumed lack of Flotation Tailings deposition downstream of the FTB as the simulated flood progresses, and the flow properties of the flood wave (modeled as equal to water), it is likely that many of these homes would actually be outside of the lateral and/or vertical extent of the inundation area were more realistic modeling feasible.

The time to first arrival of flood flows at the nearest residence would be on the order of 60 minutes or greater (Figure 3 of Attachment H). Time to peak flows is greater as shown on Figure 3.

While the complexity of dam break analysis requires that conservative modeling assumptions be made for simplicity, the model outcomes remain a useful guide for understanding the areas potentially impacted in the unlikely event of a dam break as modeled for the north side of Cell 2E.

4.0 Operational Plan

Flotation Tailings deposition will commence when the Beneficiation Plant begins operation in Mine Year 1. Figure 4-1 shows the overall timeline for FTB construction and operation. The following paragraphs describe the FTB operation.

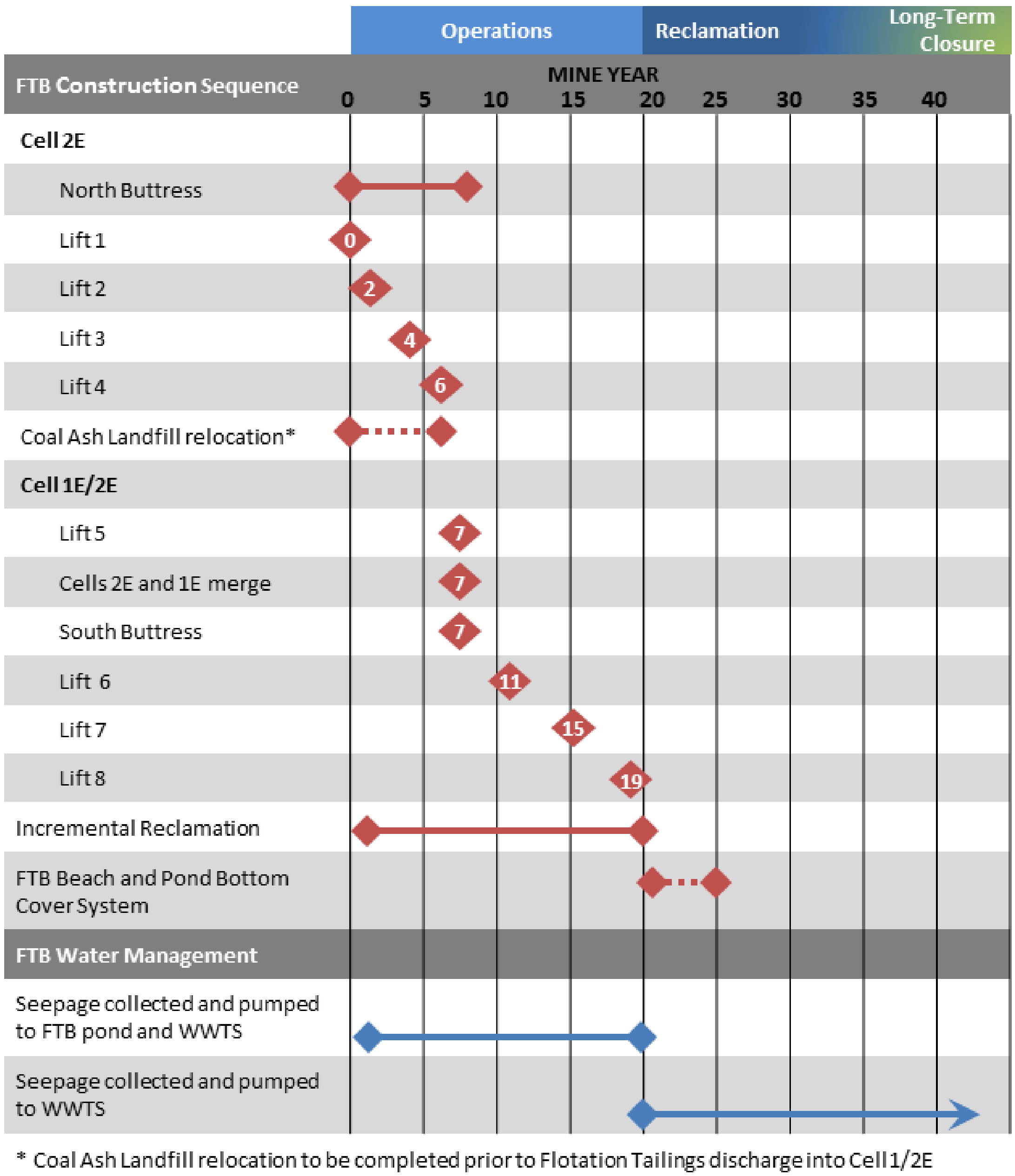

Figure 4-1 FTB Construction and Operation Timeline

4.1 Beneficiation Plant

The Beneficiation Plant has been designed to minimize the sulfur content of the Flotation Tailings by maximizing the recovery of sulfide minerals (which contain the metals of economic interest and sulfur) from the ground ore stream and directing the recovered minerals to the nickel and copper concentrate streams rather than the Flotation Tailings stream. All spillage will be returned to the process stream from which it spilled.

The chemistry of process streams will be continuously monitored by automated online analyzers. These analyzers cannot directly measure sulfur but sulfur content is related to the measurable content of metals. Automated samplers will collect a daily composite sample from various process streams, including the Flotation Tailings stream. This composite will be analyzed in a lab for metals and sulfur. The lab analysis will be used to calibrate the online analyzers.

The performance of the flotation circuit can be controlled by the amount of reagents added at various stages of the flotation process. Process control procedures will be developed and implemented. These procedures will include control of sulfur content of Flotation Tailings as an objective.

4.2 Transport and Deposition Plan

Flotation Tailings spigot points will be moved as needed to minimize grain size segregation and effectively place the tailings in all parts of the cell. When the deposited tailings have reached the desired elevation the dam will be raised using the LTVSMC coarse tailings. LTVSMC tailings beaches will underlie the FTB dam along the northern and northeastern dams of Cell 2E and the southern and eastern dams of Cell 1E. The underlying layer of LTVSMC coarse tailings will have a suitable strength as a foundation for FTB dam raises, and have a sufficient hydraulic conductivity to minimize the increase in phreatic water levels within the dams.

The area of exposed beach will depend on the water level in the cell and the slope of the Flotation Tailings on the beaches. Water level will be managed so that minimum freeboard is not exceeded and the beaches are as narrow as possible to minimize dust liftoff while maintaining the desired separation between pond edge and dam crest to maintain slope stability. Fugitive dust control measures (mulching/crimping, temporary seeding, chemical dust suppressants) will be applied to inactive beaches in accordance with requirements in the Fugitive Emissions Control Plan (Attachment A of Reference (6)).

The transport and deposition plan has been designed to coordinate expected water and tailings inputs with dam raises such that the FTB maintains the water levels that are desired for water quality, and the beach lengths that are desired for dam stability. Stability of the FTB dams is based on maintenance of a 625-foot setback between the inside crest of the dam and the edge of the pond within the FTB. However, as presented in Section 3.1, the FTB dam slope stability factors of safety are adequate even under elevated pond conditions. As shown on Drawing FTB-017, the emergency overflow channel is designed to provide 3.0 feet of freeboard to dam crest in an emergency overflow situation. Additional freeboard will be maintained during operations so the basin has capacity to temporarily store water accumulated from major precipitation events and to accommodate routine seasonal and operational pond level variations without discharging from the emergency overflow channel. This will be accomplished by maintaining pond level below the elevation of the emergency overflow inlet and maintaining the specified beach length. Table 4-1 provides a summary of preliminary pond elevation targets for routine operating conditions. Pond elevation targets will be confirmed as the design of the FTB is finalized during future permitting activities.

Table 4-1 FTB Pond Elevation and Beach Length Targets

Dam Lift	Final Dam Crest Elevation (ft)	Emergency Overflow Inlet Elevation (ft)	Pond Elevation Target at 625' Beach Length (ft) – Preliminary (rounded to nearest 1.0 ft)	Beach Length (ft)
Lift 1	1,602	1,599	1,593	625
Lift 2	1,622	1,619	1,613	625
Lift 3	1,642	1,639	1,633	625
Lift 4	1,662	1,659	1,653	625
Lift 5	1,682	1,679	1,673	625
Lift 6	1,702	1,699	1,693	625
Lift 7	1,722	1,719	1,713	625
Lift 8	1,732	1,729	1,723	625

Note: Pond elevation at 625' beach length based on beach slope of 1.0%. Beach slope to be confirmed during initial FTB operations and elevations adjusted accordingly.

Water level bounce in the FTB as the result of large rain events or rapid snowmelt will generally be less than the PMP bounce, leaving ample freeboard in the basin, as shown on Table 4-2. If increased water levels shorten beaches to less than the desired length, efforts will be made to reduce water levels as soon as possible in order to restore beach length. Options to reduce the FTB pond water level include routing a larger portion of the water from the FTB seepage capture systems to the WWTS, and reducing make-up water input to the system by drawing a larger portion of the Beneficiation Plant process water from the FTB Pond. Analyses to be performed during detailed design for permitting will be used to establish the time-frame within which water drawdown must occur in order that the phreatic surface within the FTB dams remain within limits of the design. Further, the proposed operations-phase emergency overflow channel will provide a means by which overtopping of the dams will be prevented in the event of rapid pond bounce in response to occurrence of the PMP or some large fraction thereof.

Table 4-2 Estimated Water Level Bounce and Available Post-Bounce Freeboard for Pond Initiating at Elevation Target

	1/3 PMP		2/3 PMP		PMP	
Dam Lift	Bounce (ft)	Post-Bounce Freeboard (ft)	Bounce (ft)	Post-Bounce Freeboard (ft)	Bounce (ft)	Post-Bounce Freeboard (ft)
Lift 1 (Cell 2 E – Mine Year 1)	2.25	7.00	4.25	5.00	6.00	3.25
Lift 4 (Cell 2 E – Mine Year 7)	1.50	7.75	3.25	6.00	4.75	4.50
Lift 4/5 (Cell 1 E – Mine Years 1 through 7)	4.75	4.50	8.00	3.00	10.75	3.00
Lift 8 (Cell 1/2E -Mine Year 20)	1.50	7.75	2.75	6.50	4.00	5.25

Note: Pond bounce and post-bounce freeboard estimates based on 625' beach length and pond at target elevation at initiation of partial or full PMP rainfall event. Emergency overflow to be designed to maintain minimum freeboard to dam crest of 3.0 feet.

During winter operation, Flotation Tailings deposition will remain essentially unchanged. The tailings from the Beneficiation Plant will be moving and discharge water will be approximately 72^{o} F, a high enough temperature to prevent freezing within the pipeline while in operation. As with other tailings basins with spigotted discharges, the warm water at the discharge point melts snow and ice as the water and tailings follow a braided and meandering channel pattern to their ultimate point of deposition. As such, there is not anticipated to be preferential deposition of fine tailings on beaches during winter operations. If frigid conditions (e.g., -30^{o} F) were to occur and tailings deposition issues were to develop, tailings could be directly deposited in the pond via the barge and tremie diffuser system. Because some winter pond freeze-up could occur, making barge and tremie diffuser operations more difficult, bubbler systems may be required to maintain open pond areas in targeted operating areas during extended stretches of frigid conditions. If pumps are shut off, pipes should drain automatically by gravity flow into the FTB, but air release valves or temporary pipe joint separation may be required to facilitate complete drainage.

4.3 General Maintenance

Typical maintenance of the FTB may include:

- snow removal from the dam crest to allow access during winter months
- reconstruction of eroded dam crest, slope or toe

- seeding and mulching to facilitate the growth of vegetation and control of fugitive dust in accordance with requirements in the Fugitive Emissions Control Plan (Attachment A of Reference (6))
- grading of dam crest and replacement of surface material
- maintenance of Return Water System pump and piping
- repair of Flotation Tailings and Return Water pipelines and valves
- repair and/or replacement of damaged instrumentation and monitoring devices

The majority of the non-mechanical maintenance work at the FTB will be carried out on an as-required basis, rather than on a scheduled basis because it is driven by weather events rather than hours of operation. Mechanical components will be incorporated into a planned inspection and maintenance program.

4.4 Water Level Control

The FTB consists of Cells 1E and 2E through Mine Year 7, and combined Cell 1/2E thereafter. Water level within the cells is affected by the inputs and outputs to the cells. The primary inputs and outputs are listed in Table 4-3and can generally be characterized as:

- Steady – during routine plant operations the flow rate is relatively constant.
- Variable – during routine plant operations the flow rate is variable; flow rate may be independent of plant operations.
- Controllable – the flow rate is controllable; operations personal have the capability to maintain, increase, or decrease the flow.
- Uncontrollable – the flow rate is uncontrollable; operations personal have little or no capability to maintain, increase, or decrease the flow.

Operations personnel will track the majority of the inputs and outputs, resulting in a database that allows estimation of the pond level and any proactive actions that may be required to manage pond level within the constraints of facility operating permits. For example, operations personnel will be able to estimate the affect that several inches of precipitation will have on pond level and can adjust the inputs and outputs over which they have control in order to maintain desired pond level.

Table 4-3 Tailings Basin Ponds – Primary Inputs and Outputs

Input	Steady	Variable	Controllable	Uncontrollable
Flotation Tailings	X		X	
Raw Water Makeup		X	X	
Precipitation		X		X
Recovered Seepage	X			X
Output	**Steady**	**Variable**	**Controllable**	**Uncontrollable**
Storage in Tailings Deposit		X		X
Water Return to Plant	X		X	
Storage in Basin Ponds		X	X	
Treated Water Discharge		X	X	
Seepage from Basin	X			X
Evaporation		X		X

As noted in Table 4-3, there are a number of inputs and outputs that are controllable and, because they are also variable, are useful as primary pond level control mechanisms. In addition to gathering data and maintaining a data base on each of the inputs and outputs, automated pond level monitoring is anticipated as a means to routinely/systematically track water levels and to plot water level trends. An ancillary benefit will be to establish alarms at trigger levels that signify a trend above desired water levels and a drop below preferred water levels.

Target water levels will be established and routinely reset based on factors such as:

- Dam safety criteria for beach length and freeboard
- Process water objectives for water clarity
- Process water objectives for water storage and availability

In the event that water levels are trending upward, then raw water makeup can be reduced, water withdrawal and treatment can be increased, tailings/water spigotting into the basin (and corresponding operations) can temporarily be discontinued, or some combination of these actions can be taken. For example, estimated process water discharge rate into the basin is 60 acre-feet per day. Termination of this discharge into the basin while maintaining other outputs from the basin would have a fairly rapid and significant effect on basin water level. Water Treatment System capacity, at 1,900 gpm and greater, can also be used to affect the basin water level (on the order of 10-acre feet per day). In the most extreme case of elevated water levels, reliance would be made on the basin emergency overflow channel to control water level and to prevent overtopping of the tailings basin dams.

5.0 Monitoring

The monitoring program will support proper long-term construction and performance of the FTB. Monitoring activities include construction material sampling, geotechnical instrumentation installation, data collection and review, geotechnical investigations, and systematic dam safety inspections. As FTB operations proceed, the monitoring program will be updated to be current with the ongoing incremental development of the FTB.

5.1 Material Properties Verification

Upon plant start-up, samples of NorthMet flotation tailings, LTVSMC coarse tailings borrow, and buttress material will be collected and tested to verify the strength characteristics used in the geotechnical modeling (Appendix B of this application). Material properties sampling and testing will be on-going during the first year of operation, with bi-yearly sampling after that, to identify trends in variability of the construction materials. Alterations to the dam design may be appropriate if the materials are found to be stronger or weaker than those obtained during previous explorations.

5.2 Geotechnical Instrumentation

Geotechnical monitoring will provide data for dam safety analysis and inspection, and contribute to the overall understanding of the Plant Site water balance. Existing and proposed geotechnical instrumentation will link the observed FTB performance with the seepage, stability, and deformation modeling. Instrumentation is summarized below and described in detail in the Dam Stability Instrumentation and Monitoring Plan (Attachment D).

5.2.1 Piezometers

Existing and proposed piezometers will monitor phreatic surface within the dams. The location of the phreatic surface has a significant impact on slope stability. Piezometer measurements will periodically be compared to phreatic surface location estimated by slope stability and seepage modeling to confirm that the location of the phreatic surface is within acceptable limits. Piezometer readings will be taken twice per year at a minimum, plotted against time, and sent to the *Design Engineer* for review.

5.2.2 Inclinometers

Inclinometers will be installed to monitor the movement of the FTB dams. Actual movement as monitored by the inclinometers will be compared to movement estimated by deformation modeling of the FTB dams. Manual inclinometer readings will be taken twice per year at a minimum, plotted against time, and sent to the *Design Engineer* for review and analysis.

5.2.3 Survey Monitoring Hubs

Survey monitoring hubs will be established to facilitate the monitoring of horizontal and vertical deformation of the FTB dams. The survey monitoring hubs will be surveyed twice per year (minimum). The readings will be recorded on a standard form, plotted against time, and sent to the *Design Engineer* for review and analysis.

5.2.4 Semi Continuous Data Collection

In addition to manual measurement, vibrating wire technology may be utilized to obtain semi-continuous measurements of pore water pressure and slope inclination. Further details can be found in the Instrumentation and Monitoring Plan (Attachment D).

5.3 Monitoring of Other Systems

The procedures for monitoring the chemistry (including sulfur) of Flotation Tailings delivered to the FTB are described in Section 4.1. The following additional monitoring procedures are required for the FTB and associated systems.

5.3.1 Flotation Tailings Transport System

The pipes that carry Flotation Tailings from the Beneficiation Plant to the FTB and associated pipeline connections will be inspected to confirm that the components are in good condition at all times and leaks do not occur. Inspections will be performed on a regular basis (Section 5.5) and if damaged or worn out components are observed or if leaks are detected, the affected parts will be repaired or replaced.

The amounts of tailings and water delivered to the FTB will be recorded (manually or via automated systems) daily.

5.3.2 Pond Level and Beach Length

The pond water levels will be recorded daily (manually or via automated systems) to confirm that water containment within the FTB dams provides sufficient freeboard. Pond level data will then be used to confirm beach length. Insufficient freeboard and beach length will immediately be brought to the attention of the *Operations Contact*. The size of the surface water pond will be monitored for general agreement with the projected operational limits and requirements.

5.3.3 Flotation Tailings Deposition

Stability of the FTB dams is based on maintenance of a 625-foot setback between the inside crest of dam and the edge of the pond within the FTB. As noted in Section 5.3.2, while desired slope stability factors of safety are maintained even if pond bounce causes shorter beaches, maintenance of specified beach length provides an indicator that adequate freeboard exists to manage pond bounce from severe precipitation events. Following commencement of Flotation Tailings deposition, monitoring to confirm maintenance of the required setback will occur on a daily basis, and more frequently in the event of prolonged and/or intense rainfall events that have the potential to cause rapid rise in pond elevation. In addition to daily or more frequent setback observations, the FTB dams and Flotation Tailings deposition profile will be monitored within the first year of operations and then at least once every other year via bathymetric surveying. Further, strength of the deposited Flotation Tailings will be confirmed within the first year of operations and then at least once every other year using cone penetration test (CPT) soundings or standard penetration test (SPT) borings. The updated profiles and Flotation Tailings strength data will be part of the Dam Safety Review and used to update design models and deposition practices as required to maintain FTB stability.

5.3.4 Return Water System

The components of the return water system including pipes, connections, sumps, pumps, barges, rafts, etc. will be inspected on a regular basis (Section 5.5) to confirm that the components are in good condition at all times. Damaged or worn out components will be repaired or replaced.

The amount of water returned to the Beneficiation Plant will be recorded (manually or via automated systems) daily.

5.4 Geotechnical Modeling

Geotechnical explorations (Section 5.1) will provide information on material strengths and seepage conditions as the FTB is developed. Additional modeling will be performed in conjunction with geotechnical exploration updates to verify stability of the proposed dam under the actual conditions observed. Alterations to the construction sequence and/or ultimate dam design will be made as needed in response to the outcomes of these future evaluations.

Similar investigations and modeling analyses will be performed on an on-going basis throughout the construction of the dam to allow for immediate corrections to the design to maintain stability. It is recommended that these investigations take place on a bi-yearly basis. The reoccurrence of the investigations may be re-evaluated after eight years as the rate of dam construction decreases thereafter.

5.5 Weekly/Daily Dam Safety Inspections

Routine dam inspection activities will occur on an ongoing basis and will supplement the more detailed Dam Safety Inspections (DSIs). The purpose of weekly/daily dam inspection is to observe the conditions and performance of the FTB dams and associated facilities so that any changes to dam conditions or performance can be identified and any potentially hazardous conditions can be promptly addressed. The *Operations Contact* will confirm that dam inspections are conducted per the guidance provided in this document.

Dam inspection will primarily involve routine and event driven observations of the dam and associated facilities. When documenting dam inspections, a standard form (Attachment E) will be used. Digital images will be taken from a reference location for conditions that may vary with time (e.g., increased seepage or deformation of the dam structure, or progressive erosion). A GPS-linked camera shall be used for other photos so that photo location and viewing direction are automatically recorded with each photo taken.

Observations of suspected irregularities of the dam structure will be immediately reported to the *Operations Contact* and *Design Engineer*. Additional reporting will be performed as required by facility permits.

Observations to be made during the daily dam inspections will include:

- piping (tailings transport, return water, seepage capture) system integrity
- possible evidence of subsidence or sinkholes in the dams
- confirmation that no physical damage has occurred to the FTB as a result of factors such as weather, vandalism, or malfunction of components

Observations to be made during the weekly inspections will include:

- the daily observations listed above
- evidence of dam structure deformation (e.g., slope bulging or crest settlement)
- evidence of unexpected seepage
- uncontrolled overland runoff and erosion
- possible evidence of piping/subsurface erosion downstream of the dam
- any/other unusual conditions in the dam area

Dam inspections will occur at least weekly and the *Design Engineer* will accompany the *Operations Contact* during a formal dam inspection at a minimum of twice per year. All dam inspection reports will be reviewed by the *Operations Contact*, circulated to management personnel as appropriate, and filed.

5.6 Semi-Annual Dam Safety Inspections

The purpose of a Dam Safety Inspection (DSI) is to evaluate, on a regular basis, the current and past performance of the FTB dams and to observe potential deficiencies in their condition, performance, and/or operation. DSIs will consist of detailed observations made by the *Design Engineer* and an evaluation of information on dam performance, operating and other relevant conditions obtained from routine monitoring.

The *Design Engineer* conducting the DSI must be qualified to conduct dam safety evaluations and be familiar with the designs and other site-specific conditions and requirements pertaining to the dam. It is the responsibility of the *Operations Contact* to confirm that a qualified and experienced *Design Engineer* is retained.

DSIs are initially to be conducted on a semi-annual basis. The *Operations Contact* will accompany the *Design Engineer* for all or part of the DSI. The DSI frequency should be reviewed at the time of each annual Dam Safety Review. A non-routine DSI may be required as a follow up to the reporting of an unusual event or observation.

Each DSI will incorporate a routine review, in addition to direct evaluation of dam safety, of the following:

- the operations and maintenance manual
- the availability at the site of all documents pertaining to dam safety
- change in relevant regulatory requirements since the last DSI

The *Design Engineer* carrying out the DSI will issue a report within six weeks following the DSI. The report will include conclusions and any necessary recommendations in clear and explicit statements. The *Operations Contact* will review each DSI report. The *Operations Contact* will be responsible for preparing and executing an appropriate action plan to confirm that all recommendations made in a DSI report are followed. Copies of the reports will be available at the office of the *Operations Contact* and in the office of the *Design Engineer*.

5.7 Inspections After Unusual Events/Observations

Unusual events/observations must be immediately brought to the attention of the *Operations Contact* who will document the event/observation and immediate action taken, initiate a special inspection and, if necessary, contact the *Design Engineer*. Examples of unusual events/observations that would require attention with respect to dam safety are listed in Table 5-1.

Table 5-1 FTB Unusual Events/Observations That Warrant a Non-Routine Inspection

Event/Observation	Possible Immediate Action
Extreme runoff event.	Inspect the slopes and the crest of the dam looking for areas of concentrated runoff or erosion. Make a note of saturated ground or soft ground conditions at dam slopes and toes. Examine dam slopes for indications of localized slumping/instability. Inspect tailings/reclaim pipeline route. Check water levels in the pond relative to critical levels and continue monitoring until the pond inflows subside. Initiate findings review by Design Engineer.
Rupture of pipeline at dam structure.	Stop the pump. Check for dam erosion. Initiate findings review by Design Engineer.
Significant, relatively rapid erosion (any cause) of dam slope or sudden seepage break-out at dam slope or downstream of dam in form of continuous seepage or boils.	Take actions to divert or eliminate the flow that is causing erosion. In consultation with Design Engineer, place free-draining and filtering buttress material at seep or boil locations. Reduce pond levels to reduce seepage rate until seepage is further evaluated and a solution identified and implemented. Measure size of erosion and/or estimate seepage area and flow Rate. Consult with Design Engineer.
Deformation at dam crest, slope, or toe area, including development of a continually saturated area at ground surface.	Examine dam slopes for indications of localized slumping/instability. Consult with Design Engineer. Review existing monitoring data and install additional instrumentation and collect additional data if required in consultation with Design Engineer. Review seepage and stability modeling and variance from expected modeling outcomes. Implement follow-up actions as recommended by Design Engineer.
Significant change in the piezometer level/levels.	Check piezometer readings again to confirm findings. Initiate findings review by Design Engineer.
Other events/observations.	Consult Operations Contact

5.8 Dam Safety Review

Routine Dam Safety Reviews (DSRs) at the FTB will be carried out every five years after initial operation. This scheduling requirement should be confirmed or revised at the time of each DSI. The principal objective of a DSR is to ascertain that a dam has an adequate margin of safety, based on the current Dam Safety Permit, current engineering practice, and updated operations and design input data. A DSR may also be carried out to address a specific problem. The team conducting a DSR will be qualified (qualified geotechnical engineer registered in the State of Minnesota) to conduct dam safety evaluations and be familiar with the designs and other site-specific conditions and requirements pertaining to operations of the FTB.

A detailed scope of work for each DSR will be defined by the leader of the DSR team prior to conducting the DSR, and be consistent with engineering practice at the time it is conducted. Each DSR will incorporate, in addition to direct evaluation of dam safety, a detailed review of the following:

1. the adequacy of past DSI practice, the DSI recommendations, and their implementation
2. the Operations, Maintenance and Inspection Plan
3. timing for the next regular DSR

Each DSR report will include conclusions and, if necessary, recommendations pertaining to the safety of the dam. As in the case of DSI reports, an action plan will be prepared by the *Operations Contact* to address the DSR recommendations. A copy of each report will be available at the office of the *Operations Contact*.

5.9 Contingency Action Plan

A Contingency Action Plan (CAP) has been prepared (Attachment F) to provide initial guidance to on-site personnel and emergency responders in the case of unplanned occurrences at the FTB. The CAP identifies and specifies initial actions in response to a variety of occurrences representing differing levels of severity and complexity. In most cases initial responses will be followed up with review by the *Design Engineer* to confirm that initial responses are adequate and to identify any further actions that may be required. In severe situations time of response is of the essence and the *Design Engineer* should be notified immediately of the conditions on site so that additional recommendations can be identified and established immediately.

6.0 Reporting and Adaptive Management

6.1 Annual Reporting

The DNR Dam Safety Permit and Permit to Mine will require that annual reports be submitted. The content requirements for those reports will be defined in those permits. The following paragraphs list what is anticipated to be required.

An Annual Dam Safety Report will be submitted to the DNR. It is anticipated to include:

- a summary and analysis of geotechnical monitoring
- a summary of construction completed and associated costs
- a photographic record of FTB conditions
- a summary of DSIs and DSRs conducted during the year
- a summary of all routine inspections that occurred during the past year
- a summary of all unusual events/observations that occurred during the past year
- identification of any planned changes in operations that could impact dam stability

An Annual Permit to Mine Report will be submitted to the DNR. Tailings basin-specific content is anticipated to include:

- sulfur content of Flotation Tailings as a daily average
- the total tons of Flotation Tailings placed in the FTB from the start of operations through the past year and remaining planned capacity
- a map showing where Flotation Tailings were placed and where vegetation was established for dust control or reclamation during the past year
- a map showing where Flotation Tailings are planned to be placed and where vegetation is planned to be established for dust control or reclamation during the coming year
- identification of any planned changes in operations that could impact reclamation
- an update of the Flotation Tailings waste characterization program

Planned changes in operations that could impact reclamation will be reviewed with the DNR Division of Lands and Minerals and DNR Dam Safety.

6.2 Annual Comparison to Slope Stability Models and Model Refinements

Annual reports will include comparison of actual dam stability performance to the performance estimated by the Project dam slope stability modeling for the conditions existing at the time of the report. This comparison will entail:

- summary and review of instrumentation monitoring data, including but not limited to inclinometers and piezometers
- updates to seepage model inputs based on monitoring data review
- updates to slope stability models based on seepage model updates and updates to account for changes in dam geometry since the prior year review
- review and updates to material strength parameters to incorporate geotechnical data gathered, if any, since the prior year review

The Project dam safety modeling developed in Geotechnical Data Package Volume 1 (Appendix B of this application) includes all time periods of the Project. If the annual comparison of the model shows differences that can be logically explained as being caused by modeling assumptions (i.e., material strength parameters) that have been demonstrated to be incorrect, the model will be refined.

The adjusted model will be used to update the Project dam safety estimates. If the update indicates that outcomes will not be acceptable, adaptive management will be initiated as described in Section 6.3.

6.3 Adaptive Management

Adaptive management practices for the FTB are founded on the Observational Method, which provides for FTB design or operation to be modified, if needed, based on operational experience. Tailings characteristics and dam performance monitoring data will routinely be collected and reviewed, and stability models will be updated as new information becomes available. If updated stability models project that the planned or constructed FTB dams may not meet required factors of safety, adaptive management steps will include some or all of the following:

1. Initiate any field or laboratory studies that may be necessary to update material strength parameters.
2. Update stability modeling using as-built dimensions and on-site observations. If factors of safety in updated model do not meet requirements proceed to Step 3

3. Conduct stability modeling to estimate the effects of potential operational changes such as adjusting tailings deposition procedures to modify beach width or modifying the pond elevation to modify phreatic surface conditions within the dam.
4. If operational changes (such as change to slurry density, change to dam lift timing, modified pond operations) can achieve the required factors of safety, implement that change and include it in the updated Flotation Tailings Management Plan.
5. If stability modeling indicates that operational changes cannot achieve the required factors of safety, implement contingency mitigation (Section 6.4) that will restore required factors of safety, and include that contingency mitigation in the updated Flotation Tailings Management Plan.
6. Monitor and model to estimate dam stability effects with new or adjusted engineering control. If issue persists begin Step 1 again.

Adaptive management does not apply to unexpected and potentially hazardous conditions threatening the integrity and performance of the FTB, which are addressed in Attachment F.

6.4 Contingency Mitigation

If monitoring or the refined model estimates show that with operational changes the FTB dams may not meet required factors of safety, mitigations are available. Contingency mitigation does not apply to unexpected and potentially hazardous conditions threatening the integrity and performance of the FTB, which are addressed in the CAP (Attachment F). In general, stability can be modified by:

- modifying buttressing to modify resisting force at the toe of the FTB
- including free-draining underdrain layers or drains to reduce the phreatic surface in the FTB dams
- adjusting the overall slope angle of future lifts to modify driving force at the toe
- adjusting bench widths of future dam lifts
- adjusting future dam lift offsets, and/or
- adjusting future dam lift heights and/or rate of construction

The mitigation measures listed above can be implemented individually or in combinations as needed to achieve the required mitigation outcomes.

7.0 FTB Reclamation and Postclosure Maintenance

Reclamation of the FTB will include measures to control fugitive dust, reduce infiltration of oxygen and water, and manage water flows. Upon completion of ore processing operations (after 20 years of operation), the FTB will be closed in accordance with Minnesota Rules, part 6132.3200. Dam stability will be periodically evaluated after closure by a qualified geotechnical engineer at a frequency and for the duration required by the facility Dam Safety Permit. It is anticipated that the frequency and intensity of these evaluations will decrease over time as vegetation becomes fully established and as it is confirmed that any areas prone to erosion have been fully and permanently remediated.

7.1 Incremental Reclamation

As dams are constructed, exterior slopes will be stabilized and vegetated in accordance with requirements in the Fugitive Emissions Control Plan (Attachment A of Reference (6)). During construction of FTB dams, the exterior face of the dams will be amended with a bentonite layer to limit oxygen infiltration into the Flotation Tailings as indicated on Drawing FTB-024. The bentonite amendment will entail addition of granulated bentonite (approximately 3% by dry weight) to an 18-inch thick layer of the dam construction material, overlain by an additional 30-inch layer of dam construction material. The exterior dam faces will be permanently vegetated by a qualified reclamation contractor according to Minnesota Rules, part 6132.2700 and requirements of the Reclamation Seeding Plan. Template construction specifications are provided as Attachment G. Inactive interior beach areas will be temporarily vegetated as necessary for fugitive dust control.

7.2 Final Reclamation

The FTB final reclamation plan includes strategies to avoid, minimize, and mitigate environmental impacts, including the following measures:

- Upland areas will be mulched and planted with permanent vegetation to control dust in accordance with requirements in the Fugitive Emissions Control Plan (Attachment A of Reference (6)). Vegetation types will be selected to limit root penetration to within the top 24-inches of the Flotation Tailings in order to minimize the potential for root penetration into the underlying bentonite-amended Flotation Tailings layer planned for 30-inches below the Flotation Tailings surface. Fertilizer may be used but care will be taken to minimize carry-over into pond areas, which would encourage algae growth.

- Interior portions will be graded to provide a gently sloping surface that effectively routes stormwater runoff to the interior of the FTB, accommodates future differential settlement of the underlying Flotation Tailings, and maximizes ponding of water in the reclaimed FTB Pond.

- Exposed beach areas will be amended with bentonite to limit oxygen infiltration into the Flotation Tailings. Granulated bentonite (approximately 3% by dry weight) will be added to an 18-inch thick layer of Flotation Tailings, overlain by an additional 30-inch layer of Flotation Tailings (see Drawing FTB-024 and Attachment G). The bentonite will be injected via agricultural equipment such as that commonly used for below-grade manure injection. This will entail pneumatic injection of bentonite through hollow tines of a rake pulled through the tailings, at the desired depth and at the desired rate of bentonite injection. If access proves difficult and/or to facilitate further mixing of the bentonite and tailings, the upper layer of tailings will be peeled back and the equipment produced by Amazone of Germany and distributed by AMS Incorporated of Ogden, IL; that produced by Residue Solutions of Queensland, Australia (i.e., their MudMaster equipment), or similar equipment will be utilized to facilitate bentonite application and thorough mixing. The cover layer of tailings will then be replaced and vegetated in accordance with requirements of the Reclamation Seeding Plan. If necessary, purpose-built equipment will be developed to combine bentonite deployment and mixing, and the adequacy of the approach will be validated during a field test and Quality Assurance/Quality Control testing just prior reclamation.

- The pond bottom will be amended with bentonite as described in Section 5.0 of Reference (5). The bentonite-amended pond bottom will reduce the percolation from the FTB Pond, thereby maintaining a permanent pond that will provide an oxygen barrier above the Flotation Tailings to reduce oxidation and resultant production of chemical constituents. It will also reduce the amount of water collected by the FTB seepage capture systems.

Long-term performance of the bentonite amended dams, beaches and pond bottom can be detrimentally impacted by differential settlement and erosion of the overlying soils. As part of initial postclosure maintenance, annual inspections will include identification of any detrimental effects from differential settlement and erosion. Areas where differential settlement is occurring may require retreatment with bentonite to remediate affected areas. As with liner systems, the bentonite is likely to be an effective barrier to root penetration. However, depth of root penetration will be evaluated once vegetation becomes well established to confirm that most roots are shallower than the depth of the bentonite amendment and/or are spreading laterally rather than vertically once the bentonite amended zone is encountered. Areas where erosion is occurring and exposing the bentonite amended layer will be remediated with additional erosion control measures and/or regrading as needed to prevent further erosion. If erosion does occur into or through the bentonite amended zone, the appropriate segments of the eroded area will be backfilled with a soil-bentonite mix, covered and revegetated.

The 30-inch layer of tailings above the bentonite amended tailings will reduce impacts of evaporation during extended dry periods. Given the depth of the bentonite layer and with the low bentonite content (3% by weight), the potential for desiccation cracking of the bentonite amended tailings should be limited. Because historically on an annual basis precipitation is greater than evapotranspiration at the location of the FTB, sufficient moisture will typically be available to maintain desired pond levels and further limit the potential for desiccation cracking of the bentonite amended tailings.

The overall objectives of bentonite amendment of the FTB dams, beaches, and pond bottom are to:

- limit oxygen infiltration through the FTB dams into the Flotation Tailings
- limit oxygen infiltration through FTB beaches into the Flotation Tailings
- limit oxygen infiltration through the FTB pond area by reducing the average areal percolation through the FTB pond bottom, thereby maintaining a permanent pond that will limit oxygen infiltration into the Flotation Tailings (and also reduce the amount of water collected by the FTB seepage capture systems and requiring treatment)

Template for Pilot/Field-Testing of Bentonite Amendment of Tailings (Attachment I) describes the process by which the bentonite amendment of tailings methods and performance will be evaluated.

Establishment of dense vegetative cover and root mass is among the most effective methods to minimize erosion, so the quality and density of the vegetation will be periodically reviewed after final reclamation construction is complete. Areas where vegetation is not becoming well established will receive additional seeding and/or fertilizer and other amendments in accordance with requirements of the Reclamation Seeding Plan until the vegetation has become well established and self-sustaining.

7.3 Structure Removals

During reclamation of the FTB the following will be removed:

- Tailings Transport Pipeline, Booster Pumphouses and Tailings Disposal Diffuser Raft
- Water Transfer Pipeline and Transfer Pump Raft
- Return Water Barge
- Return Water Pipeline
- 13.8Kv and 4.16Kv power lines
- power substations

In general, removal will be prior to bentonite amendment of the FTB beach and pond areas. However, if components are needed to implement the bentonite amendment, those components will be removed after the bentonite amendment is complete.

Structures needed to pump pond water to the WWTS to prevent overflow will remain in place as long as needed (Section 2.5).

7.4 Overflow Structures

See Section 2.5 for discussion of Overflow Structures for operations, reclamation, and postclosure maintenance.

7.5 Postclosure

Once reclamation is complete, a postclosure period will begin. Postclosure activities for the FTB include dam safety monitoring and FTB maintenance.

Dam safety monitoring tasks described in Section 5.2 (Geotechnical Instrumentation), Section 5.6 (Semi-Annual Dam Safety Inspections), and Section 5.8 (Dam Safety Review) will be continued until the DNR provides adjustment or release from those activities. An Annual Dam Safety Report will be submitted to the DNR. It is anticipated to include a summary and analysis of geotechnical monitoring and a summary of DSIs and DSRs conducted during the year.

Long-Term FTB maintenance tasks will include:

- annual inspection of vegetation on the exterior dam faces and interior beaches, with erosion repaired and vegetation reseeded in accordance with requirements of the Reclamation Seeding Plan as needed until released from these activities by the DNR
- snow removal from the dam crest to allow access during winter months
- reconstruction of eroded dam crest, slope or toe
- mulching for fugitive dust control in accordance with requirements in the Fugitive Emissions Control Plan (Attachment A of Reference (6))
- repair and/or replacement of damaged instrumentation and monitoring devices

Consistent with requirements of Minnesota Rule, part 6115.0390 Termination of Operations and Perpetual Maintenance, the FTB dams and appurtenances will be perpetually maintained so as to maintain their integrity.

7.6 Reclamation Estimates

The following sections provide an overview of the reclamation plan for the Construction Phase and Mine Year 1. For more specific details on reclamation and the associated cost estimates, see the Reclamation Plan and Reclamation Estimates that will be part of the Permit to Mine application.

7.6.1 Construction Phase (end of construction/development)

If closure were to occur at the end of the Construction Phase the activities described in Sections 7.2 to 7.5 would be implemented. No Flotation Tailings will have been deposited in the FTB.

This plan is used to develop the Construction Phase Contingency Reclamation Estimate that will be the basis for financial assurance required by Minnesota Rules, part 6132.1200 required before a Permit to Mine can be granted.

7.6.2 Mine Year 1 (end of first year of operations)

If closure were to occur at the end of Mine Year 1, the activities described in Sections 7.2 to 7.5 would be implemented.

Approximately 11 million tons of Flotation Tailings will have been deposited in the FTB, a portion of Lift 1 will have been constructed, and the dam crest will be at elevation 1590 (± 5) feet. The Transfer Pump Raft and Tailings Disposal Diffuser Raft will be operational. The FTB area requiring bentonite amendment will be approximately 445 acres; consisting of approximately two-thirds to three-quarters of the exposed beaches, with the remainder consisting of pond area. Exterior slope areas will have previously been reclaimed as part of dam construction.

This plan is used to develop the Mine Year 1 Contingency Reclamation Estimate that will be the basis for financial assurance required by Minnesota Rules, part 6132.1200 the first or second calendar year (depending on construction progress) after the issuance of the Permit to Mine. Financial assurance will be required before operations can begin. This plan and estimate will be updated annually to include contingency reclamation for the site conditions representative of the end of the upcoming year of operation.

Revision History

Date	Version	Description
10/31/2011	1	Initial release
12/7/2012	2	Includes Instrumentation and Monitoring Plan and Template Construction Specifications Updates Permit Application Support Drawings Eliminates wetland establishment in FTB Pond during reclamation
04/12/2013	3	Incorporates edits in response to DNR review and comment on Version 2. Adds results of additional stability modeling required by Geotechnical Work Plan Version 3.
11/21/2014	4	Incorporates edits to update slope stability analysis results and to incorporate edits in response to unresolved DNR review comments on Version 3.
03/03/2015	5	Incorporate edits in response to DNR review and comment on Version 4.
07/11/2016	6	Version 6 adds signed PE certification and updated instrumentation and monitoring plan, and inclusion of FTB Dam Failure Notification Flowchart within FTB Contingency Action Plan in response to DNR comment on Version 5.
05/15/2017	7	Version 7 updates Cell 2E buttress information and construction schedule, updates slope stability factor of safety values resulting from buttress modification, adds Attachment I, and provides additional information on tailings basin pond level control.

References

1. **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.

2. **Poly Met Mining Inc.** NorthMet Project Water Management Plan - Plant (v6). May 2017.

3. —. NorthMet Project Geotechnical Data Package Vol 1 - Flotation Tailings Basin (v8). May 2017.

4. —. NorthMet Project Waste Characterization Data Package (v12). February 2015.

5. —. NorthMet Project Adaptive Water Management Plan (v11). May 2017.

6. —. NorthMet Project Air Quality Management Plan - Plant (v7). December 2014.

List of Tables

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Large Tables

Large Table 1 Flotation Tailings Basin Stage Development Summary

Mine Year	Dam Lift	Average FTB Elevation (FT)	Increased FTB Elevation (FT)	Dam Crest Elevation (FT)	Approximate FTB Area at Crest (acres)	Dam Material (CY)	Cumulative Dam Material (CY)	FTB Capacity (CY)	Cumulative FTB Capacity (CY)
Cell 2E									
--	Lift 1	1570.0	0.0	1602	533	2,480,000	2,480,000	21,600,000	21,600,000
1		1585.0	15.0				2,480,000		21,600,000
2	Lift 2	1597.0	12.0	1622	536	1,700,000	4,180,000	16,500,000	38,100,000
3		1609.0	12.0				4,180,000		38,100,000
4	Lift 3	1622.0	13.0	1642	537	1,660,000	5,840,000	16,550,000	54,650,000
5		1633.0	11.0				5,840,000		54,650,000
6	Lift 4	1646.0	13.0	1662	545	1,600,000	7,440,000	16,800,000	71,450,000
7		1658.0	12.0				7,440,000		71,450,000

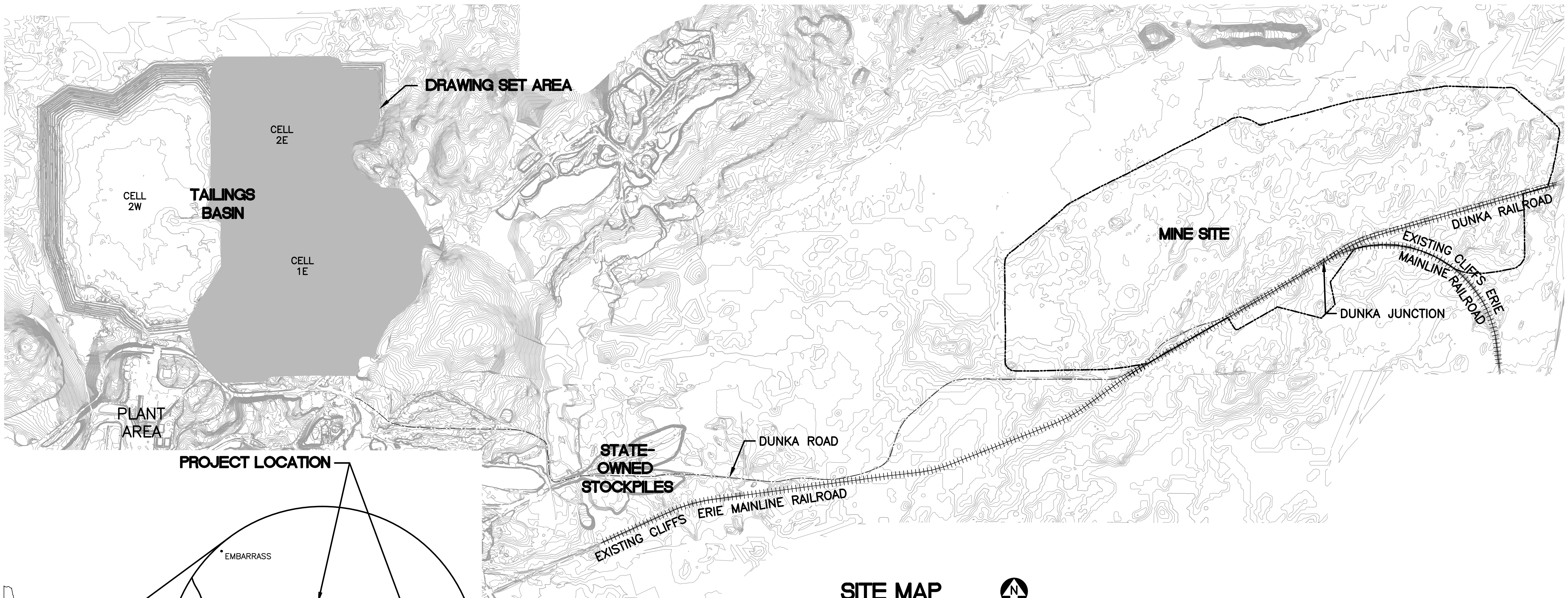
Mine Year	Dam Lift	Average FTB Elevation (FT)	Increased FTB Elevation (FT)	Dam Crest Elevation (FT)	Approximate FTB Area at Crest (acres)	Dam Material (CY)	Cumulative Dam Material (CY)	FTB Capacity (CY)	Cumulative FTB Capacity (CY)
Cell 1/2E (merged 1E and 2E)									
7	Lift 5	1658.0	0.0	1682	1,363	2,420,000	9,860,000	29,590,000	101,040,000
8		1666.0	8.0				9,860,000		101,040,000
9		1674.0	8.0				9,860,000		101,040,000
10		1678.5	4.5				9,860,000		101,040,000
11	Lift 6	1683.5	5.0	1702	1,372	2,990,000	12,846,000	42,045,000	143,075,000
12		1688.5	5.0				12,846,000		143,075,000
13		1693.0	4.5				12,846,000		143,075,000
14		1697.5	4.5				12,846,000		143,075,000
15	Lift 7	1702.5	5.0	1722	1,361	3,570,000	16,411,000	42,564,000	185,639,000
16		1707.0	4.5				16,411,000		185,639,000
17		1712.0	5.0				16,411,000		185,639,000
18		1716.5	4.5				16,411,000		185,639,000
19	Lift 8	1720.0	3.5	1732	1,342	1,720,000	18,126,000	21,600,000	207,239,000
20		1724.0	4.0				18,126,000		207,239,000

Attachments

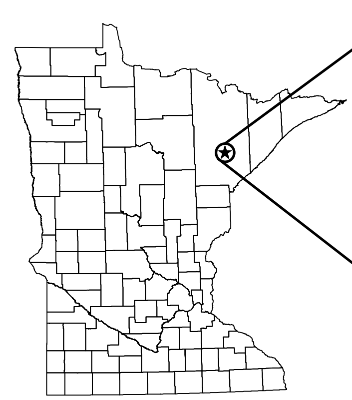
Attachment A

NorthMet Project Flotation Tailings Basin Permit Application Support Drawings

POLY MET MINING, INC. NORTHMET PROJECT
PERMIT APPLICATION SUPPORT DRAWINGS
FLOTATION TAILINGS BASIN
HOYT LAKES, MINNESOTA

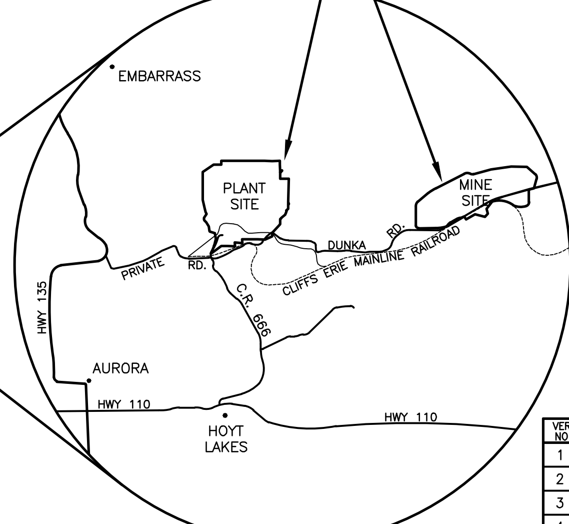


SITE MAP



LOCATION MAP

NOT TO SCALE



VICINITY MAP

NOT TO SCALE

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
5	03/03/15	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 5 – ATTACHMENT A
6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–

NOT APPROVED FOR CONSTRUCTION.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LOCATION MAP AND SITE MAP

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-001

REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-001.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 8:37 AM

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GENERAL LEGEND

- 1000 — EXISTING CONTOUR – MAJOR
- EXISTING CONTOUR – MINOR
- 1000 — PROPOSED CONTOUR – MAJOR
- PROPOSED CONTOUR – MINOR
- EXISTING POWER POLE
- EXISTING RAILROAD
- EXISTING ROAD
- EXISTING TRAIL
- EXISTING STRUCTURES
- TREE LINE
- WETLAND BOUNDARY
- EXISTING CULVERT
- P — EXISTING PIPELINE
- OE — OVERHEAD ELECTRIC
- PROPOSED DAMS
- DW — PROPOSED DEWATERING PIPE
- D — PROPOSED DISCHARGE PIPELINE
- R — PROPOSED RETURN PIPELINE
- PROPOSED CULVERT (NON–MINE WATER)
- PROPOSED BORROW AREA
- PROPOSED ACCESS ROADS
- BUTTRESS

ABBREVIATIONS

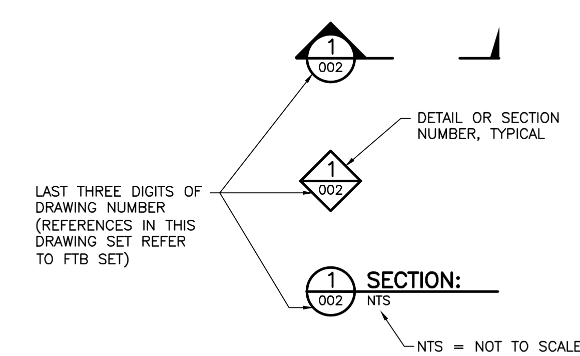
APPROX.	–	APPROXIMATE
CMP	–	CORRUGATED METAL PIPE
CPEP	–	CORRUGATED POLYETHYLENE PIPE
CY	–	CUBIC YARD
DR	–	DIMENSION RATIO
DWG	–	DRAWING
EL.	–	ELEVATION
F	–	DIAMETER
FTB	–	FLOTATION TAILINGS BASIN
GCL	–	GEOSYNTHETIC CLAY LINER
HDPE	–	HIGH DENSITY POLYETHYLENE
HRF	–	HYDROMETALLURGICAL RESIDUE FACILITY
LDPE	–	LOW DENSITY POLYETHYLENE
LF	–	LINEAR FEET
LTVSMC	–	LTV STEEL MINING COMPANY
MCY	–	MILLION CUBIC YARDS
mil	–	ONE THOUSANDTH OF AN INCH
MIN	–	MINIMUM
MSL	–	MEAN SEA LEVEL
NTS	–	NOT TO SCALE
SCH.	–	SCHEDULE
SDR	–	STANDARD DIMENSION RATIO
TYP.	–	TYPICAL

SHEET INDEX

SHEET NO. TITLE

GENERAL DRAWINGS

DRAWING NUMBERING



NOTES

1. COORDINATE SYSTEM IS MINNESOTA STATE PLANE NORTH ZONE, NAD83.
2. ELEVATIONS ARE MEAN SEA LEVEL (MSL), NAVD88.
3. EXISTING TOPOGRAPHIC INFORMATION SHOWN ON THE DRAWINGS WAS PREPARED BY AEROMETRIC, INC. FROM LIDAR DATA COLLECTED ON MARCH 17, 2010.
4. EXISTING TOPOGRAPHIC INFORMATION WAS UPDATED FOR AREAS SOUTH EAST OF COAL ASH LANDFILL AND EAST OF OUTCROP BETWEEN CELLS 1E AND 2E USING CONTOURS FROM DATA COLLECTED IN 1999.
5. FLOTATION TAILINGS BASIN DESIGN WAS BASED ON CONTOURS FROM DATA COLLECTED IN 1999. PROPOSED DAM LAYOUTS MAY NOT EXACTLY MATCH THE EXISTING TOPOGRAPHY FROM 2010 LIDAR.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
5	03/03/15	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 5 – ATTACHMENT A
6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–

NOT APPROVED FOR CONSTRUCTION

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69–0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LEGEND AND SHEET INDEX

POLYMET MINING

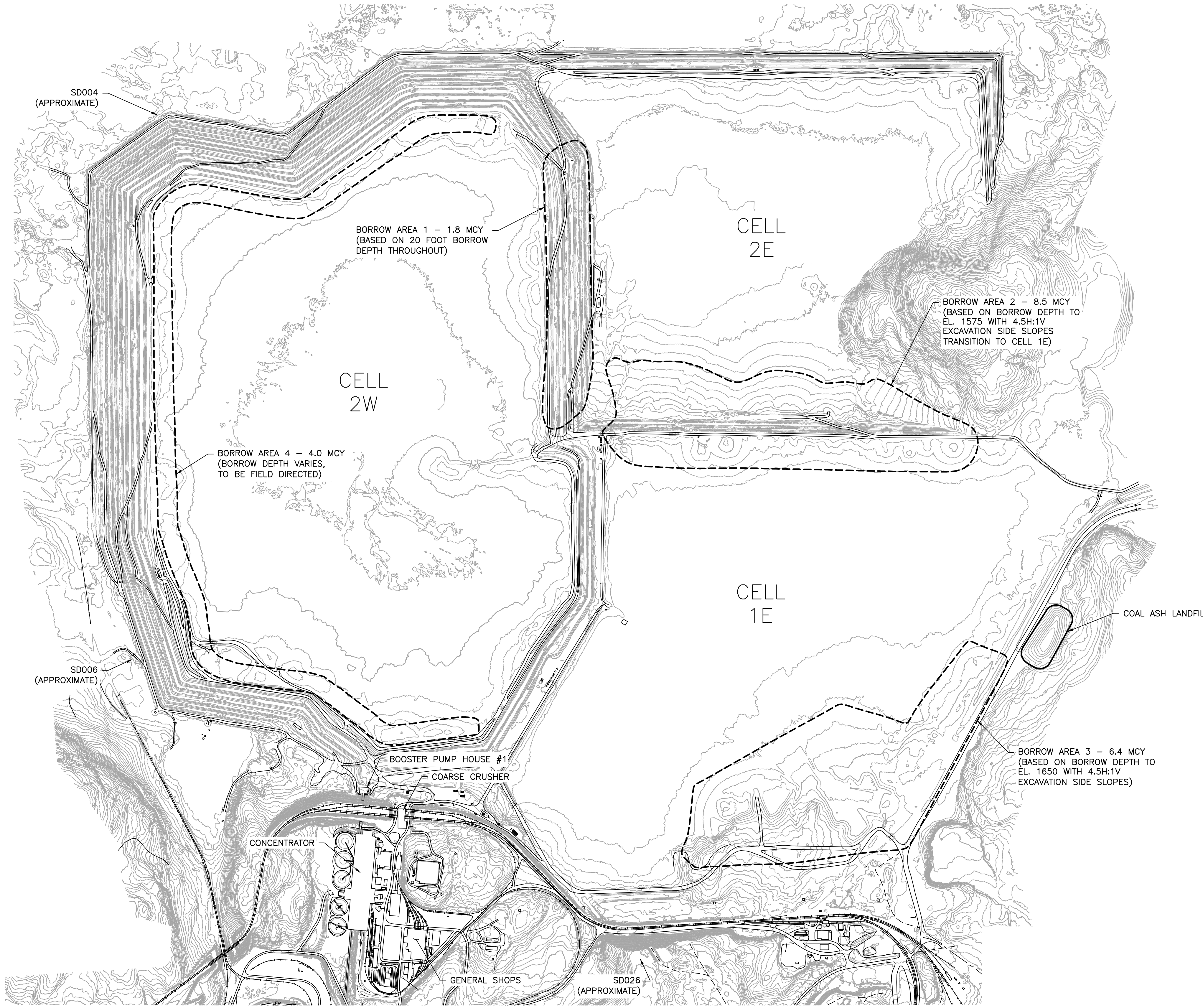
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1–800–632–2277

DWG. NO. FTB–002
REV A

INCHES 1 2



NOTES:

1. CONTOURS DO NOT REFLECT BORROW REMOVAL.
2. THE GENERAL BORROW SEQUENCING WILL BE:
   - AREAS THAT WILL BE INUNDATED BY OPERATIONS
   - AREAS NEAREST THE POINT OF USE
   - REMAINING BORROW AREAS
3. COAL ASH LANDFILL TO BE RELOCATED TO HYDROMET RESIDUE FACILITY OR ALTERNATE PERMITTED FACILITY PRIOR TO TAILINGS DEPOSITION IN CELL 1E.

1 PLAN: EXISTING CONDITIONS

0 800 1600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–
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DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EXISTING CONDITIONS

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING CO.
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DWG. NO. FTB–003
REV A

CADD USER: Cristion A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-003.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 10:04 AM

INCHES 1 2

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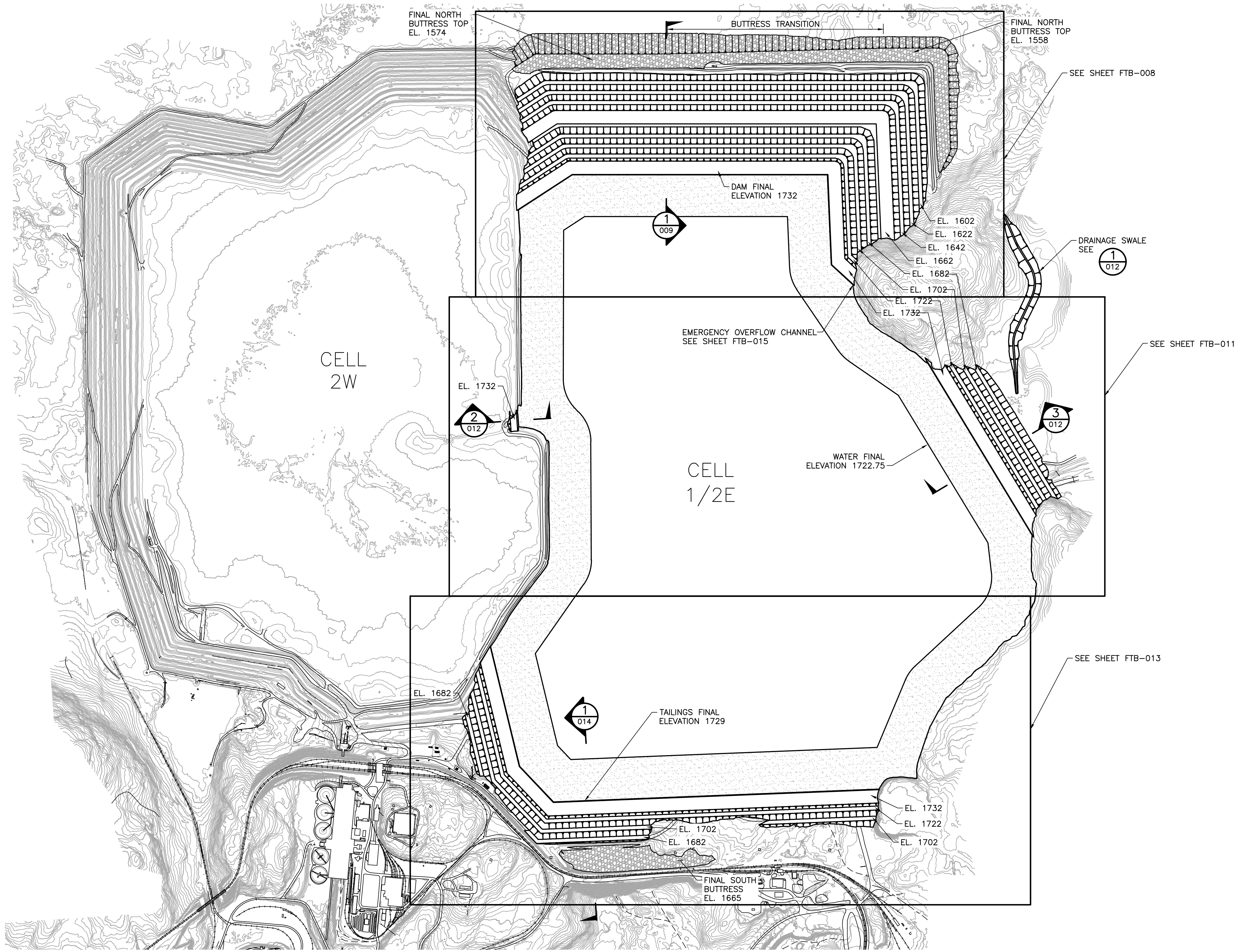

PLAN: FLOTATION TAILINGS BASIN LAYOUT MINE YEAR 20

0 800 1600

SCALE IN FEET

INCHES 1 2

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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DRAWN: CAD

CHECKED: TJR

BARR PROJECT NO.: 23/69-0C29

SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LAYOUT MINE YEAR 20

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
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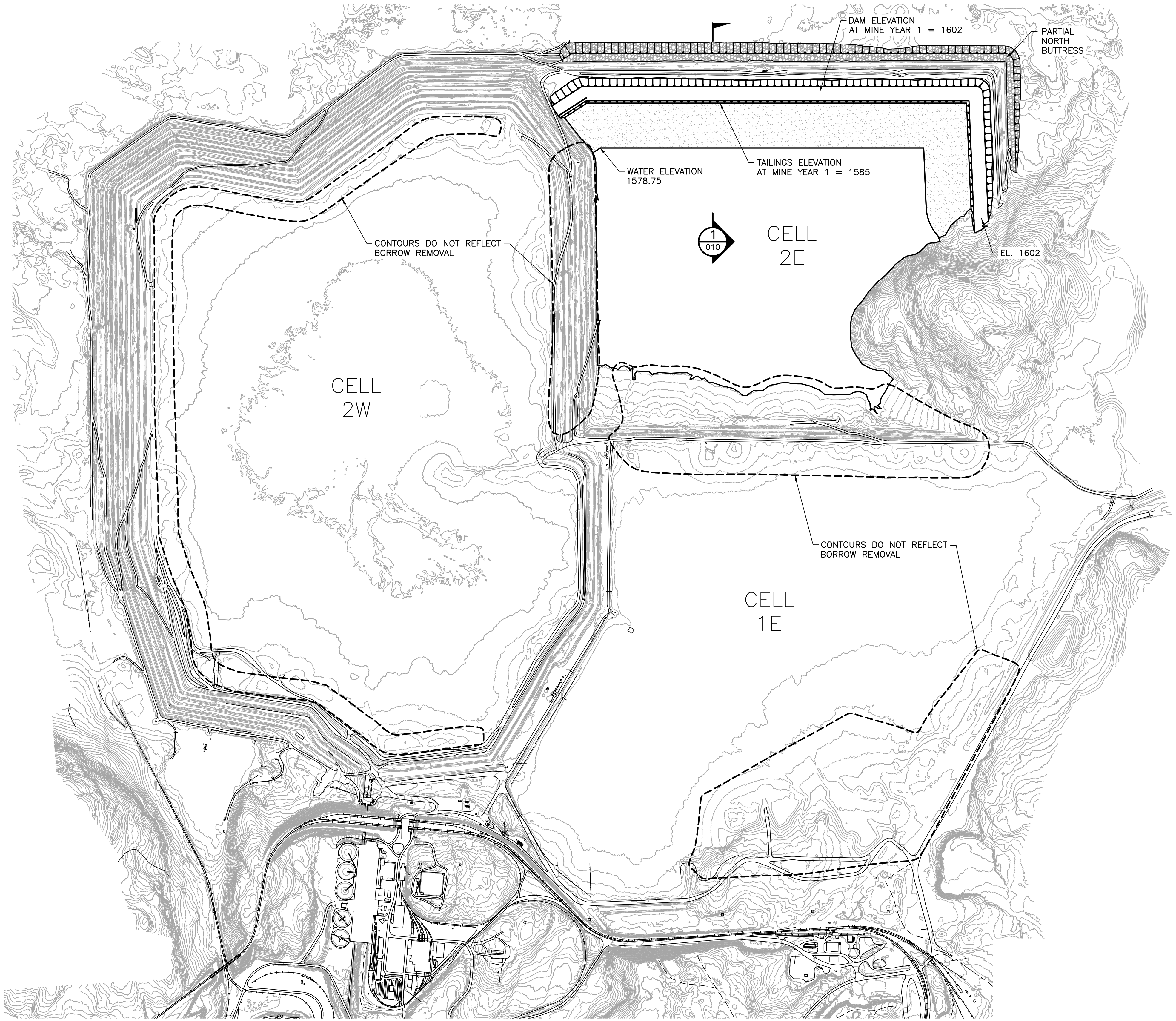
DWG. NO. FTB-004

REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-005.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 8:50 AM



NOTES:

1. SEE SHEET FTB–015 FOR OPERATIONS–PHASE EMERGENCY OVERFLOW CHANNEL.

2. CONSTRUCT NORTH BUTTRESS FOLLOWING THE SCHEDULE AND ELEVATIONS SPECIFIED IN THE FLOTATION TAILINGS MANAGEMENT PLAN.

1 PLAN: FLOTATION TAILINGS BASIN LAYOUT MINE YEAR 1

0 800 1600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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CHECKED: TJR
BARR PROJECT NO.: 23/69–0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LAYOUT MINE YEAR 1

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

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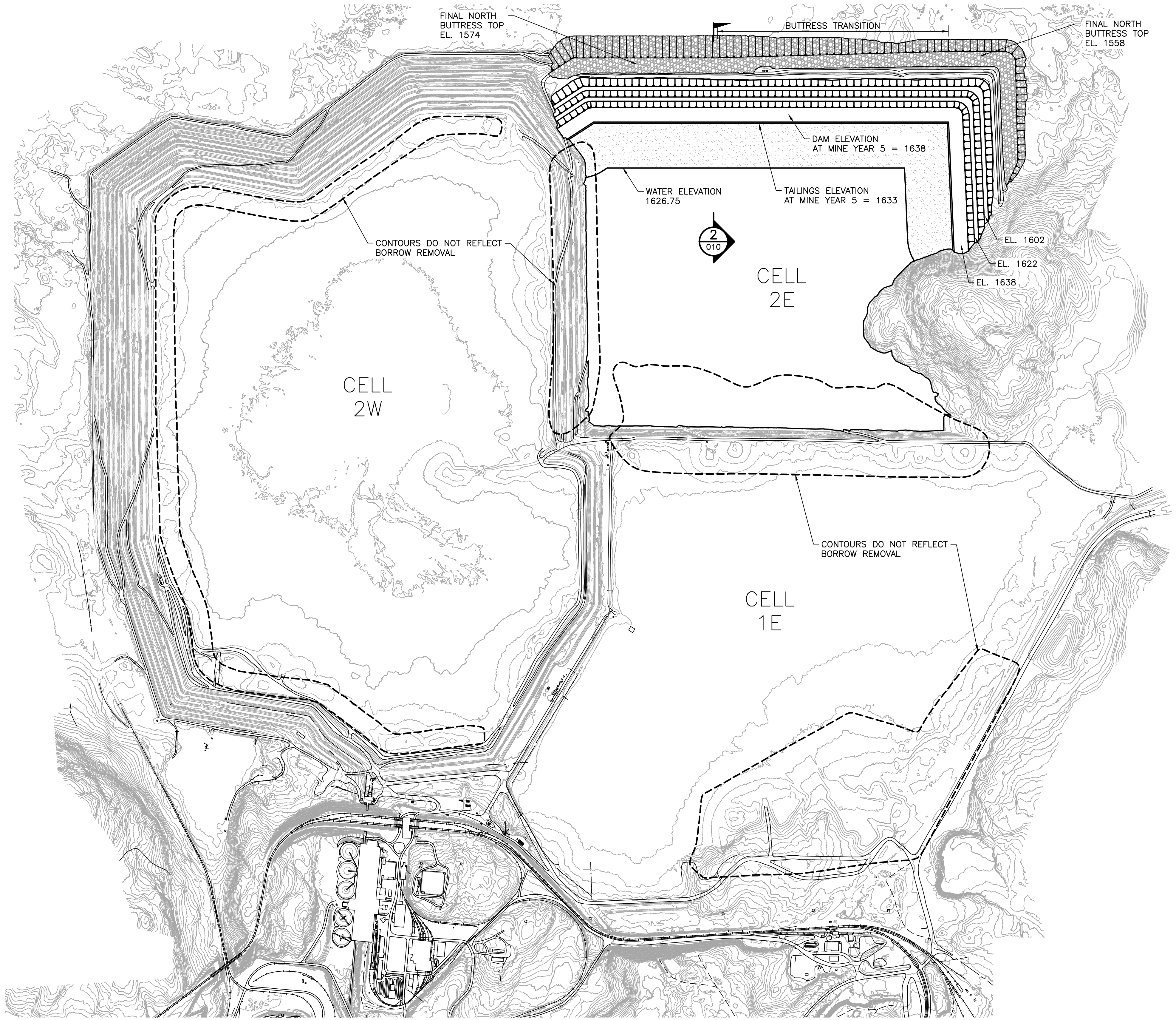
DWG. NO. FTB–005

REV A

INCHES 1 2

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-006.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 8:55 AM



NOTES:

1. SEE SHEET FTB-015 FOR OPERATIONS-PHASE EMERGENCY OVERFLOW CHANNEL.

1 PLAN: FLOTATION TAILINGS BASIN LAYOUT MINE YEAR 5

0 800 1600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LAYOUT MINE YEAR 5

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

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SUITE 200
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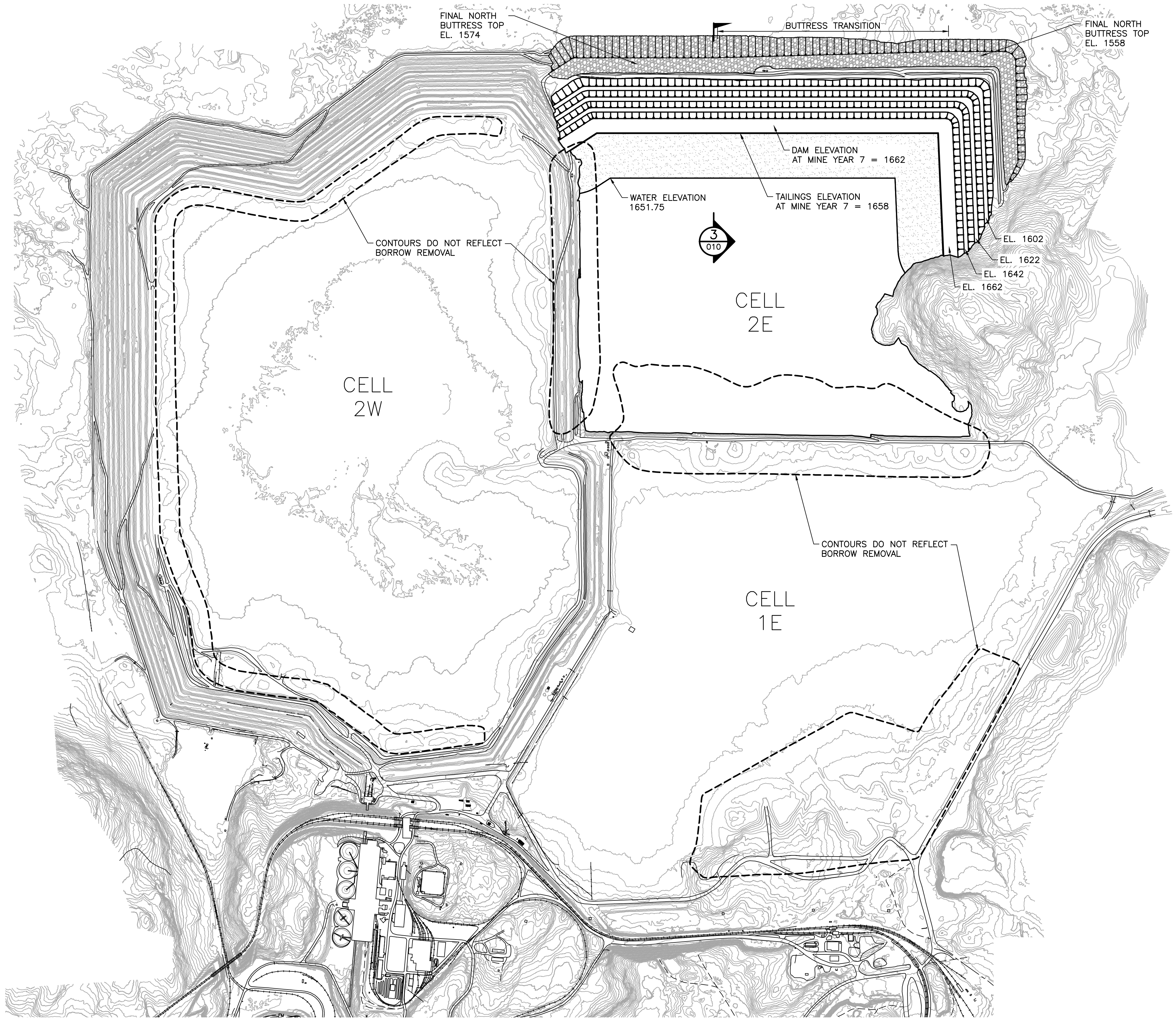
Ph: 1-800-632-2277

DWG. NO. FTB-006

REV A



NOTES:

1. LAST YEAR BEFORE COMBINING CELLS 2E AND 1E FOR TAILINGS.
2. SEE SHEET FTB–015 FOR OPERATIONS–PHASE EMERGENCY OVERFLOW CHANNEL.

1 PLAN: FLOTATION TAILINGS BASIN LAYOUT MINE YEAR 7

0 800 1600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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FOR CONSTRUCTION	–	–
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DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
LAYOUT MINE YEAR 7

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

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SUITE 200
MINNEAPOLIS, MN.
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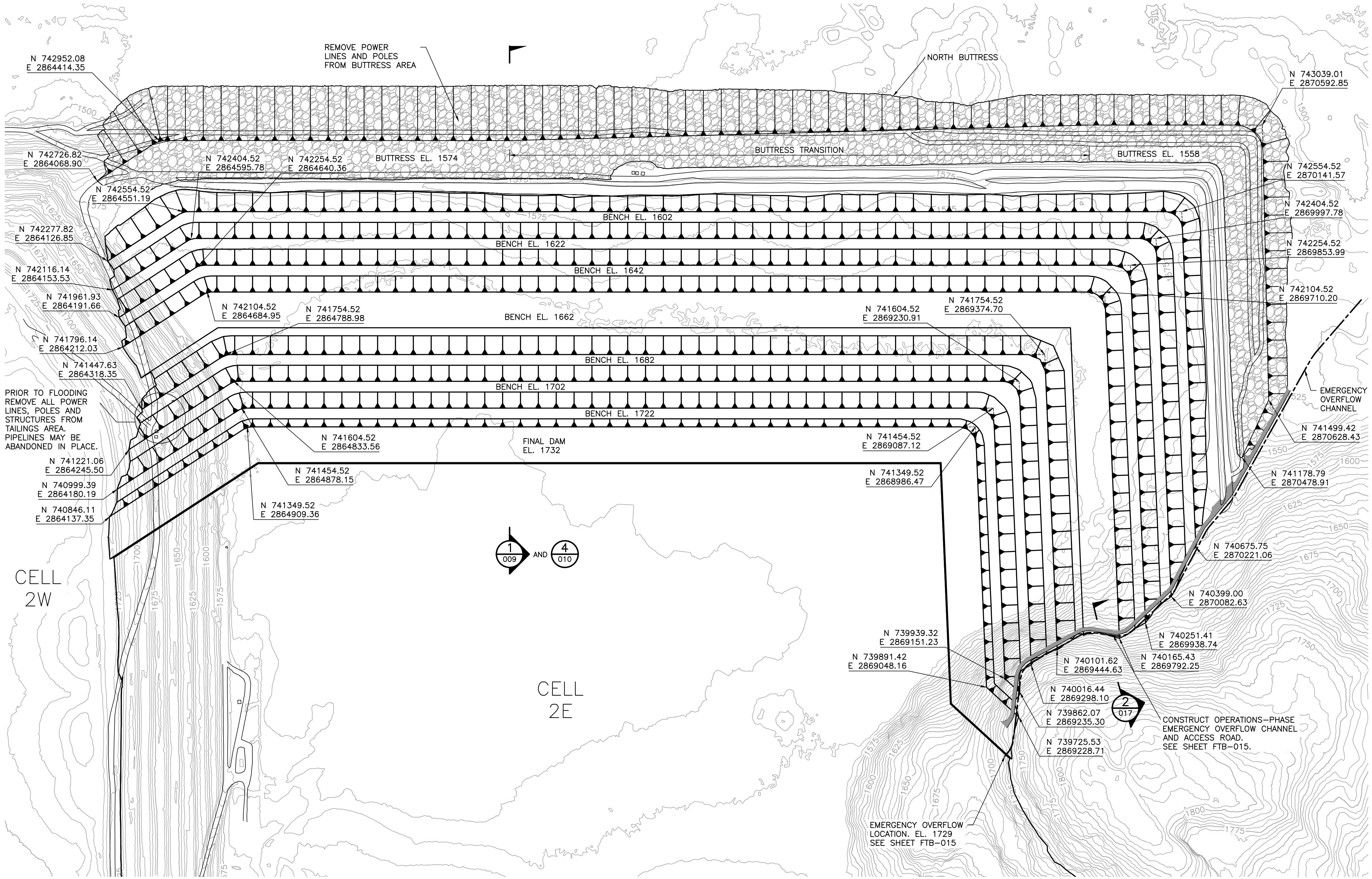
DWG. NO. FTB–007
REV A

INCHES 1 2



NOTES:

1. DAM ACCESS ROAD LOCATION IS APPROXIMATE. FIELD LOCATE TO PROVIDE PREFERRED SLOPE AND DRAINAGE.

2. EXTEND ACCESS ROAD TO AREA 5 STOCKPILES AND TO PLANT (NOT SHOWN).

3. PEAT TO BE REMOVED FROM BUTTRESS FOUNDATION AREA UNDER THE DIRECTION OF A GEOTECHNICAL ENGINEER.

1 PLAN: NORTH DAM LAYOUT

0 300 600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
NORTH DAM
MINE YEAR 20 LAYOUT

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

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DWG. NO. FTB–008
REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-008.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:03 AM

INCHES 1 2

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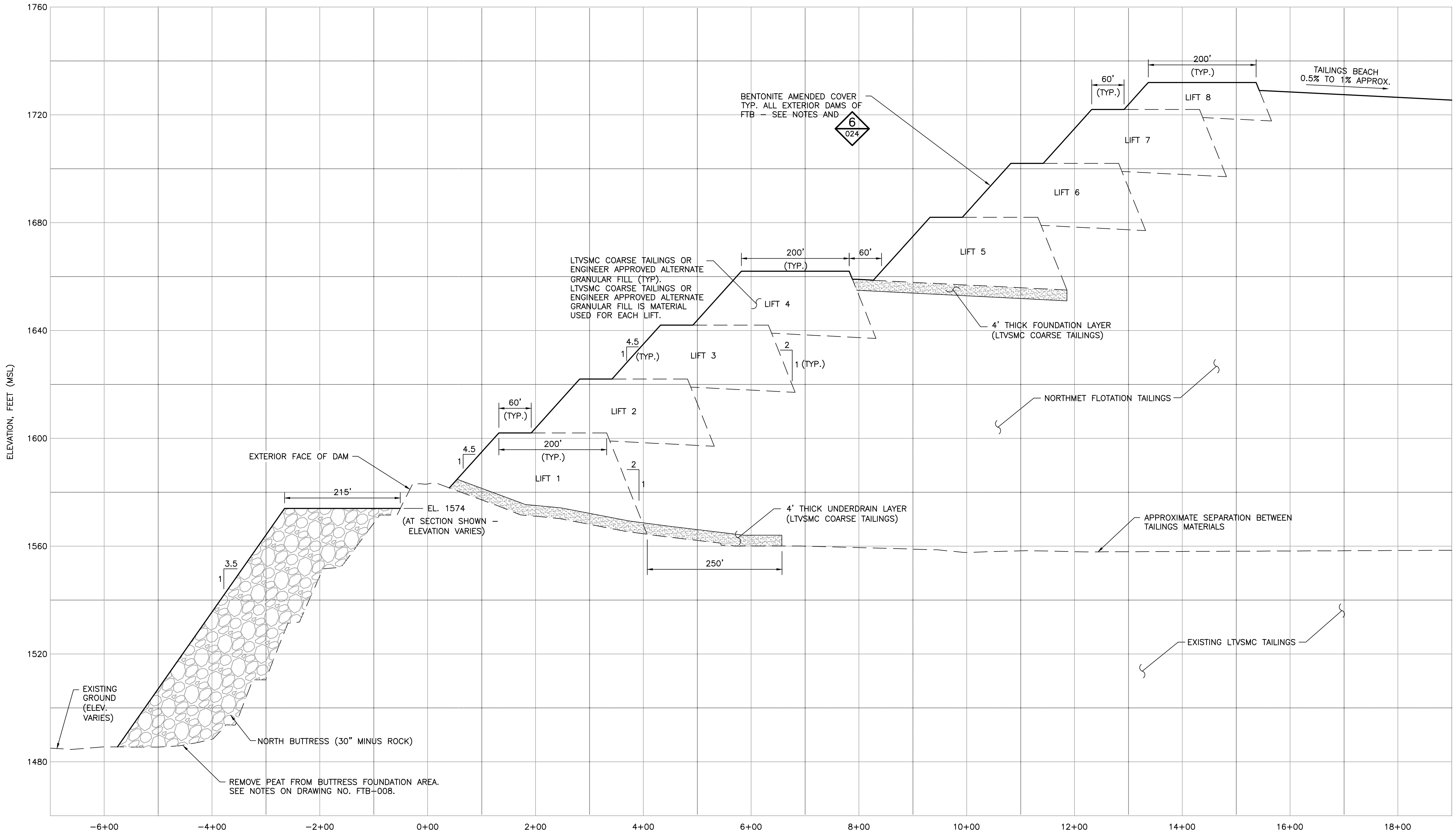

1 – ELEVATION: NORTH DAM TYPICAL CROSS SECTION

0 100 200
HORZ. SCALE IN FEET

NOTES:

1. DAMS AND BUTTRESS DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE DAM STABILITY PERFORMANCE DATA.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
NORTH DAM
TYPICAL CROSS SECTION

POLYMET MINING
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

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MINNEAPOLIS, MN.
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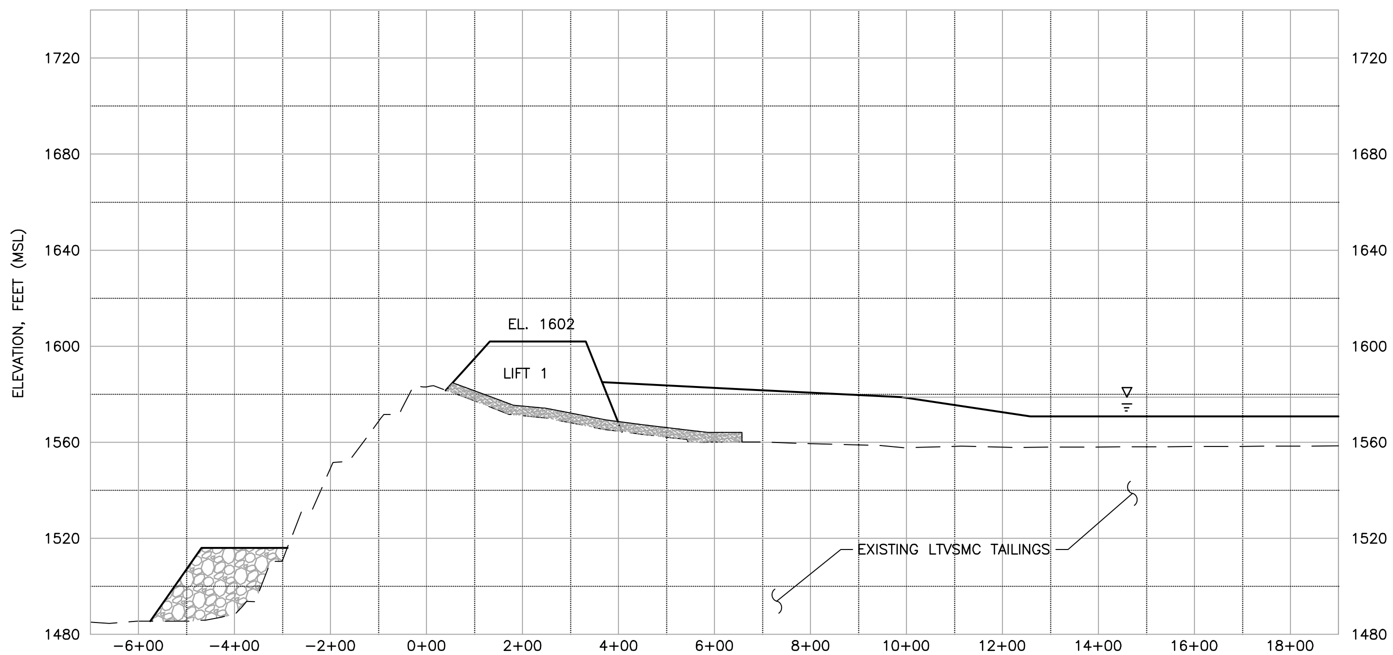
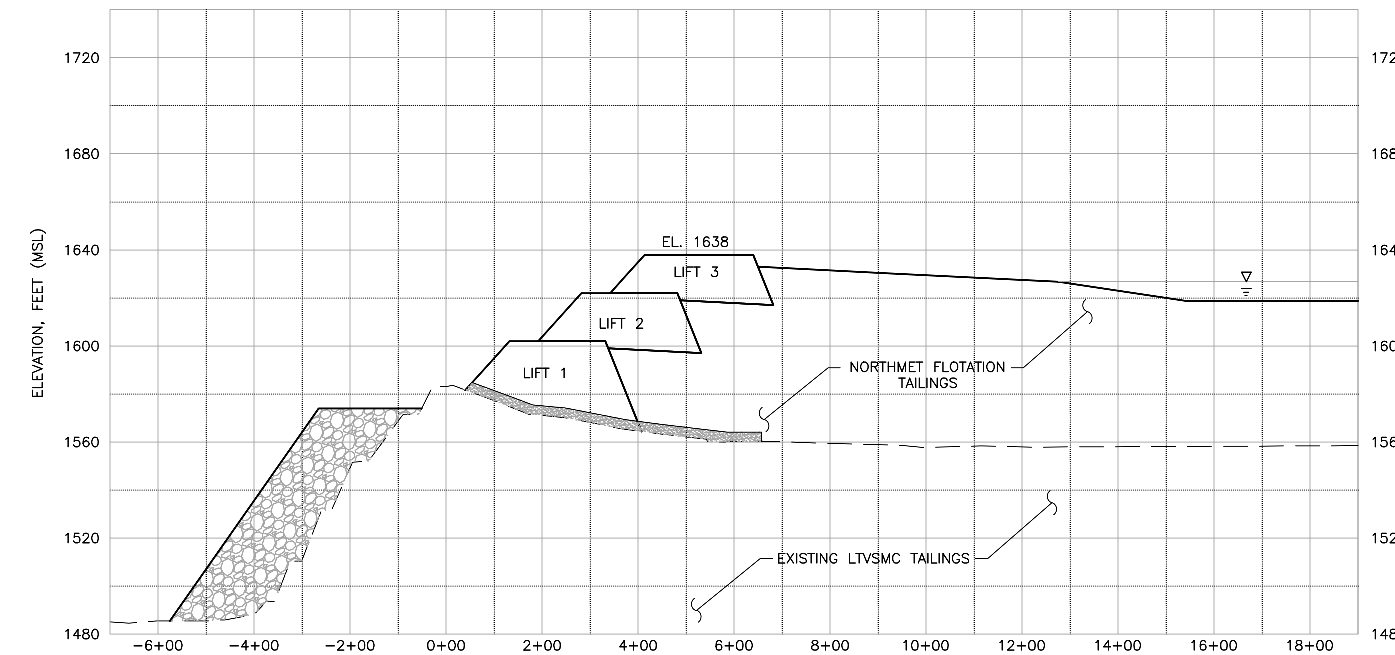
DWG. NO. FTB-009
REV A

INCHES 1 2



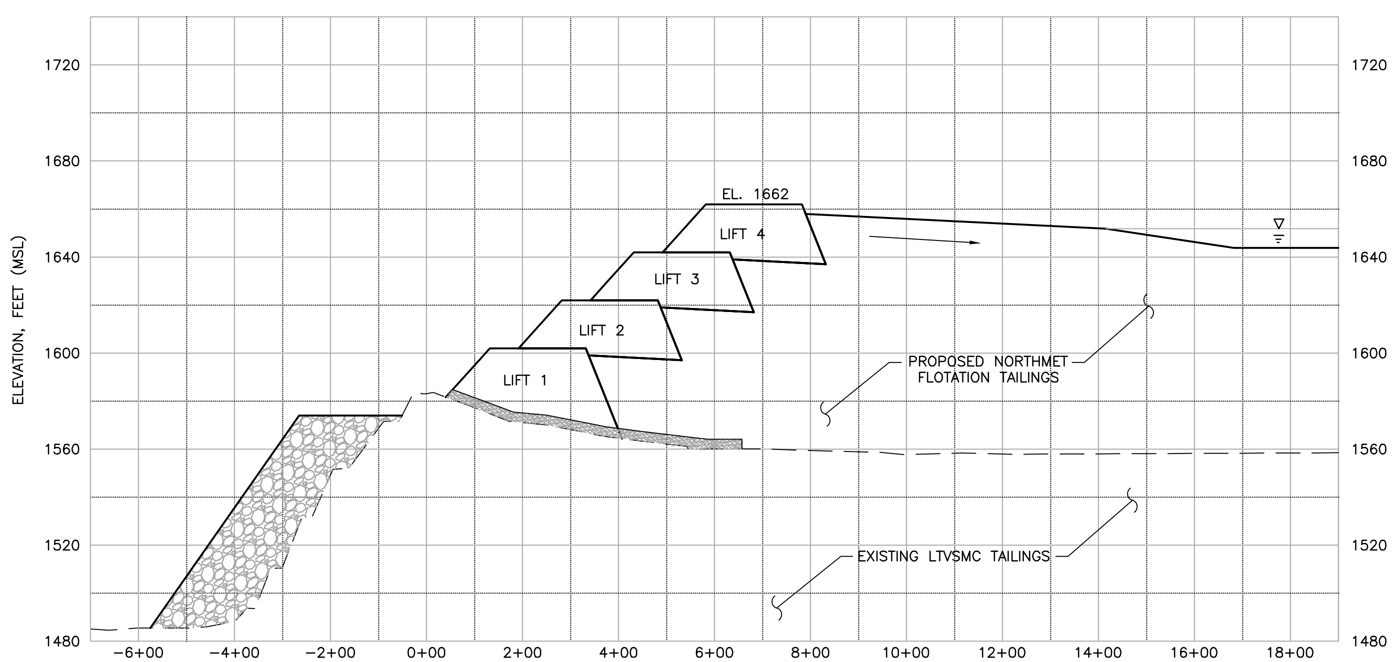
1 – ELEVATION: TYPICAL CROSS SECTION 1 – MINE YEAR 1

0 200 400
HORZ. SCALE IN FEET



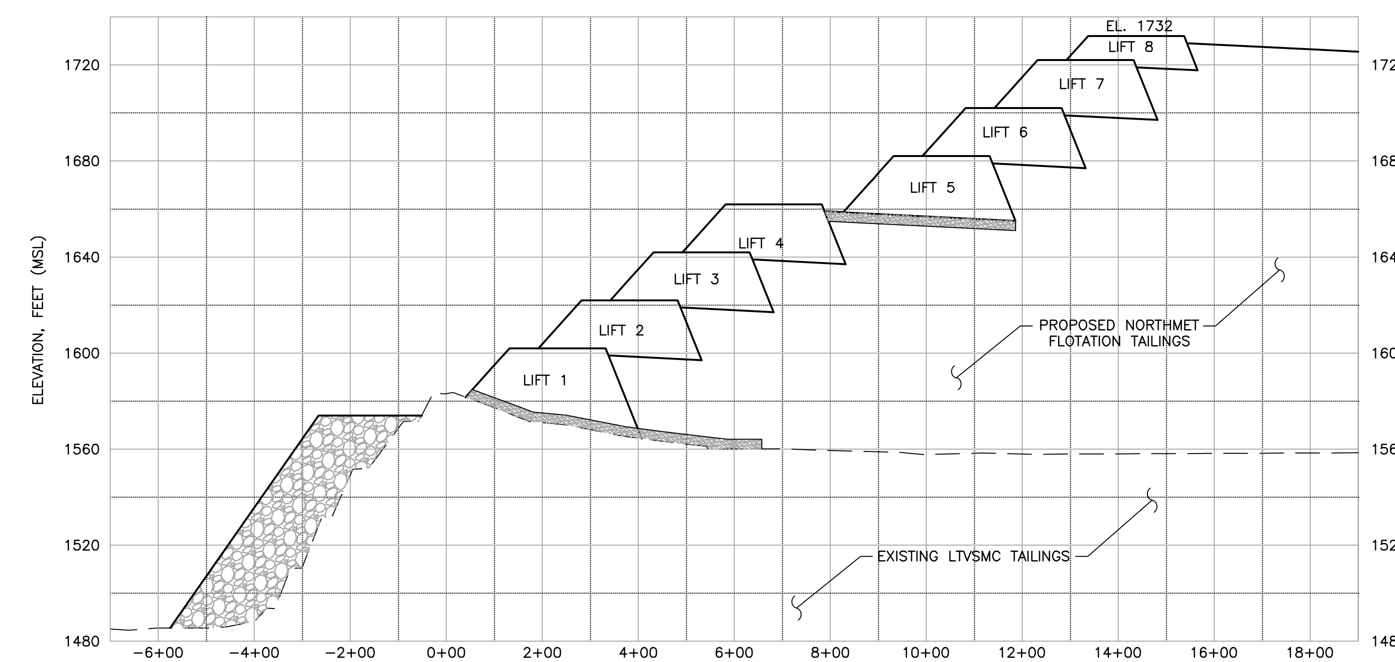
2 – ELEVATION: TYPICAL CROSS SECTION 1 – MINE YEAR 5

0 200 400
HORZ. SCALE IN FEET



3 – ELEVATION: TYPICAL CROSS SECTION 1 – MINE YEAR 7

0 200 400
HORZ. SCALE IN FEET



4 – ELEVATION: TYPICAL CROSS SECTION 1 – MINE YEAR 20

0 200 400
HORZ. SCALE IN FEET

NOTE:

1. DAM AND BUTTRESS DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE DAM STABILITY PERFORMANCE DATA.
2. PLACE BENTONITE AMENDED SOIL COVER ON OUTSIDE FACE OF NEW DAMS.
3. CONSTRUCT NORTH BUTTRESS FOLLOWING THE SCHEDULE AND ELEVATIONS TO BE SPECIFIED AT TIME OF CONSTRUCTION.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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SIGNATURE Thomas J. Radue
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DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
NORTH DAM
STAGED CONSTRUCTION

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

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4300 MARKETPOINTE DRIVE
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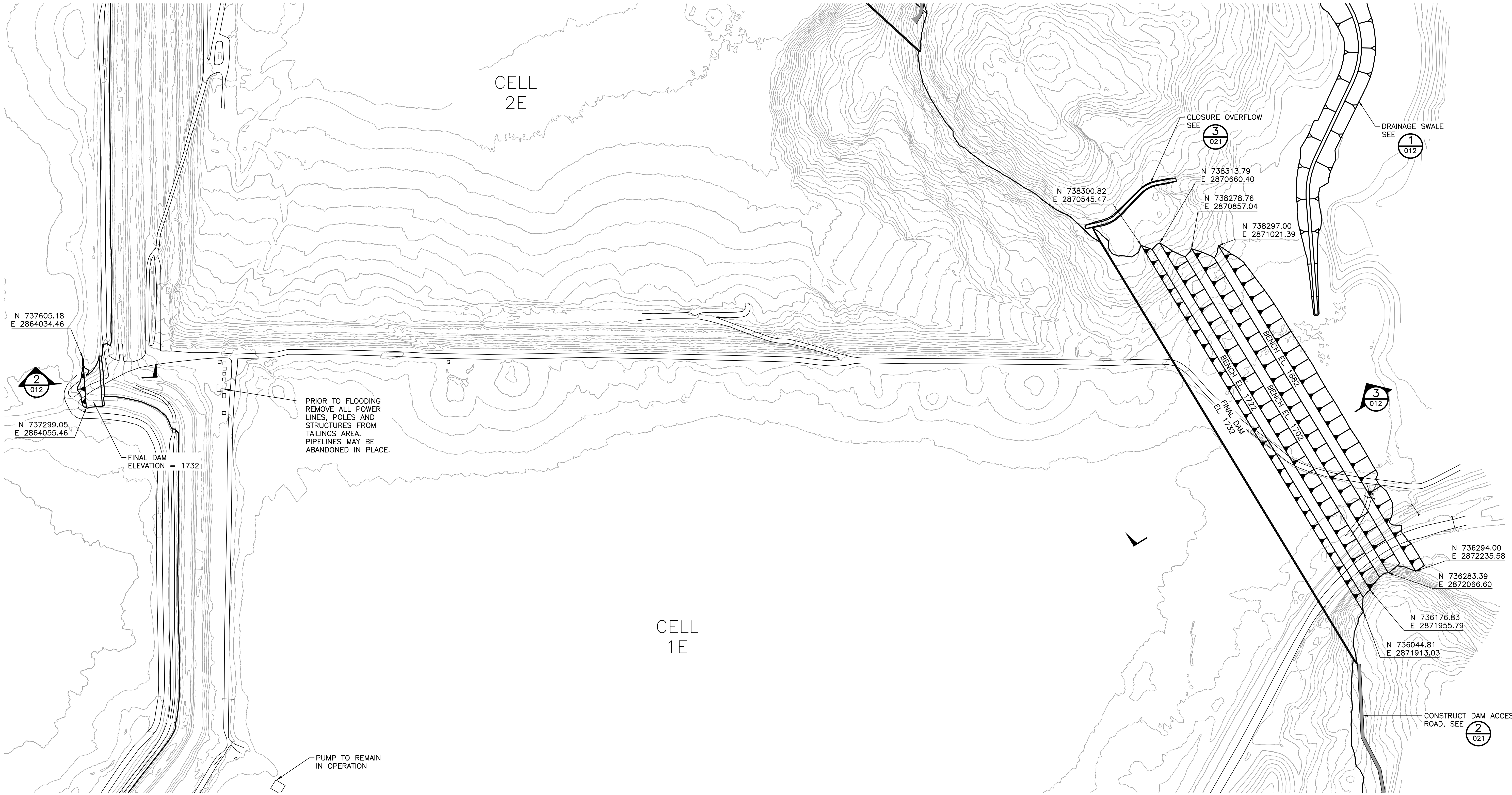
Ph: 1-800-632-2277

DWG. NO. FTB-010
REV A

INCHES 1 2



1 PLAN: EAST AND WEST DAM LAYOUTS

0 300 600

SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EAST AND WEST DAMS
MINE YEAR 20 LAYOUT

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

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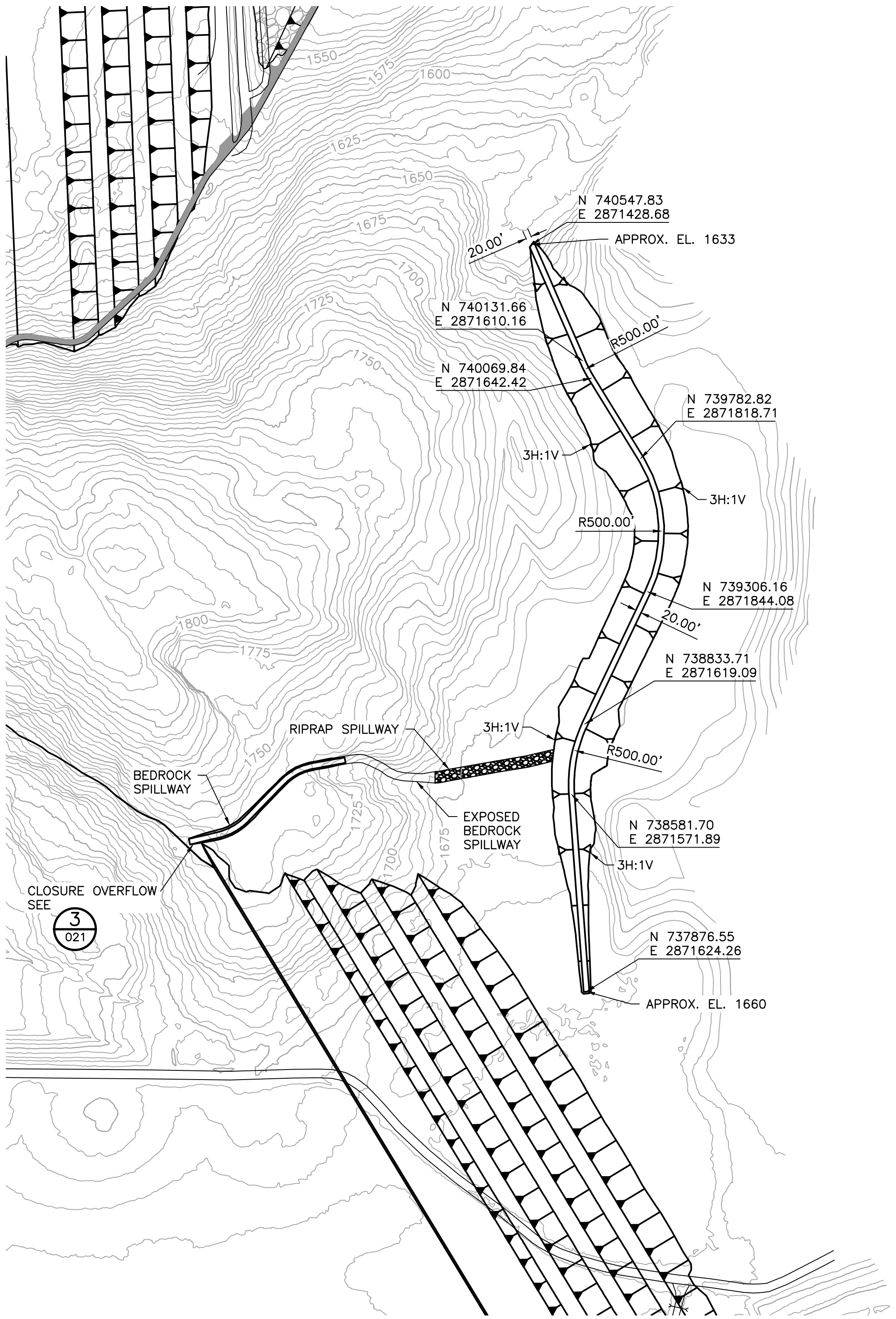
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-011

REV A

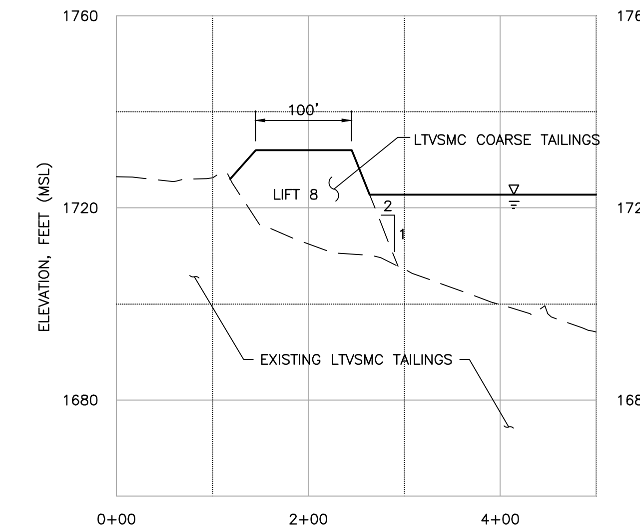
CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-011.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:13 AM

INCHES 1 2



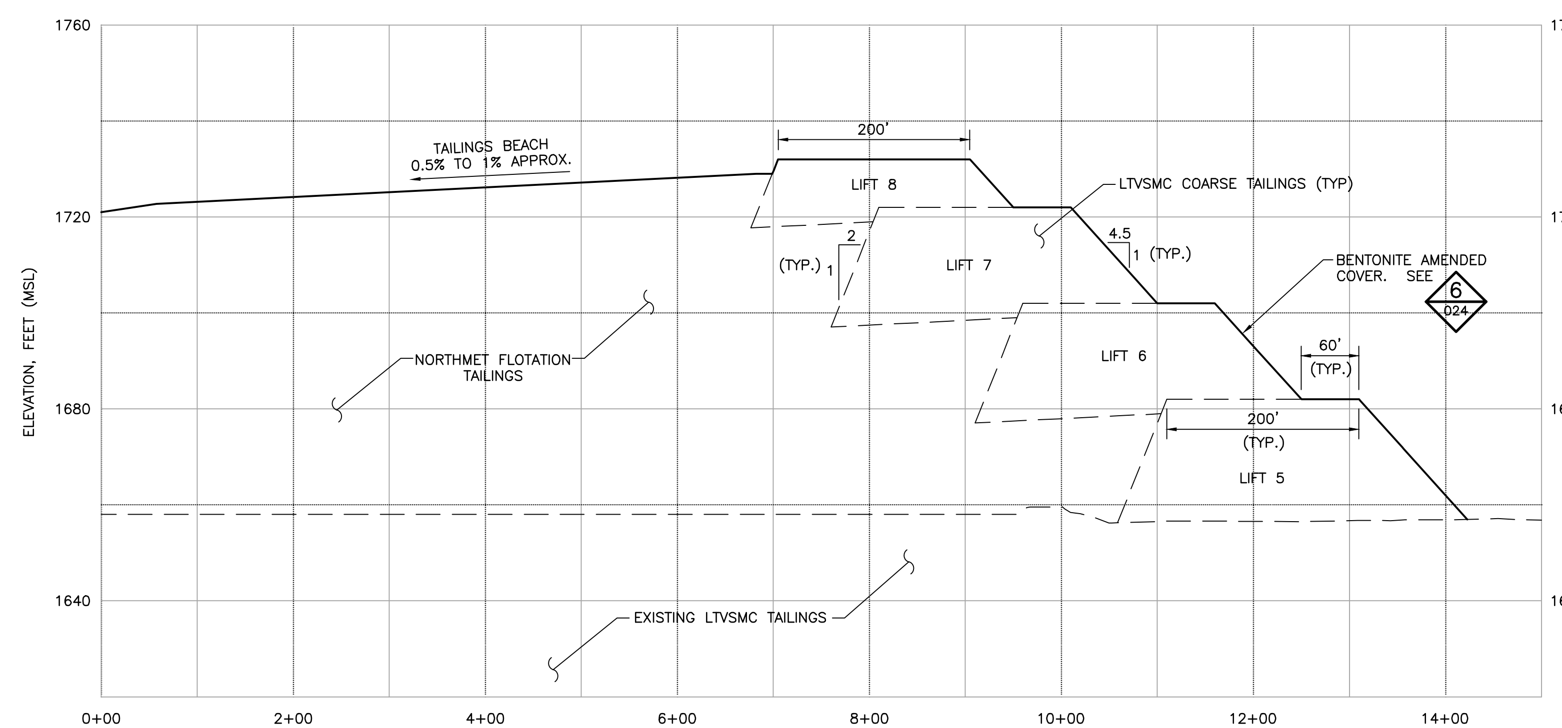
1 PLAN: DRAINAGE SWALE LAYOUT

0 300 600 SCALE IN FEET



2/011 ELEVATION: WEST DAM TYPICAL CROSS SECTION

0 100 200 HORZ. SCALE IN FEET



3/011 ELEVATION: EAST DAM TYPICAL CROSS SECTION

0 100 200 HORZ. SCALE IN FEET

NOTES:

1. CLOSURE OVERFLOW IS FOR EMERGENCY OVERFLOW ONLY UNTIL POND WATER QUALITY MEETS DISCHARGE WATER QUALITY REQUIREMENTS.

2. DAM DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE DAM STABILITY PERFORMANCE DATA.

INCHES 1 2

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
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6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–
NOT APPROVED FOR CONSTRUCTION		

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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EAST AND WEST DAMS TYPICAL CROSS SECTIONS AND DRAINAGE SWALE

POLYMET MINING

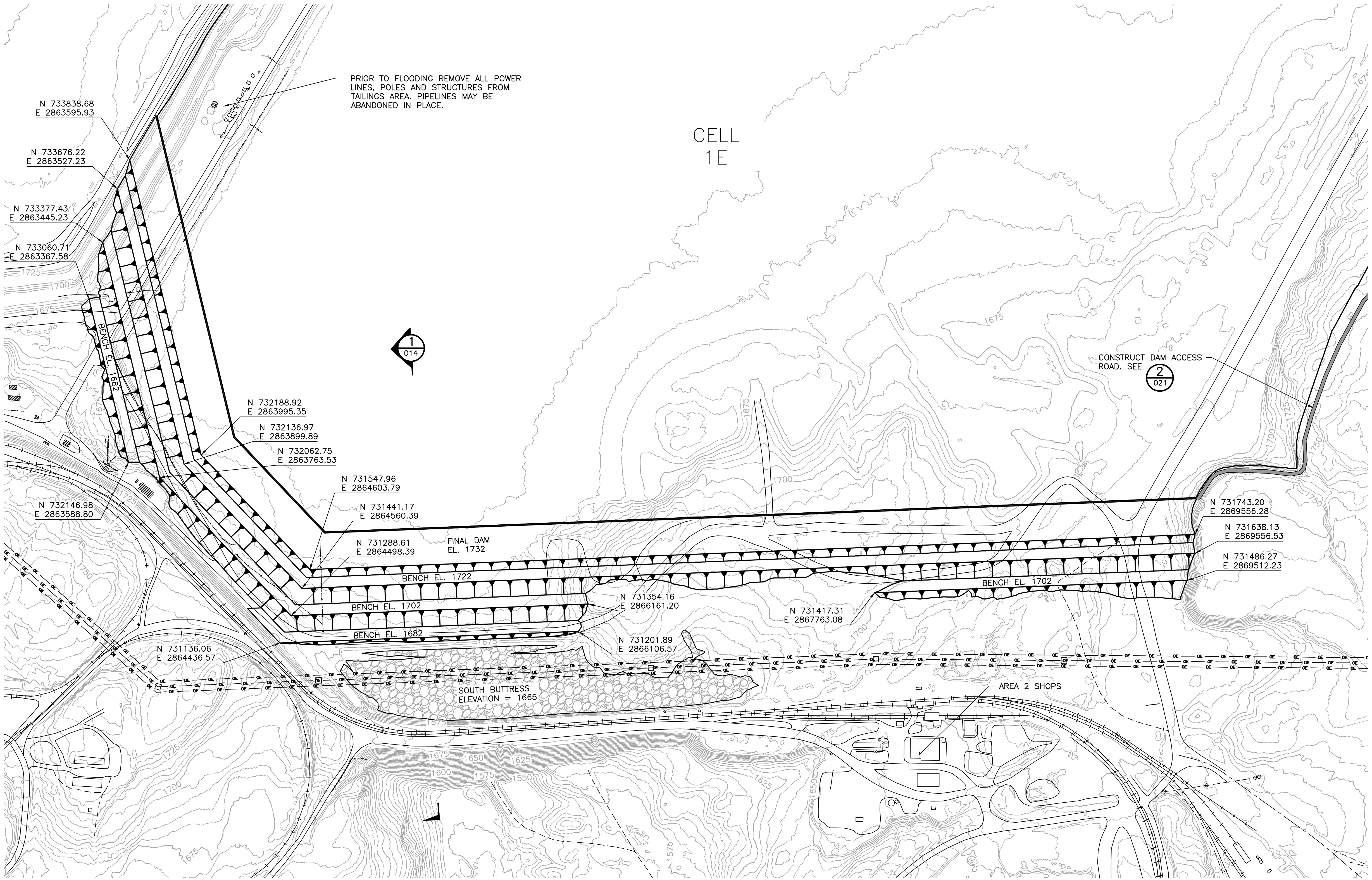
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-012

REV A



1 PLAN: SOUTH DAM LAYOUT

0 300 600

SCALE IN FEET

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-013.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:22 AM

INCHES 1 2

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
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FOR PERMITTING	7	5/12/17
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PRINTED NAME THOMAS J. RADUE

SIGNATURE Thomas J. Radue

DATE 5/12/17 LICENSE# 20951

DRAWN: CAD

CHECKED: TJR

BARR PROJECT NO.: 23/69-0C29

SCALE: AS SHOWN

PLANT DRAWING NUMBER:

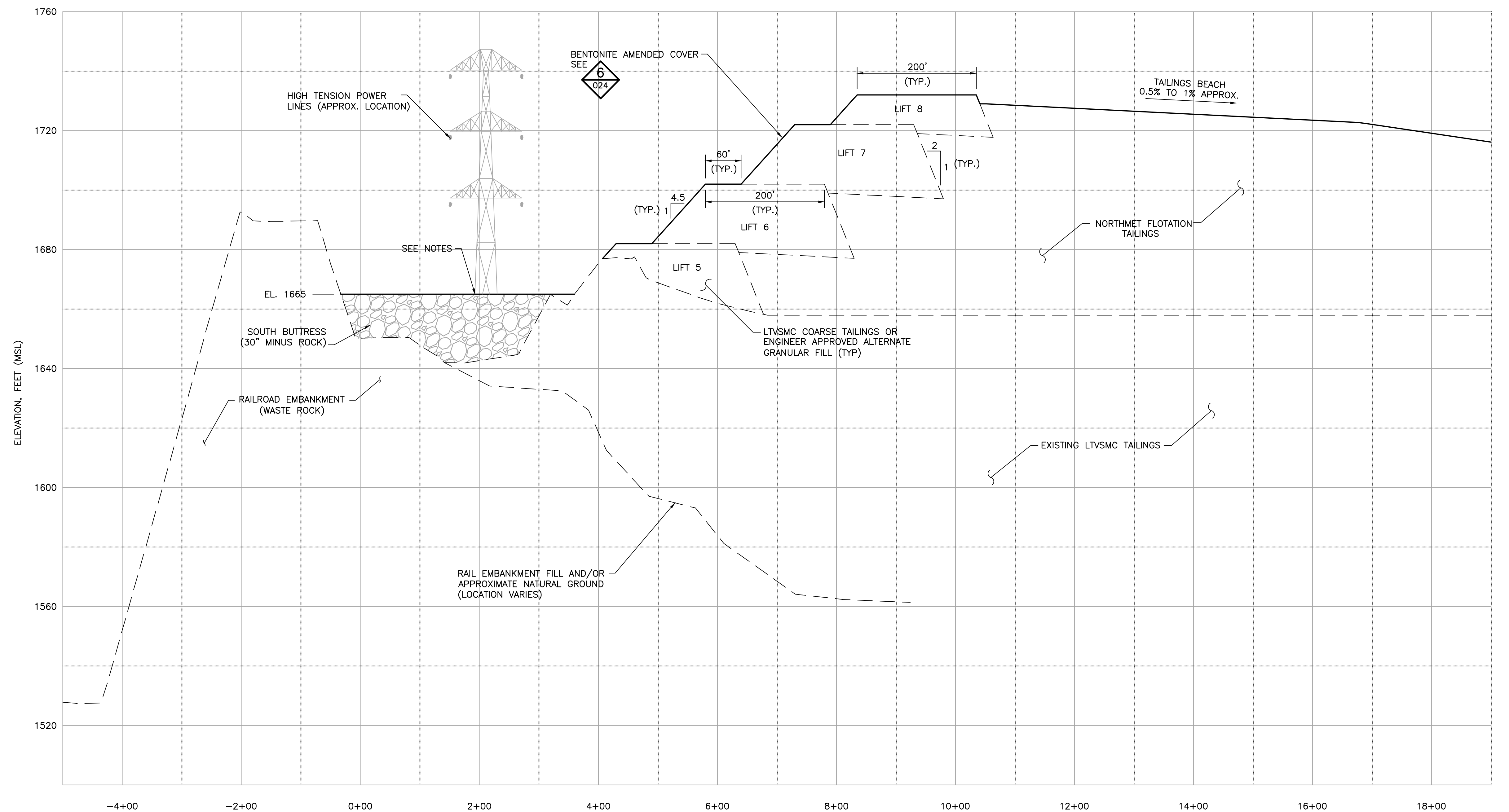
FLOTATION TAILINGS BASIN
SOUTH DAM
YEAR 20 LAYOUT

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-013

REV A



1 – ELEVATION: SOUTH DAM TYPICAL CROSS SECTION

0 100 200
HORZ. SCALE IN FEET

NOTES:

1. DAM DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE PERFORMANCE DATA.

2. HIGH TENSION POWER LINES SHOWN FOR REFERENCE. TOWER FOUNDATIONS ARE LOCATED OUTSIDE OF THE AREA COVERED BY THE BUTTRESS.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
SOUTH DAM
TYPICAL CROSS SECTIONS

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

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MINNEAPOLIS, MN.
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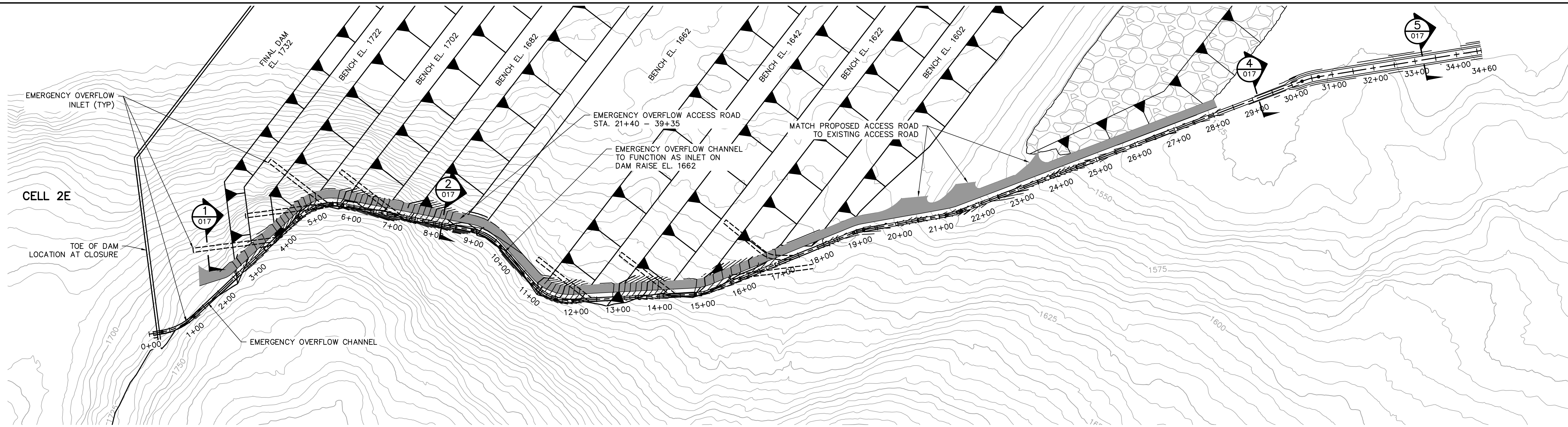
DWG. NO. FTB-014

REV A

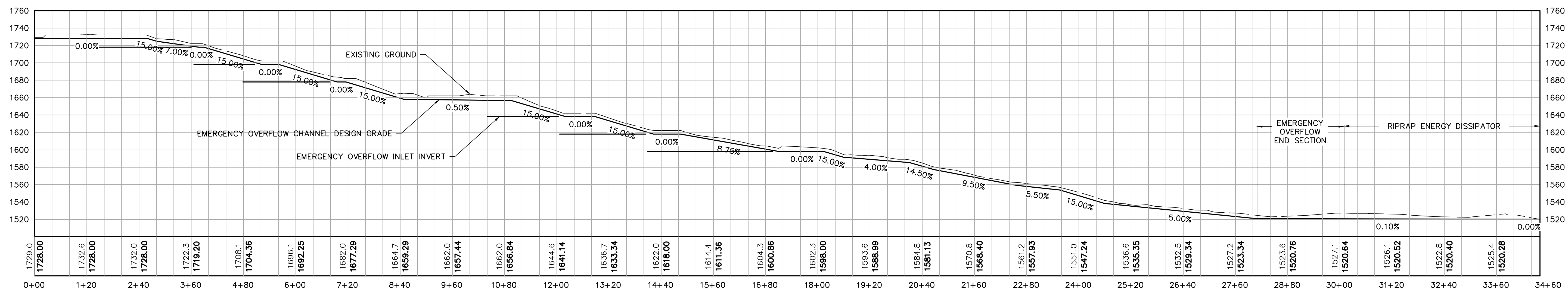
CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-014.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:24 AM

INCHES 1 2



1 PLAN: EMERGENCY OVERFLOW CHANNEL (OPERATIONS–PHASE)

0 120 240
SCALE IN FEET



2 PROFILE: EMERGENCY OVERFLOW CHANNEL (OPERATIONS–PHASE)

0 120 240
HORIZONTAL SCALE IN FEET

0 60 120
VERTICAL SCALE IN FEET

VER NO	DATE	DESCRIPTION
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SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EMERGENCY OVERFLOW CHANNEL
LAYOUT

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
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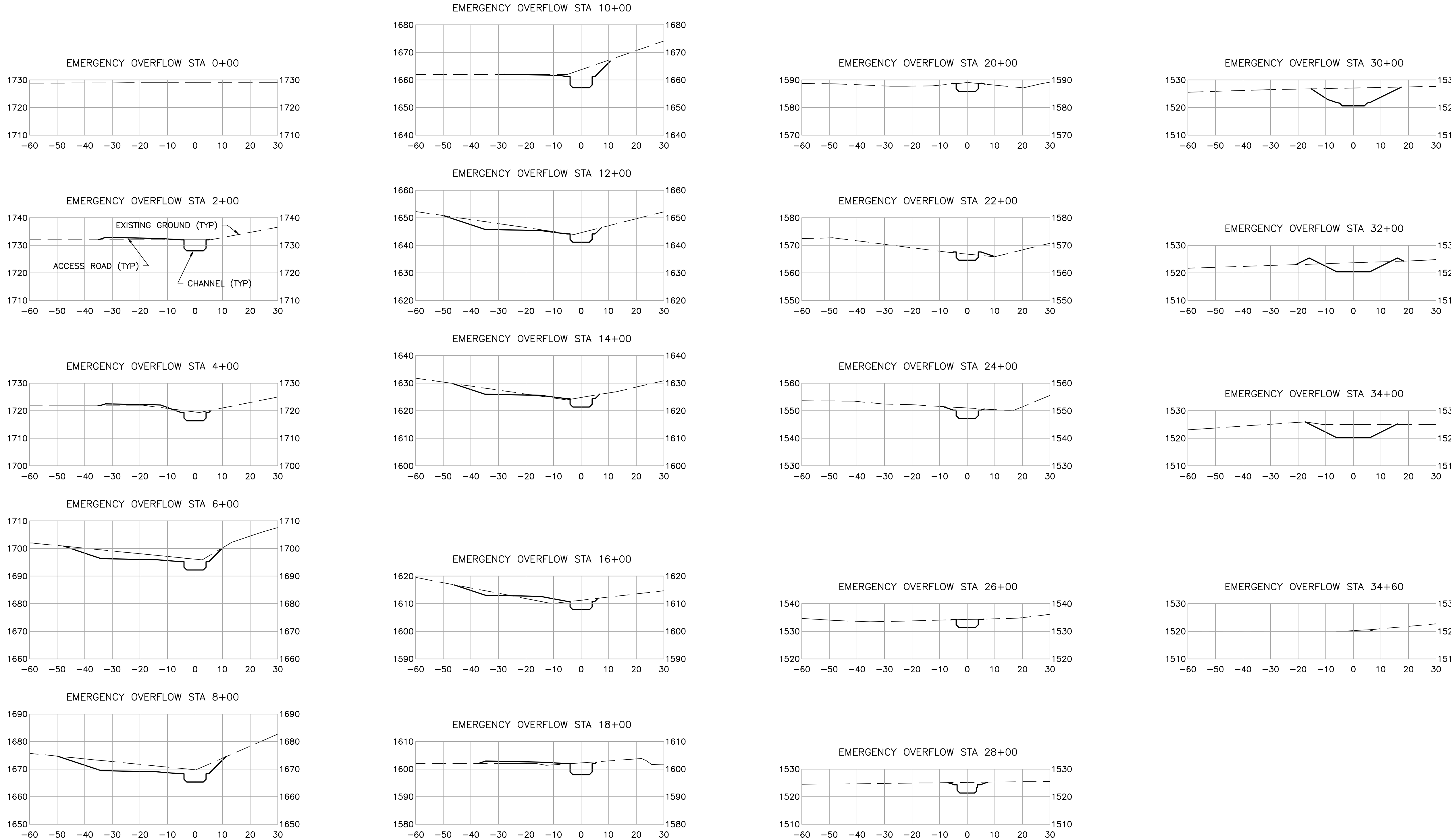
DWG. NO. FTB–015
REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-015.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:28 AM

INCHES 1 2



1 SECTIONS: EMERGENCY OVERFLOW CHANNEL

0 20 40
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EMERGENCY OVERFLOW CHANNEL
SECTIONS

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

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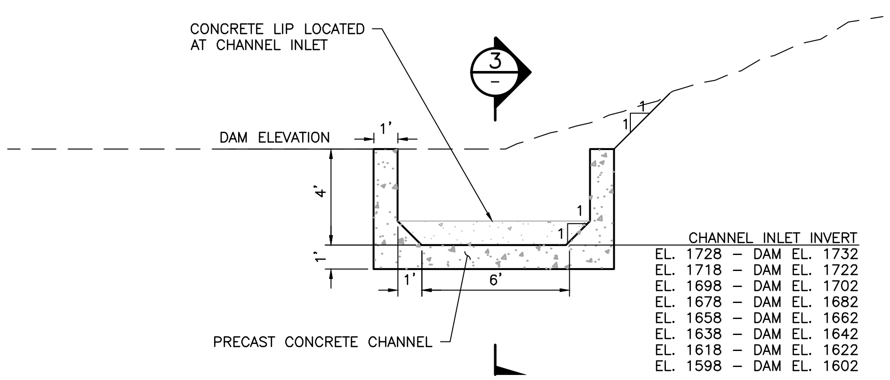
Ph: 1-800-632-2277

DWG. NO. FTB-016

REV A

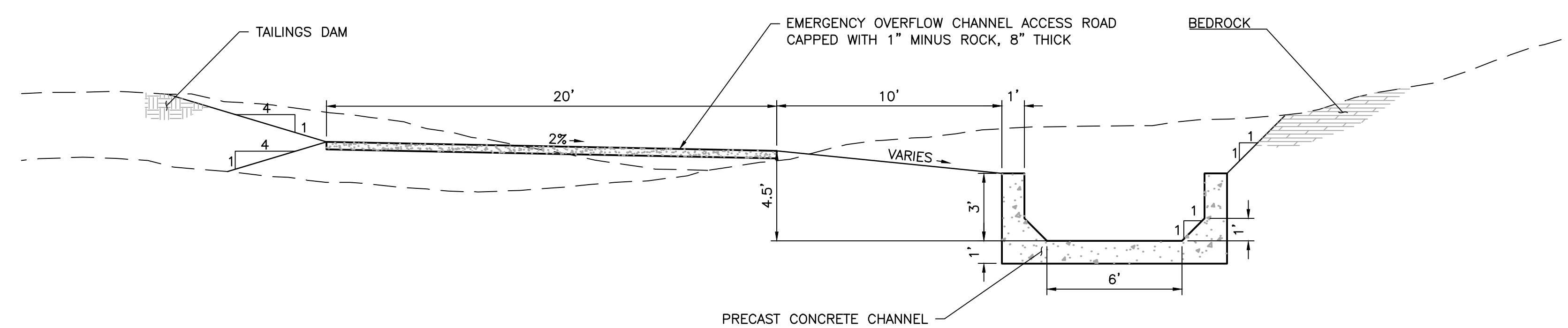
CADD USER: Cristion A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-016.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:30 AM

INCHES 1 2



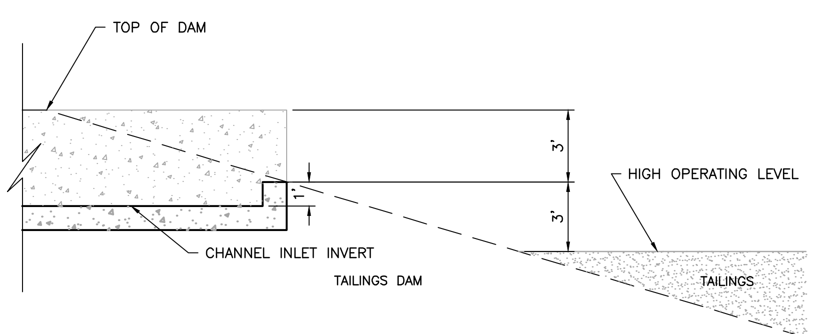
1 015 SECTION: TYPICAL EMERGENCY OVERFLOW CHANNEL INLET
NTS

NOTE:
PROTECT SOILS AT CHANNEL INLET WITH NEEDLE–PUNCHED NON–WOVEN HEAVY DUTY GEOTEXTILE AND RIPRAP. FIELD FIT (NOT SHOWN ON DRAWINGS).

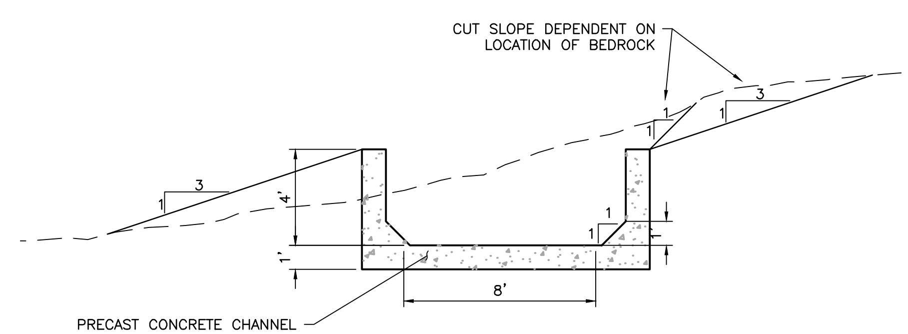


2 015 SECTION: EMERGENCY OVERFLOW CHANNEL
NTS

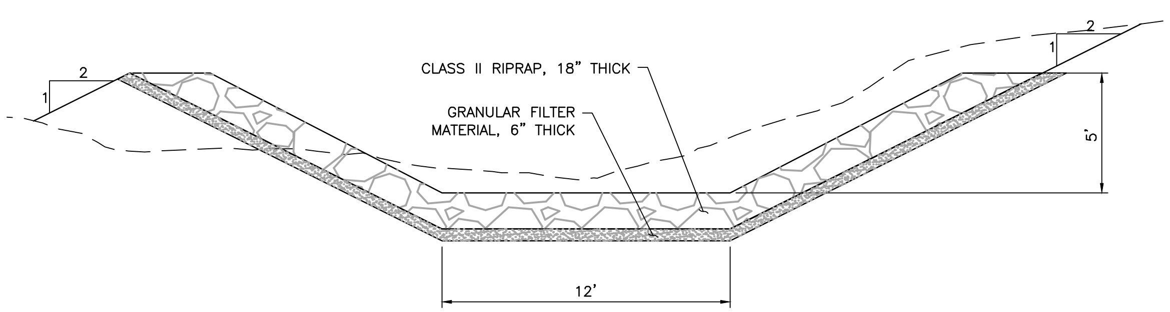
NOTE:
INCREASE EMERGENCY OVERFLOW CHANNEL DEPTH TO 4' WHEN CHANNEL SLOPE IS 0%



3 – DETAIL: EMERGENCY OVERFLOW CHANNEL INLET
NTS



4 015 SECTION: EMERGENCY OVERFLOW CHANNEL END SECTION – STA. 28+10 – 30+10
NTS



5 015 SECTION: RIPRAP OVERFLOW CHANNEL ENERGY DISSIPATOR – STA. 30+10 – 34+60
NTS

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69–0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

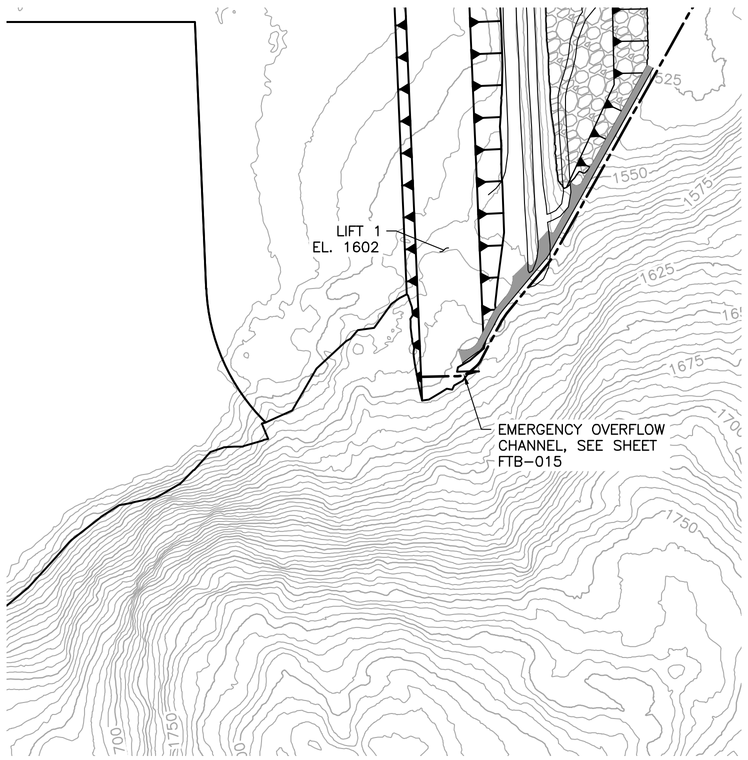
FLOTATION TAILINGS BASIN
EMERGENCY OVERFLOW CHANNEL
DETAILS

POLYMET MINING
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

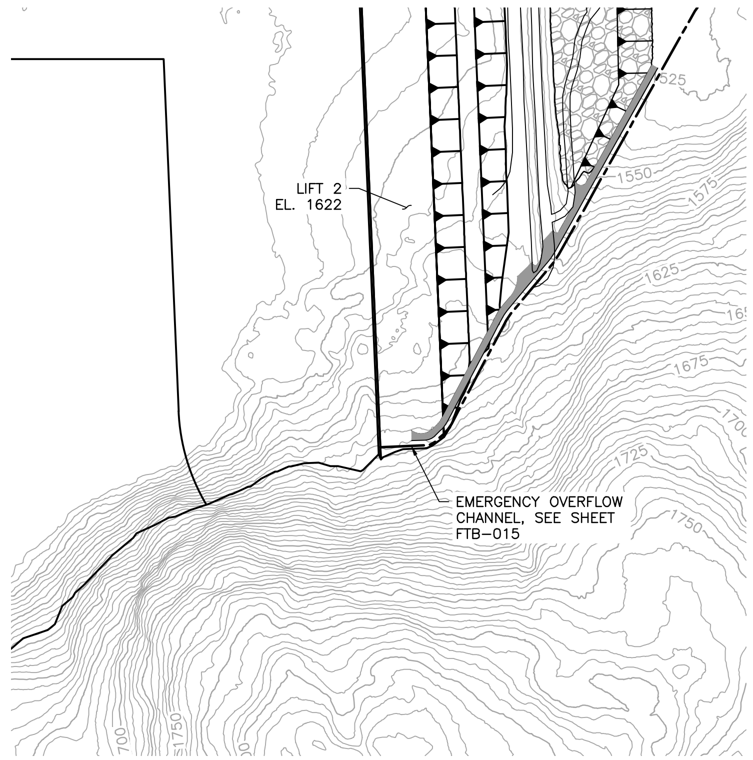
BARR
BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1–800–632–2277

DWG. NO. FTB–017
REV A

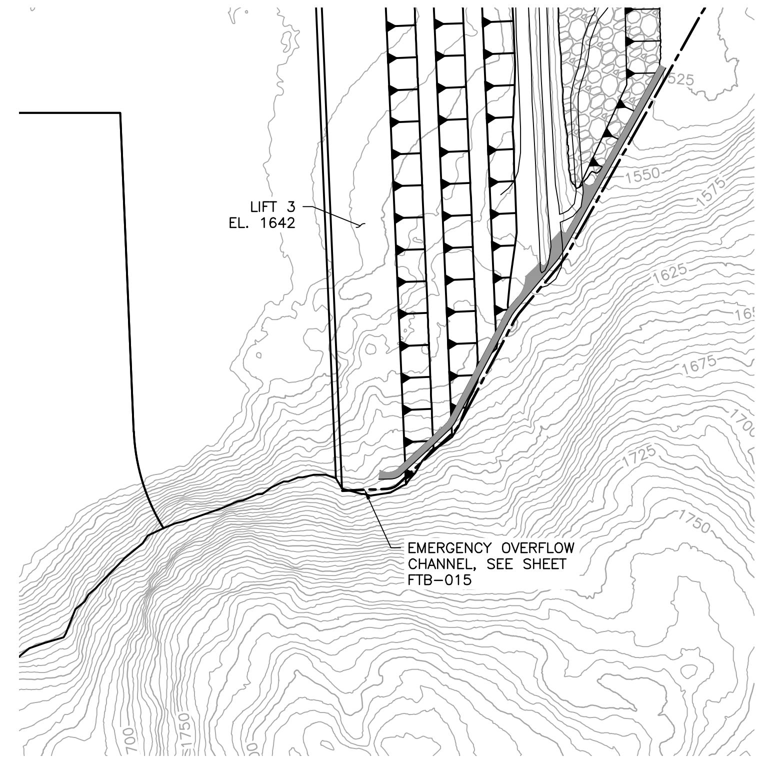
INCHES 1 2



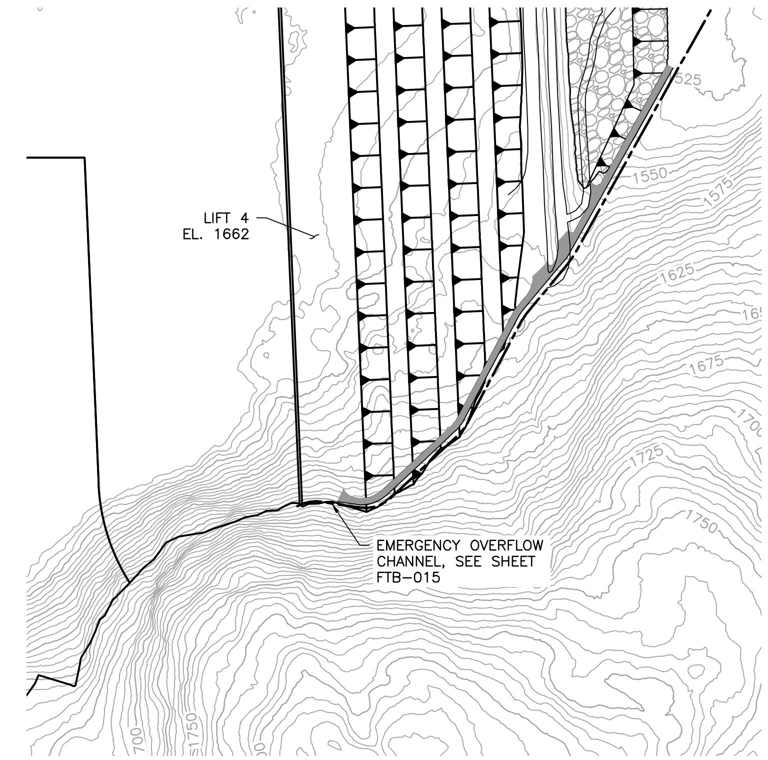
1 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 1



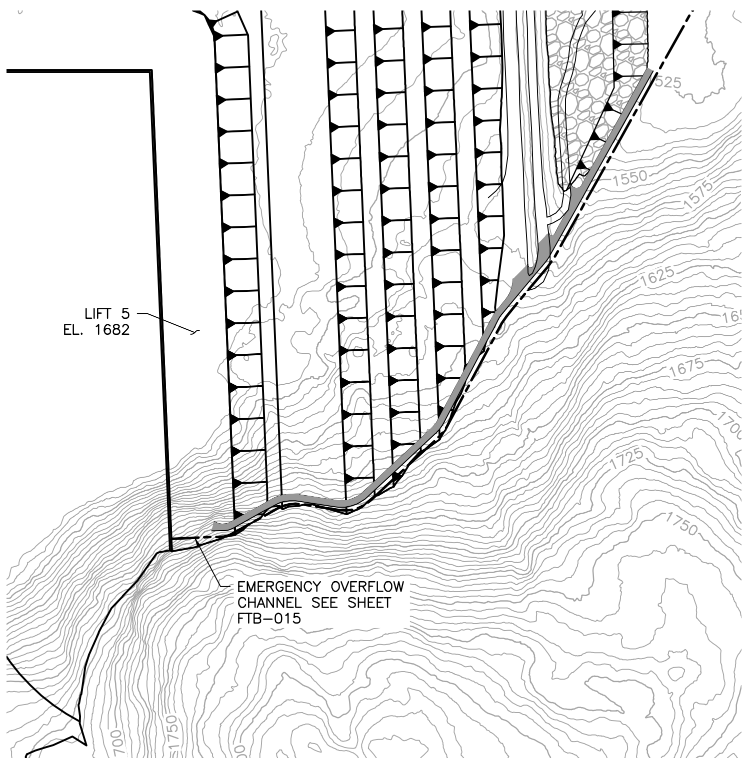
2 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 2



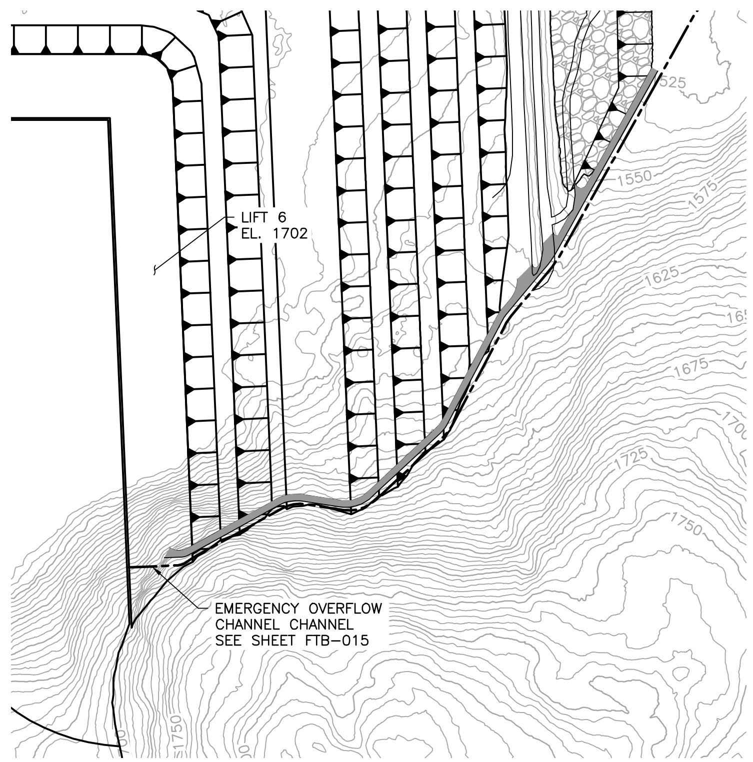
3 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 3



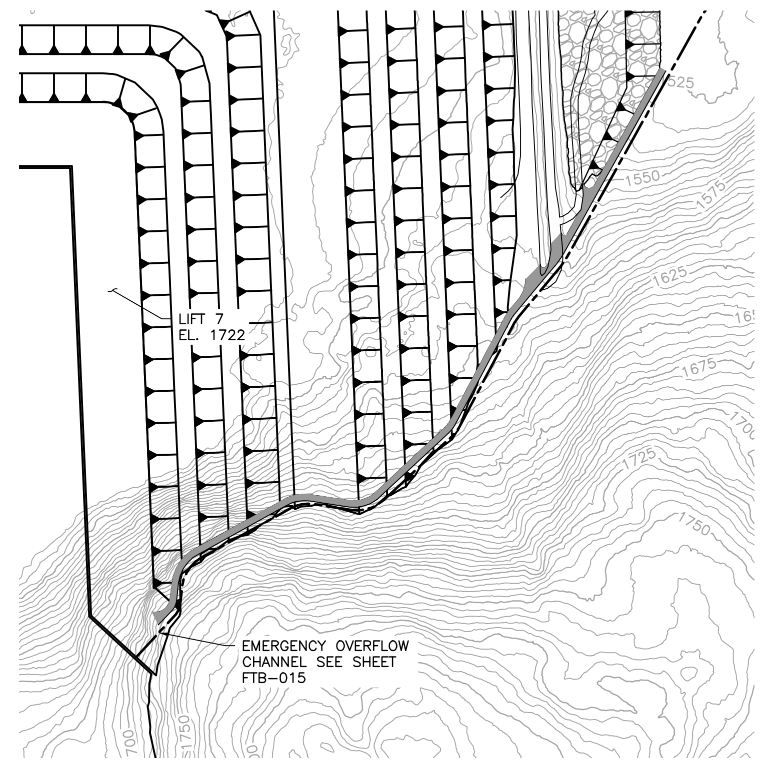
4 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 4



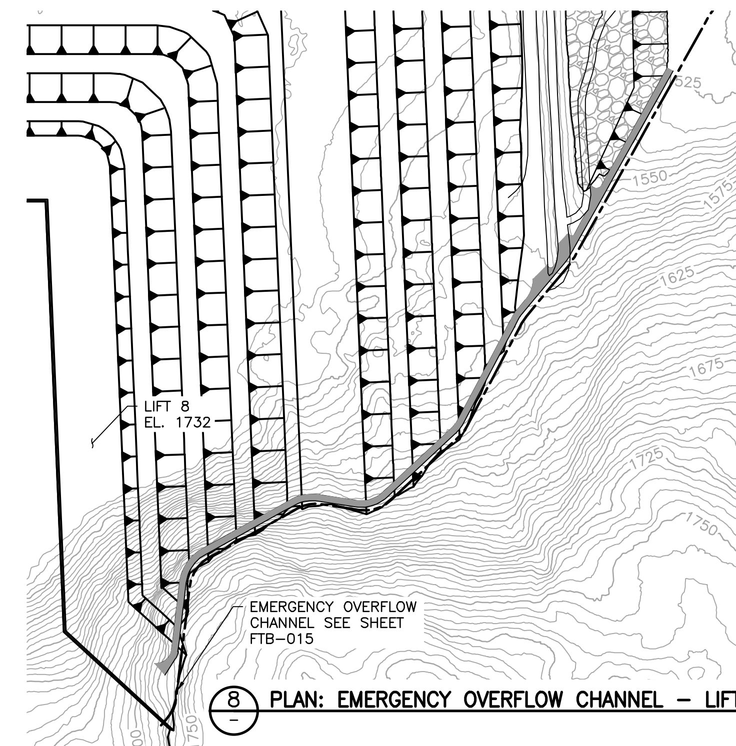
5 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 5



6 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 6



7 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 7



8 PLAN: EMERGENCY OVERFLOW CHANNEL – LIFT 8

NOTES:

1. EMERGENCY OVERFLOW CHANNEL PLAN VIEW NOT SHOWN, SEE SHEET FTB-015 FOR REFERENCE.

N

0 300 600
SCALE IN FEET

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
EMERGENCY OVERFLOW CHANNEL
SEQUENCING

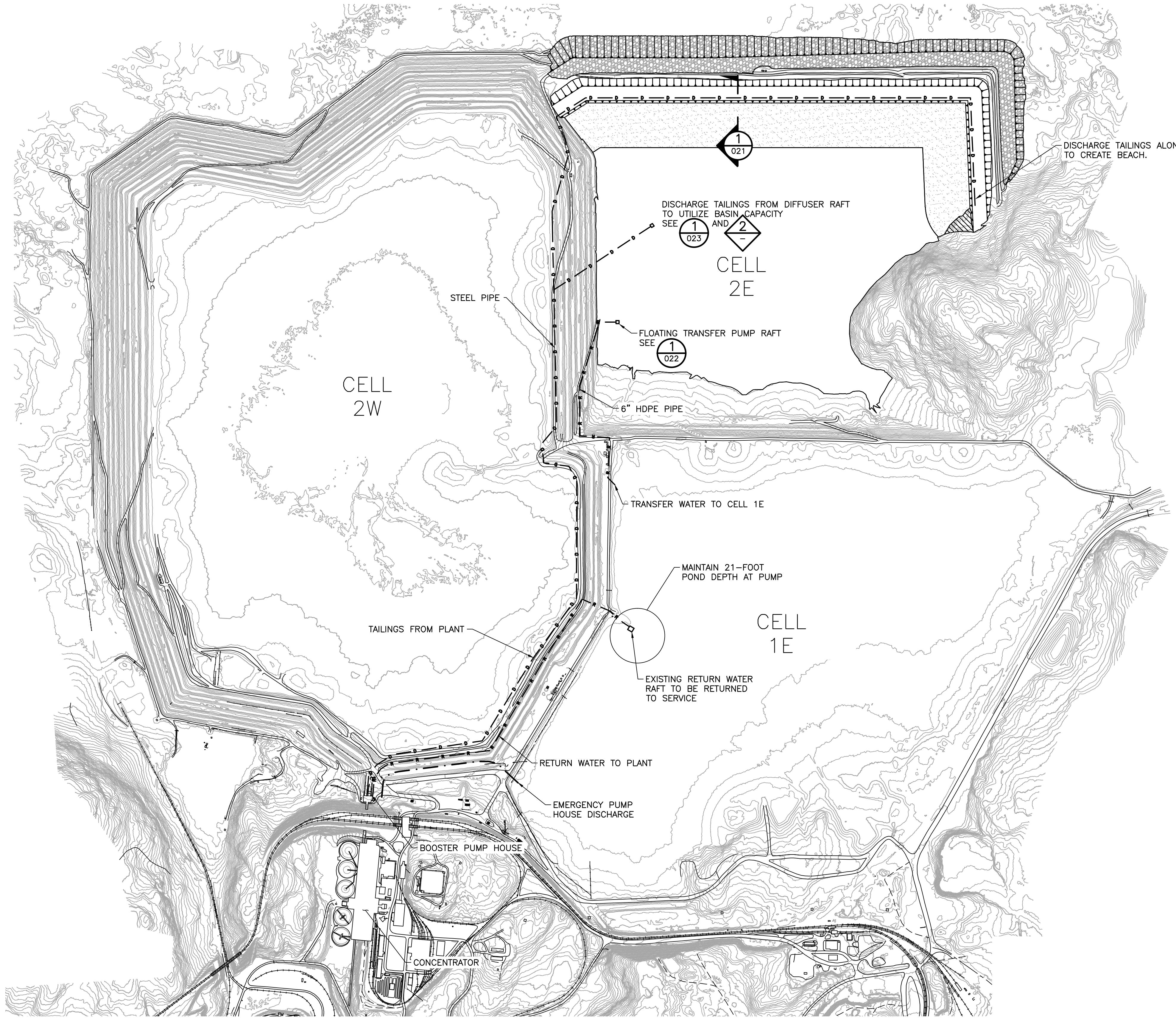
POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR
BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

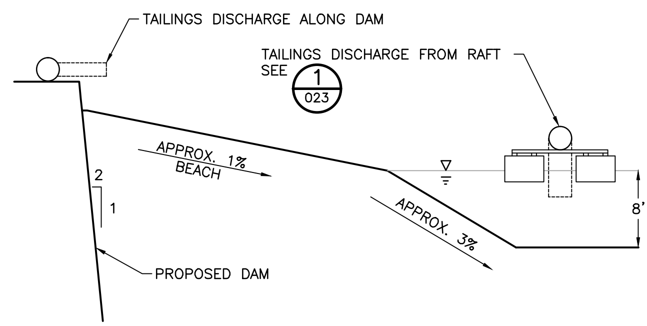
DWG. NO. FTB-018
REV A

INCHES 1 2



1 / -- PLAN: PIPING LAYOUT CELL 2E

0 800 1600
SCALE IN FEET



2 / – DETAIL: TAILINGS DISCHARGE ALONG DAM
NTS

NOTES:

1. CONTOURS DO NOT REFLECT BORROW REMOVAL.
2. PIPELINE LOCATIONS ARE PRELIMINARY.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
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DRAWN: CAD
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BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
PIPING LAYOUT CELL 2E

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR
BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-019
REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-019.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:42 AM

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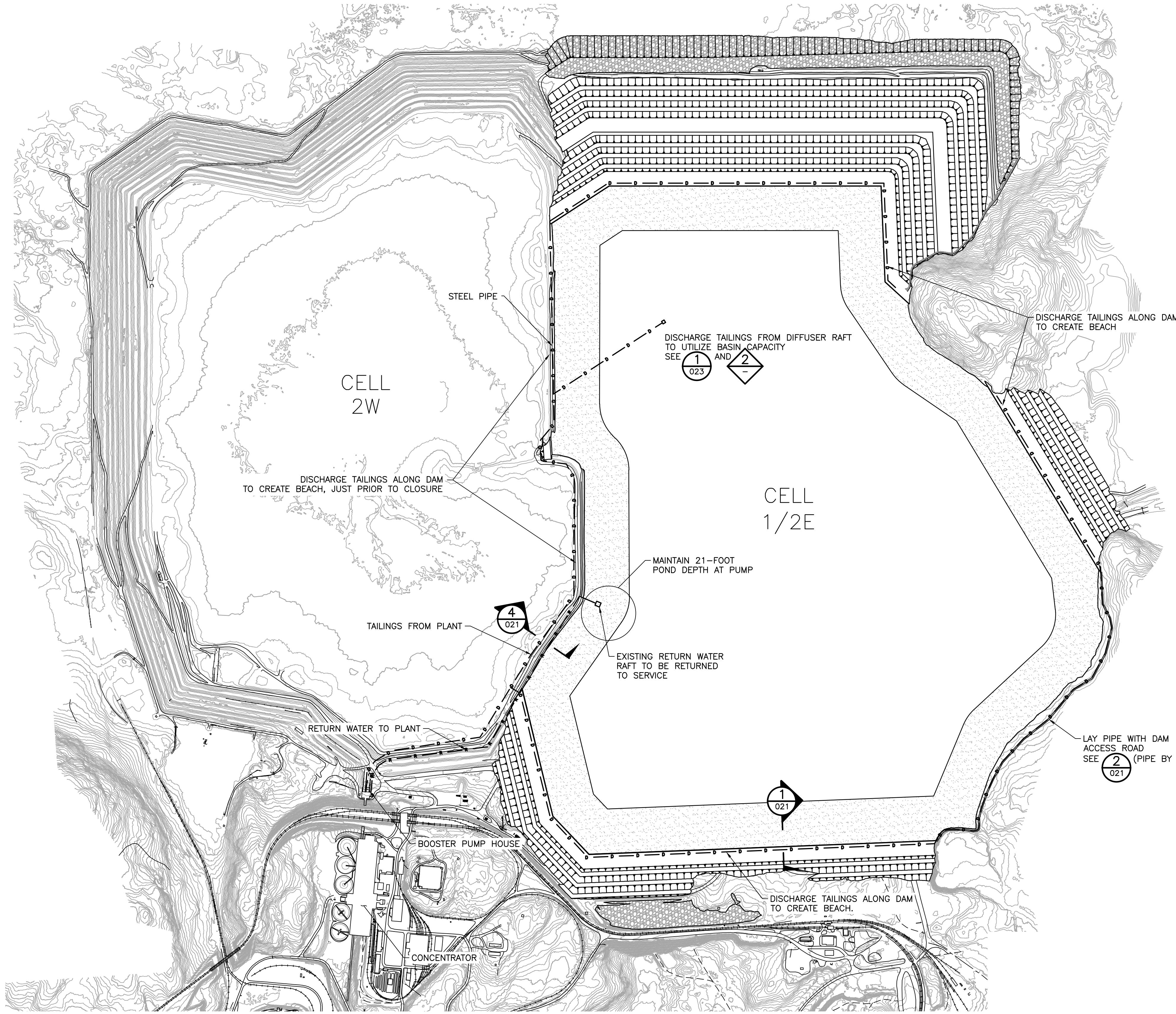

1 PLAN: PIPING LAYOUT CELL 1/2E

0 800 1600

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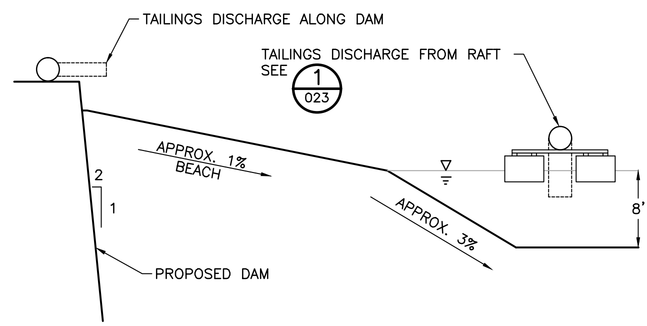

2 DETAIL: TAILINGS DISCHARGE ALONG DAM

NTS

NOTES:

1. PIPELINE LOCATIONS ARE PRELIMINARY.

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2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
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SIGNATURE Thomas J. Radue

DATE 5/12/17 LICENSE# 20951

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CHECKED: TJR

BARR PROJECT NO.: 23/69-0C29

SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
PIPING LAYOUT CELL 1/2E

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
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DWG. NO. FTB-020

REV A

CADD USER: Cristion A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-020.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:46 AM

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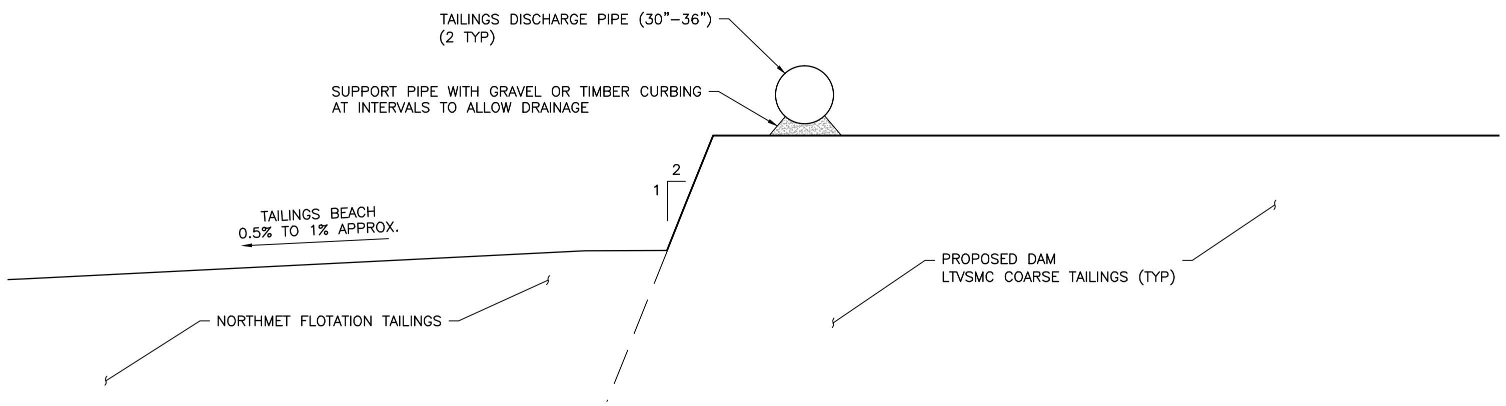
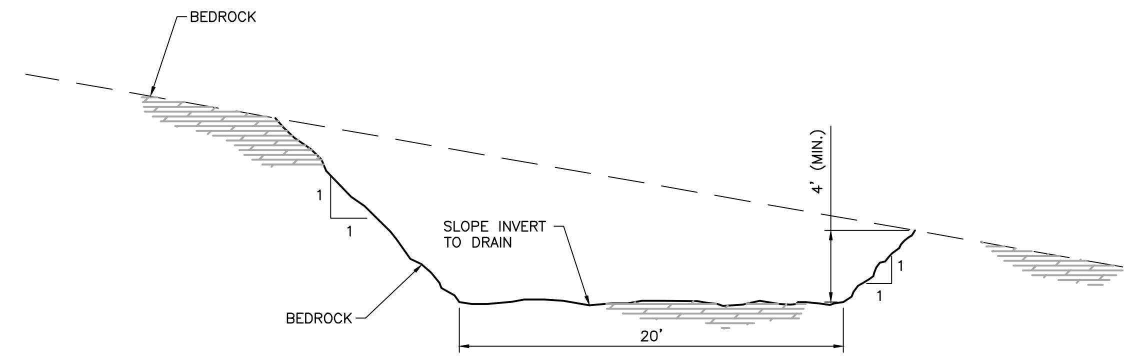


1 / 019 SECTION: TYPICAL PIPE LAYOUT
NTS



3 / 011 SECTION: CLOSURE EMERGENCY OVERFLOW
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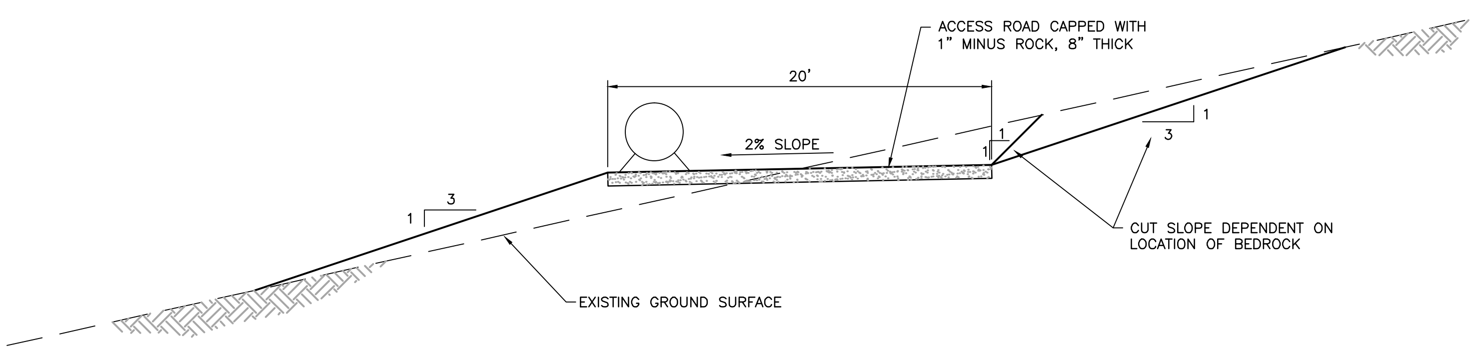
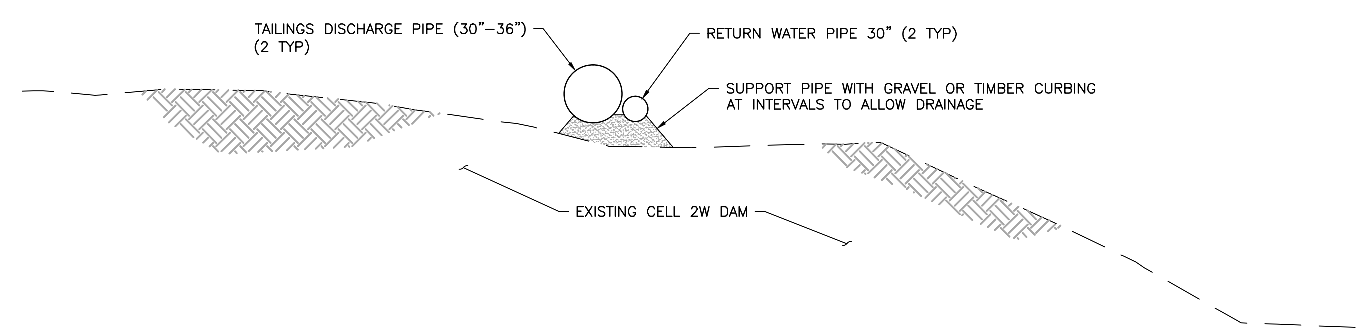


2 / 011,013,020 SECTION: DAM ACCESS ROAD
5 10
SCALE IN FEET



4 / 020 SECTION: TYPICAL RETURN PIPE LAYOUT
NTS

NOTES:

1. EMERGENCY OVERFLOW SIZING AND CONFIGURATION IS PRELIMINARY.
2. PIPELINE INFORMATION IS PRELIMINARY.
3. CONSTRUCT CLOSURE EMERGENCY OVERFLOW AT CLOSURE. OPERATIONS–PHASE EMERGENCY OVERFLOW TO BE MAINTAINED OR REMOVED AT OWNER'S DETERMINATION.
4. ALL PIPE SIZES SHOWN ARE PRELIMINARY.

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SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN DETAILS

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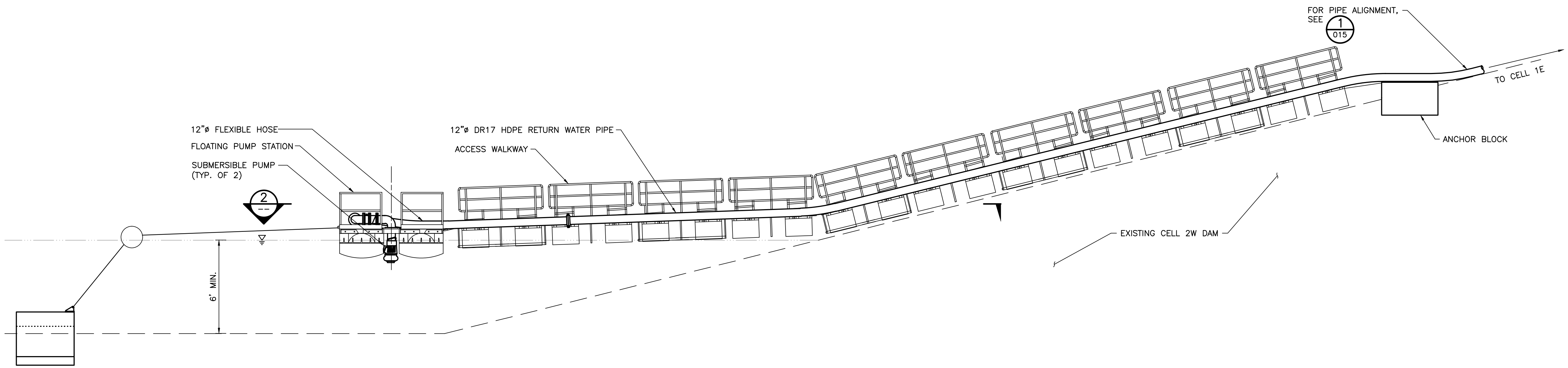
DWG. NO. FTB–021
REV A

INCHES 1 2



1 ELEVATION: TRANSFER PUMP RAFT

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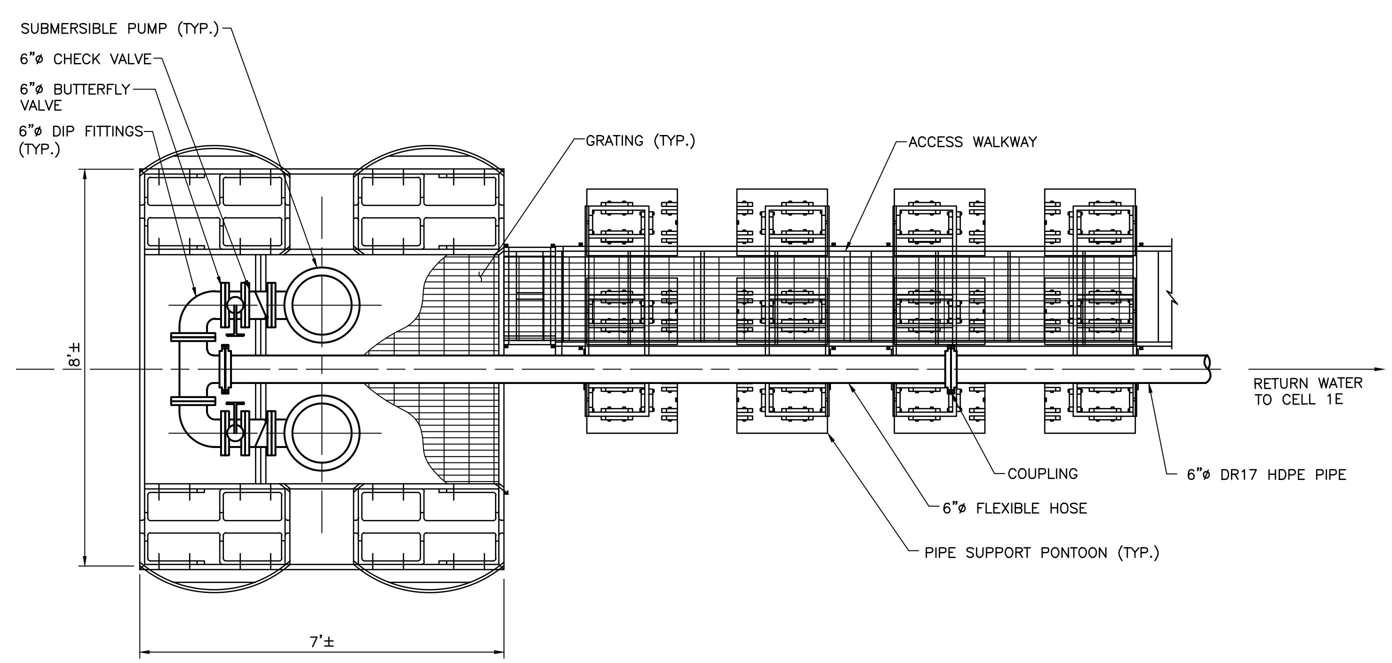

2 PLAN: TRANSFER PUMP RAFT

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SCALE IN FEET

NOTES:

1. ALL PIPE SIZES SHOWN ARE PRELIMINARY.

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PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
TRANSFER PUMP RAFT

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REV A

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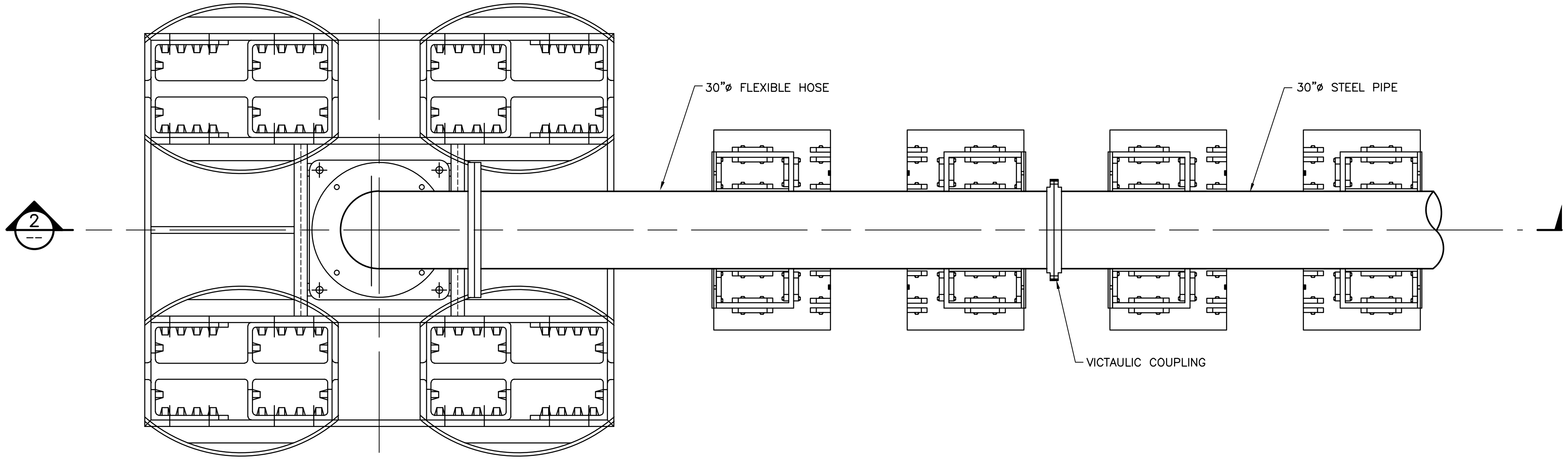
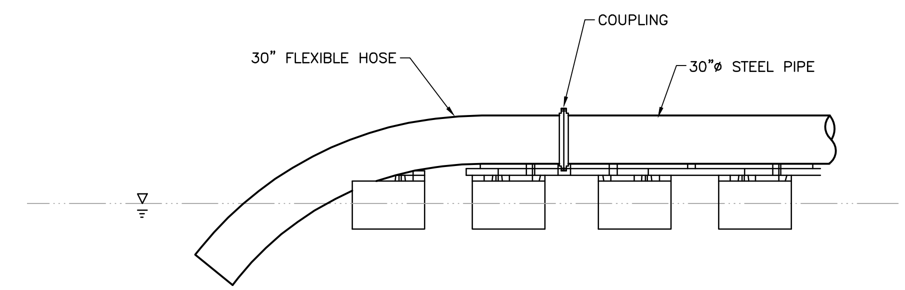


1 PLAN: TAILINGS DISPOSAL DIFFUSER RAFT
NTS



3 ELEVATION: PIPE OPEN END OPTION
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NOTES:

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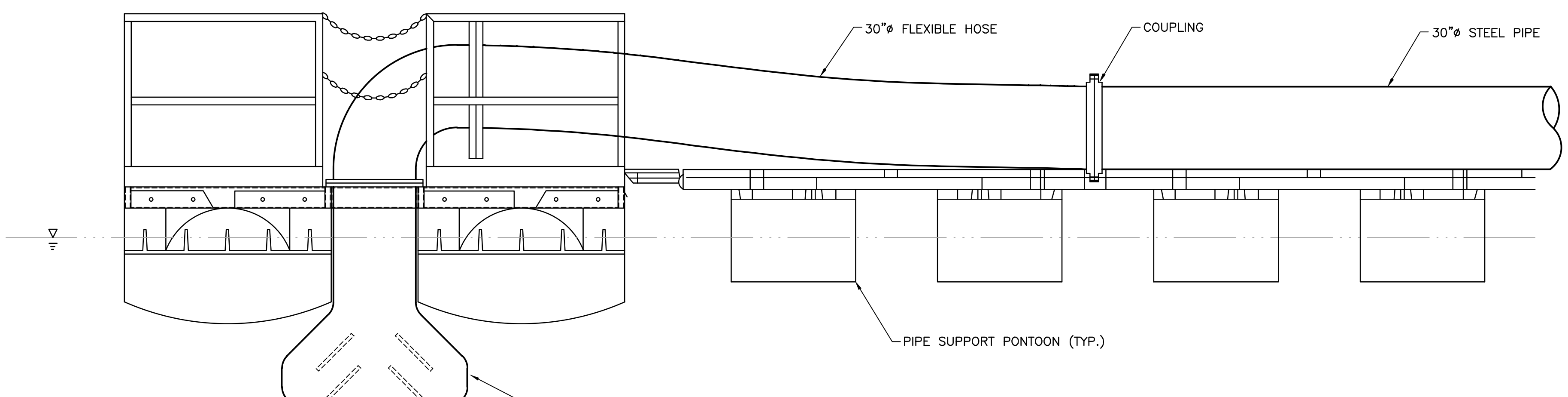

DIFFUSER
SEE 3
FOR OPTIONAL CONFIGURATION

2 ELEVATION: TAILINGS DISPOSAL DIFFUSER RAFT
NTS

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
TAILINGS DISPOSAL DIFFUSER RAFT

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REV A

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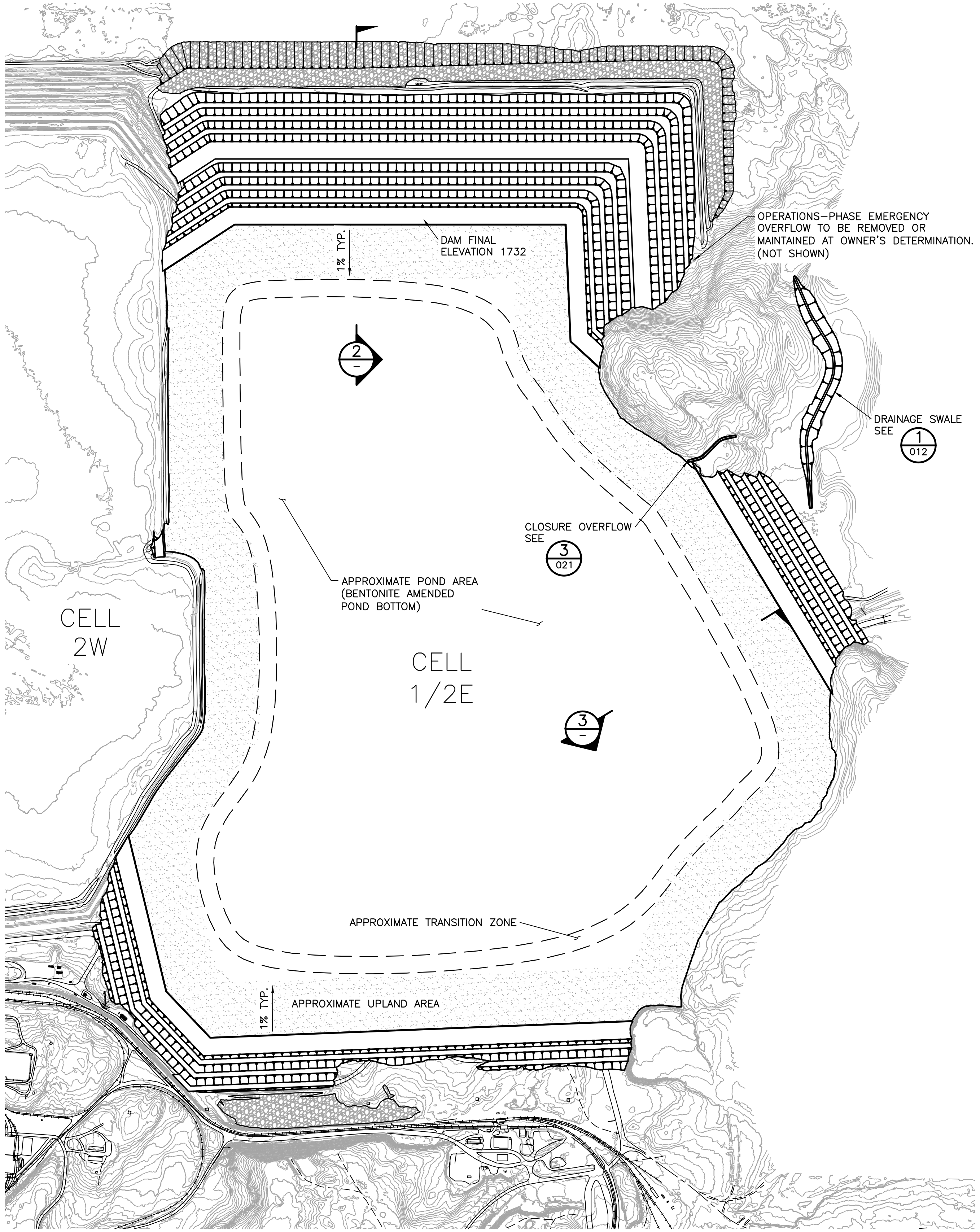

1 PLAN: PROPOSED CLOSURE PLAN
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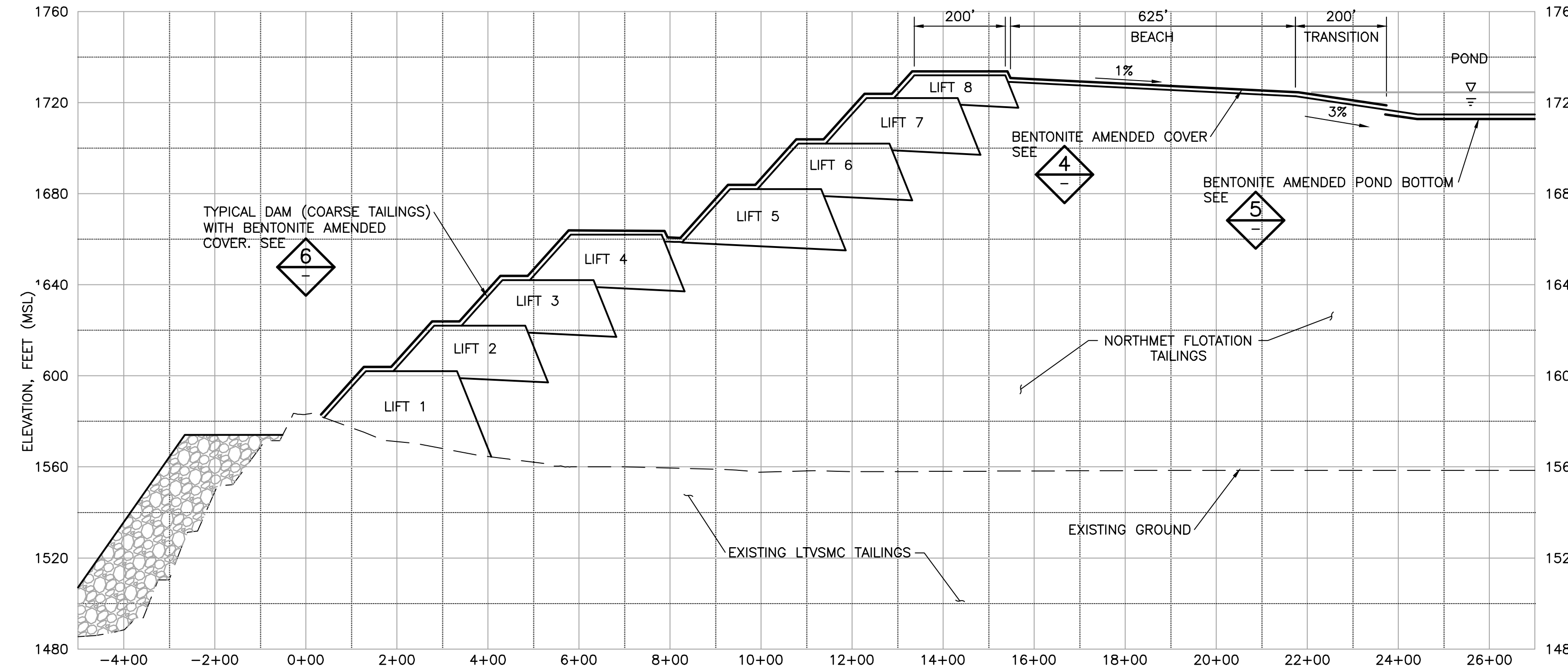

2 SECTION: CELL 2E TAILINGS BASIN CLOSURE TYPICAL SECTION
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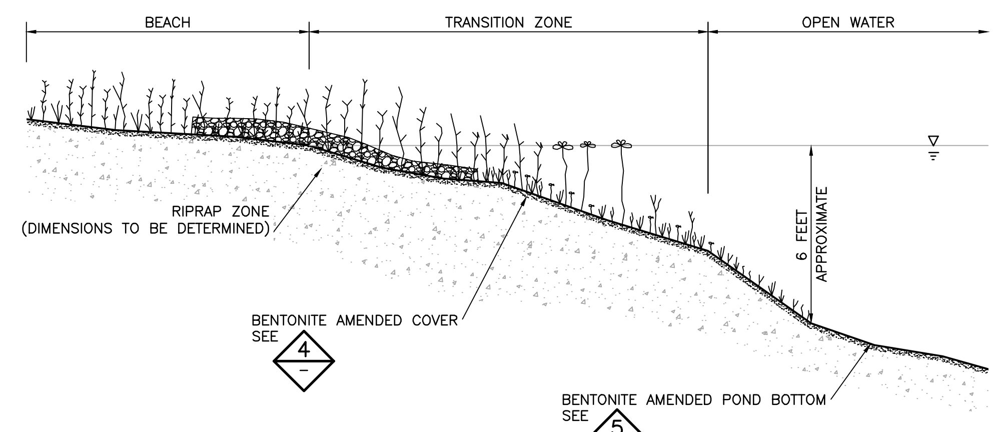

3 SECTION: SCHEMATIC TAILINGS BASIN CLOSURE SURFACE
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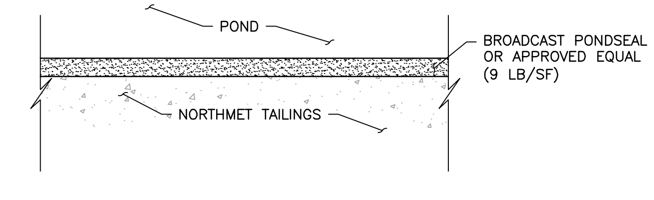
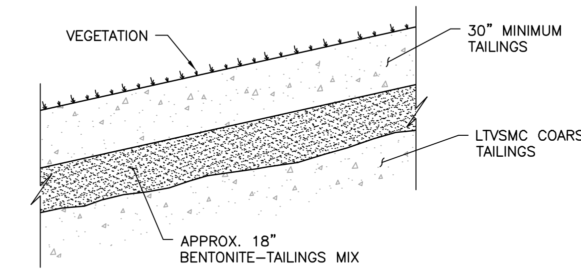


5 DETAIL: BENTONITE AMENDED POND BOTTOM
NTS



6 DETAIL: DAM SLOPE BENTONITE AMENDED COVER
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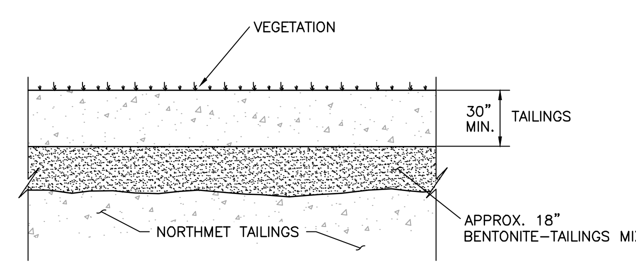

4 DETAIL: BENTONITE AMENDED BEACH COVER
NTS

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
CLOSURE PLAN

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NORTHMET PROJECT
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DWG. NO. FTB-024
REV A

INCHES 1 2

Attachment B

Saint Anthony Falls Tailings Deposition Modeling Report (previously submitted)

May 5, 2011

Stuart Arkley
Department of Natural Resources
500 Lafayette Road
PO Box 25
St. Paul, MN 55155-4025

Jennifer Engstrom
Department of Natural Resources
500 Lafayette Road
PO Box 45
St. Paul, MN 55155-4045

Re: PolyMet Tailings Basin Delta Formation Study – St. Anthony Falls Laboratory

Dear Stuart and Jennifer:

On behalf of PolyMet Mining Inc, Barr is providing the attached documents which are being used in conjunction with the design and water quality impacts modeling of the NorthMet project Flotation Tailings Basin. The attached documents consist of:

- Physical Model Study of Fine-Grained Tailings Delta Formation Under Various Inflow Conditions: Project Report, Prepared by Saint Anthony Falls Laboratory (SAFL) – University of Minnesota, March 2011.
- Practical Interpretation of the SAFL Report, Barr Engineering Company Memorandum, May 2011.

The Executive Summary of the SAFL report provides a brief overview of their study objectives and findings. The SAFL work was undertaken to accomplish the following:

- Using lab-scale experiments, estimate the degree of flow channelization and particle size sorting that can be expected on the full-scale Flotation Tailings Basin, with an emphasis on estimating the minimum percent fines (percent smaller than 74 microns) that can be expected to be retained within the exposed beach of the tailings basin.
- Using lab scale experiments, estimate the range in beach slope that can be expected on the full-scale Flotation Tailings Basin.
- As a secondary objective, evaluate the hydraulic conductivity of the deposited tailings.

The Practical Interpretation of the SAFL Report Memorandum provides a summary of Barr's interpretation of the March 2011 SAFL report and the recommended approach to application of the SAFL data to the modeling of the water quality impacts from the Flotation Tailings Basin.

While the SAFL study was carefully planned to thoroughly assess the physical properties of the tailings in SAFL lab-scale experiments, there was no plan to collect samples for chemical analyses as part of the experiment. However, during the conduct of the experiment, it was recognized that it might be informative to assess sulfur content in the tailings after the experiment was completed. As an afterthought, SAFL was informally requested to collect a few samples from the concluded experiment. The samples were collected, sent to PolyMet and subsequently forwarded to ALS-Chemex for analysis. Since this work was not part of SAFL's scope of work, a summary of this work and data will be provided under separate cover from PolyMet.

Barr recommends that if there are questions as to how the SAFL results and Barr's interpretation of those results are utilized in the upcoming project modeling, that the those questions be addressed through the Modeling Phase Agency Technical Teams.

Please note that the SAFL report and interpretation memo provided with this transmittal will ultimately be incorporated into the Geotechnical Data Package.

Best regards,

Thomas J. Radue

Tom Radue
Barr Engineering Company

Encl: Ref. This Letter, First Paragraph for List of Enclosure

Physical Model Study of Fine-Grained Tailings Delta Formation under Various Inflow Conditions: Project Report

Project Report Number 551

Prepared by

St. Anthony Falls Laboratory
University of Minnesota

For

Barr Engineering Company

March 2011

Project General Information

Title:
Physical Model Study of Fine-Grained Tailings Delta Formation under Various Inflow Conditions

Principal Investigator:
Jeffrey Marr

Project Team:
Jeffrey Marr (PI), Chris Paola (Co-PI), Craig Taylor, Sara Johnson, Aaron Ketchmark, & Anne Haws

Institution:
Regents of the University of Minnesota

Sponsor:
Tom Radue
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4700 West 77th Street
Minneapolis, MN 55435-4803
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Web: www.safl.umn.edu

Table of Contents

Executive Summary

The University of Minnesota's St. Anthony Falls Laboratory (SAFL) was contracted by Barr Engineering Co. to perform a series of physical laboratory models related to tailings delta formation as part of an Environmental Impact Study for the development of new copper/nickel mine in northern Minnesota. Phase I of the project involved 1D flume experiments, at field scales, to evaluate the potential for debris flow behavior and channelization as well as to develop an initial beach slope prediction matrix. In Phase II of the project, two laboratory scale deltas were grown in SAFL's delta basin. The delta experiments were designed such that the laboratory scale delta would have a similar degree of channelization as the field scale delta. The Phase II experiments also looked at the range of fines (<74 micron) retention in the deposit with focus on generated deposits that represent lower limit of fines concentration in the final surface of the deposit.

Prototype tailings were used in the Phase I study and were provided by Polymet. Phase I experiments indicated that debris flow-type behavior will not be the transport and depositional mechanism rather the delta be constructed from fluvial-braide processes and channelized. Phase I also indicated that, within the expected range of slurry discharges, the beach slope will likely range between 0.5% and 2%.

Phase II of the project focused on 2D basin experiments to evaluate grain size sorting, heterogeneity, and hydraulic conductivity in the deposit. An 5 m by 5 m by 0.4 m deep research basin located at SAFL-UMN was used for the tests. The degree of fines retention within the delta was measured from surface scrape samples taken from the beach at various times during basin operation. Scrape samples were analyzed for coarse/fine fraction by washing the samples through a 74 micron sieve. The degree of channel-lens formation in the deposit was investigated on two cross-sectional freeze slices taken from the Run 2 deposit. The Phase II results showed clear visual indication of sorting. Grain size sorting was present in the form of downstream fining (particle size segregation toward smaller grain size along the flow) and coarse/fine lenses (internal structures formed by filling abandoned flow channels with sediment). The results of Phase II suggest that the field scale delta will likely exhibit significant heterogeneity related to channelization. The field delta should have a minimum of 30% (by weight) fines retention throughout. Hydraulic conductivity measurements made on the laboratory deposits showed a decrease in conductivity with distance from the slurry source, suggesting that the groundwater transport through the delta will likely be greater at the upstream end than at the downstream end.

Prediction of the degree of water retention in the field scale deposit cannot be done conclusively. The estimated deposit thickness and the Soil-Water Characteristic Curve (SWCC) for the tailings suggests that suction (the tailings ability to wick water) will not be great enough to keep the deposit saturated; however, internal structures such as lenses, grainsize discontinuities, or micro-pore structure developed from natural deposition may increase the suction pressure of the material and decrease permeability.

1.0 Introduction

The University of Minnesota's St. Anthony Falls Laboratory (SAFL) was contracted by Barr Engineering Co. (BARR) to perform a series of physical laboratory models related to tailings delta formation as part of an Environmental Impact Study for the development of a new copper/nickel mine in northern Minnesota. At the site, a tailings basin would be created to collect sediment from process water effluent. The tailings production would be approximately 32,000 tons/day and would discharge to the tailings basin as a 31.5% solids (by weight) slurry via a pressurized pipe. Multiple input points would be designed around the perimeter of the basin giving operators control on feed-points.

It is not feasible to reproduce, in the same experiment, both the local flow and sediment-transport conditions and a fully developed channel network. Accordingly, our strategy was to run two sets of experiments: one to study field-scale flow and sediment dynamics in a relatively narrow, long flume (Phase I); and the second to study channelization and its effect on deposit heterogeneity at a substantially reduced scale in an open basin (Phase II).

Phase I of the project involved 1D flume experiments, at field scales, to evaluate the potential for debris flow behavior and channelization as well as to develop an initial beach slope prediction matrix. These experiments were conducted in a 6-inch wide glass-walled flume with a metered slurry input at the proximal end and a pooled tailbox at the distal end.

Phase II of the project focused on 2D basin experiments to evaluate grain size sorting, heterogeneity, and hydraulic conductivity of the deposit. The goals of the 2D experiments were to 1) determine the expected lower limit of fines concentration in the deposit, 2) determine the degree of grain size segregation both vertically and horizontally within the deposit, and 3) evaluate the potential range of hydraulic conductivity throughout the model delta.

Phase II was conducted in a rectangular research basin located at SAFL. The research basin is designed for studying deltas and tailings ponds and is referred to as DeltaBasin2. Figure 1 is a schematic of the delta basin. The delta basin had inlet controls, pool level controls, overhead camera, and a topographic scanning system. The data collected for Phase II included grain coarse/fine fraction, hydraulic conductivity, topography, aerial images, freeze slices, and lens grain size distributions. The experimental facility, setup, and data collection is discussed in more detail in the sections below.

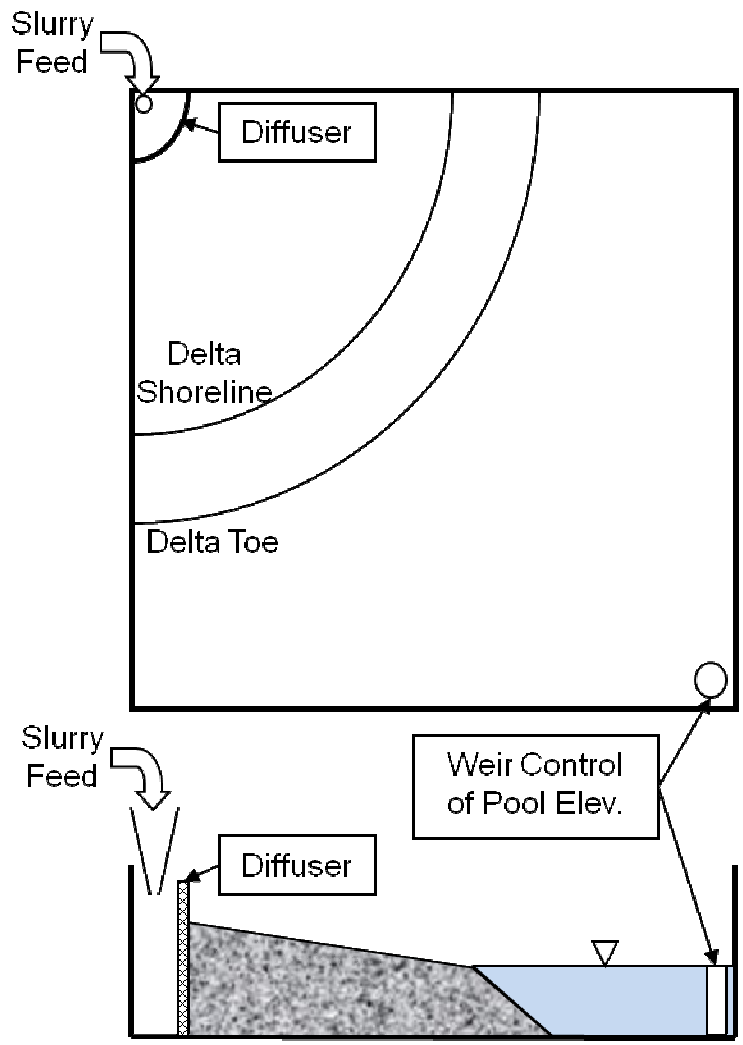

Figure 1 – Schematic of the delta basin. Top is plan view of the basin. Bottom is section view.

2.0 Tailings Supply Information

At the field site, the tailings would be delivered to the basin in the form of a high concentration slurry. Under this design scenario, the slurry is expected to deposit sediment to create a sloping subaerial deposit termed the “beach”. The planned slurry flow rate is 31.1 cfs with a solids fraction of 31.5% by weight (Table 1). The slurry would be delivered to the tailings basin at several locations, each location forming a radial fan with a spatial scale on the order of hundreds of feet. Laboratory testing focused on a single feed point.

The standard definition for the division between clay and silt size particles and between silt and sand size particles is 0.005 mm and 0.075 mm. The tailings material used in this study was prototype material provided by Polymet and was composed of fine sand to clay-sized particles, with a D_{50} (median grain size) of 60 microns (See Appendix A for Soil Engineering Testing, Inc. grain size distribution). By weight, the material averages around 41% (between 35 and 48%) of the tailings sediments were greater than 74 microns (also used as the division for “fine- “ or “coarse-grained” material). Laser diffraction analysis of the tailings indicate that, although the material had many clay-sized particles, it did not contain much mineral clay.

It should be noted that PolyMet provided two grind types (grain size distributions) for their tailings however the difference between the two was minor. The grain sizes reported here are for the final grind. The preliminary grind was similar with 32% of the sediment greater than 74 microns by weight. Due to a limited supply of tailings from the pilot plant, the first run and 1D flume testing was conducted with the preliminary grind tailings supply, and the second run was conducted with the final grind tailings supply. It is believed that the two grinds are similar enough that they will produce similar delta characteristics.

Table 1 – Slurry Source Information

Item	Qty	Unit
Solids Production*	1452	tons/hour
Tailings Production (wt)	34848	tons/day
Tailings Production (wt)	806.7	lb/sec
Liquor Flow*	3161	tons/hour
Liquor Flow	75864	tons/day
Liquor Flow	1756.1	lb/sec
Slurry Flow*	4614	tons/hour
Slurry Flow	110736	tons/day
Slurry Flow	2563.3	lb/sec
Solids Fraction by wt in slurry*	31.5	% wt
Specific Gravity of Solids*	3	
Specific Weight of Solids	187.2	lb/ft^3
Specific Gravity of Slurry*	1.322	
Specific Weight of Slurry	82.5	lb/ft^3
Tailings (Solids) Production (volume)	4.3	ft^3/sec
Water Flow Rate (volume)	28.1	ft^3/sec
Volumetric Flow Rate for Slurry	31.1	ft^3/sec
Volumetric Flow Rate for Slurry*	13947	gal/min
Solids Fraction by Volume	13.90%	% vol

* Value provided by Barr Engineering.

3.0 Phase I – 1D Flume Experiments

3.1 Phase I Experimental Design

3.1.1 Design Theory

The 1D flume experiment was run approximately at field scale. The sediment and water flows in the flume were adjusted to model different locations on the tailings beach. When Phase I was set up, we had no way of knowing the general nature of the flow regime to be expected on the beach, i.e. channelized fluvial versus some form of mass or debris flow. One of the main goals of Phase I was to determine this. For design purposes, we assumed that the tailings beach would have sheet flow (i.e. no flow channelization or braiding) over a 180° fan. On a radial beach, the water flow spreads out as it flows away from the inlet. Although the total water discharge across the delta does not change with radial position, the unit discharge (flow per unit width) decreases as the flow spreads. The relationship between radial position and unit discharge is given by equations 1 and 2 (Figure 2). Once the unit discharge has been determined for any given radius, the required equivalent flume water discharge can be determined by multiplying by the flume width (6 inches). Results from these calculations are included in Table 2.

$$L(r) = \pi * r \qquad (1)$$

$$q(r) = \frac{Q_w}{L(r)} \qquad (2)$$

Where: Q_w = Water discharge at inlet

r = Radius

L = Arc length of the delta

q = Unit discharge of water

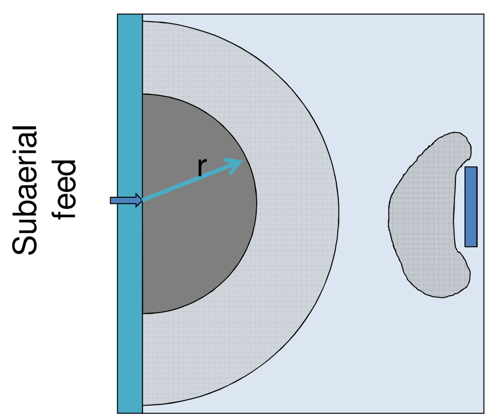

Figure 2 – Diagram of 180° delta fan.

Table 2 – Radial Position and Model Discharge

r (ft)	L (ft)	qw (cfs/ft)	Model (cfs)	Model (GPM)
50	157	0.198	0.0990	44.40
100	314	0.099	0.0495	22.20
150	471	0.066	0.0330	14.80
200	628	0.049	0.0247	11.10
250	785	0.040	0.0198	8.90
300	942	0.033	0.0165	7.40
350	1100	0.028	0.0141	6.30
400	1257	0.025	0.0124	5.60
450	1414	0.022	0.0110	4.90
500	1571	0.020	0.0099	4.40
550	1728	0.018	0.0090	4.00
600	1885	0.016	0.0082	3.70
650	2042	0.015	0.0076	3.40
700	2199	0.014	0.0071	3.20
750	2356	0.013	0.0066	3.00
800	2513	0.012	0.0062	2.80

Like the water discharge, the sediment discharge also decreases with distance from the inlet. This is due not only to spreading of the flow across delta but more importantly to sediment being deposited over the length of the delta. In other words, the sediment unit discharge and concentration decrease with increasing radial position.

Phase I experiments focused on observing the character of the flow and quantifying slopes of the delta for various water discharge and sediment concentrations using prototype tailing provided by PolyMet. The experiments provided a clear picture of the flow regime to be expected and an understanding of the range of possible slopes and sediment concentrations as functions of radial position for the tailing beach being modeled.

3.1.2 Phase I Apparatus

The testing setup for the 1D study consisted of a mixing tank, a six-inch flume, and a tail box. The mixing tank was a 220-gallon stainless steel cylindrical tank with a conical bottom. A 0.25 hp Lightin© tank mixer with a seven-inch propeller was used to keep the solids fraction of the slurry in suspension. The outlet of the mixing tank was 8.5 feet above the inlet of the flume. Slurry was conveyed from the mixing tank to the flume inlet via 24 feet of 2-inch pvc pipe. There were ball valves at each end of the pipe and one gate valve at the downstream end to control the flow rate. The flow rate was measured using an inline Seametrics© EX-81 Electromagnetic Flow Sensor. The flume was 6 inches wide by 22 feet long with no slope and glass walls. Figure 3 is an image of the upstream half of the flume. After this picture was taken a diffuser grate was added two feet downstream of the inlet. The tail box was design to capture all of the effluent from the flume. The tail box had 400 gallons of storage below its outlet. Effluent water was stored in the tail box until all fine material dropped out of suspension, at which point excess water was siphoned off and the remaining solids were removed.

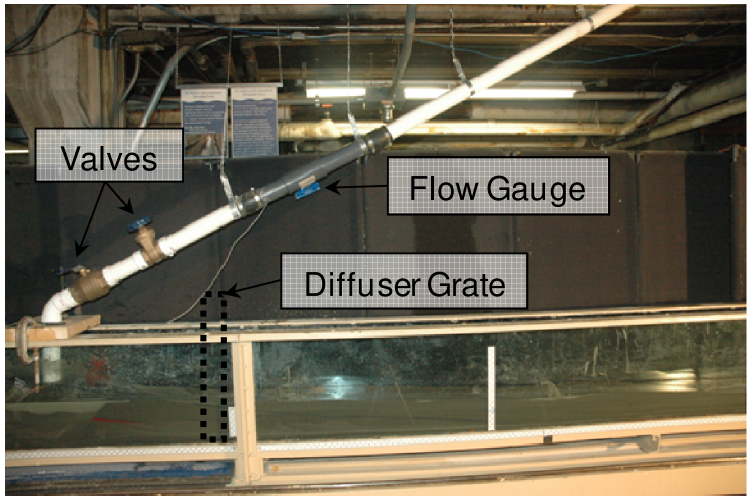

Figure 3 – Image of flume inlet.

The electromagnetic flow meter measurement was compared with that derived using a sharp crested weir placed at the downstream end of the empty flume. The flow sensor reported a discharge of 0.30 gallons/sec. The weir was 2 7/8 inches tall by 6.0 inches wide. The flow depth over the weir was 1.0 inches. Using a sharp crested weir equation, this yields a flow rate of 0.301 gallons/sec.

3.1.3 Phase I Experimental Procedure

Given the argument above that sediment concentration is expected to decrease down the beach, runs were conducted for a high and low solids fraction and slurry flow rates ranging from 5 to 60 GPM. Each run continued until the delta slope for that concentration and discharge was at equilibrium. One batch of slurry mix contained enough slurry for several runs. Runs were conducted in series starting with a high discharge and reducing for each consecutive run. The reducing discharge resulted in steeper slopes for each consecutive run, meaning that all runs were aggradational. This allowed the deltas from consecutive runs to be built on top of each other.

3.1.4 Phase I Sampling Plan

Sample locations and types are depicted in Figure 4. During the runs, grab samples were taken at the inlet and outlet of the flume. Siphon samples were also taken from the flow over the delta. Grab and siphon samples were measured for solids fraction. The upstream grab samples were used only to confirm influent solids fraction. After each run the deposit profile was measured using a point gauge. Shallow (0.4 in) scrape samples were taken from the bed. These samples were sieved to determine the grain size distribution and coarse fraction. Mini-core samples were also taken from the top 0.8 in of the bed. These samples were taken with a known volume and used to measure the porosity of the bed.

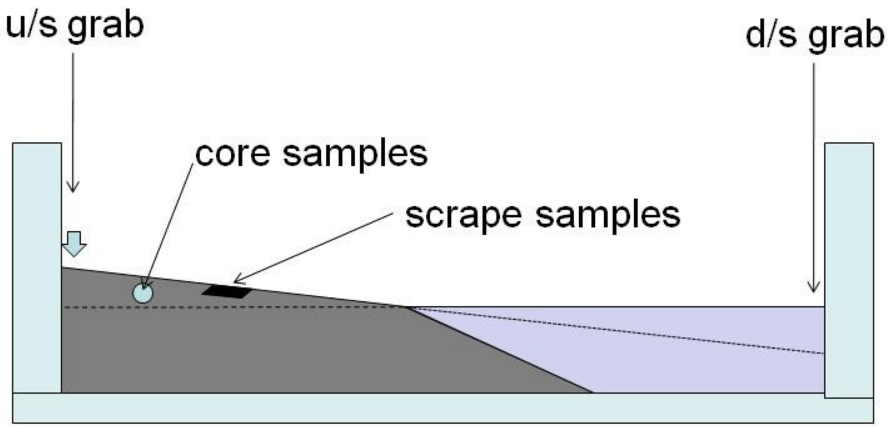

Figure 4 – Sample locations

3.2 Phase I Results

3.2.1 Qualitative Observations

Of the 16 flume runs conducted, none exhibited debris ("mud") flow behavior. Tailings were transported by the moving water as bedload and suspended load as is typical in fluvial systems. Surface flow showed a tendency to channelize and braid, even in the relatively narrow flume. Figure 5 shows cross-flow and asymmetric bedforms within the flume. These observations indicate strongly that the field scale tailings beach will also operate in a fluvial, braided and channelized regime and addresses the first two objectives of Phase I (evaluate the potential for debris flow behavior and channelization) by ruling out concerns of more complicated non-Newtonian rheologies (i.e. mud-like behaviors) and flow.

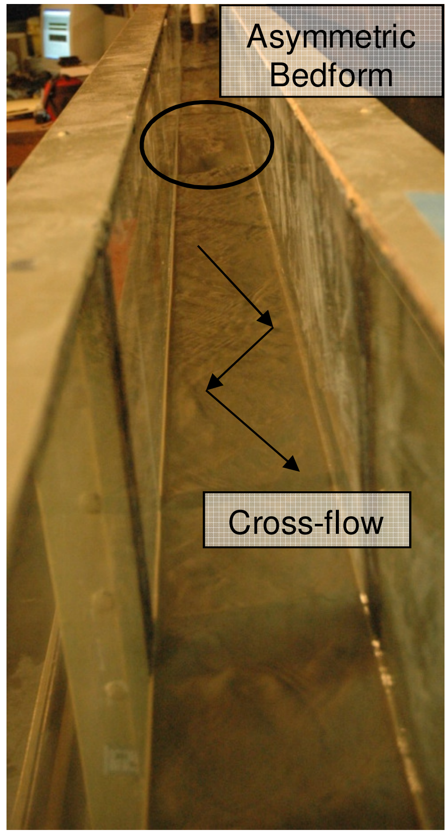

Figure 5 – Flume picture looking upstream

Nearly all runs also exhibited upstream migrating antidunes. Antidunes occur when the flow is near critical and are present in other tailings basins. They mix the upper layer of the deposit and have the potential to resuspend fine particles. A video of an upstream migrating antidune is included in Appendix D.

3.2.2 Slope Measurements

Final bed surface slopes were recorded after each test. Recall that each test provides a slope associated with a different position on the beach and is not by itself an actual beach profile. The run results have been binned into two categories - low and high solids fractions. Figures 6 and 7 show the bed profiles based on solids fraction. In both categories the slope decreased with increasing flow rates. The large spikes in the profiles are due to antidunes. The profiles for the higher discharge tests have more small spikes. These are due to the cross-flow (depicted in Figure 5) forming alternating dunes within the flume deposit. Figure 8 summarizes the slope results for Phase I showing deposit slopes for different discharges and solids fractions. Except very near the inlet, the beach slope should range between 0.5% and 2%.

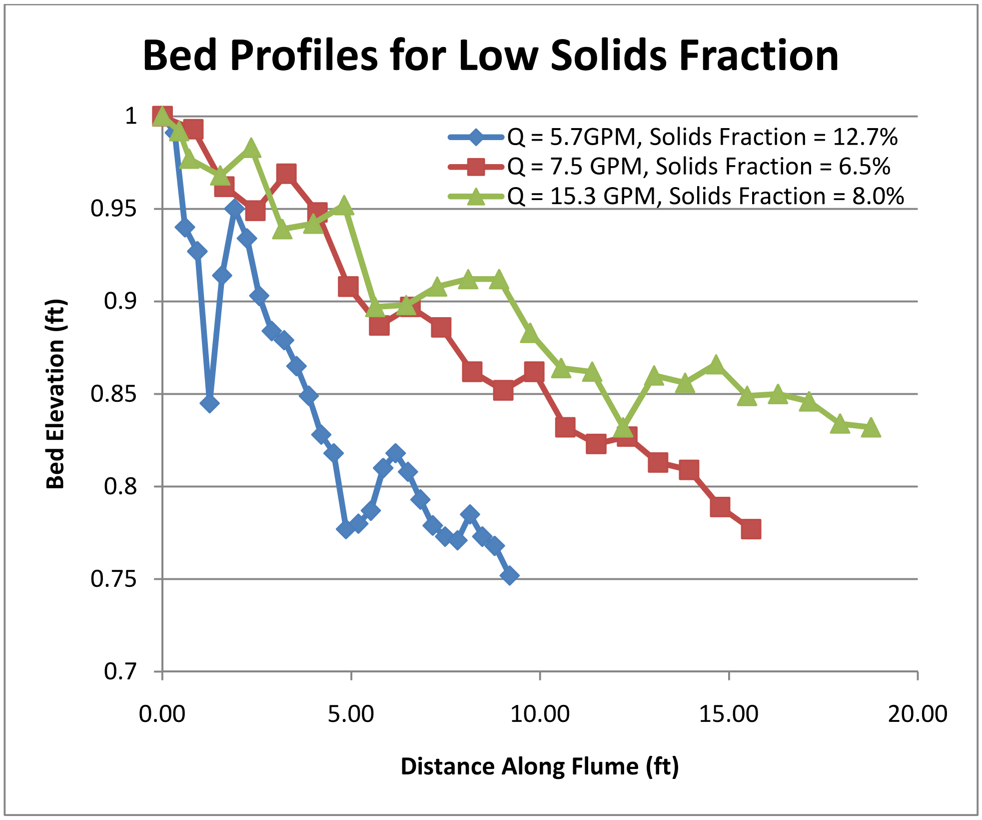

Figure 6 – Bed profiles for the low solids fraction runs

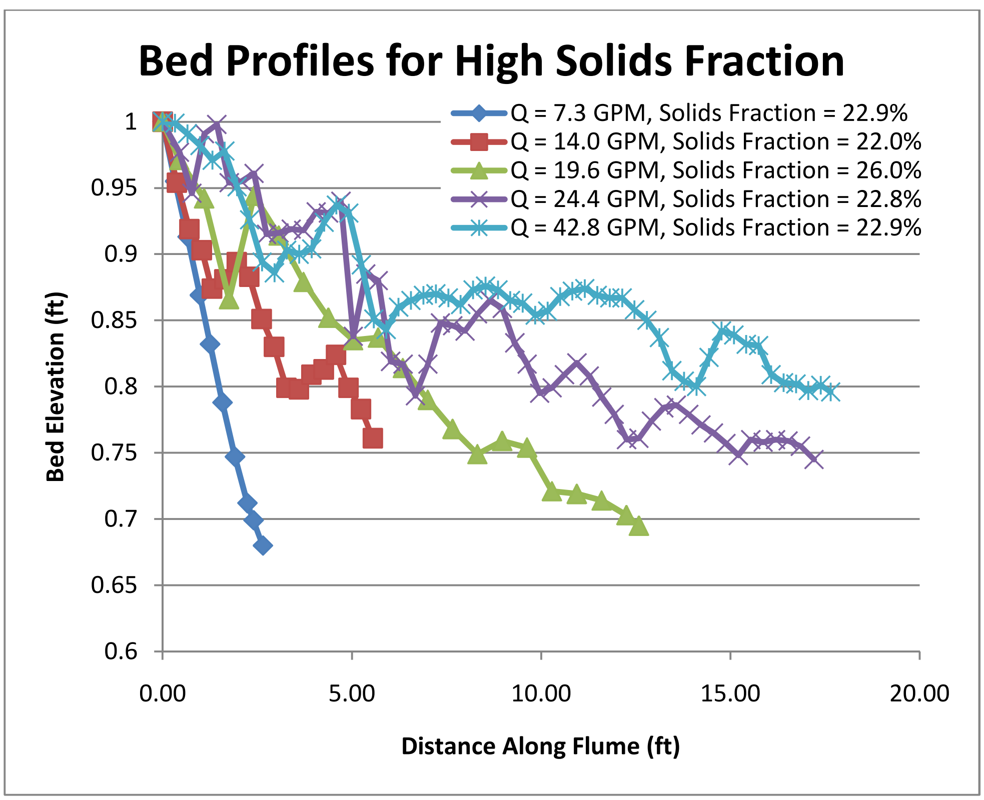

Figure 7 – Bed profiles for the high solids fraction runs

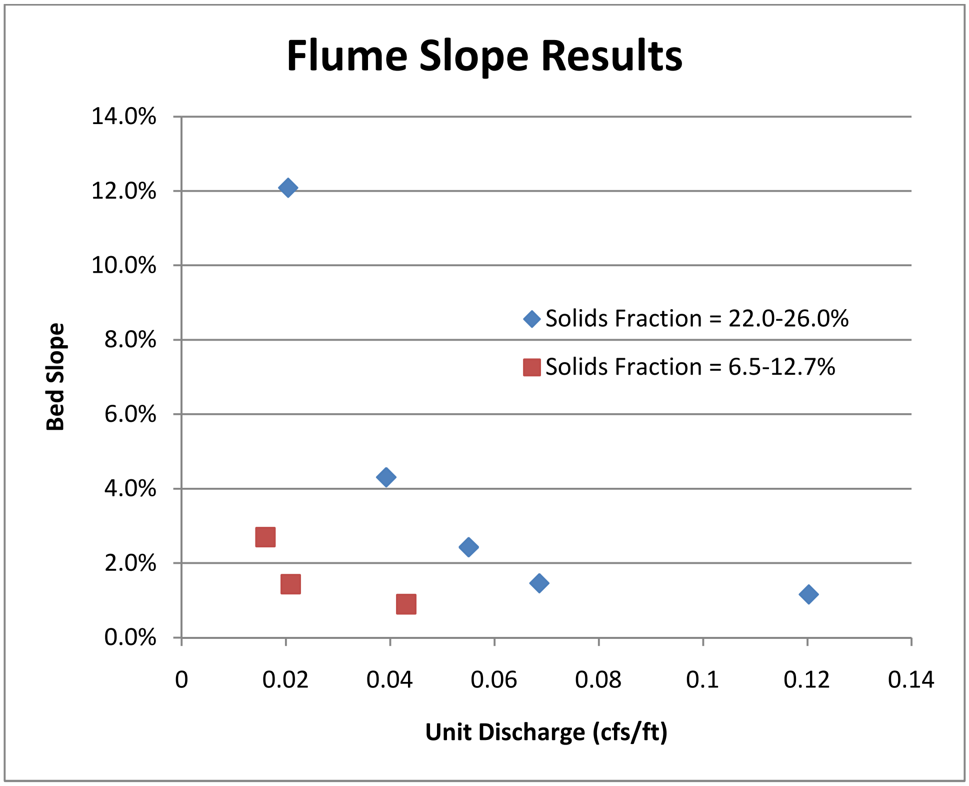

Figure 8 – Slope vs Discharge plots for high and low solids fractions.

3.2.3 Sediment Measurements

Downstream grab samples were taken from several of the runs. These samples were analyzed for solids fraction (Table 3). Samples taken at the downstream end of the flume consisted of suspended load only.

Table 3 – Downstream Solids Fraction

Q (GPM)	Feed Solids Fraction	Down Stream Solids Fraction
6.1	19.00%	6.30%
6.1	19.00%	7.00%
7.5	6.50%	2.70%
7.5	6.50%	3.50%
14.3	11.50%	2.90%
14.3	11.50%	3.00%
19.6	26.00%	4.30%
19.6	26.00%	6.10%

Porosity was measured at the end of four runs (Figure 9) using mini-core samples. A thin-walled, sharp-edged mini-corer was first inserted 0.8 in into the deposit. The deposit was then excavated away from around the mini-core and a blade was slid under the base of the mini-core to remove a known volume of saturated deposit. The samples were then weighed saturated and dry to determine water weight. The water weight was then used to determine void volume and porosity. There does not appear to be a strong trend in porosity. The variability in porosity is likely driven by the localized flow phenomena occurring at the end of the test such as bedforms. The measured values for these samples were similar to the values measured for the 2D experiments (§5.3).

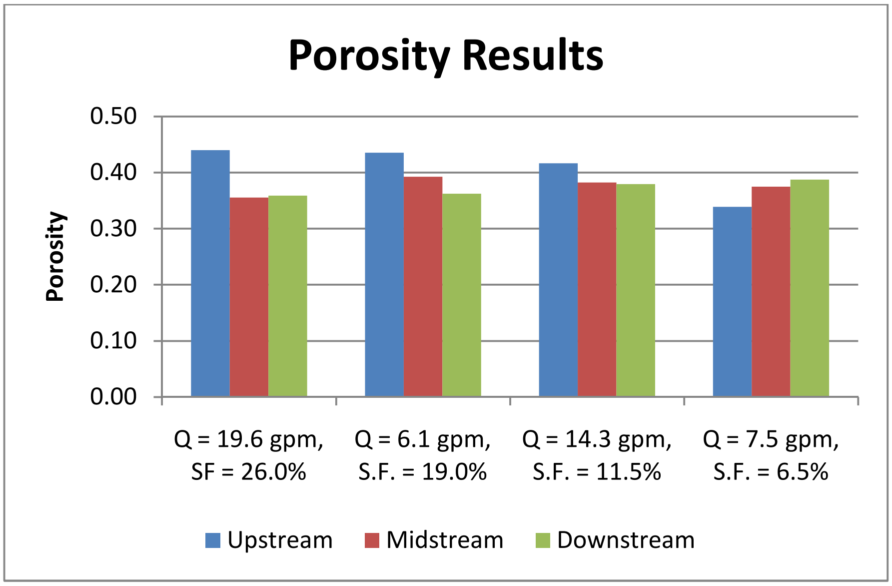

Figure 9 – 1D Experiment Porosity Measurements

Surface grain size was measured at various locations of the bed surface using surface scrape sampling method. The method involved sliding a blade 0.4 in below the surface to remove a 1.6 in square surface sample. Grain size distributions were measured for the 1D experiment scrape samples (Figure 10) by sieving. A comparison of the scrape samples to the fine tail of the bulk material showed that the deposit lost material in the 10 to 100 micron size range. This is the size range that remained in suspension and was transported out of the flume. Table 4 provides the coarse and fine fractions (above and below 74 microns) for the Figure 10 data. The coarse fraction is the total weight of sample retained on the 74 micron or larger sieve. The fine fraction is the total weight of sample passing the 74 micron sieve.

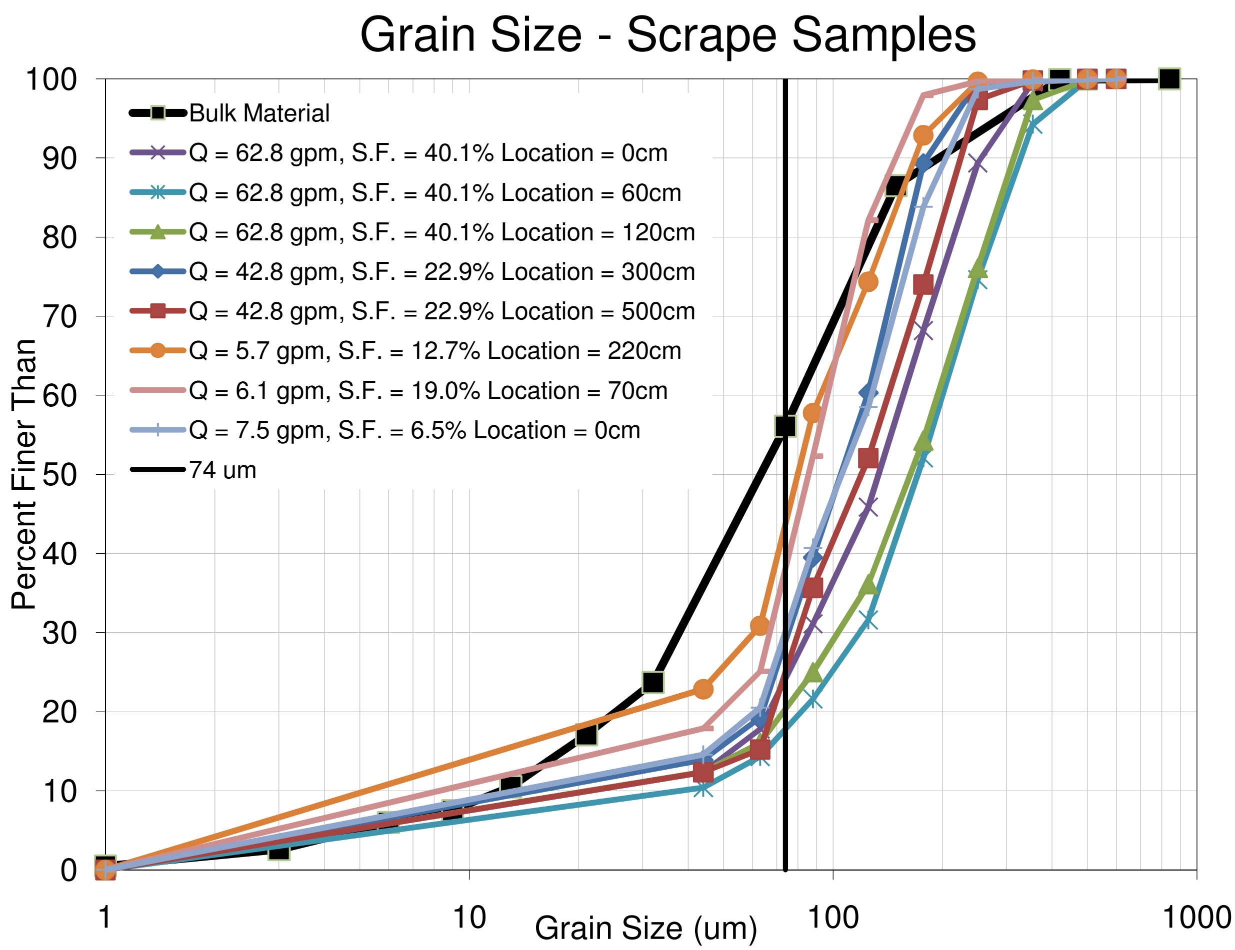

Figure 10 – 1D Experiment Scrape Sample Grain Size Distribution

Table 4 – 1D Experiment Scrape Sample Coarse and Fine Fractions (by Wt)

Discharge (GPM)	Solids Fraction	Distance from outlet	Coarse Fraction (%)	Fine Fraction (%)
62.8	40.1%	0 cm	76.3%	23.7%
62.8	40.1%	60 cm	82.5%	17.5%
62.8	40.1%	120 cm	80.0%	20.0%
42.8	22.9%	300 cm	71.8%	28.2%
42.8	22.9%	500 cm	75.8%	24.2%
5.7	12.7%	220 cm	57.3%	42.7%
6.1	19.0%	70 cm	62.9%	37.1%
7.5	6.5%	0 cm	70.6%	29.4%

3.3 Phase I Experiment Conclusions

Phase I experiments provided the opportunity to observe the flow characteristics of the prototype material under conditions of sediment concentration and unit discharge similar to those expected in the field. The tests indicate that the beach will not exhibit mass-flow (mud like) behavior and that the full 2D beach will be channelized, with a braided network. Bedforms and channelization will likely play a large role in the variability of fines retention, porosity, and permeability. We expect this would be true over the length of a field-scale beach as well and that the channelization will create heterogeneity that will affect the bulk permeability and conductivity of the deposit. Within the expected range of discharges and solids fractions the delta beach will have a slope between 0.5% and 2%. At high concentration near the inlet to the basin, local slopes could reach 4-6%.

The tests show that a fraction of fine material is transported beyond and not retained in the deposit. In the region of higher unit discharge near the inlet, the deposit contains a lower fraction of fine material than the near the shoreline of fan where lower unit discharge make it easier for finer grains to be deposited; however, the test data suggest that even at high discharges 15-30% (by wt) of the deposit is comprised of material sizes <74 micron.

4.0 Phase II – 2D Basin Experiments

Phase II of the project focused on a two dimensional physical model of a single delta using prototype tailing to observe processes and to evaluate grain size sorting and hydraulic conductivity of the deposit. The goals of the 2D experiments were to 1) determine the expected lower limit of fines concentration in the deposit, 2) determine the degree of grain size segregation both vertically and horizontally within the deposit and 3) evaluate the potential range of hydraulic conductivity throughout the model delta.

Phase II experiments were performed as “scaled” experiments using the approach described below. Experiments were conducted in a specially designed “Delta Basin” at SAFL, which provided access to several precision data acquisition tools.

4.1 Scaling Approach

Phase I experiments used field-scale unit discharges and actual tailings material to investigate flow and transport processes and deposit characteristics. Given the conclusion from Phase I that the flow would be channelized on the beach top, in Phase II the goal was to employ a reduced-scale modeling approach to investigate the formation and behavior of channels on the tailings beach without lateral constraints. Again, the prototype tailings material was used.

It is obviously not feasible to conduct full scale experiments on large deltas and therefore these experiments were done at substantially reduced scale. SAFL has over 15 years of experience in physical experiments of deltaic systems and this experience was applied in this project. The scaling methods used in projects of this type differ from traditional hydraulic physical models where near-exact geometric scaling and dynamic scaling of flow is possible. The scaling approach adopted for this project sought to provide similarity in Froude number (Froude scaling), general sediment-transport regime, and the ratio between normal flow depth to radial width of the delta. This ratio is defined as the aspect ratio, A. It has been shown that the aspect ratio is a predictor of channel morphology such as braiding, meandering or straight (Parker, 1976). This work also showed that for the low aspect ratio/high slope regime expected on the tailings beach, the degree of braiding is relatively insensitive to the exact value of A as long as A is sufficiently high (a few hundred or more). To determine input parameters for the laboratory delta, we made estimates of the aspect ratio for the field scale beach and used these aspect ratios to help set discharge and concentration parameters for the lab experiments.

For the experimental design, the delta is idealized with normal, sheet flow over a 90° opening angle. This assumption means that the flow width is equal to the arc length of the delta at any radial position, yielding for the aspect ratio.

$$A = \frac{H}{L(r)} \qquad (3)$$

Where: A = Aspect ratio

H = Flow depth

L = Arc length at a given radial position (r)

r = radial position

The first step for determining the field aspect ratio is to determine the estimated flow depth in the field. Water unit discharge along the delta is described by:

$$q_w = \frac{2Q_w}{\pi r} \qquad (4)$$

Where: q_w = Water unit discharge

Q_w = Total water discharge

Next the boundary shear stress can be derived from the normal flow assumption (Eq. 5) and by fluid drag (Eq. 6). A continuity equation relating unit discharge and flow velocity is also needed (Eq. 7).

$$\tau_b = \rho g H S \qquad (5)$$

$$\tau_b = \rho U^2 C_f \qquad (6)$$

$$q_w = UH \qquad (7)$$

Where: τ_b = Boundary shear stress
ρ = Density of water
g = Acceleration of gravity
S = Bed slope
U = Average flow velocity
C_f = Coefficient of drag

Combining equations 5, 6 and 7 yields an expression for the flow depth (Eq. 8) which can be used to estimate the flow depth in the field. Equation 3 can then be used to determine the aspect ratio in the field.

$$H = \left(\frac{q_w^2 C_f}{gS}\right)^{\frac{1}{3}} \qquad (8)$$

Table 5 shows the predicted flow depths and aspect ratios for the field. The same methods can be used to determine the aspect ratio for the experimental case. The aspect ratio of the experimental delta's shoreline is then used to estimate the equivalent radial position of the field scale beach. Run 1 had a water discharge of 4.90×10^{-4} m^3/s (1.73×10^{-2} cfs) and a sediment discharge of 7.35×10^{-5} m^3/s (2.60×10^{-3} cfs), which resulted in an aspect ratio of 1500 at the shoreline (r ~ 1.5 m, 5 ft). This translates to a radial position of about 40 m (130 ft) on the field delta. Run 2 had a water discharge of 5.18×10^{-4} m^3/s (1.83×10^{-2} cfs) and a sediment discharge of 7.77×10^{-5} m^3/s (2.74×10^{-3} cfs) which yields an aspect ratio of 3700 at the shoreline (r~2.5m, 8.2ft). This translates to a radial position of about 70 m (230ft) on the field delta.

Table 5 – Aspect ratios for the field delta with a water discharge of 0.80 m^3/s (28.1 cfs) and a sediment discharge of 0.12 m^3/s (4.3 cfs).

r (m)	L (m)	H (m)	A
5	3.9	0.108	36
10	7.9	0.062	126
15	11.8	0.045	262
20	15.7	0.036	440
25	19.6	0.030	657
30	23.6	0.026	912
35	27.5	0.023	1204
40	31.4	0.021	1531
45	35.3	0.019	1892
50	39.3	0.017	2287
55	43.2	0.016	2715
60	47.1	0.015	3176
65	51.1	0.014	3668
70	55	0.013	4192
75	58.9	0.012	4746
80	62.8	0.012	5330
85	66.8	0.011	5945
90	70.7	0.011	6589
95	74.6	0.010	7263
100	78.5	0.0099	7965
105	82.5	0.0095	8696
110	86.4	0.0091	9456
115	90.3	0.0088	10244
120	94.2	0.0085	11059
125	98.2	0.0082	11902
130	102.1	0.0080	12773
135	106	0.0078	13671
140	110	0.0075	14596
145	113.9	0.0073	15547
150	117.8	0.0071	16526

4.2 Experimental Setup

The facility used in Phase II was an existing delta basin at SAFL (Figure 1). The delta basin is square, 5 m (16.4ft) on a side, and 40 cm (1.3ft) deep. Water and sediment were fed into one corner of the basin at a constant rate for each experiment. Prototype tailings were used as the sediment for the tests and were provided by the sponsor. Dry tailings material was fed using an auger-style sediment feeder and feeder discharge was calibrated using a capture and weigh technique.

City water was used for all experiments and the water feed rate was controlled by a gate valve and a rotameter flow meter. The water and sediment were allowed to mix in a funnel before discharging into the basin. The pool elevation in the model tailings basin was set by a computer-controlled siphon and weir that were adjusted at one-minute intervals and provided precise control of the water surface elevation throughout each experiment.

Prior to beginning the tests a drainage layer was placed in the basin that was composed of fine to medium sand. The depth of the drainage layer was 3 cm (1in) and it extended radially out from the source for 3m (10ft). This layer is typically installed in all SAFL experimental deltas to promote dewatering of the deposit post-run and to shorten drying time required before the deposit can be sectioned.

The basin was equipped with a data collection carriage including a laser scanner that can measure topography accurate to 0.5 mm vertically. The carriage was used to map surface topography throughout the testing. A digital SLR camera, mounted above the basin, was calibrated for optical distortion and used to collected time-lapse images of the delta formation and surface processes.

4.3 Experimental Procedure

Two deltas were constructed in Phase II (Run 1 and Run 2). Each delta was constructed in three phases. The first phase (growth phase) modeled the initial formation of a delta into a sediment free basin with a stationary pool elevation of 30 mm (1.2in) (Figure 11). During this phase the delta grew out to a radius of approximately 1.5 meters (5ft). The second phase (building phase) involved slowly raising the pool elevation such that the shoreline position was constant (Figure 12). This continued until the delta thickness increased by a total of 10 cm (4in). The third phase involved a slow decrease in pool elevation in order to promote delivery of tailing to the shoreline position and to minimize deposition on the fan surface except for the coarsest material (Figure 13).The third phase (falling phase) of each experiment was designed to generate the coarsest possible deposit, with the strongest lateral segregation of material possible. The goal was to understand how coarse and permeable the delta deposit could be for a “worst case” transport scenario. Analysis of the third phase deposit provides a reference case for permeability and other characteristics of a deposit created under the most extreme conditions of sorting and coarse-sediment retention.

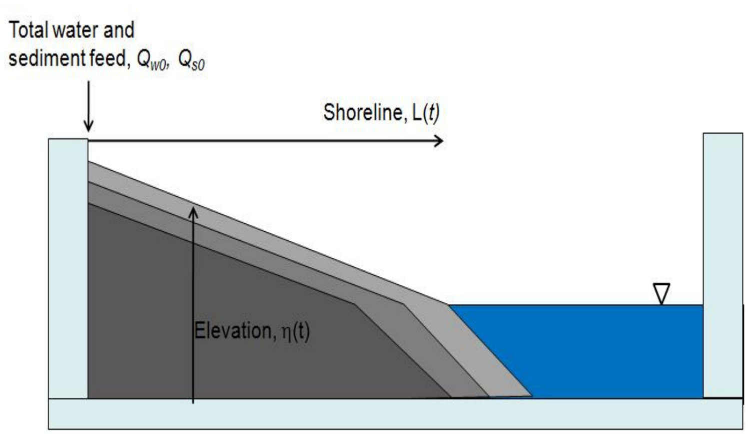

Figure 11- Delta growth with constant pool elevation

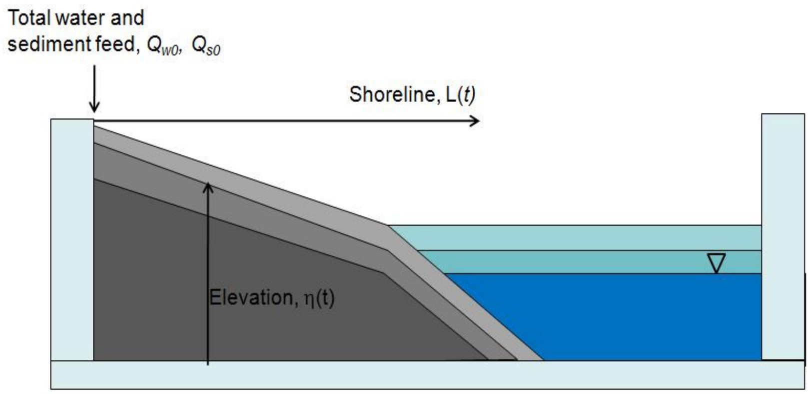

Figure 12 – Delta growth with fixed shoreline by balanced pool rise

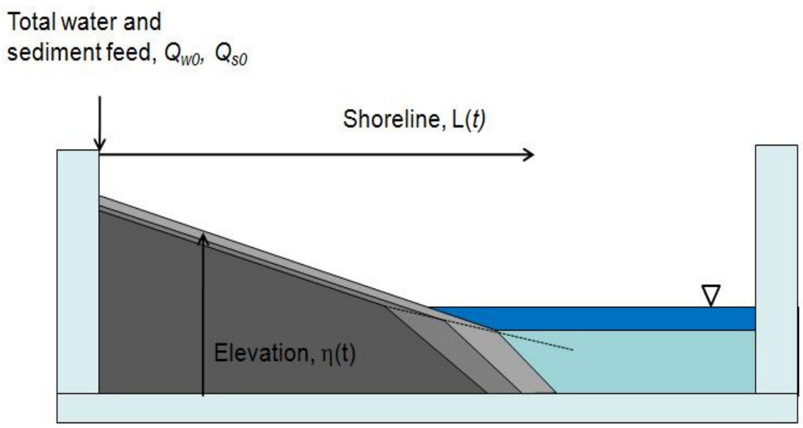

Figure 13 – Delta growth with falling pool elevation

Using the scaling approach described above, for Run 1 the water discharge was set at 0.49 liters/second (0.017 cfs). Sediment concentration was set equal to prototype design conditions giving a sediment supply rate of 0.074 liters/second (0.0026 cfs). For Run 2 the water discharge was set at 0.51 liters/second (0.018cfs) and sediment discharge at 0.078 liters/second (0.0028cfs).

4.4 Phase II Data Collection

Topographic Scans

A three axis data carriage was used to scan the surface of the subaerial deposit at the end of each pool control phase (growth, building and falling). Data are collected with a laser-based distance meter accurate to 0.5mm vertically. Scans were done on a 2mm x 2mm horizontal grid. Data were post processed and are presented later in the report.

Pool and Scrape Samples

Forty-five scrape samples were taken along 5 radial lines. Scrape samples covered approximately 10 cm^2 (1.5 in^2) of the surface and 1 cm (0.4 in) of depth (Figure 14). Three scrape samples were taken from the bottom set (bottom of the pool downstream of delta) of the delta deposit for grain size analysis.

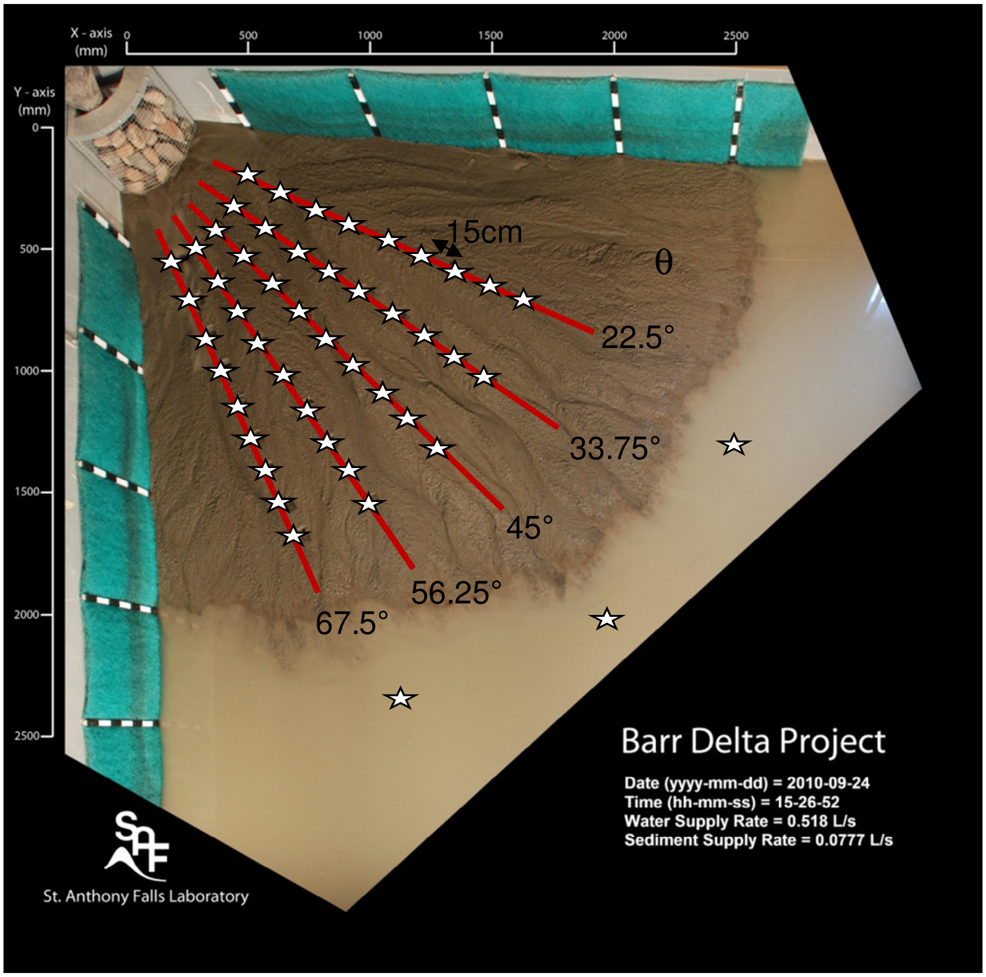

Figure 14 – Scrape sample locations

Digital Photographs
A digital SLR camera mounted above the basin and connected to a computer allowed continuous time-lapse documentation of the delta surface. Images were collected at a rate of 3 per minute. Images were post processed to correct for distortion.

Porosity Mini-Cores
At the end of each run, 6 mini-cores (2 cm, 0.75in deep) were taken to determine the porosity of the surface layer. A thin-walled, sharp-edged mini-core was first inserted 2 cm (0.75in) into the deposit. The deposit was then excavated away from around the mini-core and a blade was slid under the base of the mini-core to remove a known volume of saturated deposit. The samples were then weighed saturated and dry to determine water weight. The water weight was then used to determine void volume and porosity. Of these 6 mini-cores, three were taken at the upstream end of the delta – one each in the main channel, an old channel, and out of the channel. The other three were taken in the same locations at the downstream end of the deposit.

Freeze Slices
To record deposit structure, a 20-inch wide steel wedge with a vertical face on the upstream edge was inserted into the saturated deposit (Figure 15). The wedge was filled with dry ice and methanol. The two substances react to rapidly freeze the surrounding one-half inch of sediment to the wedge. When the wedge is removed, the frozen sediment is removed with it. The wedge is then filled with room temperature water. This delaminates the freeze slice from the working face of the wedge. At this stage the working face of the frozen sediment slice has residual ice buildup due to contact with the freeze core. To remove imperfections due to ice buildup, the working face is heated with a heat gun. This leaves one-eighth inch of slurry on top of three-eighths inch frozen sediment slice. The slurry is removed with a blade and the surface is brushed with a feather duster to remove any displaced particles from the blade. The remaining frozen slice of sediment preserves the delta stratigraphy and is ready to be photographed. For Run 2 two freeze slices were taken transverse to flow at 55 cm (1.8ft) and 150 cm (5ft) downstream of the feed point. These slices were photographed and subsampled for grain size analysis.

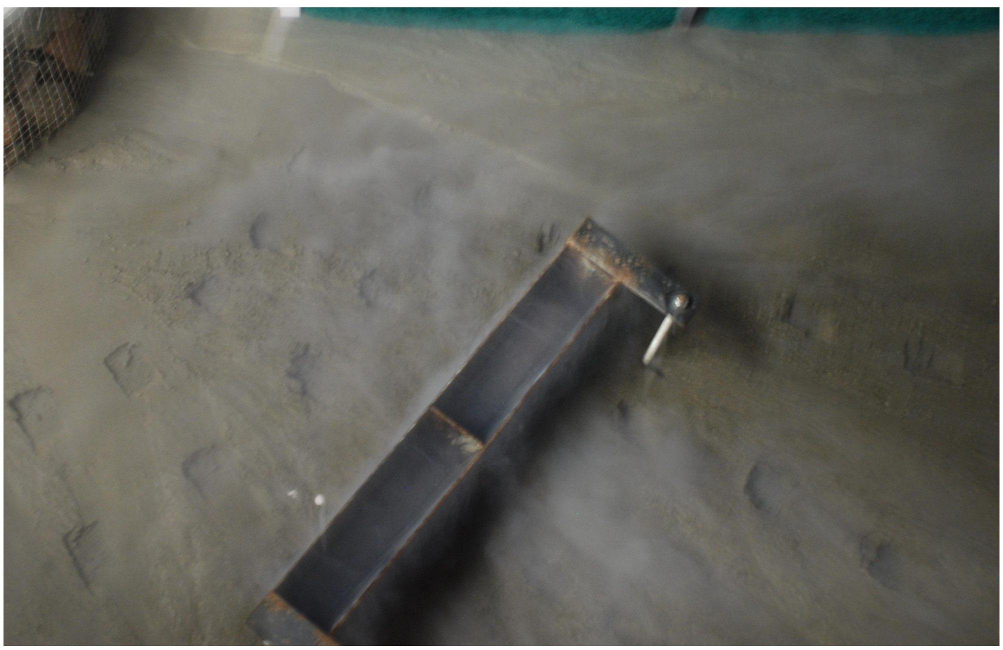

Figure 15a – Freeze slice apparatus.

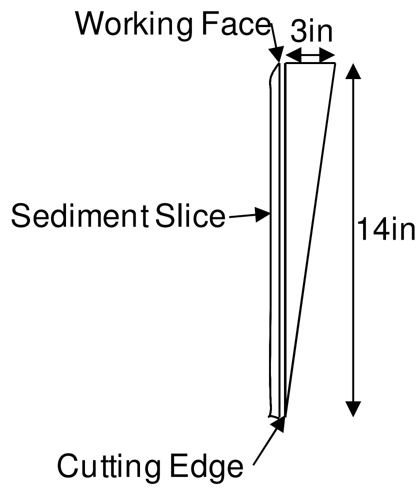

Figure 15b – Freeze Slice apparatus

Hydraulic conductivity samples

For Run 1 twenty full-depth piston cores were also taken along 3 radial lines within the beach. The hydraulic conductivity was tested on the cores using a rigid-walled, falling-head analysis. The benefit of this method is that the core cylinders can be inserted directly into the test apparatus without transferring the samples. Additionally, the percentage of fines in these samples exceeded the limits for the traditional constant head tests, and the hydraulic conductivities also exceed the limits for the traditional flexible-walled permeameter tests.

The test equations (Eq. 9 & 10) for the rigid-walled, falling head analysis are the same as for the flexible-walled permeameter.

$$k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right) \qquad (9)$$

$$\kappa = k\frac{\mu}{\rho g} \qquad (10)$$

Where:
k = Hydraulic conductivity
κ = Permeability
a = Standpipe cross-sectional area
A = Soil sample cross-sectional area
L = Soil sample length
h_1 = Water head at start of the test
h_2 = Water head at end of the test
t = Total test time
μ = Water viscosity
ρ = Water density
g = Acceleration of gravity

Other sediment sampling

During operation, samples of the pool water were taken for grain size analysis. The grain size analysis was performed using Horiba® laser diffraction. Laser diffraction was chosen in cases where sample volumes were too small for sieving or hydrometer tests.

5.0 Phase II – Results

The Run 1 delta had a 2 m (6.5ft) radius and was approximately 20 cm (8in) thick. The radius of the Run 2 delta was 2.5 m (8.2ft) and approximately 15 cm (6in) thick. 20-second timelapse videos of the evolution of each of the runs are provided in Appendix D. The data acquired from Runs 1 and 2 are described below.

5.1 Pool and Scrape Sample Particle Size Analysis

5.1.1 Sieve Analysis of Scrape Samples

5.1.1.1 Run 1 Scrape Samples

The bulk material from Run 1 (preliminary grind) had a coarse fraction of about 41%. The coarse fraction is defined as the fraction of material by weight retained on a 74 micron sieve. 82% of the scrape samples taken from the beach had a coarse fraction of greater than 41%. The higher coarse fraction indicates that a portion of the fines bypassed the beach deposit and were flushed into the pool.

Figure 16a is an aerial photo of the Run 1 delta at the end of the growth phase. Figure 16b is the coarse fraction results from the scrape samples taken at that time across each radial sampling line and at various radii across the basin. The key indicates the location of the radial line relative to the left wall of the basin (looking downstream) and listed in radians and equivalent to 22.5, 33.75, 45, 56.25, and 67.5 degrees, respectively (Figure 14). Appendix B contains tabular results of the grain size analyses from all the scrape samples. Note in Figure 16b that the coarse fraction peaks at a radius of 55 cm. Figure 16a shows that the coarse peak at 55 cm is the same location as the flow transition from sheet flow to channelized flow. The general downward trend after the 55 cm radius confirms that the relative quantity of fines in the deposit increases with distance from the source. The variability in coarse fraction observed for the five radial transects are likely due to the chaotic nature of the braided system which means the delta surface includes a range of geomorphic features such as in-channel, channel bank, and floodplain. Similar evidence for local grain segregation was observed in other data: light and dark lenses observed in the suction cores and freeze slices taken from the final deposit(s) (See §5.4).

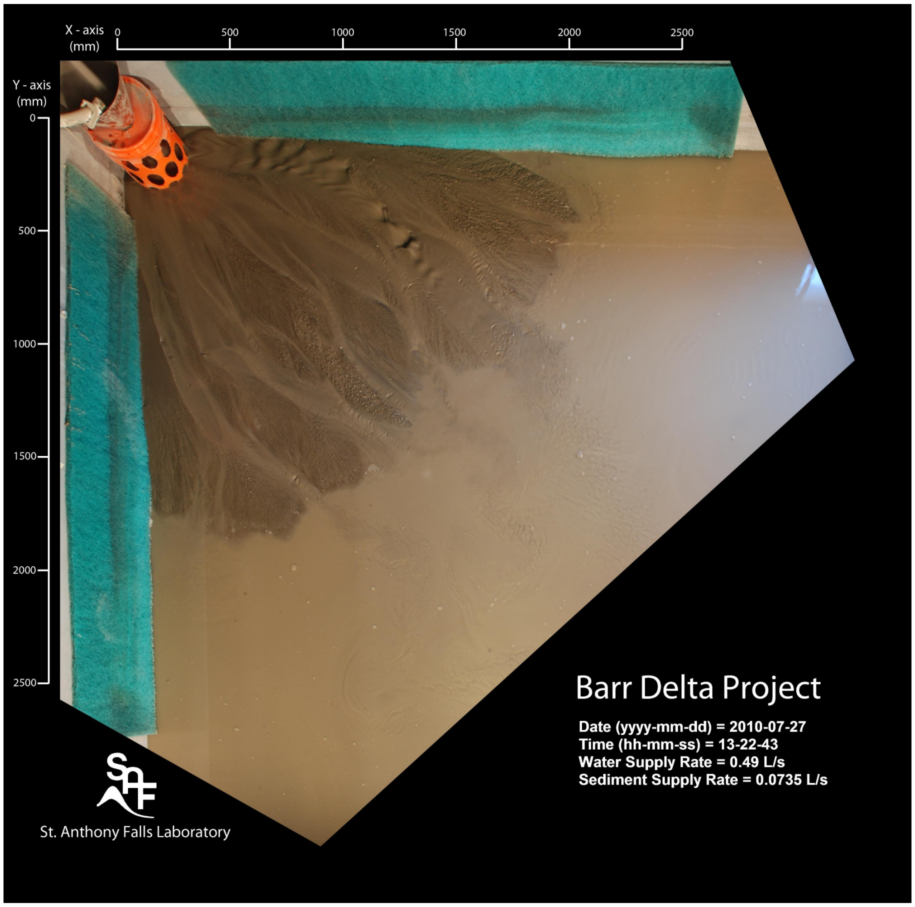

Figure 16a – Run 1 aerial photo of at the end of the growth phase.

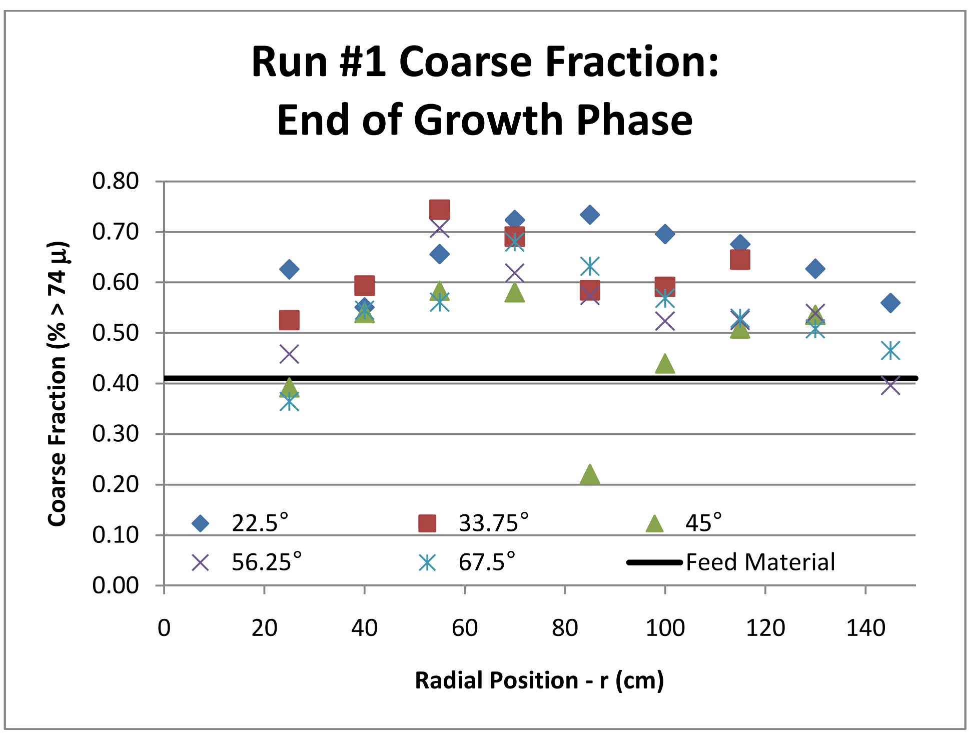

Figure 16b – Run 1 coarse fraction plot at the end of the growth phase.

Figure 16c is an aerial photo taken during Run 1 at the end of the falling phase (i.e. the final deposit), and Figure 16d is the results of the scrape samples taken at that time. Recall that during this falling phase the pool level was slowly lowered with the intent of promoting bypass of fine and preferential deposition of coarse material. In Run 1, a distinct single channel formed in the deposit at approximately the position of radial line at $\theta = 67.5°$ and this channel remained for most of the phase. All other radial lines for scrape samples were located in overbank settings. The data in Figure 16 may help to distinguish grain size distribution typical of in-channel versus overbank settings. The upper limit of the coarse fraction is reflected in the 5 scrape samples along the radial line at $\theta = 67.5°$that were taken from the main channel and range from 70-75%. The other samples taken from the floodplain range from 40-60% coarse material. These samples also show a slight downward trend indicative of downstream fining. Figure 16e compares the scrape results from each phase of Run 1. In general all samples were coarser than the input mixture indicating some loss of fine material. An upper limit is observed however as no deposit was coarser than 75% coarse sediments- even within an active channel.

After Run 1 was complete, the basin was slowly drained over a 25-day period of time. Three scrape samples were then taken from the bottomset, the subaqueous deposit on the sea floor less than 10cm (4in) beyond the delta toe. When sieved, 100% of each of these samples was less than 74 microns in diameter. These samples were saved for laser diffraction grain size analysis (§ 5.1.2). These results are expected since the bottomset is submerged by the pool, and the bottomset material is deposited via settling.

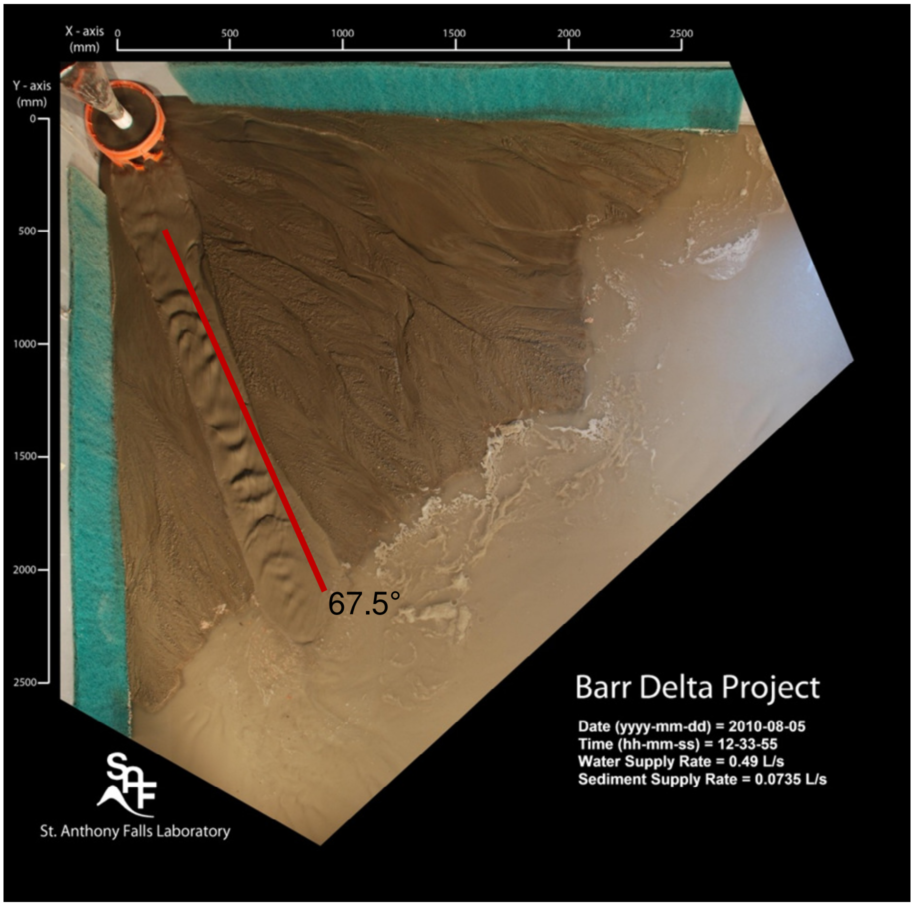

Figure 16c – Run 1 aerial photo of at the end of the falling phase.

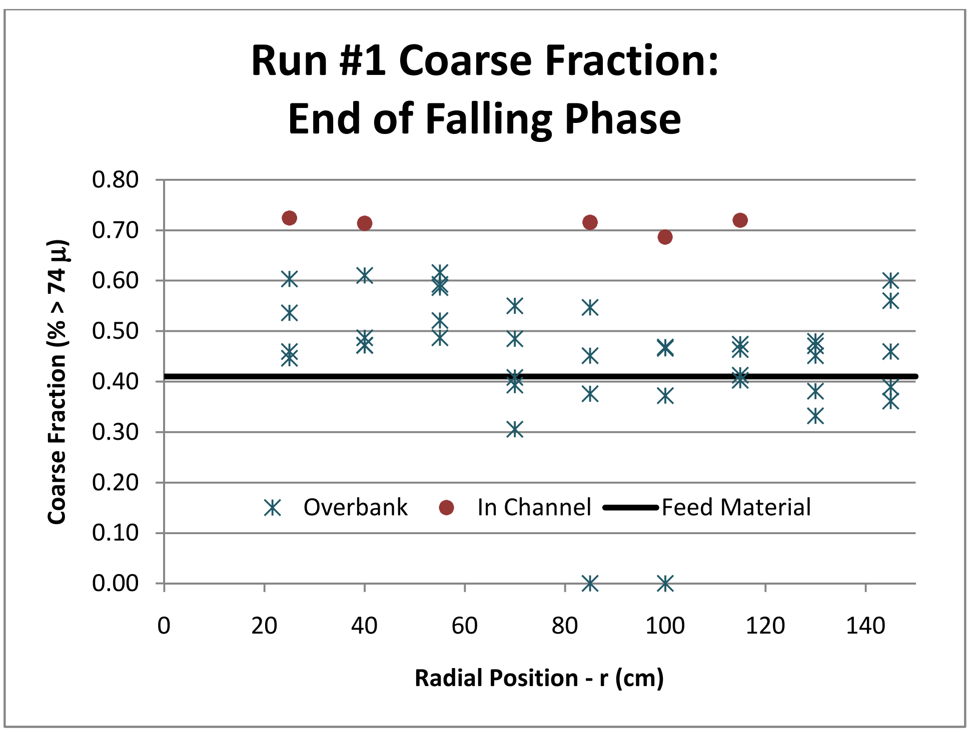

Figure 16d – Run 1 coarse fraction plot at the end of the falling phase.

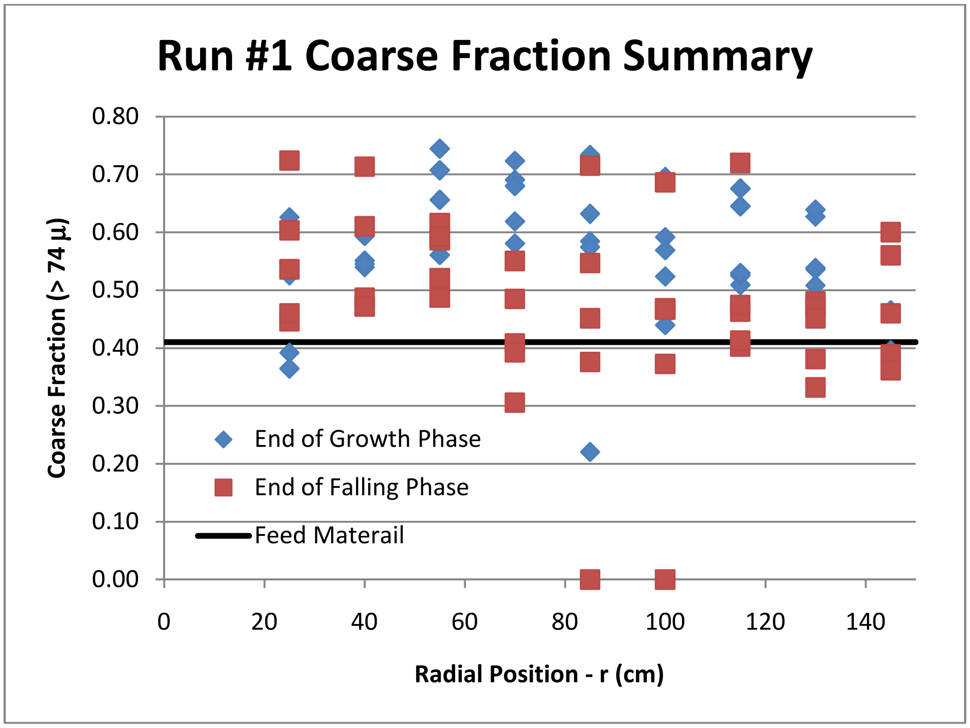

Figure 16e – Run 1 coarse fraction plot for all phases.

5.1.1.2 Run 2 Scrape Samples

The bulk material from Run 2 (final grind) also has a coarse fraction of about 41%. The higher coarse fractions found in 68% of the scrape samples indicate that a portion of the fines bypassed the beach deposit and were flushed into the pool. Figures 17a and 17b are the overhead photo and scrape sample results from the end of the growth phase. Like Run 1, there is a general downward trend in the coarse fraction indicative of downstream fining. The $\theta = 33.75°$ radial line sample does jump at the downstream end of the beach. This sample location was partially submerged by the pool which causes settling of coarse material.

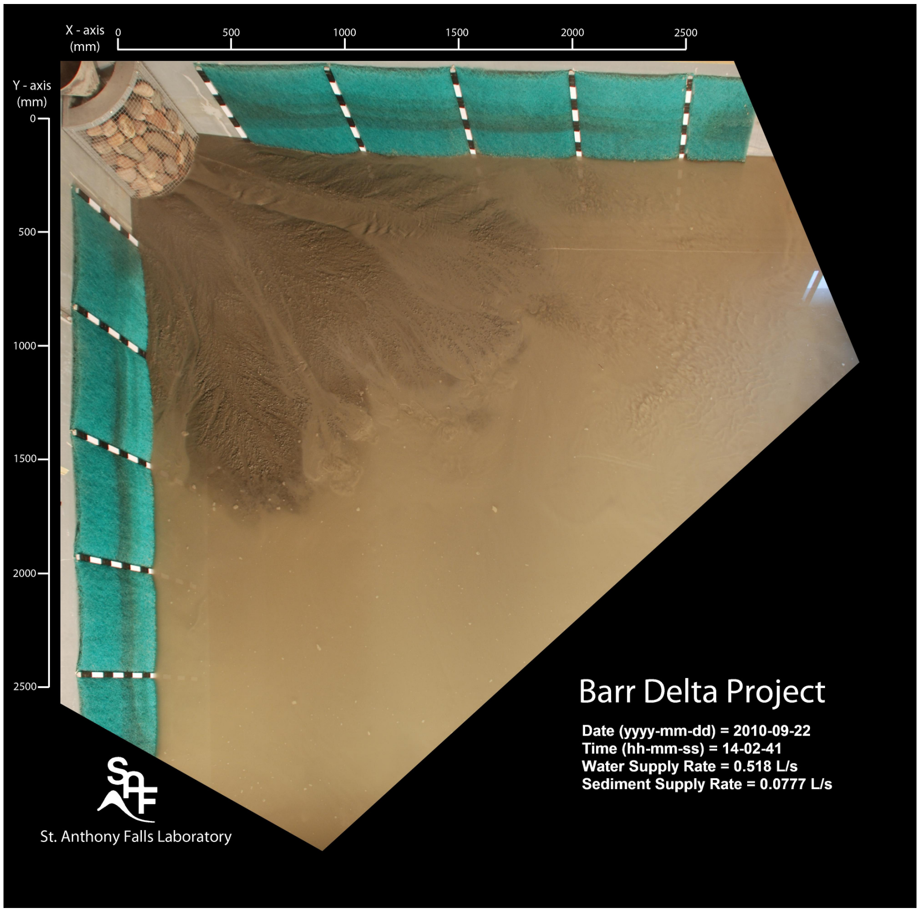

Figure 17a – Run 2 aerial photo of at the end of the growth phase.

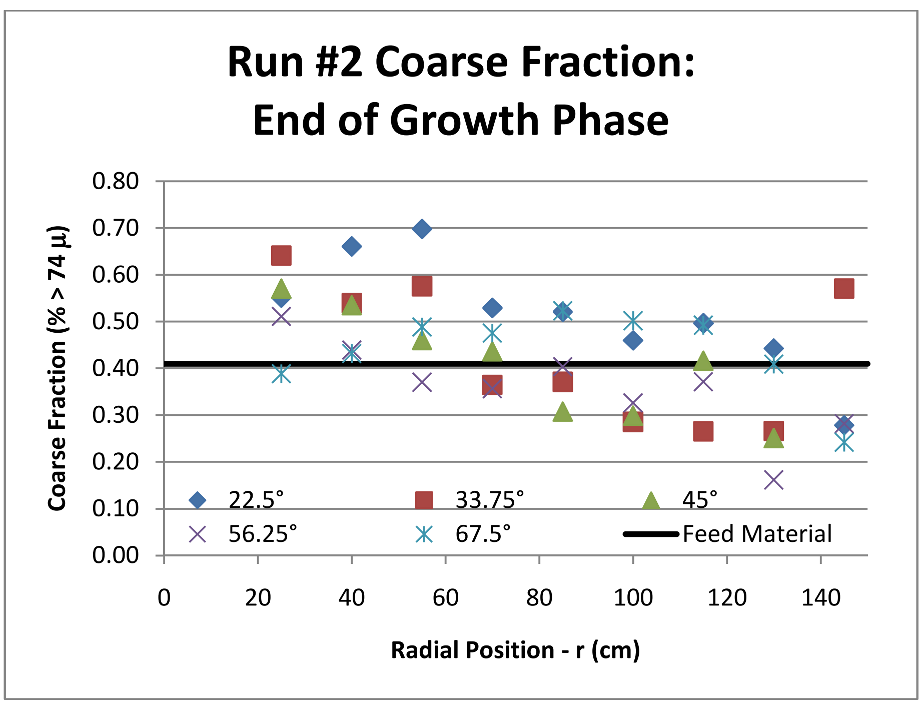

Figure 17b – Run 2 coarse fraction plot at the end of the growth phase.

Figure 17c is the overhead photo taken at the end of the building phase. The coarse fraction plot for the building phase is shown in Figure 17c. The results are similar to previously shown data where there is general fining of the deposit down slope and a variability in coarse fraction that ranges from 40% to 65%. The variability in the coarse fraction is largely due to the influence of bedforms and the braided channel morphology on the deposit. The image in Figure 17c highlights the chaotic nature of the fan surface with multiple braided channels and anti-dune bedforms (highlighted).

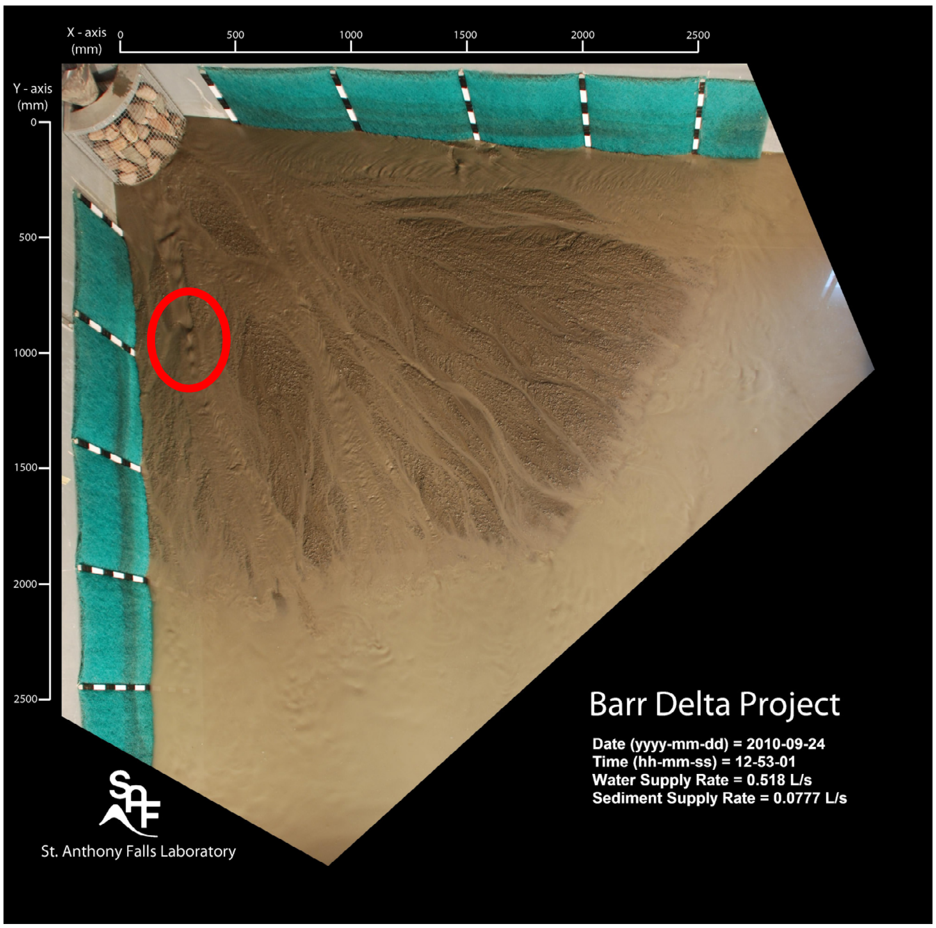

Figure 17c – Run 2 aerial photo of at the end of the building phase.

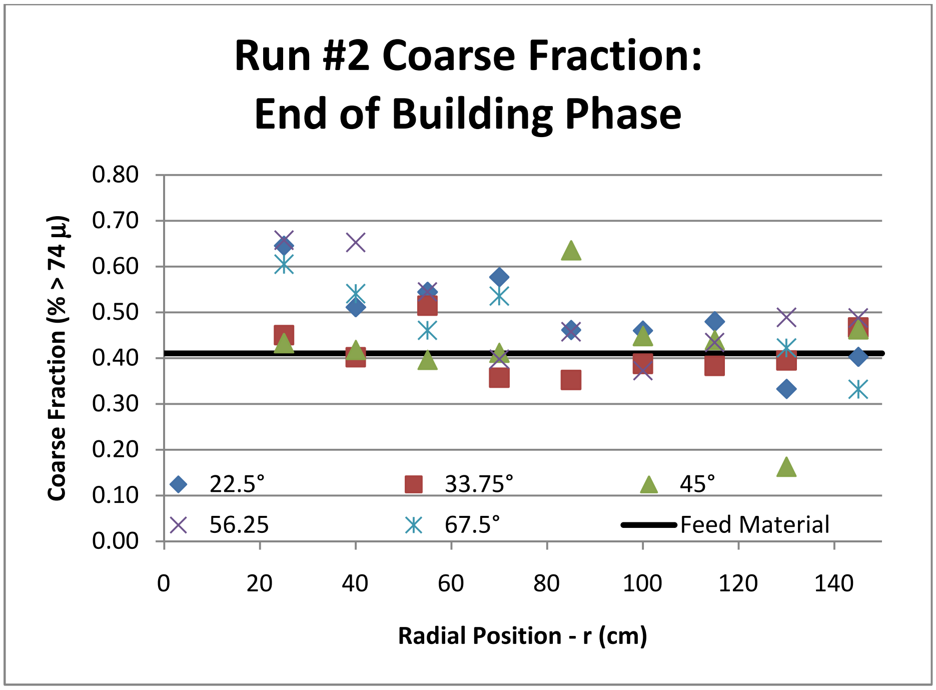

Figure 17d – Run 2 coarse fraction plot at the end of the building phase.

Figures 17e and 17f are the aerial photo and coarse fraction plot for the end of the falling phase. The photo highlights the anti-dune formations prevalent in the main channel. Figure 17g shows that the falling phase is generally the coarsest phase of Run 2, and the results from Figure 17f should be considered the worst case scenario for fines retention.

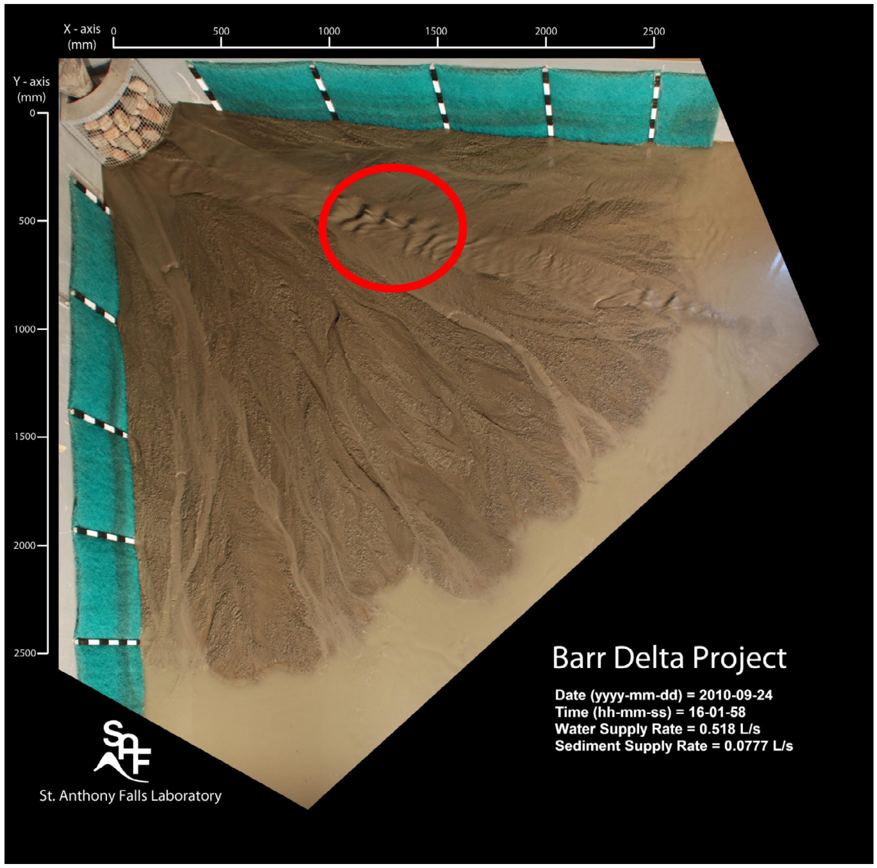

Figure 17e – Run 2 aerial photo of at the end of the falling phase.

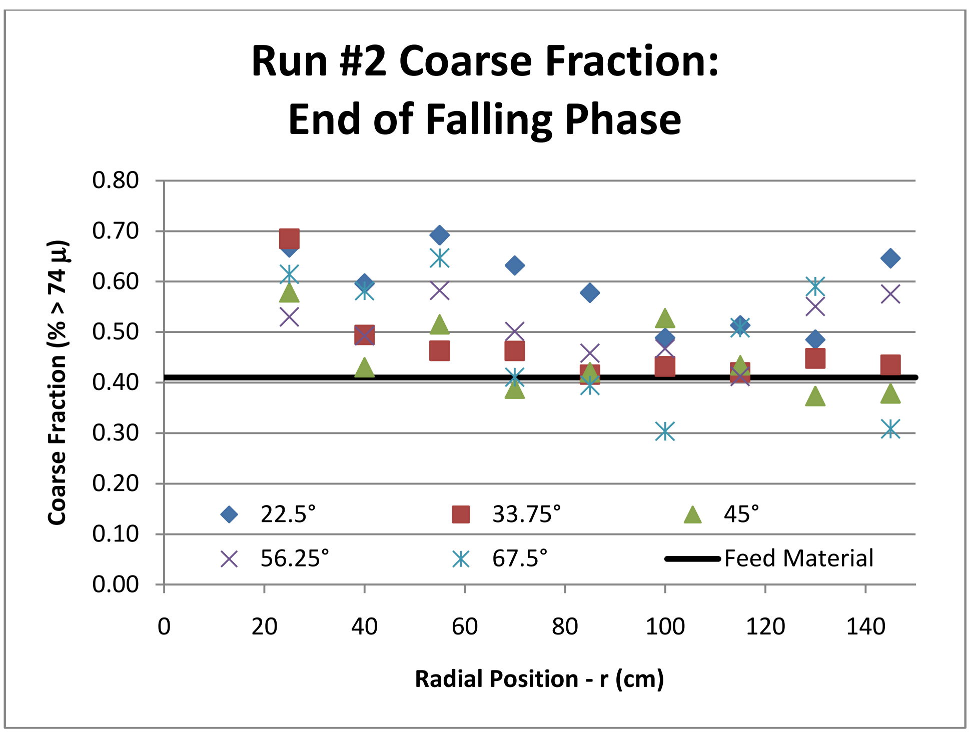

Figure 17f – Run 2 coarse fraction plot at the end of the falling phase.

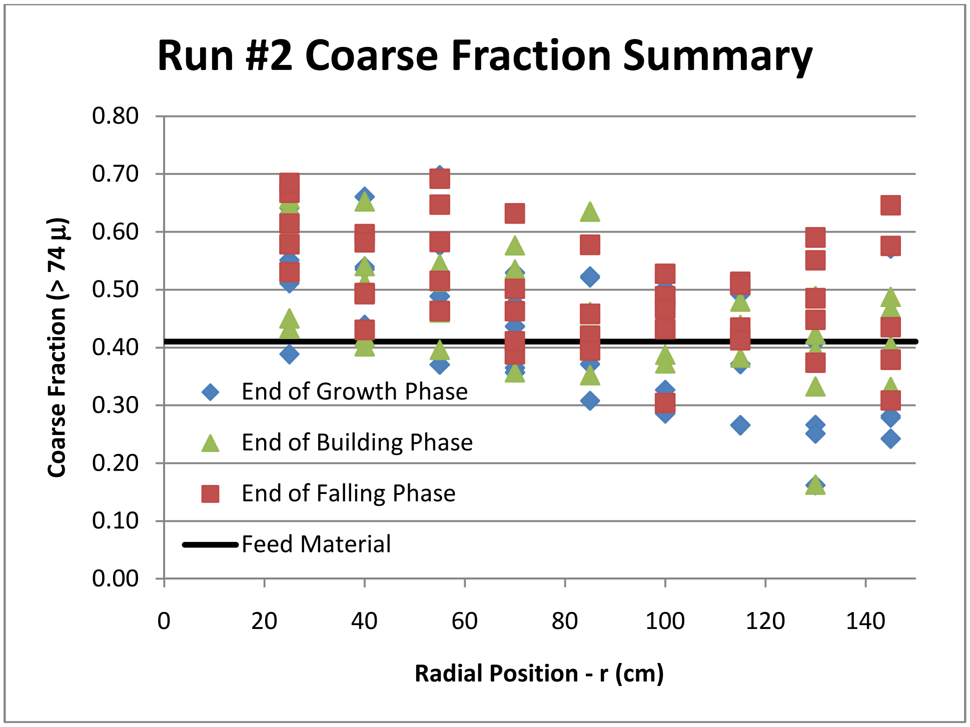

Figure 17g – Run 2 coarse fraction plot for all phases.

5.1.2 Horiba® Laser Diffraction Analysis of Pool Samples and Bottomset Scrape Samples

Water samples were taken from the pool during the run from two locations within the basin. The percent solids and sediment concentration of each of these samples is provided in Table 6. Figure 18 contains the grain size distribution for the pool samples plotted with the fine fraction of the bulk feed material. Grain size of these fine samples was performed using laser diffraction. All pool samples contain more fine material than the fine fraction of the bulk feed material. The pool sample that was taken near the shoreline where overland flow was entering the pool has the distribution that is most similar to the fine fraction of the bulk feed material. Samples collected away from the shoreline have finer distributions. The results suggest that the tailings can settle out of the water column. The estimated hydraulic residence time for water leaving the shoreline position to the basin outlet is about 85 minutes for the experiments reported here. The hydraulic residence time is the average amount of time needed to replace all of the water in the basin. It is equal to the volume of water in the basin divided by the flow rate of water entering the basin. This means that the sediment in the pool samples near the outlet have been in suspension for about 85 minutes. In other words, 85 minutes after entering the basin over 99.8% of delivered sediment has been deposited. Hydraulic residence time is actually an upper estimate of the transit time of sediment from the shoreline to basin outlet due to the presence of "short circuiting", the occurrence of preferential, faster flow paths in the water body.

Table 6 – Solids fractions measured in pool samples

Run	Sample	Sample Location	% Solids	Concentration (kg/m³)
1	1	At basin outlet	0.12%	1.2
1	2	At basin outlet	0.17%	1.7
2	2	Away from outlet	0.06%	0.6
2	4	Near shoreline	1.62%	15.9
2	6	At basin outlet	0.16%	1.6

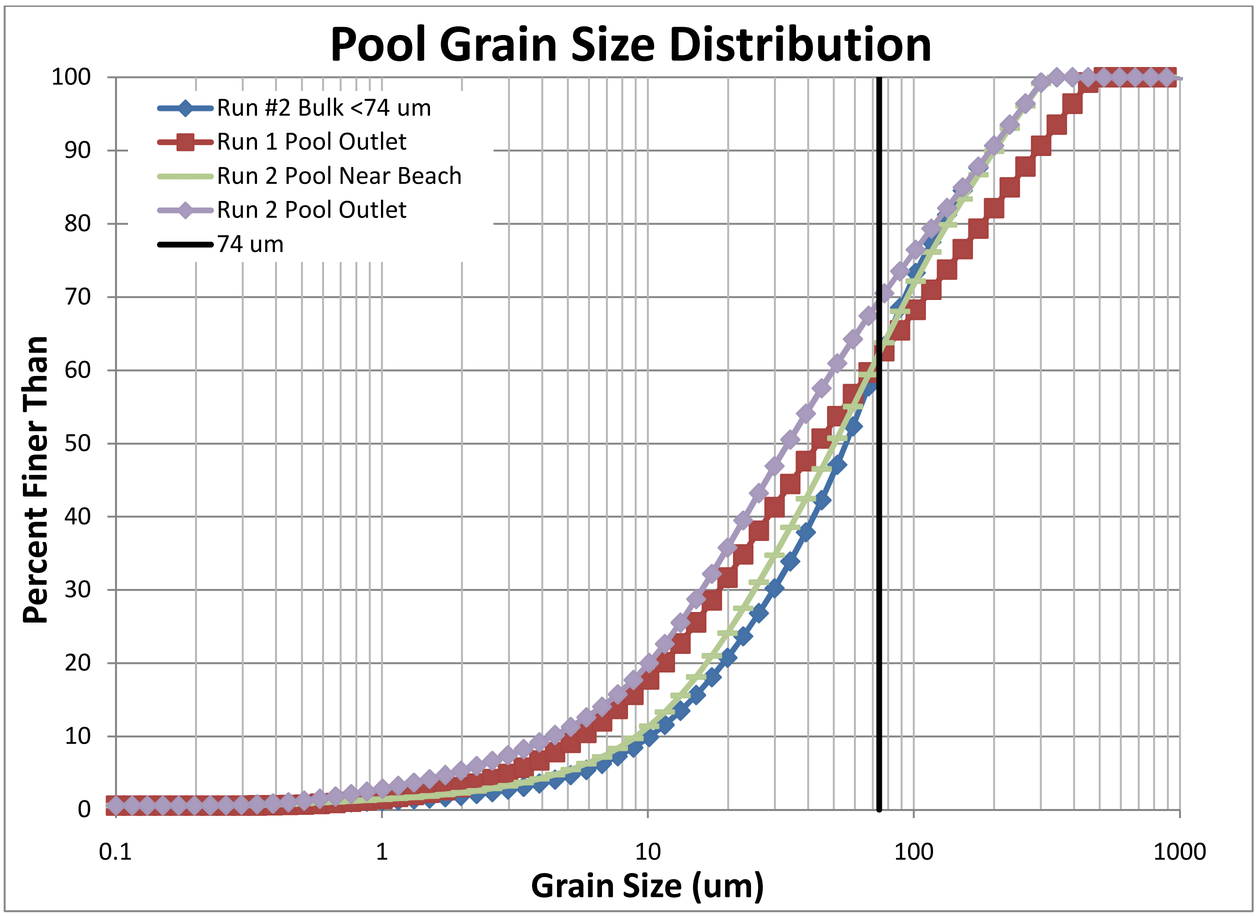

Figure 18 – Grain size distribution from pool sample.

Three bottomset scrape samples were taken from each final deposit. The grain size distributions provided in Figure 19 show that the bottomset particles fall within the fine fraction. The Run 1 bottomset scrape samples were taken within 10 cm (4in) of the toe of the deposit. The Run 2 bottomset scrape samples were taken about 30 cm (1ft) from the deposit toe. The coarser range of bottomset particles for Run 1 may be attributed to more settling near the toe. Figure 19 shows that the Run 2 bottomset has fewer 1-74 micron size particles than the fine fraction of the bulk material. These missing particles were most likely trapped within the delta deposit.

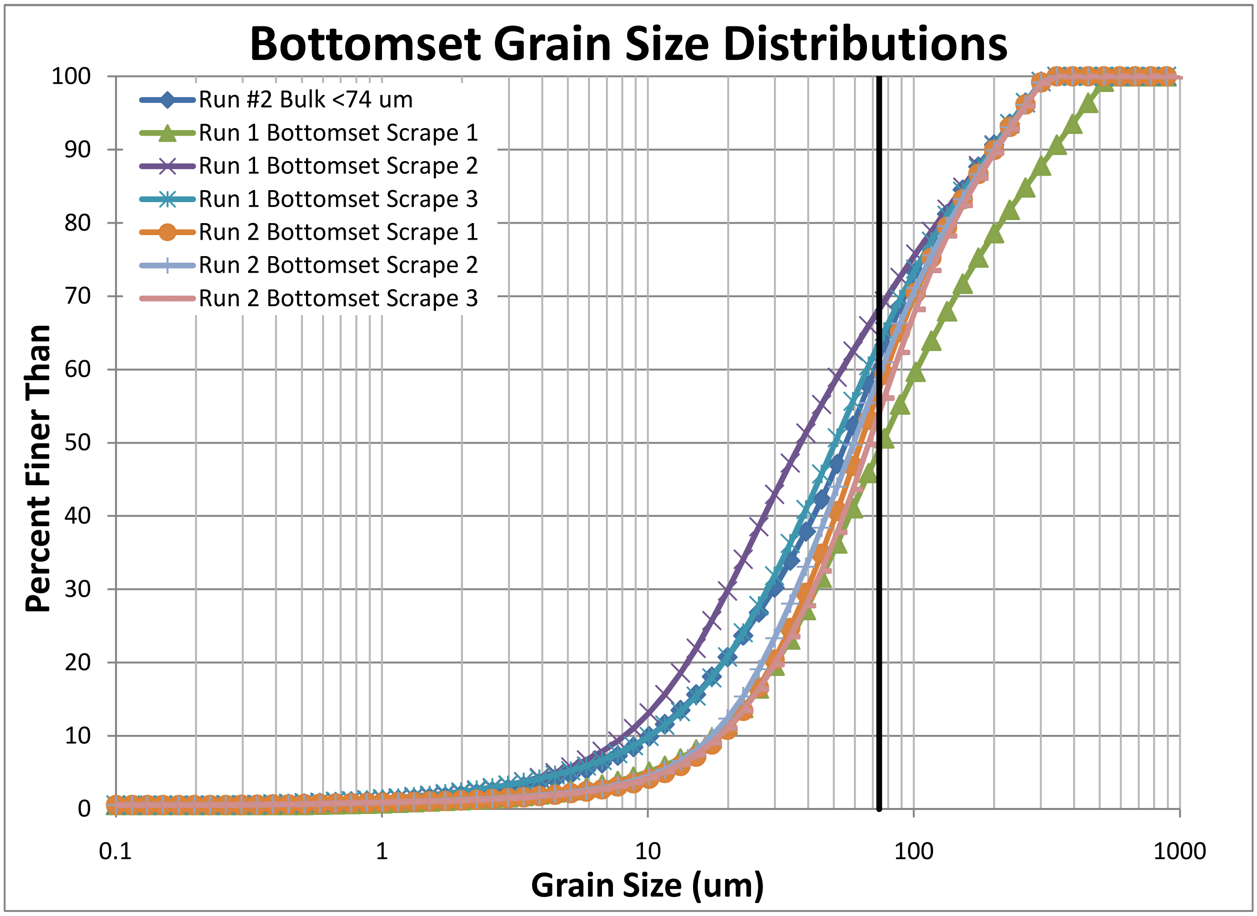

Figure 19 – Bottomset Scrape Sample Grain Size Distributions Measured Using Horiba® Laser Diffraction

5.2 Hydraulic Conductivity

Table 7 lists the results from the hydraulic conductivity tests. The data show that the hydraulic conductivity throughout the Run 1 deposit was quite low, although the values from various cores range over nearly one order of magnitude from 1.7×10^{-6} to 1.3×10^{-5} m/s. It is important to note that light and dark lenses were observed within the cores (§ 5.4.1) and that these lenses represent bodies of distinct grain size or fines content. The hydraulic conductivity test performed on the cores forces the vertically flowing water to pass through all elements of the deposit stratigraphy. Fine lenses are limiting layers which reduce the measured hydraulic conductivity. In the unconfined delta it is possible that the groundwater will simply flow around the fine lenses, depending on how the lenses are connected spatially. This would result in higher groundwater transport rates than are reflected by the hydraulic conductivity test. Section 5.4.2 has discussion of the connectivity of the fine and coarse lenses. Subject to this caveat about the possibility of bypassing the fine lenses, the trends of the measurements are descriptive of the sorting properties within the delta. The results, plotted in Figure 20, clearly show that vertical hydraulic conductivity changes with position in the delta. The primary factors influencing permeability are the D_{50} grain size and the degree of sorting (Beard and Weyl 1973). The decreasing trend shown in Figure 20 is likely a result of the increasing fraction of fines with radial position (i.e. downstream fining). This is the expected trend in depositional fans and thus would be predicted for the field case as well.

Table 7 – Run 1 results of falling head hydraulic conductivity tests

Sample #	r (cm)	L (cm)	h_1 (cm)	h_2 (cm)	t (sec)	k (m/sec)	k (cm/sec)	k (ft/min)	κ^* (Darcy)
1	30	27	230	159.5	6723	1.0E-05	1.0E-03	2.1E-03	1.08
2	60	23.4	225.6	167.9	5269	9.3E-06	9.3E-04	1.8E-03	0.96
3	90	21.8	227.6	138	8093	9.6E-06	9.6E-04	1.9E-03	0.49
4	120	21.3	228.2	142.3	12360	5.8E-06	5.8E-04	1.1E-03	0.99
5	150	19.7	210.1	161.9	9850	3.7E-06	3.7E-04	7.3E-04	1.35
6	180	19.3	226.8	191.8	8393	2.7E-06	2.7E-04	5.4E-04	0.48
7	210	17.5	229.4	169.7	7956	4.7E-06	4.7E-04	9.3E-04	1.23
8	30	24.5	228.7	138.6	6695	1.3E-05	1.3E-03	2.6E-03	0.36
9	60	23.5	226.3	146.5	8400	8.6E-06	8.6E-04	1.7E-03	0.28
10	90	23	227	170.2	9047	5.2E-06	5.2E-04	1.0E-03	0.89
11	120	21	222.9	158.7	8892	5.7E-06	5.7E-04	1.1E-03	0.18
12	150	19.8	227.1	166.5	8887	4.9E-06	4.9E-04	9.7E-04	0.54
13	180	17.8	229.9	202.8	9110	1.7E-06	1.7E-04	3.4E-04	0.60
14	210	19	221.6	175.7	6817	4.6E-06	4.6E-04	9.0E-04	0.46
15	30	24.6	226.2	149.6	6071	1.2E-05	1.2E-03	2.3E-03	0.51
16	60	23.3	225.5	145.9	11128	6.5E-06	6.5E-04	1.3E-03	0.59
17	90	22.2	226.7	147.3	9779	6.9E-06	6.9E-04	1.4E-03	0.28
18	120	20.2	227.3	154.4	12428	4.5E-06	4.5E-04	8.8E-04	0.67
19	150	19.6	229.2	184.7	11241	2.7E-06	2.7E-04	5.3E-04	0.72
20	180	18	227.1	193.2	5958	3.5E-06	3.5E-04	6.8E-04	0.38

* Note: κ is permeability, 1 Darcy = 9.869×10^{-13} m² = 1.062×10^{-11} ft²

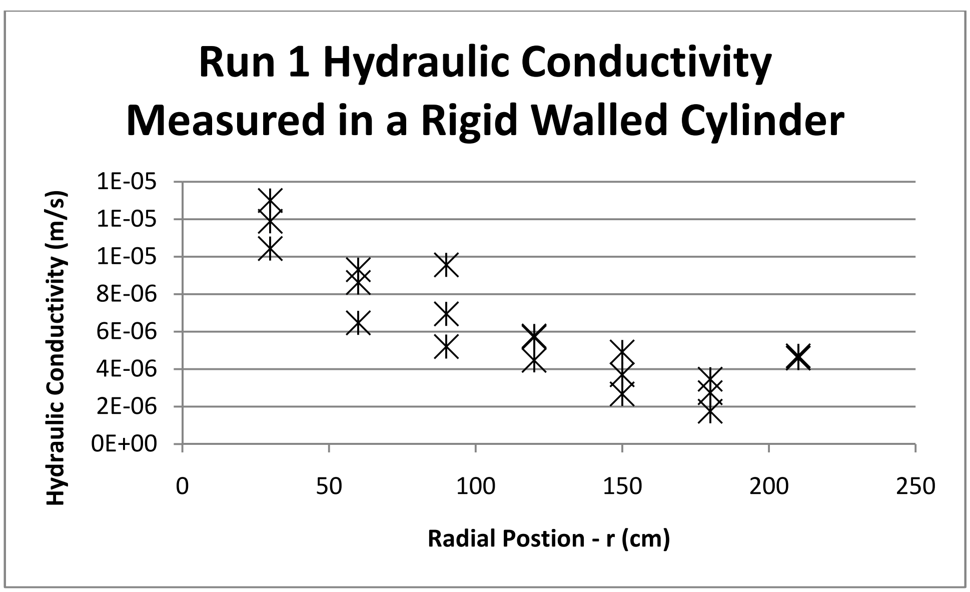

Figure 20 – Run 1 hydraulic conductivity variation with radial position along delta.

5.3 Porosity

The porosity of the Run 1 delta was measured using two methods. The first was mini-cores that measure porosity in the top 2 cm (0.75in) of the final delta surface. The second method is the bulk porosity measured from the full depth piston cores.

Table 8 lists the results from the surface porosity measurements. There is some variability at the different locations; however, there is no indication of spatial trends. Table 9 lists the bulk porosity from the Run 1 core samples.

Table 8 – Run 1 surface porosity taken via mini-cores

Sample Location	Porosity
Upstream in Main Channel	0.42
Upstream in Secondary Channel	0.37
Upstream out of Channel	0.37
Downstream in Main Channel	0.35
Downstream in Secondary Channel	0.42
Downstream out of Channel	0.42

Table 9 – Run 1 bulk porosity taken from suction cores.

Core #	r (cm)	Porosity
3	90	0.43
4	120	0.43
12	150	0.43

5.4 Stratigraphy

5.4.1 Suction Cores

After the Run 1 piston cores were tested for hydraulic conductivity, the four samples were extruded from the cylinder and split open for imaging. Figures 21a – 21d show images of the split cores. These images show light and dark bands within the deposit. Different color bands are associated with different grain sizes or sorting properties.

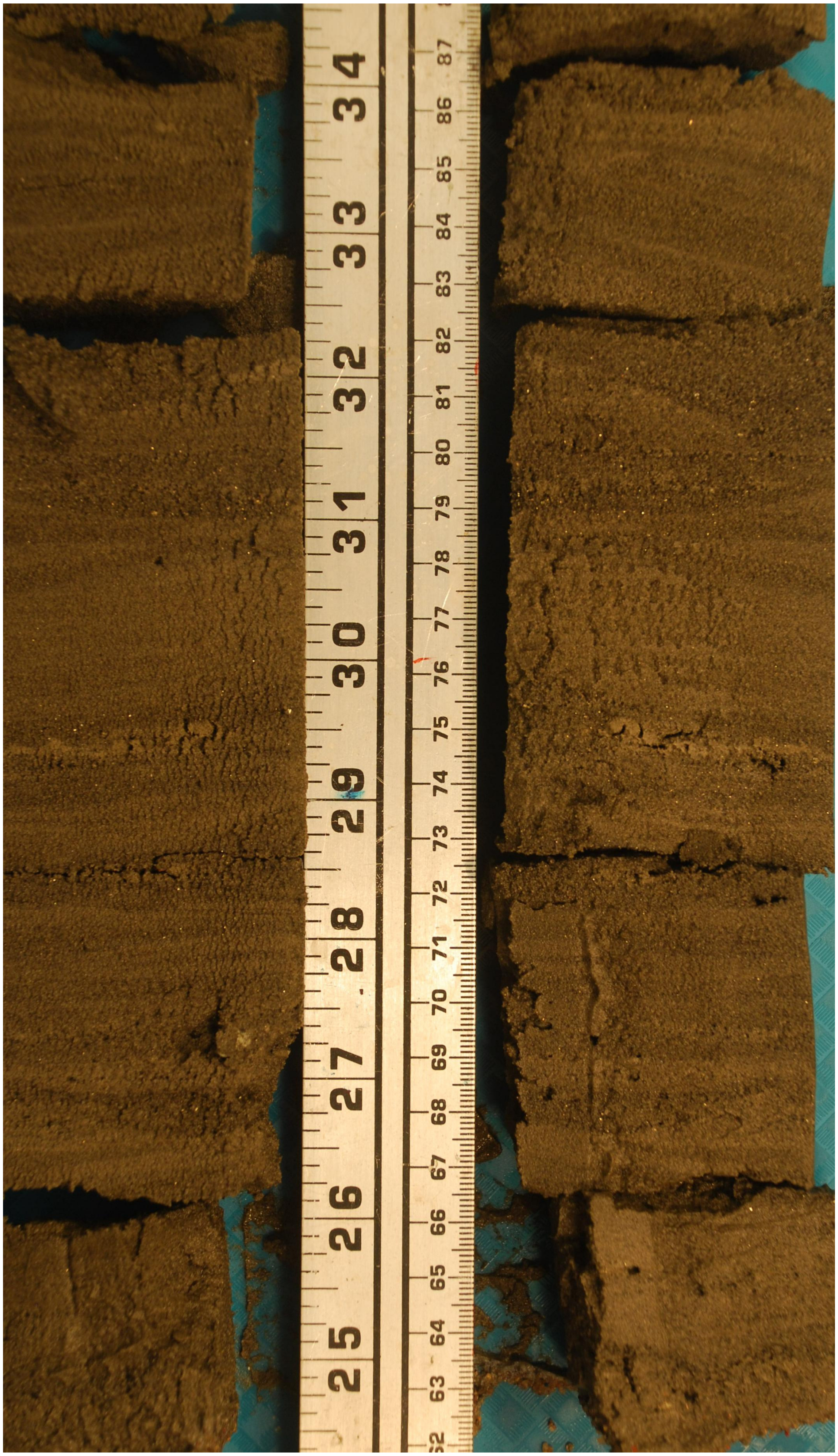

Figure 21a – Grain image from piston core 01 (r = 30cm)

Figure 21b – Grain image from piston core 03 (r = 90cm)

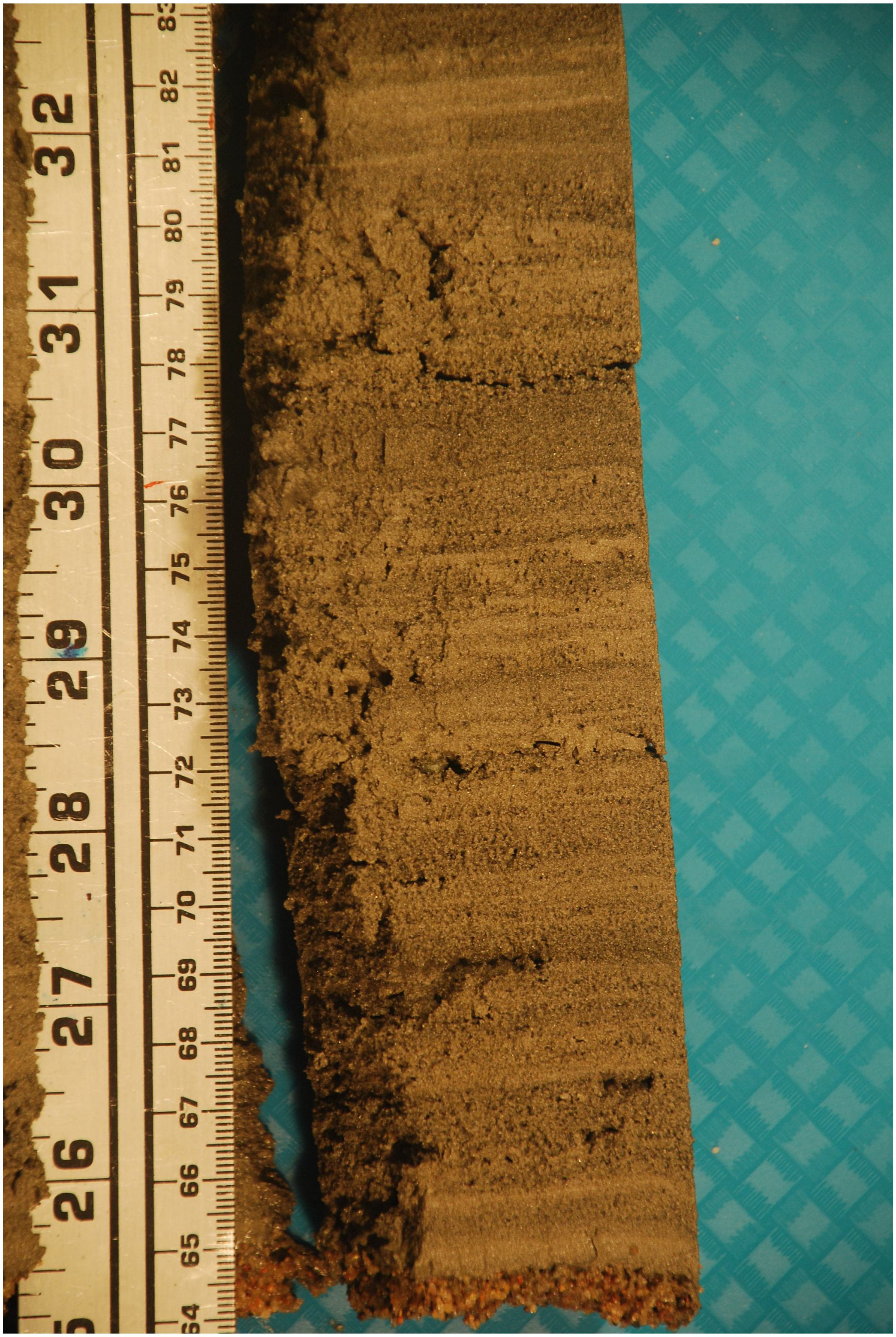

Figure 21c – Grain image from piston core 04 (r = 120cm)

Figure 21d – Grain image from piston core 12 (r = 150cm)

5.4.2 Freeze Slices

As noted in Section 5.4.1 light and dark lenses were observed within the suction cores. The freeze slices, taken from the final deposit of Run 2, were intended to determine the lateral extent of the lenses and how interconnected they are. Figure 22a shows the freeze slice locations, and Figures 22b and c are images of frozen sediment slices from Run 2 taken at r = 55cm (1.8ft) and r = 150cm (5ft), respectively. Figure 22b shows that at the upstream end of the delta the dark lenses are large and often connected over the length of the deposit. The crack in the Figure 22b slice is due to the thawing process. It was not present within the deposit. In Figure 22c, at the downstream end of the delta, the dark lenses are more likely to be completely encased in fines.

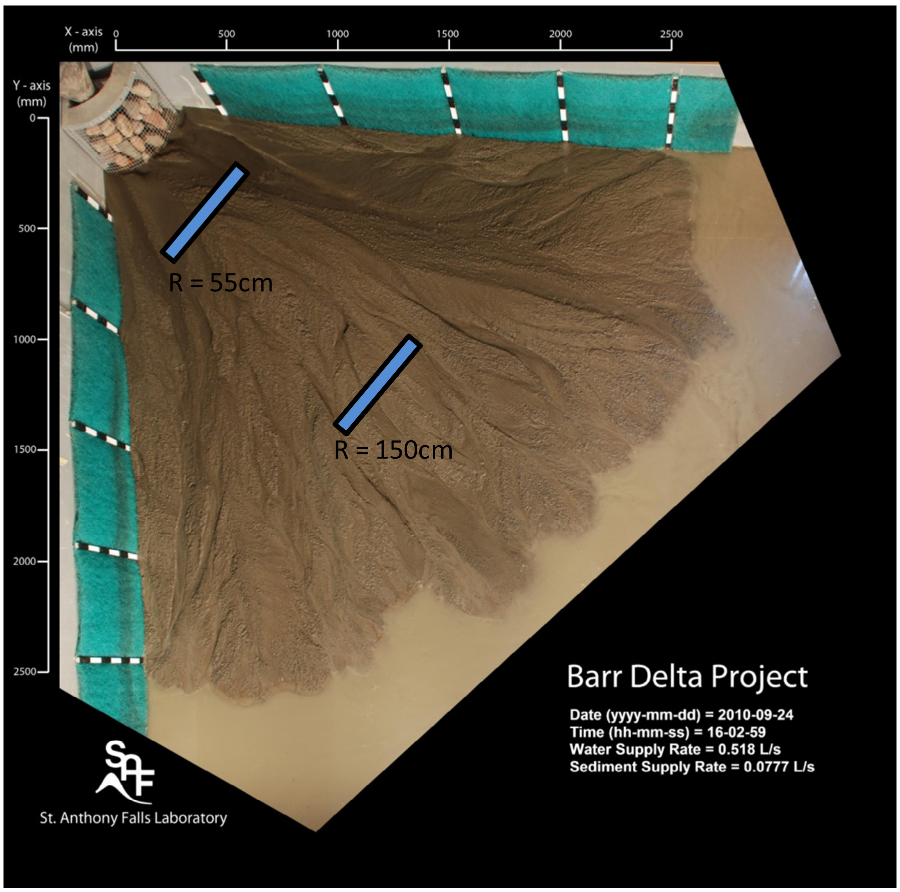

Figure 22a – Freeze slice locations.

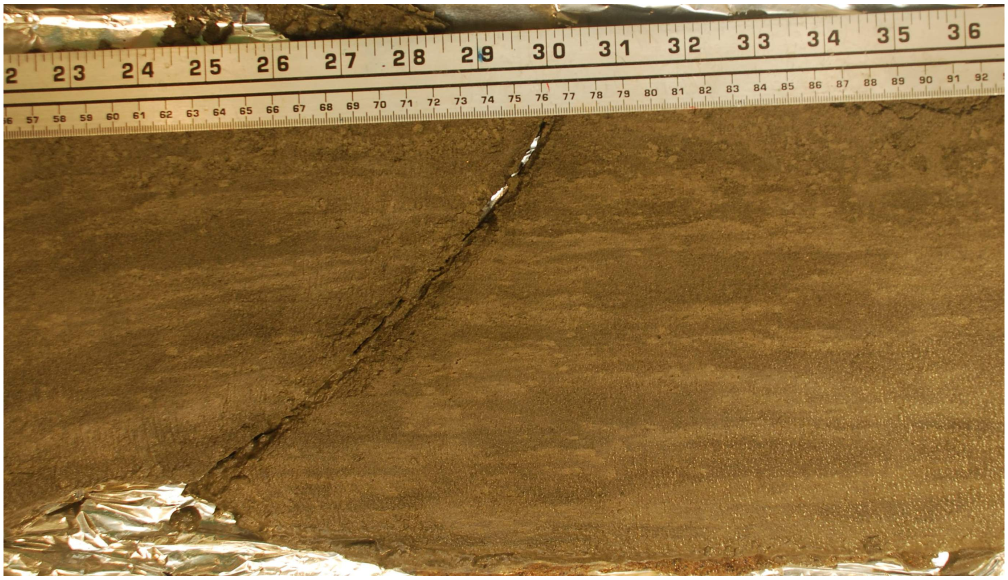

Figure 22b – Run 2 freeze slice taken at r = 55cm. Looking upstream.

Figure 22c – Run 2 freeze slice taken at r = 150cm. Looking upstream.

5.4.2.1 Freeze Slice Grain Size Distributions

The freeze slices were subsampled to determine the grain size distributions from the light and dark lenses. The sampling locations are given in Figures 23a and 23b. The samples were analyzed for grain size distribution using Horiba® laser diffraction. The results provided in Figure 24 show that there is quite a bit of variability in the 10 to 74 um grain sizes. Figures 25a and 25b have the coarse fractions (above 74 microns) labeled directly on the freeze slice images. Note the darker lenses tend to have higher coarse fractions than the lighter lenses, though the trend seem to be less consistent at 150cm The coarse fraction observed in the freeze sliced are within the range of coarse fractions observed in the scrape samples (Fig. 17g).

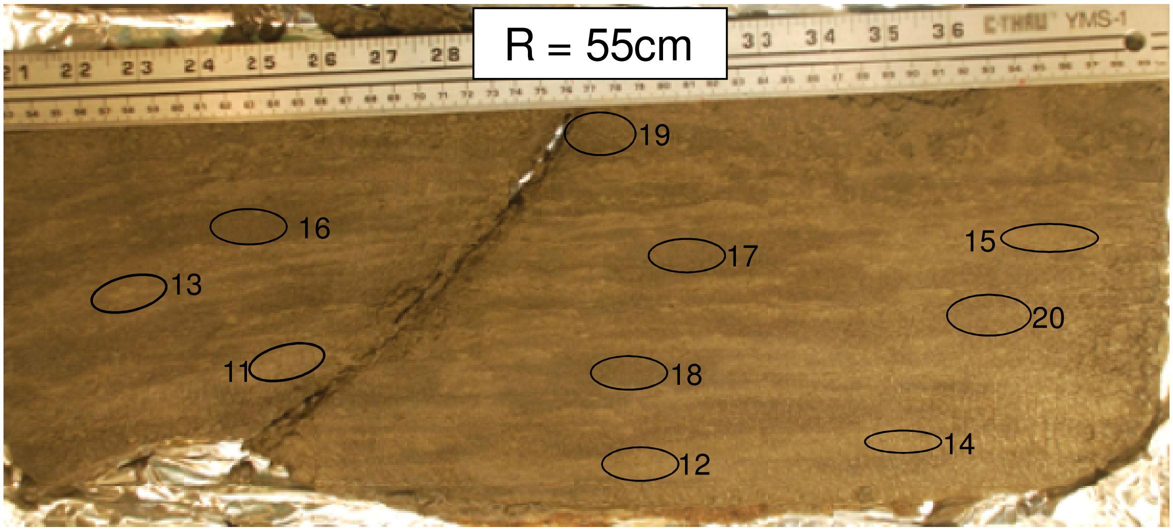

Figure 23a – Subsample Locations for the Freeze Slice at r = 55cm (The sample number are indicated)

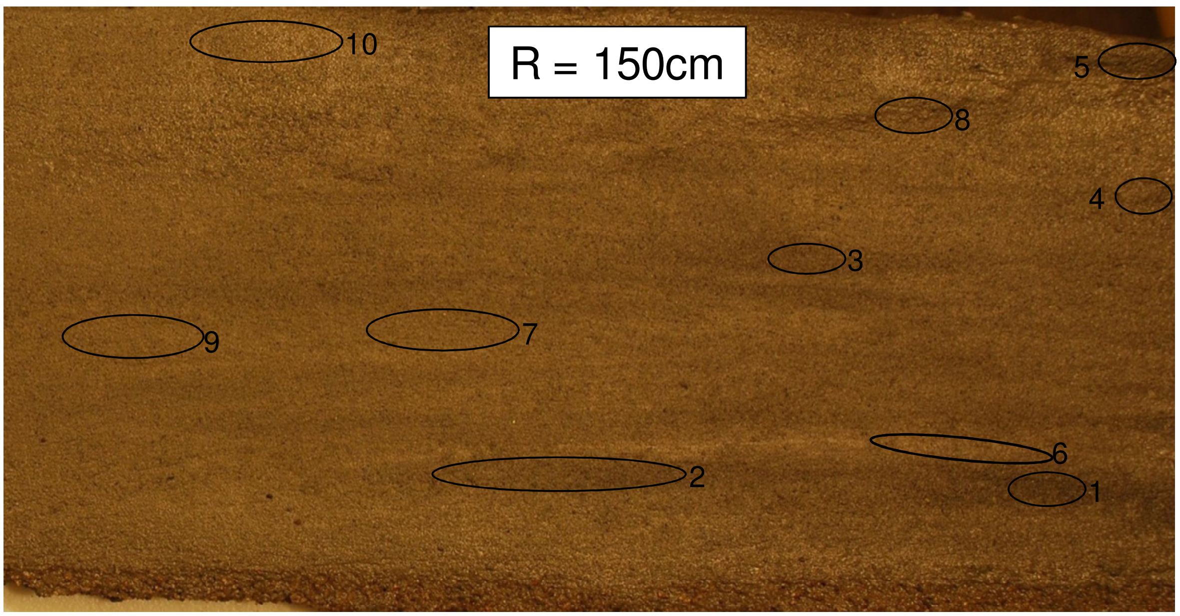

Figure 23b – Subsample Locations for the Freeze Slice at r = 150cm (The sample number are indicated)

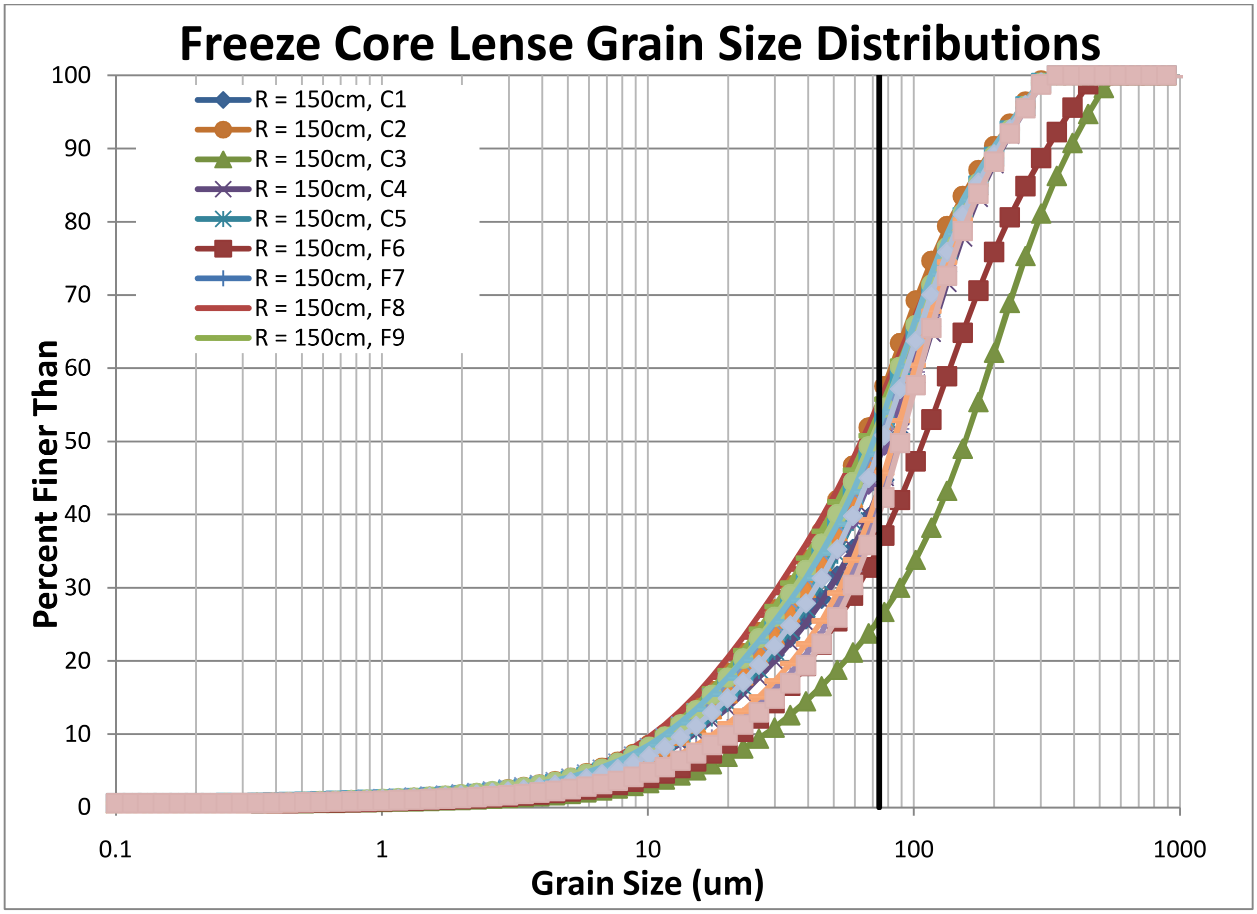

Figure 24 – Grain Size Distributions from Freeze Slice Subsamples

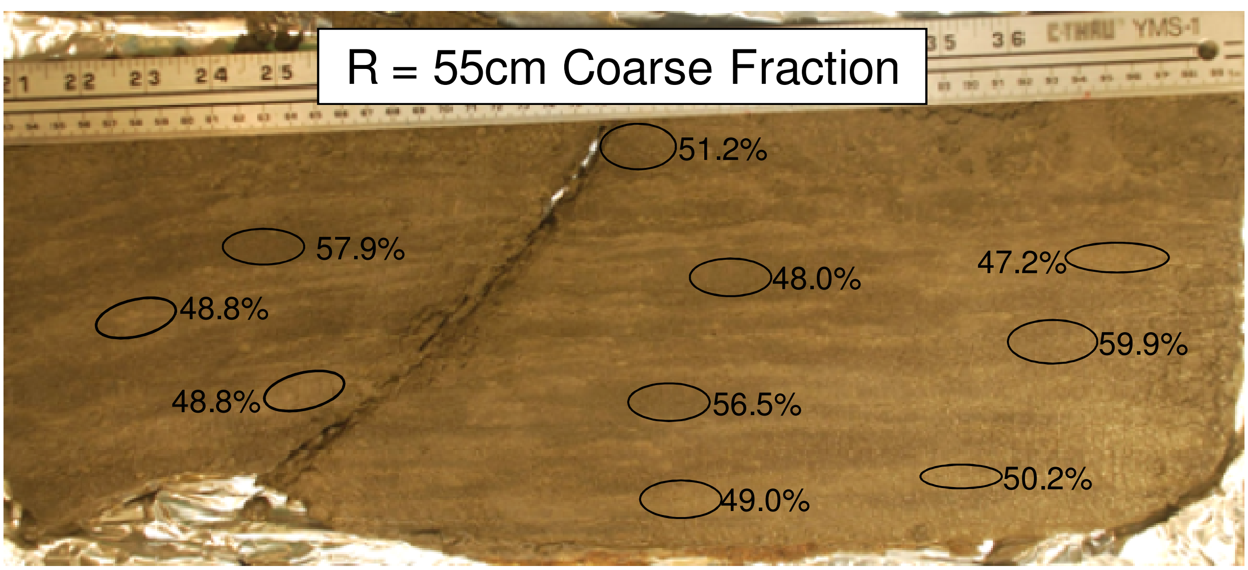

Figure 25a – Coarse Fraction (above 74um) from the Freeze Slice at r = 55cm

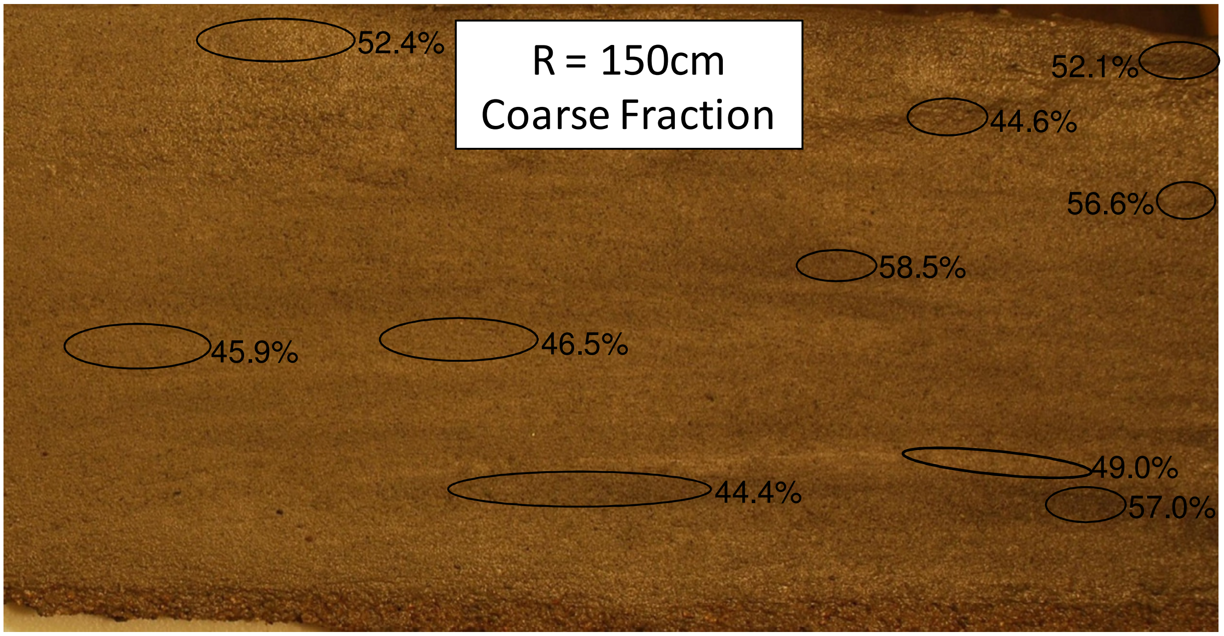

Figure 25b – Coarse Fraction (above 74um) from the Freeze Slice at r = 150cm

5.4.2.2 Freeze Slice Permeability

Although it is not possible to directly measure the permeability at each of the sampling points within the freeze slices, the permeability can be estimated from the grain size distribution. Beard and Weyl (1973) studied how the grain size distribution of artificially-mixed, wet-packed sand influences permeability. They found that permeability increases with increasing D_{50} (mean grain size) and decreases with an increasing sorting coefficient (D_{75}/D_{25}). D_{25}, D_{50}, and D_{75} are the grain diameters corresponding to 25, 50, and 75 percent finer than in Figure 24. The relationship between the sorting coefficient and permeability is stronger than the relationship between grain size and permeability. In other words, a coarser material is more conductive, but adding a small amount of fines fouls the coarse matrix and reduces flow. The matrix of grain size, sorting coefficients, and permeability developed by Beard and Weyl can be approximated using a power law equation. Because different materials are used, the permeability from Beard and Weyl's matrix may not predict the actual permeability of the tailings deposit; however, the range and spatial distribution of the subsample permeabilities should give a good relative indication about which zones of the freeze slice are more likely to allow or impede water flow.

Figures 26a and 26b provide the Beard and Weyl estimate of permeability (in mDarcy) for the different lenses of the freeze slices. The average Beard and Weyl permeability in the upstream freeze slice is higher than in the downstream freeze slice. This result is consistent with the rigid wall hydraulic conductivity measurements from Run 1 (Figure 20). At the downstream end the Beard and Weyl permeability is similar throughout the slice; however, at the upstream end the Beard and Weyl permeability is typically greater for the darker lenses. This result is consistent with the findings from Figure 25. We also note that the highest estimated permeabilities would control the bulk permeability for cases where the coarse (dark) depositional units are connected so as to provide an unbroken flow path through the deposit.

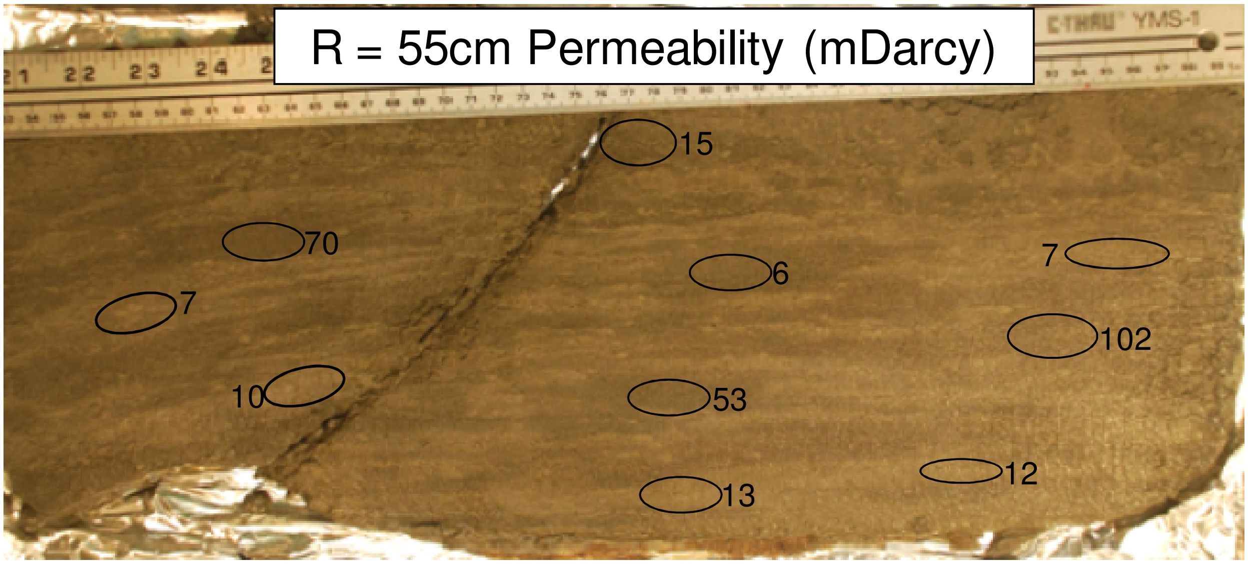

Figure 26a – Beard and Weyl permeability (in mDarcy) for the Freeze Slice at r = 55cm

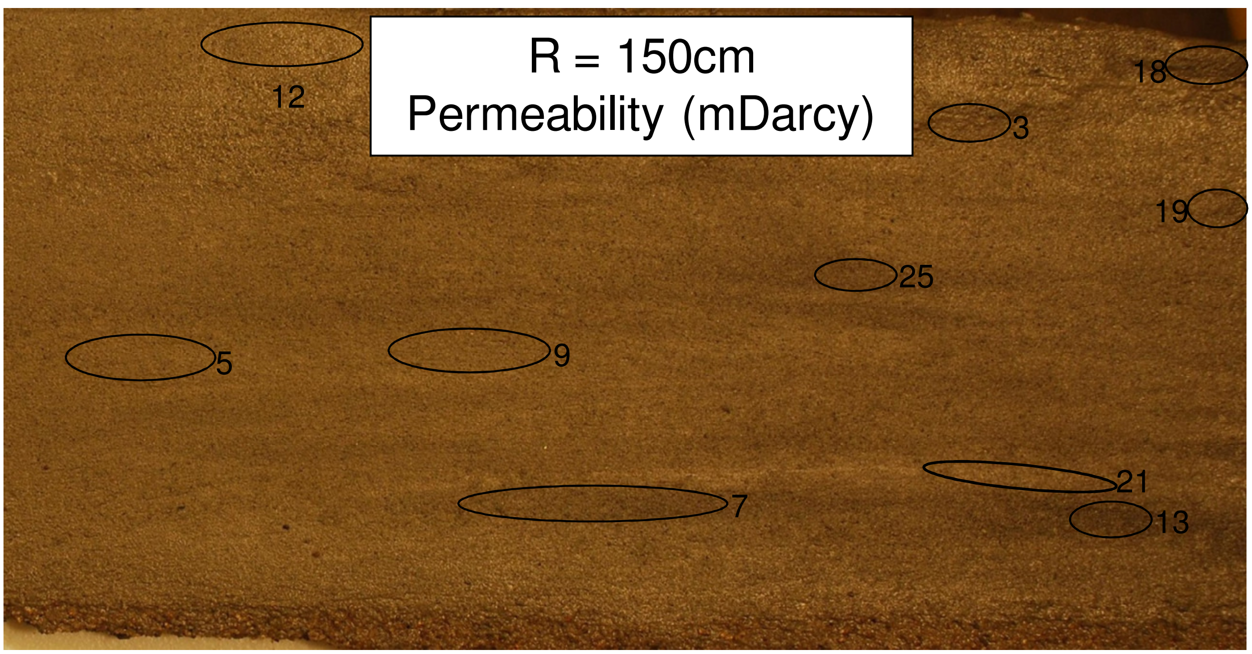

Figure 26b – Beard and Weyl permeability (in mDarcy) for the Freeze Slice at r = 150cm

5.5 Topographic Scans

The field delta geometry was evaluated as part of the one-dimensional experiments. The reduced slurry discharge required to preserve the aspect ratio resulted in a model delta geometry that does not directly translate to the field delta. For Run 1, the beach slope was on the order of 4%. Figure 27(a-g) shows topographic maps of the Run 1 and 2 deltas at the end of each phase. The figures provide further documentation of the variability of the surface topography and chaotic nature of the deposition process. It is interesting to note the shape of the shoreline and how it deviates from an ideal cone-shape. Also, studying the distal portion of the deltas in all images shows distinct depositional lobes that appear to weave together as the distal fan is constructed. These are the processes that create variability in the grain size, coarse fraction, and visual variability that was observed in these tests.

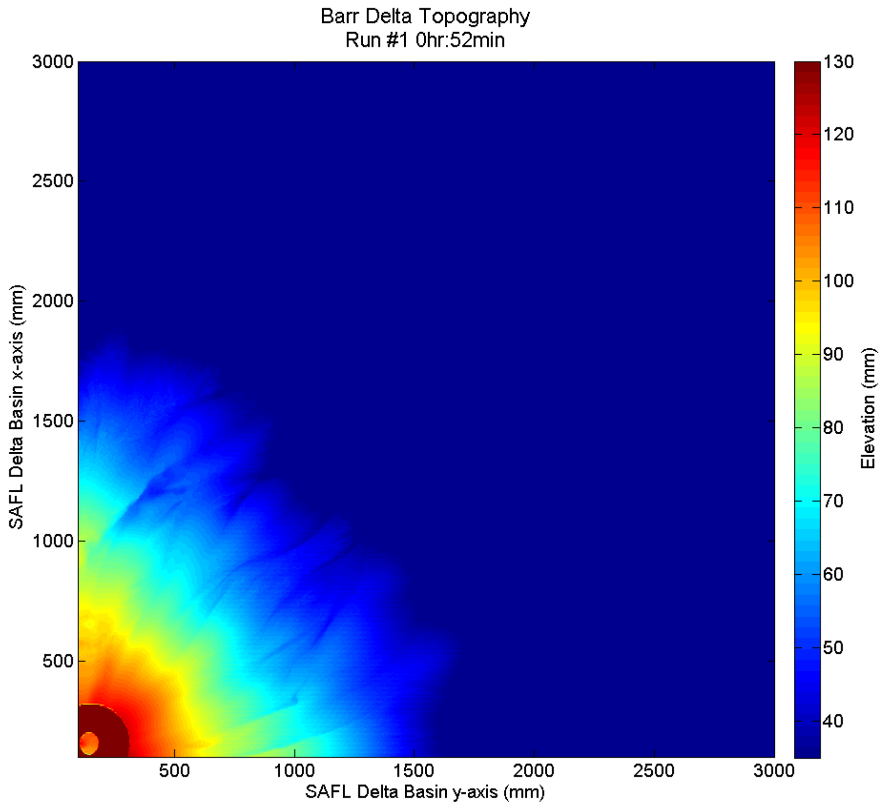

Figure 27a – Run 1 topography at the end of the growth phase

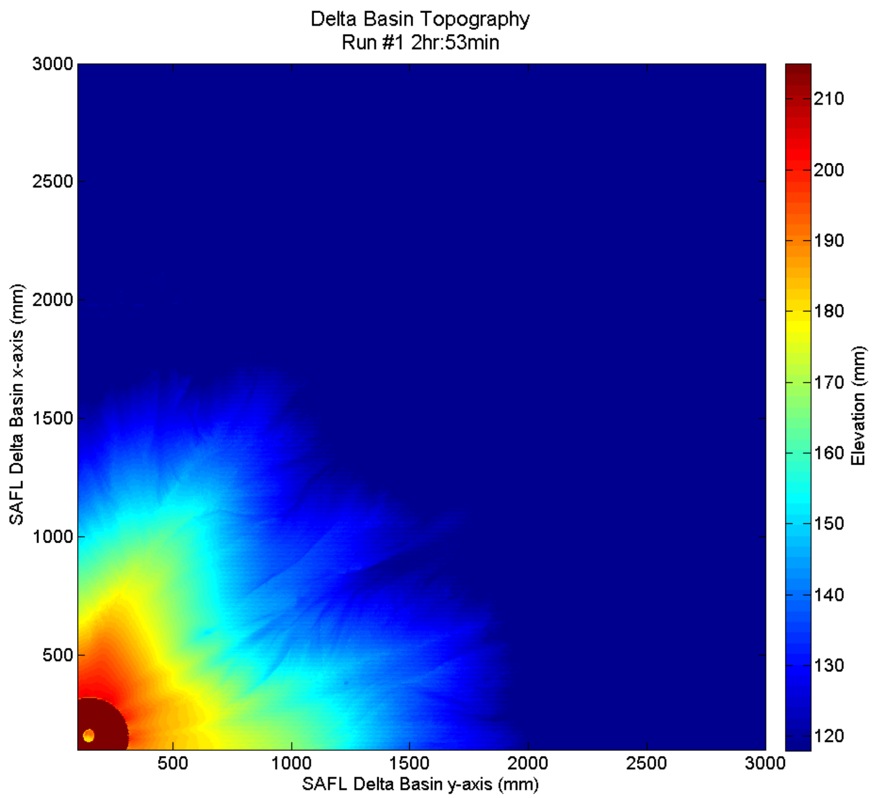

Figure 27b – Run 1 topography during the building phase

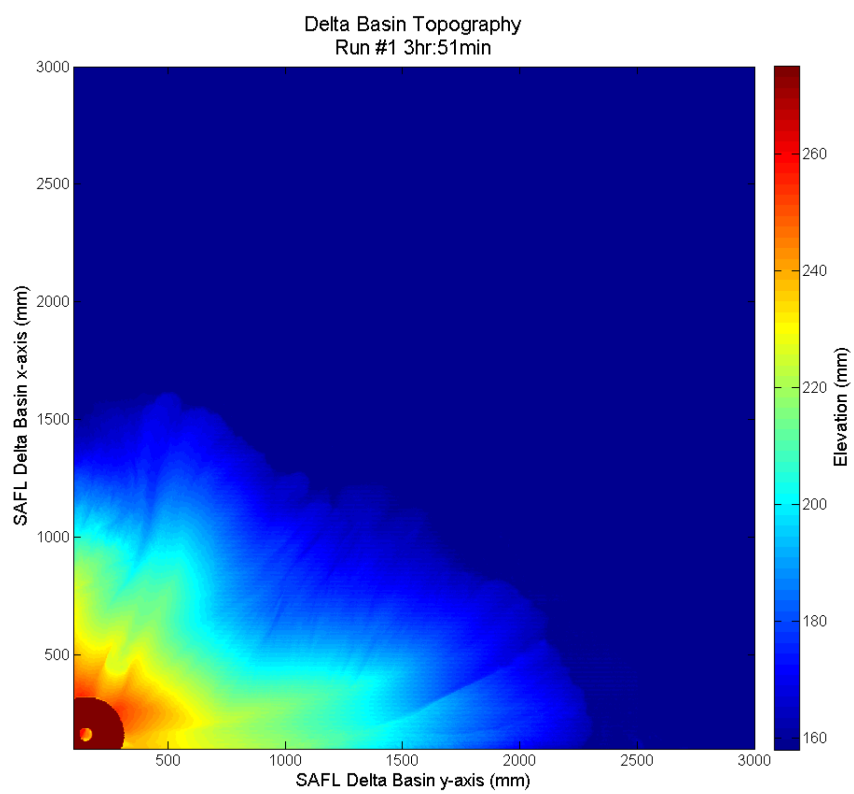

Figure 27c – Run 1 topography at the end of the building phase

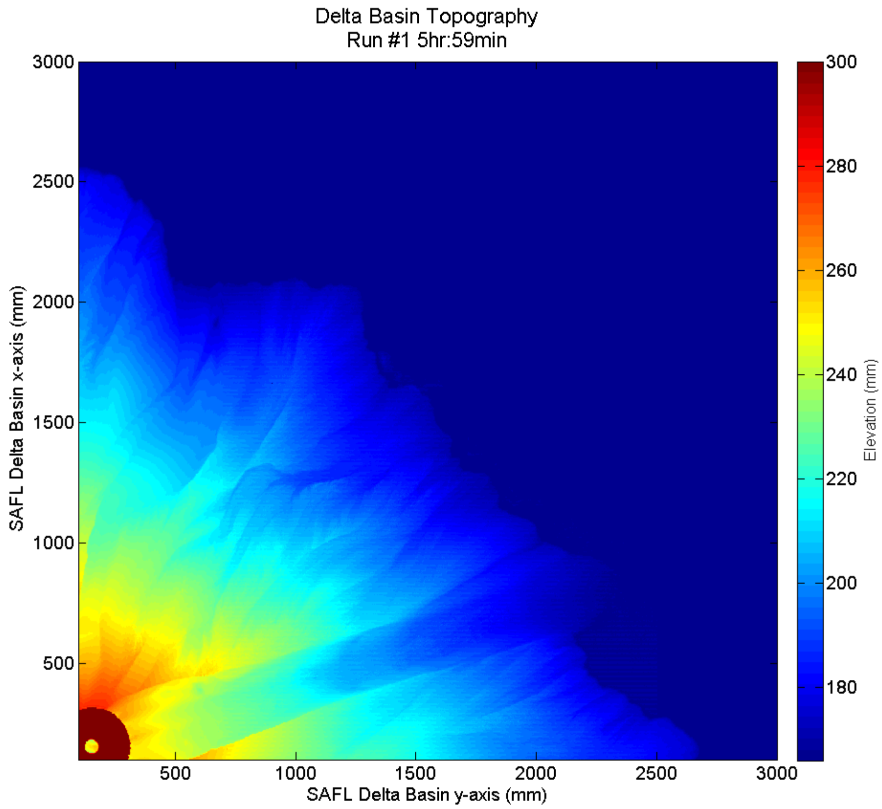

Figure 27d – Run 1 topography at the end of the falling phase

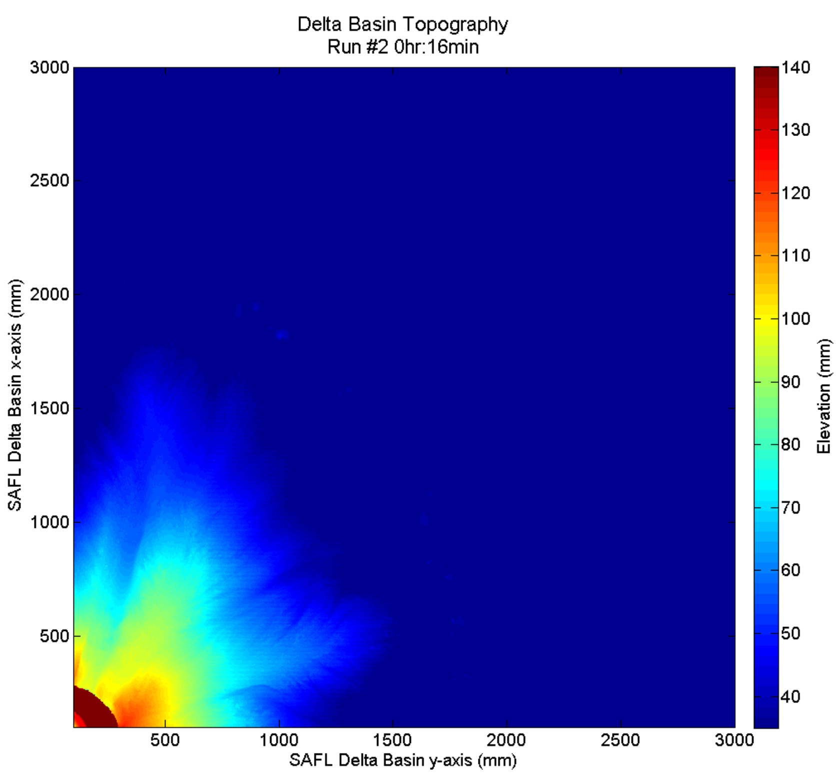

Figure 27e – Run 2 topography at the end of the growth phase

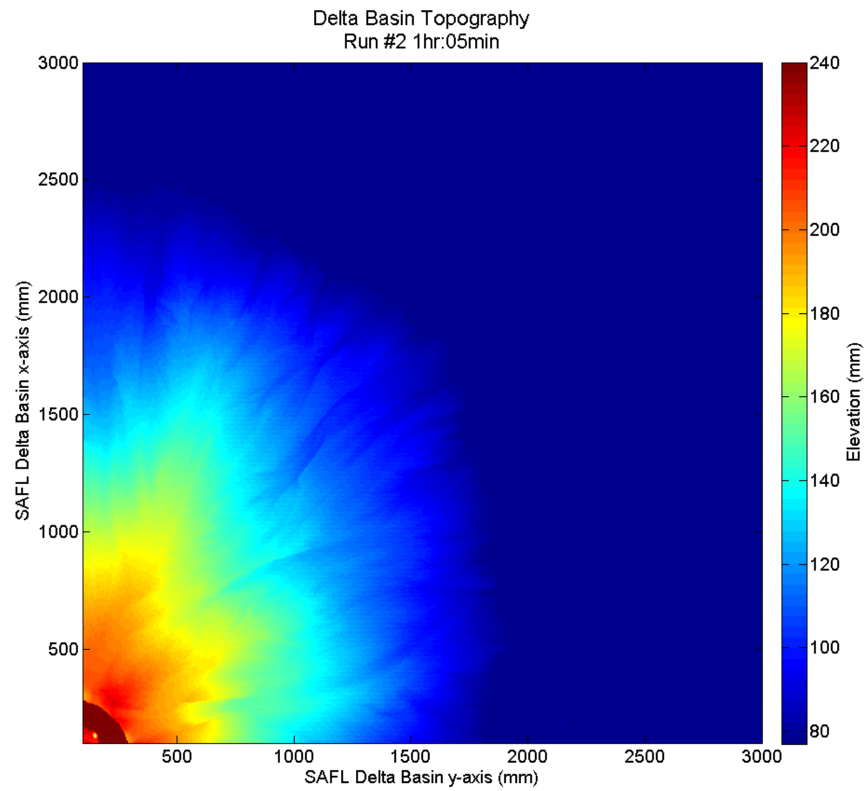

Figure 27f – Run 2 topography at the end of the building phase

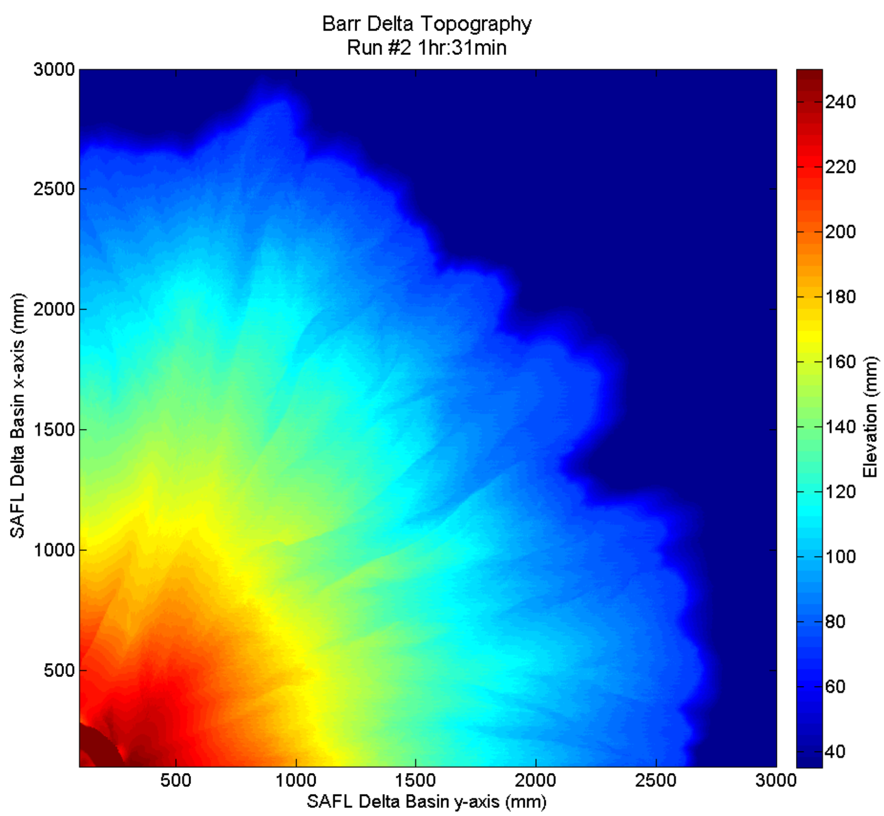

Figure 27g – Run 2 topography at the end of the falling phase

6.0 Phase II – Discussion

6.1 Phase II Results

The goals of the 2D experiments were to 1) determine the expected lower limit of fines concentration in the deposit, 2) determine the degree of grain size segregation both vertically and horizontally within the deposit and 3) evaluate the potential range of hydraulic conductivity throughout the model delta.

The lower limit of fines concentration and the degree of grain size segregation are both functions of fines retention within the deposit. There are several factors that likely influenced fine particle retention within the deposit. One such factor is that the grain size distribution and concentration of the tailings was conducive to fines retention. The range of particle sizes was sufficient and the concentration was high enough that in a shallow flow, such as the flow seen on a delta fan, the larger particles interact with the smaller particles strongly, and both are deposited together. This was observed in the generally high fines contents measured in the scrape samples and in the freeze cores.

The data consistently showed a downstream (nearer the shoreline) trend of increasing fines fraction within the deposit. This observation is likely representative of what would be observed in the field. The coarsest material will deposit in the proximal region of the delta and distally, where the energy of the flow is distributed across a larger fan surface and slopes are milder, fine material will be preferentially deposited. This process is depicted in the mild downward trend seen in Figures 16b, 16b, and 16d. Variability of downstream fining is likely due to the chaotic nature of deltaic transport and deposition of sediment. Braiding, avulsion (see step three of delta evolution below), and bar and bedform movement act to mix surface layers both vertically and horizontally, even as local channel processes create spatially distinct grain size zones. The effect of these processes can be seen in all of the aerial photos and their influence on fines retention is evident in the spikes seen in Figure 16d. Throughout the evolution of the delta, channels with flowing water and sediment sweep across the surface. This process likely accounts for the variability of the coarse fraction data seen in Figures 16e and 16g. This process also accounts for the light and dark lenses seen in Figures 26a and b. The larger, more pronounced lenses in the r = 55 cm freeze slice (Figure 26a) are due to narrower, deeper, and more active channels at the upstream end of the delta. At the downstream end much more of the delta is covered with unchannelized sheet flow. This results in the thinner, wider, and less distinct lenses seen in the r = 150 cm freeze slice (Figure 26b). Figures 28 show these channel characteristics and a sequence of channel evolution.

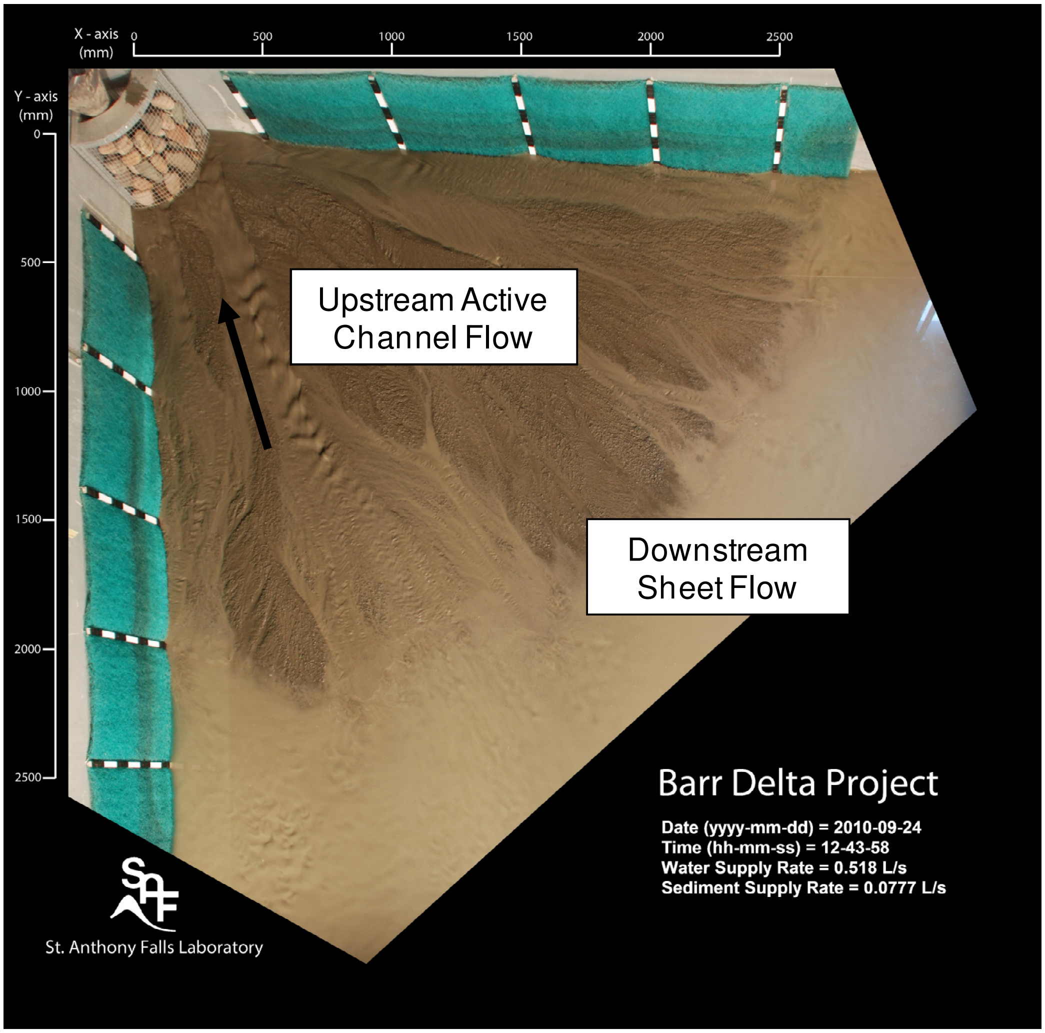

Figure 28a – Channel Evolution Step 1

As more sediment is delivered downstream, the downstream sheet flow zone grows a lobe and the channel cut begins to fill in.

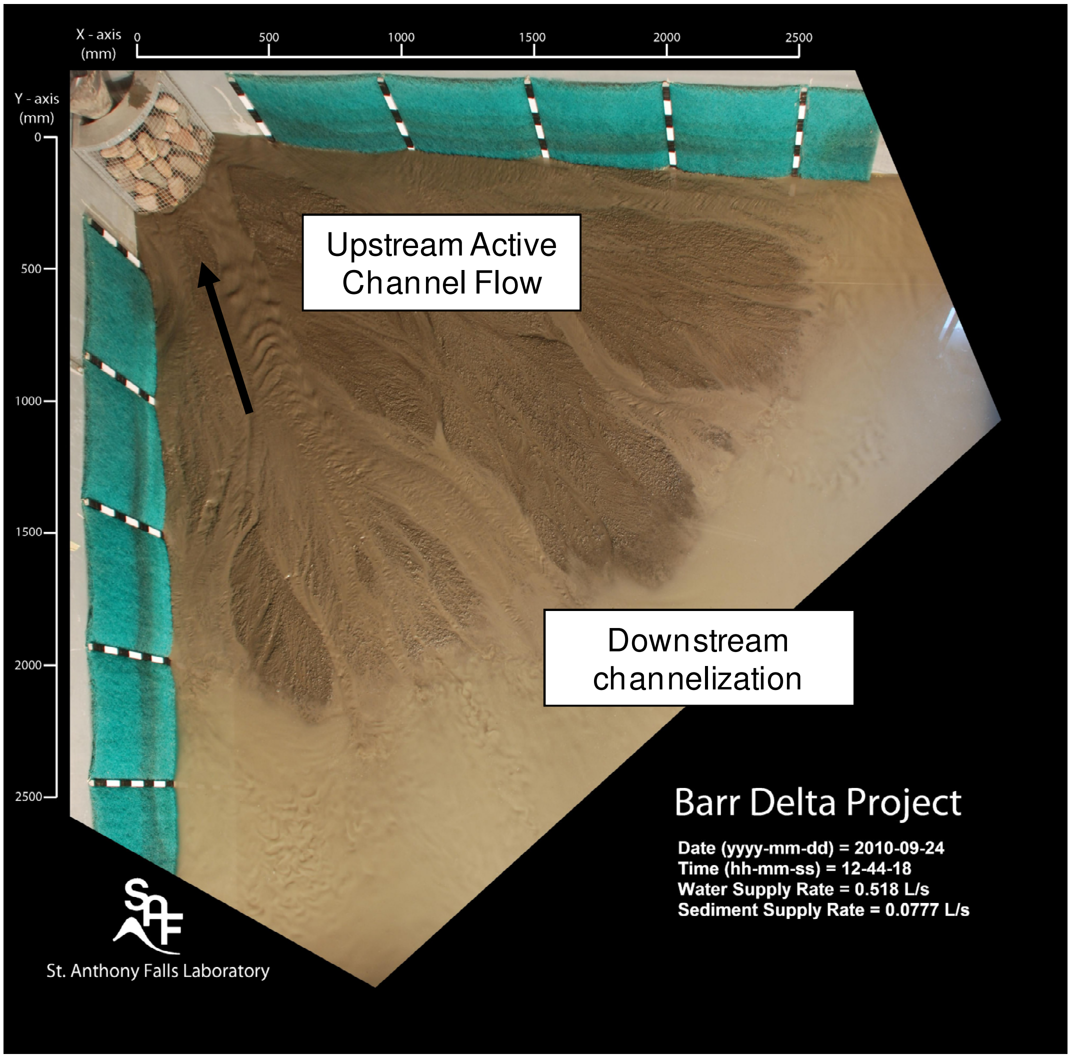

Figure 28b – Channel Evolution Step 2

Once the downstream deposit below the downstream lobe becomes too thick the downstream sheet flow splits into smaller channels, delivering sediment to the lower downstream areas. The upstream channel continues to fill in.

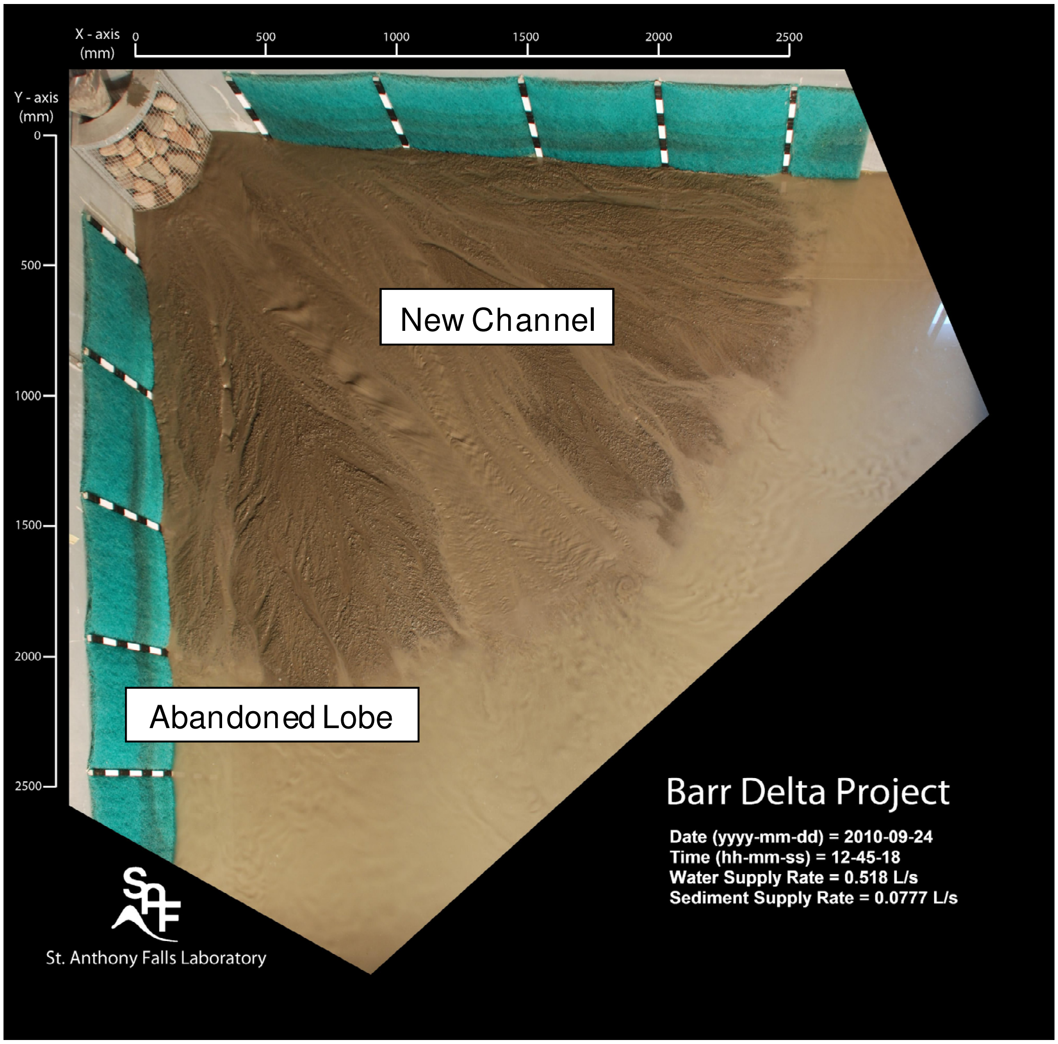

Figure 28c – Channel Evolution Step 3

Once the upstream channel fills in with sediment it avulses to a new location, cutting a new channel and abandoning the previous downstream lobe.

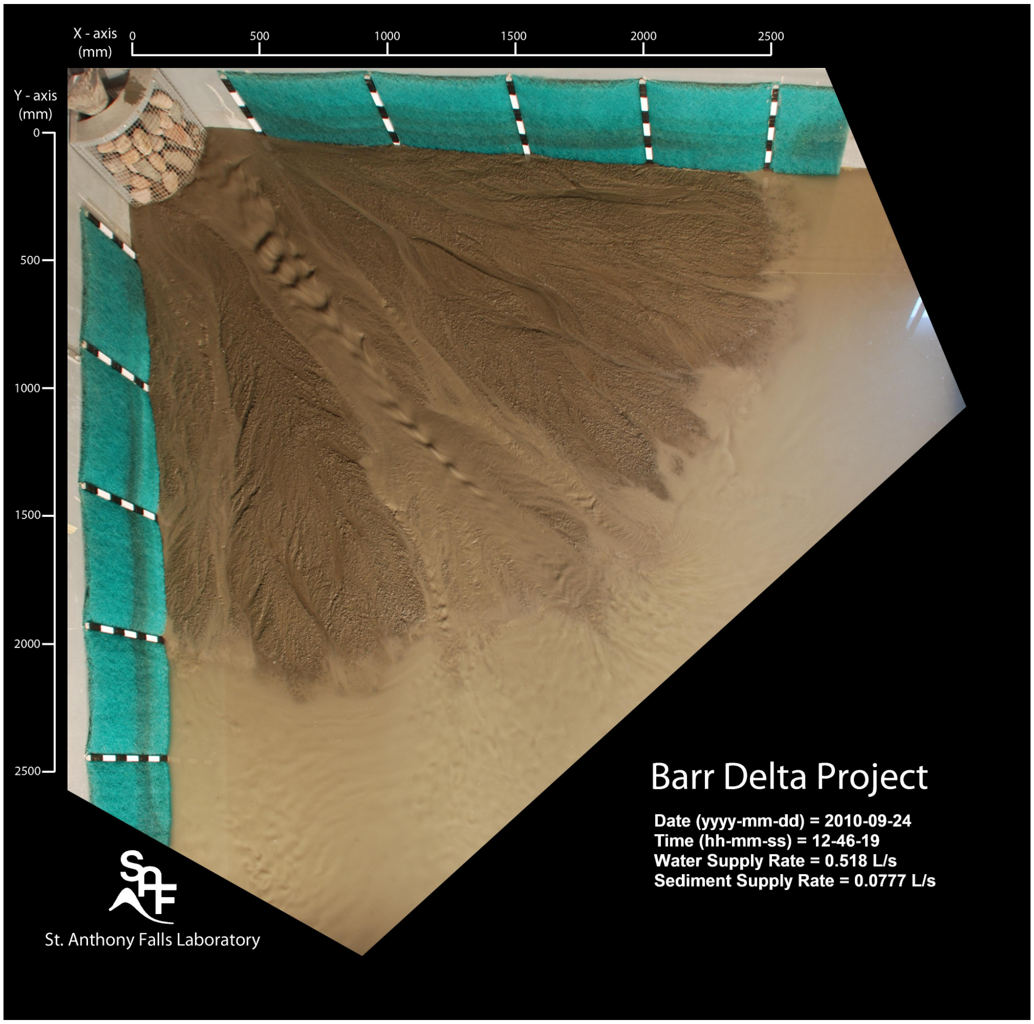

Figure 28d – Channel Evolution Step 4

Finally a new lobe forms at the downstream end of the new channel and the avulsion process start over again. This process has been observed over a range of scales and settings (Sheets and Hoyal 2009).

With these fines retention processes in mind, remember that the falling phase of the runs were designed to maximize channelization on the surface of the deposit. Maximum channelization results in minimum fines retention. This leads to the conclusion that the delta surface at the end of the falling phase should contain the absolute minimum fines that can be expected anywhere within the delta. This conclusion is supported by Figure 16g. From this conclusion one can expect a minimum of 30% fines retention everywhere within the delta.

The final deposit does show some grain size sorting characteristics. The upstream end of the delta spends more time under deep, narrow channels that generate thicker and more pronounced coarse lenses while the downstream end of the delta spends more time under shallower wider channels that generate thinner, more uniform lenses. In general, the results suggest that the field scale delta will have more pronounced coarse lenses at the upstream end of the fan with an overall trend of downstream fining. Even these coarse lenses, however, should retain a fines fraction of ~30% or more.

At the upstream end the thickness and interconnected nature of the dark/coarse lenses indicate that infiltrating groundwater will likely bypass the light/fine lenses; consequently, groundwater transport will likely be greater at the upstream end of the delta than at the downstream end. This means that the hydraulic conductivity measurements taken in Section 5.2 can only be used as a lower limit of the effective hydraulic conductivity.

The laboratory experiment was designed to capture the main processes and channelization expected in the tailings pond delta. In other words, the laboratory delta is expected to grow and maintain its surface by the same mechanisms as the field scale delta. As such, the minimum fines retention and degree of grain size sorting seen in the experiment should be similar to that in the field scale delta. The field scale delta should also exhibit spatially variable hydraulic conductivity comparable to that seen in the laboratory scale delta.

6.2 Delta Drainage

Many experimental deltas have been built in the SAFL delta basins. In most cases the delta basin is drained at the end of the experiment and the delta is dry enough to be sliced in about a week. Six weeks after the completion of Run 1 the delta deposit was still near saturation. The following questions need to be addressed: 1) why did the laboratory scale delta retain water, and 2) will the field scale delta also retain water at near saturation? There are several possible explanations for this behavior which will be discussed in the following sections.

6.2.1 Low Permeability

Firstly, considering the primary difference between these laboratory scale deltas and previous delta experiments, the tailings used in this study had much higher fines content than previous experiments. In previous experiments the sediment was hand mixed. For both physical and safety reasons in previous experiments coal was used in place of the finest fraction of the sediment. The lower density of coal allows it to transport at a rate similar to the prototype (actual) fine material; however, the larger particle sizes of coal increase the permeability of the deposit. The inclusion of the “real” fine particles in the deposit greatly reduce the permeability of the deposit and thereby increase the drainage time; however, the decreased permeability alone is not sufficient to describe the prolonged water retention within the delta deposit.

6.2.2 Suspended Capillary Water

In order for water to be trapped in the delta deposit via capillary suction, the material must be unsaturated. In addition, soil suction and percent saturation are inversely related (see the SWCC provided by Daniel B. Stephens & Associates (DBS&A) Laboratory). The inclusion of fine material instead of coarser coal increases the soil suction pressures over previous experiments. The deposit was fully saturated at the end of the experimental run. The moment the delta began to drain the deposit became unsaturated. Figure 29 is a diagram of the system being investigated and the corresponding pressures.

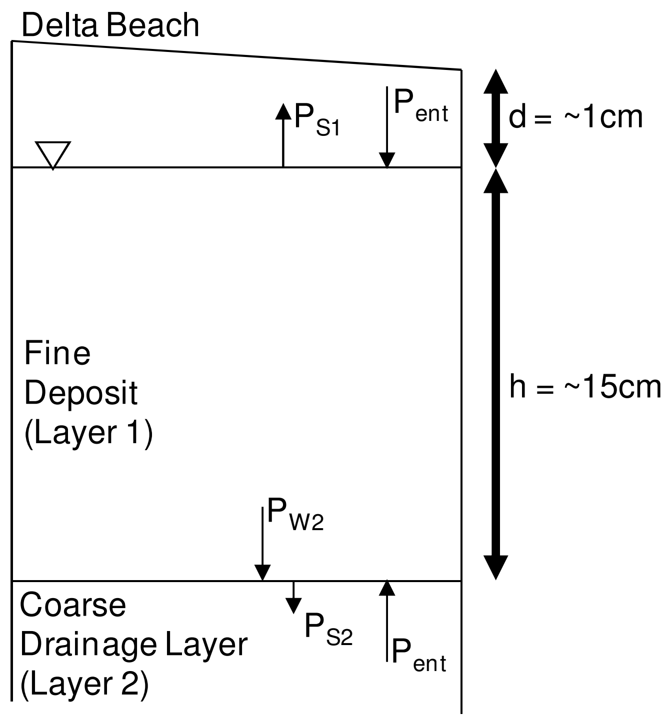

Figure 29 – Diagram of water column and associated pressures.

Where: P_{S1} = suction pressure of the deposit layer

P_{S2} = suction pressure of drainage layer

P_W = water pressure at bottom of the deposit

P_{ent} = atmospheric entrance pressure

The fine deposit layer has an upward suction pressure inversely related to the percent saturation. The coarse drainage layer has a much lower downward suction pressure. The water pressure balance for trapping water in the fine layer above a coarse layer is given by equation 11.

$$P_{S2} + P_W > P_{S1} \qquad (11)$$

The drainage layer suction pressure and the weight of the water act to drain water from the delta, while the deposit suction pressure acts to retain water within the delta. The suction pressure of the drainage layer is much lower than the suction pressure of the deposit and can be neglected. As such, if the water pressure due to the height of the deposit is equal to the suction pressure of the deposit, the water in the deposit will be retained. The water pressured generated by 15 cm (6in) of water is 1.47 kPa or 0.0174 bar. Based on the SWCC provided by DBS&A for the tailings material, the suction pressure of the deposit is equal to 0.0174 bar when the percent saturation is equal to 85-98%. In conclusion, suspended capillary water itself is sufficient to explain the water retention within the laboratory delta deposit.

6.2.3 Influence of Fluvial Deposition

The SWCC generated by DBS&A was created by testing artificially sorted and mixed tailings samples. It is entirely possible that the SWCC will be different for a fluvial deposit created from the same material. A flowing system may orient the particles differently or change the packing characteristics. This is a common problem in the construction industry. When mechanically placing construction fill it can be challenging to achieve compactions as high as field conditions and impossible to match them. The opposite is also true in laboratory settings; it can difficult to achieve loose compaction conditions or match fluvial deposition conditions.

Under fluvial deposition, angular fine particles may orient themselves and interlock in such a way that nearly all of the void space is composed of "micropores." Micropores are pore spaces so small that water contained within them will not drain by gravity and is only removed by suction and evaporation. The influence of fluvial deposition in itself is sufficient to explain the water retention found in the laboratory delta deposit.

6.2.4 Field Delta Drainage

The lack of drainage in the laboratory scale can be satisfactorily explained by suspended capillary water and/or fluvial deposition processes. Unfortunately the qualitative observations made of the laboratory scale delta drainage are insufficient to definitively say which process is responsible the water retention. It is most likely a combination of the processes.

In the field scale delta the thickness of the deposit means that suspended capillary water will not be able to retain water at near the saturation point as in the experiments, because the column pressure will be higher. On the other hand, if the fluvial deposition mechanism does actually generate the majority of void space as micropores, then the field scale delta could also retain a high percentage of water.

7.0 Conclusions

Physical experiments were conducted to explore the transport and depositional characteristics of prototype tailings material. The experiments were conducted in two phases; the first phase used 1D flume experiments under field-scale conditions and Phase II involved 2D scaled experiments to investigate channelization and its consequences. The experimental findings are summarized here:

- Field scale slopes are anticipated to range from 0.5 to 2%. The 1% slope used for field scale design is reasonable.

- The delta will operate in a fluvial braided channelized regime characterized by multiple channels, rapid channel migration, and dynamic bar and bedform processes.

- The deposit will likely experience both vertical and horizontal sorting of grains. The coarsest portion of the deposit will be the proximal region of the delta and the distal region will have higher fines content.

- The multi-channel fluvial processes will create a deposit that has buried channels in the subsurface. The hydraulic interconnectedness of these channels has not been explored quantitatively in this study but visual observation suggests that channels will be connected vertically and laterally, especially in the upstream part of the deposit.

- Even under the most extreme plausible transport conditions, it was difficult to generate a deposit with less than 30% fines content in the deposit. This suggests that, even though channelization generally moves fine material offshore, bypassing the subaerial delta, a significant fraction of the fines in the tailings material is co-deposited with coarser material. These levels of trapped fines will significantly reduce conductivity relative to a well sorted deposit of the same median size.

- Hydraulic conductivities measured on piston cores taken from the laboratory deposits are relatively low due to conductivity in cores being limited by the presence of fine layers in the cores. Because 3D groundwater flow in the field may exploit connected high-conductivity pathways through the deposit, the values measured with cores represent the low end of conductivities expected for field conditions.

- The degree of water retention in the field scale deposit was inconclusive. The estimated deposit thickness and the SWCC for the tailings suggests that suction will not be great enough to keep the deposit saturated; however, internal structures such as lenses, discontinuities, or micro-pores associated with the natural deposition of the deposit may increase the suction pressure of the material.

There are several design alternatives that could potentially increase fines retention. Reducing the water content of the slurry such that the delta/beach behaves as a debris (“mud”) flow would be expected to enhance fines retention although no tests were done on this transport mode in this study. The delta could be operated such that there are periods of receding shoreline produced by raising the pool level. Switching between multiple spigot locations could also be timed to achieve a similar effect. These alternatives focus only on increasing fines retention. There may be other physical or operational considerations that make them unfeasible.

8.0 References

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Hoyal, D. C. J. D., and B. A. Sheets (2009), Morphodynamic evolution of experimental cohesive deltas, J. Geophys. Res., vol 114, doi:10.1029/2007JF000882.

Parker, G., 1976, On the causes and characteristic scales of meandering and braiding in rivers, J.Fluid Mechanics, vol 76, part 3, pp 457-480.

Appendix A – Feed Material Grain Size Distribution

Appendix B – Scrape Sample Grain Size Analysis

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
1	End of Growth	1	$\pi/8$	25	0.63	0.37	1.67
1	End of Growth	2	$\pi/8$	40	0.55	0.45	1.23
1	End of Growth	3	$\pi/8$	55	0.66	0.34	1.91
1	End of Growth	4	$\pi/8$	70	0.72	0.28	2.62
1	End of Growth	5	$\pi/8$	85	0.73	0.27	2.76
1	End of Growth	6	$\pi/8$	100	0.70	0.30	2.29
1	End of Growth	7	$\pi/8$	115	0.68	0.32	2.08
1	End of Growth	8	$\pi/8$	130	0.63	0.37	1.68
1	End of Growth	9	$\pi/8$	145	0.56	0.44	1.27
1	End of Growth	10	$3\pi/16$	25	0.53	0.47	1.11
1	End of Growth	11	$3\pi/16$	40	0.59	0.41	1.46
1	End of Growth	12	$3\pi/16$	55	0.74	0.26	2.91
1	End of Growth	13	$3\pi/16$	70	0.69	0.31	2.23
1	End of Growth	14	$3\pi/16$	85	0.58	0.42	1.41
1	End of Growth	15	$3\pi/16$	100	0.59	0.41	1.45
1	End of Growth	16	$3\pi/16$	115	0.65	0.35	1.82
1	End of Growth	17	$3\pi/16$	130	0.64	0.36	1.77
1	End of Growth	19	$\pi/4$	25	0.39	0.61	0.64
1	End of Growth	20	$\pi/4$	40	0.54	0.46	1.17
1	End of Growth	21	$\pi/4$	55	0.58	0.42	1.40
1	End of Growth	22	$\pi/4$	70	0.58	0.42	1.38
1	End of Growth	23	$\pi/4$	85	0.22	0.78	0.28
1	End of Growth	24	$\pi/4$	100	0.44	0.56	0.78
1	End of Growth	25	$\pi/4$	115	0.51	0.49	1.04
1	End of Growth	26	$\pi/4$	130	0.54	0.46	1.15
1	End of Growth	28	$5\pi/16$	25	0.46	0.54	0.85
1	End of Growth	30	$5\pi/16$	55	0.71	0.29	2.41
1	End of Growth	31	$5\pi/16$	70	0.62	0.38	1.62
1	End of Growth	32	$5\pi/16$	85	0.57	0.43	1.35
1	End of Growth	33	$5\pi/16$	100	0.52	0.48	1.10
1	End of Growth	34	$5\pi/16$	115	0.53	0.47	1.11

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
1	End of Growth	35	$5\pi/16$	130	0.54	0.46	1.17
1	End of Growth	36	$5\pi/16$	145	0.40	0.60	0.66
1	End of Growth	37	$3\pi/8$	25	0.36	0.64	0.57
1	End of Growth	38	$3\pi/8$	40	0.55	0.45	1.20
1	End of Growth	39	$3\pi/8$	55	0.56	0.44	1.28
1	End of Growth	40	$3\pi/8$	70	0.68	0.32	2.12
1	End of Growth	41	$3\pi/8$	85	0.63	0.37	1.72
1	End of Growth	42	$3\pi/8$	100	0.57	0.43	1.32
1	End of Growth	43	$3\pi/8$	115	0.53	0.47	1.13
1	End of Growth	44	$3\pi/8$	130	0.51	0.49	1.03
1	End of Growth	45	$3\pi/8$	145	0.47	0.53	0.87
1	End of Falling	1	$\pi/8$	25	0.45	0.55	0.81
1	End of Falling	2	$\pi/8$	40	0.47	0.53	0.89
1	End of Falling	3	$\pi/8$	55	0.62	0.38	1.60
1	End of Falling	4	$\pi/8$	70	0.41	0.59	0.69
1	End of Falling	5	$\pi/8$	85	0.38	0.62	0.60
1	End of Falling	6	$\pi/8$	100	0.37	0.63	0.59
1	End of Falling	7	$\pi/8$	115	0.40	0.60	0.67
1	End of Falling	8	$\pi/8$	130	0.33	0.67	0.50
1	End of Falling	9	$\pi/8$	145	0.60	0.40	1.50
1	End of Falling	10	$3\pi/16$	25	0.54	0.46	1.16
1	End of Falling	11	$3\pi/16$	40	0.49	0.51	0.95
1	End of Falling	12	$3\pi/16$	55	0.59	0.41	1.42
1	End of Falling	13	$3\pi/16$	70	0.31	0.69	0.44
1	End of Falling	14	$3\pi/16$	85	0.55	0.45	1.21
1	End of Falling	15	$3\pi/16$	100	0.47	0.53	0.88
1	End of Falling	16	$3\pi/16$	115	0.41	0.59	0.70
1	End of Falling	17	$3\pi/16$	130	0.38	0.62	0.62
1	End of Falling	18	$3\pi/16$	145	0.46	0.54	0.85
1	End of Falling	19	$\pi/4$	25	0.46	0.54	0.85
1	End of Falling	20	$\pi/4$	40	0.47	0.53	0.90
1	End of Falling	21	$\pi/4$	55	0.49	0.51	0.95
1	End of Falling	22	$\pi/4$	70	0.48	0.52	0.94

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
1	End of Falling	23	$\pi/4$	85	0.45	0.55	0.82
1	End of Falling	24	$\pi/4$	100	0.47	0.53	0.87
1	End of Falling	25	$\pi/4$	115	0.46	0.54	0.86
1	End of Falling	26	$\pi/4$	130	0.48	0.52	0.92
1	End of Falling	27	$\pi/4$	145	0.39	0.61	0.64
1	End of Falling	28	$5\pi/16$	25	0.60	0.40	1.52
1	End of Falling	29	$5\pi/16$	40	0.61	0.39	1.57
1	End of Falling	30	$5\pi/16$	55	0.52	0.48	1.09
1	End of Falling	31	$5\pi/16$	70	0.39	0.61	0.65
1	End of Falling	32	$5\pi/16$	85	0.00	1.00	0.00
1	End of Falling	33	$5\pi/16$	100	0.00	1.00	0.00
1	End of Falling	34	$5\pi/16$	115	0.47	0.53	0.90
1	End of Falling	35	$5\pi/16$	130	0.47	0.53	0.89
1	End of Falling	36	$5\pi/16$	145	0.36	0.64	0.57
1	End of Falling	37	$3\pi/8$	25	0.72	0.28	2.63
1	End of Falling	38	$3\pi/8$	40	0.71	0.29	2.49
1	End of Falling	39	$3\pi/8$	55	0.59	0.41	1.46
1	End of Falling	40	$3\pi/8$	70	0.55	0.45	1.22
1	End of Falling	41	$3\pi/8$	85	0.72	0.28	2.51
1	End of Falling	42	$3\pi/8$	100	0.69	0.31	2.19
1	End of Falling	43	$3\pi/8$	115	0.72	0.28	2.57
1	End of Falling	44	$3\pi/8$	130	0.45	0.55	0.82
1	End of Falling	45	$3\pi/8$	145	0.56	0.44	1.27
2	End of Growth	1	$\pi/8$	25	0.55	0.45	1.23
2	End of Growth	2	$\pi/8$	40	0.66	0.34	1.95
2	End of Growth	3	$\pi/8$	55	0.70	0.30	2.31
2	End of Growth	4	$\pi/8$	70	0.53	0.47	1.12
2	End of Growth	5	$\pi/8$	85	0.52	0.48	1.09
2	End of Growth	6	$\pi/8$	100	0.46	0.54	0.85
2	End of Growth	7	$\pi/8$	115	0.50	0.50	0.99
2	End of Growth	8	$\pi/8$	130	0.44	0.56	0.79
2	End of Growth	9	$\pi/8$	145	0.28	0.72	0.39
2	End of Growth	10	$3\pi/16$	25	0.64	0.36	1.78

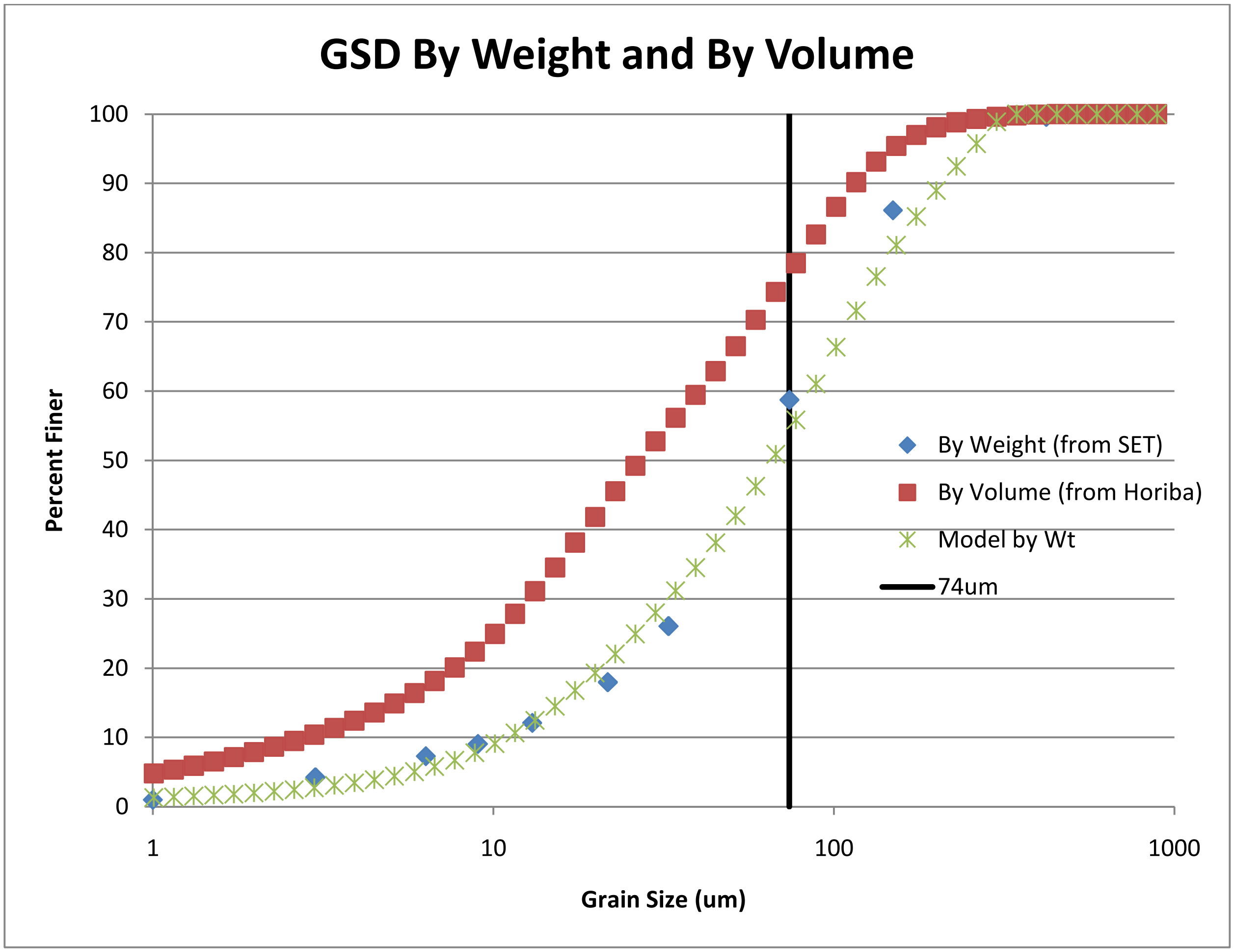
Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
2	End of Growth	11	3π/16	40	0.54	0.46	1.17
2	End of Growth	12	3π/16	55	0.58	0.42	1.36
2	End of Growth	13	3π/16	70	0.36	0.64	0.57
2	End of Growth	14	3π/16	85	0.37	0.63	0.59
2	End of Growth	15	3π/16	100	0.29	0.71	0.40
2	End of Growth	16	3π/16	115	0.27	0.73	0.36
2	End of Growth	17	3π/16	130	0.27	0.73	0.36
2	End of Growth	18	3π/16	145	0.57	0.43	1.33
2	End of Growth	19	π/4	25	0.57	0.43	1.33
2	End of Growth	20	π/4	40	0.53	0.47	1.15
2	End of Growth	21	π/4	55	0.46	0.54	0.85
2	End of Growth	22	π/4	70	0.44	0.56	0.77
2	End of Growth	23	π/4	85	0.31	0.69	0.44
2	End of Growth	24	π/4	100	0.30	0.70	0.43
2	End of Growth	25	π/4	115	0.42	0.58	0.71
2	End of Growth	26	π/4	130	0.25	0.75	0.34
2	End of Growth	28	5π/16	25	0.51	0.49	1.04
2	End of Growth	29	5π/16	40	0.44	0.56	0.78
2	End of Growth	30	5π/16	55	0.37	0.63	0.59
2	End of Growth	31	5π/16	70	0.36	0.64	0.55
2	End of Growth	32	5π/16	85	0.40	0.60	0.68
2	End of Growth	33	5π/16	100	0.33	0.67	0.48
2	End of Growth	34	5π/16	115	0.37	0.63	0.59
2	End of Growth	35	5π/16	130	0.16	0.84	0.19
2	End of Growth	36	5π/16	145	0.28	0.72	0.39
2	End of Growth	37	3π/8	25	0.39	0.61	0.63
2	End of Growth	38	3π/8	40	0.43	0.57	0.76
2	End of Growth	39	3π/8	55	0.49	0.51	0.95
2	End of Growth	40	3π/8	70	0.48	0.52	0.91
2	End of Growth	41	3π/8	85	0.52	0.48	1.10
2	End of Growth	42	3π/8	100	0.50	0.50	1.01
2	End of Growth	43	3π/8	115	0.49	0.51	0.97
2	End of Growth	44	3π/8	130	0.41	0.59	0.69

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
2	End of Growth	45	$3\pi/8$	145	0.24	0.76	0.32
2	End of Building	1	$\pi/8$	25	0.65	0.35	1.82
2	End of Building	2	$\pi/8$	40	0.51	0.49	1.05
2	End of Building	3	$\pi/8$	55	0.54	0.46	1.19
2	End of Building	4	$\pi/8$	70	0.58	0.42	1.36
2	End of Building	5	$\pi/8$	85	0.46	0.54	0.86
2	End of Building	6	$\pi/8$	100	0.46	0.54	0.85
2	End of Building	7	$\pi/8$	115	0.48	0.52	0.92
2	End of Building	8	$\pi/8$	130	0.33	0.67	0.50
2	End of Building	9	$\pi/8$	145	0.40	0.60	0.67
2	End of Building	10	$3\pi/16$	25	0.45	0.55	0.82
2	End of Building	11	$3\pi/16$	40	0.40	0.60	0.67
2	End of Building	12	$3\pi/16$	55	0.51	0.49	1.06
2	End of Building	13	$3\pi/16$	70	0.36	0.64	0.56
2	End of Building	14	$3\pi/16$	85	0.35	0.65	0.54
2	End of Building	15	$3\pi/16$	100	0.39	0.61	0.63
2	End of Building	16	$3\pi/16$	115	0.38	0.62	0.62
2	End of Building	17	$3\pi/16$	130	0.40	0.60	0.65
2	End of Building	18	$3\pi/16$	145	0.47	0.53	0.88
2	End of Building	19	$\pi/4$	25	0.43	0.57	0.76
2	End of Building	20	$\pi/4$	40	0.42	0.58	0.72
2	End of Building	21	$\pi/4$	55	0.40	0.60	0.66
2	End of Building	22	$\pi/4$	70	0.41	0.59	0.70
2	End of Building	23	$\pi/4$	85	0.64	0.36	1.74
2	End of Building	24	$\pi/4$	100	0.45	0.55	0.81
2	End of Building	25	$\pi/4$	115	0.44	0.56	0.78
2	End of Building	26	$\pi/4$	130	0.16	0.84	0.19
2	End of Building	27	$\pi/4$	145	0.46	0.54	0.86
2	End of Building	28	$5\pi/16$	25	0.66	0.34	1.92
2	End of Building	29	$5\pi/16$	40	0.65	0.35	1.88
2	End of Building	30	$5\pi/16$	55	0.54	0.46	1.20
2	End of Building	31	$5\pi/16$	70	0.40	0.60	0.66
2	End of Building	32	$5\pi/16$	85	0.46	0.54	0.84

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
2	End of Building	33	$5\pi/16$	100	0.37	0.63	0.59
2	End of Building	34	$5\pi/16$	115	0.43	0.57	0.77
2	End of Building	35	$5\pi/16$	130	0.49	0.51	0.96
2	End of Building	36	$5\pi/16$	145	0.49	0.51	0.95
2	End of Building	37	$3\pi/8$	25	0.61	0.39	1.53
2	End of Building	38	$3\pi/8$	40	0.54	0.46	1.18
2	End of Building	39	$3\pi/8$	55	0.46	0.54	0.85
2	End of Building	40	$3\pi/8$	70	0.54	0.46	1.15
2	End of Building	44	$3\pi/8$	130	0.42	0.58	0.73
2	End of Building	45	$3\pi/8$	145	0.33	0.67	0.50
2	End of Falling	1	$\pi/8$	25	0.67	0.33	2.01
2	End of Falling	2	$\pi/8$	40	0.60	0.40	1.48
2	End of Falling	3	$\pi/8$	55	0.69	0.31	2.25
2	End of Falling	4	$\pi/8$	70	0.63	0.37	1.72
2	End of Falling	5	$\pi/8$	85	0.58	0.42	1.37
2	End of Falling	6	$\pi/8$	100	0.49	0.51	0.96
2	End of Falling	7	$\pi/8$	115	0.51	0.49	1.06
2	End of Falling	8	$\pi/8$	130	0.49	0.51	0.94
2	End of Falling	9	$\pi/8$	145	0.65	0.35	1.83
2	End of Falling	10	$3\pi/16$	25	0.68	0.32	2.17
2	End of Falling	11	$3\pi/16$	40	0.49	0.51	0.98
2	End of Falling	12	$3\pi/16$	55	0.46	0.54	0.86
2	End of Falling	13	$3\pi/16$	70	0.46	0.54	0.86
2	End of Falling	14	$3\pi/16$	85	0.42	0.58	0.71
2	End of Falling	15	$3\pi/16$	100	0.43	0.57	0.76
2	End of Falling	16	$3\pi/16$	115	0.42	0.58	0.72
2	End of Falling	17	$3\pi/16$	130	0.45	0.55	0.81
2	End of Falling	18	$3\pi/16$	145	0.44	0.56	0.77
2	End of Falling	19	$\pi/4$	25	0.58	0.42	1.37
2	End of Falling	20	$\pi/4$	40	0.43	0.57	0.76
2	End of Falling	21	$\pi/4$	55	0.52	0.48	1.06
2	End of Falling	22	$\pi/4$	70	0.39	0.61	0.63
2	End of Falling	23	$\pi/4$	85	0.42	0.58	0.73

Run #	Phase	Sample #	θ	r (cm)	% > 74μ	% < 74μ	Coarse/Fine Fraction
2	End of Falling	24	$\pi/4$	100	0.53	0.47	1.12
2	End of Falling	25	$\pi/4$	115	0.43	0.57	0.77
2	End of Falling	26	$\pi/4$	130	0.37	0.63	0.60
2	End of Falling	27	$\pi/4$	145	0.38	0.62	0.61
2	End of Falling	28	$5\pi/16$	25	0.53	0.47	1.13
2	End of Falling	29	$5\pi/16$	40	0.49	0.51	0.97
2	End of Falling	30	$5\pi/16$	55	0.58	0.42	1.40
2	End of Falling	31	$5\pi/16$	70	0.50	0.50	1.01
2	End of Falling	32	$5\pi/16$	85	0.46	0.54	0.85
2	End of Falling	33	$5\pi/16$	100	0.47	0.53	0.88
2	End of Falling	34	$5\pi/16$	115	0.41	0.59	0.70
2	End of Falling	35	$5\pi/16$	130	0.55	0.45	1.23
2	End of Falling	36	$5\pi/16$	145	0.58	0.42	1.36
2	End of Falling	37	$3\pi/8$	25	0.61	0.39	1.59
2	End of Falling	38	$3\pi/8$	40	0.58	0.42	1.39
2	End of Falling	39	$3\pi/8$	55	0.65	0.35	1.83
2	End of Falling	40	$3\pi/8$	70	0.41	0.59	0.70
2	End of Falling	41	$3\pi/8$	85	0.39	0.61	0.65
2	End of Falling	42	$3\pi/8$	100	0.30	0.70	0.44
2	End of Falling	43	$3\pi/8$	115	0.51	0.49	1.04
2	End of Falling	44	$3\pi/8$	130	0.59	0.41	1.44
2	End of Falling	45	$3\pi/8$	145	0.31	0.69	0.45

Appendix C – Comparison of Grain Size Distribution by Volume (Horiba® Laser Diffraction) and by Weight (Sieve and Hydrometer Tests from SET Labs)



The percent finer by weight can be estimated using the following equation:

$$\%Finer_W = \%Finer_V \cdot F \cdot [A \cdot ln(C \cdot Dia + E) + B] + G$$

Where: $\%Finer_W$ = Percent finer by weight

$\%Finer_V$ = Percnet Finer by volume

Dia = Particle diameter (um)

A = 0.214826

B = -0.21006

C = 0.83509

E = 4.470231

F = 1.006547

G = 0.574739

Appendix D – Videos

See supplemental CD or attached video files for Phase I video and Phase II 20-second time laps aerial videos of each run.

Technical Memorandum

To: Stuart Arkley and Jennifer Engstrom
From: Cory Anderson and Miguel Wong
Subject: Practical Interpretation of the SAFL Report
Date: May 5, 2011
Project: 23690862.00 042 002

Background

During the summer of 2010, a question was posed concerning the segregation of tailings during delta formation and deposition in the proposed NorthMet flotation tailings basin. For modeling purposes, it is important to know whether the delta that is formed can be treated as one "bulk" zone of tailings or needs to be further refined into multiple zones of different grain size fractions. The University of Minnesota's St. Anthony Falls Laboratory (SAFL) was charged to perform experiments to quantify the potential for segregation in the tailings delta, and to determine some of the important hydraulic properties of the tailings that are deposited. SAFL performed two phases of experiments. Phase I was a flume experiment, designed to use field-scale flow conditions to evaluate the potential for debris flow versus channelized or sheet flow as the delta is formed. Phase II was a 2D lab scale experiment designed to answer the questions about segregation and hydraulic properties.

Interpretation and Summary

The Phase I experiment clearly showed that the behavior of the delta is one of a fluvial system characterized by channelized or sheet flow. In other words, debris flow will not occur. The solids were transported throughout the delta as bedload and suspended load. The tendency of the tailings slurry discharge was to channelize and form braids, with bars and bedforms that developed in the active channels. Therefore, the deposition patterns are characteristic of those observed in other tailings basins and deltaic systems in general, where the combined fluvial processes of erosion, transport and deposition at the channel and larger scales (not at the individual grain size scale) determine the configuration and characteristics of the delta.

The Phase II experiment was scaled down from field to laboratory conditions to provide similarity in Froude number (i.e., the ratio of inertial to gravity forces), general sediment-transport regime, and the aspect ratio. Extensive field and laboratory research has shown that the aspect ratio (here defined as normal flow depth to radial width of the delta) is a simple but very robust predictor of channel morphology in deltaic systems. As described in the report and due to the method of scaling (aspect ratio), the laboratory delta is expected to grow and maintain its surface by the same mechanisms as the field scale delta. The fines retention and the degree of grain size sorting seen in the experiment should be similar to that in the field scale delta.

Because one of the objectives of the Phase II experiment was to determine the *potential* for segregation of coarse and fine tailings in the delta, conditions were created to maximize segregation. High flows were used which would tend to transport more material to the pond area; during the falling phase of the Phase II experiment, the pool elevation was slowly decreased to promote delivery of tailings to the shoreline position and minimize deposition except for the coarsest material. Despite the attempt to maximize segregation, one of the major and firm conclusions from the Phase II experiment is that there will be a minimum of 30% (by mass) fines (passing mesh #200; particle sizes smaller that 74 micron) in the delta. Even under the most extreme plausible transport conditions, it was difficult to generate a deposit with less than 30% fines content.

It is important to note that the individual samples taken from the delta for analysis are just that; individual samples at specific locations. These results are useful for estimating the approximate degree of sorting in the delta and characterizing the tailings at any one location. However, they are not necessarily appropriate (as individual samples) for characterizing the tailings delta as a whole.

Barr used the SAFL report, supplemented with information from field-scale tailings basins, to reach important conclusions regarding data inputs that are necessary for the water quality modeling in GoldSim.

- Due to naturally developing slopes in the Phase I experiment, the 1% slope used for the field-scale design, and therefore the water quality modeling, is reasonable.
- It can be assumed that the tailings delta (portion of the tailings deposited above the water pond) is one zone. Although downstream fining is evident in the experiments, and it has been documented in field examples, the expected range of variation for the fines (i.e., passing mesh #200) fraction for NorthMet tailings (more than 50% is passing mesh #200) does not justify modeling two or more zones.

- Of the tailings discharged aerially to form the NorthMet delta, the tailings delta would contain 100% of the coarse (i.e., above mesh #200) fraction.
- In any given year, the NorthMet tailings delta would on average have a fines fraction characterized by P5 = 30%, P50 = 35%, and P95 = 40% throughout the entire delta area. A normal distribution with mean and standard deviation of 0.3500 and 0.0304 respectively will be used to describe the uncertainty in the percent fines in the delta as they are formed.
- The average porosity of the tailings throughout the NorthMet delta is primarily a function of fluvial mixing rather than grain size distributions and is characterized by P5 = 0.38, P50 = 0.41, and P95 = 0.45. A triangular distribution with lower, mode, and upper values of 0.3668, 0.4012, and 0.4685 respectively will be used to describe the uncertainty in the NorthMet delta porosity.
- The average porosity of the tailings under the proposed pond is primarily a function of turbidity current and settling and is characterized by P5 = 0.43, P50 = 0.52, and P95 = 0.56. A triangular distribution with lower, mode, and upper values of 0.4049, 0.5602, and 0.5696 respectively will be used to describe the uncertainty in the tailings porosity under the pond.
- The annual average solid fraction of the slurry discharged from the plant will be a mixture of coarse tailings and fine tailings. This coarse tailings fraction (by mass) in the mixture will be characterized by P5 = 0.38, P50 = 0.41, and P95 = 0.44. A normal distribution with mean and standard deviation of 0.4100 and 0.0182 respectively will be used to describe the uncertainty in the percent coarse in the feed material.

The distributions described in the bulleted conclusions above were not developed using statistical analysis of the tabulated data in the SAFL report for various reasons. First, the method proposed to model the tailings delta requires describing them on the whole rather than at any given location. Therefore, the spatially averaged condition is more appropriate than the potential range of values at any location in the delta. For example, in one location, the porosity might be 0.44. But in another location, the porosity could be 0.38. Examining a roughly 100 acre beach as a whole would see extreme (high and low) independent values balance out and the mean value prevail (spatially averaged). Second, the bulleted conclusions above were drawn using a combination of NorthMet specific experimental data and knowledge of operational tailings basins. It is Barr's intention to have discussions with the Lead Agencies (via the Modeling Phase Agency Technical Teams) concerning these distributions and to come to agreement on the values used to describe them.

Practical Use in the Water Quality Model

The proposed water quality model describes the condition (hydrologically, hydraulically, and chemically) of the Flotation Tailings Basin in any given year. Therefore, inputs to the model are required on an annual basis. The distributions proposed for specific areas of the model (delta, pond, etc.), which again are spatially averaged since they are describing areas on the whole, are selected from the probability distribution annually in the model. The distributions above have additional important implications on the modeling because they will be used directly to determine other important model parameters on an annual basis.

- The percent fines in the tailings delta, the porosity in the delta and under the pond, and the percent coarse tailings in the feed material are all used to determine the average annual split of the process plant discharge between delta and subaqueous delivery. This is necessary to ensure proper basin development (i.e., the rate of depth increase in the delta and under the pond is equal).
- The percent fines and the porosity in the tailings delta are used to determine the average annual Van Genuchten (VG) parameters necessary for unsaturated flow in porous media. The VG parameters are not independently generated because the relationships are clearly evident (i.e., increased percent fines results in decreased hydraulic conductivity). These relationships should be maintained in the modeling.
- The Van Genuchten parameters, along with annually variable flow inputs (climate, plant discharge flows, etc.), are used to determine the average annual or steady-state saturation of the tailings delta.
- The average annual saturation of the tailings delta determines the depth at which oxygen can penetrate the tailings due to diffusion which in turn determines the volume of tailings oxidized and pollutant loading in any given year.

Clearly, the distributions outlined in this memo affect many aspects of the water quality model. Therefore, it is important that consensus is reached between PolyMet, their consultants, and the Lead Agencies. The distributions above were created using results from the SAFL report along with professional judgment and knowledge from other operational tailings basins. It is most important that the distributions agreed upon are appropriate for the field-scale Flotation Tailings Basin, and that they properly address the required inputs to the model (spatial/temporal averages versus instants in time or specific locations).

Attachment C

Hydrologic Study of Flotation Tailings Basin

resourceful. naturally.
engineering and environmental consultants

Memorandum

To: PolyMet
From: Rita Weaver, Barr Engineering
Subject: FTP Pond Bounce Analysis for Freeboard Determination
Date: September 15, 2011
Project: 23/69-0862

As part of the final design requirements for Cell 2E and Cell 1E of the FTB, it was necessary to conduct a hydrology study to determine the bounce in the cells during the Probable Maximum Precipitation (PMP), 1/3 PMP, and 2/3 PMP events. Because the starting water surface elevation and dam heights change over the course of 20 years, Barr evaluated the bounce in the following scenarios:

1st year layout in Cell 2E, which is the lowest dam height for Cell 2E.

7th year layout in Cell 2E, which is the highest dam height for Cell 2E before Cells 2E and 1E combine.

1st year layout in Cell 1E, which will represent the cell layout through year 7.

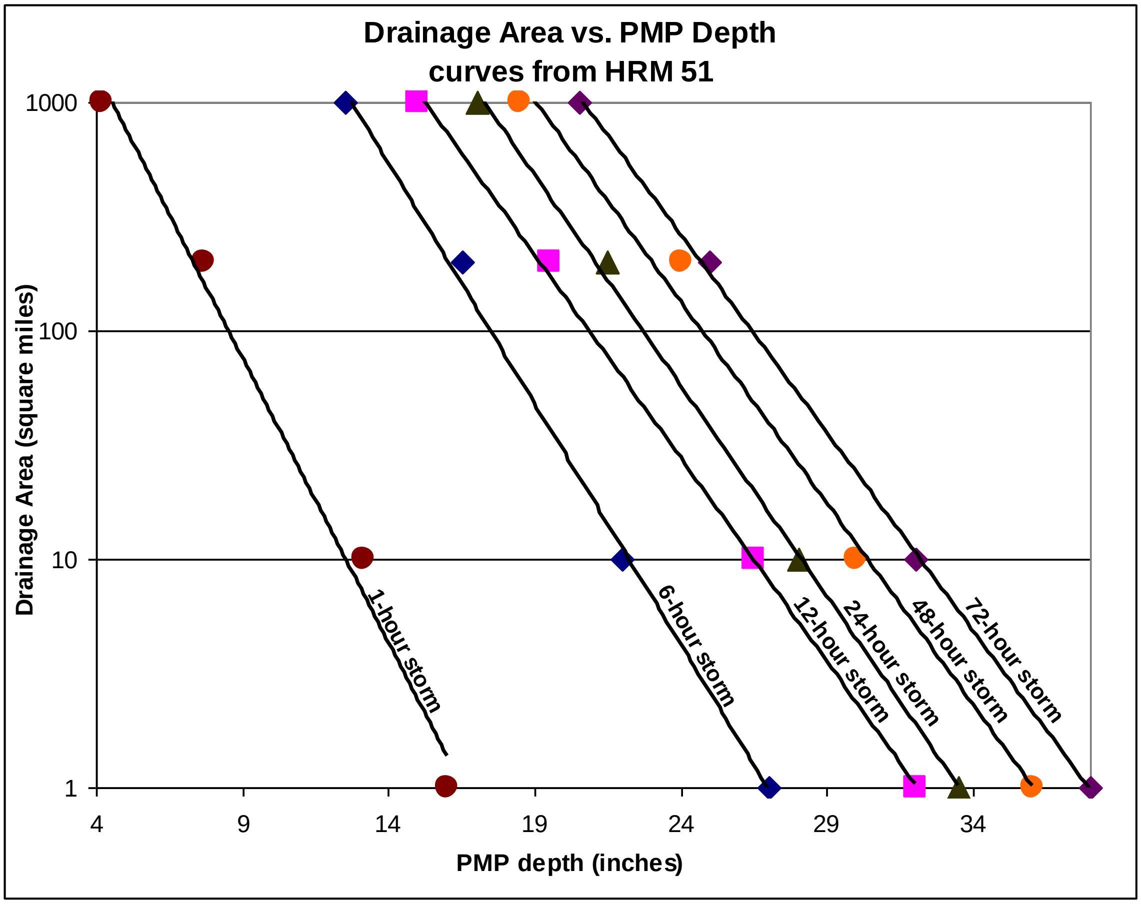
- 20 year layout in Cell 1/2 E, which is the highest and final dam height.

The following section describes the methodology of calculating the volume of runoff from the cells' watersheds and the bounce in each cell.

Hydrology Calculations

The volume of precipitation at the cells was estimated using methods outlined in the Hydrometeorological Report 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, and Hydrometeorological Report 52, Application of Probable Maximum Precipitation Estimates – United States East of the 105th Meridian (HMR51 and HMR52).

The depth of rainfall for a PMP event is presented in the HMR 51 for watershed sizes of 10 square miles to 20,000 square miles. Because the watersheds of Cell 1E, Cell 2E and Cell 1/2E varied from one to three square miles, Barr extrapolated the given rainfall depths from drainage areas of 10, 200, and 1,000 square miles down to the drainage areas of the cells. The following figure shows the distribution of the rainfall depths to the drainage area on a log scale. Depths for the 10, 200, and 1,000 square mile drainage areas are taken from HMR 51. Depths for the 1 square-mile drainage area have been extrapolated. The maximum PMP depth occurred during the 72-hour storm, so 38" was used for a one square-mile watershed.



This exercise was repeated to determine the PMP depth for the 2 square-mile and 3 square-mile drainage areas and the maximum depths were 36" for a two square-mile watershed and 35" for a three square-mile watershed. The depths for the 1/3 PMP and 2/3 PMP events are 1/3 of the PMP and 2/3 of the PMP respectively.

Using the precipitation depth and the area of the watershed, Barr estimated the volume of rainfall that would be stored in each cell. The following table summarizes the rainfall depths and runoff volumes for each scenario.

Precipitation Depth and Runoff Volume for each Scenario

		1/3 PMP		2/3 PMP		PMP	
Watershed	**Watershed Area (sq-mi)**	**precip depth (in)**	**runoff volume (ac-ft)**	**precip depth (in)**	**runoff volume (ac-ft)**	**precip depth (in)**	**runoff volume (ac-ft)**
Cell 2 E – Mine Year 1	1.1	12.7	757	25.3	1513	38.0	2270
Cell 2 E – Mine Year 7	1.0	12.7	672	25.3	1338	38.0	2010
Cell 1 E – Mine Year 1 through Mine Year 7	2.8	11.7	1729	23.3	3457	35.0	5186
Cell 1/2 E at 20 years	2.4	12.0	1523	24.0	3046	36.0	4570

Bounce Calculations

The starting water surface elevation is unknown and will vary over time, so Barr determined a range of acceptable starting water surface elevations. By defining a beach length of 625' and then 1250', we were able to calculate the range of available storage volumes for each scenario. The shorter beach length results in the smallest bounce, but the highest peak water surface elevation in the cell. The longer beach length results in a lower peak water surface elevation, but shows the maximum bounce in the cell.

We compared the runoff volume to the available storage volume to determine the bounce in each cell. The following two tables show the estimated bounce and peak water surface elevation for each storm event and each scenario using the 625' or 1250' beach length.

Bounce and Peak Water Surface Elevation, assuming a beach width of 625'

			1/3 PMP		2/3 PMP		PMP	
Watershed	**Assumed Starting WSE**	**Max Dam Elev.**	**Bounce**	**Peak Elev.**	**Bounce**	**Peak Elev.**	**Bounce**	**Peak Elev.**
Cell 2 E – Mine Year 1	1578.75	1602	2.25	1581.00	4.25	1583.00	6.00	1584.75
Cell 2 E – Mine Year 7	1651.75	1662	1.50	1653.25	3.25	1655.00	4.75	1656.50
Cell 1 E – Mine Year 1 through Mine Year 7	1650	1672(1)	4.75	1654.75	8.00	1658.00	10.75	1660.75
Cell 1/2E at 20 years	1722.75	1732	1.50	1724.25	2.75	1725.50	4.00	1726.75

(1) Maximum dam elevation for the Cell 1E north dam is approximate.

Bounce and Peak Water Surface Elevation, assuming a beach width of 1250'

			1/3 PMP		2/3 PMP		PMP	
Watershed	**Assumed Starting WSE**	**Max Dam Elev.**	**Bounce**	**Peak Elev.**	**Bounce**	**Peak Elev.**	**Bounce**	**Peak Elev.**
Cell 2 E – Mine Year 1	1572.5	1602	3.00	1575.50	6.00	1578.50	8.00	1580.50
Cell 2 E – Mine Year 7	1645.5	1662	2.00	1647.50	4.25	1649.75	6.00	1651.50
Cell 1 E – Mine Year 1 through Mine Year 7(1)	1640	1672(2)	9.00	1649.00	14.00	1654.00	17.50	1657.50
Cell 1/2E at 20 years	1716.5	1732	1.80	1718.30	3.50	1720.00	5.00	1721.50

(1) Used bathymetry to calculate volume; not average beach slope.
(2) Maximum dam elevation for the Cell 1E north dam is approximate.

The estimated bounce in the cells ranges from 1.5’ to 17.5’, and the estimated distance between the pond surface and the maximum dam elevation ranges from 5.25’ to 26.5’.

Attachment D

Dam Stability Instrumentation and Monitoring Plan

Tailings Basin Geotechnical Instrumentation and Monitoring Plan

Cell 2E

Prepared for
Poly Met Mining, Inc.

Version 3

May 15, 2017

4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435-4803
Phone: 952.832.2600
Fax: 952.832.2601

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Certifications

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota.

Thomas J. Radue

Thomas J. Radue
PE #: 20951
Senior Geotechnical Engineer

05/15/2017
Date

1.0 Introduction

This Tailings Basin Geotechnical Instrumentation and Monitoring Plan (Plan) describes the plan for geotechnical instrumentation and monitoring of Cell 2E, the first cell of the Tailings Basin that will be reactivated for disposal of Flotation Tailings for Poly Met Mining, Inc.'s (PolyMet's) NorthMet Project (Project). In this document, the Flotation Tailings Basin (FTB) refers to the proposed NorthMet Flotation Tailings impoundment placed atop Cells 1E and 2E of the former LTV Steel Mining Company (LTVSMC) tailings basin, and the Tailings Basin is the combined LTVSMC tailings basin and the FTB. The purpose of this Plan is to guide monitoring of the Cell 2E dams to maintain safe operation of the Tailings Basin. Cell 2E is located in the northeast portion of the Tailings Basin as shown on Large Figure 1. The design and operation of the FTB dams are described in this Flotation Tailings Management Plan.

Stability monitoring will be required throughout construction, operations, and after closure to verify that FTB dam design constraints are met. Stability monitoring will include existing and proposed piezometers to monitor the piezometric surface in the FTB dams, and inclinometers and survey monuments to monitor dam movement. The instrumentation will be located within the perimeter dams of Cell 2E (the north dam of Cell 2E, the dam between Cell 2E and 1E, the dam between Cell 2E and 2W), and in a section of the north face of the dam connecting Cell 2E and 2W. The monitoring system will be expanded as tailings deposition transitions from Cell 2E to Cell 1E/2E, and data will periodically be gathered and analyzed from other existing monitoring points as necessary to confirm overall Tailings Basin dam stability. Large Figure 2 shows the locations of existing instruments.

This Plan for Cell 2E includes:

- Stability monitoring plans, including instrument locations, instrument descriptions, and data collection and analysis plans
- Planned monitoring activities that provide information related to dam stability, including construction monitoring, pond level monitoring, and tailings deposition monitoring
- Reporting
- Exhibit A – Technical Specifications – Fully Grouted Vibrating Wire Piezometers
- Exhibit B – Technical Specifications – Standpipe Piezometers
- Exhibit C – Technical Specifications – Inclinometer Installations

This Plan provides detail on Cell 2E instrumentation upgrades and monitoring to be performed prior to development of the FTB. This Plan will be updated once construction and tailings deposition begins. The Plan will also be reviewed on a periodic basis and updated as needed due to dam raises, when the FTB expands from Cell 2E to combined Cells 1E/2E, as instrumentation becomes worn or obsolete, and as otherwise needed to maintain sufficient geotechnical instrumentation and monitoring of the Tailings Basin dams.

This Plan focuses on Cell 2E, the only cell that will receive tailings for deposition through Mine Year 7, with dam raises occurring to maintain required tailings capacity and freeboard. Concurrent with the specified Cell 2E monitoring, monitoring instrumentation planned to remain in dam sections for Cells 1E and 2W will continue to be monitored and periodically improved or replaced as needed. Prior the point in time where Cells 2E and 1E merge and dam raises on the combined Cell 1E/2E begin, a comprehensive update of this Plan will occur to identify instrumentation upgrades and additions required to monitor the combined cells.

2.0 Stability Monitoring

Stability monitoring of Cell 2E will be carried out during all phases of the Project: construction, operations, and closure. Prior to and during construction, piezometers will be installed to monitor pore water pressures within the dam and foundation, and inclinometers and survey monuments will be installed to monitor for deformation of the dams. This instrumentation and data will add to that already in place. A comprehensive monitoring database will be developed to save and track piezometer, inclinometer, and survey data for the dam throughout the 20-year period of construction and operation. Monitoring of the dam will continue upon Tailings Basin closure until the Minnesota Department of Natural Resources allows reduction or discontinuance.

Selection of locations to be monitored is based on a variety of factors:

- To monitor dam performance at dam cross-section locations believed to be more susceptible to movement than other cross-section locations, due to factors such as cross-section specific foundation conditions, tailings layering and strength characteristics, and/or seepage conditions
- To provide piezometric and inclinometer data along dam cross-sections to facilitate seepage and stability analysis
- To monitor dam cross-sections that may be irregular in geometry or subject to unique loading conditions
- To compare current and future dam performance to historic performance when historic data exists

Stability monitoring, in conjunction with future geotechnical explorations, will provide data for Dam Safety Inspections (Section 5 this Flotation Tailings Management Plan). It will also be used to validate and refine the slope stability models (Appendix B of this Dam Safety Permit). As described in this plan new instrumentation will be installed prior to restarting the Tailings Basin. Additional geotechnical data and baseline instrument readings will be gathered concurrent with and following the instrument installations. Following the second year of operation, a geotechnical exploration will be performed to verify that the Flotation Tailings have been deposited in accordance with the initial slope seepage and stability modeling. Similar explorations and modeling analyses will be performed on a periodic basis throughout the construction of the FTB dams to allow for immediate corrections to the design, if needed, to maintain stability.

Instrumentation and monitoring for Cell 2E dams will consist of:

- **Vibrating Wire and Standpipe Piezometers** – to monitor the piezometric surface in the dams and foundations and the increases in pore water pressure resulting from the dam construction and tailings deposition
- **Inclinometers** – to monitor dam movement during and after construction of the dam

- **Survey Monuments** – to monitor dam movement
- **Construction Monitoring** – to monitor material type and compaction and target grade elevations
- **Pond Level Monitoring** – to monitor pond elevation, pond size, and beach length
- **Tailings Deposition Monitoring** – to monitor pond setbacks, tailings deposition profile, and material strength

Personnel who will be responsible for Cell 2E dam management are:

- *PolyMet Operations Contact* – Beneficiation Division Manager or designee – Responsible for overall Cell 2E design, planning, operations, maintenance, and monitoring.
- *Design Engineer* (a Minnesota-registered professional engineer retained as an independent consultant specifically for dam safety expertise) – Responsible for geotechnical explorations and data gathering, performance monitoring data review and interpretation, dam safety inspection and reporting assistance, tailings dam planning and design assistance, and permitting assistance.

2.1 Instrumentation System

The stability monitoring program for Cell 2E will use a combination of existing and new instruments to monitor the piezometric surface in the dams, increases in pore water pressure, and dam movement. Instruments in the monitoring network will be evaluated for maintenance and/or replacement as part of reporting procedures discussed in Section 4.0. Instruments may be added to or removed from this network as necessary in conjunction with changes to the Project. Not all existing instruments will be part of the ongoing monitoring plan: some will be decommissioned. Large Figure 2 identifies the existing instruments. Table 1 and Table 2 describe the current condition of the instrumentation (based on review in 2016), and recommend instrumentation for continued use or for decommissioning. Large Figure 3 shows existing and proposed instruments to be used in the Cell 2E monitoring network.

2.1.1 Instruments Condition Review

An instrumentation conditions review is completed annually in conjunction with instrumentation data review. As described in the following sections a number of instruments are recommended for decommissioning, and in some cases for replacement. This includes a number of inclinometers as identified in Table 1, all pneumatic piezometers, and one pneumatic piezometer/inclinometer. The inclinometers are being decommissioned because valid data cannot be collected due to inclinometer casing abnormalities. Pneumatic piezometers will be reviewed concurrent with new instrument installations and if those that require maintenance (Table 2) cannot be returned to full functionality, they may also be replaced at that time. Decommissioning of these instruments will occur concurrent with or in advance of Cell 2E construction activities.

2.1.1.1 Inclinometers

The basin has been inactive since January of 2001. Monitoring of inclinometers has continued since then, but the inclinometers have not been routinely maintained or replaced because their usefulness tends to diminish with time (the risk of dam movement at the inactive Tailings Basin and the relative value of the inclinometer data diminishes with time). Prior to reactivation of the basin new inclinometers will be installed as described later in this plan. Of the existing inclinometers, four are fully functional, four are suspect, and three are recommended for decommissioning, as listed in Table 1. The inclinometers are being decommissioned because valid data cannot be collected. Decommissioning of these instruments will occur concurrent with or in advance of Cell 2E construction activities.

Table 1 Inclinometer Condition Review

Instrument	Cross-Section Location	Status	Comments
DH96-10	E	Functional	Continue to collect and review data
DH96-12	E	Suspect – collect to evaluate for changing conditions, but flag for replacement	Apparent settlement-based casing errors (DPE) which may worsen with time
DH96-18	A	Functional	Continue to collect and review data
DH96-19	A	Decommission – replace prior to basin restart	Probe cannot reach the bottom of the casing, data are not meaningful
DH96-28	H	Functional	Continue to collect and review data
DH96-32	H	Decommission – replace prior to basin restart	Casing abnormalities, data are not meaningful
DH96-37	J	Suspect – collect to evaluate for changing conditions for now, but consider for replacement	Apparent settlement-based casing errors (DPE) which may worsen with time
DH96-46	F	Suspect – collect to evaluate for changing conditions, but flag for replacement	Casing abnormalities, lack of confidence in data
DH96-47	F	Decommission – replace prior to basin restart	Casing abnormalities, data are not meaningful
DH99-1	H	Suspect – collect to evaluate for changing conditions, but flag for replacement	Casing abnormalities, lack of confidence in data
2E_2016_INC_K2	K	Functional	New installation, continue to collect and review data

2.1.1.2 Piezometers

Multiple types of piezometers exist at the site, including standpipe piezometers, vibrating wire (VW) piezometers, and pneumatic piezometers. Due to age and lack of maintenance and issues with failing or stuck diaphragms, all pneumatic piezometers are recommended for decommissioning. New vibrating wire piezometers in the existing Cell 1E/2E splitter dam at Cross-Section K are collecting baseline data and have no apparent issues. The condition of standpipe piezometers are described in Table 2. These instruments will be decommissioned concurrent with or in advance of Cell 2E construction activities.

Table 2 Piezometer Condition Review

Instrument	Cross-Section Location	Status	Comments
A-1	A	Functional	Continue to collect and review data
A-3	A	Functional	Continue to collect and review data
A-9	A	Functional	Continue to collect and review data
B-2	B	Functional	Continue to collect and review data
P1B1-99	B	Functional	Continue to collect and review data
P1B-99	B	Functional	Appears to be dry now, continue to collect and review data
D-1	D	Functional, but recommend maintenance	Continue to collect and review data; redevelop and slug test piezometer to assess quality of data and condition of piezometer
D-4	D	Functional, but recommend maintenance	Continue to collect and review data; redevelop and slug test piezometer to assess quality of data and condition of piezometer
E-5	E	Requires maintenance	Blockage at 20 feet – recommend flushing and using downhole camera to review
F-2	F	Functional, but recommend maintenance	Continue to collect and review data; redevelop and slug test piezometer to assess quality of data and condition of piezometer
G-2	G	Functional, but recommend maintenance	Continue to collect and review data; redevelop and slug test piezometer to assess quality of data and condition of piezometer
P2HA-99	H	Functional, but recommend maintenance	Continue to collect and review data; redevelop and slug test piezometer to assess quality of data and condition of piezometer
P2HB-99	H	Functional	Continue to collect and review data
P1H-99	H	Functional	Continue to collect and review data
P3H1-99	H	Functional	Appears to be dry now, continue to collect and review data
P2H1-99	H	Functional	Appears to be dry now, continue to collect and review data

Instrument	Cross-Section Location	Status	Comments
P1H1-99	H	Functional	Continue to collect and review data
P3H-99	H	Functional	Appears to be dry now, continue to collect and review data
K-1	K	Functional	Continue to collect and review data
K-2	K	Functional	Continue to collect and review data
K-3	K	Functional	Continue to collect and review data

2.1.2 Existing Instruments to Be Used

Table 1 and Table 2 list the existing instruments, their current level of functionality, and their intended use in the future. Existing instruments to be used in the Cell 2E monitoring network include standpipe piezometers, and vibrating wire piezometers as identified on Large Figure 3 and shown in detail on Large Figure 4 through Large Figure 10.

2.1.3 New Instruments to be Installed

Proposed new instruments consist of 72 nested vibrating wire (VW) piezometers and 12 inclinometers as identified on Large Figure 3 and shown in detail on Large Figure 4 through Large Figure 10. The new instruments will be located in the Cell 2E perimeter dams that correspond to six cross-section locations (H, J, F, G, D and I) shown on Large Figure 3. Installation will occur prior to FTB dam construction and deposition of Flotation Tailings in Cell 2E.

Future instrument installations will occur with alternating lifts of dam construction and will be evaluated as part of future stability monitoring plan updates. The overall philosophy for instrumentation placement and objectives for monitoring is summarized in Section 0 and described further in Section 3.0.

2.2 Instrument Details

The following sections provide instrumentation details for the Cell 2E monitoring network. Monitoring locations will be reviewed annually and modified as needed throughout the life of Cell 2E. Monitoring points that become non-functional or that no longer warrant monitoring based on the annual evaluation will be properly decommissioned. However, it will be preferable to consistently monitor the same points throughout the life of the FTB; supplemented with additional instrument installations as dam height increases.

2.2.1 Piezometers

Nested VW piezometers will be installed along the typical cross-sections modeled as a part of the dam design process and at other nearby locations as necessary for ongoing performance monitoring of the dams. The piezometers will be placed to allow for monitoring of pore water pressures within the dam profile. Each piezometer nest will include three piezometers. The bottom piezometer at each location will be installed in the native till below the dam (referred to as piezometer “c” in the nest) to understand pore water pressure within the relatively permeable foundation. The middle piezometer will generally be placed at an elevation of 10 feet above the native material and tailings interface to monitor conditions along typical modeled slope failure surfaces (referred to as piezometer "b" in the nest). The top piezometer will generally be placed in the existing slimes and fine tailings below the existing LTVSMC coarse tailings (referred to as piezometer "a" in the nest), where pressures are often elevated due to the fine nature of those existing slimes and fine tailings. Having nested piezometers allows for an understanding of whether upward or downward flow (or both) are occurring at given location.

For Cross-Sections H, J, F, and G on Large Figure 3, the piezometer nests will be installed at four locations along the dam profile, as shown on Large Figure 4 through Large Figure 7. For Cross-Sections D and I on Large Figure 3, the piezometer nests will be installed at the crest of the existing dams as shown on Large Figure 8 and Large Figure 9. Piezometers at Cross-Section K shown on Large Figure 10 have been installed at the crest, mid-slope of the north-facing slope, and at the north toe of the dam. Monitoring zones for these piezometers are preliminary and will be confirmed in the field at the time of installation.

VW piezometers will be installed per requirements of the Technical Specifications (Exhibit A) and Installation Diagram (Large Figure 11). If standpipe piezometers are installed at a future date, installation will generally follow the configurations shown on Large Figure 11 and follow specifications in Exhibit B.

2.2.2 Inclinometers

Standard inclinometers were previously installed along a number of alignments in all Tailings Basin cells. However, according to recent dam safety inspections (Reference (1)) those inclinometers have been compromised and will be decommissioned. New inclinometers will be installed at Cross-Sections H, J, F, G, D, and I to monitor for deformation. The inclinometers will be positioned such that they intersect the anticipated surface of greatest deflection; the model-estimated surface yielding the lowest slope stability safety factor. An inclinometer is already installed at Cross-Section K. Inclinometers may be combined with select proposed piezometer boreholes if deemed appropriate during geotechnical installations. Typical installation details are included on Large Figure 11 and technical specifications are provided in Exhibit C.

2.2.3 Survey

A full topographic survey of Cell 2E will be performed at least annually; with localized topographic surveys performed more frequently during dam construction activities, generally on the order of monthly or quarterly. At least once during the year, survey measurements will be taken of 21 survey monuments along Cross-Sections H, J, F, G, D, I, and K, checking for any sign of horizontal or vertical movement. The survey monuments are identified on Large Figure 3 and shown in detail on Large Figure 4 through 10. A reference datum will be selected such that benchmarks are on solid ground well beyond the footprint of the dam. Survey frequency will decrease in the future after Cell 2E closure.

2.3 Data Collection & Analysis

Piezometer, inclinometer, and survey readings will be taken quarterly, at a minimum, to detect any potential instability. Readings will be collected more frequently during construction activities to guide any real-time adjustment of the construction rate needed to maintain stability. Frequency will be dependent on the rate of construction and will be determined at the time the construction schedule is determined. A Project data network will collect data continuously from VW piezometers (and VW inclinometers if subsequently installed). The continuous readings will be recorded using a datalogger and are recommended to be downloaded monthly or at an increased frequency if the need arises.

Preconstruction data analysis will generally be performed annually with the dam safety review, or more frequently if conditions are observed to be changing (i.e., high pond levels, etc.). Further evaluations of data will be performed on a monthly to quarterly basis during the first stage of construction. These analyses will include field measurements of standpipe piezometers and inclinometers to verify readings obtained by the monitoring system. The frequency of ongoing analyses will be re-evaluated as construction and operation progress.

Ongoing monitoring will be performed by the Design Engineer or authorized representative to allow for real-time modification of construction, monitoring, and operation means and methods as required to maintain dam safety.

Each dam raise will require data collection and analysis. The piezometric surface of water flowing through the Tailings Basin and FTB dams must be controlled to maintain the phreatic surface at or below the surface determined in SEEP/W modeling (Appendix B of this Dam Safety Permit). Prior to each FTB dam raise, the allowable water level elevations in piezometers and the movements predicted to occur in inclinometers will be established. Elevation data consisting of the dam surface elevation, instrument depth, allowable water level, and measured water level will be collected, and observed elevations will be compared to allowable elevations. Threshold values will be established as described in Section 3.2. Variation between observed piezometric water levels and allowable piezometric water levels (toward or beyond threshold values) will require review and consultation with the Design Engineer to determine what actions, if any, are required to reduce water levels. Threshold vertical and lateral movement for inclinometers and survey markers will be established for each monitoring location.

2.4 Related Monitoring Activities

Ongoing monitoring and periodic updates to data utilized in seepage and stability modeling will be part of the overall stability monitoring activities. Additional detail on these related monitoring activities can be found in other facility documents including this Flotation Tailings Management Plan. Results of these monitoring activities will be included in the annual reporting and the dam safety inspections.

2.4.1 Construction Monitoring and Quality Control

Construction activity associated with Cell 2E includes construction of buttressing for the north dam, and upstream dam construction of eight individual lifts, the first starting during the first year of operation. Construction monitoring and construction quality control requirements are outlined in the construction specifications and therefore are not repeated herein. Further, construction quality control testing and monitoring requirements will be outlined in detail prior to each construction event as a means by which the personnel assigned by PolyMet to be responsible for tailings basin construction can readily track and confirm that the necessary construction monitoring and quality control is being implemented. Construction monitoring and quality control activities will fall into three broad categories:

- *Quality Control Surveying* – to collect data on elevations, grades, slopes, and material thickness. Survey data includes finished elevations and dam features. Specific locations for survey points include the dams, bentonite-amended cover, buttresses, and tailings discharge and return water pipelines as described in the construction specifications (Attachment G of Flotation Tailings Management Plan).
- *Soil & Material Testing* – to include in-field and in-laboratory material testing by an independent geotechnical exploration contractor and soils testing laboratory. Field and laboratory tests are outlined in the construction specifications and include sieve analysis, soil compaction tests, and other tests that may be required (Attachment G of Flotation Tailings Management Plan), in addition to construction event specific geotechnical explorations that may be specified. Testing of materials used for dam construction will occur for each phase of construction to identify trends in variability of the construction materials.
- *Instrumentation Monitoring* – to include non-routine instrument-specific (i.e., inclinometers, piezometers, survey markers) monitoring and reporting through the course of specific construction events.

Information collected as part of construction will be included in annual reporting.

2.4.2 Pond Level Monitoring

Pond water levels will be routinely monitored and managed to maintain sufficient freeboard between the pond water level and the top of the Cell 2E dams. Pond water levels will be recorded daily (manually or via automated systems.) A data trend toward insufficient freeboard will immediately be brought to the attention of the *Operations Contact*. Pond water level records will be included in annual reporting.

2.4.3 Tailings Deposition Monitoring

Tailings deposition in Cell 2E will be monitored through a variety of activities including:

- *Setback Observations* – observations of the beach width to maintain the specified setback between the inside crest of the dam and the edge of the pond provides an indicator of adequate freeboard to manage the pond during severe precipitation events. Observations will occur daily and become more frequent with prolonged and/or intense rainfall events (Section 5.3.3 of this Flotation Tailings Management Plan).
- *Bathymetric Survey* – a bathymetric survey of the dams and Flotation Tailings will monitor the deposition profile of tailings and allow for updates to deposition practices as necessary. The survey will occur during the first year of operations and then once every other year (Section 5.3.3 of this Flotation Tailings Management Plan).

- *Material Strength Investigations* – cone penetration test (CPT) soundings, vane shear tests (VST) and/or standard penetration test (SPT) borings will confirm the strength of deposited Flotation Tailings in Cell 2E. The investigation will occur within the first year of operations and then at least once every other year (Section 5.3.3 of this Flotation Tailings Management Plan).

3.0 Observational Method

The observational method employs sequences of data gathering, detailed calculations and performance predictions, additional data gathering and observations, and design modifications as needed to maintain required operating conditions at the Tailings Basin. First, the engineer uses available information to prepare an initial concept and design that will predict the behavior of the basin. As the stages of construction progress, the engineer monitors and tests the site to obtain more detailed information. Information from this instrumentation and monitoring program is an example of this stage in the Observational Method. The predicted behavior is now compared with the measured behavior, enabling the engineer to revise the original predictions. Repeating this process leads to successive refinements in tailings basin dam design and construction. Tailing basin dams are typically built in stages, thus the observational method to design is well suited for minimizing risk.

3.1 Data Updates

Part of the Observational Method entails additional data gathering, followed by data interpretation and then design review and adjustment as needed in response to the new data. Data types that will typically be updated through the course of Tailings Basin development include:

- Geotechnical Data – from future instrumentation installation activities, geotechnical explorations and in-laboratory material testing
- Instrumentation Data – piezometric data and deformation data from inclinometers and survey monuments
- Observations and Monitoring Data – from pond level data, from construction observations, from topographic surveys, and from systematic and periodic site review

The gathered data will, when appropriate and necessary, be used to adjust material strength, basin geometry, and/or basin operating criteria.

3.2 Instrumentation Thresholds

A threshold value for instrumentation is a reading that indicates a significant departure from the expected range of readings based on design modeling and prompts an action such as increased surveillance or an emergency action. A threshold value is set in consideration of the values used in the analysis or design, and is influenced by the historical data and predictions of future performance. Threshold values must be established based on the specific circumstances of the site. They may be used to identify unusual readings, readings outside the limits of the instrument's historic range, and/or readings that, in the judgement of the responsible engineer, need evaluation. Both magnitude and rate of change in values may need to be established. Threshold values for various instruments (e.g., piezometers, inclinometers, and survey monuments) will be established following completion of instrumentation installation and baseline monitoring (prior to initiating operations at the Tailings Basin) and revised throughout the project life, based on the following list of factors.

- Historical data: Historic data, considering seasonal fluctuations, variations due to historical construction activities and considering magnitude and rate of changes.
- Sensitivity analysis: For selected critical sections, sensitivity analysis will be performed to identify threshold values such as pore pressures, stresses and deformation that trigger a failure in the model (limit equilibrium method). Combinations of selected instruments (e.g., piezometers or inclinometers) will be utilized in sensitivity analyses to trigger a failure in the model. Advanced numerical analysis (e.g., FLAC) will be considered, if warranted, to set threshold criteria related to deformation, considering progressive failures and excessive deformations that the limit equilibrium method is unable to accommodate.
- Trend analysis: The established threshold values may be modified and updated based on overall trends. Data will follow trends, such as decreasing or increasing with time or depth, seasonal fluctuation, direct variation with basin water level, direct variation with temperature, or a combination of such trends. Data inconsistent with established trends will be investigated and verified.
- Failure mode: The threshold values will be associated with potential failure mode, such as piezometer readings associated with stress increase and strength decrease sufficient to induce slope instability. Inclinometers or survey monuments will be associated with displacement or deformation of the dam that may or may not be directly associated with eminent failure. The threshold values will be established based on the potential failure modes.
- Visual monitoring: The instrumentation threshold values will be established along with the visual monitoring program.
- Revision: The established threshold values (magnitude and rate of changes) will be regularly calibrated in response to ongoing data acquisition and review.

Table 3 is an example of the expected and threshold data values that will be established for each inclinometer and each piezometer as a means to compare predicted data values with measured values. The table will be fully populated once the new instrumentation is installed, baseline data is established, and corresponding geotechnical models updated to produce the table data.

Table 3 Instrumentation Summary and Thresholds (Sample Table)

Monitoring Device	Purpose	Name and Location	Monitoring Frequency	Normal Data Range
Vibrating Wire Piezometers	Measurement of Pore Water Pressure (Hydraulic Head)	XX-XX-X1	Continuous	Pore water pressure between XX and YY
		XX-XX-X2		Pore water pressure between XX and YY
		XX-XX-X3		Pore water pressure between XX and YY
ShapeAccelArray (SAA) Inclinometers	Measure Horizontal Slope Movement	YY-YY-Y1	Continuous	Distance vs Time (TBD)
		YY-YY-Y2		Distance vs Time (TBD)
		YY-YY-Y3		Distance vs Time (TBD)
Survey Monuments (Alignment Hubs)	Measure Horizontal and Vertical Slope Movement	AA-AA-A1	As Specified During Construction Events Monthly During Routine Operations	Distance vs Time (TBD)
		AA-AA-A2		Distance vs Time (TBD)
		AA-AA-A3		Distance vs Time (TBD)

3.3 Response to Instrumentation Threshold Incursion

Once an instrument reading falls above or below the established threshold value, an action is required. The range of action levels will depend on degree of departure of the data, number of instruments that show similar indications, severity of the situation and potential failure modes. Examples of situations that may require action include:

- A minor departure from the historical record (possibly in order to simply receive an alert from the person reading the instrument thus verifying that measurements are being monitored)
- A major departure from the historical record (possibly indication of a developing failure mode)
- A departure from historical reaction to changes in other instruments
- Levels indicating the approach of potential instability or other forms of failure such as piping

Once threshold values are established following instrument installation and baseline monitoring, this Instrumentation and Monitoring Plan will be updated to document instrumentation names, locations, and monitoring frequencies.

Recommended response actions to instrumentation threshold incursion are summarized in Large Table 1 and Large Table 2.

4.0 Reporting and Plan Updates

Annual reports will present a compilation and evaluation of the information collected from instrumentation and monitoring described in this Plan, and may include the following:

- Evaluation of survey data
- Evaluation of monthly data downloaded from VW piezometers (and SAA or automated inclinometers if subsequently installed)
- Evaluation of the adequacy of the existing instrumentation and determination of the need for any changes (new installations, maintenance, or instrument decommissioning)
- Updates to cross-sections documenting construction activities associated with dam lifts
- QAQC of the monitoring data to identify potential errors and trends that may warrant instrument maintenance and/or replacement

In cases where updates to seepage and slope stability models are warranted based on data from instrumentation and monitoring varying from what is expected, any resulting recommendations for modifications to dam design and/or Tailings Basin operations or monitoring will be included in the annual report.

This Plan will be updated periodically based on changes to facility operations, instrumentation, and construction activity. These updates are expected to occur:

- Prior to initial construction
- Prior to each subsequent dam raise

Revision History

Date	Version	Description
December 7, 2012	1	Initial release as Attachment D to Version 2 of the Flotation Tailings Management Plan
April 12, 2013	1	Attachment D to Version 3 of the Flotation Tailings Management Plan
November 21, 2014	1	Attachment D to Version 4 of the Flotation Tailings Management Plan
March 3, 2015	1	Attachment D to Version 5 of the Flotation Tailings Management Plan
July 11, 2016	2	Attachment D to Version 6 of the Flotation Tailings Management Plan
May 15, 2017	3	Attachment D to Version 7 of the Flotation Tailings Management Plan

References

1. **Barr Engineering Co.** 2013-2014 Tailings Basin Dam Safety Inspection Report. Prepared for Cliffs Erie, LLC. February 2015.

Large Tables

Large Table 1 Visual Warning Signs

Visual Warning Sign and Typical Location	Corresponding Change in Instrumentation Values (depending on location of movement relative to instrumentation)	Potential/Actual Consequences and Notification Procedures	Required Action
Signs of slowly forming erosion at toe and/or exterior face of slope.	No change in instrumentation values expected.	Potential dam instability and/or eventual dam failure if erosion continues. **Level 1 and Level 2 (see Table Notes)**	1) Discuss findings with the Design Engineer. 2) Be prepared to carry out one or more responses such as: a. Resolve source of erosion. b. Repair erosion area. c. Re-establish vegetation (modify design if recommended by Design Engineer). d. Re-inspect area on weekly basis until area is fully restored.
Soft toe condition or increased seepage at downstream slope or dam toe.	Potential increase in piezometric levels.	Internal erosion or slope slumping and eventual dam failure. **Level 1 and Level 2**	1) Discuss the findings with the Design Engineer. 2) Commission a field investigation program if so recommended. 3) Be prepared to carry out one or more responses including: Modification of basin pond operating procedures. Placement of graded overburden/buttress. Installation of drain system. Other design modifications if recommended by Design Engineer.
Cracks developing at dam crest or in slope.	Potential increase in piezometric levels. Potential slope deformation at inclinometers. Potential deflection in alignment monuments.	Deformation of dam structure that may lead to eventual dam failure. **Level 2; potential Level 3**	1) Increase frequency of dam walk-overs to daily until the problem is understood and addressed. 2) Seek advice from the Design Engineer. 3) Monitor crack development for increase in size, spacing, etc. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Modification of pond and/or basin operating procedures. b. Placement of graded overburden/buttress. c. Temporary cessation of operations. d. Reduction in pond elevation (planned or emergency).
High turbidity in dam seepage flow.	Potential increase in piezometric levels.	Internal erosion and eventual dam failure. **Level 2; potential Level 3**	1) Increase frequency of dam walk-overs to daily until the problem is understood and addressed. 2) Seek advice from the Design Engineer. 3) Take water samples for suspended solids determination if recommended by Design Engineer. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Modification of pond operating procedures. b. Placement of graded overburden/buttress. c. Installation of drain system. d. Reduction in pond elevation (pumping and/or cessation of tailing discharge).
Pond level close to or approaching overflow level; loss of freeboard.	Potential increase in piezometric levels.	Pond water discharge to environment via emergency overflow. **Level 1**	1) Confirm functionality of emergency overflow channel. 2) Immediately undertake actions to reduce the pond level (increased pumping to WWTP as necessary). 3) Temporarily discontinue seepage recovery. 4) Temporarily terminate tailings discharge to pond. 5) Consult with Design Engineer to identify other actions as needed.

Visual Warning Sign and Typical Location	Corresponding Change in Instrumentation Values (depending on location of movement relative to instrumentation)	Potential/Actual Consequences and Notification Procedures	Required Action
Any other change in seepage conditions.	Potential increase in piezometric levels.	Dam stability safety margin affected. **Level 2; potential Level 3**	1) Seek advice from the Design Engineer. 2) Initiate other responses as may be required (temporarily discontinue seepage recovery). 3) Reduction in pond elevation (pumping and/or cessation of tailing discharge).
Slumping, sliding or bulging of a dam slope or adjacent ground.	Potential increase in piezometric levels. Potential slope deformation at inclinometers. Potential deflection in alignment monuments.	Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Construct stabilizing berm per direction of the Design Engineer. 2) Initiate geotechnical evaluation per direction of the Design Engineer.
Boils observed downstream of dam.	Potential increase in piezometric levels.	An internal erosion failure possible, with potential breach of the dam. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Place granular filter buttress over the boils, if approved by the Design Engineer. 2) Initiate geotechnical evaluation per direction of the Design Engineer.
Water vortex within the pool.	No change in instrumentation values expected.	An internal erosion failure in progress, with potential breach of the dam. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Check downstream of the dam area for increased and/or turbid seepage discharge. 2) Place granular filter buttress against any such areas, if approved by the Design Engineer. 3) Initiate geotechnical evaluation per direction of the design engineer.
Severe flood/intense rainstorm or rapid snowmelt resulting in extreme pond level.	Potential increase in piezometric levels.	Overtopping of dam and resulting erosion and over-steepening of the downstream slope, leading to dam failure. **Level 3**	1) Initiate chain of communications and ensure safety of people. 2) Confirm functionality of emergency overflow channel. 3) Stop discharge into the pond. 4) Lower pond by any practical means approved by the Design Engineer.

Notes for Notification Procedures:

Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution.

Level 2 – Potential emergency if condition is sustained or allowed to progress; requires response plan.

Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Large Table 2 Instrumentation Warning Signs

Instrument Type and Typical Location	Instrumentation Warning Sign	Corresponding Visual Changes (dependent on magnitude of movement)	Potential/Actual Consequences and Notification Procedures	Required Action
Piezometer (single or nested) – Located on Perimeter Dams/Slopes and on Cell Splitter Dams/Slope (ref. Instrumentation and Monitoring Plan for Piezometer Names and Locations)	Gradual or Sudden Increase in Water Level in One or More Piezometers, Above Threshold Action Levels (ref. Instrumentation and Monitoring Plan for Piezometer Reading Values – Predicted and Threshold)	1) Soft toe condition or increased seepage at downstream slope or dam toe. 2) Elevated pond level in basin. 3) Increased turbidity in seepage flows. 4) Boils observed downstream of dam.	1) Excessive seepage through dam and potential for dam breach. 2) An internal erosion failure possible, with potential breach of the dam. 3) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	1) Check the reading again; confirm instrumentation functionality. 2) Intensify reading frequency to daily. 3) Seek advice from the Design Engineer. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Check downstream of the dam area for increased and/or turbid seepage discharge. b. Place granular filter buttress against any such areas, if approved by the Design Engineer. c. Initiate geotechnical evaluation per direction of the design engineer. d. Modify pond and/or basin operating procedures. e. Temporary cease operations/stop discharge into the pond. f. Lower pond by any practical means approved by the Design Engineer.
Inclinometer – Located on Perimeter Dams/Slopes and on Cell Splitter Dams/Slopes (ref. Instrumentation and Monitoring Plan for Inclinometer Names and Locations)	Gradual or Sudden Movement in Horizontal Direction in One or More Inclinometers (ref. Instrumentation and Monitoring Plan for Inclinometer Reading Values – Predicted and Threshold	1) Cracks developing at dam crest or in slope. 2) Slumping, sliding or bulging of a dam slope or adjacent ground.	1) Deformation of dam structure that may lead to eventual dam failure. 2) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	As above (blue shaded box).
Survey Monument – Located on Crest of Perimeter Dams and on Crest of Cell Splitter Dams	Gradual or Sudden Movement in Horizontal and/or Vertical Direction in One or More Survey Monuments	1) Cracks developing at dam crest or in slope. 2) Slumping, sliding or bulging of a dam slope or adjacent ground.	1) Deformation of dam structure that may lead to eventual dam failure. 2) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	As above (blue shaded box).

Notes for Notification Procedures:

Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution.

Level 2 – Potential emergency if condition is sustained or allowed to progress; requires response plan.

Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Large Figures

Project Areas
Tailings Ponds
Public Waters Inventory (PWI) Watercourses[1]
National Hydrography Dataset (NHD) Rivers & Streams[2]
Existing Private Railroad

0 750 1,500 3,000
Feet

[1]These are provisional representations of PWI watercourses found on the current paper regulatory maps.
[2]The NHD is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from MnDNR 24K Streams and 1:24,000 USGS quadrangle maps.
Note: Due to previous disturbance, both data sources may show watercourses that no longer exist.

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CELL 2E LOCATION
MAP NorthMet Project
Poly Met Mining Inc.

Large Figure 1
Tailings Basin Geotechnical
Instrumentation and Monitoring Plan

VW Piezometer	Inclinometers	Standpipe Piezometer	Pneumatic Piezometers
2E_2016_PZ_K1top	DH96-10	A-1	DH96-10
2E_2016_PZ_K1bottom	DH96-12	A-3	DH96-11
2E_2016_PZ_K2top	DH96-18	A-9	DH96-28A
2E_2016_PZ_K2middle	DH96-19	B-2	DH96-28
2E_2016_PZ_K2bottom	DH96-28	D-1	DH96-30
2E_2016_PZ_K2bedrock	DH96-32	D-4	DH96-32A
2E_2016_PZ_K3middle	DH96-37	E-5	DH96-37A
2E_2016_PZ_K3bottom	DH96-46	F-2	DH96-37A
	DH96-47	P2HA-99	PN1J-99
	DH99-1	P2HB-99	PH1F-99
		P1H-99	
		P3H1-99	
		P2H1-99	
		P1H1-99	
		P3H-99	
		P1B199	
		P1B99	
		G-2	

Inclinometers
Pneumatic Piezometers and Inclinometers
Pneumatic Piezometers
Standpipe Piezometers
Vibrating Wire Piezometers

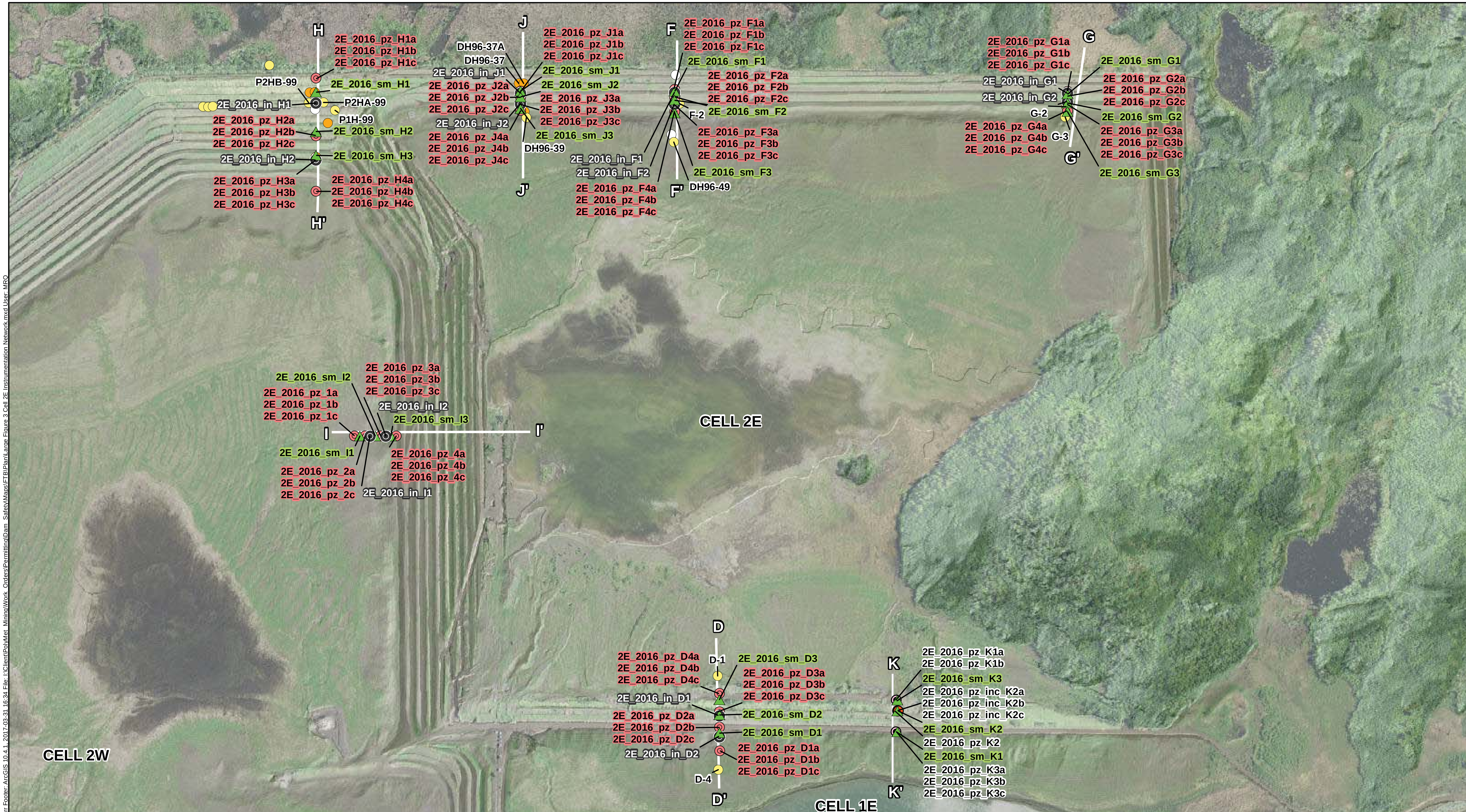
N

0 1,500 3,000
Feet

BARR

INSTRUMENTATION LOCATIONS
NorthMet Project
Poly Met Mining Inc.

Large Figure 2
Tailings Basin Geotechnical
Instrumentation and Monitoring Plan



Cross Section Locations

Proposed Locations

- Survey Monument
- VW Inclinometer
- Nested VW Piezometer

Existing Locations

- Inclinometer
- Inclinometer with Nested VW Piezometer
- Nested VW Piezometer
- Pneumatic Piezometer
- Pneumatic Piezometer & Inclinometer
- Standpipe Piezometer
- VW Piezometer

0 750 1,500
Feet

BARR

CELL 2E
INSTRUMENTATION NETWORK
NorthMet Project
Poly Met Mining Inc.

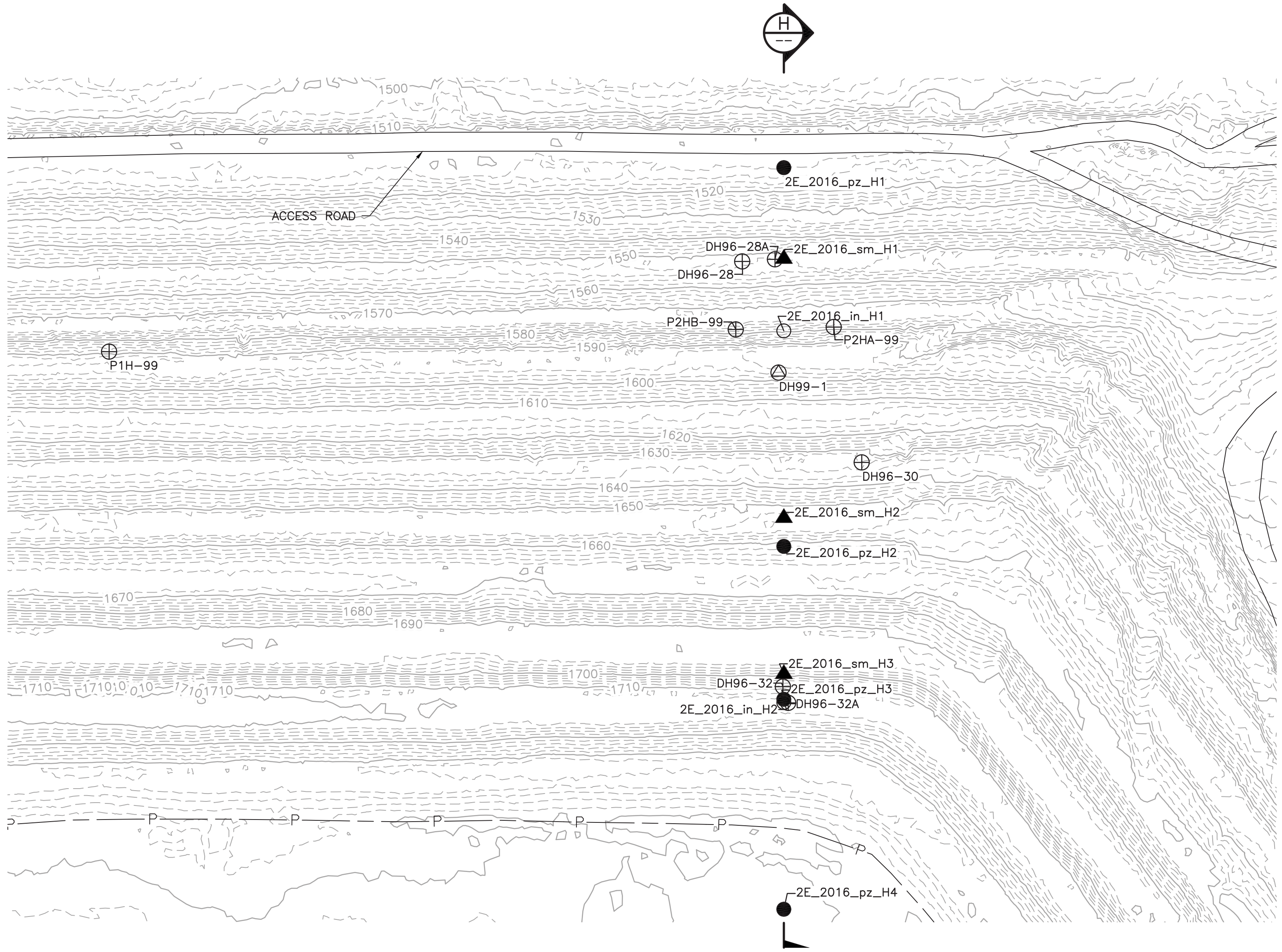
Large Figure 3
Tailings Basin Geotechnical
Instrumentation and Monitoring Plan

LEGEND:

- ⊕ STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- ● PROPOSED VW PIEZOMETER
- ○ PROPOSED INCLINOMETER
- ▲ PROPOSED SURVEY MONUMENT

NOTE:

INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.



1 PLAN: CROSS-SECTION H

0 100 200 SCALE IN FEET

EXISTING INSTRUMENTATION

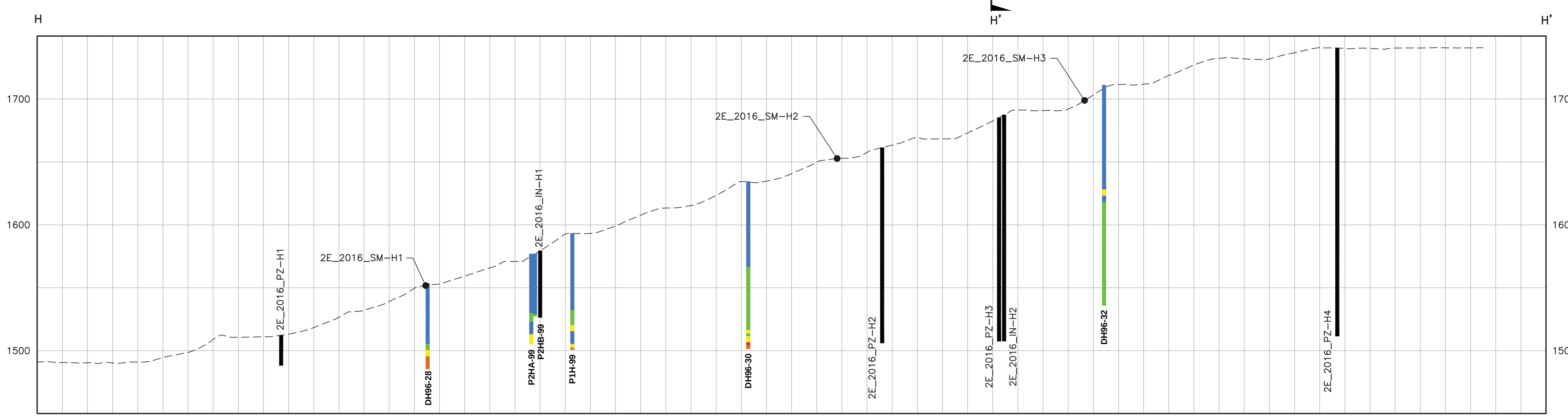
NAME	INSTRUMENTATION	LOCATION	CELL
P2HB-99	Standpipe Piezometer	Toe	2W
P2HA-99	Standpipe Piezometer	Toe	2W
P1H-99	Standpipe Piezometer	Embankment	2W
DH96-28	Pneumatic Piezometer (D)	Toe	2W
DH96-28A	Pneumatic Piezometer (D)	Toe	2W
DH96-32	Pneumatic Piezometer & Inclinometer (D)	Crest	2W
DH96-30	Pneumatic Piezometer (D)	Embankment	2W
DH96-32A	Pneumatic Piezometer (D)	Crest	2W
DH99-1/I1H-99	Inclinometer (D)	Toe	2W

NOTE:

(D) INDICATES INSTRUMENT THAT WILL BE DECOMMISSIONED

PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_H4c	Nested VW Piezometer	Interior	2W
2E_2016_pz_H4b	Nested VW Piezometer	Interior	2W
2E_2016_pz_H4a	Nested VW Piezometer	Interior	2W
2E_2016_pz_H3c	Nested VW Piezometer	Crest	2W
2E_2016_pz_H3b	Nested VW Piezometer	Crest	2W
2E_2016_pz_H3a	Nested VW Piezometer	Crest	2W
2E_2016_pz_H2c	Nested VW Piezometer	Embankment	2W
2E_2016_pz_H2b	Nested VW Piezometer	Embankment	2W
2E_2016_pz_H2a	Nested VW Piezometer	Embankment	2W
2E_2016_pz_H1c	Nested VW Piezometer	Toe	2W
2E_2016_pz_H1b	Nested VW Piezometer	Toe	2W
2E_2016_pz_H1a	Nested VW Piezometer	Toe	2W
2E_2016_in_H2	Inclinometer	Crest	2W
2E_2016_in_H1	Inclinometer	Embankment	2W
2E_2016_sm_H3	Survey Monument	Interior	2W
2E_2016_sm_H2	Survey Monument	Crest	2W
2E_2016_sm_H1	Survey Monument	Embankment	2W



1 SECTION: CROSS-SECTION H

0 50 100 SCALE IN FEET

LEGEND:

- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

NOTE:

STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	2	3-31-17
FOR CONSTRUCTION	–	–

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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 3-31-17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN GEOTECHNICAL INSTRUMENTATION PLAN SECTION H

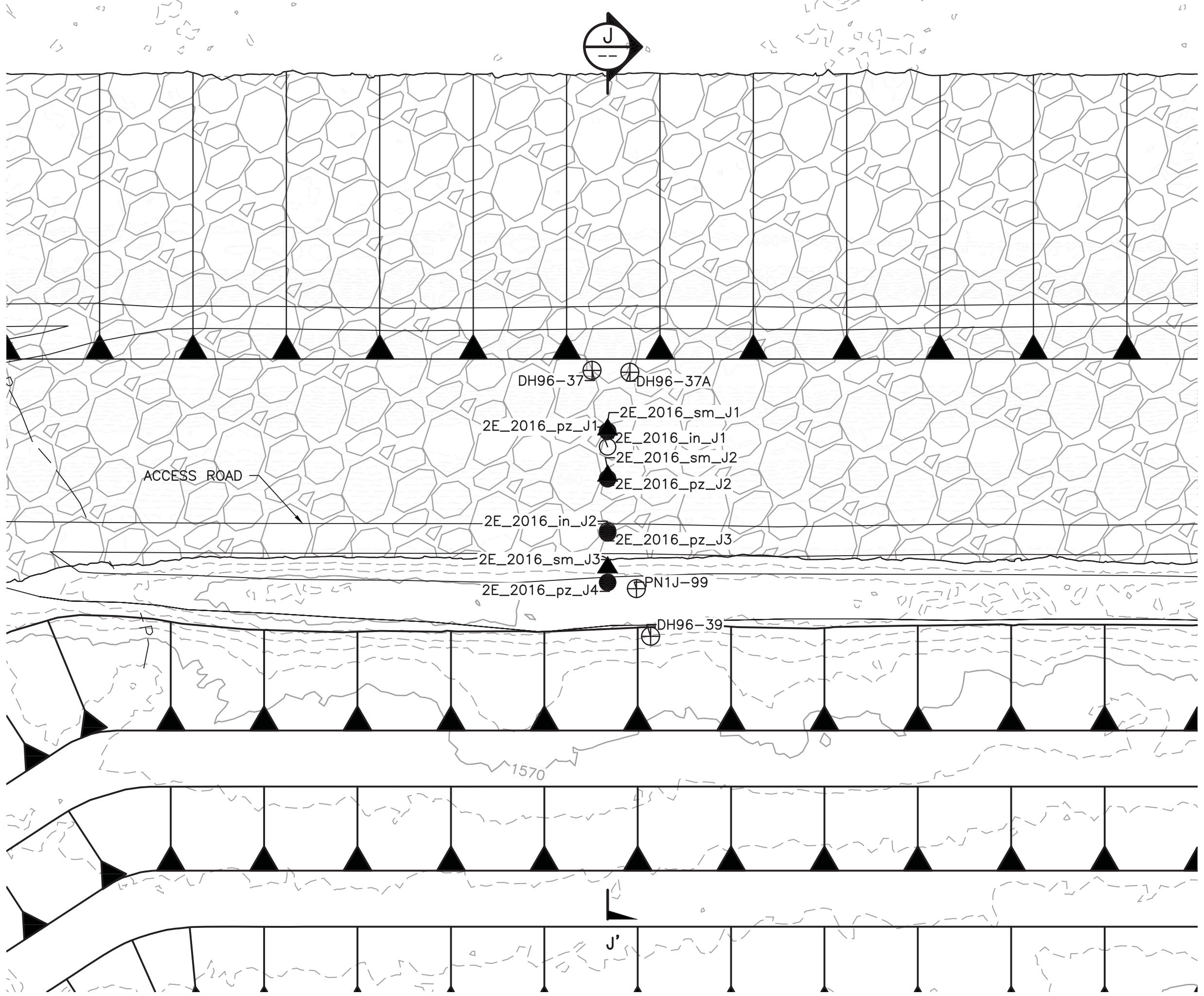
POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 4

REV .



PLAN: CROSS-SECTION J

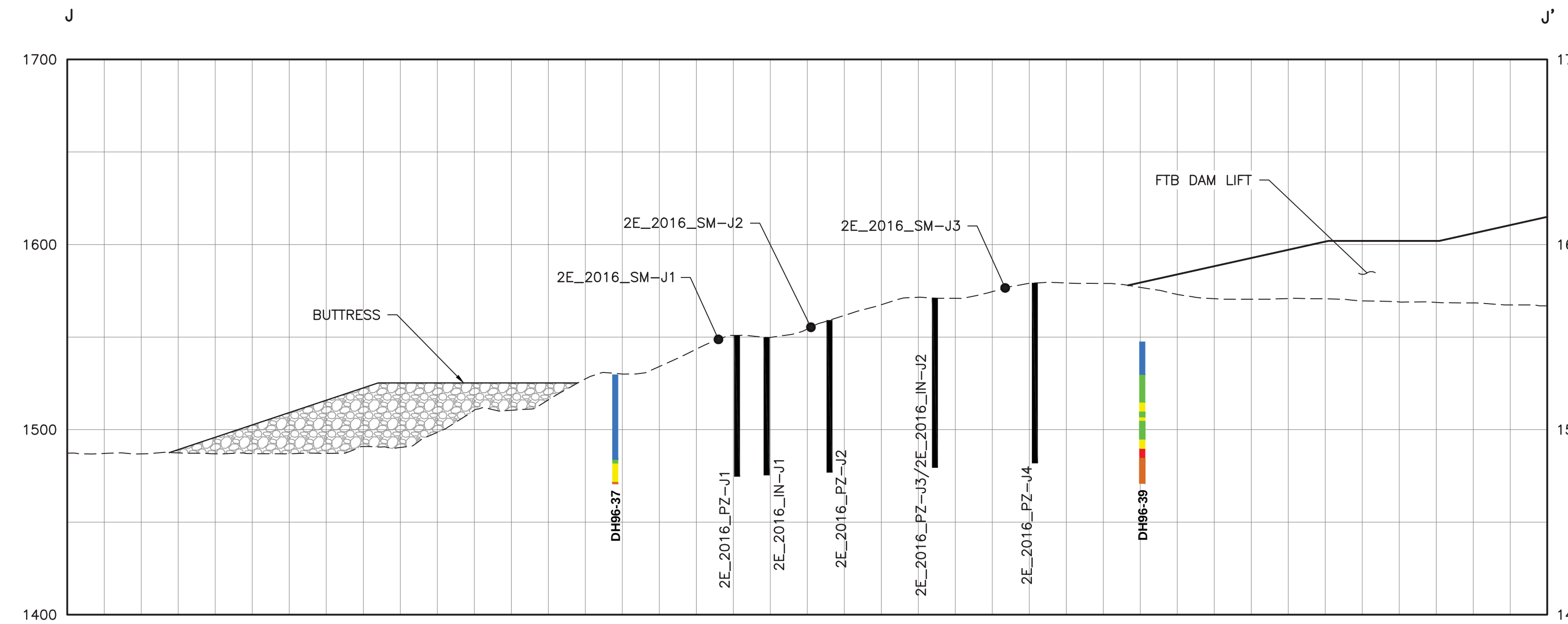
0 100 200
SCALE IN FEET

LEGEND:

- STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- PROPOSED VW PIEZOMETER
- PROPOSED INCLINOMETER
- PROPOSED SURVEY MONUMENT

NOTE:

INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.



LEGEND:

- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

SECTION: CROSS-SECTION J

0 50 100
SCALE IN FEET

NOTE:

STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

EXISTING INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
DH96-39	Pneumatic Piezometer	Tailings/Crest	2E
DH96-37	Pneumatic Piezometer (D)	Embankment	2E
DH96-37A	Pneumatic Piezometer (D)	Embankment	2E
PN1J-99/DH96-40	Pneumatic Piezometer (D)	Tailings/Crest	2E

NOTE:

(D) INDICATES INSTRUMENT THAT WILL BE DECOMMISSIONED

PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_J4c	Nested VW Piezometer	Interior	2E
2E_2016_pz_J4b	Nested VW Piezometer	Interior	2E
2E_2016_pz_J4a	Nested VW Piezometer	Interior	2E
2E_2016_pz_J3c	Nested VW Piezometer	Crest	2E
2E_2016_pz_J3b	Nested VW Piezometer	Crest	2E
2E_2016_pz_J3a	Nested VW Piezometer	Crest	2E
2E_2016_pz_J2c	Nested VW Piezometer	Embankment	2E
2E_2016_pz_J2b	Nested VW Piezometer	Embankment	2E
2E_2016_pz_J2a	Nested VW Piezometer	Embankment	2E
2E_2016_pz_J1c	Nested VW Piezometer	Toe	2E
2E_2016_pz_J1b	Nested VW Piezometer	Toe	2E
2E_2016_pz_J1a	Nested VW Piezometer	Toe	2E
2E_2016_in_J2	Inclinometer	Crest	2E
2E_2016_in_J1	Inclinometer	Embankment	2E
2E_2016_sm_J3	Survey Monument	Interior	2E
2E_2016_sm_J2	Survey Monument	Crest	2E
2E_2016_sm_J1	Survey Monument	Embankment	2E

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN GEOTECHNICAL INSTRUMENTATION PLAN SECTION J

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS		
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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 3-31-17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

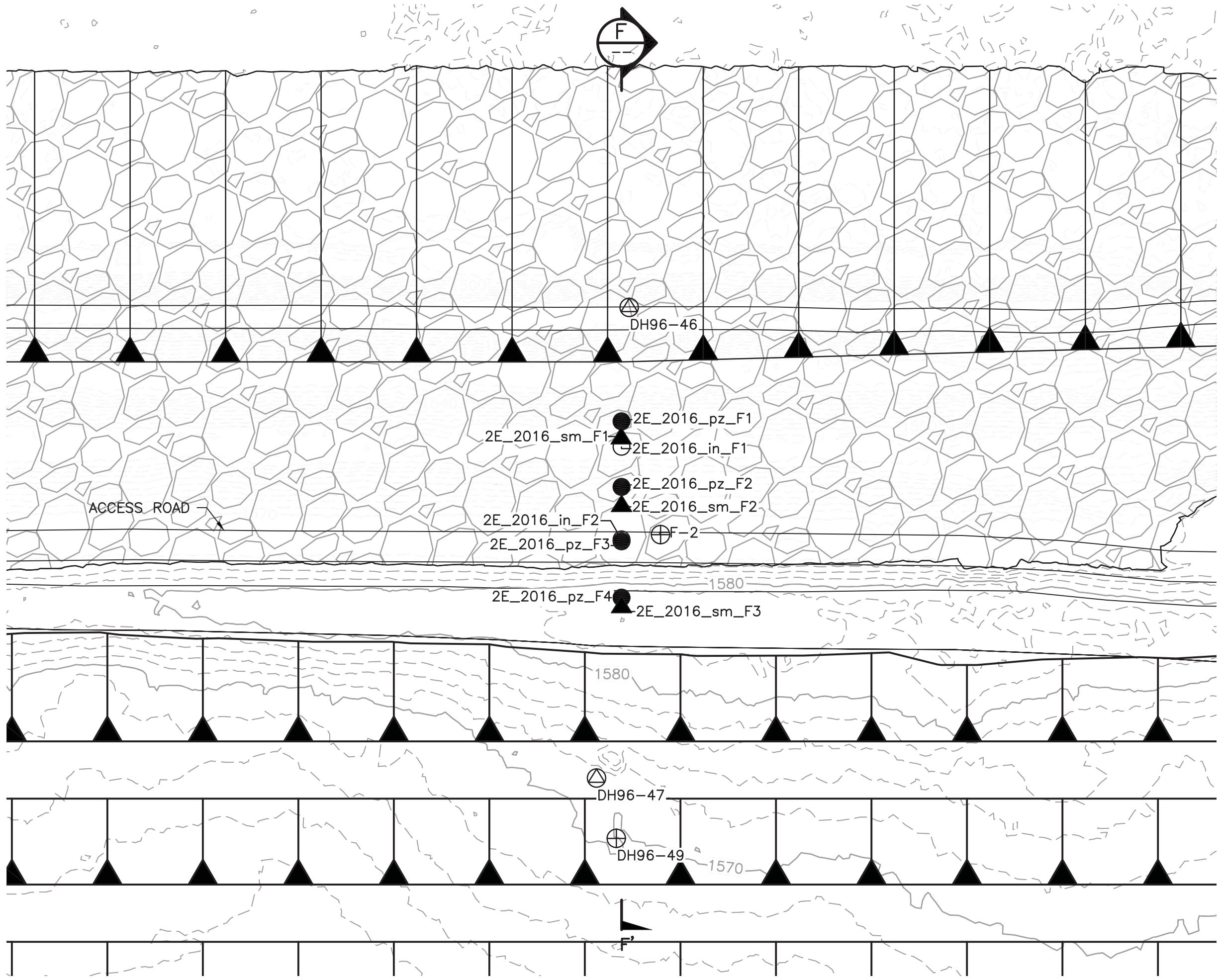
POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 5
REV .



1 PLAN: CROSS–SECTION F

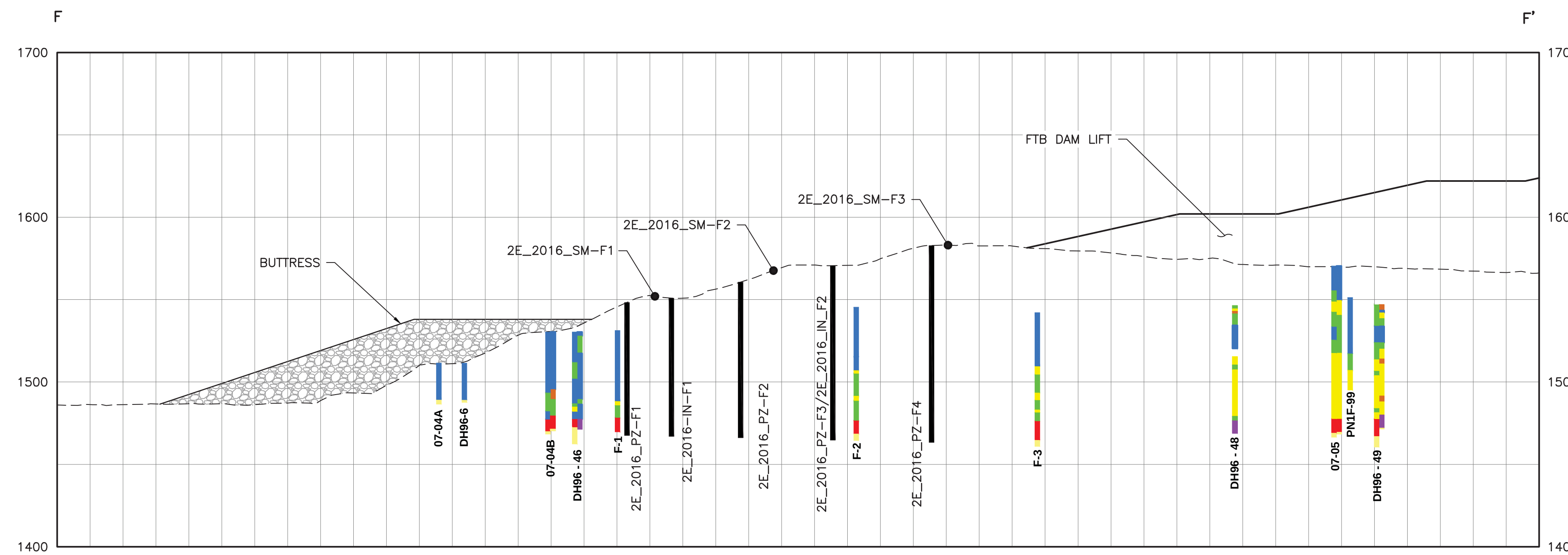
0 100 200
SCALE IN FEET

NOTE:

INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.

LEGEND:

- STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- PROPOSED VW PIEZOMETER
- PROPOSED INCLINOMETER
- PROPOSED SURVEY MONUMENT



LEGEND:

- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

1 SECTION: CROSS–SECTION F

0 50 100
SCALE IN FEET

NOTE:

STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_F4c	Nested VW Piezometer	Interior	2E
2E_2016_pZ_F4b	Nested VW Piezometer	Interior	2E
2E_2016_pz_F4a	Nested VW Piezometer	Interior	2E
2E_2016_pz_F3c	Nested VW Piezometer	Crest	2E
2E_2016_pz_F3b	Nested VW Piezometer	Crest	2E
2E_2016_pz_F3a	Nested VW Piezometer	Crest	2E
2E_2016_pz_F2c	Nested VW Piezometer	Embankment	2E
2E_2016_pz_F2b	Nested VW Piezometer	Embankment	2E
2E_2016_pz_F2a	Nested VW Piezometer	Embankment	2E
2E_2016_pz_F1c	Nested VW Piezometer	Toe	2E
2E_2016_pz_F1b	Nested VW Piezometer	Toe	2E
2E_2016_pz_F1a	Nested VW Piezometer	Toe	2E
2E_2016_in_F2	Inclinometer	Crest	2E
2E_2016_in_F1	Inclinometer	Embankment	2E
2E_2016_sm_F3	Survey Monument	Interior	2E
2E_2016_sm_F2	Survey Monument	Crest	2E
2E_2016_sm_F1	Survey Monument	Embankment	2E

EXISTING INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
F-2	Standpipe Piezometer	Crest	2E
DH96-49/PN1F-99	Standpipe Piezometer	Tailings	2E
DH96-46	Inclinometer (D)	Embankment	2E
DH96-47	Inclinometer (D)	Tailings	2E

NOTE:

(D) INDICATES INSTRUMENT THAT WILL BE DECOMMISSIONED

VER NO	DATE	DESCRIPTION
1	7–11–16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3–31–17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	2	3–31–17
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PRINTED NAME THOMAS J. RADUE
SIGNATURE
DATE 3–31–17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69–0862
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

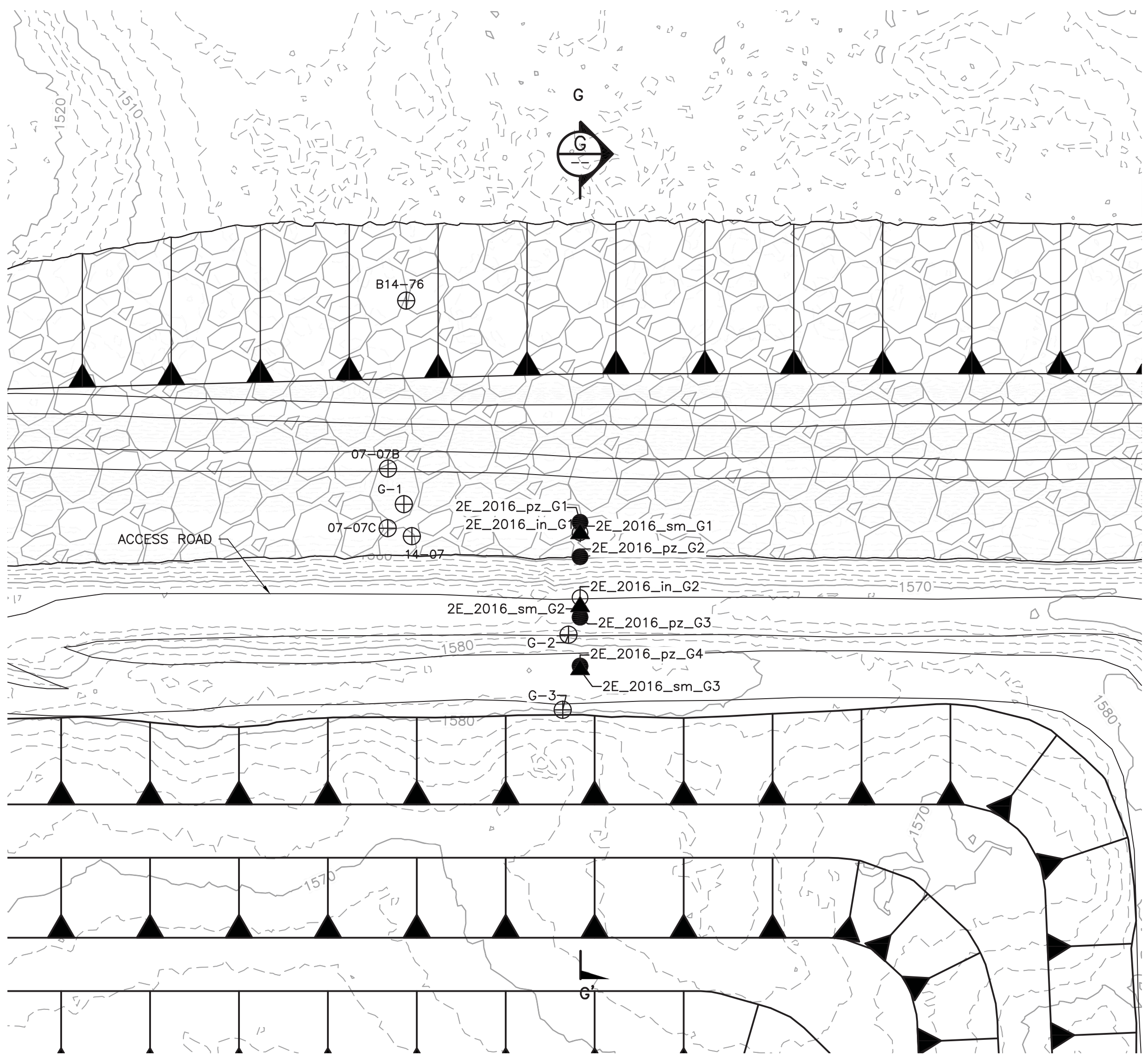
FLOTATION TAILINGS BASIN GEOTECHNICAL INSTRUMENTATION PLAN SECTION F

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1–800–632–2277

DWG. NO. LARGE FIGURE 6
REV

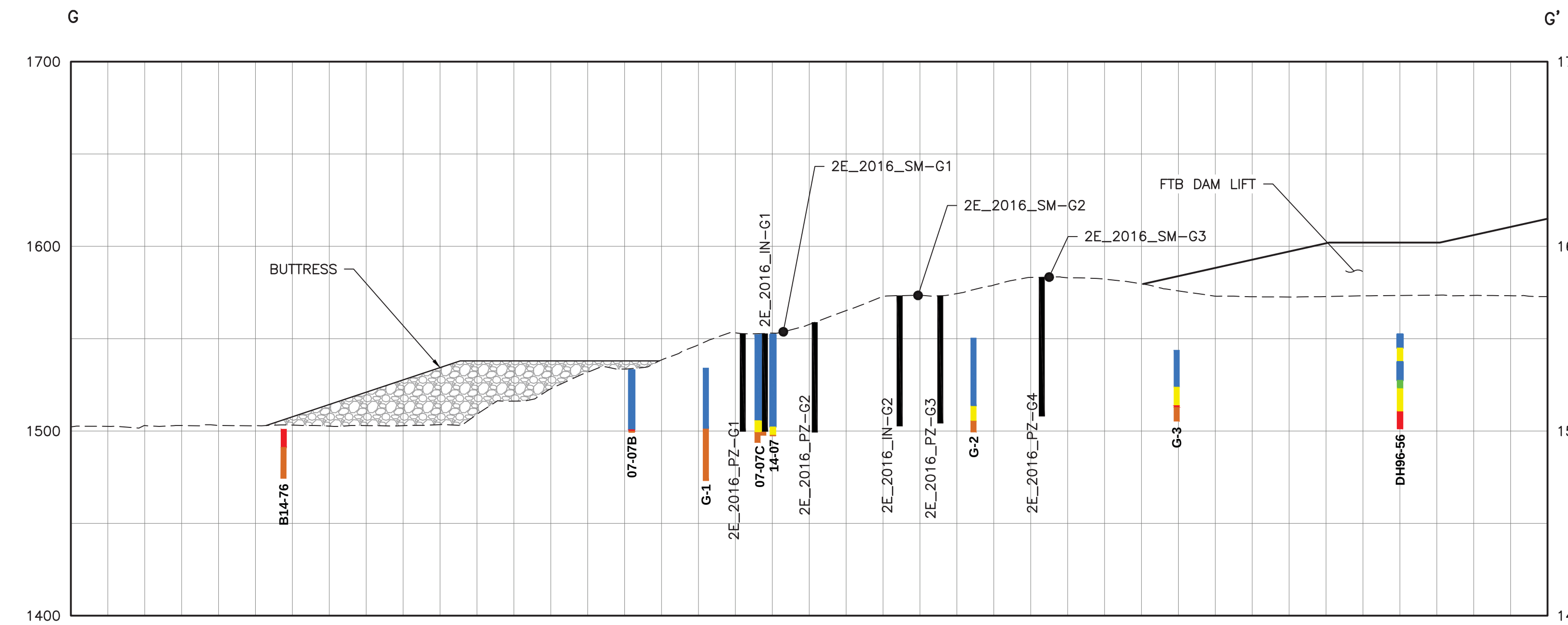


PLAN: CROSS-SECTION G

0 100 200
SCALE IN FEET

NOTE:
INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.

LEGEND:
- STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- PROPOSED VW PIEZOMETER
- PROPOSED INCLINOMETER
- PROPOSED SURVEY MONUMENT



LEGEND:
- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

SECTION: CROSS-SECTION G

0 50 100
SCALE IN FEET

NOTE:
STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_G4c	Nested VW Piezometer	Interior	2E
2E_2016_pz_G4b	Nested VW Piezometer	Interior	2E
2E_2016_pz_G4a	Nested VW Piezometer	Interior	2E
2E_2016_pz_G3c	Nested VW Piezometer	Crest	2E
2E_2016_pz_G3b	Nested VW Piezometer	Crest	2E
2E_2016_pz_G3a	Nested VW Piezometer	Crest	2E
2E_2016_pz_G2c	Nested VW Piezometer	Embankment	2E
2E_2016_pz_G2b	Nested VW Piezometer	Embankment	2E
2E_2016_pz_G2a	Nested VW Piezometer	Embankment	2E
2E_2016_pz_G1c	Nested VW Piezometer	Toe	2E
2E_2016_pz_G1b	Nested VW Piezometer	Toe	2E
2E_2016_pz_G1a	Nested VW Piezometer	Toe	2E
2E_2016_in_G2	Inclinometer	Crest	2E
2E_2016_in_G1	Inclinometer	Embankment	2E
2E_2016_sm_G3	Survey Monument	Interior	2E
2E_2016_sm_G2	Survey Monument	Crest	2E
2E_2016_sm_G1	Survey Monument	Embankment	2E

EXISTING INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
G-2	Standpipe Piezometer	Tailings	2E
G-3	Standpipe Piezometer	Crest	2E

NOTE:
LOCATION FOR INSTRUMENTS B14-76, 07-07B, G-1, 07-07C AND 14-07 ARE APPROXIMATE.

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS

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SIGNATURE
DATE 3-31-17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

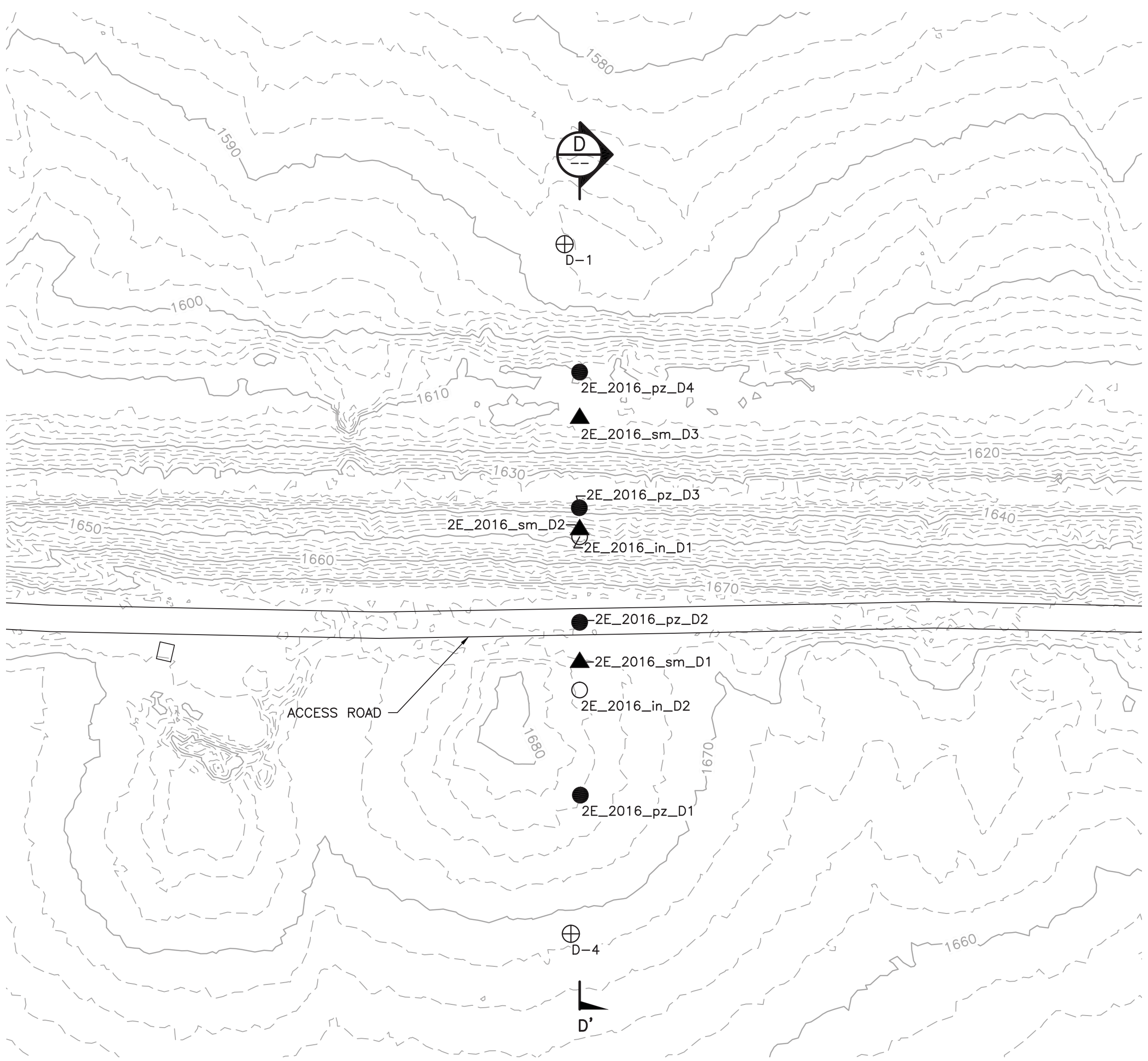
PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
GEOTECHNICAL INSTRUMENTATION PLAN
SECTION G

POLYMET MINING
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR
BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 7
REV .



1 PLAN: CROSS-SECTION D

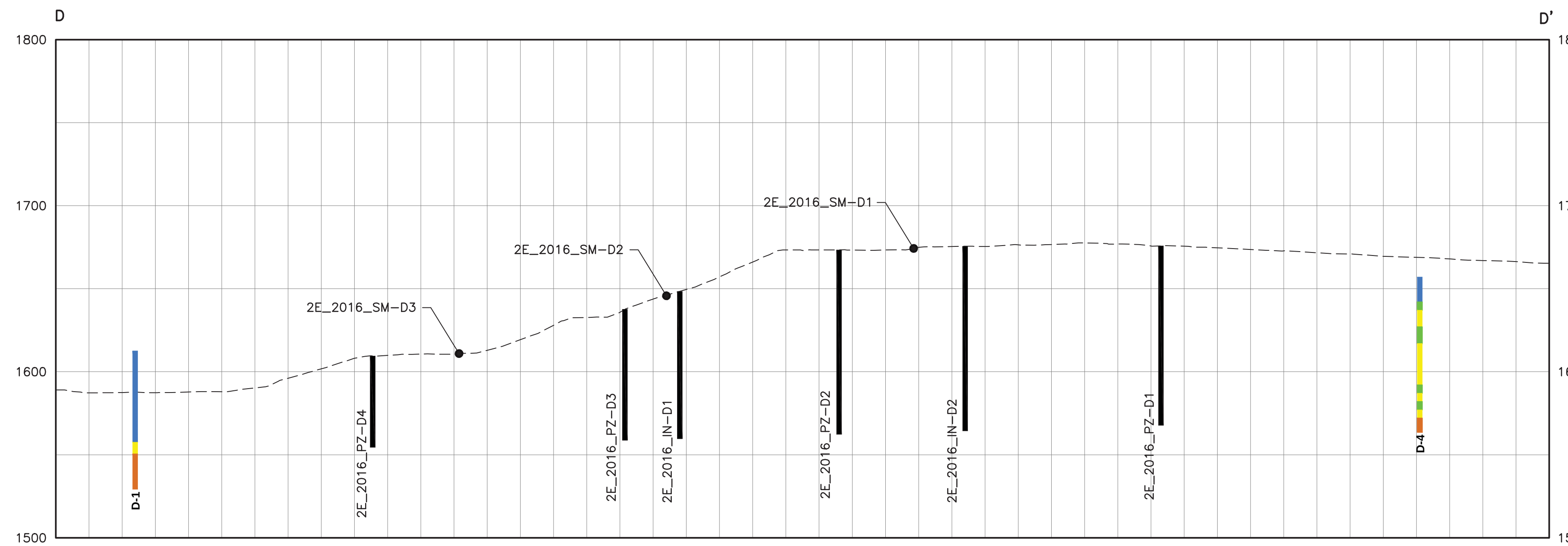
0 100 200
SCALE IN FEET

NOTE:

INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.

LEGEND:

- STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- PROPOSED VW PIEZOMETER
- PROPOSED INCLINOMETER
- PROPOSED SURVEY MONUMENT



LEGEND:

- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

1 SECTION: CROSS-SECTION D

0 50 100
SCALE IN FEET

NOTE:

STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_D4c	Nested VW Piezometer	Crest	1E
2E_2016_pz_D4b	Nested VW Piezometer	Crest	1E
2E_2016_pz_D4a	Nested VW Piezometer	Crest	1E
2E_2016_pz_D3c	Nested VW Piezometer	Crest	1E
2E_2016_pz_D3b	Nested VW Piezometer	Crest	1E
2E_2016_pz_D3a	Nested VW Piezometer	Crest	1E
2E_2016_pz_D2c	Nested VW Piezometer	Crest	1E
2E_2016_pz_D2b	Nested VW Piezometer	Crest	1E
2E_2016_pz_D2a	Nested VW Piezometer	Crest	1E
2E_2016_pz_D1c	Nested VW Piezometer	Crest	1E
2E_2016_pz_D1b	Nested VW Piezometer	Crest	1E
2E_2016_pz_D1a	Nested VW Piezometer	Crest	1E
2E_2016_in_D2	Inclinometer	Crest	1E
2E_2016_in_D1	Inclinometer	Embankment	1E
2E_2016_sm_D3	Survey Monument	Interior	1E
2E_2016_sm_D2	Survey Monument	Crest	1E
2E_2016_sm_D1	Survey Monument	Embankment	1E

EXISTING INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
D-1	Standpipe Piezometer	Toe of 2E	1E
D-4	Standpipe Piezometer	Tailings	1E

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS

ISSUED	VERSION	DATE
FOR PERMITTING	2	3-31-17
FOR CONSTRUCTION	–	–

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PRINTED NAME THOMAS J. RADUE
SIGNATURE
DATE 3-31-17 LICENSE# 20951

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CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
GEOTECHNICAL INSTRUMENTATION PLAN
SECTION D

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 8
REV .

CADD USER: Andrew T. Dillon FILE: K:\DESIGN\23690C29.10\POLYMET GEOTECH SECTIONS CMB2.DWG PLOT SCALE: 1:1 PLOT DATE: 3/31/2017 3:06 PM
BARR M:\AutoCAD 2011 Support\enu\Template\Barr_2011_Template.dwt Plot at 1 10/05/2010 14:03:50

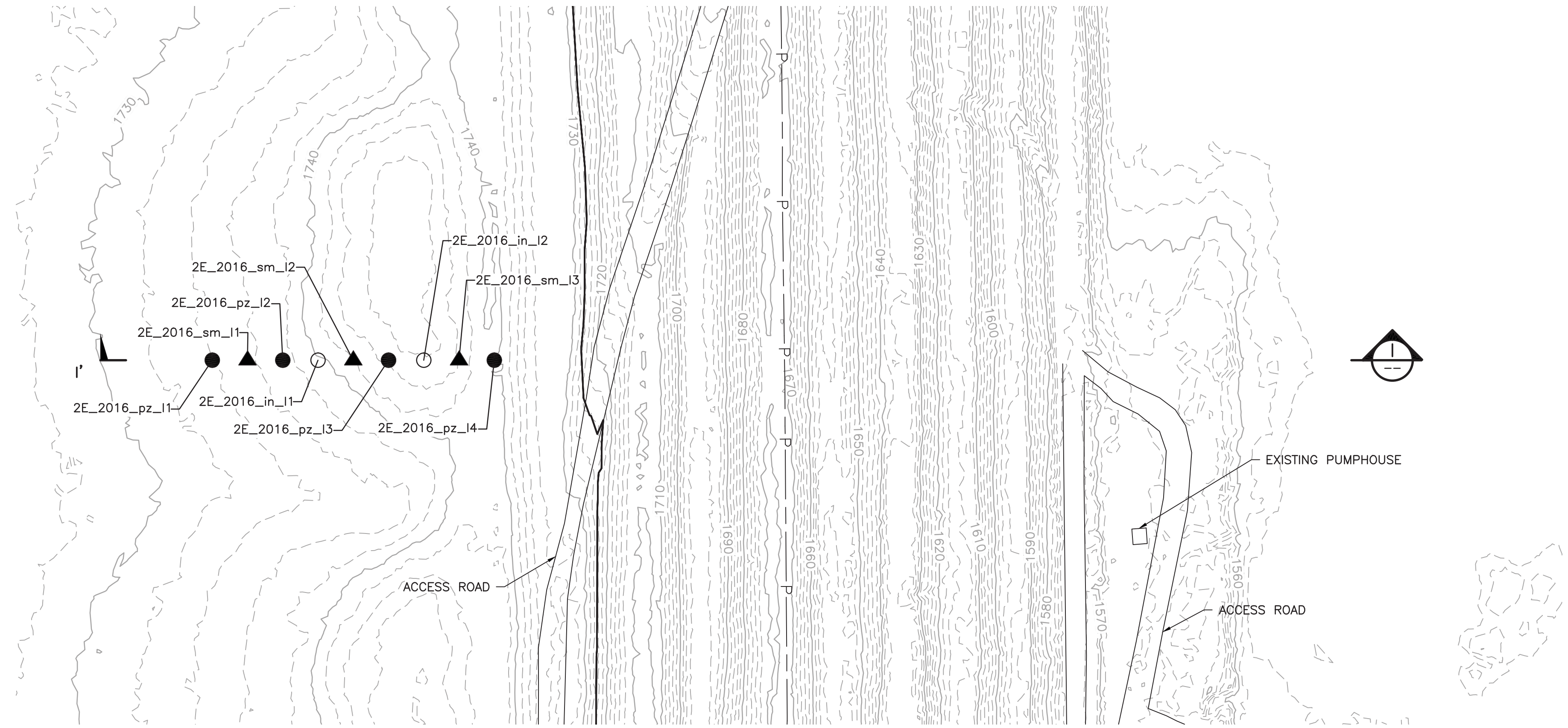
INCHES 1 2

LEGEND:

- STANDPIPE PIEZOMETER LOCATION
- INCLINOMETER LOCATION
- PROPOSED VW PIEZOMETER
- PROPOSED INCLINOMETER
- PROPOSED SURVEY MONUMENT

NOTE:

INSTRUMENT LOCATIONS ARE APPROXIMATE AND WILL BE CONFIRMED IN THE FIELD.

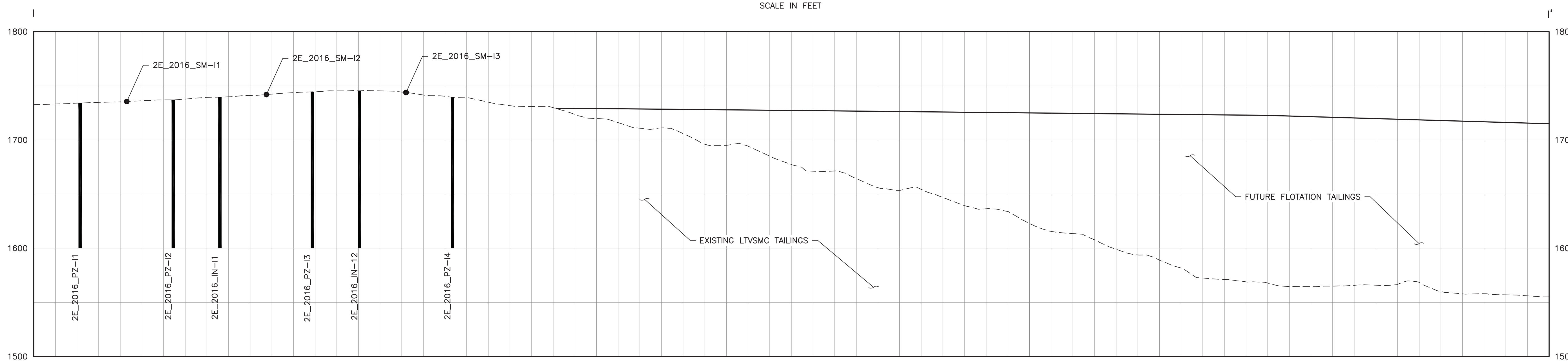


PROPOSED INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_pz_I4c	Nested VW Piezometer	Crest	2E
2E_2016_pz_I4b	Nested VW Piezometer	Crest	2E
2E_2016_pz_I4a	Nested VW Piezometer	Crest	2E
2E_2016_pz_I3c	Nested VW Piezometer	Crest	2E
2E_2016_pz_I3b	Nested VW Piezometer	Crest	2E
2E_2016_pz_I3a	Nested VW Piezometer	Crest	2E
2E_2016_pz_I2c	Nested VW Piezometer	Crest	2E
2E_2016_pz_I2b	Nested VW Piezometer	Crest	2E
2E_2016_pz_I2a	Nested VW Piezometer	Crest	2E
2E_2016_pz_I1c	Nested VW Piezometer	Crest	2E
2E_2016_pz_I1b	Nested VW Piezometer	Crest	2E
2E_2016_pz_I1a	Nested VW Piezometer	Crest	2E
2E_2016_in_I2	Inclinometer	Crest	2E
2E_2016_in_I1	Inclinometer	Embankment	2E
2E_2016_sm_I3	Survey Monument	Interior	2E
2E_2016_sm_I2	Survey Monument	Crest	2E
2E_2016_sm_I1	Survey Monument	Embankment	2E

1 PLAN: CROSS-SECTION I

0 100 200
SCALE IN FEET



1 SECTION: CROSS-SECTION I

0 50 100
SCALE IN FEET

LEGEND:

- COARSE TAILINGS
- FINE TAILINGS
- SLIMES
- NATIVE TILL
- PEAT

NOTE:

STRAGRAPHY AND INSTRUMENT DEPTH IS APPROXIMATE AND WILL BE UPDATED AS PART OF FUTURE GEOTECHNICAL INSTRUMENT INSTALLATIONS.

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS

ISSUED	VERSION	DATE
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SIGNATURE

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CHECKED: SJW

BARR PROJECT NO.: 23/69-0862

SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
GEOTECHNICAL INSTRUMENTATION PLAN
SECTION I

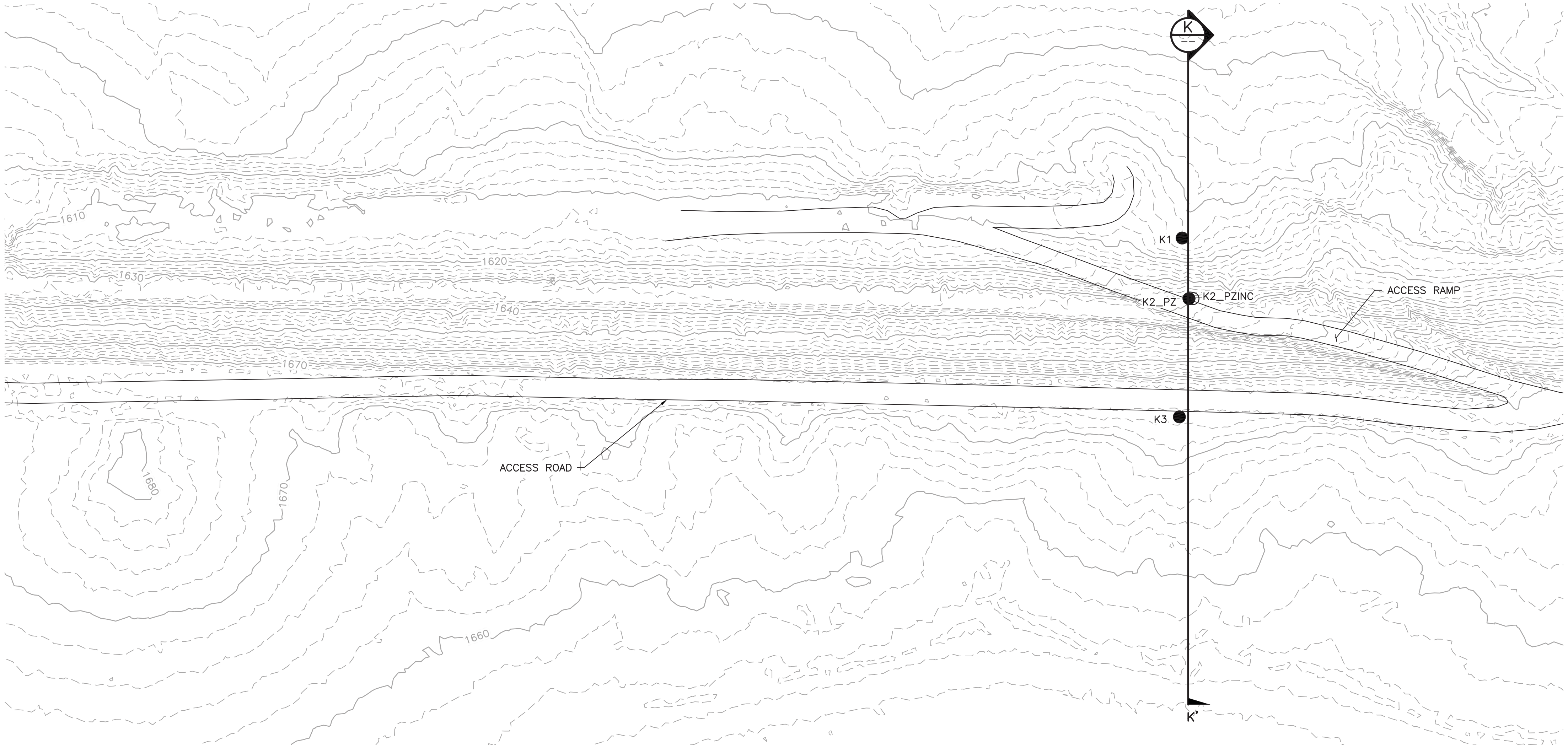
POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 9

REV .

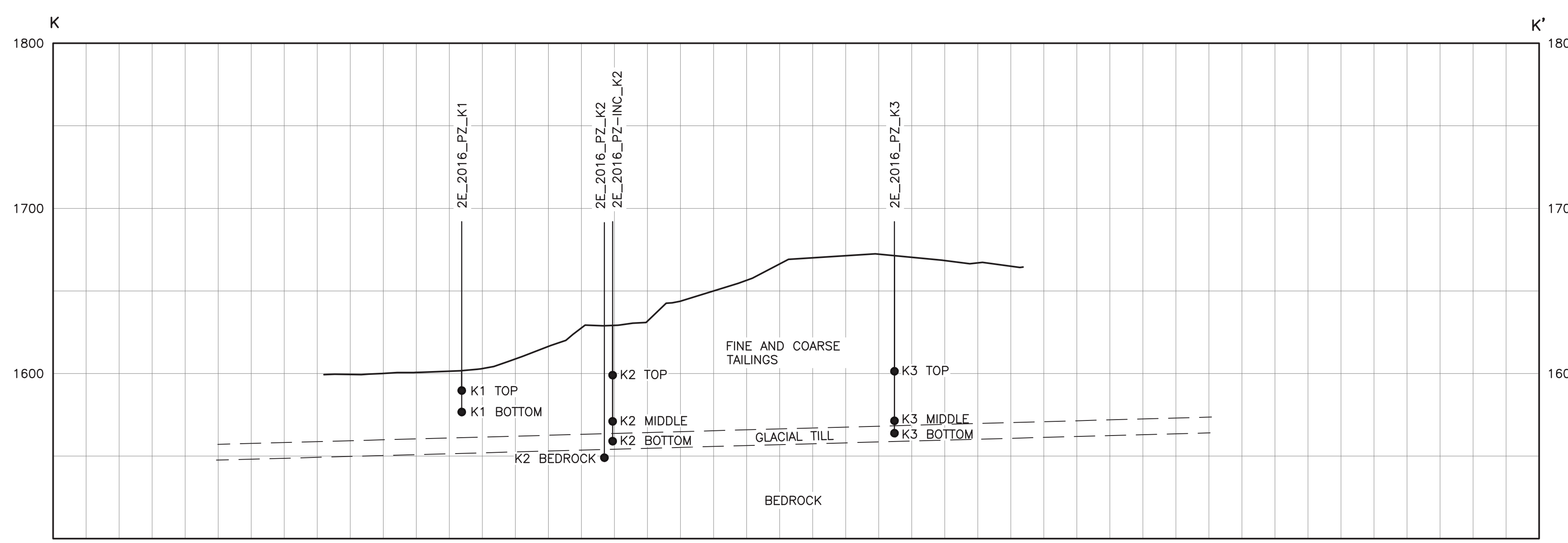


LEGEND:

- VW PIEZOMETER
- INCLINOMETER WITH NESTED VW PIEZOMETER
- SEEP LOCATION

1 PLAN: CROSS-SECTION K

0 100 200
SCALE IN FEET



2 SECTION: CROSS-SECTION K

0 50 100
SCALE IN FEET

EXISTING INSTRUMENTATION

NAME	INSTRUMENTATION	LOCATION	CELL
2E_2016_PZ_K1 top	Nested VW Piezometer	Perimeter Dam Toe	2E
2E_2016_PZ_K1 bottom	Nested VW Piezometer	Perimeter Dam Toe	2E
2E_2016_PZ-INC_K2 top	Inclinometer with Nested VW Piezometer	Mid-Slope	2E
2E_2016_PZ-INC_K2 middle	Inclinometer with Nested VW Piezometer	Mid-Slope	2E
2E_2016_PZ-INC_K2 bottom	Inclinometer with Nested VW Piezometer	Mid-Slope	2E
2E_2016_PZ_K2 bedrock	VW Piezometer	Mid-Slope	2E
2E_2016_PZ_K3 top	Nested VW Piezometer	Crest	2E
2E_2016_PZ_K3 middle	Nested VW Piezometer	Crest	2E
2E_2016_PZ_K3 bottom	Nested VW Piezometer	Crest	2E

NOTES:

1. GROUND SURFACE FROM 2016 SURVEY.
2. STRATIGRAPHY IS APPROXIMATE AND FOR CONCEPTUAL PURPOSES ONLY.

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	2	3-31-17
FOR CONSTRUCTION	–	–

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PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 3-31-17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
GEOTECHNICAL INSTRUMENTATION PLAN
SECTION K

POLYMET MINING

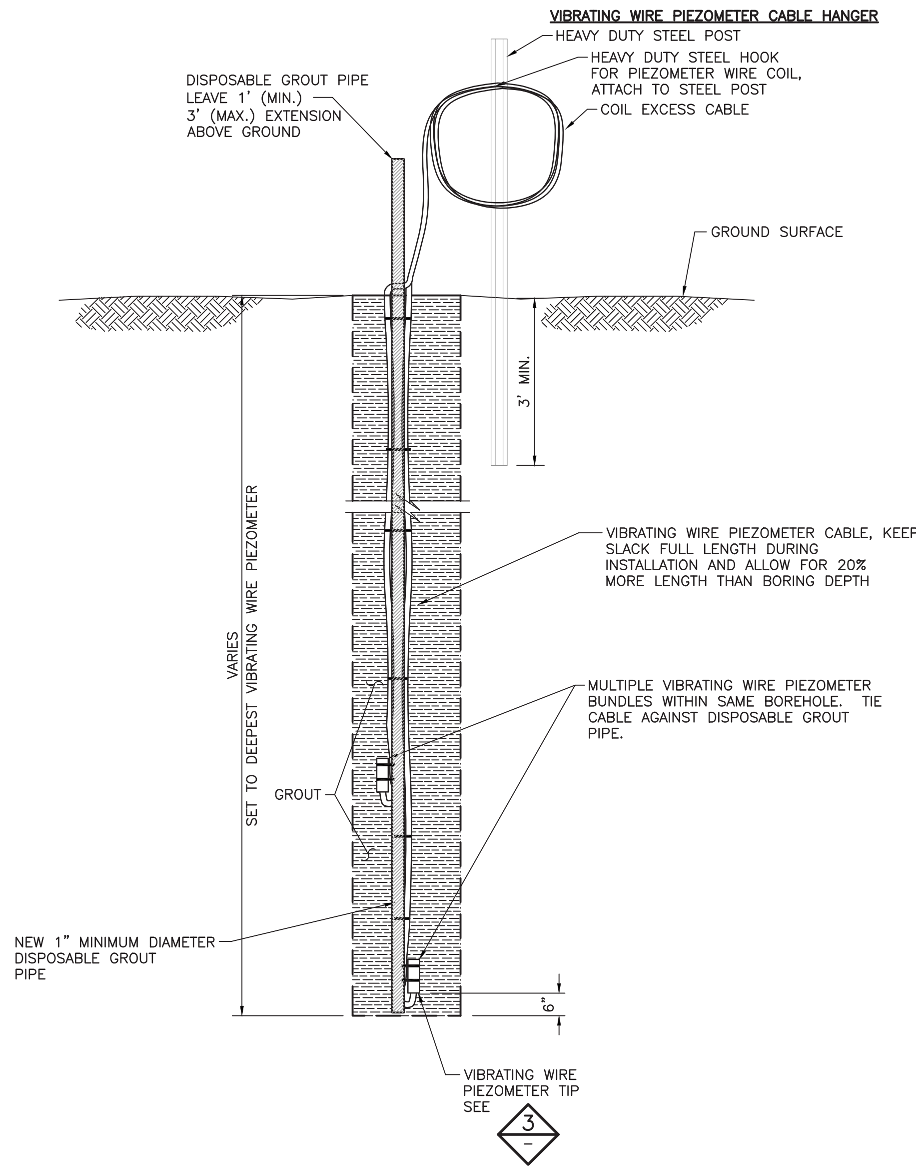
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

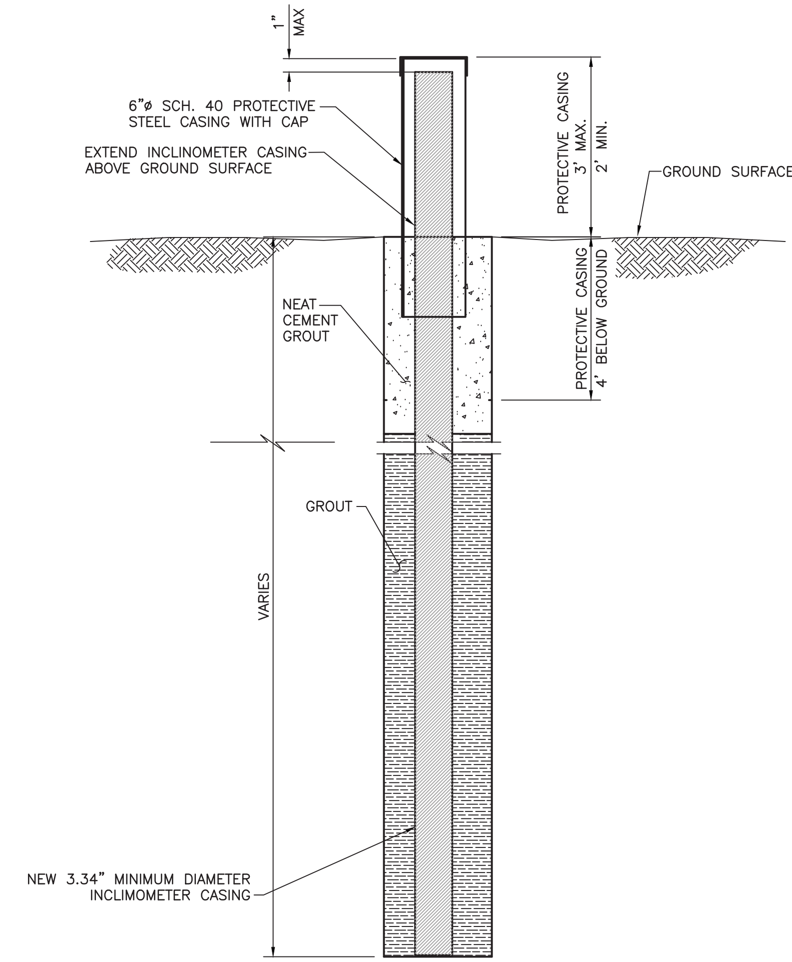
BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 10

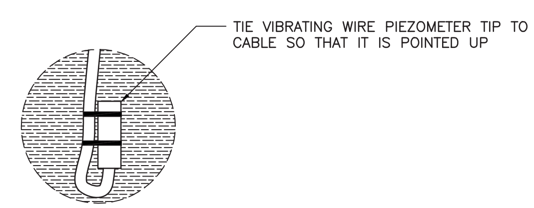
REV .



1 – DETAIL: TYPICAL (VW) VIBRATING WIRE PIEZOMETER INSTALLATION
N.T.S.



2 – DETAIL: TYPICAL INCLINOMETER INSTALLATION
N.T.S.



3 – DETAIL: TYPICAL VIBRATING WIRE PIEZOMETER TIP
N.T.S.

VER NO	DATE	DESCRIPTION
1	7-11-16	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 6 – ATTACHMENT D
2	3-31-17	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 7 – ATTACHMENT D

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	2	3-31-17
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SIGNATURE
DATE 3-31-17 LICENSE# 20951

DRAWN: CMB2
CHECKED: SJW
BARR PROJECT NO.: 23/69-0862
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN GEOTECHNICAL INSTRUMENTATION PLAN DETAILS

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING COMPANY
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. LARGE FIGURE 11
REV .

Exhibits

Exhibit A

Technical Specifications – Fully Grouted Vibrating Wire Piezometers

TECHNICAL SPECIFICATIONS
FULLY GROUTED VIBRATING WIRE PIEZOMETERS

1.0 SCOPE

The work covered under this section of the Specifications consists of furnishing all labor, materials, equipment, and performing all operations necessary to construct and install vibrating wire piezometers using the fully grouted method. The piezometer tips will be provided by the OWNER'S REPRESENTATIVE. The proposed piezometer locations are shown on Large Figures 4 through 9 of the Tailings Basin Geotechnical Instrumentation and Monitoring Plan (Plan). Minor adjustments to the proposed locations and elevations may be made in the field by the OWNER'S REPRESENTATIVE.

2.0 RERENCE STANDARDS

2.1 ASTM D-1586 Standard Test Method for Standard Penetration (SPT) and Split-Barrel Sampling of Soils

2.2 ASTM C-150 Specifications for Portland Cement

In case of conflict between these Technical Specifications and the above standards, the Technical Specifications will prevail.

3.0 SUBMITTALS

3.1 Concrete sand product sheet.

3.2 Sand pack gradation product sheet.

3.3 Bentonite product sheet.

3.4 Portland cement product sheet.

3.5 Drilling fluid addition product sheet.

4.0 MATERIALS

4.1 Drilling Fluid

Drilling fluid for boreholes used for vibrating wire piezometers shall be drilling mud, potable water (defined as water which is safe for human consumption in that it is free from impurities in amounts sufficient to cause disease or harmful physiological effects) and bentonite. Other additives may not be added to maintain a stable borehole.

4.2 Portland Cement

Portland Cement (Type I) shall meet the requirements of ASTM C-150.

4.3 Bentonite

Bentonite shall be finely ground, premium-grade bentonite, equal to Quick Gel manufactured by NL Baroid Industries, Inc. of Houston, Texas. The bentonite shall be free from lumps and objectionable material that would prevent easy mixing into a smooth fluid, free from lumps of unmixed bentonite.

4.4 Vibrating Wire Piezometer Tip and Cable

The vibrating wire piezometer shall be a 250 psi tip that meets the specifications of the Slope Indicator Company's Model 52611040 vibrating wire piezometer or approved equal. The cable shall be marked at the factory, at the end where the readout gate is connected, with the following minimum details: length, serial number, and pressure range. These will be supplied by the OWNER'S REPRESENTATIVE.

4.5 Grout for Backfill of Vibrating Wire Piezometers

The grout for backfilling the boreholes of the vibrating wire piezometers shall consist of a mixture of Portland Cement (one bag approximately 94 pounds) to 29 gallons of water to approximately 30 pounds of bentonite as needed. Portland Cement and bentonite shall be weighed and amounts recorded for each batch used for backfill. Water and cement shall be mixed first. The bentonite shall be added slowly under high agitation to make grout creamy, yet pumpable. This yields a cement-water-bentonite ratio by weight of 1:2.5:0.3.

INVESTIGATION CONTRACTOR shall provide a scale to weigh out the proportions of this mix, accurate to the nearest pound. Water proportion shall be measured by 5-gallon bucket that is marked at 1-gallon increments. The OWNER'S REPRESENTATIVE shall approve the grout mix before it is placed in the borehole.

4.6 Concrete Grout for Protective Casing

Concrete grout for piezometer protective casing installation shall consist of 1 part potable water, 2 parts Portland cement, and 2 parts clean sand.

4.7 Protective Casings

Protective casings shall be embedded into the ground surface and extended over the protruding portions of the piezometer casings. The tops of the protective casings shall extend no more than 4 feet above the ground surface and should be embedded a minimum of 2 feet below ground. The protective casings shall consist of Schedule 40 steel with caps and be at least 12 inches in diameter.

4.8 Grout Pipe (Disposable)

The disposable grout pipe shall have a large enough diameter to facilitate grout injection into bottom of borehole while fitting inside hollow-stem auger casing. The disposable grout pipe shall be PVC.

5.0 PERFORMANCE

The INVESTIGATION CONTRACTOR shall practice good piezometer/monitoring well construction procedures that conform with ASTM or other procedures in these specifications. If, in the opinion of OWNER'S CLIENT or OWNER'S REPRESENTATIVE, the INVESTIGATION CONTRACTOR'S procedure is inadequate to construct a useable piezometer, the INVESTIGATION CONTRACTOR shall change procedures to meet the requirements of these specifications. The piezometers shall be constructed in the borings specified by OWNER'S REPRESENTATIVE at the time of drilling.

5.1 Piezometer/Monitoring Well Locations

The general locations of the required piezometers are identified on the previously referenced Figures. OWNER'S REPRESENTATIVE will stake the locations of the borings in the field for INVESTIGATION CONTRACTOR.

5.2 Vibrating Wire Piezometer Construction

Each boring shall be advanced to the design depth with a 6¼- inch, minimum inside diameter, hollow-stem auger. Each piezometer shall be assembled and installed so that the tip is at the design depth. The porous piezometer filter tip shall be properly saturated before installation into the borehole and set with the tip up and taped to the disposable grout pipe and/or inclinometer casing as appropriate at each borehole location. Final position of the VW piezometer shall be determined in the field by OWNER'S REPRESENTATIVE.

Once the VW tip has been saturated, the INVESTIGATION CONTRACTOR shall assemble the tip, disposable pipe, and cables in a way to prevent the tip from becoming desaturated. If, due to complications during installation, the tip does become desaturated the tip shall be resaturated.

Each VW piezometer tip shall be calibrated by the OWNER'S REPRESENTATIVE prior to installation.

Grout for backfilling the vibrating wire piezometers shall be placed in the borehole by pumping under pressure through the disposable grout pipe (tremie pipe). The hollow-stem auger shall be withdrawn as necessary during the grouting process. The grout pipe shall permanently remain in the boring.

Grout for backfilling the vibrating wire piezometers shall be mixed to a smooth and thick cream-like consistency, to where it is as heavy as it is feasible to pump. The

INVESTIGATION CONTRACTOR shall be responsible for supplying a pump that is capable of pumping a heavy slurry mix as previously described.

5.3 Piezometer Protection

The protective casing shall be installed to an approximate depth of 2 feet in the borehole. The exact depth shall be adjusted so that the top of the casing is even with the top of the capped riser pipe. The annulus between the protective casing and the borehole wall shall be filled with concrete grout from the ground surface to a depth of 5 feet. The grout surface outside the casing shall be sloped away from the casing. The annulus between the riser pipe and the protective casing shall be filled with grout to a level no more than 12 inches below the top of riser pipe. Well protection shall only be installed at locations designated by OWNER'S REPRESENTATIVE.

5.4 Care and Maintenance of Piezometers

During the course of drilling, the INVESTIGATION CONTRACTOR shall be responsible for the care and maintenance of the piezometers and shall maintain the site in such a condition and protect the piezometers in such a manner that no undesirable materials are spilled, dripped, or introduced into the borehole by any means.

5.5 Borehole Abandonment

If for any reason a borehole or piezometer cannot be completed, the INVESTIGATION CONTRACTOR shall contact OWNER'S REPRESENTATIVE for permission to abandon it. The INVESTIGATION CONTRACTOR shall not abandon any borehole without being directed to do so by the OWNER'S REPRESENTATIVE. Borehole abandonment includes removing all casing, and/or tools from the borehole, sealing the borehole as nearly as possible for its full length with tremied cement grout and restoring the site. If the INVESTIGATION CONTRACTOR abandons a borehole without being directed to do so by OWNER'S REPRESENTATIVE, no payment for work performed on that borehole or piezometer shall be made.

6.0 MEASUREMENT AND PAYMENT

Payment for all materials, equipment, supplies, and labor necessary to perform the work requested under the terms of this Contract will be made according to EXHIBIT D, SCHEDULE OF UNIT PRICES, included with the Contract Documents. All functions not specifically covered by a pay item shall be considered incidental to the work performed. Payment shall be made only for those items ordered or approved by OWNER'S REPRESENTITIVE and meeting the contract requirements.

6.1 Install Vibrating Wire Piezometers

Payment for vibrating wire piezometer installation will be measured per foot of grout placed. Payment will be on a unit price basis and will constitute full compensation for all labor, equipment, and grout required for vibrating wire piezometer installation, and all other items and operations required for piezometer construction. Borehole advancement for piezometer installation is not included in payment for piezometer installation but will be paid as described under Borehole Advancement by Hollow-stem Auger in the situations where a piezometer is not installed in an SPT boring.

6.2 Furnish and Install Grout Tube

Grout tube payment shall be measured per foot of tube installed. Payment shall be on a unit price and will constitute full compensation for all labor, equipment, and materials required for grout tube installation.

6.3 Backfilling Boreholes – Fully Grouted Boreholes

Grouting fully grouted boreholes used for vibrating wire piezometers will be measured for payment by the foot of borehole grouted. Payment will be by the unit price per foot and will constitute full payment for all materials, labor, and equipment required to seal the borehole, and regrade the area. No payment will be made for work performed to abandon a boring or for an equivalent replacement boring when abandonment is necessary because of some fault of the INVESTIGATION CONTRACTOR'S personnel, equipment, procedure, materials, or for boreholes abandoned without specific direction by OWNER'S REPRESENTATIVE to do so. Work performed and accepted by OWNER'S REPRESENTATIVE prior to abandonment will be counted for payment.

Exhibit B

Technical Specifications – Standpipe Piezometers

TECHNICAL SPECIFICATIONS
STANDPIPE PIEZOMETERS

1.0 SCOPE

The work covered under this section of the Specifications consists of furnishing all labor, materials, equipment, and performing all operations necessary to construct and install all porous stone tip standpipe piezometers and perform well development as required within. The proposed piezometer locations are shown on Large Figures 4 through 9 of the Tailings Basin Geotechnical Instrumentation and Monitoring Plan (Plan). Minor adjustments to the proposed locations and elevations may be made in the field by the OWNER'S REPRESENTATIVE.

2.0 REFERENCE STANDARDS

2.1 ASTM D-5092 Standard Practice for Design and Installation of Ground Water Monitoring Wells

2.2 ASTM C-150 Specifications for Portland Cement

In case of conflict between these Technical Specifications and the above standards, the Technical Specifications will prevail.

3.0 SUBMITTALS

3.1 Concrete sand product sheet.

3.2 Porous stone tip manufacturer's certificates.

3.3 Sand pack gradation product sheet.

3.4 Bentonite product sheet.

3.5 Portland cement product sheet.

3.6 Drilling fluid addition product sheet.

4.0 MATERIALS

4.1 Drilling Fluid

Drilling fluid for boreholes used for porous stone tip standpipe piezometers shall be potable water, which is defined as water which is safe for human consumption in that it is free from impurities in amounts sufficient to cause disease or harmful physiological effects. No additives shall be added to water used for the borings to be used as standpipe piezometers.

Drilling fluid for boreholes used for open pipe piezometers shall use a biodegradable additive such as Revert, an organic polymer manufactured by Johnson Screens of St. Paul, Minnesota or approved equal. Bentonite will not be allowed.

If Revert is used, prior to installation of the piezometer; the INVESTIGATION CONTRACTOR shall flush the borehole with “clean” mud to remove any clay or loose material that has been mixed with the mud while advancing the borehole. The clean mud should be as thin as possible, so that placement of backfill material is not obstructed, but that it does not sacrifice the stability of the borehole. After installation of the piezometer, the piezometer shall be developed to clear any filter cake from the borehole wall alongside the piezometer. To develop, the INVESTIGATION CONTRACTOR shall create inward flow by removing water from the standpipe, allowing formation water to flow inward and break down the filter cake. Piezometer development shall be continued until a sediment-free piezometer is obtained. After the piezometer is developed, ten well volumes of water shall be removed from the piezometer.

4.2 Porous Stone Standpipe Piezometer Tip

The piezometer tip shall consist of a 12-inch porous stone that meets the specifications of the Slope Indicator Company’s Standpipe Piezometer Tips, Model 51405102 or approved equal. The piezometer tip shall be joined to the casing by water tight couplings.

4.3 Sand Pack

The sand pack shall consist of a clean, durable, uniformly graded natural sand meeting the specifications of the #30 sand produced by Red Flint Sand and Gravel, Eau Claire, Wisconsin.

4.4 Standpipe Riser Pipe and Fittings

The riser pipe shall be 2-inch inner diameter, schedule 40, PVC pipe. Fittings shall be flush male and female threads and of the same material as the riser pipe as well as water tight. A vented end cap shall be supplied for the top of the riser pipe.

4.5 Standpipe Tip to Riser Coupler

The open pipe piezometer porous tip shall be joined to the riser pipe by a coupler that meets the specifications of the Slope Indicator Company’s Pipe Adaptors or approved equal. The piezometer tip shall be joined to the casing by water tight couplings.

4.6 Portland Cement

Portland Cement (Type I) shall meet the requirements of ASTM C-150.

4.7 Neat Cement Grout

The neat cement grout shall consist of a mixture of one bag (94 pounds) Portland cement (Type I) to not more than 6 gallons of potable water. Bentonite up to 5 percent by weight of cement may be added. No other admixtures shall be allowed.

4.8 Bentonite Pellets

Bentonite pellets shall be organic-free, high-swelling, 100 percent pure bentonite compressed into 3/8-inch-diameter pellets equal to NL Baroid Industries of Houston. The pellets shall be kept dry and transported to the site in such a way as to minimize abrasion. The pellets should be coated so as to minimize bridging during placement.

4.9 Concrete Grout for Protective Casing

The concrete grout shall consist of 1 part potable water, 2 parts Portland cement, and 2 parts clean sand.

4.10 Stick-up Protective Casings

Protective steel casings shall be embedded into the ground surface and extended over the protruding portions of the piezometer casings. The tops of the protective casings shall extend no more than 3 feet above the ground surface and should be embedded a minimum of 4 feet below ground. The protective casings shall consist of Schedule 40 steel and be at least 12 inches in diameter. The protective casings shall have a locking cover. The exposed portion of the casing shall be painted with a compatible metal corrosion-resistant primer and a red finish coat prior to delivery on-site. The protective casing cap shall be a painted overlapping steel cap of the same quality as the casing and finished with a hasp for attachment to the protective casing. Protective casings will only be installed at locations as directed by the OWNER'S REPRESENTATIVE.

4.11 Protective Casing Locks

The OWNER/OWNER's REPRESENTATIVE will provide locks for protective casings.

4.12 Protective Posts

Protective posts shall be 4-inch-diameter, schedule 40, 8 feet in length. Posts shall be filled with concrete. The exposed portion of the posts shall be painted with a compatible metal corrosion-resistant primer and red finish coat prior to delivery on site. Protective posts will only be installed at locations as directed by the OWNER'S REPRESENTATIVE.

5.0 PERFORMANCE

The INVESTIGATION CONTRACTOR shall practice good piezometer construction procedure that conform with ASTM or other procedures in these specifications. If, in the opinion of OWNER'S REPRESENTATIVE, the INVESTIGATION CONTRACTOR'S procedure is inadequate to construct a useable piezometer, the INVESTIGATION CONTRACTOR shall change procedures to meet the requirements of these specifications. The piezometers shall be constructed in the borings specified on the previously referenced Figures.

5.1 Piezometer Locations

The general locations of the required piezometers are identified in the previously referenced Figures. The location will be staked for the INVESTIGATION CONTRACTOR by the OWNER’S REPRESENTIVE.

5.2 Boring Advancement

The INVESTIGATION CONTRACTOR shall employ hollow-stem auger or the approved drilling techniques at all piezometer locations to the required depth of penetration or to depths at which hollow-stem auger advancement ceases to be feasible. The hollow-stem auger shall be equipped with a retractable bottom plug, advanced with the lead auger, and removed prior to each sampling attempt. Auger with 6¼-inch inner diameter shall be used.

If rotary drilling methods are used beyond the ceased advancement of the hollow-stem auger, a minimum 5½-inch diameter hole shall be drilled with a noncoring type roller, fishtail, or other suitable bit.

5.3 Standpipe Piezometer Construction

The boring shall be advanced to the design depth with 6¼-inch minimum inside diameter, hollow-stem auger. Bentonite drilling mud shall not be used during boring advance. The piezometer tips and the riser pipe shall be assembled and installed so that the screen is at the design depth and the riser pipe extends 2 to 3 feet above the ground surface. The sand pack shall be installed, as the auger or casing is pulled back, in a manner that shall minimize segregation and ensure the sand pack fills, as nearly as practical, the annular space between the well screen and the borehole wall to a depth of 2 feet above the screen.

A bentonite pellet seal shall be placed above the sand pack to a depth of 4 feet above the top of the piezometer tip. The pellets shall be allowed to swell a minimum of ½ hour under a head of water prior to continuing the installation. Neat cement grout shall be placed above the seal to the ground surface by pumping under pressure through a tremie pipe. After 6 inches of grout have been placed in the borehole, the discharge point of the tremie pipe shall be maintained at 3 inches or more below the grout surface. The hollow-stem auger shall be withdrawn as necessary during the grouting process. Concrete full strength grout should be placed to within 5 feet of the ground surface. The annular space between the riser pipe and the borehole wall above the cement grout shall be filled with concrete. The concrete surface at ground level shall be sloped away from the riser pipe.

5.4 Piezometer Alignment and Clearance

Piezometers shall be sufficiently plumb, straight, and free from restrictions to allow a measuring device ¾ inch in diameter and 12 inches long to pass freely through the full length of the piezometer. The INVESTIGATION CONTRACTOR shall prove the alignment and clearance are adequate prior to acceptance by OWNER'S REPRESENTIVE.

5.5 Piezometer Protection

The protective casing shall be installed to an approximate depth of 4 feet in the borehole. The exact depth shall be adjusted so that the top of the casing is even with the top of the capped riser pipe. The annulus between the protective casing and the borehole wall shall be filled with concrete grout from the ground surface to a depth of 5 feet. The grout surface outside the casing shall be sloped away from the casing. The annulus between the riser pipe and the protective casing shall be filled with grout to a level no more than 12 inches below the top of riser pipe. Piezometer protection shall only be installed at locations designated by the OWNER'S REPRESENTATIVE.

5.6 Protective Posts

If requested by the OWNER's REPRESENTATIVE, protective posts painted red shall be placed 2 feet from the protective casing in a manner as to protect the piezometer from incoming traffic. The posts shall be set 2 feet into the ground in 12-inch-diameter boreholes. The annulus between the boreholes and the posts and the inside of the posts shall be filled with concrete. Protective posts shall only be installed at locations designated by the OWNER'S REPRESENTATIVE.

5.7 Care and Maintenance of Piezometers

During the course of drilling, the INVESTIGATION CONTRACTOR shall be responsible for the care and maintenance of the piezometers and shall maintain the site in such a condition and protect the piezometers in such a manner that no undesirable materials are spilled, dripped, or introduced into the borehole by any means.

5.8 Borehole Abandonment

If for any reason a borehole or piezometer cannot be completed, the INVESTIGATION CONTRACTOR shall contact OWNER'S REPRESENTIVE for permission to abandon it. The INVESTIGATION CONTRACTOR shall not abandon any borehole without being directed to do so. Borehole abandonment includes removing all screens, casing, and/or tools from the borehole, sealing the borehole as nearly as possible for its full length with tremied cement grout, and restoring the site. If the INVESTIGATION CONTRACTOR abandons a borehole without being directed to do so by OWNER, no payment for work performed on that borehole or piezometer shall be made.

6.0 MEASUREMENT AND PAYMENT

Payment for all materials, equipment, supplies, and labor necessary to perform the work requested under the terms of this Contract will be made according to EXHIBIT D, SCHEDULE OF UNIT

PRICES, included with the Contract Documents. All functions not specifically covered by a pay item shall be considered incidental to the work performed. Payment shall be made only for those items ordered or approved by OWNER and meeting the contract requirements.

6.1 Furnish and Install Porous Tip for Standpipe Piezometers

Standpipe piezometer tip payment will be measured per porous tip installed. No more than one tip shall be installed at each piezometer location. Payment shall be on a unit price basis and shall constitute full compensation for all labor, equipment, and materials required for piezometer installation and development including but not limited to the porous tip, casing adapters, development, and all other items and operations required for tip construction.

6.2 Furnish and Install Casing for Standpipe Piezometers

Standpipe piezometer payment shall be measured per foot of casing installed. Payment shall be on a unit price basis and shall constitute full compensation for all labor, equipment, and materials including sand pack, bentonite, and grout required for standpipe piezometer installation and development including but not limited to the casing adapters, development, and all other items and operations required for tip construction. Borehole advancement for piezometer installation is not included in payment for piezometer installation and development but shall be paid as described under Borehole Advancement by Hollow-stem Auger.

6.3 Setup on a Soil Boring – Piezometer

Payment for setting up on an additional boring at the direction of the OWNER'S REPRESENTATIVE for the purpose of installing a piezometer with hollow-stem auger or water rotary methods will be measured by the boring. Payment will be at the unit price per boring and will constitute full compensation for all labor, equipment, and materials required to move the drill rig and other equipment between borings, to arrange for utility clearance at the boring location, to establish the necessary work zones, and to set up at a boring location in preparation for drilling.

6.4 Borehole Advancement

Borehole advancement by 6¼-inch hollow-stem auger will be measured for payment to the nearest foot from the ground surface to the bottom of the auger. Payment will be by the unit price per foot and will constitute full compensation for all labor, equipment, and materials required to set and remove the auger. Borehole advancement and payment shall include SPT sampling.

6.5 Furnish and Install Stick-up Protective Covers

Payment will be made for each casing installation, including the cost of the casing themselves, the concrete, and all labor and materials required to assemble and install the casing.

6.6 Furnish and Install Protective Posts

Payment will be made for each post installation, including the cost of the posts themselves, the concrete, and all labor and materials required to assemble and install the posts.

Exhibit C

Technical Specifications – Inclinometer Installations

TECHNICAL SPECIFICATIONS
INCLINOMETER INSTALLATION

1.0 SCOPE

The work covered under this section of the Technical Specifications consists of furnishing all labor, materials, equipment, and performing all operations necessary to install inclinometers. The location of inclinometer installations are shown on Large Figures 4 through 9 of the Tailings Basin Geotechnical Instrumentation and Monitoring Plan (Plan). Minor adjustments to the proposed locations and elevations may be made in the field by the OWNER'S REPRESENTATIVE.

2.0 REFERENCE STANDARDS

2.1 ASTM C150 Specifications for Portland Cement

2.2 ASTM D-6230 Standard Test Method for Monitoring Ground Movement Using Probe-Type Inclinometers

In case of conflict between these Technical Specifications and the above standards, the Technical Specifications will prevail.

3.0 SUBMITTALS

3.1 Concrete sand product sheet

3.2 Portland cement product sheet.

3.3 Bentonite product data sheet.

3.4 Inclinometer casing data sheets.

3.5 Drilling fluid addition product sheet.

4.0 MATERIALS

4.1 Drilling Fluid

Drilling fluid shall be drilling mud, a combination of potable water and bentonite. Potable water is defined as water that is safe for human consumption in that it is free from impurities in amounts sufficient to cause disease or harmful physiological effects. Other additives may not be added to maintain a stable hole.

4.2 Portland Cement

Portland Cement (Type I) shall meet the requirements of ASTM C-150.

4.3 Bentonite

Bentonite shall be finely ground, premium-grade bentonite, equal to Quick Gel manufactured by NL Baroid Industries, Inc. of Houston, Texas or approved equal. The bentonite shall be free from lumps and objectionable material that would prevent easy mixing into a smooth fluid of unmixed bentonite.

4.4 Inclinometer Casing

Inclinometer casings shall have an outside diameter of 3.34 inches (85 mm) and be constructed of ABS plastic with a load rating of 1,400 pounds. An example of an acceptable product casing is manufactured by Slope Indicator Company (CPI large diameter casing) or as approved by the OWNER'S REPRESENTATIVE. Approval of material is required prior to ordering materials.

4.5 Inclinometer Protection

Inclinometer protection shall consist of a steel casing that shall be embedded into the ground surface and extended over the protruding portions of the inclinometer casing. The tops of the protective casing shall extend no more than 3 feet above the ground surface and should be embedded a minimum of 4 feet below ground. The protective casing shall consist of Schedule 40 steel and be at least 8 inches in diameter. The protective casing shall have a locking cover. The exposed portion of the casing shall be painted with a compatible metal corrosion-resistant primer and a red finish coat prior to delivery on-site. The protective casing cap shall be a painted overlapping steel cap of the same quality as the casing and finished with a hasp for attachment to the protective casing.

4.6 Inclinometer Cement-Bentonite Grout Backfill

The grout for backfilling the inclinometer boreholes shall consist of a mixture of Portland Cement (one bag approximately 94 pounds) to 29 gallons of water to a minimum 30 pounds of Quick Gel bentonite as needed. Water and cement shall be mixed first. The bentonite shall be added slowly under high agitation to make grout creamy, yet pumpable. This yields a cement-water-bentonite ratio by weight of 1:2.5:0.3. Modifications to the cement-bentonite grout mix design including increased water and bentonite or cement should be anticipated in the field in order to accurately represent similar strength as the in-situ soil and prevent segregation of cement. These modifications shall be approved by the OWNER'S REPRESENTATIVE.

4.7 Inclinometer Casing Buoyancy – Anchors

The INVESTIGATION CONTRACTOR shall utilize one of the following options for overcoming inclinometer casing buoyancy, "floating," while placing cement-bentonite grout:

- Casing anchors, such as Durham Geo Slope Indicator Casing Anchors, sized to the appropriate casing diameter, or approved equal.
- Temporary suspension of a steel pipe or drill rods inside the casing.
- Weight pre-attached to the bottom of the casing.
- Grouting the borehole, with casing installed, in stages.

The INVESTIGATION CONTRACTOR shall not apply force to the top of the inclinometer casing to overcome buoyancy.

Barite or any substance considered a contaminant by the EPA is not allowed to be used as a weighted solution inside the inclinometer casing.

4.8 Inclinometer Grout Valves

Grout valves (with or without casing anchors) used to provide a means of cement-bentonite grouting the inclinometer casing in narrow annulus space situations shall consist of Durham Geo Slope Indicator Casing Valves, sized to the appropriate casing diameter, or approved equal.

4.9 Protective Casing Locks

Locks for protective casings will be provided by OWNER'S REPRESENTATIVE.

4.10 Protective Posts

Protective posts shall be 12-inch diameter, schedule 40, 8 feet in length. Posts shall be filled with concrete. The exposed portion of the posts shall be painted with a compatible metal corrosion-resistant primer and red finish coat prior to delivery on site. Protective posts will only be installed at locations as directed by the OWNER'S REPRESENTATIVE.

4.11 Concrete Grout for Protective Casings

The concrete grout for protective casings shall consist of Portland cement (three bags approximately 94 pounds) to 30 gallons of water. This yields a cement-water ratio by weight of 1:1.1.

5.0 PERFORMANCE

The INVESTIGATION CONTRACTOR shall practice good drilling procedure that conforms with ASTM or other procedures specified in these Contract Documents. If, in the opinion of OWNER'S REPRESENTATIVE, the INVESTIGATION CONTRACTOR'S procedure is inadequate to obtain samples or install the inclinometer correctly, the INVESTIGATION CONTRACTOR shall change procedures to meet the requirements of these specifications. The inclinometer shall be constructed in the borings specified in the previously referenced Figures.

5.1 Inclinometer Location

The locations of the required inclinometers are shown on the previously referenced Figures. The locations will be staked/identified for the INVESTIGATION CONTRACTOR by OWNER'S REPRESENTATIVE.

5.2 Boring Advancement

The INVESTIGATION CONTRACTOR shall employ hollow-stem auger techniques at the inclinometer locations to depths at which hollow-stem auger advancement ceases to be feasible. The hollow-stem auger shall be equipped with a retractable bottom plug, advanced with the lead auger, and removed prior to each sampling attempt. The diameter of the hollow-stem auger shall be sufficient to accommodate split-barrel samplers, tremie tube for grouting, and inclinometer casings.

In the case that a boring started with hollow-stem auger cannot be completed by the hollow-stem auger method due to heaving sands, extremely hard drilling conditions, cobbles or boulders, bedrock or other conditions that make auger advancement unfeasible, the INVESTIGATION CONTRACTOR shall notify the OWNER'S REPRESENTATIVE and shall extend the boring by mud-rotary methods in the same borehole, leaving the auger in place as a temporary casing until the boring has been completed.

5.3 Inclinometer Installation

The inclinometer shall be installed in the borehole and grouted in place with a minimum of 2 feet within bedrock or as directed by the OWNER'S REPRESENTATIVE. A casing anchor and/or grout plug shall be installed on the tip of casing as directed by the OWNER'S REPRESENTATIVE. The inclinometer shall be constructed such that no more than 3 feet and no less than 2 feet stick up above the ground surface. Inclinometer grout shall be placed from the base of the inclinometer to the ground surface by pumping under pressure through a tremie pipe/pipe attached to the grout valve gasket at the tip of the inclinometer casing. After 6 inches of grout have been placed in the borehole, the discharge point of the tremie pipe shall be maintained at 3 inches or more below the grout surface. The hollow-stem auger borehole casing shall be withdrawn as necessary during the grouting process. Augers shall not be spun upon removal from the ground.

The inclinometer shall be installed so that the difference in alignment of any section is no greater than 3 percent of the depth to that part. If the inclinometer is not installed to meet this tolerance, the INVESTIGATION CONTRACTOR shall abandon the location and install a new inclinometer at a location identified by the OWNER'S REPRESENTATIVE at no additional cost to the OWNER. The verification of verticality shall be made after the grout has set and two datasets are collected.

After installation, the casing groove spiral shall not exceed 1 degree per 10 feet of length; the orientation of the grooves at the top of the casing shall be within 10 degrees of the planned orientation (A-0 grooves in the downhill direction perpendicular to the slope).

5.4 Inclinometer Protection

The protective casing shall be installed to an approximate depth of 4 feet in the borehole. The exact depth shall be adjusted so that the top of the casing is even with the top of the inclinometer casing. The annulus between the protective casing and the borehole wall shall be filled with concrete grout from the ground surface to a depth of 5 feet. The concrete grout surface outside the casing shall be sloped away from the casing. The annulus between the inclinometer casing and the protective casing shall be filled with concrete grout to a level no more than 12 inches below the top of inclinometer casing.

5.4 Protective Posts

If requested by the OWNER's REPRESENTATIVE, protective posts painted red shall be placed 2 feet from the protective casing in a manner as to protect the inclinometer from incoming traffic. The posts shall be set 2 feet into the ground in 12-inch-diameter boreholes. The annulus between the boreholes and the posts and the inside of the posts shall be filled with concrete. Protective posts shall only be installed at locations designated by the OWNER'S REPRESENTATIVE.

5.5 Borehole Abandonment

If for any reason a borehole or inclinometer cannot be completed, the INVESTIGATION CONTRACTOR shall contact OWNER'S REPRESENTATIVE for permission to abandon it. The INVESTIGATION CONTRACTOR shall not abandon any borehole without being directed to do so by the OWNER'S REPRESENTATIVE. Borehole abandonment includes removing all casing, and/or tools from the borehole, sealing the borehole as nearly as possible for its full length with tremied cement grout and restoring the site. If the INVESTIGATION CONTRACTOR abandons a borehole without being directed to do so by OWNER'S REPRESENTATIVE, no payment for work performed on that borehole or piezometer shall be made.

6.0 MEASUREMENT AND PAYMENT

Payment for all materials, equipment, supplies, and labor necessary to perform the work requested under the terms of this Contract will be made according to EXHIBIT D, SCHEDULE OF UNIT PRICES, included with the Contract Documents. All functions not specifically covered by a pay item will be considered incidental to the work performed. Payment will be made only for those items ordered or approved by OWNER'S REPRESENTATIVE and meeting the contract requirements.

6.1 Furnish and Install Inclinometer Casing

Inclinometer casing payment shall be measured per foot of casing installed. Payment shall be on a unit price basis and shall constitute full compensation for all labor, equipment, and materials including grout required for inclinometer installation, and all other items and operations required for inclinometer installation. Borehole advancement with soil sampling for inclinometer installation is not included in payment for inclinometer installation but shall be paid as described under Borehole Advancement and Sampling in Section.

6.2 Furnish and Install Protective Casing for Inclinometers

Payment will be made for each casing installation, including the cost of the casing themselves, the concrete, and all labor and materials required to assemble and install the casing.

6.3 Furnish and Install Protective Posts

Payment will be made for each post installation, including the cost of the posts themselves, the concrete, and all labor and materials required to assemble and install the posts.

6.4 Furnish and Install Casing Anchors

Payment will be made for each casing anchor installation, including the cost of the anchors, and all labor and materials required to assemble and install the anchors.

6.5 Furnish and Install Grout Valves

Payment will be made for each grout valve installation, including the cost of the grout valves themselves, the concrete, and all labor and materials required to assemble and install the grout valves.

Attachment E

Dam Safety Inspection Form

Facility Inspected: | **Inspection Date:**
Inspection By: | **Weather Conditions:**

Area Inspected:

General Information

Current Freeboard:

Inlet Type: Pipe with Slurry Discharge **Outlet Type/Level Control:** Floating Discharge

Observed Features	Yes	No	Comments
1.0 (visible part of) Upstream Slope			
1.1 Erosion protection			
1.2 Evidence of erosion			
1.3 Evidence of horizontal or lateral movement			
1.4 Evidence of sloughing			
1.5 Evidence of cracking			
1.6 Mark of high pond level			
1.7 Residue adjacent dam			
1.8 Vegetation condition			
1.9 Slope visually uniform			
1.10 Other unusual conditions			
1.11 Evidence of repairs			
2.0 Crest			
2.1 Breach / wash-out			
2.2 Evidence of horizontal or lateral movement			
2.3 Evidence of settlement			
2.4 Evidence of cracking			
2.5 Shoulder erosion			
2.6 Reduced width			
2.7 Other unusual conditions			
2.8 Evidence of repairs			

Observed Features	Yes	No	Comments
3.0 Downstream Slope			
3.1 Erosion protection			
3.2 Evidence of erosion			
3.3 Evidence of horizontal or lateral movement			
3.4 Evidence of sloughing			
3.5 Evidence of cracking			
3.6 Evidence of seepage			
3.7 Seepage (if any) clear			
3.8 Vegetation condition			
3.9 Slope visually uniform			
3.10 Other unusual conditions			
3.11 Evidence of repairs			
4.0 Downstream Toe			
4.1 Toe drain exists			
4.2 Toe drain working well			
4.3 Toe ditch exits			
4.4 Flow in toe ditch			
4.5 Evidence of seepage			
4.6 Seepage (if any) clear			
4.9 Soft toe condition			
4.10 Evidence of sloughing			
4.11 Evidence of boils			
4.12 Pond at toe of slope			
4.13 Vegetation			
4.14 Evidence of repairs			
4.15 Other unusual conditions			

Observed Features	Yes	No	Comments
5.0 General			
5.1 Embedded/buried structures			
5.2 Pipelines at this dam			
5.3 Crest accessible by truck			
5.4 Depressions or sinkholes in Residue surface			
5.5 Any unusual conditions			

Notes:

Sketches (if any) Saved At:

Photos Taken: Yes ___ No ___

Photos Saved At:

Attachment F

Contingency Action Plan

NorthMet Project

Contingency Action Plan for the Flotation Tailings Basin

Version 5

Issue Date: May 15, 2017

Table of Contents

1.0 Contingency Action Plan Summary

1.1 Purpose

The purpose of the Flotation Tailings Basin (FTB) Contingency Action Plan (CAP) is to:

- identify potential basin failure modes that could occur during construction events and during routine operations; conditions that if left undetected and unresolved could instigate instability of basin dams
- proactively identify contingency plans (i.e., operation change, design change if needed) for each potential failure mode, if observed
- identify instrumentation and monitoring that confirms acceptability of construction and operating activities, and proactively alerts construction, operations, and management personnel to basin conditions that if left unresolved could initiate a potential failure mode
- define responsibilities and provide procedures for responding to unexpected and potentially hazardous conditions threatening the integrity and performance of the FTB

This document will evolve throughout the permitting, operating, reclamation, and postclosure maintenance phases of the NorthMet Project (Project). It will be reviewed and updated as necessary in conjunction with changes that occur in facility operating and maintenance methods or requirements. Each revision will be provided to the Department of Natural Resources (DNR) dam safety permitting personnel for informational purposes such that they remain fully informed as plan updates are incorporated. Any plan updates that may affect permit conditions will be discussed with dam safety permitting personnel. A Revision History is included at the end of the document.

This CAP is intended to be a stand-alone guide to initial response to emergency conditions that could potentially develop at the FTB. As with any emergency condition, ongoing real-time decision-making will be required once the situation is assessed. Poly Met Mining, Inc. (PolyMet) will establish and maintain a project-wide emergency action plan (EAP) that should be referenced in the event of other potential conditions such as severe weather (i.e., tornado) or fire that are not a part of this plan and which do not constitute a significant or ongoing threat to the FTB.

1.2 Notification Flowchart

The Notification Flowchart (Large Figure 1) summarizes the sequence of actions required during a situation involving threat of dam failure. Contact lists are provided in Section 3.0. Notification procedures for other hazardous situations are described in Section 0.

1.3 Site Description

The FTB is a tailings basin located on the PolyMet Plant Site. The Plant Site is located south of the Embarrass River in St. Louis County. The area between the FTB and the Embarrass River is sparsely populated forest.

Personnel responsible for FTB management are:

- *Operations Contact* - Beneficiation Division Manager or designee – Responsible for overall FTB design, planning, operations, maintenance, and monitoring. The plant site will be staffed full-time during operations and alternate contacts shall be designated to support the Beneficiation Division Manager in CAP implementation.

- *Design Engineer* (an independent consultant retained specially for dam safety expertise and a registered engineer) – Responsible for performance monitoring data analysis and interpretation, dam safety inspection and reporting assistance, tailings dam planning and design assistance, and permitting assistance.

1.4 Observational Method

The Observational Method as stated by Peck (1969) in his Rankine Lecture is the method by which the integrity of the Tailings Basin dams will be monitored and basin operations and/or design adjusted as needed in response to observations. The steps in the Observational Method and their status as of the writing of this version of the Contingency Action Plan are summarized in Table 1-1.

Table 1-1 Observational Method

Activity	Summary	Status	Related Reference Documents
1. Geotechnical Exploration	Geotechnical exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.	Complete	Geotechnical Data Package – Volume 1 (Appendix B of the Dam Safety Permit Application-FTB)
2. Initial Design	Establishment of the design based on a working hypothesis of behavior anticipated under the most probable conditions.	Complete	See Geotechnical Data Package – Volume 1 (Appendix B of the Dam Safety Permit Application-FTB)

Activity	Summary	Status	Related Reference Documents
3. Select Instrument Values to Observe	Selection of instrument values to observe as construction and operations proceed and calculation of the anticipated values on the basis of the working hypothesis. Values to observe will be quantified after installation and baseline monitoring of the new instrumentation listed in the Instrumentation and Monitoring Plan.(1)(Attachment D of this management plan)	Partially Complete; framework for values to be observed are reported herein and in the Instrumentation and Monitoring Plan.(Attachment D of this management plan)	Instrumentation and Monitoring Plan (Attachment D of this management plan)
4. Calculate Instrument Values to Observe	Calculation of instrument values to observe under the most unfavorable conditions.	To be quantified after installation and baseline monitoring of the new instrumentation listed in the Instrumentation and Monitoring Plan.1(Attachment D of this management plan)	Instrumentation and Monitoring Plan (Attachment D of this management plan)
5. Pre-Selection of Course of Action in Response to Observed Instrumentation Values	Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.	Complete – see subsequent sections of this Contingency Action Plan.	NA
6. Measurement of Values to be Monitored and Evaluation of Actual Conditions	Measurement of values to be monitored and evaluation of actual conditions.	To be initiated following baseline monitoring and initiation of operations.	NA
7. Modification of Design to Suit Actual Conditions	Modification of design to suit actual conditions.	To be implemented as needed during operations.	NA

1) Instrument installation to occur after permitting, prior to initiation of operations.

1.5 Supporting Documentation

Geotechnical Data Package – Volume 1 (Appendix B of the Dam Safety Permit Application-FTB) presents the findings from site geotechnical explorations and the associated in-field and in-laboratory test data, and the seepage and slope stability model outcomes for the most probable geotechnical slope stability conditions and the unfavorable slope conditions evaluated to date.

Design of the FTB as guided by findings presented in the Geotechnical Data Package is presented in this Flotation Tailings Management Plan which provides a full description of the FTB.

The Flotation Tailings Basin Instrumentation and Monitoring Plan (Attachment D of this management plan) presents the plan for instrumentation installation to be completed after permitting but prior to initiation of basin operations. Following instrumentation installation, baseline instrument monitoring data will be gathered and, in conjunction with the additional geotechnical data gathered during instrument installation; seepage and slope stability models will be updated and typical instrument values at each instrument location will be established for normal and high pond conditions. Threshold values will be documented and the initial actions to be taken in response to data trends toward threshold values will be reviewed and updated as needed (Figure 1-1).

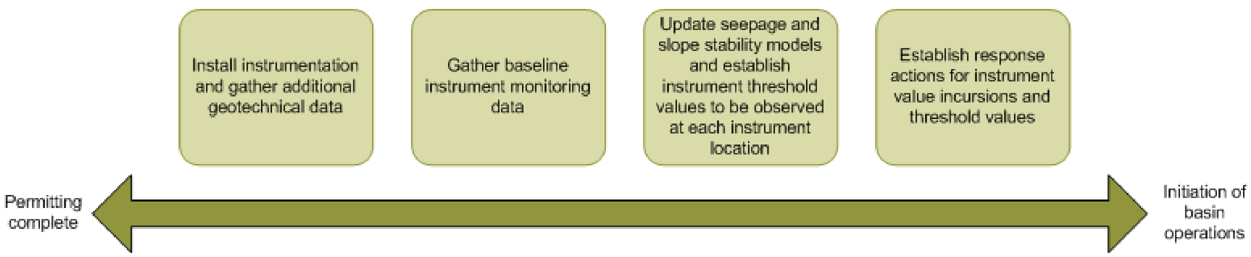

Figure 1-1 Instrumentation Timeline

The details of the instrumentation and monitoring (instrument types, locations, threshold values) will be retained within the Instrumentation and Monitoring Plan, with periodic updates to that plan as needed as instrumentation is installed and/or replaced, and as construction and operations of the FTB proceeds.

1.6 Outline

The outline of this document is:

Section 1.0 Contingency Action Plan Summary.

Section 2.0 Warning signs of unusual, hazardous, or emergency conditions associated with construction and operation of the FTB, and response actions.

Section 3.0 Internal and external emergency notification procedures.

Section 5.0 Emergency Mobilization Procedures.

Section 6.0 Emergency Evacuation Procedures.

2.0 Unusual, Hazardous and/or Emergency Conditions Warning Signs and Response Actions

Unusual, hazardous, and/or emergency conditions warning signs may be visually evident during routine or special tailings basin inspections, and/or may be evidenced by changed monitoring values in piezometers, inclinometers, and/or survey monuments. Some unusual conditions may not warrant an emergency response, but require prompt investigation and resolution. Events which may cause unusual, hazardous, and/or emergency conditions may include (but are not limited to):

- Natural weather events, which could impact pond levels or cause erosion, including:
  - high precipitation event
  - significant snowmelt in combination with high precipitation event
- Operational disruptions, which could cause erosion or impact the phreatic surface within the dam, including:
  - an unrepaired pipe break or
  - prolonged pump stoppage
- Construction changes, which could impact the phreatic surface of the dam or create excess pore water pressures within the dam, including:
  - increase in the rate of construction
  - over steepening of dam slopes

Unusual conditions will typically involve an investigation, intensified monitoring, inspecting and/or testing, and defining and implementing possible corrective measures. Some conditions represent a potential emergency if sustained or allowed to progress. In such cases it will be necessary to discuss and define a response plan, at the site, under the direction of the *Operations Contact*, and then to implement the plan. The first actions in the event of any emergency condition are:

- initiate the appropriate chain of communications
- check that all persons who could possibly be affected are safe
- immediately undertake the appropriate response actions

Sections 3, 4 and 5 describe actions to be initiated if an emergency situation occurs. The following sections list potential visual and monitoring instrument warning signs.

2.1 Visual Warning Signs

Large Table 1 provides a listing of visual warning signs and initial response actions for unusual, hazardous, and/or emergency conditions that could develop at the Tailings Basin. It is important to note that each condition is unique and that seemingly harmless conditions could quickly progress into something more serious if timely and appropriate action is not taken. To detect visual warning signs, daily and weekly inspections, semi-annual inspections, and inspections after unusual events/observations will be carried out as specified in this Flotation Tailings Management Plan.

2.2 Monitoring Instrument Warning Signs

Large Table 2 provides a listing of monitoring instrument warning signs and initial response actions for unusual, hazardous, and/or emergency conditions that could develop at the Tailings Basin. As with visual warning signs, it is important to note that each monitoring instrument warning sign condition is unique and that seemingly harmless conditions could quickly progress into something more serious if timely and appropriate action is not taken. Instrumentation data collection will in many cases be automated, allowing for real-time notification of data that is approaching pre-defined threshold values. Instruments that are not automated (e.g., alignment hubs, some inclinometers and some piezometers) will be read at the specified frequency. Further detail is provided in the Instrumentation and Monitoring Plan (Attachment D of this management plan).

3.0 Contacts

Emergency contacts are summarized in Tables 3-1 through 3-3. These tables will be updated prior to initiation of basin operations and on a routine basis as company personnel and responsibilities change.

Table 3-1 NorthMet Tailings Basin Structural Integrity Emergency Contact List

Emergency Contact	Name	Mobile	Office
Mining Manager (as alternate to General Manager)	Jim Tieberg	218-248-0952	218-471-2165
Operations Contact (Manager of Operations and Development)	Dave Hughes	TBD	218-471-2158
PolyMet Mining Environmental Compliance Manager	Kevin Pylka	218-750-2054	218-471-2162
Environmental Site Director	Christie Kearney	218-461-7746	218-471-2163
Director of Environmental Permitting and Compliance	Jennifer Saran	651-600-5457	651-389-4108
Design Engineer	Tom Radue	952-240-4051	952-832-2600
Emergency Health and Safety			
Fire/Ambulance/Police – Dependent on Incident Severity	N/A	911	911
Hospital – Grand Itasca Clinic and Hospital	General Number	N/A	218-326-3401
Government Agencies			
Minnesota Duty Officer			800-422-0798
National Response Center			800-424-8802
US EPA Region V			312-353-2318
Minnesota Pollution Control Agency (24 hrs)			612-296-8100 or 612-296-6300
Minnesota Emergency Response Commission			612-643-3000

Table 3-2 City of Hoyt Lakes Emergency Contact List

Title	Name	Phone	Email
Police Chief	Tim Soular	218-225-2000	police@eastrangepd.com
Sergeant	Heather Krueger	218-225-2000	police@eastrangepd.com
911 Emergency Communications	Emergency Non-Emergency	911 218-742-9825	N/A
Residents and/or businesses in affected inundation area will be added to this list			

Table 3-3 St Louis County Emergency Contact List

Title	**Name**	**Phone**	**Email**
Sheriff	Ross Litman	218-726-2340	County_Sheriff@stlouiscountymn.gov
Undersheriff	Dave Philips	218-726-2340	County_Sheriff@stlouiscountymn.gov
911 Emergency Communications	Emergency Non-Emergency	911 218-727-8770	County_Sheriff@stlouiscountymn.gov
Mine Inspector	Steve Manninen	218-742-9840	manninen@stlouiscountymn.gov

PolyMet will work with local emergency agency personnel to establish and confirm the list of residences who may need to be contacted in case of some emergencies at the FTB, the means to be used for contact, and the assignment of responsibility for maintenance of the contact list.

4.0 Notification Procedures

The top priority in case of imminent or actual dam failure is to warn and evacuate people in downstream areas. Large Figure 1 presents the notification procedures for an emergency involving threat of dam failure. Attachment A describes responsible persons and their responsibilities for notification, emergency operations and repairs, and post-emergency action. Section 6.0 describes emergency evacuation procedures.

Emergency notification procedures vary depending on the condition/s existent that prompt the notification and can be divided into three levels:

Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution.

Level 2 – Potential emergency if condition is sustained or allowed to progress; requires response plan.

Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Level 1, Level 2, and Level 3 conditions that could occur at the Tailings Basin are listed in Large Table 1 and Large Table 2.

4.1 Internal Notification Procedures

The notification procedures for Level 1 and Level 2 conditions are:

- the person first noticing a Level 1 or Level 2 condition will notify the *Operations Contact* and initiate responses and intensified monitoring
- the *Operations Contact* will notify the *Design Engineer* as appropriate

The notification procedure for Level 3 conditions are:

- the person first noticing a Level 3 condition will notify the General Manager, the *Operations Contact* and initiate responses immediately, and
- The *Operations Contact* will notify the *Design Engineer*.

4.2 External Notification Procedures

No external notification is required for Level 1 or 2 conditions. The notification procedure for a Level 3 condition is as follows:

- If the condition presents the threat of dam failure, the notification procedures shown in Large Figure 1 and the evacuation procedures presented in Section 6.0 will be implemented

- Once Level 3 actions are implemented, but in no case longer than 4 hours after the occurrence, the *Operations Contact* will notify the responsible regulatory personnel at the DNR and/or Minnesota Pollution Control Agency (as appropriate to permit coverage and compliance requirements)

- Notification will occur first via telephone, with follow-up E-mail or other written correspondence to document initial and any follow-up telephone conversations

In the event of an emergency situation resulting from actual or potentially imminent dam failure, the *Operations Contact* will also initiate evacuation procedures as described in Section 6.0.

Copies of this FTB Contingency Action Plan and the plant-wide Emergency Action Plan shall be kept in the office of the *Operations Contact*.

5.0 Emergency Mobilization Procedures

All those involved in response, after first having communicated with the appropriate parties, should consider two types of actions as first steps in the response, with respect to the protection of human life and health, environment and property:

- What can be done to prevent the situation from worsening?
- What can be done to reduce the consequences of the impending or actual failure?

Any such action must be presented to the *Operations Contact* who will decide on its implementation in consultation with the *Design Engineer*. Most obvious mobilization requirements associated with Level 2 and Level 3 conditions are detailed in Table 5-1.

Table 5-1 FTB Mobilization Plan for Level 2 or 3 Situations

Component Failure	Level 2 Condition	Level 3 Condition
Failure of a dam (during construction and/or routine operations).	Planning for mobilization of earthmoving equipment, pumps and pipelines, as well as lowering of the pond level may be necessary, after all communications are carried out.	Immediate mobilization of earthmoving equipment, pumps, pipelines, power generator(s) available at site locations, and lights, will most likely be necessary. Immediate lowering of the pond level will typically be necessary.
Failure of a pump station.	After the repair work is initiated, plan for mobilization of pumping equipment if the timing for repairs would affect the pumping needs.	Immediate mobilization of pumping equipment and, if required, the availability of a power generator may be necessary.
Failure of a pipeline.	Initiate pipe or pipe section replacement.	Initiate chain of communications after initiating pipe or pipe section replacement.
Localized power failure.	Identify systems affected. Prepare for cessation of tailings deposition if power outage exceeds 24 hours.	Identify systems affected. Cease tailings deposition if power outage exceeds 24 hours.
Regional power failure.	No action required. FTB operations cease in absence of power.	No action required. FTB operations cease in absence of power.

In conjunction with Level 2 and Level 3 Conditions it will be the responsibility of the *Operations Contact* to compile a list of the specific equipment needs, size/type, source (company, name, contact information), and availability to respond to component failure. The list shall be populated prior to the initiation of basin operations and be reviewed and updated on an annual basis thereafter. This is so that a timely response can be made in the event that emergency mobilization is required. For emergency response equipment that does not have local 24-hour 7-day-per-week availability, provisions shall be made for permanent on-site stationing of the equipment. Primary emergency response equipment will typically consist of on-site earthwork equipment, mobile pumping systems and supplementary piping and power supply, and mobile/emergency lighting carts with power supply.

6.0 Emergency Evacuation Procedures

During operations, personnel will be on-site 24 hours a day, 7 days per week. Personnel will therefore be able to review conditions and monitor for changing conditions. Additionally, monitoring instrumentation is planned to be automated by a remote monitoring system, which includes thresholds and automated alarms data trends toward or falls outside of pre-established thresholds.

In the event of a failure of the FTB dam, residences located between the FTB and the Partridge River could be flooded. The Dam Break Analysis (Attachment H of this Management Plan) presents an inundation map and describes approximate floodwave travel times. The Dam Break Analysis indicates that there would be adequate time to provide emergency warning. There is some chance that a problem may not be identified, recognized, or responded to in a timely manner. Therefore, any early warning signs will be treated with the highest level of priority. If evacuation notices are given, it will be understood that the notice is at minimum due to a prudent level of caution and those potentially affected will be instructed to evacuate without delay.

A list of residences and businesses having the potential to be impacted by a dam break will be assembles and attached to this CAP prior to the start of FTB operations. As noted previously, PolyMet will work with local emergency agency personnel to establish and confirm the list of residences who may need to be contacted, and the means to be used for contact.

Revision History

Date	Version	Description
10/31/2011	1	Initial release
12/07/2012	2	Dam Break Analysis results incorporated by reference. FTB Dam Failure Notification Flowchart placeholder added. Outline expanded for development during DNR Dam Safety permitting.
04/12/2013	3	Revisions made to address DNR comments that not all situations are Emergencies. Hence, renamed document Contingency Action Plan and expanded on contingency actions to be implemented in response to various potential on-site conditions.
07/11/2016	4	Revisions made to submit for permitting and to include Notification Flowchart (Large Figure 1).
05/15/2017	5	Revisions made to add detail to Observational Method and Construction Phase warning signs and response actions.

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Large Table 1 Visual Warning Signs

Visual Warning Sign and Typical Location	Corresponding Change in Instrumentation Values (depending on location of movement relative to instrumentation)	Potential/Actual Consequences and Notification Procedures	Required Action
Signs of slowly forming erosion at toe and/or exterior face of slope.	No change in instrumentation values expected.	Potential dam instability and/or eventual dam failure if erosion continues. **Level 1 and Level 2 (see Table Notes)**	1) Discuss findings with the Design Engineer. 2) Be prepared to carry out one or more responses such as: a. Resolve source of erosion. b. Repair erosion area. c. Re-establish vegetation (modify design if recommended by Design Engineer). d. Re-inspect area on weekly basis until area is fully restored.
Soft toe condition or increased seepage at downstream slope or dam toe.	Potential increase in piezometric levels.	Internal erosion or slope slumping and eventual dam failure. **Level 1 and Level 2**	1) Discuss the findings with the Design Engineer. 2) Commission a field investigation program if so recommended. 3) Be prepared to carry out one or more responses including: a. Modification of basin pond operating procedures. b. Placement of graded overburden/buttress. c. Installation of drain system. d. Other design modifications if recommended by Design Engineer.
Cracks developing at dam crest or in slope.	Potential increase in piezometric levels. Potential slope deformation at inclinometers. Potential deflection in alignment monuments.	Deformation of dam structure that may lead to eventual dam failure. **Level 2; potential Level 3**	1) Increase frequency of dam walk-overs to daily until the problem is understood and addressed. 2) Seek advice from the Design Engineer. 3) Monitor crack development for increase in size, spacing, etc. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Modification of pond and/or basin operating procedures. b. Placement of graded overburden/buttress. c. Temporary cessation of operations. d. Reduction in pond elevation (planned or emergency).
High turbidity in dam seepage flow.	Potential increase in piezometric levels.	Internal erosion and eventual dam failure. **Level 2; potential Level 3**	1) Increase frequency of dam walk-overs to daily until the problem is understood and addressed. 2) Seek advice from the Design Engineer. 3) Take water samples for suspended solids determination if recommended by Design Engineer. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Modification of pond operating procedures. b. Placement of graded overburden/buttress. c. Installation of drain system. d. Reduction in pond elevation (pumping and/or cessation of tailing discharge).
Pond level close to or approaching overflow level; loss of freeboard.	Potential increase in piezometric levels.	Pond water discharge to environment via emergency overflow. **Level 1**	1) Confirm functionality of emergency overflow channel. 2) Immediately undertake actions to reduce the pond level (increased pumping to WWTP as necessary). 3) Temporarily discontinue seepage recovery. 4) Temporarily terminate tailings discharge to pond. 5) Consult with Design Engineer to identify other actions as needed.

Visual Warning Sign and Typical Location	Corresponding Change in Instrumentation Values (depending on location of movement relative to instrumentation)	Potential/Actual Consequences and Notification Procedures	Required Action
Any other change in seepage conditions.	Potential increase in piezometric levels.	Dam stability safety margin affected. **Level 2; potential Level 3**	1) Seek advice from the Design Engineer. 2) Initiate other responses as may be required (temporarily discontinue seepage recovery). 3) Reduction in pond elevation (pumping and/or cessation of tailing discharge).
Slumping, sliding or bulging of a dam slope or adjacent ground.	Potential increase in piezometric levels. Potential slope deformation at inclinometers. Potential deflection in alignment monuments.	Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Construct stabilizing berm per direction of the Design Engineer. 2) Initiate geotechnical evaluation per direction of the Design Engineer.
Boils observed downstream of dam.	Potential increase in piezometric levels.	An internal erosion failure possible, with potential breach of the dam. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Place granular filter buttress over the boils, if approved by the Design Engineer. 2) Initiate geotechnical evaluation per direction of the Design Engineer.
Water vortex within the pool and/or sinkhole on the tailings beach.	No change in instrumentation values expected.	An internal erosion failure in progress, with potential breach of the dam. **Level 2; potential Level 3**	As above (blue shaded box) and: 1) Check downstream of the dam area for increased and/or turbid seepage discharge. 2) Place granular filter buttress against any such areas, if approved by the Design Engineer. 3) Initiate geotechnical evaluation per direction of the design engineer.
Severe flood/intense rainstorm or rapid snowmelt resulting in extreme pond level.	Potential increase in piezometric levels.	Overtopping of dam and resulting erosion and over-steepening of the downstream slope, leading to dam failure. **Level 3**	1) Initiate chain of communications and ensure safety of people. 2) Confirm functionality of emergency overflow channel. 3) Stop discharge into the pond. 4) Lower pond by any practical means approved by the Design Engineer.

Notes for Notification Procedures:

Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution.

Level 2 – Potential emergency if condition is sustained or allowed to progress; requires response plan.

Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Large Table 2 Instrumentation Warning Signs

Instrument Type and Typical Location	Instrumentation Warning Sign	Corresponding Visual Changes (dependent on magnitude of movement)	Potential/Actual Consequences and Notification Procedures	Required Action
Piezometer (single or nested) – Located on Perimeter Dams/Slopes and on Cell Splitter Dams/Slope (ref. Instrumentation and Monitoring Plan for Piezometer Names and Locations)	Gradual or Sudden Increase in Water Level in One or More Piezometers, Above Threshold Action Levels (ref. Instrumentation and Monitoring Plan for Piezometer Reading Values – Predicted and Threshold)	1) Soft toe condition or increased seepage at downstream slope or dam toe. 2) Elevated pond level in basin. 3) Increased turbidity in seepage flows. 4) Boils observed downstream of dam.	1) Excessive seepage through dam and potential for dam breach. 2) An internal erosion failure possible, with potential breach of the dam. 3) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	1) Check the reading again; confirm instrumentation functionality. 2) Intensify reading frequency to daily. 3) Seek advice from the Design Engineer. 4) Commission a field investigation if so recommended. 5) Be prepared to carry out one or more responses including: a. Check downstream of the dam area for increased and/or turbid seepage discharge. b. Place granular filter buttress against any such areas, if approved by the Design Engineer. c. Initiate geotechnical evaluation per direction of the design engineer. d. Modify pond and/or basin operating procedures. e. Temporary cease operations/stop discharge into the pond. f. Lower pond by any practical means approved by the Design Engineer.
Inclinometer – Located on Perimeter Dams/Slopes and on Cell Splitter Dams/Slopes (ref. Instrumentation and Monitoring Plan for Inclinometer Names and Locations)	Gradual or Sudden Movement in Horizontal Direction in One or More Inclinometers (ref. Instrumentation and Monitoring Plan for Inclinometer Reading Values – Predicted and Threshold)	1) Cracks developing at dam crest or in slope. 2) Slumping, sliding or bulging of a dam slope or adjacent ground.	1) Deformation of dam structure that may lead to eventual dam failure. 2) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	As above (blue shaded box).
Survey Monument – Located on Crest of Perimeter Dams and on Crest of Cell Splitter Dams	Gradual or Sudden Movement in Horizontal and/or Vertical Direction in One or More Survey Monuments	1) Cracks developing at dam crest or in slope. 2) Slumping, sliding or bulging of a dam slope or adjacent ground.	1) Deformation of dam structure that may lead to eventual dam failure. 2) Catastrophic dam breach resulting in release of water or water and liquefied tailings. **Level 1, 2 or 3 (situation dependent)**	As above (blue shaded box).

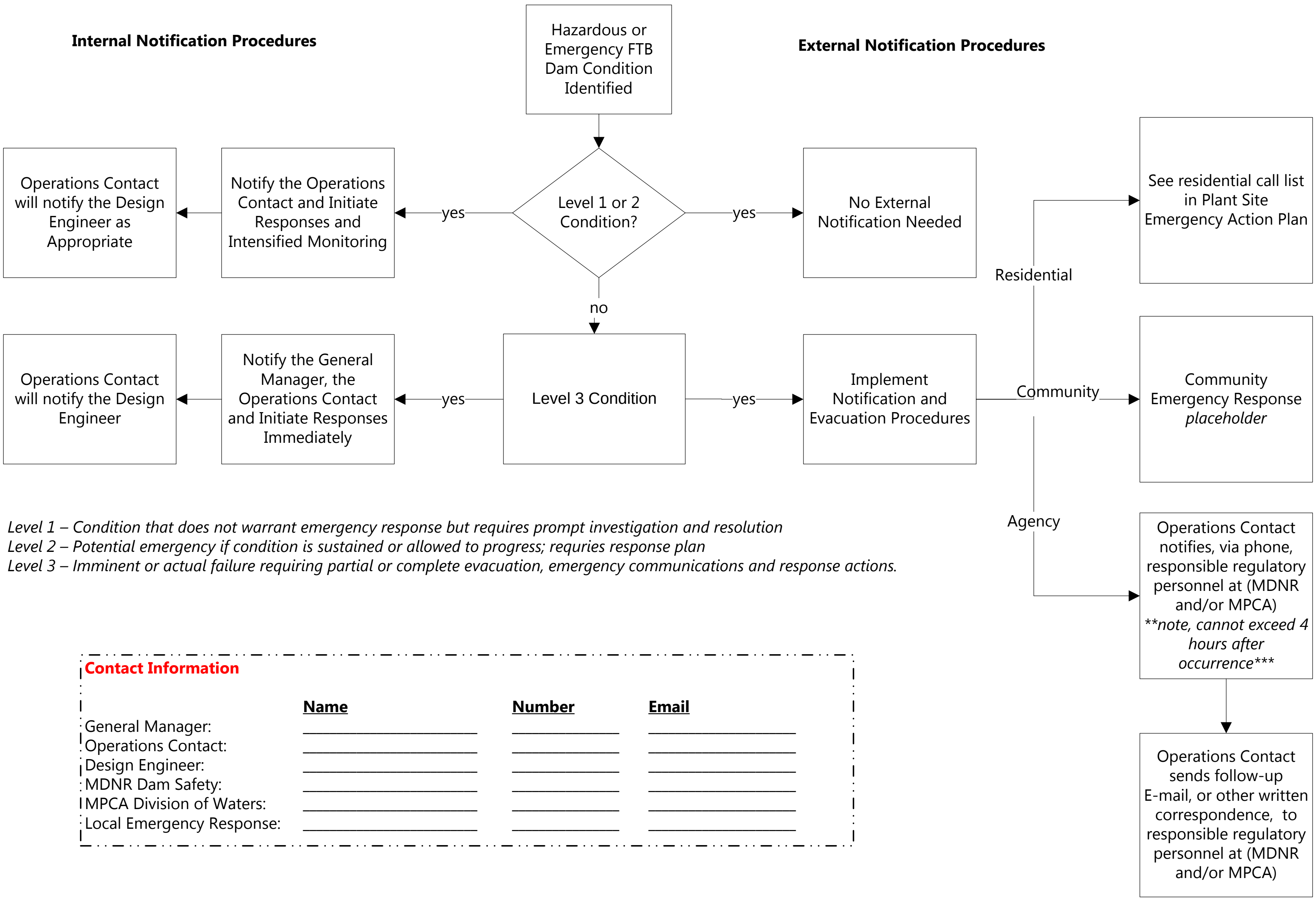
Notes for Notification Procedures:

Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution.

Level 2 – Potential emergency if condition is sustained or allowed to progress; requires response plan.

Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Large Figures



Level 1 – Condition that does not warrant emergency response but requires prompt investigation and resolution
Level 2 – Potential emergency if condition is sustained or allowed to progress; requries response plan
Level 3 – Imminent or actual failure requiring partial or complete evacuation, emergency communications and response actions.

Contact Information

	Name	Number	Email
General Manager:	____________	________	____________
Operations Contact:	____________	________	____________
Design Engineer:	____________	________	____________
MDNR Dam Safety:	____________	________	____________
MPCA Division of Waters:	____________	________	____________
Local Emergency Response:	____________	________	____________

Large Figure 1 Notification Procedures for an Emergency Involving Threat of FTB Dam Failure

Attachment G

Template Construction Specifications

Technical Specifications for Permitting
NorthMet Flotation Tailings Basin

Polymet Mining Corporation
NorthMet
Hoyt Lakes, MN

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SECTION 01010

SUMMARY OF WORK

PART 1 GENERAL

1.01 SPECIFICATIONS

A. The format of these Specifications is based upon the CSI MASTERFORMAT; however differences in format and subject matter location do exist. These Specifications are written in imperative and streamlined form. This imperative language is directed to the Contractor, unless specifically noted otherwise. It is solely the Contractor's responsibility to thoroughly read and understand these Specifications and request written clarification of those portions which are unclear.

B. Division of the Work as made in these Specifications is for the purpose of specifying and describing work which is to be completed. There has been no attempt to make a classification according to trade or agreements which may exist between Contractor, Subcontractors, or trade unions or other organizations. Such division and classification of the Work shall be solely the Contractor's responsibility.

1.02 EXISTING SITE CONDITIONS AND USES

A. The Project Site is located at Poly Met Mining Inc.'s NorthMet Project near Hoyt Lakes, Minnesota.

B. The Flotation Tailings Basin (FTB) is located northeast of the processing plant area and immediately east of, and adjacent to, Cell 2W.

1.03 WORK COVERED BY SPECIFICATIONS

A. The overall scope of the Work which is more fully described in these Specifications includes, but is not necessarily limited to, furnishing all labor, tools, equipment, and materials necessary to:

1. Mobilize and demobilize labor, equipment, materials, and temporary facilities.
2. Obtain any necessary permits prior to performing the Work to the extent that such permits have not previously and/or are not planned to be obtained by Owner.
3. Site preparation of all dam construction areas and borrow areas (including surface preparation and stripping topsoil).
4. Protect all existing instrumentation and Project Site features, which include but are not limited to existing above ground pipelines, underground pipelines, pipeline discharge locations, electric utilities, inclinometers, piezometers, monitoring wells, and survey benchmarks.
5. Excavate LTVSMC Coarse Tailings from areas shown on the Drawings, then place and compact LTVSMC Coarse Tailings to create proposed dams and access roads.
6. Excavate, transport and place off-site borrow materials required for dam construction.
7. Place Bentonite amended cover on exterior of all proposed dams and final beaches within the Flotation Tailings Basin.
8. Construct North and South Buttresses as shown on the Drawings.
9. Construct Tailings Discharge and Return Water Pipelines as shown on the Drawings.
10. Construct Emergency Overflow as shown on the Drawings.

11. Construct Drainage Swale as shown on the Drawings.
12. Fabricate and Install Diffuser Raft and Transfer Pump Raft.
13. Refurbish and return Return Water Barge to service.
14. Perform permanent site restoration of all areas disturbed by the Work.
15. Submit construction documentation as specified.

B. It is the intent of these Specifications to cover all aspects of the Project except items that may specifically be excluded as described herein. Should there be some item or items not shown on the Drawings or not described in these Specifications which are required for the Work, those items and the furnishing of all labor, materials, and equipment shall be considered incidental to the Work and no additional compensation will be provided.

C. The Work includes the furnishing of all labor, equipment, tools, machinery, materials, and other items required for the construction of a complete Project as specified and shown on the Drawings. Equipment furnished shall be in safe operating condition and of adequate size, capacity, and condition for the performance of the Work. Contractor shall obtain all measurements necessary for the Work and shall be responsible for establishing all dimensions, levels, and layout of the Work.

D. Contractor shall be solely responsible for the coordination of its activities with regard to the Project and the Owner, and for the coordination and its Subcontractor's activities with regard to the Project and the Owner.

E. Contractor shall utilize material sources designated by Owner and shall develop necessary access roads to transport material sources to the Project Site.

F. Contractor shall provide soil testing as required in Section 02220.

1.04 WORK BY OWNER OR OTHERS

A. Owner will provide bench-mark and site coordinate information necessary for construction of the Work. Once provided, it is Contractor's responsibility to protect the bench-marks. Contractor shall request benchmark and site coordinate information from Owner a minimum of five days prior to the time when such information is needed.

B. Owner will provide electrical service (voltage phase and KVA TBD) and connection to the Contractor's trailer.

C. Others will construct the FTB Seepage Containment and Stream Augmentation Systems. Such systems are separate from/not integral to FTB construction and operations and their construction is excluded from this Scope of Work. It shall be the Contractor's responsibility to integrate their Work and activities with that of others working on or adjacent to the FTB.

1.05 OWNER FURNISHED PRODUCTS

A. Owner will provide borrow sources for the construction of dams.

1.06 CONTRACTOR USE OF PREMISES

A. Definition of Project Site: The Project Site is defined as the area within the construction limits shown on Drawings to be provided to Contractor by Owner prior construction, plus a nearby material and equipment storage and staging area, the location of which will be designated by Owner. Contractor shall limit operations, including material and equipment storage, to within those boundaries. Any disturbance outside the construction limits shall be fully restored at Contractor's expense in accordance with Laws and Regulations. Contractor shall obtain pre-approval of Owner at all locations where Contractor uses land not included in the construction limits.

B. Hours of Operation: Working hours shall be set by Contractor, subject to approval by Owner.

C. Protection and Repair of Existing Facilities and Utilities: Contractor shall perform operations carefully and in such a manner as to protect existing facilities and utilities. Obstructions not shown on the Drawings may exist and shall be exposed by Contractor without damage. Contractor shall be responsible for damage to existing facilities and utilities resulting from Contractor's operations, and shall repair or replace damaged items to Owner's satisfaction. Groundwater monitoring wells shall be protected during construction unless directed otherwise by Owner.

D. Unfavorable Construction Conditions: When unfavorable weather, soil, drainage, or other unsuitable construction conditions exist, Contractor shall confine operations to work which will not be adversely affected by such conditions. No portion of the Work shall be constructed under conditions which would adversely affect the quality of the Work or the safety of workers, unless special means or precautions are taken to perform the Work in a proper, safe and satisfactory manner.

E. Survey Markers: Contractor shall conduct operations so as to preserve bench-marks, survey reference points, and stakes existing or established by Owner for the construction. Contractor will be charged the expense of repairing or replacing survey markers and shall be responsible for mistakes or lost time resulting from damage or destruction of survey markers due to Contractor's operations.

F. Environmental Protection: Contractor shall conduct operations so as to fully comply with all state required and project-specific environmental protection requirements including but not limited to surface water runoff control and water quality protection, fugitive dust emissions control and air quality protection, groundwater quality protection, and noise abatement.

PART 2 PRODUCTS [NOT USED]

PART 3 EXECUTION [NOT USED]

END OF SECTION 01010

SECTION 01200

MEETINGS

PART 1 GENERAL

1.01 PRECONSTRUCTION CONFERENCE

A. After Owner and Contractor have executed the Agreement, Owner will schedule a preconstruction conference at Project Site that shall be attended by Owner, Contractor, Engineer, Owner's On-site Representative, and others as appropriate. The meeting will be scheduled within twenty-eight (28) calendar days following formal agreement to Contract. The purpose of the meeting will be to ensure that all parties understand their responsibilities and the procedures that will be used to assure efficient completion of the Work.

B. Agenda items may include:

1. Distribution of Plans and Specifications.
2. Designation of responsible personnel for all parties, lines of communication, and lines of authority.
3. Scope of work and the anticipated schedule of operations.
4. Critical work sequencing.
5. Submittal and field test reporting procedures.
6. Record documents and reporting.
7. Project Site safety and security procedures.
8. List of major subcontractors.
9. Procedures for processing change orders.
10. Use of premises including equipment and material storage.
11. Major equipment deliveries.
12. Housekeeping procedures.
13. Other items for consideration during construction activities.

1.02 PROGRESS MEETINGS

A. Weekly progress meetings will be scheduled by the Owner’s On-Site Representative at a regular time mutually agreeable to by the Owner, Contractor, and Owner’s On-Site Representative. The Contractor shall attend these meetings and shall coordinate and require the attendance of subcontractors whose work may be in progress at the time or whose presence may be required for any purpose. Scheduling of required attendees shall meet with the approval of the Owner's On-Site Representative.

B. Following each meeting, the Owner’s On-Site Representative will prepare and distribute to Owner and Contractor copies of the minutes of the meeting. These will include a brief summary of the progress of the Work since the previous meeting.

C. The weekly meeting agenda will include at least the following:

1. Administrative/Purchasing issues.
2. Technical/Construction issues.
3. Design issues.
4. Schedule/Progress issues.
5. Project Site safety issues.
6. Status review of required submittals.

1.03 UNSCHEDULED MEETINGS

A. The Contractor shall attend other unscheduled meetings which may be reasonably requested by Owner's On-Site Representative or Owner to discuss unanticipated changes in the Work or conditions at the Project Site and which must be resolved before progression of work.

1.04 BASIS FOR COMPENSATION

A. The Contractor's cost for work under this Section shall be included in the Bid Price and no additional compensation will be provided.

PART 2 PRODUCTS [NOT USED]

PART 3 EXECUTION [NOT USED]

END OF SECTION 01200

SECTION 01300

SUBMITTALS

PART 1 GENERAL

1.01 GENERAL PROCEDURES

A. This Section stipulates the requirements for transmission of submittals from Contractor to Owner's On-Site Representative and actions taken by Owner's On-Site Representative regarding submittals.

B. Submittals shall be identified with the project name, name of submittal, and Specification Section for which the submittal is required.

C. Owner's On-Site Representative will accept submittals only from Contractor. Submittals from subcontractors, vendors, suppliers, or others will be returned without review or action.

D. Owner's On-Site Representative will accept only those submittals required by the Specifications. Unsolicited submittals will be returned without review or action.

E. All engineering data, regardless of origin, shall be stamped with the approval of the Contractor. The Contractor's stamp of approval will be a representation to the Owner and Owner's On-Site Representative that the Contractor has assumed full responsibility for determining and verifying all quantities, dimensions, field construction criteria, materials, catalog numbers, and similar data, and that he has reviewed or coordinated each submittal with the requirements of the Specifications.

F. All engineering data shall be identified by use of the nomenclature established by the Plans and Specifications. Equipment drawings shall have the equipment name and number clearly displayed. Material drawings shall have the structure name and structure number (when applicable) clearly displayed.

1.02 CORRESPONDENCE

A. Correspondence forwarding engineering data shall be addressed to the Owner and Owner’s On-site Representative as follows.

To the Owner:
Poly Met Mining Inc.
NorthMet Project
P.O. Box 475; County Road 666
Hoyt Lakes, MN 55750-0475
Attention: **Mr. Jim Tieberg**

To the Owner’s On-site Representative:
c/o _________________
Poly Met Mining Inc.
NorthMet Project
P.O. Box 475; County Road 666
Hoyt Lakes, MN 55750-0475
____

Copies to the Owner:
Poly Met Mining Inc.
Attention: **_TBD_______________**
____

Copies to the Project Engineer:
TBD

B. A letter of transmittal shall accompany all submittals of engineering data and shall include a list of the data included in the transmittal. Lists shall include manufacturer's drawing numbers identified with the corresponding project equipment or structure nomenclature as applicable. The letter shall be identified by the project name.

1.03 PROGRESS SCHEDULE

A. Submit an estimated progress schedule and a finalized progress schedule in accordance with the requirements of the General Conditions.

B. Update the schedule on a weekly basis for presentation, discussion, and distribution at the weekly progress meeting.

1.04 SCHEDULE OF VALUES AND PROGRESS PAYMENT SCHEDULE

A. Submit a schedule of values for the Work. The schedule shall be broken out as follows for each Bid Price item and each Unit Adjustment Price item on the Bid Form:

1. Item description.
2. Unit of measure upon which the item is based.
3. Contractor’s estimated quantity (number of units upon which the total price for the item is based: for Unit Adjustment Price items, enter 0 for quantity).
4. Total unit price, including materials, equipment, labor, overhead, and profit (for Unit Adjustment Prices, shall be same unit price as on the Bid Form).
5. Extension (total price for the item, calculated by multiplying the number of units by the total unit price).

B. Submit a schedule of anticipated progress payment requests with the schedule of values. The proposed progress payment schedule shall be based on monthly or target-percentage invoicing for Work completed, and shall be closely coordinated with the schedule of values. Resubmit a revised schedule of anticipated progress payment requests whenever the progress schedule is updated or revised. Update the payment schedule each time an actual payment request varies more than 10 percent from the schedule. The progress payment schedule shall take into consideration retainage if applicable.

C. The schedule of values and anticipated progress payment schedule shall be subject to review and approval by Owner. If, in the opinion of Owner, the schedules do not contain sufficient detail or appear to be unbalanced, the Owner may require Contractor to revise and resubmit the schedules and/or provide documentation to justify Contractor's distribution. Contractor shall correct such deficiencies and resubmit the schedules.

1.05 REVIEW OF SUBMITTALS

A. The Owner's On-Site Representative's review of engineering data will cover only general conformity of the data to the Specifications, external connections, and interfaces with equipment and materials furnished under separate specifications. The Owner's On-Site Representative's review does not indicate a thorough review of all dimensions, quantities, and details of the equipment, material, device, or item indicated or the accuracy of the information or documentation submitted; nor shall review or approval by the Owner's On-Site Representative be construed as relieving the Contractor from any and all responsibility for errors or deviations from the requirements of drawings and specifications.

1.06 SUBMITTAL FOR INFORMATION OR DOCUMENTATION

A. Submit 2 copies to Owner's On-Site Representative and 2 copies to Owner.

B. Unless otherwise specified, submittal shall be made at least 1 day before the subject of the submittal is to be incorporated into the Work.

C. Submittal is for the purpose of formal verification that the subject of the submittal conforms to the requirements of the Specifications, for formal documentation of the Work, or both.

D. No action is required by Owner or Owner's On-Site Representative. Owner's On-Site Representative will generally notify Contractor if deficiencies are identified; however Contractor is solely responsible for ensuring that the subject of the submittal conforms to the requirements of the Specifications.

1.07 SUBMITTAL FOR REVIEW

A. Submit 2 copies to the Owner's On-Site Representative.

B. Unless otherwise specified, submittal shall be made at least 10 days before the subject of the submittal is to be incorporated into the Work. Owner's On-Site Representative will respond within 5 days from receipt of submittal.

C. Submittal is for the purpose of providing opportunity to Owner's On-Site Representative for review and comment on the subject of the submittal.

D. Owner's On-Site Representative will respond to the submittal either with a list of comments or indicating no comments.

E. If Owner's On-Site Representative's comments indicate a deficiency with respect to the requirement of the Specifications, Contractor shall amend the submittal and resubmit. Owner's On-Site Representative will again respond to the resubmittal.

F. If Owner's On-Site Representative's comments are in regards to an issue which is based on Contractor's discretion, Contractor shall furnish additional information, provide justification, and otherwise cooperate in addressing and resolving Owner's On-Site Representative's comments.

G. Contractor shall remain solely responsible for ensuring that the subject of the submittal conforms to the requirements of the Specifications.

1.08 RECORD DOCUMENTS

A. Submit record documents prior to Substantial Completion.

B. Record documents shall accurately reflect the as-constructed condition.

1.09 WARRANTY AND GUARANTEE CERTIFICATES

A. Submit warranty and guarantee certificates prior to Substantial Completion.

B. Warrantee and guarantee certificates shall be signed by Contractor, Installer, Manufacturer, and others as required by the Specifications.

1.10 BASIS FOR COMPENSATION

A. The Contractor's cost for work under this Section shall be included in the Bid Price and no additional compensation will be provided.

PART 2 PRODUCTS [NOT USED]

PART 3 EXECUTION [NOT USED]

END OF SECTION 01300

SECTION 01400

QUALITY CONTROL

PART 1 GENERAL

1.01 FIELD QUALITY CONTROL

A. Complete construction quality control for the Work as described in these Specifications, unless specified as the responsibility of the Owner.

B. Retain an independent registered land surveyor licensed in the State of Minnesota for performing quality control on line and grade of the Work. The quality control survey data shall be available for review at all times by Owner and Owner's On-Site Representative.

C. Retain an independent soil and material testing firm(s) for performing the quality control testing. The quality control data shall be available for review at all times by Owner and Owner's On-Site Representative.

D. All quality control test results will be used by Owner to demonstrate compliance with Project permit requirements. Tests shall be performed and samples shall be collected at random locations such that the test results may be considered representative. Testing shall be performed or samples collected at specific locations determined by Owner's On-Site Representative, if requested.

E. Owner's On-Site Representative shall have full authority to direct testing activities of Contractor-retained independent soil and material testing firm (s) including, but not limited to: selecting locations and materials for testing, reviewing all raw and final test data, and conducting audits of testing company field and in-laboratory testing procedures and equipment. In cases where testing firm personnel violate Project Site safety procedures or otherwise appear to lack the competence required to fully perform the required testing, Owner's On-Site Representative with concurrence of Owner shall also have the authority to dismiss testing firm personnel from the Project Site.

1.02 SUBMITTALS

A. Submit for approval name(s) and qualifications of Contractor's independent registered land surveyor and Contractor's independent soil and material testing firm(s).

B. Submit for information on a daily basis, the following information:

1. Survey data for each day that survey work is performed.
2. Soil compaction data for each day that soil compaction data is collected.
3. Other soil and material test data daily as it is available.

C. Submit for documentation a tabulation of all results of survey work performed. This submittal shall be made prior to substantial completion. The tabulation shall be signed by the registered land surveyor. The tabulation shall contain the following information for each survey location:

1. A unique identification number.
2. Coordinates.

3. Elevation of the finished surface of each material (e.g. top of LTVSMC Coarse Tailings for dam and access road construction; top of bentonite amended cover on exterior of dams and interior beaches; top of Tailings Discharge and Return Water Pipelines; existing surface and finished surface for stockpiled construction materials; other as needed).

D. Submit for documentation the results of all soil compaction and other material testing performed. Test results shall be compiled in a report-format and submitted prior to substantial completion of Work.

E. Submit for approval supplier information for bentonite to be used for bentonite augmentation of tailings. Submittal shall include:

1. Supplier's business name and address.
2. Source location of bentonite.
3. Bentonite packaging and delivery methods.
4. Bentonite handling and storage methods upon receipt on site.

1.03 SURVEY VERIFICATION REQUIREMENTS

A. Contractor's independent registered land surveyor shall verify that elevations, grades, slopes, and material thickness constructed by Contractor are within the tolerances specified in Section 02220. Material thickness shall be determined from the elevation difference between shots taken at the same coordinate location. On slopes, the surveyed vertical thickness shall be adjusted by calculating the thickness perpendicular to the slope for presentation in the submittals. The surveying work shall include determining elevations at specific locations on a matrix of survey points as described below.

1. Dams: For elevation, grade, and material thickness verification, survey shots shall be taken on the top of LTVSMC Coarse Tailings and top of Bentonite Amended Cover. The toe, midpoint, and top of each dam shall be surveyed at 100-foot intervals along the dam alignment.
2. Bentonite Amended Cover: For elevation, grade, and material thickness verification, survey shots shall be taken on the top of each layer (i.e. top of LTVSMC/Flotation Tailings, top of bentonite-tailings mix layer, and top of cover layer) of the Bentonite Amended Cover at 100' grid spacing.
3. Buttresses: For elevation and grade verification, survey shots shall be taken of the final grade of each buttress. The toe, midpoint, and top of each buttress shall be surveyed at 100-foot intervals along the buttress alignment.
4. Tailings Discharge and Return Water Pipelines: For elevation and grade verification, survey shots shall be taken on the top-of-pipe elevations at a maximum of 50-foot intervals (lineal) in the areas where pipe has little or no significant change in elevation, and at changes in grade. Coordinate the location of these shots with Owner or Owner's On-Site Representative.

1.04 CONTRACTOR TESTING RESPONSIBILITIES

A. Retain an independent testing laboratory(s).

B. Perform all the testing requirements described in these Technical Specifications unless noted as the responsibility of the Owner.

1.05 OWNER TESTING RESPONSIBILITIES

A. Contractor shall provide material samples, and/or coordinate with and provide access to work areas for Owner's On-Site Representative and Owner's independent testing firms for sampling and/or testing.

B. Work failing to meet Specifications shall be repaired at Contractor's expense. Owner will perform additional testing after repairs are completed. The expense of retesting may be charged to Contractor. Contractor may ask to review results of Owner's testing during construction.

1.06 PRESENTATION OF DATA

A. All survey and compaction test data shall be summarized and submitted to Owner or Owner's On-Site Representative on a daily basis. Failure to submit data on a daily basis shall be cause for Owner to suspend Contractor's operations until submittals are made current. Contractor shall not be entitled to additional compensation for any suspension of operations ordered by Owner due to Contractor's failure to submit data on a daily basis.

B. Survey data shall be summarized in a tabular format listing each survey point by unique identification number, coordinate, elevation, difference from previous elevation (material thickness), and required material thickness as appropriate. Required material thickness is measured perpendicular to the slope. Material thickness based upon survey shots at the same coordinate location shall be corrected to the perpendicular-to-slope thickness.

C. Compaction test data shall be summarized in a tabular format listing each compaction test by unique identification number, horizontal coordinate, elevation (within 0.5 foot vertical of actual location), reference proctor, in-place moisture content, dry density, percent compaction, and compaction specification requirement.

1.07 BASIS FOR COMPENSATION

A. The Contractor's cost for work under this Section shall be included in the Bid Price and no additional compensation will be provided.

PART 2 PRODUCTS [NOT USED]

PART 3 EXECUTION [NOT USED]

END OF SECTION 01400

SECTION 01510

TEMPORARY UTILITIES

PART 1 GENERAL

1.01 TEMPORARY UTILITIES

A. Water: Potable water is not available at the Project Site. Make all arrangements necessary to provide water for potable consumption. Water used for construction purposes need not be potable but must meet all applicable surface water quality criteria. Non-potable water will be available from an on-site location designated by Owner. The costs of furnishing potable and other water and water usage shall be included in the Bid Price and no additional compensation will be provided.

B. Sanitary Facilities: Contractor shall provide sanitary facilities for use by Contractor's employees, subcontractors, suppliers, Owner's On-Site Representative, Owner and all other persons to be working on the Project Site. Sanitary facilities shall, as a minimum, comply with the requirements of applicable Laws and Regulations for temporary sanitary facilities and shall be emptied and sanitized at the frequency needed to be maintained in a clean and useable condition. Sanitary facilities shall be maintained until Substantial Completion unless earlier removal is approved by Owner or Owner's On-Site Representative. The cost of sanitary facilities shall be included in the Bid Price and no additional compensation will be provided.

C. Electricity: Furnish portable electric power generators necessary for construction of the Work. Should Contractor need electric power service for Contractor's purposes, it shall be the Contractor's responsibility to arrange for and pay for such service. The cost shall be included in the Bid Price and no additional compensation will be provided. Owner will provide access to electric service connection at the location of the Contractor's office location, and provide electric service to the Office Trailer furnished for Owner's On-Site Representative's use.

D. Telephone and Fax: Phone service is not readily available at the Project Site. Cellular phone service may not be available throughout the entire Project Site. Make arrangements for the Contractor's phone and fax service during the Project. The cost of Contractor's telephone service, fax service, and usage, shall be included in the Bid Price and no additional compensation will be provided.

E. Fire Protection: Make all arrangements necessary to ensure that the Project Site and the Work have adequate fire protection services throughout the duration of the Work. Any special fees or charges imposed by governmental units or other organization to provide such services shall be paid by Contractor. The cost of fire protection shall be included in the Bid Price and no additional compensation will be provided.

1.02 OFFICE TRAILER

A. Contractor shall furnish office trailer space for use by Owner and Owner's On-Site Representative. The space for Owner's On-Site Representative shall have a minimum of 120 square feet of floor area, and at minimum be equipped with a desk, a table, and two chairs. The space shall be furnished with electrical service, operable lighting, heat, and air conditioning. This office space may be located in a trailer with other facilities but must be accessible to Owner and Owner's On-Site Representative at all times and must be secured by a separation wall and lockable door. Owner will provide 240 volt, 110 AMP service to the trailer and will make and disconnect electrical service as requested by the Contractor.

1.03 BASIS FOR COMPENSATION

A. The Contractor's cost for work under this Section shall be included in the Bid Price and no additional compensation will be provided.

PART 2 PRODUCTS [NOT USED]

PART 3 EXECUTION [NOT USED]

END OF SECTION 01510

SECTION 01560
STORM WATER EROSION PREVENTION AND SEDIMENT AND DUST CONTROL

PART 1 GENERAL

1.01 DESCRIPTION

A. This section covers construction of all stormwater erosion prevention and sediment controls as needed to conduct the Work in accordance with the Technical Specifications, Drawings, Agreement, and in compliance with local, county, state, federal and other jurisdictional rules and regulations.

B. This work consists of: 1) managing storm water runoff and project related water discharges in order to minimize sediment pollution during construction and over the life of the contract and 2) managing the discharges as set forth in any applicable regulatory agency permit. The work includes furnishing, installing, maintaining and utilizing storm water best management practices and any work specified in conjunction therewith as well as removing temporary sediment control devices when no longer necessary.

C. Control dust generation on access roads to the Project Site and within construction limits. Comply with requirements of project-specific Air Quality Management Plans/Fugitive Emissions Control Plans.

1.02 BASIS FOR COMPENSATION

A. The Contractor’s cost for work under this Section shall be included in the Bid Price and no additional compensation will be provided.

1.03 REFERENCES

A. Protecting Water Quality in Urban Areas, MPCA 2000.

B. Stormwater Management for Construction Activities, EPA 1992.

C. Developing Pollution Prevention Plans and Best Management Practices, EPA 1992.

D. Erosion Control Handbook, Mn/DOT 2006.

E. Minnesota Stormwater Manual, Version 2, January 2008.

F. Stormwater and Wetlands: Planning Evaluation Guidelines, MPCA 1997.

G. Construction Stormwater Pollution Prevention Plan (SWPPP) – NorthMet Project Plant Site, Barr 2016.

PART 2 PRODUCTS

2.01 MATERIALS

A. Water used for dust control may be obtained from an on-site location designated by Owner.

B. Acceptable temporary erosion control devices include, but are not necessarily limited to, silt fence, straw and hay bales, mulch, geotextiles, and vegetative cover.

2.02 EQUIPMENT

A. Water tank trucks equipped with water cannon capable of delivering water through either front or rear-mounted nozzles. Tank trucks shall be of sufficient size and mobility and carry a sufficient quantity of water to control dust generated by Contractor's activities.

PART 3 EXECUTION

3.01 STORM WATER SEDIMENT AND EROSION CONTROL

A. The Owner is responsible for obtaining the MPCA General Stormwater Construction Permit (MNR 100001) for authorization to discharge storm water associated with the project construction activity under the National Pollutant Discharge Elimination System (NPDES) program and providing a copy of the permit to the Contractor prior to beginning construction activities at the Project site. The Contractor will be required to co-sign the MPCA Stormwater Permit Application and is jointly responsible for compliance with Parts II.B, Part II.C, and Part IV of the MPCA Stormwater Construction Permit (MNR 100001).

B. The Owner is responsible for preparing the Storm Water Pollution Prevention Plan (SWPPP) required under the General Stormwater Construction Permit (MNR 100001) and providing a copy of the SWPPP to the Contractor prior to beginning construction activities at the Project Site.

C. The Owner is responsible for coordinating and obtaining any City, Town, or County permits.

D. The Contractor is responsible for conducting all construction activities in full compliance with the applicable requirements of the MPCA General Stormwater Construction Permit (MNR 100001), the SWPPP and any additional requirements that may be contained in any City, Town or County permits. The Owner will provide the Contractor with copies of all relevant permits and the SWPPP prior to the start of construction activities.

E. The Contractor is responsible for compliance with all requirements specified in Section 3.01 D until construction is complete, and the Project Site has undergone final stabilization. Once the Owner is satisfied that these conditions have been met, the Owner will prepare and submit the Notice of Termination (NOT) to the MPCA.

F. Install erosion control devices and materials at locations as directed by Owner or Owner's On-Site Representative where soil erosion at the Project Site may occur due to Contractor's activities.

G. Install temporary erosion control devices during the progress of the work and maintain them until permanent erosion control (turf establishment, aggregate surfacing, etc.) has been established.

H. Strictly follow all additional requirements of Owner's SWPPP (to be provided by Owner under separate cover).

3.02 EROSION PREVENTION AND SEDIMENT CONTROL

A. The Contractor has responsibility for charge and care of the Project and shall take necessary precautions against injury or damage to the Project by action of the elements. In addition, the Contractor shall take necessary precautions to prevent off site damage resulting from work conducted on the Project or Project related storm water runoff.

B. The Contractor is responsible for preventing or minimizing sediment loss from the Project by directing storm water runoff to constructed ponds and sediment traps as well as installing temporary sediment control devices in drainage locations where runoff can leave the Project limits and/or enter into environmentally sensitive areas. The Contractor shall schedule, construct and/or install temporary sediment control and storm water management measures as required by the Contract and as stated in the permits required for the Project.

C. The Contractor shall install temporary storm water management and sediment control devices in conformity with the details, typical sections, and elevation controls shown in the Drawings. The actual installation location of temporary storm water management and sediment control devices may be adjusted from that indicated in the Plan to better accommodate the actual field conditions and increase the effectiveness of a device.

D. Sediment control measures must be installed down gradient prior to or in conjunction with soil disturbing activities. The Contractor shall schedule, install and maintain temporary sediment control measures as an ongoing effort on a site-by-site basis over the life of the Contract. The Contractor is responsible for minimizing the potential for sedimentation after temporary sediment control devices have been installed by implementing a good quality erosion control program and staging construction as needed.

E. The Contractor shall schedule and phase construction in critical resource areas to the best of his ability in order to minimize the potential of sediment entering into a critical resource. Critical resources include but are not limited to, protected wetlands, surface waters, trout streams, Special Waters, impaired waters, rivers, and endangered species habitat. Measures to minimize sediment potential include practices such as hand clearing and grubbing, limited bare soil exposure time, and immediate final establishment of vegetation.

3.03 FUGITIVE DUST EMMISSIONS CONTROL

A. The Owner is responsible for obtaining air quality permits and preparing and complying with a Fugitive Dust Emissions Control Plan.

B. The Contractor is responsible for complying with the Fugitive Dust Emissions Control Plan. A copy of the Plan will be provided by the Owner.

C. Apply water to roads used by Contractor's equipment as directed by Owner or Owner's On-Site Representative to control dust generated by wind or by Contractor's vehicle traffic.

D. Apply water to ground surfaces within the construction limits as directed by Owner or Owner's On-Site Representative to control dust generated by Contractor's activities at the Project Site.

E. Strictly follow all additional requirements of Owner's Fugitive Emissions Control Plan (to be provided by Owner under separate cover).

END OF SECTION 01560

SECTION 02220

EXCAVATING, BACKFILLING, AND COMPACTING

PART 1 GENERAL

1.01 SECTION INCLUDES

A. All work included in this Section shall be performed in accordance with the following paragraphs, the General Requirements set forth in Division 1 of these Specifications, and the provisions of the other Contract Documents.

B. Work covered by this section includes furnishing all supervision, labor, materials, and equipment required to complete all earthwork at the Project Site to grade and lines shown on the Drawings including, but not limited to:

1. Material source development to obtain construction materials.
2. Surface preparation of existing ground for dam construction.
3. Placement and compaction of LTVSMC Coarse Tailings fill for dam construction.
4. Placement and compaction of Bentonite Amended Cover on exterior slopes and tops of dams of the Flotation Tailings Basin (FTB).
5. Placement and compaction of Bentonite Amended Cover on interior beaches of the FTB (at final reclamation only).
6. Placement of rock fill for buttress construction.
7. Placement of Rip-Rap at specified locations.
8. Placement of erosion protection material.
9. Controlling dust within work areas.

1.02 BASIS FOR COMPENSATION

A. Work included under this Section of these Specifications shall be included under the Bid Price.

1.03 SUBMITTALS

A. Submit soil testing and survey data as specified in Section 01400 – Quality Control.

B. LTVSMC Coarse Tailings and Granulated Bentonite Mixing and Placement Plan for Flotation Tailings Basin Dams. Placement Plan content to include but not be limited to:

1. LTVSMC Coarse Tailings and Granulated Bentonite Mixing Equipment, Procedures and QAQC to ensure uniform distribution of granulated bentonite with LTVSMC Coarse Tailings.
2. Pre-placement moisture conditioning plans (if any).
3. Material transport, spreading and compaction plan including equipment types and sequencing.

C. Flotation Tailings and Granulated Bentonite Mixing and Placement Plan for Flotation Tailings Basin Beaches (at final reclamation only at time requested by Owner).

D. Fugitive Dust Emissions Control Plan.

E. Granulated Bentonite manufacturer and supplier information and product specifications.

1.04 REFERENCES

A. American Society for Testing and Materials, Current Edition, hereafter referred to as ASTM.

B. Minnesota Department of Transportation Standard Specifications for Construction; 2014 Edition.

1.05 SEQUENCING AND SCHEDULING

A. Owner will evaluate results of the independent registered land surveyor's grade, slope, and material thickness verifications, collect material samples, and conduct field testing of materials throughout the duration of the Project, as described in Section 01400 of these Specifications. Do not proceed with subsequent operations until Owner or Owner's On-Site Representative has been notified, has been given opportunity to test or review the Contractor's test data, and has informed the Contractor of any test results that have been gathered.

B. The required completion date for the Work as described in these Contract Documents is specified elsewhere in these Contract Documents.

1.06 JOB CONDITIONS

A. It shall be solely the Contractor's responsibility to review available tests and reports, conduct additional tests, and otherwise determine to its own satisfaction the location and nature of all surface and subsurface features and the soil and water conditions that may be encountered. Owner's information on Project Site conditions may be reviewed at Owner's offices as scheduled with Owner.

B. Use of explosives will be permitted only at the times and locations approved by Owner.

C. Contractor shall be solely responsible for determining the means and methods for meeting the excavation and compaction requirements unless otherwise specified herein, except that compaction by flooding or puddling or other means that involve saturation or over-wetting the soil will not be permitted.

D. Provide all shoring, bracing, sheet piling, trench boxes, tie backs, and other measures required to perform all Work in accordance with Laws and Regulations. Specifically, all excavations shall conform to the requirements of OSHA set forth in 29 CFR 1926, Subpart P (Occupational Safety and Health Standards-Excavations).

E. Perform all work and maintain all equipment and personnel training in accordance with applicable provisions of Mine Safety and Health Administration (MSHA) Code of Federal Regulations – 30 CFR.

F. Comply with all Owner site-specific training and safety requirements (to be provided at time of Bidding).

1.07 QUALITY CONTROL

A. Contract a qualified soils testing firm, subject to approval by Owner, to conduct all sampling and testing of LTVSMC Coarse Tailings and other soil materials, as specified in these Specifications. The testing laboratory shall perform appropriate tests including sieve analysis, standard Proctor moisture-density testing an in-place moisture-density testing, and other tests as needed and/or specified.

B. Provide testing firm safe access to the Work and materials to be tested, in accordance with the following minimum provisions:

1. All fill material used shall be assessed on a regular basis by testing firm and Owner or Owner's On-Site Representative. Owner or Owner's On-Site Representative will reject all material which does not conform to the material specifications herein as required for each fill zone. Rejected material placed shall be removed at Contractor's expense.
2. Particle size samples shall be taken of fill materials at least twice for each material source and at least once for every 20,000 cubic yards of material placed.

C. Construction Testing: The following testing shall be conducted during construction:

1. Perform Standard Proctor moisture-density relationship analyses according to ASTM D 698 for at least two samples for each borrow source location.
2. Conduct soil classification according to ASTM D 2487 for at least two samples for each borrow source location.
3. Perform in-place moisture-density testing of LTVSMC Coarse Tailings according to ASTM D-2922 (nuclear densometer) at least once every lift at a minimum frequency of approximately 500 feet of dam length, and at least once a day when compaction activities are being performed.
4. Report whether each in-place moisture-density test passed or failed. If any test fails, report what actions were taken to correct material compaction, and what additional tests will be submitted to demonstrate acceptable (passed) compaction.
5. Only passing tests will be considered in the count of material tests taken, as specified above.

PART 2 PRODUCTS

2.01 GENERAL

A. All fill materials shall be free of wood, organic soils, large boulders, topsoil, snow, ice, and other unsuitable materials detrimental to performance of the dam.

2.02 MATERIALS AND MATERIAL SOURCES

A. LTVSMC Coarse Tailings: Materials conforming to the specifications for Dam Fill and Access Roads are located within designated Owner-supplied material sources. The general location of material sources are indicated on the Drawings as 'Borrow Area 1' through 'Borrow Area 4'. All materials used must be approved by Owner or Owner's On-Site Representative. If unsuitable Owner supplied materials are encountered, Contractor shall notify Owner and Owner will direct Contractor to alternate material source sites. The material for use as the dam fill shall consist of inorganic soil classified as a SM or SP as defined by the Unified Soil Classification System (USCS) from the proposed LTVSMC Coarse Tailings borrow areas (1 through 4).

B. Granulated Bentonite: A granulated Bentonite manufactured and supplied by Wyo-Ben Inc. American Colloid Company, Bentonite Performance Minerals LLC, or other Owner approved Bentonite product manufacturer and supplier.

C. Rip-Rap: Rip-Rap materials used shall be in accordance with Section 3601 of Minnesota Department of Transportation's 2014 Edition of Standard Specifications for Construction.

D. Area 5 Waste Rock: Area 5 Waste Rock shall be obtained from an on-site location designated by Owner. Materials shall be well graded to ensure no large voids are present after placement.

PART 3 EXECUTION

3.01 GENERAL

A. Locate and protect overhead and underground utilities, unless indicated otherwise on the Drawings.

B. Provide temporary controls such as diversions and dewatering equipment to prevent surface runoff from entering excavations and to remove ponded water from excavations. Maintain excavations in a dry and stable condition at all times.

C. Examine the area prior to and while performing earthwork. If unsatisfactory conditions occur during the Work do not proceed with the Work until satisfactory conditions have been established.

D. Determine the location and nature of all surface and subsurface obstacles, and the soil and water conditions that will be encountered during construction.

E. Institute and maintain, as directed by Owner, adequate dust control measures such as sprinkling, for all work areas, haul routes, and parking areas.

3.02 PREPARATION

A. Make arrangements to locate all existing utilities and underground facilities in the areas of the Work. Provide adequate means of protection for utilities and underground facilities that are to remain in place during earthwork operations.

B. Protect structures, fences, utilities, groundwater quality wells, piezometers, inclinometers, survey benchmarks, and other facilities from damage caused by settlement, lateral movement, undermining, washout and other hazards created by earthwork operations.

C. Control surface water sufficiently to permit placement of materials in dry conditions.

3.03 EXCAVATION

A. Construct excavations in accordance with applicable Laws and Regulations.

B. Excavate LTVSMC Coarse Tailings to the lines, elevations, slopes, and dimensions shown on the Drawings, or as necessary to complete the Work shown on the Drawings.

C. Materials excavated for construction that are unsuitable for reuse in the project shall be neatly stockpiled as described in Subpart 3.07.

3.04 MATERIAL PLACEMENT AND COMPACTION

A. Placement of fill materials will be performed over the existing ground as shown on the Drawings. Contractor shall keep Owner or Owner's On-Site Representative informed of its operations so that proper inspection and testing can be implemented. No fill material shall be placed on frozen subgrade unless approved by Owner or Owner's On-Site Representative.

B. Finish all areas to the lines and grades shown on the Drawings within the tolerances provided in this Specification and as approved by Owner or Owner's On-Site Representative. All finish grading shall be accomplished using normal mechanical construction equipment. The final constructed dam tops shall be covered and finished with materials shown on the Drawings.

C. Compact the placed Dam Fill and Access Road materials as shown on the Drawings. All fill shall be compacted in approximately horizontal lifts. Compact each layer to required density for each area classification.

D. Remove and replace fill that is too wet to permit compaction as specified.

E. Compact the material around structures with hand-compaction equipment which is designed for the compaction of backfill. Heavy equipment shall not be utilized for compaction within three (3) feet of structures, or a greater distance if necessitated by equipment or Project Site conditions.

F. Place and compact fill as specified on the Drawings to an in-place density as measured by ASTM D 698 (Standard Proctor) or ASTM D 1556 (Modified Proctor) as specified.

1. Dam and Access Road Fill: Uniformly compact the full depth of each lift with a vibratory compactor. Lifts shall not exceed 15 inches in loose thickness prior to compaction. Compact each lift to at least 95% of Standard Proctor maximum dry density. Moisture content shall be uniform throughout each lift and maintained throughout placement and compaction work.
2. Bentonite Amended Cover on FTB Dams: Bentonite Amended Cover construction on the exterior slopes and tops of the FTB dams shall be performed in accordance with the Owner-approved Placement Plan. At minimum the amended cover shall be placed to the final thickness specified, within the specified tolerances, and be uniformly compacted to the full depth of each lift. Lifts shall not exceed 12 inches in loose thickness prior to compaction. Compact each lift to at least 95% of Standard Proctor maximum dry density. Moisture content shall be uniform throughout each lift and maintained throughout placement and compaction work.
3. Bentonite Amended FTB Beach Area: Bentonite Amended FTB interior beach construction shall be performed in accordance with the Owner-approved Placement Plan. Flotation tailings and bentonite shall be mixed after bentonite injection such that the resulting bentonite-tailings mix contains a uniform bentonite content of 3 percent by weight. Compact the bentonite amended tailings to at least 90% of Standard Proctor maximum dry density or as otherwise approved by Engineer. Moisture content shall be uniform throughout each lift and maintained throughout placement and compaction work.

G. Place Waste Rock for buttress construction in uniform 24" lifts to the elevations shown on the Drawings.

H. Place Rip-Rap according to Section 2511.3 of Minnesota Department of Transportation's Standard Construction Specifications, 2014 Edition, and as shown on the Drawings.

3.05 PROJECT SITE GRADING

A. Grade intermediate slopes to minimize erosion potential. Maintain temporary erosion controls as necessary to minimize erosion. Maintain strict compliance with Stormwater Pollution Prevention Plan (SWPP).

B. Smooth-grade finished ground on exterior slopes of berms, along access roads, and other areas disturbed by Contractor's activities, to uniform levels or slopes between points where elevations are shown, or between such points and existing ground.

3.06 ACCESS ROAD CONSTRUCTION

A. Determine location of temporary access roads and ramps to each construction area, subject to approval by Owner.

B. Construct permanent access roads and ramps at the locations shown on the Drawings or as directed by Owner.

C. Access roads and ramps shall be crowned or sloped to promote surface water runoff.

3.07 DISPOSAL OF EXCAVATED SOIL

A. All excavated materials not incorporated into the construction shall be stockpiled in a location designated by Owner. All stockpiles left in place by Contractor shall be left in a neat condition and be appropriately graded so as to provide proper drainage, and appropriately vegetated or contained to prevent off-site sediment transport.

3.08 TOLERANCES

A. Construct the excavation and backfill work within the dimensional tolerances given below. Alignment, elevation and thickness tolerances are acceptable deviations from the elevations and material thicknesses shown on the Drawings. No compensation will be made for additional work or materials required by Contractor as a result of construction beyond specified elevations, thicknesses, or grades.

B. Alignment Tolerances – Horizontal Control:

1. Dam Centerline: +/- 0.2 foot.

2. Crest of Slope:
   a. Interior crest of slope: +/- 1.0 foot.
   b. Exterior crest of slope: +/- 1.0 foot at any location, +/- 0.5 foot average.

3. Toe of Slope:
   a. Interior toe slope: +/- 1.0 foot.

b. Exterior toe slope: +/- 1.0 foot at any location, +/- 0.5 foot average.

C. Elevation Tolerances – Vertical Control:

1. Crest of Dams: + 0.2 foot, -0.0 foot.

D. Thickness Tolerances (Bentonite Amended Cover on FTB dams and beaches)

1. Bentonite-Tailings Mix: -0.0 foot, +0.2 foot

E. Thickness Tolerances (Rip-Rap)

1. Rip-Rap: -0.0 foot, +0.5 foot

F. Granulated Bentonite Distribution within LTVSMC Coarse Tailings – Uniformly distributed to achieve average percent by weight specified at sampling and testing interval specified.

G. Hydraulic Conductivity – Geometric mean hydraulic conductivity of bentonite-amended LTVSMC tailings tests on exterior face and crest of dams shall be equal to or less than 1×10^{-6} cm/sec.

3.09 DEBRIS MANAGEMENT

A. Manage debris resulting from the Work or encountered on Project Site in accordance with applicable Laws and Regulations. Debris may include abandoned electrical cable, abandoned well materials, abandoned piping, old power poles, miscellaneous refuse, or other man-made objects.

END OF SECTION 02220

SECTION 02240

DEWATERING AND DIVERSION

PART 1 GENERAL

1.01 DESCRIPTION

A. All work included in this Section shall be done in accordance with the following paragraphs as well as the general requirements as outlined in Division 1 of these Specifications.

B. The work covered by this section of the Specifications consists of furnishing all labor, equipment, and materials, and performing all operations necessary for dewatering the Project Site during construction.

1.02 REFERENCES

A. Protecting Water Quality in Urban Areas, MPCA 2000.

B. Stormwater Management for Construction Activities, EPA 1992.

C. Developing Pollution Prevention Plans and Best Management Practices, EPA 1992.

D. Erosion Control Handbook, Mn/DOT 2006.

E. Minnesota Stormwater Manual, Version 2, January 2008.

F. Stormwater and Wetlands: Planning Evaluation Guidelines, MPCA 1997.

G. Construction Stormwater Pollution Prevention Plan (SWPPP) – NorthMet Project Plant Site, Barr 2016.

1.03 BASIS FOR COMPENSATION

A. Work included under this Section of these Specifications shall be included under the Bid Price.

PART 2 PRODUCTS

2.01 PUMPS

A. Supply and maintain pumps capable of pumping water from excavation areas to permitted discharge locations in the event of heavy rains or runoff so work will not be significantly delayed and water will not saturate the soils.

PART 3 EXECUTION

3.01 GENERAL

A. Furnish and operate temporary controls such as diversions and dewatering equipment to prevent surface water and groundwater from entering and ponding in excavations and to allow construction under dry conditions.

B. Contractor shall be aware that flows will vary in proportion to recent rainfall events, and with rapid and heavy rains, ponded water may accumulate. Contractor shall be responsible for and take measures to protect his personnel, equipment, and supplies from such an event.

C. Discharge water from construction de-watering to an area designated by Owner. Identify conditions requiring water discharge and propose discharge points to Owner. Provide necessary measures to prevent erosion or transportation of sediments at the discharge locations. Remove and dispose of transported sediment.

END OF SECTION 02240

SECTION 02271

RIP RAP

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Work included in this section includes providing the rip-rap and associated materials as shown on the Drawings and specified herein, including ditch check construction as may be required for erosion control but not shown on Drawings.

1.02 BASIS FOR COMPENSATION

A. Compensation for all Work included under this Section shall be included in the Bid Price.

1.03 SUBMITTALS

A. Location of source and type of rip-rap material.

B. Test results.

C. Submit in accordance with Section 01300.

1.04 REFERENCES

A. Minnesota Department of Transportation Standard Specifications for Construction; 2016 Edition.

B. Latest edition of the following American Society for Testing and Materials (ASTM) standards:

1. ASTM D 5519- Standard Test Methods for Particle Size Analysis of Natural and Man-Made Riprap Materials.

1.05 QUALITY CONTROL

A. Contractor is responsible for completion of construction quality control as described below, except where specified as the responsibility of the Owner.

1. Rip-rap Soundness: 1 per source.
2. Particle Size Analysis (ASTM D 5519): 1 per source.

PART 2 PRODUCTS

2.01 MATERIALS

A. Rip-rap shall meet the requirements of MnDOT Construction Standard Specification 2511.2.

B. Filter Material shall meet the requirements of MnDOT Construction Standard Specification 2511.3.

PART 3 EXECUTION

3.01 PREPARATION

A. Grade and dress areas on which rip-rap is to be placed to lines and grades shown on Drawings or as required by Owner's On-Site Representative.

B. Place filter material under rip-rap and cover completely. No filter material shall be exposed along edges or under rip-rap. Place rip-rap so filter material is not damaged.

3.02 INSTALLATION

A. Place rip-rap in areas as shown on Drawings.

B. Place rip-rap for ditch checks as needed for permit compliance and as specified herein.

END OF SECTION 02271

SECTION 02610

PIPES AND FITTINGS

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Furnishing and installing 18” steel Tailings Discharge Pipelines.

B. Furnishing and installing 6” HDPE Return Water Pipelines.

1.02 BASIS FOR COMPENSATION

A. Work included under this Section of these Specifications shall be included under the Bid Price.

1.03 REFERENCES

A. American Society for Testing and Materials, current edition, hereafter referred to as ASTM.

1. ASTM A-53 Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.
2. ASTM A-234 Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service.
3. ASTM A-307 Standard Specification for Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength.

B. American National Standards Institute, current edition, hereafter referred to as ANSI.

1. ANSI/ASME B18.2.1 Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series).
2. ANSI/ASME B1.1 Unified Inch Screw Threads (UN and UNR Thread Form).
3. ANSI/ASME A-13.1 Standards for Pipe Identification.
4. ANSI/ASME B31 Standards of Pressure Piping.

PART 2 PRODUCTS

2.01 STEEL PIPE AND FITTINGS

A. Pipe

1. Less than 150 psi: ASTM A-53, Grade B, seamless or ERW carbon steel, standard weight, black, plain ends, plain end mechanical coupling.
2. 150 to 275 psi: Spiral butt-weld pipe, 3/16” wall thickness, 150# forged steel flat face slip on flanges, exterior coal tar epoxy coating, Naylor pipe or equal.
3. Greater than 275 psi: Spiral butt-weld pipe, 3/8” wall thickness, 300# forged steel flat face slip on flanges, exterior coal tar epoxy coating, Naylor pipe or equal.

B. Fittings

1. 3 Inch and Larger: Standard weight, carbon steel, bevel ends, ASTM A-234, Grade WPB, 90-degree elbows—long radius.
2. Branches 2-1/2 inches and larger—nozzle weld.

C. Bolting

1. For Flanges: Hex head machine bolts, ASTM A-307, Grade B, nuts to be hexagon, heavy series carbon steel, ANSI B18.2 with coarse thread ANSI B1.1, Class 2.

D. Valves

1. Stop Valve, 3 Inch and Larger: Knife gate valve, flanged ends, replaceable gum rubber sleeves, handwheel, air or hydraulic actuator. Clarkson KGA or equal.

E. Lining

1. All steel Tailings Discharge pipe: Gum rubber, 40 Durometer, 1/4 inch inside with 1/8 inch on face of flanges.

2.02 HIGH-DENSITY POLYETHYLENE PIPE AND FITTINGS

A. HDPE pipe shall be manufactured from materials meeting the requirement of ASTM D 1248 for Type III, Grade P34, Category 5, Class C, and have a PPE rating of PE3408. The pipe produced from this material shall have the dimensions and wall thickness as set forth in ASTM F 714 for the size and Standard Dimension Ratio (SDR) shown on the Drawings.

B. HDPE pipe shall be marked at maximum 5 foot intervals with the manufacturer's name or trademark, nominal size and SDR, cell classification, ASTM D 1248, and extrusion date, period of manufacture, or lot number.

C. Polyethylene pipe fittings shall be manufactured from resin having the same classification and properties as the pipe resin, and shall be supplied by the pipe manufacturer. Molded fittings shall be used instead of fabricated fittings, if available. All fittings, bends, and couplings for the HDPE piping shall meet the requirements of this pipe specification and shall have an SDR at or lower than the pipe it is being connected to as shown on the Drawings.

D. Electrofusion fittings (if needed) shall be Central Plastics PE3408 Black 3 Pin 150 Class, or approved equal. Electrofusion fittings shall be sized and installed in accordance with manufacturer recommendations for coupling HDPE pipe of the size and class shown on the Drawings.

E. Valves:

1. Flanged
2. Non-rising stem
3. Grade E bronze components
4. Nitrile rubber O-rings and gaskets

F. Flanges:

1. Bolts and Nuts for pipe flanges shall be carbon steel conforming to the requirements of ASTM A307, Grade B. Bolts shall have hex heads to conform to ANSI B18.2.1. Hex nuts shall conform to ANSI B18.2.2. Bolt and nut threads shall conform to ANSI B1.1. Plain washers shall conform to ANSI B18.22.1.
2. Slip-on metal flanges shall be 150-lb. stainless steel and furnished with full-face rubber gaskets.
3. Flange adapter and slip-on flanges shall be drilled to ANSI 16.1/16.47/16.5 Class 125/150 bolt circles and AWWA C-207 class D (type).

PART 3 EXECUTION

3.01 INSTALLATION

A. Provide all materials required to furnish and install the products as specified. Damaged products will not be allowed for installation.

B. Install piping sized and in locations as shown on the Drawings. Install piping such that it is neat in appearance, convenient to operate, properly supported, and provides for proper expansion and drainage.

C. Pipe sizes shown on the Drawings are nominal pipe sizes, not outside diameters.

D. The right is reserved to authorize minor route changes to avoid conflict with other trades or existing obstructions at no additional cost to the Owner.

E. Protection and Cleaning

1. Treat all steel pipes for complete removal of oil and mill scale. Check for the complete removal of such scale and oil before fabrication and installation.
2. Particular care must be exercised to prevent loose welding metal, welding rods, dirt, and miscellaneous scrap from getting into the piping systems.
3. After installation and before final connection to complete the piping systems, hammer each piping section to remove any remaining scale. Flush pipe clean with water until clear of all foreign material. Make temporary connections as required to thoroughly clean pipes.
4. All equipment and accessories shall be cleaned out after all lines have been flushed out.

3.02 HDPE JOINTS AND FUSION

A. General Steps for butt-fusion joints:

1. Surfaces of fusion tools, pipe, and fittings shall be free of contaminants prior to use. Pipe ends shall be trimmed as necessary prior to joining.
2. Heat both pipe ends simultaneously at specified temperature for specified time.
3. Remove heater and press melted surfaces together to form joint.
4. Maintain uniform pressure until solidified. Prevent rough handling (testing, stress movements, pulling, or laying) until fully cooled to ambient material temperatures.

B. General steps for electrofusion:

1. Surfaces of fusion tools, pipe, and fittings shall be free of contaminants prior to use. Pipe ends shall be trimmed as necessary prior to joining.

2. Follow manufacturer's recommendations for electrofusion techniques.

3. Fusion Unit Operators
   a. Each operator of fusion units shall demonstrate to Owner's or Owner's On-Site Representative's satisfaction that operator is qualified to perform consistently correct fusion joints acceptable to Owner. Contractor shall replace without additional cost to Owner any fusion unit operator to which Owner or Owner's On-Site Representative has reasonable objection based on the operator's failure to perform consistently correct fusion joints as recommended by pipe manufacturer or the provisions of this Section.

4. Internal fusion bead removal
   a. The internal fusion bead from each butt weld shall be removed from the return water pipelines by using the Bead Trimmer II or approved equal. This equipment is manufactured by R&L manufacturing and distributed by:

      Crookston Welding
      Highway 75 South
      Crookston, MN 56716
      Phone: (218) 281-6911
      Fax: (218) 281-7255

   b. Quality control shall be by inspecting the external and extracted internal fusion bead. The internal bead shall also have a smooth root cut of the wall area; this may include wall mass that has been misaligned during fusion process. However any wall mass that is removed should not exceed 1/10th of the wall thickness of the pipe.

3.03 IDENTIFICATION

A. Label all new pipe in accordance with ANSI A-13.1 standard, or as directed by Owner's Representative.

B. Mark pipes at 50-foot maximum intervals on long straight runs, near 90-degree elbows, near either side of wall penetrations and on each branch.

C. Identify pipes using 2-inch high vinyl marker tape with pressure sensitive adhesive back.

3.04 STEEL PIPE HYDROSTATIC TESTING AND ACCEPTANCE

A. After completion of Work, thoroughly test, to the satisfaction of the Owner's Representative, all the Work installed hereunder. Test all closed piping systems before the system is placed in operation.

B. Perform hydrostatic pressure testing in accordance with ASME B31.

C. Provide temporary equipment for testing, including pump and gages. Test piping systems before insulation is installed wherever feasible and remove control devices before testing. Test each natural section of each piping system independently but do not use piping system valve to isolate sections where test pressure exceeds valve pressure rating. All piping blanked off or piping components removed in order to perform the test shall be reinstalled at no extra cost. Fill each section with water and pressurize for indicated pressure and time. Heated water or ethylene glycol solution must be used when hydrotesting outdoor piping during freezing weather.

1. Required test period is two hours.
2. Test each piping system at 150 percent of operating pressure indicated, but not less than 25 psi test pressure.
3. While holding the test pressure, visually inspect all joints for leaks. Maintain test pressure until released by the Owner's Representative. Test fails if leakage is observed or if pressure drop exceeds 5 percent of test pressure.

D. Promptly repair piping system sections that fail required piping test by disassembly and reinstallation, using new materials to extent required to overcome leakage. Do not use chemicals, stop-leak compounds, mastics, or other temporary repair methods.

E. Drain test water from piping systems after testing and repair work has been completed.

F. Maintain records for each piping installation tested. Records shall include date, system being tested, test fluid, test pressure, and Owner's Representative's approval. Submit test records to Owner.

3.05 HDPE PRESSURE TESTING

A. HDPE pipelines shall be tested using water as the pressure medium. Testing shall be done in sections not to exceed 700 feet in length. A final pressure test shall be conducted after the pipes have been installed.

B. The Contractor shall fill the pipelines with water to a pressure of 160 psi for SDR 11 HDPE and 200 psi for SDR 9 HDPE pipe. The contractor shall maintain this pressure in the pipe for a period of one hour.

3.06 FIELD QUALITY CONTROL

A. Pipe and pipe installations will be subject to rejection for any of the following reasons:

1. Failure to conform to specifications, particularly compaction under and around pipe.
2. Fractures or cracks passing through pipe wall.
3. Chips or fractures on interior of pipes.
4. Cracks which, in the opinion of Owner or Owner's On-Site Representative, may impair strength, durability, or serviceability of pipe.
5. Defects indicating improper proportioning, mixing, or molding.
6. Damaged ends where such damage would prevent making a satisfactory joint.

END OF SECTION 02610

SECTION 03100

BENTONITE-AMENDED TAILINGS

PART 1 GENERAL

1.01 SECTION INCLUDES

A. All work included in this Section shall be performed in accordance with the following paragraphs, the General Requirements set forth in Division 1 of these Specifications, and the provisions of the other Contract Documents.

B. Work covered by this section includes furnishing all supervision, labor, materials, and equipment required to complete the work summarized below including, but not limited to:

1. Complete bentonite/tailings mixing for the Work described in these Specifications, unless specified as the responsibility of the Owner.

2. Retain an independent soil and material testing firm(s) for performing the quality control testing on samples to be sent for laboratory testing. The quality control data shall be available for review at all times by Owner and Owner's On-Site Representative.

3. All mixing quality control test results will be used by Owner to confirm compliance with Specifications. Tests shall be performed and samples shall be collected at random locations within the designated material source, mixing zones, and placement areas such that the test results may be considered representative. Testing shall be performed or samples collected at specific locations determined by Owner's On-Site Representative, if requested.

4. Owner's On-Site Representative shall have full authority to direct testing activities of Contractor-retained independent soil and material testing firm(s) including but not limited to: selecting locations and materials for testing, reviewing all raw and final test data, conducting audits of testing company field and in-laboratory testing procedures and equipment.

5. In cases where testing firm personnel violate Project Site safety procedures or otherwise appear to lack the competence required to fully perform the required testing, Owner's On-Site Representative with concurrence of Owner shall also have the authority to dismiss testing firm personnel from the Project Site.

6. Conduct a Pilot Test of the bentonite/tailings mixing method, quality control testing, and placement and compaction procedure. The Pilot Test shall be conducted prior to initial bentonite tailings/mixing activities. The Pilot Test shall be agreed to by the Owner's on-site representative, and conducted by the Contractor at the commencement of the project.

7. Pilot Testing shall be repeated prior use of a new tailings borrow source and/or in the event that an alternate approved brand/source of bentonite is used in place of the brand/source initially tested.

1.02 BASIS FOR COMPENSATION

A. Work included under this Section of these Specifications shall be included under the Bid Price.

1.03 SUBMITTALS

A. Submit for information on a daily basis to the Owner's on-site representative, the results of all observation documentation and testing of the tailings borrow, the bentonite material, and the bentonite-tailings mixture. Results shall be documented in the Bentonite/Tailings QAQC Template.

PART 2 PRODUCTS

2.01 COARSE TAILINGS BORROW

A. Coarse Tailings Borrow shall meet the requirements of Section 02220 Excavating, Backfilling, Compacting.

2.02 BENTONITE

A. Bentonite supplied as a soil sealant shall be high-swelling sodium montmorillonite clay referred to as Wyoming Bentonite or Sodium Bentonite. The bentonite shall be supplied in granulated form and be manufactured by Wyo-Ben, Inc., American Colloid Company, Bentonite Performance Minerals LLC, or an equal approved by Engineer prior to bid.

B. High swelling is defined as the ability of 2 grams of bentonite, when mechanically reduced to a minus 100 mesh, to swell in water to an apparent volume of 16 cubic centimeters or more when added a little at a time to 100 cubic centimeters of distilled water contained in a graduated cylinder.

C. The colloid content of the bentonite shall exceed 70% and is measured by evaporating and weighing the suspended portion from a 2% distilled water solution after 24 hours of sedimentation.

D. Dry fineness of the bentonite product shall be: 97% minimum passing 8 mesh.

PART 3 EXECUTION

3.01 BENTONITE DELIVERY AND STORAGE

A. Bentonite shall be delivered dry, in bulk, by truck or rail, in bulk or in super sacks. Upon delivery, the dry bentonite shall be incorporated directly into the construction, or transferred by either pneumatic or mechanical conveyance systems into dry storage facilities established for the express purpose of temporary bentonite storage.

3.02 MIXING QUALITY CONTROL

A. Pre-Mixing Activities

1. Prior to bentonite/tailings mixing activities:

a. the Contractor shall conduct a Pilot Test to determine the optimal method for mixing, testing, and placement of the bentonite/tailings mixture on the dams,

b. the source of tailings borrow shall be identified and associated tailings samples tested as outlined in this specification,

c. the Bentonite source shall be identified and documented per this specification,

d. the Contractor shall locate the following zones as agreed to by the Owner's on-site representative and confirmed during the Pilot Test:

1. *Pre-Mixing Zone* – Location of tailings borrow designated as the tailings source for testing and mixing. The pre-mix zone shall be located and marked prior to testing.

2. *Mixing Zone* –The location for mixing tailings and bentonite to achieve a uniform bentonite-tailings mixture. Testing of the pre-mixed and mixed material shall occur in this zone along with repeated mixing and testing as needed.

3. *Post-Mixing Zone* –The location for placement and compaction of the bentonite/tailings mixture on the dam.

B. Mixing Activities

1. Within the designated Pre-Mix Zone, the Contractor shall peel off the upper 2.5 feet or less of tailings at the surface to expose underlying tailings borrow. The tailings borrow shall be excavated and staged in the Mixing Zone for testing. Representative samples of the staged tailings borrow shall be tested for moisture content. The quantity of staged

material to be tested will be determined during the Pilot Test, but in all cases shall be sufficient to fully evaluate production-scale equipment types and mixing and compaction procedures.

2. Based on the dry weight of the staged tailings, a quantity of bentonite shall be determined to achieve 3% bentonite by dry weight.

3. Within the Mixing Zone, the calculated quantity of bentonite shall be mixed with the tested tailings. Mixing shall occur until the bentonite is uniformly distributed with the tailings. Visual observations shall be made by the Contractor to ensure thorough mixing. Actual mixing procedures will be determined during the Pilot Test.

C. Post-Mixing Activities

1. Following the addition of bentonite and thorough mixing, a second set of representative field tests shall be made from the tailings/bentonite mixture. The Pilot Test will determine the appropriate tests and specifications prior to placement.

2. Bentonite/tailings mixtures that meet standards determined during the Pilot Test shall be mechanically placed and compacted as an 18-inch thick bentonite-amended cover on the FTB dams according to placement specifications in SECTION 02220. Additional testing of the compacted mixture will be determined during the Pilot Test.

D. Field Testing

1. Field tests of the tailings moisture content shall be made on site by the Contractor in conformance with ASTM D 2216, the standard test method for testing water content of a material. Additional tests will be determined during the Pilot Test.

2. Field tests shall be performed in an on-site testing area furnished with sufficient equipment.

E. Laboratory Testing

1. An independent laboratory shall be retained to verify field tests. Samples for laboratory testing shall be taken from the tailings/bentonite mixture placed and compacted on the dam. In-laboratory material test requirements will be determined during the Pilot Test but may include moisture content, hydraulic conductivity, sieve analysis, or others. In-laboratory material test results shall be available within 5 days from testing to track quality of the bentonite-tailings mixture.

3.03 DOCUMENTATION

A. Test Results (field or laboratory) - The Contractor shall document in the Bentonite/Tailings QAQC Template all testing information including: the date, time, location coordinates (northing, easting, elevation), and the test results. Test result documentation shall be made for tests in each zone, placed material and compacted material. Actual documentation and tracking methods will be determined during the Pilot Test.

B. Bentonite Material - The Contractor shall document in the Bentonite/Tailings QAQC Template, the name of the bentonite supplier, source of the bentonite, quantity used in each testing and mixing location, and test results associated with usage of bentonite. Additional documentation includes bentonite deliveries (date, time and quantity.)

C. Tailings Borrow – The Contractor shall document in the Bentonite/Tailings QAQC Template, the tailings borrow location, volume excavated, and general observations and characteristics of the tailings.

D. Bentonite Amended Tailings on Dams – The Contractor shall document in the Bentonite/Tailings QAQC Template, the location, volume, and general observations/characteristics of bentonite amended tailings placed on the dams.

E. Notification- any significant changes in the test results, the bentonite material and/or the tailings borrow that would affect the bentonite-amendment for the dams shall be documented and immediately be brought to the attention of the Owner's On-Site Representative.

F. Frequency- testing shall be frequent early on during the start of mixing activities and will gradually decrease once a sufficient level of data is obtained. The Pilot Test will determine the frequency of visual observations and testing frequency, which shall include a minimum of three field tests of moisture content and sieve analysis per day during active mixing activities. Testing frequency will be confirmed and adjusted as necessary during the Pilot Test.

G. Documentation shall occur with each occurrence of tailings excavation, mixing, and placement; field tests, laboratory tests of pre-mixed or mixed material; and deliveries of bentonite.

3.04 AIR QUALITY

A. Contractor shall be responsible for bentonite handling and bentonite-amendment of tailings activities in a manner so as not to allow visible wind transport of bentonite outside the immediate zone of bentonite/tailings mixing activities.

B. In cases when visible air quality impacts are occurring, Contractor shall temporarily cease or otherwise adjust construction activities until such time that suitable air quality can be achieved.

C. Owner’s On-Site Representative shall have authority to request temporary stoppage of bentonite application activities until such time activities can resume without air quality impact, at no additional cost to Owner.

END OF SECTION 03100

Construction QAQC Template -- Bentonite-Amended Tailings (Draft 01 07-27-2015)

Pre-Mixing Zone (Tailings Borrow)						
Source Location	Coordinates			Approximate Dimensions of Excavated Material (ft)		
	Northing	Easting	Elev.	Length	Width	Depth
Source Characteristics	Grain Size	Grading (Poorly Graded/Well Graded)	Moisture Characteristics (Dry/Moist/Wet)	Impurities (vegetation, other) and Other Observations		
Source Volume	Material Excavated for Mixing (cubic yards)					
Source In-Field Testing	Moisture Content					
	Sample Location	Moist Specimen Mass (g)	Oven Dry Specimen Mass (g)	Mass of Water = (Moist Specimen - Oven Dry Specimen)	Mass of Water/Mass of Solid = Water Content	Other Observations
Source In-Laboratory Testing	Sample Location	Laboratory Test1	Laboratory Test 2	Laboratory Test 3	Other Observations	
Bentonite Material						
Granular Bentonite	Supplier	Source	Quantity Delivered	Delivery Date	Comments	
Tailings Bentonite Mix						
Post-Mixing Location	Coordinates			Other Observations		
	Northing	Easting	Elev.			
Mix Quantity	Tailings Quantity	Bentonite Quantity	Bentonite % Weight	Other Observations		
Mix Characteristics	Well Mixed	Poorly Mixed	Mixing Equipment and Method			
Mix In-Field Testing	Moisture Content					
	Sample Location	Moist Specimen Mass (g)	Oven Dry Specimen Mass (g)	Mass of Water = (Moist Specimen - Oven Dry Specimen)	Mass of Water/Mass of Solid = Water Content	Other Observations
Additional Mixing	Additional Tailings Quantity	Additional Bentonite Quantity	Comments			
Mix In-Laboratory Testing	Sample Location	Laboratory Test1	Laboratory Test 2	Laboratory Test 3	Other Observations	

Note: This template is subject to change based on Pilot Testing of the bentonite-amended tailings construction process.

Attachment H

Flotation Tailings Basin Dam Break Analysis

Technical Memorandum

To: Poly Met Mining Inc. (PolyMet)
From: Rita Weaver, Barr Engineering Company
Subject: FTB Dam Break Analysis
Date: December 4, 2012
Project: 23/69-0862

Background

Barr conducted a dam break analysis for the north dam of the Flotation Tailings Basin (FTB) to provide information for the FTB Emergency Action Plan (EAP). The FTB dams have been designed to achieve necessary factors of safety (Geotechnical Data Package – Volume 1, [Reference (1)]), so a dam break is unlikely. The dam break analysis was completed to understand the potential extent of flood inundation between the FTB and the Embarrass River in the unlikely event of a failure at the dam. Results are incorporated in the EAP so emergency responders can plan for a worst-case scenario and be prepared to take all necessary actions should a dam break ever occur.

The FTB is located south of the Embarrass River in St. Louis County. The Trimble Creek watershed, shown in Figure 1, is the focus of the dam break analysis. Trimble Creek runs into the Embarrass River approximately 4 miles north of the FTB. The area between the FTB and the Embarrass River is sparsely populated forest.

A dam break analysis (also commonly referred to as dam breach analysis or dam failure analysis) uses a hydrologic model to determine the amount of runoff from a specified storm event and a hydraulic model to determine the route of the storm runoff and the dam break floodwave. Often the hydraulic model is run first without a dam break (only storm runoff flow is modeled) and then with a simulated dam break to determine the extent of additional inundation resulting from a break in the dam. The hydraulic model estimates the extent of flood inundation, the inundation depth, and the arrival time of a floodwave from a dam break. This memorandum describes the hydrologic and hydraulic modeling, documents the dam break assumptions, and presents a summary of the dam break model results.

Hydrologic Modeling

The HEC-HMS computer model, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers was used to develop the hydrologic model. The HEC-HMS model uses the following mass conservation balance equation to compute the outflow volume from each subwatershed:

Outflow Volume = Runoff ± Storage – Infiltration – Evaporation + Baseflow

Evaporation and Baseflow were considered negligible compared to the volume of flow from a large storm event. Storage for the FTB was calculated based on topographic data. Runoff and infiltration were computed using the Soil Conservation Service (SCS) dimensionless unit hydrograph method. Input parameters include sub-watershed area, lagtime (which helps define how fast runoff leaves a watershed), initial abstraction (which accounts for surface storage in depressions, puddles, etc.), SCS curve number, and percent imperviousness. Each of these input parameters are described in further detail in the following paragraphs.

Subwatershed divides were delineated in the ArcMap geographic information system (GIS) using the US Geologic Survey (USGS) quadrangle maps. The subwatersheds downstream of the FTB were subdivided in order to compute a more accurate flow hydrograph in Trimble Creek during the Probable Maximum Precipitation (PMP) event. Figure 1 shows the location of the subwatershed divides.

The time of concentration, used in calculating the lagtime, was estimated using reach lengths, slopes, and velocities in each subwatershed. Charts from the Hydrology Guide for Minnesota (Reference (2)) and the channel geometry were used to estimate runoff velocity. Lagtime was then computed as 0.6 multiplied by the time of concentration, as suggested by the SCS.

The SCS curve number is based on soil type and the land cover type. Soil type was taken from the Soil Survey Geographic Database (SSURGO) provided by the Natural Resource Conservation Service, and land cover type was determined from aerial photos. Composite curve numbers calculated for each subwatershed ranged from 72 to 74. Initial abstraction was calculated using an empirical relationship developed by the SCS, which is based on a watershed's curve number.

The hydrologic model computed runoff from the 72-hour Probable Maximum Precipitation (PMP) storm event. This event was chosen for the analysis because it results in the most significant downstream inundation, allowing estimation of worst-case flooding in Trimble Creek. The total amount of precipitation for the 72-hour PMP event was assumed to be 32.2-inches for the 10-square mile watershed, based on the Hydrometeorological Report number 51(HMR 51), *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian*. This precipitation was distributed according to the Huff's Fourth Quartile distribution, as described in the *Rainfall Frequency Atlas of the Midwest*. The 4th quartile distribution was chosen because it more closely represents a distribution for storm events longer than 24-hours.

Storm runoff from the Trimble Creek watersheds was routed downstream using the Muskingham-Cunge method of channel routing in HEC-HMS. This method uses the channel length, shape, slope and Manning's n for the channel and overbanks to route the watershed downstream. Channel length, slope, and an assumed channel shape were taken from GIS. Manning's n was determined by reviewing the aerial photos of the flow paths. Manning's n was assumed to be 0.04 for the main flow path and 0.1 for the overbanks. The runoff hydrograph for Trimble Creek had a calculated peak flow rate of approximately 6,000 cfs. This hydrograph was entered into the hydraulics model to evaluate the effect of flooding on Trimble Creek during the Probable Maximum Flood (PMF).

Storm runoff to the FTB was calculated using the same method as the Trimble Creek watersheds, however the volume of runoff from the storm event was not routed downstream. Since the FTB was designed to hold runoff from the 72-hour PMP event, it was assumed that the total runoff volume from the FTB direct watershed was added to the open water in the FTB and there was no discharge downstream.

Hydraulic Modeling

The hydraulics model HEC-RAS, also developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, was used to route the Trimble Creek runoff hydrograph from the FTB to the Embarrass River. HEC-RAS calculated the maximum water surface profile along Trimble Creek for the 72-hour Probable Maximum Flood (PMF; produced by the PMP). A 'without-failure' profile was created to show the extent of flooding during the PMF with no dam break. This profile is used to compare the flooding from the storm event with and without a dam break. For the without-failure analysis, no outflow was assumed from the FTB because the 72-hour PMP volume would be contained by the FTB.

Trimble Creek were modeled as part of this study. A total of 41 cross-sections (not including interpolated cross-sections) were used to define the geometry of the creek. Road crossings were not modeled because they would likely be inundated with or without a FTB dam failure, and have a high probability of being washed out during the PMP event.

Cross-section geometry was defined using the USGS 30-meter digital elevation models (DEMs, approximate accuracy is 10-feet). The location of cross-sections was chosen based on the location of homes and the point where the topographic data showed a defined conveyance area. Normal depth was used as the downstream boundary condition for the model because there would be no backwater effect from the Embarrass River. Manning's n values were kept consistent with the hydrologic model.

Initial runs showed that the floodwave from a dam break would cause flooding outside of the main flow channel along Trimble Creek so "breakout" paths were defined to carry flow that would not be contained in the Trimble Creek floodplain. Natural overflow geometry taken from the DEM was used to define the natural overflow to the breakout paths, and an additional 24 cross-sections were used to define the breakout paths. Flows to each breakout path were calculated by the model. Figure 2 shows the locations of the breakout paths and the location of the cross-sections included in the HEC-RAS model.

Dam Break Analysis Methodology

The topography at the proposed FTB will be formed by perimeter dams up to 200 feet high, with side slopes of approximately 4.5H:1V, and 30-foot wide benches every 20 feet vertically. The tailings basin perimeter dams consist of coarse tailings from taconite processing operations. The dam break analysis focused on the north side of the FTB, because this is the section of the dam where a break would result in the shortest warning time for potentially affected downstream properties. A breach was not considered to the east or south of the FTB because a large portion of the perimeter ties into natural ground and/or no homes are within the respective downstream flow path.

At closure, the FTB will cover approximately 1,400 acres. The final dam crest elevation will be 1732 ft. The FTB will have approximately 10 feet of freeboard and will contain flotation tailings to a depth of approximately 160 feet.

The FTB is designed as a closed system, not allowing for release of water through overflow or outlet structures during operations; however a constant discharge from the FTB was assumed to aid with model stability. All precipitation that falls within the FTB perimeter will be contained by freeboard, including the precipitation from the 72-hour PMP event. The flow into the FTB from plant operations was assumed to be negligible compared to the runoff from the storm event so it was not included in this analysis.

Piping was selected as the cause of the dam break for this study. Piping is the process whereby seepage through the dam is of sufficient velocity to initiate erosion and downstream transport of soils from the structure of the dam. Failure resulting from overtopping the dam was not considered because the dam is designed to not be overtopped even with the volume of the 72-hour PMP event.

Dam break parameters are based on recommendations by the Federal Energy Regulatory Commission (FERC) and the Bureau of Reclamation as well as a review of the *Breaching Parameters for Earth and Rockfill Dams* (Reference (3)). The recommendations for breach parameters in Reference (3) were developed by creating empirical relationships between five breaching parameters (breach depth, breach location top width, average breach width, peak outflow rate, and failure time) and five dam and reservoir variables (dam height, reservoir shape, dam type, failure mode and dam erodibility) recorded for historical dam failures. This reference was considered for our analysis because the study's evaluation of breach parameters considered dams of heights and volumes comparable to the FTB dams. Also, this method estimated failure parameters for recorded large dam failures more accurately than other potential methods. Table 1 provides a summary of breach parameters recommended by federal agencies and the breach parameters used for this evaluation. The extensive regression and empirical equations developed in Reference (3) are not summarized here, but can be found in that document.

Table 1 Dam Break Analysis Breach Parameters

Parameter	FERC Suggested Breach Parameters	Bureau of Reclamation's Suggested Breach Parameters	Breach Parameters Used for this Study
Average Width of Breach (BR)	HD* ≤ BR ≤ 5HD	$3H_w$*	2.24HD
Horizontal Component of Breach Side Slope (Z)	0.25 ≤ Z ≤ 1	N/A	0.64H:1V
Time to Failure (hours)	0.1 ≤ TFM ≤ 1	0.011BR	3

*(HD = Height of dam, Hw = Height of water, Z = Horizontal Component of Side Slope (ZH:1V), TFM = Time to Failure (in hours), BR = Breach Width (feet)

The average breach width was assumed to be 2.24 times the height of the dam, and the breach side slopes were assumed to be 0.64H:1V. These were calculated based on the methods of Reference (3), and fall within the Bureau of Reclamation agency recommendations.

Time to failure is a sensitive parameter for dam failure analysis, and all three methods were used to calculate the time to failure and were then compared. Time to failure represents the time from onset of piping to completion of the dam break. Time to failure suggested by the Bureau of Reclamation is approximately three hours. Time to failure calculated using the methods and equations in Reference (3) is closer to four hours (note FERC's recommendation is less than an hour). The Bureau of Reclamation's recommendation was selected because it is more conservative than the time to failure computed following the methods of Reference (3). FERC's recommendation of a failure time of less than one hour seemed unrealistic based on the size of the dam and final breach configuration.

The depth of breach (from dam crest to bottom of breach) was calculated at 134 feet using the empirical equation included in Reference (3). This breach depth is nearly the entire final 160-foot depth of floatation tailings.

The most significant unknown breach parameter for a tailings basin dam is how much of the tailings would be suspended and carried downstream in the event of a dam breach. Studies have shown that in many cases only 30 percent of the volume in the basin is carried downstream, however basin dam breaks have been recorded where up to 80 percent of the volume was carried downstream. The volume of tailings released is dependent on how the basin is constructed and operated. Additional unique attributes of tailings basin dam breaks are the rate of sediment deposition downstream of the basin (i.e., how quickly do the tailings flowing from the basin redeposit outside of the basin) and flow properties of the liquefied tailings compared to water. These variables will affect the floodwave volume, flow rate, and travel time.

The complexity of dam break analysis requires many simplifications, so modeling inputs were chosen to be conservative by setting each parameter in the range that could cause more severe impacts. Assumptions include:

- One hundred percent of the Flotation Tailings above the bottom breach elevation will leave the FTB. This assumption maximizes flood volume.
- None of the Flotation Tailings will be re-deposited immediately downstream of the dam breach. This assumption maximizes flood volume.
- The dam break will occur simultaneously with the peak flow from the 72-hour PMP event in the Trimble Creek watershed. This assumption maximizes the inundation area.
- The floodwave will act as water instead of liquefied Flotation Tailings. This assumption minimizes the travel time of the flood wave.
- Structures are at the ground surface elevation shown on the 30 meter DEM, rather than elevated several feet on foundations. This assumption maximizes the number of structures affected.

These conservative assumptions likely result in over estimation of inundation area, flood depth, and number of structures affected and underestimate floodwave travel time Extensive additional analysis would be necessary to realistically estimate the percentage of flotation tailings left in the FTB, to evaluate flotation tailings deposition after the breach and to better understand flow properties of the liquefied flotation tailings. Such analysis is not warranted given the objective of this dam break analysis, which is to serve as an aid in development of the facility Emergency Action Plan. In other words, in the unlikely event of a dam break at the FTB, response actions developed on the basis of this dam break analysis are expected to be conservative. The actual extent of inundation and risk to residents and infrastructure can reasonably be anticipated to be lower than suggested by this analysis.

Dam Break Analysis Results

This study shows that a dam break could increase flood elevations approximately 15 feet at the upstream end of Trimble Creek (near the FTB) and approximately 9 feet at the downstream end of Trimble Creek (at the Embarrass River). Average flow velocities range from 10 feet-per-second (fps) to 25 fps in the main channel, but are reduced to 2 fps to 10 fps along the overbanks. Note again that these velocities are based on use of physical properties of water in the model; actual flow velocities for more viscous liquefied flotation tailings may be lower than these values.

Figure 3 shows the estimated inundation areas along Trimble Creek for the 72-hour PMP event, and the estimated inundation area along the creek and overflow paths for dam breach floodwave. The breach inundation area does not include flows from the 72-hour PMP event, because modeling found that storm runoff in the Trimble Creek watershed contributed only 1% of the total flow during a dam break event. The time to peak elevation is also noted on Figure 3 at several locations along the downstream flow paths to show estimated travel times of the floodwave.

This conservative dam break analysis indicates that there are 34 properties along Trimble Creek or the breakout paths that could potentially be affected by a FTB dam break. One of these properties would be inundated in the event of a 72-hour PMP event without a dam break. Because of the conservative assumptions made for this dam break analysis, it is likely that many of these homes would remain outside of the actual area of inundation.

References

1. **Poly Met Mining Inc.** NorthMet Project Geotechnical Data Package Vol 1 - Flotation Tailings Basin (v3). November 2012.

2. **Soil Conservation Service (SCS).** Hydrology Guide for Minnesota. St. Paul, Minnesota : s.n., 1977.

3. **Xu, Y. and Zhang, L.** Breaching Parameters for Earth and Rockfill Dams. *J. Geotech Geoenviron. Eng.* 2009, Vol. 135, 12, pp. 1957-1970.

Figures

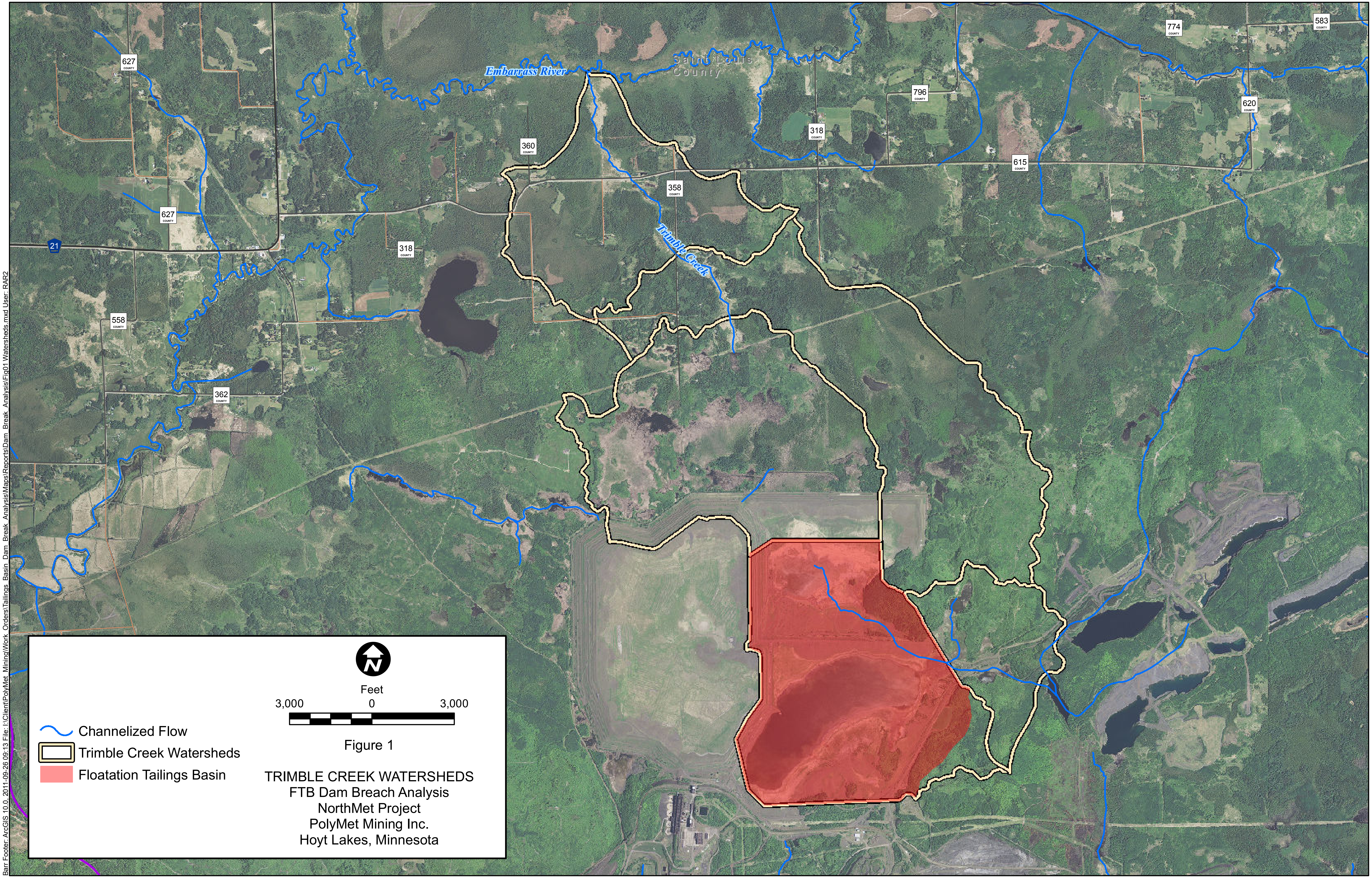


Figure 1

TRIMBLE CREEK WATERSHEDS
FTB Dam Breach Analysis
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, Minnesota

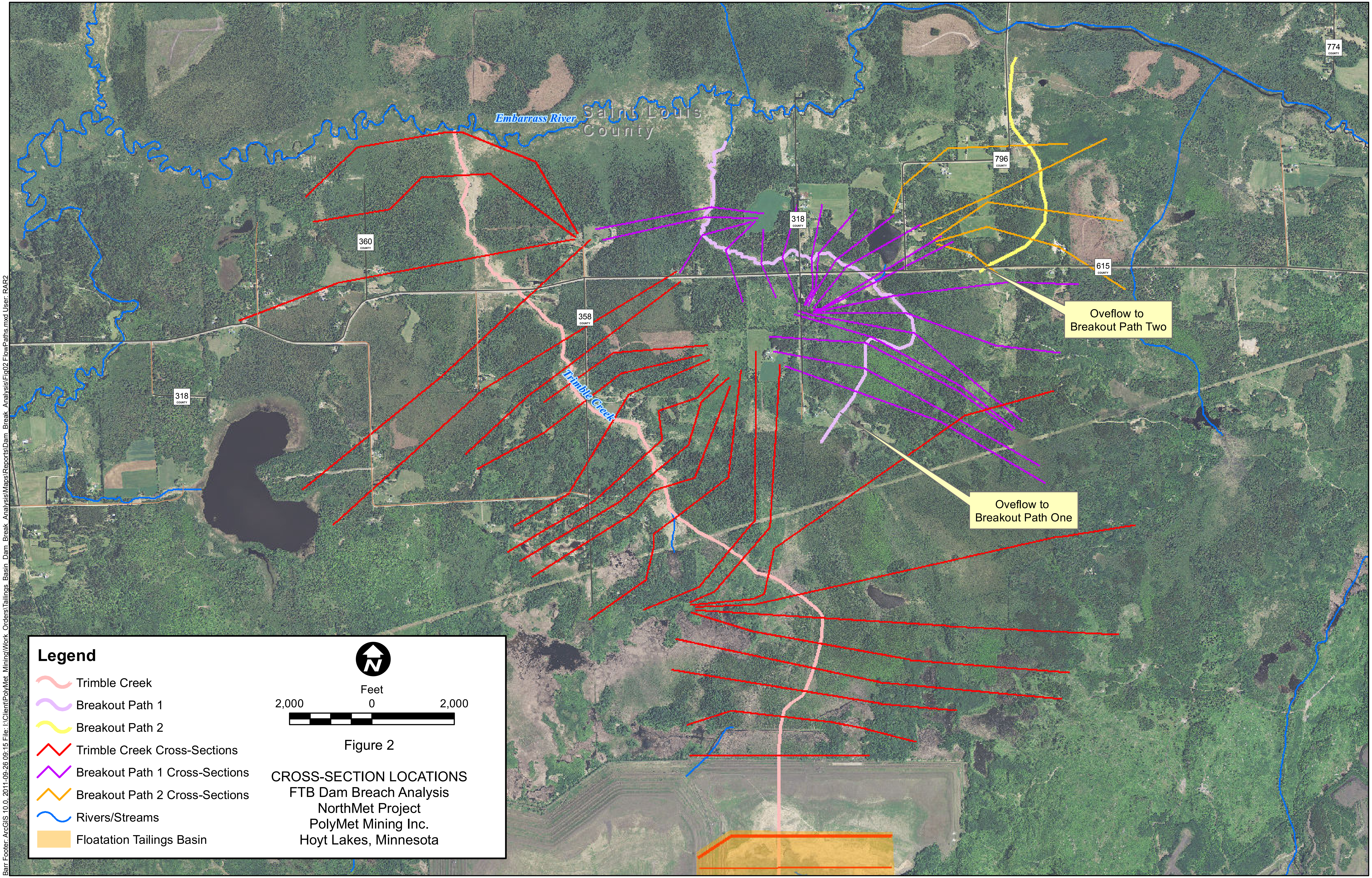
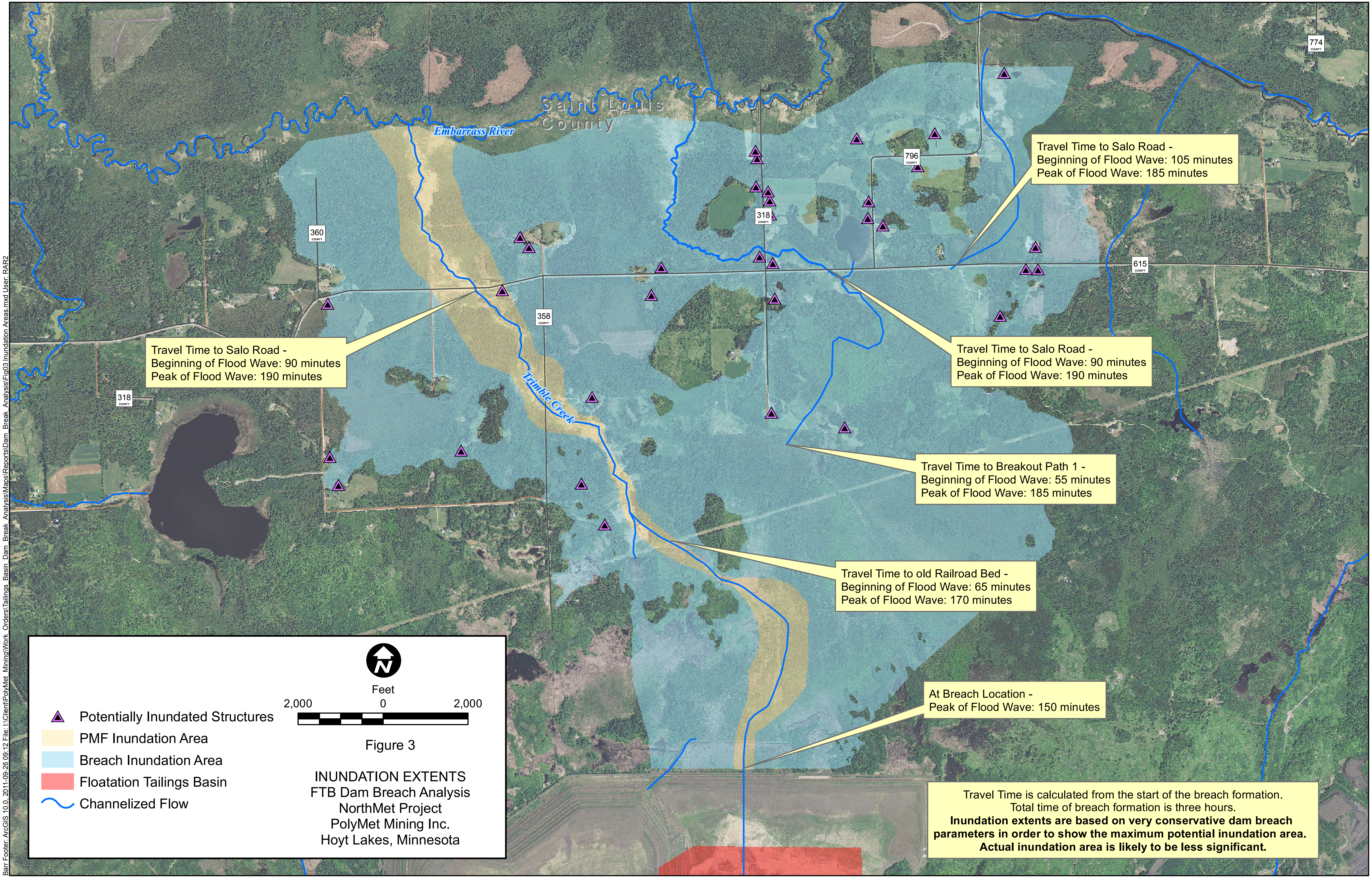


Figure 2

CROSS-SECTION LOCATIONS
FTB Dam Breach Analysis
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, Minnesota


Saint Louis County
Embarrass River
Trimble Creek
360
318
358
796
615
774
Travel Time to Salo Road -
Beginning of Flood Wave: 105 minutes
Peak of Flood Wave: 185 minutes
Travel Time to Salo Road -
Beginning of Flood Wave: 90 minutes
Peak of Flood Wave: 190 minutes
Travel Time to Salo Road -
Beginning of Flood Wave: 90 minutes
Peak of Flood Wave: 190 minutes
Travel Time to Breakout Path 1 -
Beginning of Flood Wave: 55 minutes
Peak of Flood Wave: 185 minutes
Travel Time to old Railroad Bed -
Beginning of Flood Wave: 65 minutes
Peak of Flood Wave: 170 minutes
At Breach Location -
Peak of Flood Wave: 150 minutes
Travel Time is calculated from the start of the breach formation.
Total time of breach formation is three hours.
Inundation extents are based on very conservative dam breach parameters in order to show the maximum potential inundation area.
Actual inundation area is likely to be less significant.
Potentially Inundated Structures
PMF Inundation Area
Breach Inundation Area
Floatation Tailings Basin
Channelized Flow
Feet
2,000 0 2,000
Figure 3
INUNDATION EXTENTS
FTB Dam Breach Analysis
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, Minnesota

Attachment I

Template for Pilot-Testing of Bentonite Amendment of Tailings

Template for Pilot/Field-Testing of Bentonite Amendment of Tailings

Prepared for
PolyMet Mining, Inc.

April 2017

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Template for Pilot/Field-Testing of Bentonite Amendment of Tailings

April 2017

Contents

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1.0 Introduction/Background

PolyMet submitted a draft NorthMet Dam Safety Permit Application - Flotation Tailings Basin to the Minnesota Department of Natural Resources for review and comment (Reference (1)). The permit application referenced the NorthMet Project Flotation Tailings Management Plan (Reference (2)) which states that during construction the exterior face of Flotation Tailings Basin (FTB) dams will be amended with a bentonite layer (see Section 7.1). The objective of the bentonite layer is to limit oxygen infiltration into the Flotation Tailings. Bentonite amendment will also reduce rainwater infiltration into the dams, which has a small benefit in terms of an increased slope stability safety factor. Reference (2) also states that exposed beach areas on the interior of the basin will be amended with bentonite to limit oxygen infiltration into the Flotation Tailings. Finally, Reference (2) also states that the pond bottom will be amended with bentonite as described in the NorthMet Project Adaptive Water Management Plan (Reference (3)). The bentonite-amended pond bottom will reduce the percolation from the FTB Pond, thereby maintaining a permanent pond that will provide an oxygen barrier and reduce oxidation and resultant production of chemical constituents in the underlying tailings. It will also reduce the amount of water collected by the FTB Seepage Containment System and the South Seepage Management System that will require treatment.

In summary, the design, operation, and closure of the FTB will include three separate but related applications of bentonite amendment:

- During construction of FTB dams, the exterior face of the dams will be amended with a bentonite layer
- In closure, exposed beach areas on the interior of the basin will be amended with a bentonite layer
- In closure, the pond bottom will be amended with bentonite

Attachment G - Template Construction Specifications - Section 03100 of Reference (2) requires that pilot/field-testing of bentonite amendment of soils (tailings) be performed, and this requirement is anticipated to be a condition of the Dam Safety Permit required for the FTB. This document is a template of the proposed pilot/field-test program.

2.0 Pilot/Field-Test Objectives

The objectives of bentonite amendment of the FTB dams, beaches, and pond bottom are to:

- limit oxygen infiltration through the FTB dams into the Flotation Tailings
- limit oxygen infiltration through FTB beaches into the Flotation Tailings
- limit oxygen infiltration through the FTB pond area by reducing the average areal percolation through the FTB pond bottom, thereby maintaining a permanent pond that will limit oxygen infiltration into the Flotation Tailings (and also reduce the amount of water collected by the FTB seepage capture systems and requiring treatment)

The performance of bentonite amendment of FTB dams and beaches to limit oxygen infiltration into the Flotation Tailings will be a function of the success with which a continuous areal (horizontal) zone of saturation can be established and maintained. The current plan calls for establishment of such a zone by constructing an 18-inch thick layer of bentonite-amended tailings covered by 30-inches of revegetated tailings. The 30-inch cover on the dams will consist of LTV Steel Mining Company (LTVSMC) Coarse Tailings and the 30-inch cover on the beaches will consist of Flotation Tailings. The bentonite layer will consist of 3% granulated bentonite mixed with LTVSMC Coarse Tailings or Flotation Tailings for the dams and beaches, respectively.

Therefore the **primary objectives of the dams and beaches pilot/field-test** will be to:

1. assess and demonstrate systematic and repeatable means and methods of earthwork construction to consistently create (i.e., mix bentonite and tailings) and place the bentonite layer in conformance to engineering specifications
2. assess the consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of compacted bentonite-amended tailings throughout the pilot/field-test[1]
3. observe the potential for other factors to inhibit, interfere or degrade the sustained maintenance of a continuous areal zone of saturation within an 18-inch thick layer of bentonite-amended tailings related to:
    a. desiccation cracking of the bentonite-amended tailings layer during dry weather
    b. post-construction differential settlement and/or erosion of overlying tailings
    c. deep plant root penetration below the 30-inch cover layer

[1] This does not mean to imply 18-inches of saturation, rather that there will be a continuous zone of saturation within the bentonite-amended tailings layer. The vertical dimension of the saturated zone will be determined in the pilot/field test.

d. freeze-thaw degradation of the bentonite-amended tailings layer

e. pond water chemistry along the beaches of the FTB

f. ice scour damage along the shoreline of the FTB Pond

g. other factors that could adversely affect the maintenance of saturation within a bentonite-amended tailings layer

The performance of bentonite amendment of the FTB pond bottom to reduce percolation from the pond and thus maintain a permanent pond will be a function of inducing a permanent positive water balance for the pond by reducing the areal average hydraulic conductivity of the pond bottom relative to pre-closure conditions. Unlike the bentonite amendment of the FTB dams and beaches, bentonite amendment of the pond bottom can be easily repeated if necessary through a series of approximations to reduce the average areal hydraulic conductivity of the pond bottom to sustain a permanent pond.

Therefore, the **primary objectives of the pond bottom pilot/field-test** will be to:

1. demonstrate systematic and repeatable means and methods of introducing bentonite to the pond bottom in a relatively uniform manner, which may include:

    a. broadcasting of granular or pelletized bentonite from a GPS route controlled barge

    b. injection/mixing of bentonite with pond bottom from a GPS route controlled barge

    c. placement of geosynthetic clay liner over the pond bottom from a GPS route controlled barge

2. assess the performance of bentonite introduction in achieving a positive pond water balance

It is important to note that to achieve a positive pond water balance, bentonite amendment of the pond bottom may not be required at all. The hydraulic conductivity of the deposited flotation tailings without bentonite amendment may be as low as needed to maintain a positive pond water balance.

3.0 Pilot/Field-Test – Preliminary Concepts

3.1 Dams Pilot/Field-Test

Pilot/field-testing of bentonite amendment of dams will be performed on Cell 2W to demonstrate systematic and repeatable means and methods of earthwork construction to consistently create and place the bentonite layer in conformance to engineering specification (see Dams and Beaches Objective 1 above). The materials used in the pilot/field-test will be representative of LTVSMC Coarse Tailings borrow and the bentonite that will be used in Cell 1E/2E dam construction. The means and methods for construction of test section dams will be consistent with Construction Specifications (Attachment A and Attachment G of Reference (2)). The location of the test section dams will be along the north interior crest of Cell 2W to provide a southern exposure aspect to the test section while also providing good accessibility (Figure 3-1). A southern exposure aspect should provide an increased stress related to solar radiation effects such as elevated temperatures, evapotranspiration and soil moisture deficit. Each of these effects will tend to be adverse to the maintenance of a zone of saturation within the 18-inch thick layer of bentonite-amended tailings.

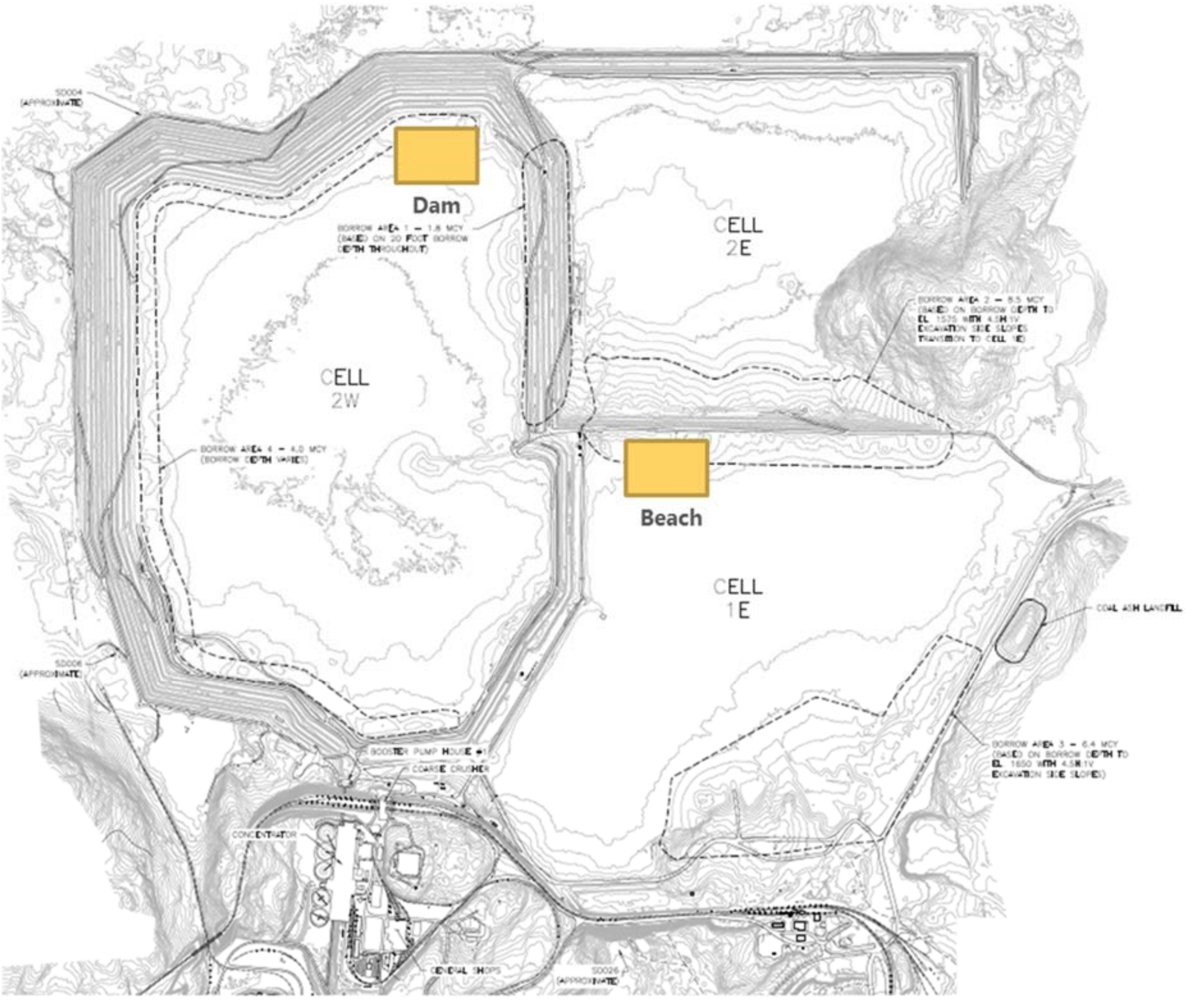


Figure 3-1 Probable Locations of Dam and Beach Pilot/Field-Test Areas

Numerous methods are available to assess the consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of bentonite-amended tailings throughout the pilot/field-test (see Dams and Beaches Objective 2 above and Reference (4), Reference (5), Reference (6)). These methods include a variety of choices for volumetric, tensiometric, gravimetric and redox indicator soil water monitoring. Each method offers certain advantages and drawbacks for application in the pilot/field-test. Important considerations for this pilot/field-test include:

- reading range that includes a saturated state
- acceptable accuracy to support test plan objectives (e.g., +/- 1% or 1 cbar)
- durability and permanence of installation (i.e., minimal need to revisit/disturb the test section)
- minimal maintenance requirements (i.e., minimal need to revisit/disturb the test section)
- minimally affected by solutes/salinity
- minimal sensitivity to soil temperature
- compatibility with clay soils
- easy and stable soil-specific calibration
- easy monitoring at multiple soil depths

It will also be desirable if the monitoring method will accommodate data logging capability and provide ease of installation.

Several methods appear to be compatible with the conditions/constraints of the pilot/field-test and will largely accommodate the considerations listed above (exceptions are noted):

- Frequency domain (FD) probes such as (Figure 3-2):
    - capacitance plates embedded in a silicon board
    - capacitance rods

  Careful installation of FD probes is necessary to avoid air pockets and the devices easily accommodate multiple sampling depths; temperature influence will need to be evaluated.

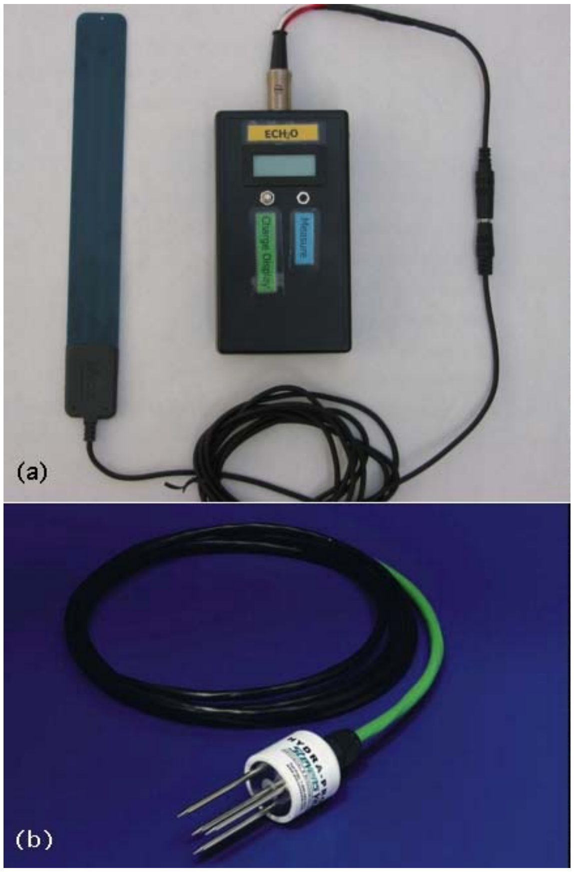
- Amplitude domain reflectometry (ADR) probe (Figure 3-3):
  The device will easily accommodate multiple sampling depths; soil-specific calibration is necessary to maintain accuracy and careful installation is required to avoid air pockets.

- Tensiometer (Figure 3-4):
  Custom modification is necessary to accommodate data logging, device may require ongoing

maintenance, will require seasonal maintenance and/or replacement, and device is more fragile than other devices described above.

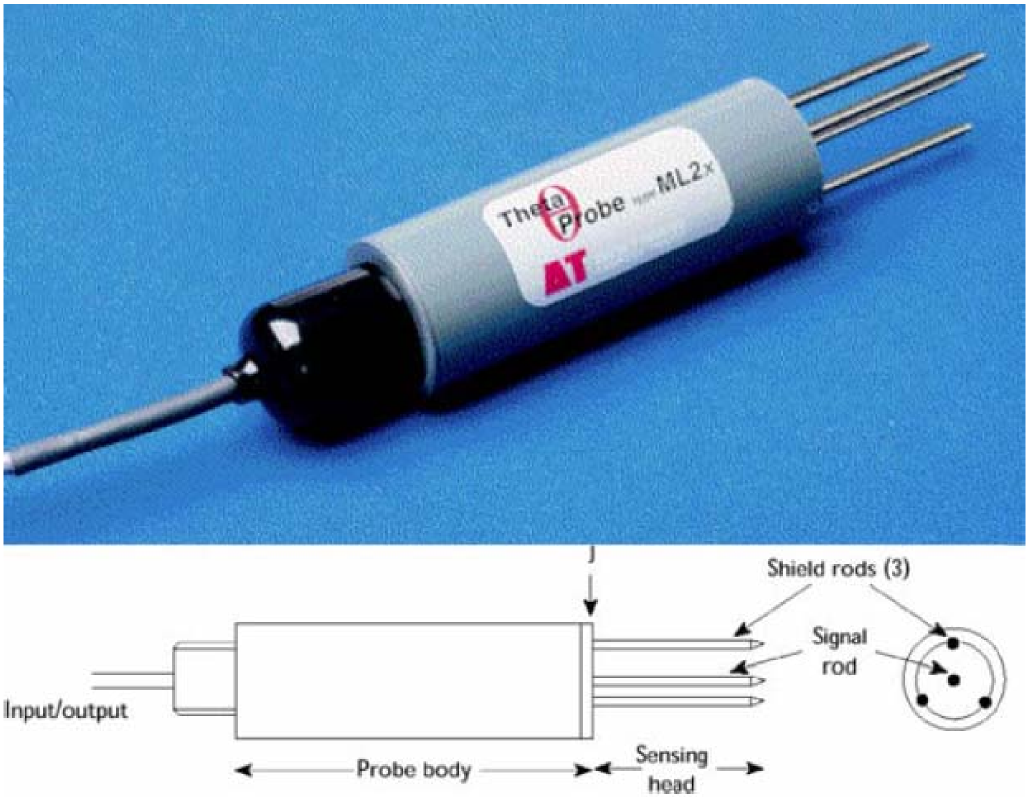
- Mild Steel Rods as described in Reference (5):
  Lack of available oxygen in saturated soils prevents rust of mild steel rods that have been driven into the soil; saturated soil will yield rust-free rod below depth of saturation. An indirect sampling method that is cheap and easy to install, compatible with assessment of gradients along transects, gives strong measure of depth of saturation, low cost allows intensive grid sampling to assess the consistency of saturation over an area; oxygen may infiltrate along the rod/soil contact.

- Gravimetric as described in Reference (6):
  An established and standardized method of measuring soil saturation by collection of soil samples, determining wet weight, dry weight, determining moisture content by difference and comparing to an established saturated baseline moisture content. Drawbacks include: physical sampling (extraction of soil at depth) must be repeated at each sampling event, sampling will cause disturbance of soils and vegetation.



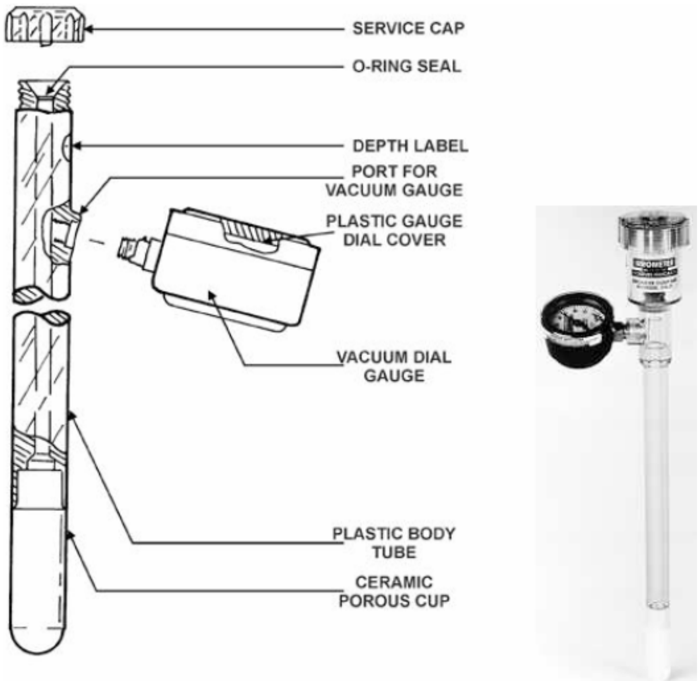
(Reference (4))

Figure 3-2 Frequency Domain (FD) Probes: a) Capacitance (plates embedded in a silicon board)



(Reference (4))

Figure 3-3 Amplitude Domain Reflectometry (ADR) Probe



(Reference (4))

Figure 3-4 Tensiometer

The number of sample locations and frequency/timing of monitoring events (or continuous monitoring) will reflect the combination of soil moisture monitoring methods incorporated into the pilot/field-test. A minimum of three replicates of each type of monitoring will be implemented at each of three depths of monitoring (3-inches, 9 inches and 15 inches) into the 18-inch bentonite-amended zone. Frequency of monitoring will vary by method, likely monthly during the growing season (April 1 and October 1). Gravimetric sampling will likely be limited to three events per growing season (to minimize test area disturbance) and yet allow a means to calibrate/confirm monitoring results from other methods.

Monitoring to observe the potential for other factors to inhibit, interfere with, or degrade the construction and sustained maintenance of a continuous areal zone of saturation (see Dams and Beaches Objective 3 above) in an 18-inch thick layer of bentonite-amended tailings in tailings dams will be accomplished through the use of the "observe and investigate" method and/or designed mini-experiments as follows:

- Observe and Investigate – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB dams can be easily observed in the dam test sections and potentially in the existing LTVSMC dams during routine dam inspection activities:
    - post construction erosion of overlying tailings
    - deep plant root penetration of 30-inch cover layer

If post construction erosion is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of this factor. If in the collection of gravimetric soil moisture samples (see above), plant roots are observed below a 20 -inch depth in the cover soils, samples of such soil can be retained and sieved to quantify the prevalence of root mass with depth to 30 -inches. Depending on the findings, future sampling and/or investigation can be designed and implemented to assess the significance of root penetration of the bentonite-amended layer; e.g., as part of post-test section demolition.

- Mini-Experiments – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB dams would be best assessed through designed experiments with comparison controls (exclusion of the factor):
    - desiccation cracking of the bentonite-amended layer during dry weather
    - freeze-thaw degradation of the bentonite-amended layer

Such experiments could be implemented in the field with small test microcosms designed to isolate and maximize the effect of the factor and accommodate ready observation. For example, wood frame structures could be built/used to evaluate desiccation cracking or freeze-thaw degradation of the bentonite-amended layer through use of observation panels (i.e., windows) in the side of the wood structure. Soil core samples could also be collected and examined. Irrigation and heating can be used to exclude the stress of dry weather and freezing on the control microcosms.

3.2 Beaches Pilot/Field-Test

Pilot/field-testing of bentonite amendment of beaches will be performed along select portions of the south side crest of the Cell 1E/2E splitter dam (Figure 3-1) to demonstrate systematic and repeatable means and methods of earthwork construction to consistently create and place the bentonite layer in conformance to engineering specifications (see Dams and Beaches Objective 1 above and Attachment A and Attachment G of Reference (2)). A limited volume of Flotation Tailings will be spigoted along the south side crest of the Cell 1E/2E splitter dam for use as a pilot/field-test area prior to the merging of Cells 1E and 2E. The materials used in the pilot/field-test will be representative of Flotation Tailings and the bentonite that will be used in construction of the bentonite amendment layer on Cell 1E/2E beaches. Test sections of beach will be constructed in the spigoted tailings using the means and methods for construction consistent with Construction Specifications (Attachment A and Attachment G of Reference (2)). Construction of the test section will be on the south side crest of the Cell 1E/2E splitter dam to provide a southern exposure aspect to the test section. A southern exposure aspect should provide an increased stress related to solar radiation effects such as elevated temperatures, evapotranspiration and soil moisture deficit. Each of these effects will tend to be adverse to the maintenance of a zone of saturation within the 18-inch thick layer of bentonite-amended tailings.

Methods for monitoring consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of bentonite-amended tailings in the test section beaches (see Dams and Beaches Objective 2 above) will be similar to the methods described for monitoring test section dams (see above). However, because the monitoring of dam test sections will take place prior to the monitoring of the beach test sections, there will be an opportunity to apply "lessons learned" to improve monitoring outcomes and efficiencies for the beach test section.

Monitoring to observe the potential for other factors to inhibit, interfere or degrade the sustained maintenance of a continuous areal zone of saturation (see Dams and Beaches Objective 3 above) within an 18-inch thick layer of bentonite-amended tailings in FTB beaches will be accomplished through the use of the "observe and investigate" method and/or designed mini-experiments as follows:

- Observe and Investigate – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB beaches can be easily observed in the beach test sections and potentially in the existing LTVSMC beaches during routine FTB inspection activities:
    - post construction differential settlement
    - deep plant root penetration of 30-inch cover layer
    - ice scour damage along the shoreline of the FTB Pond

If post construction differential settlement or ice scour damage along the shoreline of the FTB Pond is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of the factors. If in the collection of gravimetric soil moisture samples (see above), plant roots are observed below a 20 -inch depth in the cover soils, samples of such soil can be retained and sieved to quantify the prevalence of root mass with depth to 30 -inches. Depending on the findings, future sampling and/or investigation can be designed and implemented to assess the significance of root penetration of the bentonite-amended layer; e.g., as part of post-test section demolition.

- Mini-Experiments – The following factors that could inhibit, interfere or degrade the zone of saturation in FTB beaches would be best assessed through designed experiments with comparison controls (exclusion of the factor):
    - desiccation cracking of the bentonite-amended layer during dry weather
    - freeze-thaw degradation of the bentonite-amended layer
    - pond water chemistry along the beaches of the FTB

Such experiments could be implemented in the field with small test microcosms designed to isolate and maximize the effect of the factor and accommodate ready observation. These experiments could be designed in a manner similar to that described for evaluation of potential adverse factors effecting FTB dams. It is entirely likely that results of the experiments to assess desiccation cracking and freeze-thaw degradation of the bentonite-amended layer for the FTB dams will be equally applicable to the FTB beaches. The effects of pond water chemistry on the zone of saturation could be assessed in field microcosms that allowed the introduction of pond water to stress the bentonite layer. The control (comparison) microcosms will exclude introduction of pond water and substitute collected rain water.

3.3 Pond Bottom Field-Test

As described in the Adaptive Water Management Plan (Reference (3)), a field-testing and demonstration program of bentonite amendment of the pond bottom will be performed (see Pond Bottom Objective 1 above). The program will be conducted to evaluate the efficacy of the proposed method of bentonite amendment and to select a method that is effective, efficient, and economical. By this test method the hydraulic conductivity of the bentonite-amended Flotation Tailings can first be estimated in the laboratory and necessary bentonite application rates can then be confirmed in the field. The combined hydraulic conductivity and bentonite layer thickness will be specified to achieve performance requirements. Then, as part of the initial FTB Pond reclamation work in combined Cell 1E/2E, the selected construction contractor will be required to demonstrate the means and methods for bentonite application to the pond bottom that will yield the desired uniformity of bentonite application as dictated by pre-application laboratory test results.

As described previously, methods of introducing bentonite to the pond bottom in a relatively uniform manner has been proposed along with two alternate methods of introduction (Figure 3-5 through Figure 3-7):

- broadcasting of bentonite from a GPS route controlled barge (proposed)
- injection/mixing of bentonite with pond bottom from a GPS route controlled barge

- placement of geosynthetic clay liner over the pond bottom from a GPS route controlled barge

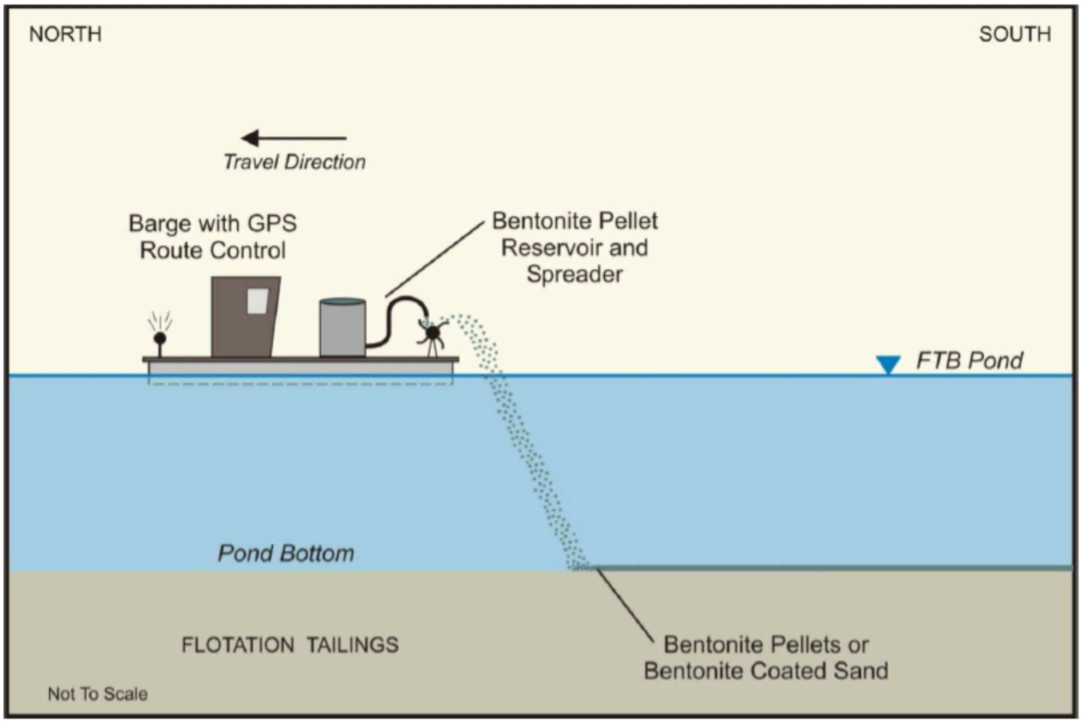


Figure 3-5 Bentonite Broadcasting

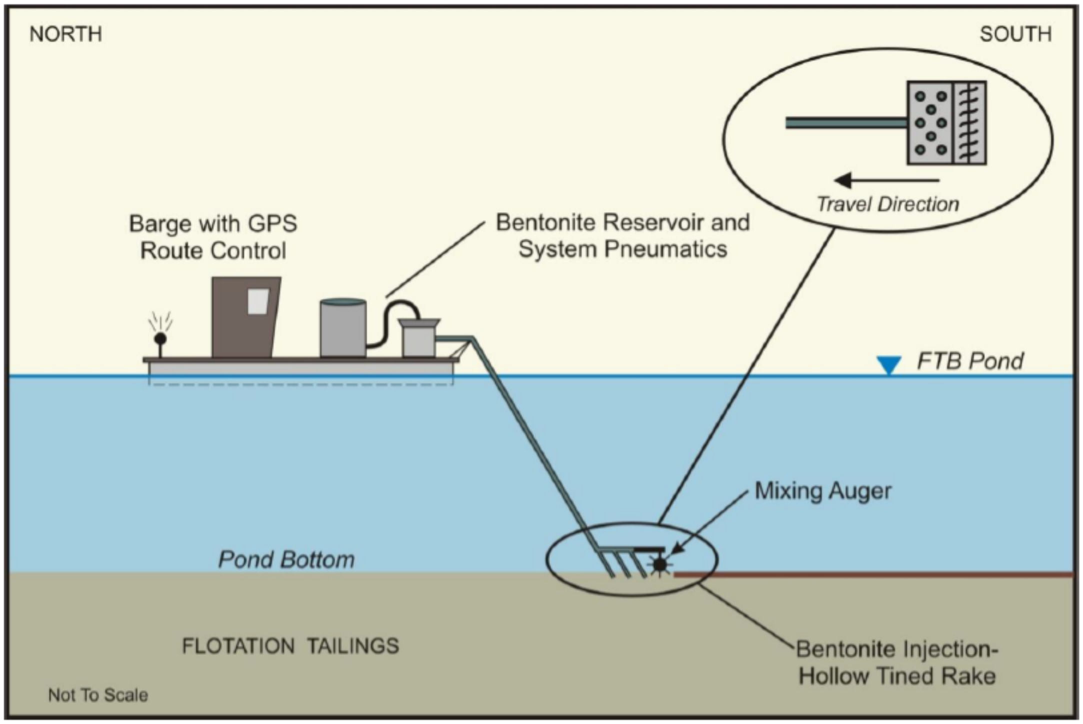


Figure 3-6 Bentonite Injection

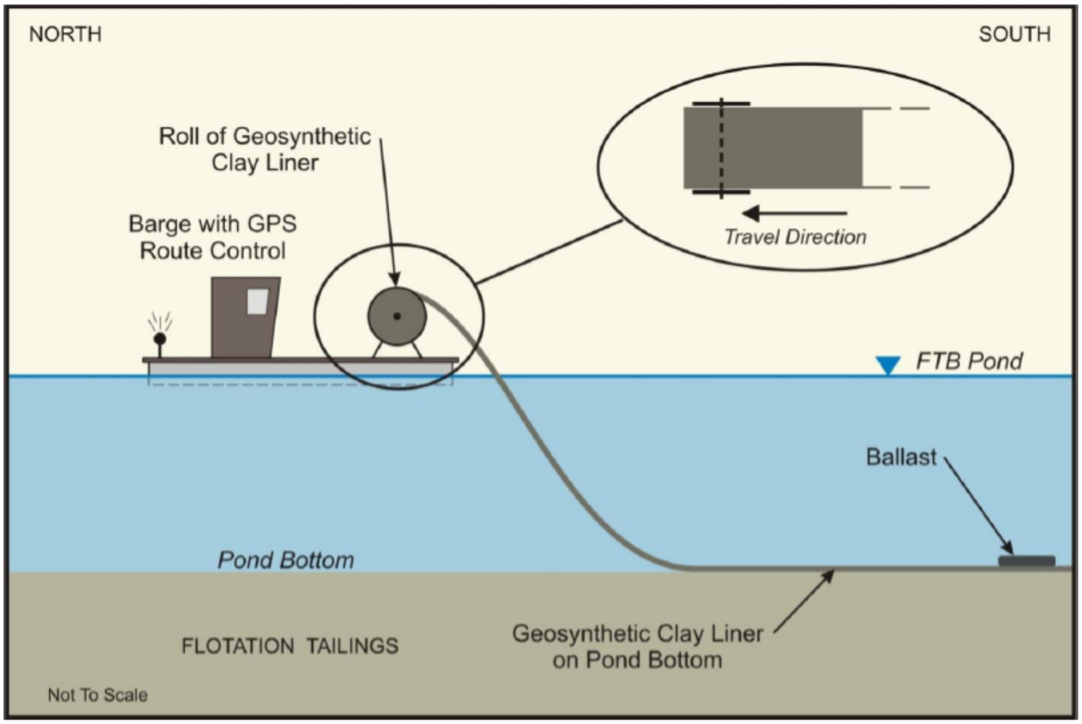


Figure 3-7 Geosynthetic Clay Liner

With the proposed method, bentonite will subsequently settle to the pond bottom where it will hydrate, swell, and due to its inherently low hydraulic conductivity, reduce percolation from the pond bottom. In the second method of bentonite application, the amendment will be mixed with the pond bottom where it will also hydrate, swell, and due to its inherently low hydraulic conductivity, reduce percolation from the pond bottom. Bentonite placed as a geosynthetic clay liner over the pond bottom would similarly hydrate, swell and reduce the percolation from the pond bottom.

All of these methods of bentonite amendment can be simulated in the laboratory using replicated clear PVC columns (Figure 3-8) filled with Flotation Tailings, and FTB pond water. This will allow an evaluation of the performance of varying rates and uniformity of introduction of bentonite amendment via broadcasting and mixing. In addition, air pressure can be applied to the tops of the columns to simulate the hydraulic head of varying pond depths on bentonite amendment performance. The performance metric for evaluation of bentonite amendment would be measured reduction in pond bottom percolation.

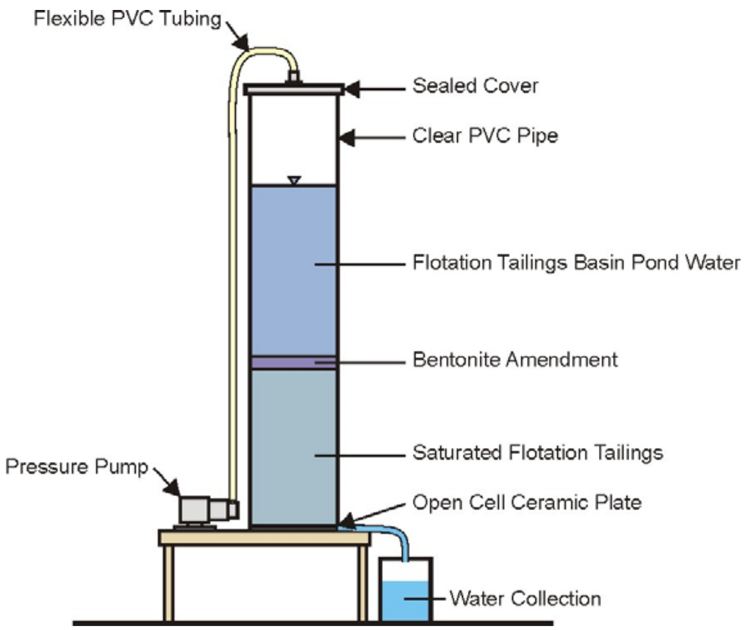


Figure 3-8 Schematic of Laboratory Column and Ceramic Plate to Assess Performance of Bentonite Amendment

Using these lab methods, the volume of water collected from the bottom of the columns over a specified time can be used to calculate the hydraulic conductivity of various methods of bentonite introduction as well as modification of the rates and uniformity of bentonite amendment as compared to control columns (w/o bentonite amendment). Finally, at the conclusion of the simulation, the columns can be disassembled and samples of the bentonite-amended layer can be collected for measurement of bentonite layer thickness.

The combined hydraulic conductivity and bentonite layer thickness will be specified (most likely in pounds per acre) to achieve the performance requirement of sustaining a stable pond level consistent with Reference (2). These specifications will then be used by the contractor to perform a field demonstration of the means and methods necessary to achieve the specifications.

During closure, indirect monitoring methods will be used to confirm the efficacy of the introduction of bentonite into the pond bottom to reduce the percolation from the FTB Pond. Indirect monitoring will include monitoring of the pond level using a continuous recording instrument to confirm achievement of a positive pond water balance (see pond bottom Objective 2 above). If pond level monitoring indicates that an inadequate reduction of pond bottom percolation has been accomplished, bentonite amendment of the pond bottom can be easily repeated if necessary through a series of approximations to reduce the average areal hydraulic conductivity of the pond bottom to sustain a positive pond water balance.

Monitoring to observe the potential for other factors to inhibit, interfere with, or degrade the sustained maintenance of a continuous areal zone of saturation within the bentonite-amended pond bottom tailings will be accomplished through the use of the "observe and investigate" method as follows:

- Observe and Investigate – Factors that could inhibit, interfere with, or degrade bentonite amendment of pond bottom include:
    - post construction differential settlement and/or erosion of shallow pond areas
    - ice scour damage along the shoreline of the FTB Pond

Inspection of the pond bottom could include observation from the pond shoreline or through use of an underwater camera attached to a shallow draft watercraft or attached to a remotely operated underwater drone. If post construction differential settlement, erosion of pond shallows or scour damage along the underwater shoreline of the FTB Pond is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of the factors.

4.0 Testing Schedule

Pilot/field testing of bentonite amendment on dams, beaches and pond bottoms will be performed upon receipt of the necessary permits and initiation of the project. The schedule for performing each type of bentonite pilot/field test is described below. Construction Specifications Section 03100 will be updated as necessary with completion of each Pilot/Field-Test.

4.1 Dams Pilot/Field-Test

Pilot/field-testing of bentonite amendment on dams (as described above) will begin in an area on Cell 2W after permits are issued; and before or concurrent with construction of the first lift of the Cell 2E dam, which will begin to be constructed upon receipt of the necessary permits and initiation of the project. The available pilot/field-test time window will be on the order of two years to accomplish the test section construction and initial monitoring prior to construction of the second FTB dam lift. However, the test section will be maintained for three additional years to evaluate longer term environmental effects on test section performance.

4.2 Beaches Pilot/Field-Test

Pilot/field-testing of bentonite amendment of beaches cannot occur until a section of Flotation Tailings beach can be established on the south crest of the Cell1E/2E splitter dam (tentatively during year-3 of FTB operations). This will provide sufficient time for PolyMet operations personnel to establish and fine-tune their basin operation activities. Once the test zone is established, the available pilot/field-test window to accomplish the pilot/field-test objectives prior the merging of Cells 1E/2E will be about four years.

4.3 Pond Bottom Field-Test

Field demonstration of the bentonite amendment of the pond bottom (as described above) will be focused on demonstrating a systematic and repeatable means and method of introducing bentonite to the pond bottom in a relatively uniform manner. This demonstration will necessarily be delayed until FTB Pond closure so as not to interfere with tailings basin operations during the life of the project, and so that the demonstration can be performed by the contractor selected for the bentonite amendment activities at closure.

Testing of bentonite amendment can be simulated in the laboratory as soon as an adequate volume of representative tailings samples from the FTB pond bottom can be collected from the FTB, possibly in Mine-Year 2.

5.0 References

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3. **Poly Met Mining Inc.** NorthMet Project Adaptive Water Management Plan (v11). May 2017.

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5. *Soil Saturation Determination for Wetland Mitigation Monitoring Using "Rusty Rods" - A Case Study.* **Gibb, Dorothy M. and Coffman, Gretchen C.** [ed.] Kathryn J. Hatcher. Athens : s.n., 1993. Proceedings of the 1993 Georgia Water Resources Conference. pp. 349-351.

6. **Johnson, A. I.** Methods of Measuring Soil Moisture in the Field. *(Geological Survey Water-Supply Paper 1619-U)*. 1962.