NorthMet Project

Adaptive Water Management Plan

Version 12

Issue Date: December 8, 2017

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

I hereby certify that portions of this report were prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota, specifically the proposed design of the Waste Water Treatment System and Non-Mechanical Treatment Systems in Sections 2.2-2.4, 4.2-4.5, and 6.0 of this report.

December 8, 2017

Don Richard, P.E., Barr Engineering Co.
PE #: 21193

Date

I hereby certify that portions of this report were prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota, specifically the preliminary design of the Category 1 Waste Rock Stockpile Cover System and the Flotation Tailings Basin Pond Bottom Cover System in Sections 3.0 and 5.0 of this report.

Thomas J. Radue

December 8, 2017

Tom Radue, P.E. , Barr Engineering Co.
PE #: 20951

Date

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Acronyms, Abbreviations and Units

Acronym	Stands For
ASTM	American Society for Testing and Materials
AWMP	Adaptive Water Management Plan (this document)
CPS	Central Pumping Station
DNR	Minnesota Department of Natural Resources
FEIS	Final Environmental Impact Statement
FTB	Flotation Tailings Basin
GCL	Geosynthetic Clay Liner
gpm	gallons per minute
HBV	Health Based Value
HDPE	High Density Polyethylene
HDS	High Density Sludge
HELP	Hydrologic Evaluation for Landfill Performance Model
HRF	Hydrometallurgical Residue Facility
HRL	Health Risk Limit
ITRC	Interstate Technology and Regulatory Council
LLDPE	Linear Low Density Polyethylene
MPCA	Minnesota Pollution Control Agency
NPDES	National Pollutant Discharge Elimination System
PP	Polypropylene
PRB	Permeable Reactive Barrier
PSB	Permeable Sorptive Barrier
PTM	Permit to Mine
PWQT	Preliminary Water Quality Targets
QA/QC	Quality Assurance and Quality Control
RAA	Risk Assessment Advice
RO	reverse osmosis
SDS	State Disposal System
SRB	sulfate reducing bacteria
USEPA	U.S. Environmental Protection Agency
VFD	Variable Frequency Drive
VSEP	Vibratory Shear Enhanced Process

WWTS	Waste Water Treatment System
ZVI	zero-valent iron

1.0 Introduction

This document describes the Adaptive Water Management Plan (AWMP) for the Poly Met Mining, Inc. (PolyMet) NorthMet Project (Project) and presents the adaptive engineering control designs that will be used to manage water quality impacts. It is one of five interrelated documents that were prepared as part of the environmental review process, and have been incorporated into the permitting process to describe the overall water management plan and fixed engineering controls for the Project. The other four documents integral to the Project water management plan are:

- the Water Management Plan - Mine (Reference (1)) describes overall management of mine water (Category 1 Stockpile Groundwater Containment System, pipes, pumps, and mine water ponds and sumps) and stormwater (dikes, ditches, and sedimentation ponds) and water quality and quantity monitoring plans at the Mine Site

- the Water Management Plan - Plant (Reference (2)) describes overall management of tailings basin seepage (FTB seepage capture systems, pipes, and pumps) and stormwater (dikes, ditches, and sedimentation ponds) and water quality and quantity monitoring plans at the Plant Site

- the Water Modeling Data Package Volume 1 - Mine Site (Reference (3)) defines expected water quality and quantity at evaluation points and describes the models used to estimate water quality and quantity for the Mine Site

- the Water Modeling Data Package Volume 2 - Plant Site (Reference (4)) defines expected water quality and quantity at evaluation points and describes the models used to estimate water quality and quantity for the Plant Site

The Project includes engineering controls to manage potential environmental impacts. Some engineering controls are fixed, and some are adaptive. Fixed engineering controls are described in the Water Management Plan - Mine, Water Management Plan - Plant, Rock and Overburden Management Plan (Reference (5)), Flotation Tailings Management Plan (Reference (6)) and Residue Management Plan (Reference (7)) (collectively referred to as Management Plans). Adaptive engineering controls are described in the AWMP (this document).

The Management Plans will be components of and/or inform the Minnesota Department of Natural Resources (DNR) Permit to Mine (PTM) application, DNR Consolidated Water Appropriation Permit application, and the Minnesota Pollution Control Agency (MPCA) National Pollutant Discharge Elimination System (NPDES) / State Disposal System (SDS) Permit application.

The Waste Water Treatment System (WWTS) will consist of:

- an Equalization Basin Area at the Mine Site

- Mine to Plant Pipelines (MPP), which will convey water between the Mine and Plant Sites

- a WWTS building at the Plant Site, which will house separate treatment trains to treat mine water and tailings basin seepage, and a Lined Pretreatment Basin

Note that some terminology associated with the WWTS has changed since the environmental review process. Changes are associated with the relocation of the mine water treatment trains that were previously at the Mine Site Waste Water Treatment Facility (WWTF) to the Plant Site WWTS, and the relocation of the Mine Site equalization basins, Central Pumping Station, and Construction Mine Water Basin south of Dunka Road. To aid review of documents prepared for the Final Environmental Impact Statement (FEIS) which are referenced in this plan, Appendix A explains WWTS terminology changes.

The Project will rely on mechanical treatment at the WWTS as long as needed to achieve PolyMet's water resource objectives. During the postclosure maintenance phase of the Project, the ultimate goal is to transition to non-mechanical treatment while still ensuring attainment of water resource objectives. Specific water resource objectives associated with engineering controls are defined in Sections 2.1.2 and 4.1.2. The general water resource objective is to achieve compliance with applicable surface water and groundwater quality standards as required upon issuance of the NPDES/SDS permits by the MPCA.

1.1 Purpose and Outline

The purpose of the AWMP is to:

- describe a system for implementing adaptive engineering controls that will achieve compliance with applicable surface water and groundwater quality standards at appropriate evaluation points as estimated by modeling and demonstrated by monitoring

- document performance parameters for adaptive engineering controls for use in modeling and changes to modeling parameters as a result of the application of those controls

- document how mechanical systems will have appropriate operating/maintenance programs and non-mechanical treatment systems will have appropriate development plans until non-mechanical treatment systems can be proven to meet long-term water quality requirements as described in Minnesota Rules, parts 6132.0200 and 6132.3200 and water quality standards during postclosure maintenance, all of which will be financially assured

Sections 2.0 through 6.0 provide details on how the adaptive engineering controls will be implemented to meet water resource objectives. For cover systems (Sections 3.0 and 5.0), proposed designs are presented along with modifications that could be made to achieve required performance. Because achievement of water resource objectives depends on the performance of these engineering controls, these sections include performance modeling and describe how the engineering control will be incorporated into the water quality model. For non-mechanical treatment systems (Section 6.0), conceptual design layouts are presented, with descriptions of the general mechanisms by which treatment will work and past successes in industry. Because achievement of water resource objectives does not depend on the non-mechanical treatment systems, detailed design and field demonstration are deferred until the non-mechanical treatment systems can be designed using relevant monitoring data and actual water to be treated. The outline of this document is:

Section 1.0 Overview including definitions and description of the adaptive management process.

Section 2.0 Overview of Mine Site adaptive water management

Section 3.0 Description of the Category 1 Waste Rock Stockpile Cover System including key factors driving the proposed design, analog examples, potential modified designs, modeling to demonstrate performance, and circumstances that would trigger a design change

Section 4.0 Overview of Plant Site adaptive water management and description of the Waste Water Treatment System (WWTS)

Section 5.0 Description of the Flotation Tailings Basin (FTB) Pond Bottom Cover System including key factors driving the proposed design, analog examples, potential modified designs, and circumstances that would trigger a design change

Section 6.0 Descriptions of Non-Mechanical Treatment Systems for the Category 1 Waste Rock Stockpile, the West Pit overflow, and the FTB, including conceptual design, basis for achieving treatment, degree of use in industry and development plan

This document will be reviewed and updated as necessary. Because this document is intended to evolve through the operations, reclamation and closure, and postclosure maintenance phases of the Project, some design details will not be provided until future versions of this document. A revision history is included at the end of the document.

1.2 Definitions

The following definitions apply in the context of this document and are illustrated in Figure 1-1.

Project: Consists of mining components (e.g., Beneficiation Plant, FTB, pits, stockpiles, Transportation and Utility Corridors), engineering controls (e.g., liners, covers, WWTS), and contingency mitigation that work as a system to accomplish the purpose of the Project and manage potential environmental impacts to water resources during and after mining activities. The Project also includes a process by which 1) adaptive engineering controls are implemented and adapted, if justified, (this document) and 2) mining components are reclaimed and closed. Financial assurance will be provided as part of the Permit to Mine to implement engineering controls necessary to comply with environmental standards and to conduct reclamation, closure, and postclosure maintenance activities.

Engineering Controls: Fixed or adaptive Project elements that control the environmental impacts of the Project to water resources. Fixed engineering controls are not expected to be modified during the life of the Project. Adaptive engineering controls may have their design, operation, and/or maintenance modified before or after installation, if justified, either in scale or type. Except for non-mechanical treatment systems, all engineering controls are included in the water quality modeling of the Project and work in combination with one another to meet water resource objectives. Planned engineering controls are not contingency mitigation.

Adaptive Water Management Plan (AWMP): A management plan that describes adaptive engineering controls. The AWMP references other Management Plans that contain descriptions of fixed engineering controls, contingency mitigation, and other details such as monitoring plans. Contingency mitigation is a component of the overall adaptive management approach, but it is not discussed in the AWMP.

Contingency Mitigation: Feasible actions that could be undertaken should planned engineering controls be unable to achieve compliance with water resource objectives. These are not modeled as part of the Project. If monitoring or modeling indicates contingency mitigation is needed, the proposed contingency mitigation would become a planned engineering control and would then be financially assured. Contingency mitigation is a component of the adaptive management sections contained in Management Plans.

Management Plans: Documents that describe the Project in detail, including fixed and adaptive engineering controls and contingency mitigation. These plans support the basis for the Project as described in relevant permit applications. Note that Management Plans also include adaptive management and contingency mitigation for aspects of the Project other than water resources, including air, wetlands, and geotechnical.

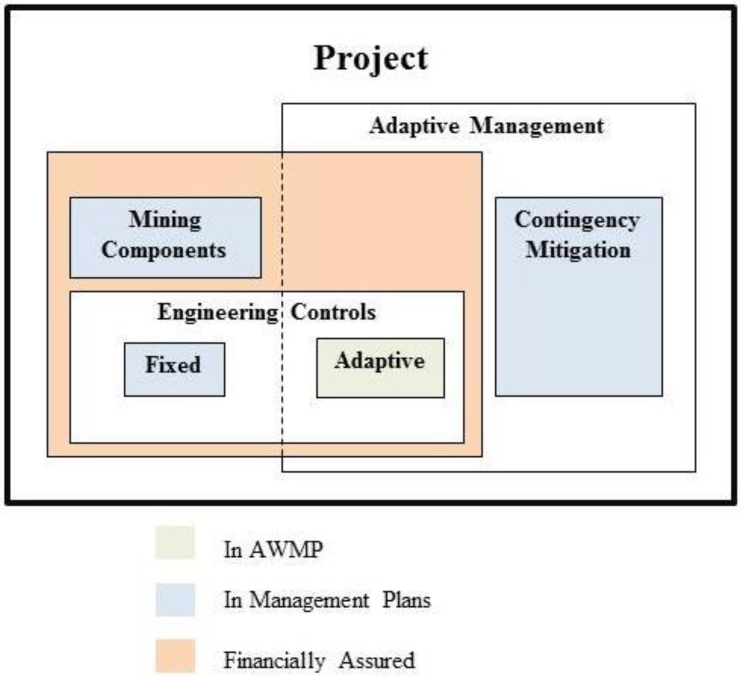


Figure 1-1 Definitions Illustrated

1.3 Adaptive Management Process

Initial engineering controls to manage water quality have been designed by professional engineers following industry-accepted standards and practices. Designs have been developed to maintain compliance with water resource objectives based on current regulations and modeling using integrated probabilistic models of the Mine Site and Plant Site water quality and quantity. Sections 3.1 through 3.3 of Reference (3) describe the modeling framework. The design flexibility afforded by the adaptive management process would be carried out in accordance with the agencies' approvals, would continue to achieve compliance, and would include appropriate testing to demonstrate the performance of any modification before it could be implemented.

The models will be evaluated annually during mining operations, using monitoring results and waste characterization updates, as described in Sections 6 of Reference (1) and Reference (2).

The updated models will be used to determine if the design or operation of the adaptive engineering controls (other than non-mechanical treatment system) should be modified as described in the Modified Design portions of those sections in this document, or if the transition to non-mechanical treatment can be made. The determination that modification or transition is warranted will be based on updated model results, measured water quality, available technology, and regulations in place at the time. If modification or transition is warranted, the proposed adaptive management actions or contingency mitigation measures will be submitted for approval as part of the annual GoldSim model assessment process, as described in the GoldSim Model Assessment Work Plan (Reference (8)).

2.0 Mine Site Adaptive Water Management

2.1 Overview

2.1.1 Mine Site Water Management Systems

Water management at the Mine Site will include fixed engineering controls (Reference (1), Reference (5)) and adaptive engineering controls. Adaptive water management features for the Mine Site will include the Category 1 Waste Rock Stockpile Cover System (Section 3.0) and the WWTS, with equalization basins located at the Mine Site (Section 2.2.4) and mine water treatment components located at the Plant Site (Section 4.0). The design of the Category 1 Waste Rock Stockpile Cover System is adaptive because the cover system design, which is based on information provided from water quantity and quality modeling for the Project, can be modified before construction or adjusted after construction to achieve water resource objectives using the monitoring data and experience gained during Project operations. The design of the WWTS is adaptive because treatment components can be modified and plant capacity can be adjusted to accommodate varying influent streams and discharge requirements that will be defined in the NPDES/SDS Permit and Water Appropriation Permits. In addition, the time the WWTS operates during reclamation and closure to remove constituent build-up from the East Pit and West Pit can be adjusted.

Three types of water will be generated at the Mine Site.

- Mine water includes precipitation, runoff, and collected groundwater (pit dewatering water) that has contacted surfaces disturbed by mining activities, such as drainage collected on stockpile liners, pit dewatering, and runoff contacting ore, waste rock, and Mine Site haul roads. Mine water requiring treatment will be pumped to the equalization basins at the Mine Site and then pumped to the WWTS at the Plant Site. Mine water that does not require treatment, construction mine water, is discussed below.

- Construction mine water, which is a subset of mine water, will be runoff and groundwater from construction areas of mainly saturated mineral overburden (i.e., dewatering). Due to commitments made during the environmental review process, runoff from the Overburden Storage and Laydown Area (OSLA) will also be managed as construction mine water. Construction mine water will be pumped to the FTB for use as plant make-up water or to the East and Central Pits for flooding in later years.

- Stormwater is the result of precipitation and runoff that has contacted natural, stabilized, or reclaimed surfaces and has not been exposed to mining activities. The term stormwater includes non-contact stormwater, construction stormwater[1], and

[1] Stormwater associated with construction activities, as defined in Minnesota Rules, part 7090.0080, subpart 4

industrial stormwater [2] and is expected to meet the requirements of the NPDES/SDS permits for the Project prior to being discharged off-site.

Figure 2-1 shows a timeline for mine water management activities. Additional details on the collection and management of mine water, construction mine water, and stormwater at the Mine Site are described in Section 2.1 and Section 2.2 of Reference (1).

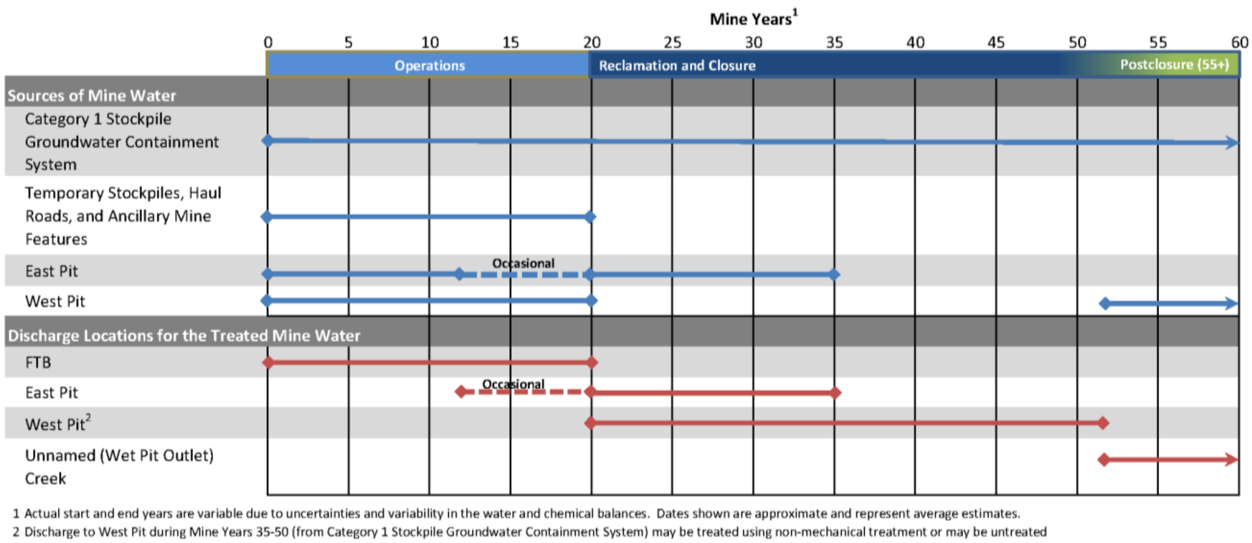


Figure 2-1 Mine Site Water Management Timeline with Mechanical Treatment

During operations, mine water from the waste rock stockpiles, haul roads, OSP, and mine pits will be collected and treated at the WWTS. Because the Project needs water at the Plant Site during this phase, mine water will be pumped to the WWTS for treatment and then routed to the FTB Pond for future use in the beneficiation process. Starting in approximately Mine Year 11, some treated mine water will be pumped back the Mine Site to help manage the water level in the East and Central Pits during backfilling and flooding. Progressive reclamation of the Category 1 Waste Rock Stockpile will begin in approximately Mine Year 14 and will be completed in Mine Year 21, gradually reducing flows of Category 1 Waste Rock Stockpile drainage.

During the reclamation and closure phase, pit dewatering will stop and the West Pit will begin to flood. Water from the flooded and backfilled East and Central Pits will be pumped to the WWTS and treated to remove the flushing load of constituents added as waste rock was backfilled to the pit and the pit walls were inundated. Water from the Category 1 Stockpile Groundwater Containment System will also be pumped to the WWTS and treated. West Pit flooding will be augmented with WWTS discharge and water from the Plant Site.

Treatment of the East Pit flushing load is expected to be complete before the West Pit is flooded. If this occurs, in the period after treatment of the East Pit flushing load is complete (about Mine

[2] Stormwater associated with industrial activities, as defined in Minnesota Rules, part 7090.0080, subpart 6

Year 35) and before the West Pit would overflow (about Mine Year 52), the only influent to the WWTS from the Mine Site would be the water from the covered Category 1 Stockpile Groundwater Containment System, with a very low volume of flow. During this period, water from the groundwater containment system could be discharged directly to the West Pit, depending on water quality and agency approval, or treatment of the water from the groundwater containment system could transition to non-mechanical treatment with gravity discharge to the West Pit as further described in Section 6.2, after the non-mechanical system has been proven to provide appropriate treatment.

The ultimate goal for water treatment during postclosure maintenance is to transition from the mechanical treatment provided by the WWTS to non-mechanical treatment. Because non-mechanical treatment designs are very site-specific and very dependent on the quality of the water to be treated, it is assumed that the WWTS would initially operate in the postclosure maintenance phase. The transition to non-mechanical treatment will take place only after the performance of a non-mechanical system has been tested on-site, proven effective, and approved by the agencies. The two non-mechanical treatment systems at the Mine Site are independent of each other. It is expected that the Category 1 Stockpile Non-Mechanical Treatment System will be deployed earlier than the West Pit Overflow Non-Mechanical Treatment System, as described in Sections 6.2 and 6.3, respectively. As noted previously, water from the Category 1 Waste Rock Stockpile will continue to be treated by the WWTS until non-mechanical treatment with gravity discharge to the West Pit has been proven to provide appropriate treatment. This may occur during closure or postclosure maintenance.

During postclosure maintenance, water from the West Pit will be maintained below the natural overflow elevation by pumping water to the WWTS. Operation of the WWTS will occur year-round with the discharge directed to Unnamed (West Pit Outlet) Creek, which flows into the Partridge River, until non-mechanical treatment has been proven effective at achieving water quality objectives. The WWTS will operate as long as necessary and will be financially assured.

2.1.2 Water Resource Objectives

The water resource objectives at the Mine Site are:

- to beneficially reuse mine water during the operations, reclamation, and closure phases of the Project
- to manage mine water during operations, reclamation, closure, and postclosure maintenance to meet the applicable groundwater standards at points of compliance at the Mine Site
- meet NPDES/SDS permit conditions with regard to stormwater discharge limits
- to meet the applicable surface water standards at the point where Project water will be discharged to the Partridge River via Unnamed (West Pit Outlet) Creek

The applicable discharge limits and points of compliance will be finalized in NPDES/SDS permitting. At this time, the applicable surface water quality standards (Table 1-3 and Table 1-4 of Attachment C of Reference (3)) are assumed to be the applicable discharge limits and the applicable groundwater standards (Table 1-2 of Attachment C of Reference (3)) are assumed to be applicable at the property boundary.

Meeting these objectives requires the integrated operation of the fixed engineering controls described in Section 2.0 of Reference (1) and the adaptive engineering controls described in Sections 2.0, 3.0, and 4.0 of this document.

2.1.3 Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in Water Appropriation and NPDES/SDS permitting. Water quantity monitoring will also be conducted in accordance with the Water Appropriation permitting requirements, while water quantity monitoring will be conducted in accordance with the NPDES/SDS permitting requirements. The program includes monitoring the flow and/or water quality of water from Mine Site Project features, stormwater, groundwater, and surface water. See Section 5 of Reference (1) for details.

2.2 Mine Water Treatment

2.2.1 Mine Water Treatment Targets

The Project is divided into phases: construction, operations, reclamation, closure, and postclosure maintenance. During all phases of the Project except construction, the mine water treatment trains at the WWTS will be operated to provide water that:

- meets the needs of the Project when the water is being treated for recycling or re-use
- meets requirements for discharge to the environment when the Project has excess water that cannot be reused

Water quality standards, NPDES/SDS permit conditions, and Project monitoring results will be used as a basis for defining the specific treatment targets needed during each phase. Treatment targets will vary over time based on the destination of the treated mine water. During operations, treated mine water will be routed to the FTB Pond. During reclamation and closure, some will be routed to the mine pits to accelerate flushing and flooding, and during postclosure maintenance, it will be discharged to the environment. The proposed treatment targets for treated mine water are summarized in Table 2-1.

Table 2-1 Proposed Water Quality Targets (PWQTs) for Mine Water Treatment

Parameter[1]	Operations	Recla-mation and Closure	Post-closure	Basis
Metals/Inorganics (µg/L, except where noted)				
Aluminum	125	125	125	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Antimony	31	31	31	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Arsenic	10	10	4	Operations, reclamation and closure: Minnesota Rules, part 7050.0221 Class 1 (Primary MCLs) Postclosure maintenance: preliminary impact assessment
Barium	2,000	2,000	2,000	MN Groundwater (HRL, HBV, or RAA)
Beryllium	4	4	4	Minnesota Rules, part 7050.0221 Class 1 (Primary MCLs)
Boron	500	500	500	Minnesota Rules, part 7050.0224 Class 4A (chronic standard)
Cadmium[2]	5.1	4.2	2.5	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
Chromium[3]	11	11	11	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
Cobalt	5	5	5	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Copper[2]	20	17	9.3	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
Iron	300	300	300	Minnesota Rules, part 7050.0221 Class 1 (Secondary MCLs)
Lead[2]	10.2	7.7	3.2	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Manganese	50	50	50	Minnesota Rules, part 7050.0221 Class 1 (Secondary MCLs)
Nickel[2]	113	94	52	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
Selenium	5	5	5	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
Silver	1	1	1	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Thallium	0.56	0.56	0.56	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)

Parameter(1)	Operations	Recla-mation and Closure	Post-closure	Basis
Zinc(2)	260	216	120	Minnesota Rules, part 7052.0100 Class 2B (chronic standard)
General Parameters (mg/L, except where noted)				
Chloride (mg/L)	230	230	230	Minnesota Rules, part 7050.0222 Class 2B (chronic standard)
Fluoride (mg/L)	2	2	2	Minnesota Rules, part 7050.0221 Class 1 (Secondary MCLs)
Hardness (mg/L)(4)	250	200	100	Hardness PWQT chosen to establish PWQTs for metals with a hardness based standard
Sodium	60% of cations	60% of cations	60% of cations	Minnesota Rules, part 7050.0224 Class 4A (chronic standard)
Sulfate (mg/L)	250	150	9	Operations: Minnesota Rules, part 7050.0221 Class 1 (Secondary MCLs) Reclamation and Closure: (5) Postclosure Maintenance: M.R. 7050.0224 Class 4A (chronic standard)

M.R.= Minnesota Rules, MCLs = Maximum Contaminant Levels, PWQT = Preliminary Water Quality Targets

(1) The Proposed Water Quality Targets parameter list has been updated from RS29T to include only the parameters modeled in GoldSim
(2) Standard based on hardness
(3) The Chromium (+6) standard of 11 µg/L is used rather than the total Chromium standard to be conservative.
(4) Minnesota Rules, part 7050.0223 Class 3C standard for hardness is 500 mg/l
(5) During the reclamation and closure phases, no water is discharged from the Mine Site. The WWTS mine water treatment effluent sulfate concentration going to the East and West Pits during these phases was established based on modeling of treatment of the East Pit porewater to remove sulfate load and the East Pit and West Pit mine water quality needed to maintain compliance with groundwater standards at the Mine Site.

2.2.2 Mine Water Treatment Phases

The Project phases when water treatment is planned are described below in terms of the sources of mine water to the WWTS (Section 4.0), the discharge location of the treated mine water, and the purpose of treatment.

2.2.2.1 Operations

During operations, the WWTS will treat mine water from the waste rock stockpiles, haul roads, OSP, and mine pits. For approximately the first 10 years, treated mine water will be routed to the FTB Pond for reuse in the beneficiation process. The purpose of mine water treatment during this phase will be to maintain the water quality in the FTB Pond at concentrations that do not have an adverse impact on beneficiation operations or future reclamation of the FTB.

Starting in Mine Year 11, some treated mine water will be sent to the East Pit to augment flooding as the pit is backfilled, with the remainder of the treated mine water continuing to go to the FTB Pond. Starting in Mine Year 17, some treated mine water will be sent to the combined East and Central Pits (herein referred to as the East Pit) to augment flooding of these pits.

2.2.2.2 Reclamation and Closure

During reclamation (while the West Pit is flooding), the WWTS will continue to treat mine water from the Category 1 Stockpile Groundwater Containment System and water from the East Pit to remove the flushing load of constituents added as waste rock and saturated mineral overburden was backfilled into the East Pit and the pit walls were inundated. The purpose of treatment will be to manage the mass of dissolved constituents in the East and West Pits such that compliance with groundwater standards at the Property boundary can be achieved if there is flow out of the pits into groundwater.

During closure, in approximately Mine Year 35, the East Pit flushing will be complete and the West Pit will still be flooding. During this phase, the only mine water requiring treatment will be from the Category 1 Stockpile Groundwater Containment System. This is expected to be a very small volume of flow after the Category 1 Waste Rock Stockpile Cover System (Section 3.0) has been installed. As noted in Section 2.1.1, during this phase, water from the groundwater containment system could be discharged directly to the West Pit, depending on water quality and agency approval, or treatment of the water from the groundwater containment system could transition to non-mechanical treatment with gravity discharge to the West Pit as further described in Section 6.2, after the non-mechanical system has been proven to provide appropriate treatment.

2.2.2.3 Postclosure Maintenance

During postclosure maintenance, the WWTS will treat water from the Category 1 Stockpile Groundwater Containment System as well as water from the West Pit as needed to prevent overflow. A portion of the WWTS discharge, approximately equal to the West Pit outflow and Category 1 Stockpile Groundwater Containment System outflow will be conveyed to Unnamed (West Pit Outlet) Creek, which flows into the Partridge River. The purpose of treatment will be to produce water that will meet the appropriate discharge limits for discharge to the receiving water.

The ultimate goal for mine water management and treatment is to transition from the mechanical treatment provided by the WWTS to non-mechanical treatment systems for the Category 1 Stockpile Groundwater Containment System and the West Pit overflow as described in Sections 6.2 and 6.3, respectively. As noted in Section 2.1.1, the non-mechanical treatment system for the water from the Category 1 Stockpile Groundwater Containment System could potentially be deployed during closure, while the West Pit is still flooding. It is assumed that the WWTS will continue to operate during postclosure maintenance until the transition to non-mechanical treatment occurs. The transition from mechanical to non-mechanical treatment will occur only after the site-specific designs for the non-mechanical systems have been proven effective during pilot-testing and approved by the appropriate regulatory agencies as noted in Section 6.0.

2.2.3 Design Basis for Mine Water Treatment

The design of the required processes for treatment of mine water at the WWTS (Section 4.0) will be based upon the following factors:

- the quantity and quality of the mine water, from various locations, requiring treatment during various phases of the Project
- the purpose of mine water treatment for each phase of the Project, as described in Section 2.2.2

The expected quantity and quality of the mine water that will be delivered to the WWTS is based on the most recent Mine Site water quality modeling (Reference (3)). The following subsections provide a summary of the estimated influent water quantity and quality for the mine water flows to the WWTS.

2.2.3.1 Mine Water Quantities

The estimated quantities of mine water, by source, are summarized in Table 2-2 for operations, reclamation and closure, and postclosure maintenance. The water quantity estimates summarized in Table 2-2 are the 90th percentile of the average annual flow rates from each of the mine water source areas for the design years used to evaluate Mine Site water quality modeling results (Reference (3)). Based on the modeling results, the design year for operation was selected as Mine Year 14. The design year selected for reclamation and closure was Mine Year 25. The design year for postclosure maintenance was Mine Year 75. The design year for each phase was selected to represent the upper bound of the average annual flows during the phase of operations after eliminating early and late year variability associated with transitioning between phases. Seasonal flows in other years were also considered n evaluating potential treatment system sizing as described in Section 2.2.4.

Table 2-2 Mine Water Flows to the WWTS

Source	90th Percentile Estimated Average Annual Flow (gpm)(1)		
	Operations(2)	Reclamation and Closure(3)	Postclosure Maintenance(4)
East Pit	1,035	1,750(5)	--
Central Pit	55	--	--
West Pit	365	--	400
Haul Roads and Rail Transfer Hopper	65	--	--
Category 1 Stockpile Groundwater Containment System	375	10	10
Category 2/3 Waste Rock Stockpile	145	--	--
Ore Surge Pile	25	--	--
Category 4 Waste Rock Stockpile	0	--	--
Total(1)	2,065	1,760	405

(1) Flows are rounded to the nearest 5 gpm; column values do not sum to 90th Percentile total value due to probabilistic modeling (P90 of totals is not equivalent to the total of the P90s).
(2) Estimates based on Reference (3) for Year 14 (Design Year), 90th Percentile.
(3) Estimates based on Reference (3) for Mine Year 25, 90th Percentile.
(4) Estimates based on Reference (3) for Mine Year 75, 90th Percentile.
(5) Flow value is total of East and Central Pits.

Actual flow rates of mine water to the WWTS from each of the Mine Site sources will vary throughout the 20-year operating phase of the Project. For example:

- the volume of mine water from the waste rock stockpiles will generally increase through Mine Year 7, be relatively constant up until Mine Year 12, and then decrease from Mine Year 13 to Mine Year 20

- beginning in Mine Year 11, waste rock from the temporary Category 4 and Category 2/3 Waste Rock Stockpiles will be moved to the East Pit for subaqueous disposal so there will no longer be mine water from these stockpiles requiring treatment

- mine water from the East Pit (including the Central Pit) will increase through Mine Year 10, then decrease for a brief period while the waste rock relocated to the East Pit is covered by groundwater flowing into the pit and supplemented with treated mine water from the WWTS

- between Mine Year 13 and Mine Year 16, some mine water may need to be removed from the East Pit to maintain the desired water level, which is designed to keep as much of the relocated waste rock submerged as possible while still providing safe working conditions in the Central Pit

- starting in Mine Year 16 when the Central Pit mining is completed, the East and Central pit dewatering will be reduced as these pits are allowed to flood; dewatering will only be performed if needed to keep water levels five feet below the surface of the backfilled waste rock during backfilling

- dewatering from the West Pit will increase rapidly through Mine Year 12 and then remain relatively constant through Mine Year 20

Mine water from other sources, including haul roads and ore handling areas, is relatively constant throughout Project operations.

In addition to long-term variations in flows during operations at the Mine Site, mine water flows are anticipated to fluctuate seasonally. The seasonal variation in mine water flow including the spring flood, average summer, and average winter flow rates are summarized in Table 2-3. The equalization basins that will be used during operations at the Mine Site (Section 2.2.4) have been designed using a three-day, high-volume pit dewatering event, which may occur during the spring flood season. The estimated discharge rates from this three-day design event are also included in Table 2-3.

During reclamation and closure, mine water flows to the WWTS will originate primarily from the flooded East Pit and the Category 1 Stockpile Groundwater Containment System. The flows during reclamation are expected to vary less than during operations, both annually and seasonally, because flows will be originating from these two stable components of the Project.

During postclosure maintenance, the two remaining sources of mine water to the WWTS will be the Category 1 Stockpile Groundwater Containment System and the West Pit. Because the West Pit will receive direct precipitation, it is expected that the flow will vary seasonally. The majority of this variability will be dampened by the volume of the West Pit and management of the West Pit water level. However, a spring event will be considered in the sizing of the WWTS processes for postclosure maintenance to manage periods of high water levels and associated high flows.

Table 2-3 Seasonal Variations in Mine Water Flows

Source	Estimated Spring Flood (3-day)/Spring Flood (1-month)/ Average Summer/ Average Winter Flow (gpm)							
	Operations(1)				Reclamation and Closure(2)		Postclosure Maintenance(3)	
	Estimated Spring Flood (3-day)(4),(7),(8)	Spring Flood (1-month)(4),(7),(8)	Average Summer(5),(6)	Average Winter Flow(5),(6)	Average Summer(5),(6)	Average Winter Flow(5),(6)	Average Summer(5),(6)	Average Winter Flow(5),(6)
East Pit	0	0	1,090	910	1750	1750	0	0
Central Pit	0	0	80	15	0	0	0	0
West Pit	2,640	705	540	75	0	0	330	310
Haul Roads & Rail Transfer Hopper	130	130	100	25	0	0	0	0
Category 1 Stockpile Groundwater Containment System	1,120	840	570	150	6	2	6	2
Category 2/3 Waste Rock Stockpile	405	405	220	55	0	0	0	0
Ore Surge Pile	70	70	35	10	0	0	0	0
Category 4 Waste Rock Stockpile	0	0	0	0	0	0	0	0
Total	4,505	2,290	2,665	1,320	1790	1750	335	310

(1) Flows are rounded to the nearest 5 gpm; Estimates for average summer and winter are based on Reference (3) for Mine Year 14, average
(2) Flows are rounded to the nearest 5 gpm; Estimates for average summer and winter are based on Reference (3) for Mine Year 25, average.
(3) Flows are rounded to the nearest 5 gpm; Estimates for average summer and winter are based on Reference (3) for Mine Year 75, average.
(4) Source: Conventional Hydrology Modeling December, 2014.
(5) Source: GoldSim Model Simulations, Version 6.0, submitted December 2014.
(6) Average total flow to WWTS shown; column values do not sum to total value in some cases due to probabilistic modeling.
(7) Stockpile spring flood flows include surface water flows only, there is no groundwater component for stockpiles.
(8) Spring flood flow calculations for operations flows will be used to size the equalization basins.

2.2.3.2 Mine Water Quality

During operations, a wide variety of mine water quality is anticipated, so mine water flows to the WWTS will be separated into two streams and routed into two different treatment processes as described in Section 4.3.1. Mine water from the temporary Category 2/3 Waste Rock Stockpile, OSP, and Category 4 Waste Rock Stockpile is anticipated to contain high concentrations of metals and sulfate throughout Project operations. Mine water containing relatively high concentrations of metals and sulfate will be routed to the High Concentration Equalization (HCEQ) Basin. Mine water from mine pit dewatering is anticipated to contain relatively low concentrations of metals and sulfate throughout the operating phase of the Project. Mine water containing relatively low concentrations of metals and sulfate will be routed to the Low Concentration Equalization (LCEQ) Basins. The Category 1 Stockpile Groundwater Containment System seepage is anticipated to contain low concentrations of metals and sulfate in Mine Year 1, with concentrations of these constituents increasing through Mine Year 10 and remaining constant thereafter. This source will be routed to the Low Concentration Equalization Basins.

Mine Site water quality from the various waste rock stockpiles and operational areas was estimated using the model described in Reference (3). Large Table 1, Large Table 2, and Large Table 3 show the 90th percentile water quality estimates that correspond with the average annual flow from each mine water source shown in Table 2-2 as well as the quality of the blended streams in the HCEQ Basin and the LCEQ Basins during operations, reclamation and closure, and postclosure maintenance. Large Table 4 summarizes the expected quality of blended mine water flows that will be routed to the WWTS during operations, reclamation and closure, and postclosure maintenance.

During reclamation and closure, the quality of the mine water pumped from the flooded East Pit and the Category 1 Stockpile Groundwater Containment System are expected to be relatively stable. Both sources will have relatively high concentrations of sulfate and other constituents. The configuration of the equalization basins at the Mine Site, which during operations facilitates routing mine water to two different treatment processes, will be removed during reclamation.

During postclosure maintenance, it is anticipated that the quality of the water collected by the Category 1 Stockpile Groundwater Containment System will be consistent with the values seen during reclamation. The quality of the West Pit overflow will likely have significantly lower concentrations than the water from the Category 1 Stockpile Groundwater Containment System.

2.2.4 Mine Site Water Management Features

Mine water will be collected and stored at the Mine Site prior to being pumped to the WWTS at the Plant Site for treatment and reuse or discharge. The Equalization Basin Area at the Mine Site will be designed to accommodate the flows presented in Table 2-3, including the peaks in flow rates, for example the estimated spring flood (3-day and 30-day).

The primary features within the Equalization Basin Area will include:

- HCEQ Basin
- Two LCEQ Basins
- Construction Mine Water Basin

- Central Pumping Station
- Construction Mine Water Pumping Station

Mine water will be routed from the collection systems to the Central Pumping Station (CPS) located in the Equalization Basin Area. Mine water containing relatively higher concentrations of metals and sulfate will flow from the CPS to the HCEQ Basin, and then be routed through the CPS to the mine water chemical precipitation treatment train at the WWTS via the High Concentration Mine Water Pipeline. Mine water containing relatively lower concentrations of metals and sulfate will flow from the CPS to the LCEQ Basins, and then be routed to the mine water filtration treatment train at the WWTS via the Low Concentration Mine Water Pipeline.

2.2.4.1 High Concentration Equalization Basin

Flow from high-concentration sources will be routed into the HCEQ Basin, as necessary, prior to being pumped to the WWTS for treatment in the mine water chemical precipitation train. The HCEQ Basin will be sized to provide sufficient storage to:

- contain the spring flood event, including a 3-day peak flow and a 30-day average flow
- provide capacity for a 100-year rainfall event within 60 days after the spring event when pumping out at the design capacity of the chemical precipitation treatment train.

For the HCEQ basin, the maximum spring event will be in Mine Year 10. These values were used to size the basin.

2.2.4.2 Low Concentration Equalization Basins

Flow from low-concentration sources is routed into the two LCEQ Basins, as necessary, prior to being pumped to the WWTS via the Low Concentration Mine Water Pipeline to the mine water filtration train. Together, the LCEQ Basins will be sized to provide sufficient storage to:

- contain the spring flood event, including a 3-day peak flow and a 30-day average flow
- provide capacity for a 100-year rainfall event within 60 days after the spring event when pumping out at the design capacity of the chemical precipitation treatment train.

For the LCEQ Basins, the maximum flow is estimated to occure in the spring of Mine Year 10. These values were used to size the LCEQ Basins.

2.2.4.3 Equalization Basin Area Layout

The Equalization Basin Area will be located south of Dunka Road and the Main Line Railroad. The location for the Equalization Basin Area is shown on Large Figure 1.

2.3 Engineering Control Performance

The overall performance of the WWTS will represent a compilation of the performance of each individual treatment unit. The expected treatment performance for the WWTS is described in Section 4.4.

2.4 Adaptive Management

To achieve the specific purpose of treatment for each of the Project phases, the operating configuration and the operating requirements of individual process units within the WWTS and the capacity of the WWTS can be modified. Additionally, the arrangement of sources going to each equalization basin can be adjusted at the Mine Site. Thus, the WWTS is considered an adaptive engineering control. The WWTS treatment processes can be adapted, as necessary, to meet the actual conditions encountered during the Project and estimated by water quality monitoring and continued model updating as described in Section 4.5.

3.0 Category 1 Waste Rock Stockpile Cover System

3.1 Project Feature

The Category 1 Waste Rock Stockpile Cover System is an engineered geomembrane cover system that will be implemented progressively starting in Mine Year 14. It is expected to be fully constructed by the end of Mine Year 21. The Category 1 Waste Rock Stockpile is the only permanent waste rock stockpile. It will contain about 168 million tons of low sulfur (maximum of 0.12%; average 0.06%) waste rock that is not projected to generate acid but is projected to release dissolved solids, including sulfate and metals (Section 2.1 of Reference (5)).

The Category 1 Waste Rock Stockpile Cover System will work together with the Category 1 Stockpile Groundwater Containment System, described in Section 2.1.2 of Reference (5), to manage constituent load from the stockpile. Groundwater flow modeling indicates that the groundwater containment system is capable of capturing 91% to greater than 99% of the mine water from the Category 1 Waste Rock Stockpile (Section 2.1.2.3 of Reference (5)). Mine water collected by the groundwater containment system will be treated at the WWTS. Modeling also indicates that the majority of the remaining drainage eventually flows to the mine pits (Section 2.1.2.3 of Reference (5)).

3.2 Planned Engineering Control

3.2.1 Purpose

The purpose of the Category 1 Waste Rock Stockpile Cover System is to reduce the constituent load from the stockpile to the WWTS and the West Pit during the operations, reclamation, closure, and postclosure maintenance phases. This is accomplished by reducing the percolation of water into the stockpile. The lower percolation rate reduces the volume of stockpile drainage and stabilizes the concentration of constituents in the drainage at their concentration caps, resulting in lower constituent loading leaving the stockpile. The cover system percolation rate is the design parameter that controls how much water will flow into the stockpile – a lower percolation rate means less flow into the stockpile.

3.2.2 Design

The engineered geomembrane cover system to be used for reclamation of the Category 1 Waste Rock Stockpile will meet the applicable requirements of Minnesota Rules, part 6132.2200, subpart 2, items B and C. Attachment B of Reference (5) presents the drawing set for the cover system. Section 3.3.1 provides a discussion of the basis for the design percolation rate. The Category 1 Waste Rock Stockpile Cover System (Figure 3-1) will consist of, from top to bottom: 18 inches of rooting zone soil consisting of on-site overburden mixed with peat soils as needed to provide organic matter, 12 inches of granular drainage material with drain pipes to facilitate lateral drainage of infiltrating precipitation and snowmelt off the stockpile cover, a geomembrane barrier layer of 40-mil (40/1000 of an inch) thickness and 6 inches of bedding layer soil below the geomembrane. Included but not shown on the drawings will be additional soil below the 6-inch soil bedding layer, placed as needed to fill surface voids in the waste rock, thereby providing a uniform foundation layer for the 6-inch soil bedding layer.

The cover system profile is modeled after requirements of Minnesota Rules, part 7035.2815, subpart 6, item D, which requires at least a 30-mil geomembrane barrier layer, at least a 6-inch thick granular drainage layer, and a top layer at least 18 inches thick. The Category 1 Waste Rock Stockpile cover utilizes a thicker geomembrane (approximately 40-mil instead of 30-mil) to better facilitate seaming. However, 30-mil is an adequate thickness to perform the required hydraulic barrier function. Because the geomembrane is designed as a hydraulic barrier and not as a structural element in the cover system, the higher strength associated with thicker geomembranes is not needed. In addition, a thicker granular drainage layer (12-inch instead of 6-inch) is used for improved hydraulic performance and reduced risk of geomembrane damage during drainage layer placement. While Minnesota Rules, part 7035.2815 is applicable to mixed municipal solid waste land disposal facilities rather than waste rock stockpiles, these rules do serve as a reasonable guide as to the MPCA-accepted cover system profile for closure of waste storage facilities in Minnesota.

The stockpile slope, at 3.75 (horizontal) to 1 (vertical) (3.75H:1V), is flat enough that routine cover construction methods will be utilized (i.e., geomembrane panel deployment from crest to toe of slope, thin-spreading of lateral drainage layer material from defined truck unloading locations, placement of remaining cover soils and establishment of vegetation). The cover system will be placed on top of the waste rock contained in the stockpile after the stockpile has been appropriately shaped and prepared.

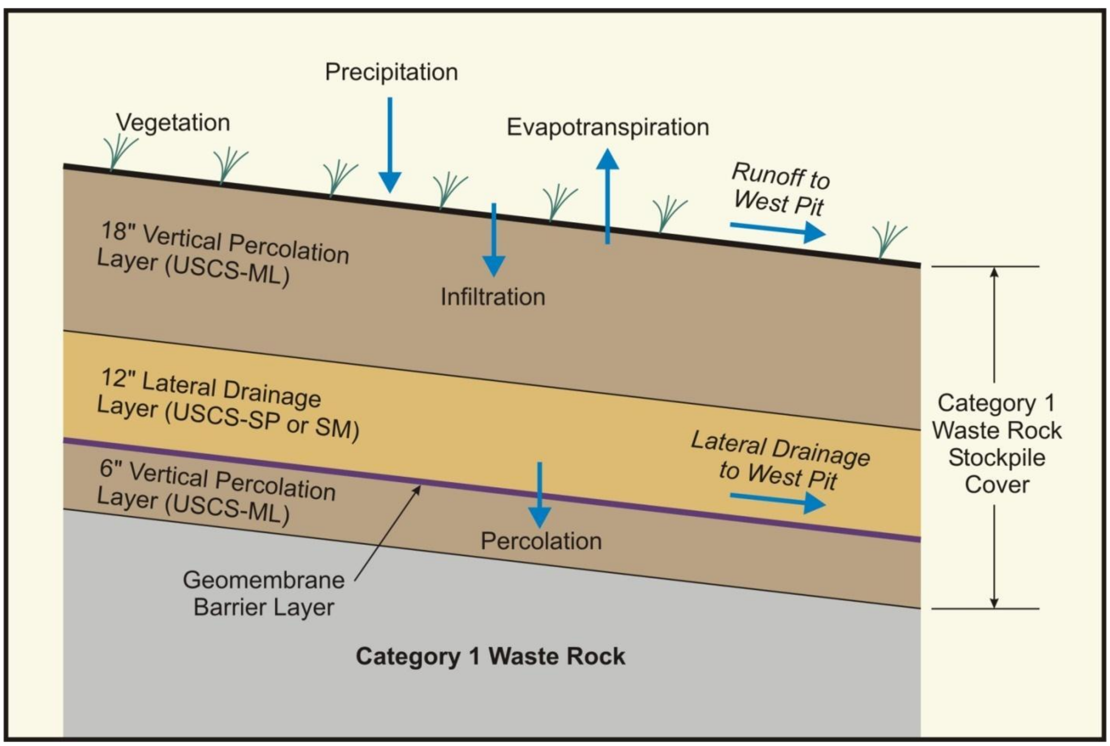


Figure 3-1 Conceptual Cross-Section: Category 1 Waste Rock Stockpile Cover System

The construction materials (except for the geomembrane) are expected to consist of unsaturated mineral overburden, peat, and other materials to be developed from on-site sources approved by the DNR prior to construction. See Section 2.2.3 of Reference (5) for details on Mine Site construction materials. Materials used above the geomembrane are assumed to be non-reactive and to produce chemistry in the runoff water similar to background. On-site borrow sources will be supplemented by off-site sources as needed, identified in conjunction with material type and quantity requirements determined during construction.

To minimize the potential for clogging of the granular drainage material, shallow-rooted grasses will be specified for the cover vegetation seed mix. This is standard practice for most cover systems despite the increased interest in utilizing deeper rooted vegetation types, shrubs, and trees for closure vegetation. Surface drainage channels and downchutes will aid in directing clean surface water runoff from the stockpile, thereby reducing infiltration and build-up of hydraulic head in the geomembrane barrier layer and cover soils. Water in the lateral drainage layer will be collected by perforated drain pipes (not shown in Figure 3-1; see Attachment B of Reference (5)) placed in the lateral drainage layer. The pipes will discharge to downchutes (Section 3.2.2.3) and subsequently to the stormwater ditch to combine with other stormwater runoff.

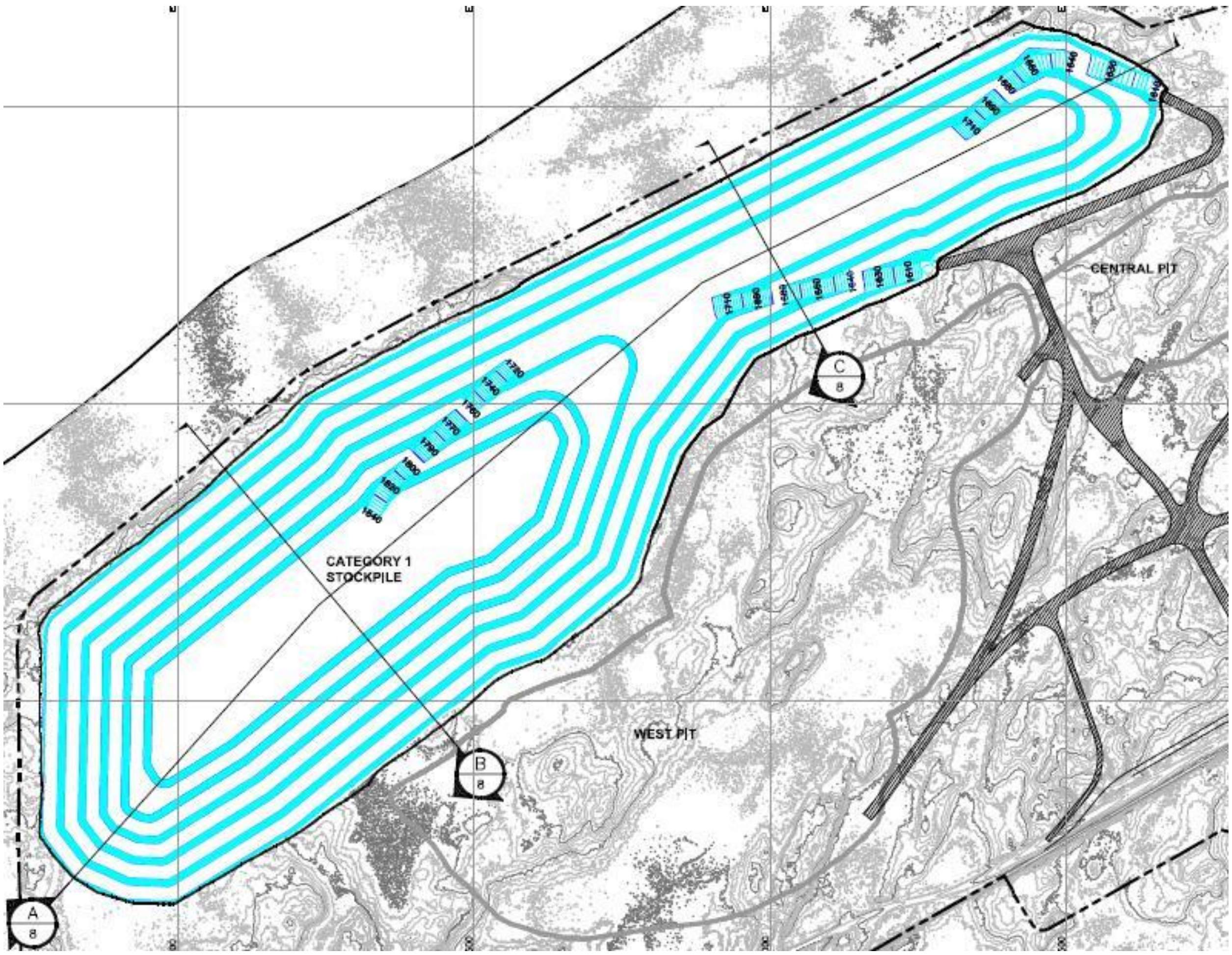
The stockpile has been designed to accommodate the geomembrane, as shown in Figure 3-2 and Figure 3-3, which show the Mine Year 13 stockpile interim configuration with waste rock at the angle of repose and the reclamation configuration with waste rock at 3.75H:1V fill slopes, respectively. The stormwater drainage features have been evaluated for the water modeling at the Mine Site and are described below.

As the cover is applied, the corresponding sections of the mine water ditch component of the Category 1 Groundwater Containment System will be covered, diverting non-impacted surface water runoff from the stockpile cover to the stormwater ditch system. Containment system pipe risers will be extended to finished cover grade to provide access for pipe cleanout (Section 7.1.1.2 of Reference (5)).

Prior to placement of the geomembrane cover on the Category 1 Waste Rock Stockpile, the stockpile will be locally contoured to provide some topographic variety to the surface and to assist in the development of a surface drainage network. The interbench slope will be reduced to 3.75H:1V to facilitate placement of the geomembrane cover system. Drainage channels will be constructed on nominal 30-foot wide benches, constructed at nominal 40-foot vertical intervals at 2% typical gradients. A drainage system using the benches has been developed to manage stormwater runoff from the cover. When reclamation contouring is complete, the geomembrane cover system will be constructed and seeded with grasses.

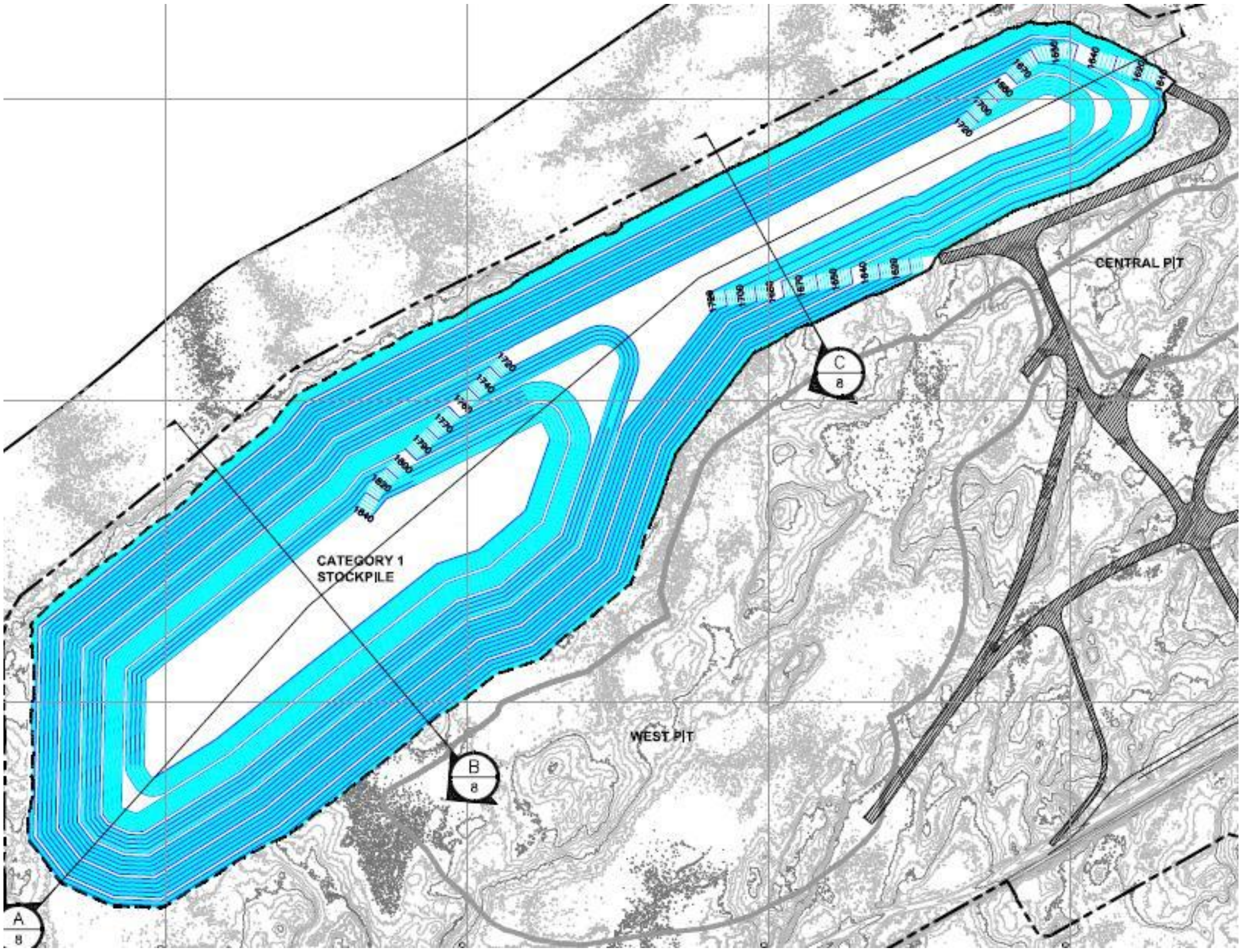
Stormwater runoff from the cover will be managed using a system of top channels and outslope bench channels that convey runoff to a series of riprap-lined downchutes. The design of top channels, outslope channels and downchutes was conducted using design criteria related to:

- the design storm event
- watershed characteristics
- design flow rates
- flow velocities
- erosion control



(see Drawing 3X "Ultimate Limits Interim Configuration" in Attachment B of Reference (5))

Figure 3-2 Plan View: Category 1 Waste Rock Stockpile Interim Configuration – Mine Year 13



(see Drawing 7 "Ultimate Limits Closure Configuration" in Attachment B of Reference (5))

Figure 3-3 Plan View: Category 1 Waste Rock Stockpile Reclamation Configuration

The channels are designed to convey the estimated peak flows resulting from the 100-year, 24-hour design storm with runoff volume estimated using the Soil Conservation Service Curve Number method, and the peak flow and routing performed using the kinematic wave method. The channel geometry and peak flows were used as inputs in the Manning's equation to solve for normal depth and velocity. Channel depth is based on providing 1.0 foot of freeboard and channels lined with riprap are designed using a minimum factor of safety of 1.5 for riprap size selection. A conventional system of outslope channels, stockpile ramp channels, downchutes and perimeter channels is designed to manage stormwater on the reclaimed stockpile outslopes. These channels were designed to convey the 100-year, 24-hour storm event to the perimeter stormwater ditches and dikes, which are described in Section 2.2.2 of Reference (1). Design of the drainage system is described in Section 2.2 of Reference (1) and in the following sections.

3.2.2.1 Top Surface Grading and Drainage

The top surface and the exposed benches of each lift of the Category 1 Waste Rock Stockpile will be graded to provide a minimum nominal slope of 1.0% post settlement. The 1.0% slope is selected based on a variety of factors including:

- Safe travel and dumping operations of the 240-ton mine trucks and bulldozers is paramount. The 1.0% final top slope is selected to provide safe travel and operations during the construction of the final surface of the stockpile.
- The waste rock is virtually incompressible and not subject to significant differential settlement once placed. Post-construction slopes are expected to remain at grades very near the final as-constructed grades.
- The waste rock will be difficult to re-grade on flat surfaces due to its large size (rock diameters up to approximately 7 feet). Once placed at a 1.0% final top slope it will remain at that slope.
- The stockpile cover performance modeling (Section 3.3.3) shows that the desired hydraulic performance of the stockpile cover system can be achieved at the 1.0% slope.

According to waste rock stockpile research by Eger and Lapakko (Reference (9)), little to no surface runoff is likely to occur from the uncovered stockpile due to the coarse nature of the material. Although surface flows are not expected on a regular basis, they could occur during major storm events. Temporary dikes will be constructed along the perimeter of the stockpile top and stockpile ramps where trucks are hauling, which will minimize surface runoff over the sides. Stockpile benches may be designed to encourage infiltration and evaporation by grading the bench to flow into the stockpile, forcing infiltration or evaporation to occur. Therefore, in general, flow paths on the uncovered stockpile will direct surface flows into the stockpile or to ditches down the stockpile ramps, which will be gradual, further encouraging infiltration or evaporation.

Typical design details were developed to illustrate the management of stormwater on the regraded top surface of the stockpile. The stormwater management system consists of one or more channels on the top surface with a minimum estimated post-settlement longitudinal slope of 1.0% that will drain stormwater from the top surface to either downchutes or to channels along stockpile ramps.

The proposed 1.0% minimum top surface and drainage channel slopes are on the basis of the limited susceptibility of the stockpile to long-term settlement after final top surface and drainage channel grading. In addition to the relatively low compressibility of the waste rock, the final grading will occur after the bulk of the stockpile has already been in place for at least 13 years. Therefore, unlike for municipal solid waste landfills and other solid waste management facilities where long-term settlement can be expected and where 2.0 to 3.0% minimum slopes are warranted to accommodate future settlement; such settlement is not anticipated in the waste rock stockpile, and the flatter 1.0% minimum slope is justified.

3.2.2.2 Outslope Grading and Drainage

Outslope channels will be constructed on the re-graded outslope reclamation benches and spaced to limit the sheet flow distance. Waste rock materials will be redistributed from the angle of repose to a 3.75H:1V interbench slope with 30-foot wide benches every 150 feet, (measured from interbench slope toe to slope crest) using the maximum bench to bench elevation of 40 feet in accordance with Minnesota Rules, part 6132.2400, subpart 2, item C.

Analysis of stability of cover soils on the 3.75H:1V stockpile slopes is presented in Geotechnical Data Package – Volume 3 (Reference (10)). In summary, the stability of cover soils is a function of the interface shear strength between the geomembrane barrier layer and the overlying cover soil component. Interface shear strength is a function of the specific soil type in contact with the geomembrane and the membrane type and surface texture (i.e., linear low-density polyethylene performs differently than high density polyethylene; textured geomembrane performs differently than smooth geomembrane). As presented in Section 6.1 of Reference (10), an adequate slope stability safety factor can be achieved using the geomembrane types (Section 3.2.2.5) and soil types proposed for the stockpile cover system. For reference, the State of Minnesota has previously approved and achieved success with slopes at least as steep as 3.5H:1V (i.e., steeper than the 3.75H:1V proposed) for cover systems utilizing geomembrane barrier layers.

Layouts displaying the direction of flow for the outslope bench channels have been developed with a nominal 2% reclamation slope. Each channel will be constructed on a 30-foot wide reclamation bench and will discharge to a downchute or stockpile ramp channel. A typical outslope channel detail was developed using the maximum estimated peak discharge and a nominal channel slope of 2%, resulting in a design channel depth of 2.4 feet, which includes one foot of freeboard.

3.2.2.3 Downchutes

Downchutes will be constructed on the Category 1 Waste Rock Stockpile slopes that are reconfigured to a 3.75H:1V slope to collect and convey stormwater runoff from the outslope bench channels and top channels into perimeter channels and off-site through the stormwater system. The downchutes are designed for a continuous 22% slope without grade breaks at the benches, with energy dissipation provided at the base of each downchute. The downchute channels will be armored. Armoring options include riprap or other engineered approved equivalents (e.g., articulated concrete blocks) to provide erosion protection from the potentially high velocities in the downchute channels during storm events.

An energy dissipation basin will be constructed to dissipate the high-energy flow at the outfall of the downchute channel from supercritical to subcritical flow prior to entering the perimeter stormwater channel.

3.2.2.4 Stockpile Ramp Channels

Category 1 Waste Rock Stockpile ramp channels will be located along the inboard slopes of the reconstructed haul road ramps. While the stockpile is being reclaimed, the ramps will also be reclaimed with cover soil and the reclamation channels will be constructed. At this time, the ramps will be reconfigured and reclaimed to slope towards the channels at 2% (minimum). Stockpile ramp channels will collect flow from the top surface, outslope benches and the ramps. The stockpile ramp channels will be armored with riprap or other approved revetment. Other engineered equivalents may be used to provide erosion protection for the potentially high velocities in the stockpile ramp channels during reclamation and postclosure maintenance. An energy dissipation basin will be constructed to dissipate the flow energy at the outfall of the ramp channel prior to entering the perimeter stormwater channel.

3.2.2.5 Geomembrane Hydraulic Barrier Layer

The Category 1 Waste Rock Stockpile Cover System cross-section is shown on Figure 3-1. The hydraulic barrier layer of the cover system will be a geomembrane. Geomembranes represent the largest group of synthetic cover materials. Geomembranes are nearly impervious polymeric sheets used primarily for lining and covering facilities intended to contain liquids or solids (Reference (11)). Common geomembrane materials include high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polypropylene, polyvinyl chloride, chlorosulfonated polyethylene, and ethylene propylene dieneterpolymer.

For the Category 1 Waste Rock Stockpile hydraulic barrier, a geomembrane was selected based on a number of factors, such as material availability, ease and rate of installation, industry use and acceptance (experience), resistance to long-term physical and chemical degradation, puncture and tear resistance, interface shear strength, and economics. An HDPE or LLDPE geomembrane will be used for the Category 1 Waste Rock Stockpile hydraulic barrier layer because they are generally regarded as the most durable and have the longest service life available (Reference (12)). LLDPE and HDPE geomembranes are extruded into thin sheets then rolled for delivery and installation. Raw materials used in the manufacture of LLDPE and HDPE geomembranes are nearly the same. Both HDPE and LLDPE meet performance requirements of the stockpile cover system.

Geomembrane panels will be joined by thermal fusion welding using a dual-track welder (primary seams) or an extrusion welder (secondary details). The dual-track welder bonds the sheets with two rows of welds with an air channel in between. The air channel is pressurized to verify the fusion weld does not contain leaks. Extrusion welders use heat and extra polymer to create welds in detail areas that cannot be accessed by a dual-track welder. Welds prepared by an extrusion welder are checked by applying vacuum or by spark-testing (Reference (13)).

After field-seaming of geomembrane sheets, selective destructive test samples are taken and shear and peel tests performed on the completed seams (Reference (13)). Typically, one sample is taken per 500 to 1000 feet of seam, but frequency is determined on a project-by-project basis. The sample is usually 3 feet in length, with 1/3 being evaluated on-site, 1/3 being sent to a quality assurance laboratory for testing, and the other 1/3 kept for archival storage. Areas where destructive test samples are taken require repair and must also be tested non-destructively after destructive testing is completed. Non-destructive testing of areas patched by extrusion welding is performed using a vacuum box to confirm patch integrity.

3.2.3 Degree of Use in Industry

Geomembranes have been used in the mining industry since the 1970s (Reference (14)). Geomembrane cover systems are widely used throughout the world in mining and other industries that have to address long-term containment of wastes (e.g., power plants for coal ash, water treatment plants for filtered solids, and municipal solid waste landfills). Because cover systems using geomembranes as the primary hydraulic barrier have been widely used and studied for decades, geomembrane selection, design, construction, and quality control procedures required for successful implementation are well understood.

While geomembranes have been widely used for decades, there has not been significant demand for geomembranes in waste rock stockpile covers (Reference (15)). A small sampling of geomembrane-based cover systems (Reference (16)) is summarized in Table 3-1 for a variety of material types over relatively small areas (average project size is less than 30 acres). While the projects listed generally do not use geomembranes for stockpile covers, Barr's experience designing and monitoring construction of geomembrane cover systems indicates that a properly sloped waste rock stockpile exhibits the characteristics necessary for successful use of geomembrane covers [i.e., a very stable foundation material (the waste rock) capable of supporting the necessary construction equipment and remaining stable indefinitely].

Table 3-1 GSE 2012 Mining Project Summary – Cover Systems

Date	Projects with Geomembrane Cover	Location	Size (acres)
2012	Lynn Lake Mine Tailings Cap	North America	140
2012	Farley Mine – Lynn Lake Cap	North America	48
2012	Farley Nickel Mine Cap	North America	32
2012	Mosaic Gypsum Stack	North America	18
2012	Cubiertas Flotantes	Latin America	13
2012	Tolko Mines Tailings Cap	North America	7
2012	Lynn Lake May	North America	6
2012	Motiva North-South	North America	3
2012	Impermeabilizacion Hormigon Tanque Acidos Coloso	Latin America	2

Literature and internet searches were conducted to identify mining sites where geomembranes have been used in covers placed over waste rock. This review indicated that most reclamation projects employed earthen covers rather than covers with geosynthetic materials due to the large surface area and the higher cost associated with geosynthetic materials relative to earthen materials. Three mine sites were identified where geomembranes were used in the cover as a hydraulic barrier over waste rock. These mine sites and the cover profiles are summarized in Table 3-2.

Table 3-2 Examples of Covers with Geomembrane Barriers for Waste Rock Stockpiles

Site	Location	Waste Rock Type	Cover Profile	Status
Blackfoot Bridge Mine	Near Afton, WY	Seleniferous waste rock from phosphate mining	1.5 feet topsoil, 1 foot alluvium, 1 foot sand drainage layer, 40 mil geomembrane laminated on GCL, chert subgrade	Approved EIS. Pilot-scale cover system constructed in 2013. Test area is approx. 1-acres.
Dunka Mine	Babbitt, MN	Taconite mining waste rock stockpiles	Soil over 30 mil LLDPE geomembrane	Constructed in 2007 and in service. Site area is approx. 54 acres.
Lava Cap Mine	Nevada County, CA	Gold mining waste rock	1.5 feet soil, geocomposite drain, 60 to 80 mil LLDPE geomembrane, nonwoven geotextile	Constructed in 2007 and in service. Site area is approx. 20 acres.

Geomembrane manufactures and suppliers routinely provide geomembranes for covering other waste types (e.g., municipal solid waste, coal ash). Other representative large-scale geomembrane cover projects in the region include the geomembrane cover systems at the Waste Management Sanitary Landfill in Burnsville, Minnesota (roughly 200-acres in area and over 100 feet in height) and the BFI, Inc. Municipal Solid Waste Landfill in Inver Grove Heights, Minnesota (nearly 200-acres in area and unknown height). Geomembrane use for cover systems began at these facilities in the late 1990s to early 2000s and continues today.

3.3 Engineering Control Performance Parameters

3.3.1 Description with Basis

3.3.1.1 Mechanisms for Percolation through Geomembrane Cover Systems

Intact geomembranes are essentially impermeable (Reference (17)). The majority of liquid migration through HDPE and LLDPE geomembranes occurs through defects introduced during manufacture, installation, and covering of the geomembrane (Reference (18)). The potential for defects to occur, particularly during installation, depends on the rigor of the QA/QC implemented during installation.

Because geomembrane sheets are essentially impermeable, the magnitude of percolation through a geomembrane cover depends upon the number and size of defects (pinholes, holes) in the geomembrane, available hydraulic head over the geomembrane to force liquid through the defects, the installation of the geomembrane such that wrinkles are eliminated to the extent practicable, and the characteristics of the geomembrane subgrade material. Each of these parameters plays a role in the performance of the geomembrane cover.

Some information in the following sections is based on a literature review, which generally documents leakage through liner systems rather than cover systems. However, because geomembrane type and manufacturing procedures, construction methods, and construction QA/QC procedures are similar whether the geomembrane is used as a hydraulic barrier in a liner or cover, it is reasonable to assume that the findings apply to cover systems.

Defects in Geomembranes: Manufacturing processes and the chemical structure of polymers produce intact geomembranes with extremely low permeabilities (Reference (19)). Manufacturing defects are identified by on-line spark testing, which is an effective and reliable quality control method. As part of the manufacturing process, the geomembrane sheet is passed over a steel roller with a high-voltage wand placed immediately above the geomembrane. Should any pinhole defects exist in the sheet, current will pass through the pinhole triggering a shutdown in the machinery, and the sheet will then be scrapped. Spark-tested geomembrane rolls are guaranteed to have zero pinhole defects prior to shipping.

The number of defects in an installed geomembrane cover system depends on the methods used during installation, quality control used during installation, punctures incurred during placement of overlying materials, and post-construction maintenance. Defects introduced during handling and installation may include punctures, tears, cuts, and defects in welds. Based on field studies, Giroud and Bonaparte (Reference (20) and Reference (21)) recommend assuming a defect frequency of 1 to 2 holes per acre when there is rigorous QA/QC during geomembrane installation. Industry standards suggest that “excellent” installation with state-of-the-art QA/QC results in a defect frequency of 0.5 to 1 defects per acre, while a “good” installation results in 1 to 4 defects per acre (Reference (22)). Giroud and Bonaparte (Reference (20)) compute leakage rates for composite liners ranging from $1x10^{-5}$ to 0.02 gallons per acre per day when good QA/QC is performed.

Leak detection studies by Forget et al. (Reference (23)) evaluated several large-scale (greater than 2.5 acres) projects for total number of leaks in a comparison of projects with a rigorous QA/QC program to projects lacking a QA/QC program. For this study, electrical leak detection surveys were performed on exposed geomembranes and soil covered geomembranes. For projects with good QA/QC programs for all aspects of geomembrane construction (described below), any defects found were repaired. For covered geomembranes, testing was performed prior to covering the geomembrane and after placement of the soil cover. For 80-mil geomembranes on projects with a good QA/QC program, exposed geomembranes contained an average of 1.3 leaks per acre, and soil-covered geomembranes (subjected to double testing) contained an average of less than 0.1 leaks per acre in the second test. For 80-mil geomembranes on projects lacking a QA/QC program, soil-covered geomembranes contained an average of 6.2 leaks per acre (these geomembranes were not tested prior to soil covering). Data were nonexistent or insufficient to define defect frequencies for a 40-mil geomembrane.

A survey of defects in geomembranes by Nosko and Touze-Foltz (Reference (24)) as cited by Needham et al., Reference (25)) determined that 24% of defects were caused during installation and 73% were caused by mechanical damage during placement of cover soils, whereas only 2% of defects were attributed to post-construction wear and less than 1% were geomembrane seam test coupon locations. Forget et al. (Reference (23)) concluded that only 6% of perforations were caused during the cover material installation. Thus, the conclusion in Nosko is probably valid only in cases where no rigorous QA/QC program has been implemented (Reference (23)). By comparison of Nosko et al. to Forget et al., it appears that the frequency of defects formed during placement of cover soils is expected to be lower when more emphasis is placed on QA/QC during placement of cover soils.

Defects can range widely in size, depending on the quality of the installation. Nosko and Touze-Foltz (Reference (24) as cited in Forget et al., Reference (23)) summarize leak sizes measured at more than 300 sites in 16 countries independent of QA/QC procedures, covered or exposed geomembranes, and geomembrane thickness. The results of this data analysis indicate that the majority of leaks are above 0.5 cm^2 and that half (50%) of the leaks fall within the range of 0.5 to 2.0 cm^2. The data also indicate that 85% of leaks are smaller than 10 cm^2. A leak size frequency plot based on these data is provided in Figure 3-4.

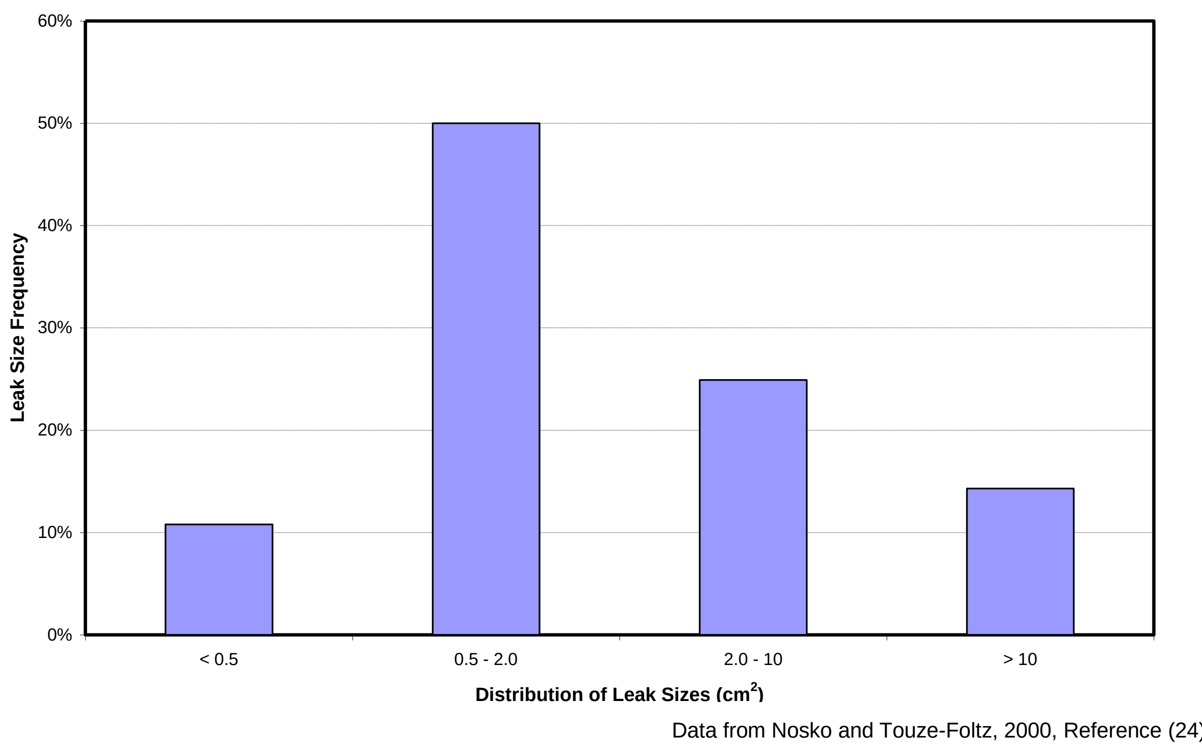


Figure 3-4 Frequency and Distribution of Leak Size

Studies of root intrusion into geomembranes by Holl in 2002 (Reference (26)), U.S. Environmental Protection Agency (USEPA) in 2006 (Reference (27)), and Phifer in 2012 (Reference (28)) show that roots are blocked by intact geomembranes and grow laterally above the surface of the geomembrane. Consequently, geomembranes are commercially marketed as root barriers (Reference (28)). Accordingly, no accommodation is necessary for defects due to root penetration of the geomembrane.

Based on a limited literature search, research is not readily available regarding the ability of insects and animals to burrow through geomembranes and the resulting impacts of insect and animal burrows on the integrity of cover systems using geomembrane hydraulic barriers. Crouse and Watson in 2002 (Reference (29)) indicate that rats were unable to penetrate geomembranes. A more extensive literature search will be required to substantiate whether animals routinely burrow through geomembrane barrier layers in cover systems. Theoretically, only materials harder than a burrower's teeth or claws can survive an attack, but vulnerability is unknown (Reference (30)). Absent evidence that animal burrows through geomembranes are a significant concern, an accommodation in cover-system performance modeling was made for the general possibility that additional defects in geomembranes could occur and that defects will vary in size (i.e., a five-times increase in defect frequency will be modeled). However, as indicated in Section 3.3.2 routine inspection to observe for impacts from burrowing animals will occur and if impacts are identified, the condition will be remedied to minimize or prevent potential impacts from burrowing animals.

<u>Hydraulic Head above Geomembrane</u>: The percolation rate through the geomembrane is in part a function of the hydraulic head on the geomembrane. Hydraulic head on the geomembrane is primarily a function of the rate of precipitation, runoff and evapotranspiration, the hydraulic conductivity of the material overlying the geomembrane, the distance between drainage features of the cover system, and the type and density of surface vegetation and its rooting depth and density. These factors collectively determine the rate at which water accumulates on the surface of the geomembrane. The hydraulic head is the force that drives liquid through the defects in the geomembrane. As hydraulic head increases, percolation through defects in the geomembrane increases.

Except for precipitation, each of the factors that affect hydraulic head on the geomembrane can be controlled and are considered as part of stockpile cover design. Hydraulic conductivity of the soil layer immediately above the geomembrane is selected to facilitate drainage of infiltrated precipitation to drainage pipes while also protecting the geomembrane from damage during and after installation. The type of vegetation is selected to achieve a dense vegetative cover that promotes evapotranspiration while limiting soil erosion from surface water runoff. These factors collectively yield a low average hydraulic head on the geomembrane cover, thus resulting in very little driving force and very low percolation through defects in the geomembrane cover.

<u>Characteristics of the Geomembrane Subgrade Material</u>: Leakage through a geomembrane is computed based in part on the hydraulic conductivity of the underlying soil layer, contact between the geomembrane and underlying soil layer, and the head on the geomembrane (Reference (18)).

Summary: The factors affecting leakage through geomembrane barrier layers used in covers are primarily the frequency and size of defects that remain in the geomembrane after construction is complete, the hydraulic head on the geomembrane, and the hydraulic conductivity of the soils underlying the geomembrane.

3.3.1.2 Methodology for Calculation of Category 1 Waste Rock Stockpile Percolation

The Hydrologic Evaluation of Landfill Performance (HELP) Model (Reference (22)) was used to estimate the percolation rate for the Category 1 Waste Rock Stockpile geomembrane cover system using the stockpile design and Project climate conditions.

The HELP Model is a tool commonly used to estimate percolation through geomembrane cover systems. The HELP model was developed by the U.S. Army Corps of Engineers to provide landfill designers and regulators with a tool to quickly and economically screen alternative cover designs. The HELP model is a quasi-two-dimensional hydrologic model of liquid migration across, through, and out of landfills. Inputs include weather information, soil data, and cover system configuration. The HELP model accounts for snowmelt, runoff, surface storage, infiltration, evapotranspiration, vegetative growth, field capacity, lateral subsurface drainage, unsaturated vertical drainage, and percolation through cover systems. Version 3 of the model was enhanced to account for defects in geomembrane barrier layers, either due to manufacturing or installation. HELP models both surface and subsurface hydrologic processes. The major assumptions and limitations of the HELP model include the following:

- Runoff is computed with the Soil Conservation Service method, based on daily rainfall and snowmelt, assuming that the area of interest acts as an independent watershed, without receiving additional runoff from adjacent areas. This is the case for the Category 1 Waste Rock Stockpile, which is elevated with no surrounding tributary area contributing surface water run-on to the stockpile surface.

- Intraday distribution of rainfall intensity is not considered. While the model cannot provide accurate estimates of runoff volumes for individual storm events (peak daily values), the model provides reasonable long-term estimates (average annual values).

- Gravity drainage dominates the flow through homogeneous soil and waste layers and through barrier soil liners.

- Geomembranes are assumed to leak primarily through defects, input as number of pinholes (manufacturing defects with a diameter of 1 mm) and installation defects (holes with an area of 1 cm^2) per acre. The model assumes the hydraulic head on the defects can be represented by the average hydraulic head across the entire geomembrane cover system. Because geomembranes are now guaranteed by the manufacturer to be defect free, pinhole defects due to manufacturing are not included in modeling; only installation defects are included in modeling.

- Aging of materials can be modeled by successive simulations. The number and size of defects cannot vary as a function of time within a single model run.

The HELP model inputs are subdivided by the layers that constitute the final cover system. These layers include the rooting zone soil (called a Vertical Percolation Layer in HELP), the granular cover soil over the geomembrane (called a Lateral Drainage Layer in HELP), the geomembrane (a Geomembrane Barrier Layer in HELP), and the soil layer directly below the geomembrane barrier layer (another Vertical Percolation Layer in HELP). HELP model input for each layer is summarized in Large Table 5.

Of note in the preceding table is the use of "good" geomembrane installation quality, which corresponds to 1 to 4 defects per acre; the frequency recommended in the HELP User's Manual (Reference (22)) for "good" installation quality. This is supported by the research previously reported in Section 3.3.1.1. However, for HELP modeling, a more conservative approach has been taken by modeling with 2 defects per acre and with 10 defects per acre (a five-time increase from 2 as described in Section 3.3.3).

Khire et al. (Reference (31)) and Albright et al. (Reference (32)) evaluated the accuracy of HELP models for estimating the hydrology of final cover systems. Both studies used data from large-scale test sections simulating covers that were constructed at or as part of actual waste containment systems. The test sections incorporated drainage lysimeters to monitor all components of the water balance. Water balance data from the lysimeters were compared with HELP model estimates and input parameters for HELP that were measured in the field. Khire et al. (Reference (31)) evaluated HELP for covers with a clay barrier layer using data from sites located in northern Georgia and eastern Washington. Albright et al. (Reference (32)) evaluated HELP for covers with geomembranes as the primary barrier layer using data from seven sites located in the Midwest and western United States. Both studies indicate that HELP estimates the seasonal trends in the water balance, but the accuracy of the estimates vary from site to site. The study by Albright et al. (Reference (32)) is directly relevant to the Project site because the study evaluated estimates for covers with geomembrane barrier layers.

Albright et al. (Reference (32)) show that HELP tends to overestimate runoff and underestimate evapotranspiration for covers with geomembrane barrier layers, and that the errors in estimates of runoff and evapotranspiration typically offset each other. Soil water storage in the cover soils overlying the geomembrane is underestimated by HELP, and lateral flow in the lateral drainage layer is overestimated, because the flow algorithm in HELP ignores the capillary barrier effect formed by the textural contrast between the lateral drainage layer and the overlying vertical percolation layers. This causes the model to estimate too much drainage out of the vertical percolation layer and into the lateral drainage layer. Percolation typically was overestimated slightly when field data were used to accurately represent the hydraulic properties of the cover soils in the HELP model input. Estimated percolation rates for geomembrane covers typically ranged from 0.01 to 0.6 in/yr, whereas measured percolation rates ranged from nil to 0.4 in/yr. Higher percolation rates were measured for one cover that was constructed with poor quality control and was believed to have extensive puncturing in the geomembrane.

The HELP model considers the hydraulic conductivity of the soil layers above the geomembrane to be constant over time. In reality, hydraulic conductivity of the vertical percolation layer and lateral drainage layers may change over time. The changes that could occur in the vertical percolation layer (function = rooting zone layer; root penetration is considered, freeze-thaw effects on hydraulic conductivity are not considered) could result in increased infiltration through this layer if hydraulic conductivity increases due to freeze-thaw cycles. The changes that could occur in the lateral drainage layer (function = drainage away from top of geomembrane; clogging of layer is not considered) could result in decreased rate of drainage away from the top of geomembrane but also reduced rate of infiltration into the lateral drainage layer. Because the changes indicated above do not affect the geomembrane defect size and/or frequency and because defects in the geomembrane primarily control quantity of percolation through the cover system, potential changes in hydraulic conductivity of the vertical percolation layer and lateral drainage layer of the cover system are not considered.

3.3.1.3 Cover Construction Quality Assurance/Quality Control (QA/QC)

Consistent with Minnesota Rules, 6132.2200, subpart 2, item C, construction QA/QC for cover systems includes documenting compliance with specifications, material testing during construction, and conformance testing of materials before they arrive on site. Specification requirements include earthwork procedures, material testing, installation procedures, geomembrane seam testing (destructive and non-destructive), visual inspections, and specific installation requirements.

In general, geomembrane QA/QC dictates panel deployment, trial welds, field seaming, field testing (destructive and non-destructive), and repair of defects. The QA/QC manual will include test methods, test parameters, and testing frequencies. Documentation from QA/QC personnel includes observations of the geomembrane during storage, handling, seam preparation, seam overlap, and verification of the adequateness of the underlying soils.

Geomembrane cover systems in Minnesota are typically installed during the prime earthwork construction season from roughly late May/early June to late November. This allows for installation and seaming of geomembrane sheets in temperatures above freezing, thereby avoiding the requirement for membrane pre-heating and modified seaming rates that can slow the installation rate and increase the installation cost in sub-freezing temperatures. Geomembrane manufacturers provide guidelines for geomembrane installation in sub-freezing conditions and these guidelines will be followed in the event that geomembrane installation occurs in sub-freezing conditions.

Destructive geomembrane testing involves removing a sample from the geomembrane or seam for QC testing by the geomembrane installer and for QA testing by an independent third party (Reference (33)). Destructive testing of geomembrane seams includes shear testing and peel testing. Destructive testing of geomembrane sheets involves tensile testing. Minimum frequencies of sampling and testing are dictated by project specifications. If destructive test results do not meet acceptance criteria, additional testing proceeds in the immediate area to determine the extent of unacceptable material or seams. This allows failing areas to be corrected with such measures as re-seaming or seaming a patch over the affected area (Reference (33)).

Common non-destructive methods for testing seams include pressure testing for double fusion welds and vacuum testing for extrusion welds. Electrical leak detection tests or surveys can also be used to identify defects in the installed geomembrane. This method provides a proactive approach to locating and repairing leaks in the constructed geomembrane cover system. Electrical leak detection was developed in the early 1980s and has been commercially available since the mid-1980s. Test methods are outlined in ASTM Methods D6747, D7002, and D7007. In these test methods, a voltage is applied across the geomembrane. Because a typical geomembrane is relatively non-conductive, discontinuities in electrical flow indicate a leak in the geomembrane (i.e., current passes through the leak to the conductive materials surrounding the geomembrane). Electrical leak detection can be applied to both exposed and covered geomembranes in order to reveal defects caused during geomembrane installation and placement of cover soils, respectively.

The minimum detectable leak size for electrical leak detection ranges from 0.006 cm^2 to 0.323cm^2, depending on the method used. Based on Figure 3-4, less than 10% of expected geomembrane defects fall below this size range. That is, electrical leak detection tests can locate most geomembrane defects, greatly reducing the number of geomembrane defects that are undetected and unrepaired.

Cover soils are specified to be free-draining to provide a highly transmissive layer to create low hydraulic head on the cover system. Cover soils must be spread in a manner that minimizes the potential for damage to the geomembrane. Cover soil is placed in a thick lift in traffic zones and initial cover soil dumping locations, and then pushed from these locations to the specified lift thickness using a low ground pressure dozer. Depending on the configuration of the cover system, electrical leak location surveys may then be conducted to detect damage that may have occurred. In addition, continuous visual observation of cover soil placement and spreading can be used as a means of detecting damage during cover soil placement. If the geomembrane is damaged, the soil is manually removed and the geomembrane is cleaned and repaired. If cover soil will not be placed in a timely fashion after geomembrane deployment, a protective sheet can be used to shield the geomembrane from construction damage.

3.3.2 Maintenance Program

Once the cover system geomembrane barrier layer is installed and protected by soil cover, further testing of the geomembrane is not required. However, consistent with Minnesota Rules, part 6132.2200, subpart 2, item C, the stockpile cover system will require annual maintenance to remain effective. Annual maintenance will consist of repair of erosion that threatens to expose the geomembrane, removal of deep-rooted woody plant species (as permits require), repair of impacts from burrowing animals, and any other conditions that, if left unresolved, could impair performance of the cover. Periodic inspections (typically each spring and fall and after rainfall events approaching or exceeding the design event) will be conducted to identify any areas requiring repair. For example, if deep animal burrows are observed that may penetrate the geomembrane, the geomembrane will be uncovered, inspected, and repaired if damaged.

Over the last two decades, considerable research has been conducted to evaluate degradation of HDPE geomembranes and factors that affect geomembrane service life. If a geomembrane is not damaged by intrusive processes such as erosion or borrowing, research has shown that temperature and constituents present in liquid contacting the geomembrane are the primary factors affecting service life. Both factors affect the rate at which antioxidants within the geomembrane are released or consumed, and the rate at which oxidation reactions break down polymer molecules in the geomembrane. The degradation process is known to occur in three stages: (i) antioxidant depletion, (ii) oxidation induction, and (iii) active polymer degradation.

The most comprehensive and long-term studies on geomembrane degradation have been conducted at Queen's University in Ontario (Reference (34)). Research at Queen's University has involved tests with durations as long as 10 years and has included conventional immersion tests on geomembrane coupons as well as large-scale physical models simulating engineered barrier systems. The research has shown that temperature, the presence of water at the geomembrane surface, and the constituents present in the contacting water influence the rate of each stage of degradation. In particular, degradation occurs more rapidly as the temperature increases, when the geomembrane is submerged (i.e., saturated conditions), and when the water contains surfactants that enhance release of antioxidants from the geomembrane.

In a cover application in a northern climate, the temperature of the geomembrane is relatively cool, the contacting soil is unsaturated, and the water contacting the geomembrane contains little if any surfactants, all of which will promote long service life. For a 60-mil HDPE geomembrane immersed in liquid with surfactants at 68°F, Rowe et al. (Reference (34)) indicate that the service life is on the order of 1,000 years. Under unsaturated conditions and at substantially cooler temperatures (the average annual temperature at the Project site is approximately 38°F), the analysis in Reference (34) indicates a life expectancy for a 60-mil HDPE geomembrane of more than 2,000 years.

This research is generally consistent with research conducted by the Geosynthetic Institute, which suggests a service life of at least 450 years at 68°F (Reference (35)) based on antioxidant depletion (i.e., first stage degradation). Similarly, Bonaparte and Koerner in their 2002 Assessment and Recommendations for Improving the Performance of Waste Containment Systems (Reference (36)) estimated the service lifetime of a 60-mil high density polyethylene geomembrane to be on the order of 970 years at 68°F. Field studies on geomembranes in covers conducted under sponsorship of the US Nuclear Regulatory Commission (Reference (37)) show that antioxidant depletion rates in the field are similar to those estimated based on laboratory tests.

The rate of degradation of geomembranes is controlled by diffusion of antioxidants out of the geomembrane and diffusion of oxygen into the geomembrane, both of which are affected by the distance over which diffusion occurs. In particular, the rate scales by the ratio of the square of the geomembrane thickness. Thus, a 40-mil geomembrane typically used in a final cover will have a service life that is approximately 2.25 times shorter than a 60-mil geomembrane [(60 x 60) ÷ (40 x 40) = 2.25]. If the service life is assumed to be at least 2,000 years at 38°F for a 60-mil HDPE geomembrane, then the service life for a 40-mil geomembrane will be approximately 900 years. If full depletion of constituents from the stockpile requires more than 1,000 years, the geomembrane may need to be replaced in the future.

If periodic testing (i.e., testing of geomembrane coupons removed from cover, visually inspected for signs of degradation and physically tested for strength) of the geomembrane confirms that the geomembrane no longer meets performance requirements, then replacement will occur. Replacement would include removal of surface vegetation from the site and systematic removal of soils overlying the geomembrane, removal of the geomembrane, compaction and fine-grading of the subgrade as needed, placement of a new geomembrane, and replacement of the overlying layers. Reconstruction would follow the construction and QA/QC procedures that were employed originally, or have been adopted as best practices by industry at the time of replacement. Procedures will be adjusted for new geomembrane types that are likely to be available hundreds of years in the future. Geomembrane replacement, if needed, would be conducted incrementally over areas that can reasonably be reconstructed each construction season (e.g., 50 to 75 acres each season).

3.3.3 Modeling of Engineering Controls

The Mine Site water quality model (Reference (3)), which estimates the impacts of the Category 1 Waste Rock Stockpile, includes the following calculations and assumptions:

- in general, release rates for each constituent have been determined from comprehensive laboratory tests of NorthMet waste rock

- the scale factor (which is used to convert release rates measured in lab-scale tests to field-scale conditions) has been determined based on field data from similar stockpiles

- the mass of waste rock in the stockpile, as a function of time, has been determined from the waste rock placement plan presented in Table 2-2 of Reference (5)

- the mass of each constituent made available for transport in a given time period is calculated as release rate (i.e., constituent mass / rock mass / time) × scale factor × mass of waste rock × time-period duration

- the percolation rate is the amount of precipitation exiting the base of the cover system and entering the underlying waste rock and is a function of the stockpile cover system configuration, as-built properties of the cover materials, and characteristics of the vegetation (i.e., soil types, hydraulic barrier layer type and corresponding defect size and frequency, surface slope and drainage features, and vegetation type and density)

- the volume of water draining from the stockpile in a given time period is calculated as percolation rate × stockpile area × time-period duration

- the potential concentration (assuming no concentration cap) of each constituent in drainage exiting the base of the stockpile is calculated as mass of constituent available for transport / volume of water draining from the stockpile

- if the potential concentration is greater than the concentration cap (thermodynamic maximum) then the concentration in drainage is equal to the concentration cap – otherwise the concentration in drainage is equal to the potential concentration

- any constituent mass retained in the stockpile due to concentration caps is available for later release from the stockpile at the level of the concentration cap until the constituent is fully depleted from the waste rock

The model assumes that the oxidation process will not be limited by oxygen (that is, the cover does not limit oxygen transport into the stockpile) and that all constituents released from the rock will ultimately be transported out of the stockpile regardless of the type of cover implemented. Collectively this means that the constituent load leaving the stockpile at any point in time can only be modeled to be reduced by limiting the amount of water percolating through the cover system to the point where concentration caps come into effect. This engineering control – the Category 1 Waste Rock Stockpile Cover System – reduces the amount of water draining through the waste rock beyond the point where concentration caps come into effect, thus reducing the constituent load to the West Pit.

The Category 1 Waste Rock Stockpile Cover System has been incorporated into the Mine Site water model. The following changes have been made to the model to reflect this engineering control:

- The stockpile will remain bare (no cover) until the geomembrane is installed.

- Geomembrane installation will begin at the beginning of Mine Year 14 and be completed 8 years after it begins (end of Mine Year 21).

- Percolation through the geomembrane will be modeled as an uncertain variable with a lognormal distribution, similar to the modeling for the geomembrane liners on the temporary stockpiles (Section 5.2.2.3 of Reference (3)). Percolation rates (as a percent of precipitation) will be randomly-selected once per realization and will remain constant for the remainder of the realization.

The HELP Model was used to estimate percolation from the base of the cover into the stockpile. The relatively flat areas (1.0% slope areas; 175 acres total) and the 3.75H:1V slope areas (26.7% slope areas; 351 acres total) of the stockpile were modeled. With the expected geomembrane defect frequency of 2 holes per acre, percolation of precipitation through flat areas of the cover is estimated to be 0.22 inches/year (0.79% of the 27.68 inches of average annual precipitation). This estimated percolation translates to 1.99 gallons/minute; or 0.0057 gallons/minute/defect. Percolation of precipitation through the side slopes of the stockpile is estimated to be 0.03 inches/year (0.11% of precipitation). This estimated percolation translates to 0.54 gallons/minute; or 0.0008 gallons/minute/defect. The expected percolation rate for the stockpile as a whole of 0.09 inches/year (0.34% of precipitation; 2.45 gallons/minute; or 0.0023 gallons/minute/defect) is established by computing the weighted average percolation through the entire stockpile ((Flat Area Percolation Rate x Flat Area) + (Sloped Area Percolation Rate x Sloped Area))/(Flat Area + Sloped Area). The weighted average percolation rate is computed to accommodate performance modeling, which treats the stockpile as a single mass of rock.

A second case was modeled to represent a scenario where animal burrowing into the geomembrane occurs and is temporarily left unrepaired (i.e., it is not possible to locate and repair burrows through the geomembrane, if they occur, immediately upon their occurrence). This is modeled by assuming that the defect frequency on the entire stockpile increases to 10 defects per acre. For this case, estimated percolation through flat areas increases to 1.01 inches/year (3.65% of precipitation) and estimated percolation through sloped areas increases to 0.16 inches/year (0.58% of precipitation). The resulting percolation rate for the stockpile as a whole for this case is 0.44 inches/year (1.60% of precipitation), which is assumed to represent the 95th percentile of possible stockpile-wide conditions based on professional judgment of the likelihood of this scenario existing across the entire stockpile. The HELP Model input and output on which the water quality modeling is based in summarized in Large Table 6.

The water quality modeling includes the potential for both cases described above. Percolation through the geomembrane cover, as a percent of precipitation, is treated as an uncertain variable, sampled once per realization. The first case presented above, with two defects per acre, represents the most likely scenario that will occur. It is assumed that the expected stockpile percolation rate for this case of 0.34% of precipitation represents the median percolation rate that will occur, and that the percolation rate for the case with 10 defects per acre, 1.60% of precipitation, represents the 95th percentile percolation rate. The resulting lognormal distribution fit through these two points is shown on Figure 3-5. The resulting distribution has a 10th percentile percolation rate of 0.1% of precipitation (0.03 in/yr), a mean of 0.53% of precipitation (0.146 in/yr) and a 90th percentile percolation rate of 1.1% of precipitation (0.30 in/yr). Using this modeled mean value, the mean total percolation through the stockpile corresponds to approximately 4 gpm. This modeled mean percolation rate is used in the remainder of this document as the mean stockpile percolation.

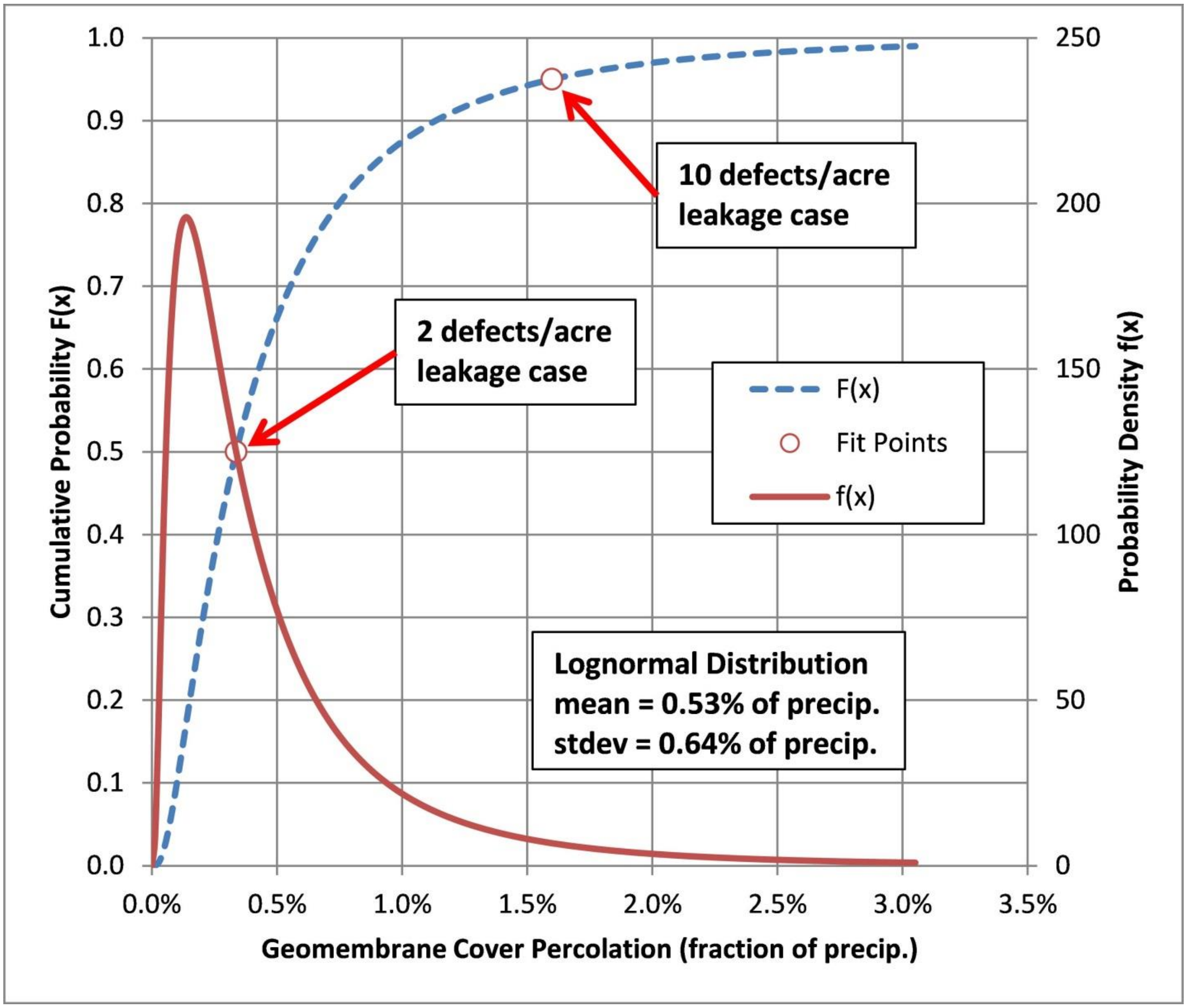


Figure 3-5 Probability Density Function and Cumulative Distribution Function for Percolation Rate from Cover with Geomembrane

3.3.4 Impact on Transition to Non-Mechanical Treatment

In the operation, reclamation and closure, and postclosure maintenance phases of the Project, the WWTS is the engineering control that will provide compliance to water resource objectives. The Category 1 Waste Rock Stockpile Cover System has no direct impact on compliance because its function is to reduce the constituent load that must be removed by the WWTS.

However, the performance of the Category 1 Waste Rock Stockpile Cover System will impact the likelihood of achieving the goal of transitioning to non-mechanical treatment during closure or postclosure maintenance. To illustrate the effect that cover performance has on this goal, the long-term steady-state conditions of the West Pit lake have been evaluated using the water quality model. This evaluation considers the water and mass loading to the West Pit lake from the Category 1 Waste Rock Stockpile, as well as and other sources of water and constituent mass to the pit lake such as direct precipitation and watershed runoff. For this illustration, there are four water quality criteria considered:

- sulfate concentration in the West Pit lake less than or equal to 100 mg/L –at a sulfate concentration of 100 mg/L, groundwater seepage from the pit does not result in the Partridge River being over 10 mg/L at SW005 (the most upstream location designated as a water used for the production of wild rice)

- cobalt concentrations less than or equal to 5 µg/L – this is the surface water standard for cobalt at the estimated hardness of the West Pit lake

- nickel concentrations less than or equal to 52.2 µg/L – this is the surface water standard for nickel at the estimated hardness of the West Pit lake

- copper concentrations less than or equal to 9.3 µg/L – this is the surface water standard for copper at the estimated hardness of the West Pit lake

Figure 3-6 shows the modeled percent of mass removal that will be necessary from the Category 1 Stockpile Non-Mechanical Treatment System (Section 6.2) with median flow and load inputs in order to meet the West Pit lake water quality criteria listed above. With the modeled mean percolation rate from the geomembrane cover of 0.53% of precipitation (Figure 3-5), neither mechanical nor non-mechanical treatment of the water collected by the groundwater containment system will be required to meet the West Pit lake water quality criteria for sulfate, cobalt, or nickel. However, if the percolation rate were higher, some load will need to be removed by the non-mechanical treatment in order to meet the West Pit lake water quality criteria. For example, if the percolation rate was 5% of precipitation (a percolation rate more likely for an engineered soil cover), the non-mechanical treatment would need to remove 73% of the sulfate load, 81% of the cobalt load, and 89% of the nickel load in order to meet the West Pit lake water quality targets. Above a percolation rate of approximately 16% of precipitation, West Pit lake water quality criteria for nickel most likely could not be met by non-mechanical treatment of the Category 1 Stockpile Groundwater Containment System water alone.

The sulfate, cobalt, and nickel criteria can be met for the West Pit Lake under a variety of percolation rates and non-mechanical treatment removal rates because the stockpile is the primary source of load to the West Pit for these constituents. This is not the case for copper, where the pit walls also provide significant load to the pit lake. For the overflow from the West Pit lake to meet the water quality criteria for copper, the West Pit Overflow Non-Mechanical Treatment System (Section 6.3) will also be needed, regardless of the amount of removal possible by the Category 1 Stockpile Non-Mechanical Treatment System.

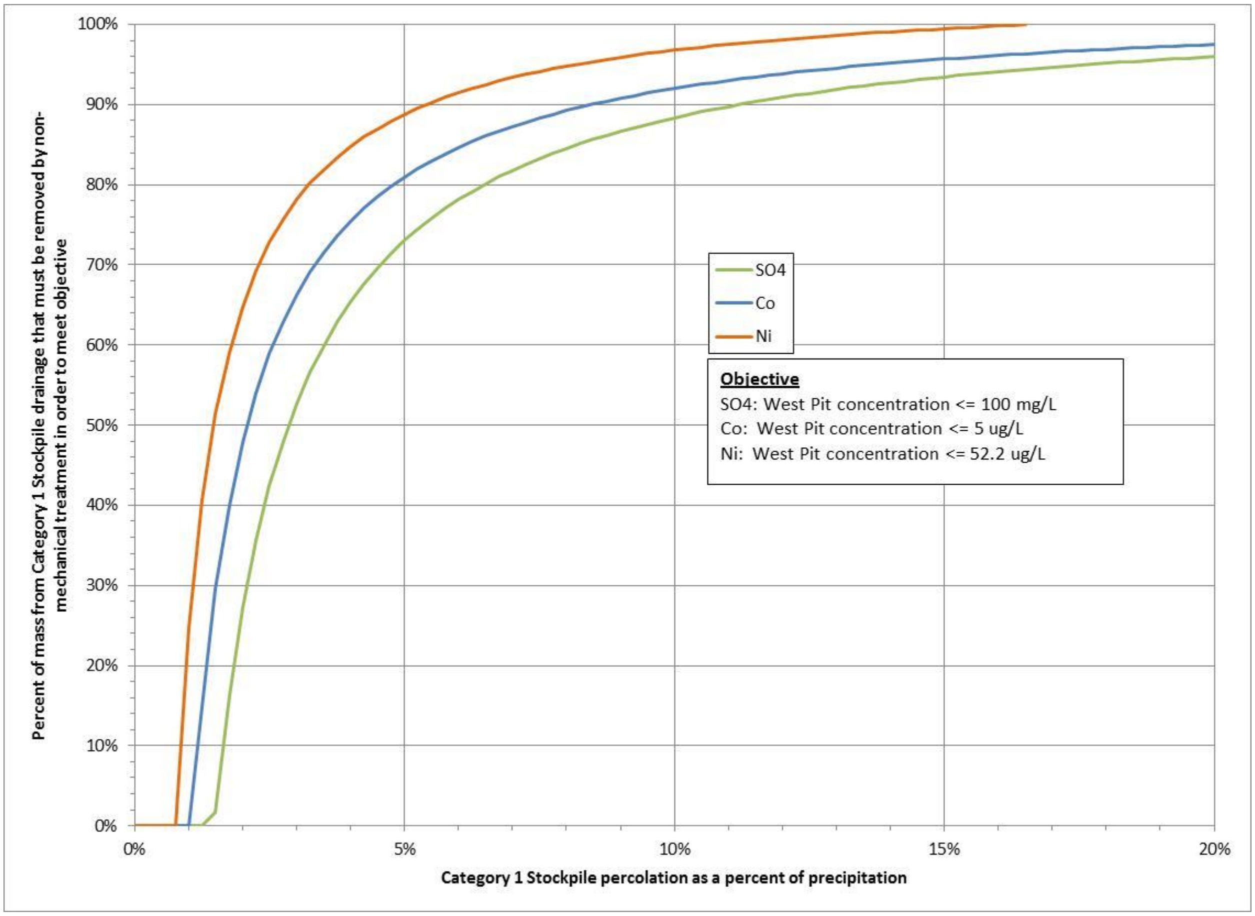


Figure 3-6 Category 1 Waste Rock Stockpile Percolation and Non-Mechanical Treatment Mitigation – Sulfate, Cobalt and Nickel

Figure 3-7 shows the amount of copper removal that would be needed by the West Pit Overflow Non-Mechanical Treatment System under a variety of different Category 1 Waste Rock Stockpile Cover System percolation rates and Category 1 Stockpile Non-Mechanical Treatment System removal rates. With a percolation rate through the geomembrane cover of 5% of precipitation, if there is no mass removal by the groundwater containment system non-mechanical treatment (0% curve in Figure 3-7), the overflow non-mechanical treatment would need to remove 88% of the copper mass in order to meet the water resource objectives. With increased removal by the Category 1 Stockpile Non-Mechanical Treatment System (30%, 60% and 90%), the amount of mass removal that must be provided by the West Pit Overflow Non-Mechanical Treatment is lower. The actual amount of copper removal possible by the Category 1 Stockpile Non-Mechanical Treatment System will be based on the results from the pilot-scale treatment testing (Section 6.2.3). However, the removal efficiencies shown on Figure 3-7 are within the range of removal efficiencies presented in literature (Reference (38)) as well as other references provided in Section 6.1.3 and Section 6.1.4.

In summary, the performance of the Category 1 Waste Rock Stockpile Cover System strongly affects the mass of cobalt, nickel and sulfate the non-mechanical treatment must remove, but has very little effect on the mass of copper removal that would be necessary for the Project to transition to non-mechanical treatment in the future.

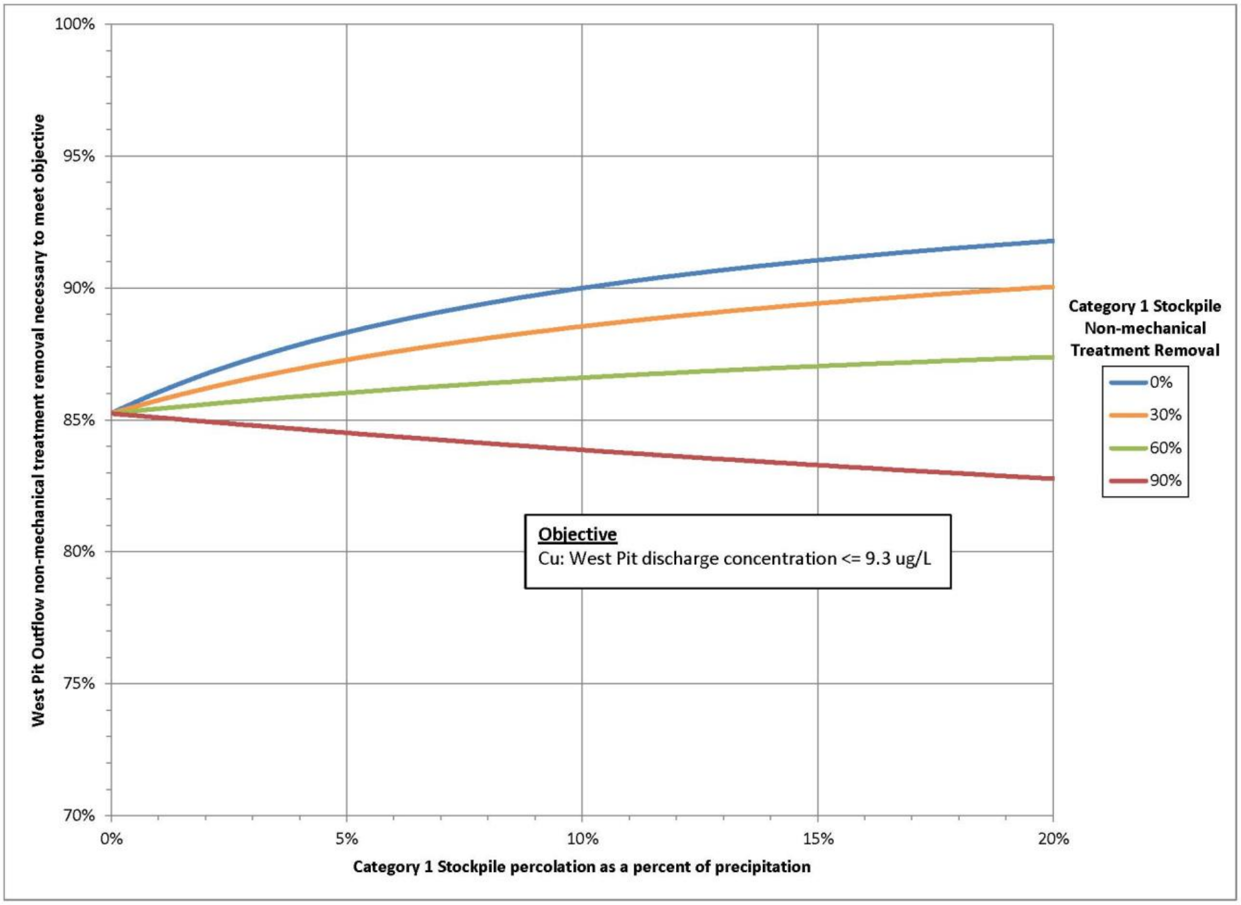


Figure 3-7 Category 1 Waste Rock Stockpile Percolation and Non-Mechanical Treatment Mitigation – Copper

3.4 Adaptive Management

3.4.1 Test Projects

There are currently no test projects planned for the Category 1 Waste Rock Stockpile Cover System. However, a future test project could include evaluations of evapotranspiration (ET) covers or other covers that are being tested by industry.

3.4.2 Reporting and Model Update

The Project includes a comprehensive water quality and quantity monitoring and reporting program that will be finalized in NPDES/SDS and Water Appropriation permitting (Section 5 of Reference (1)). The program also includes annual comparison of actual monitoring to modeled results for Category 1 Waste Rock Stockpile drainage. This comparison will be used to refine the model. Additional detail regarding the periodic model evaluation is provided in Reference (8).

3.4.3 Modified Design

If the monitored quantity or quality of water collected by the Category 1 Stockpile Groundwater Containment System, or annual updates to the model indicate that modifications are needed to meet water resource objectives, modifications could be made to the cover system, the groundwater containment system, or the WWTS. This section describes potential adaptive management actions for the cover system. Potential contingency mitigation for the Category 1 Stockpile Groundwater Containment System are described in Section 2.1.3.2 of Reference (5), and potential adaptive management aspects of the WWTS are described in Section 4.5. Additional potential adaptive management actions for water quality at the Mine Site are described in Sections 6.4 and 6.5 of Reference (1).

The cover system design can be modified up to the point of construction. After installation, post-installation adjustments can be made.

3.4.3.1 Circumstances Triggering Modification

Circumstances that could trigger a request for design modification approval include:

- Analog sites demonstrate that a modified cover design will limit the percolation rate to the extent required.

- Actual field monitoring of the Project and model updating demonstrate that the percolation rate requirement has changed and that a modified design can achieve that rate. The percolation rate requirement could change for various reasons:

    - Modeled performance of other fixed or adaptive engineering controls could change.

    - Modeled constituent load from backfilled Category 2, 3, and 4 waste rock, pit walls or Category 1 Waste Rock Stockpile could change.

    - Modeled groundwater inflow or surface runoff into the pits could change.

3.4.3.2 Options for Modified Performance

Prior to installation, the design of the geomembrane cover system can be adjusted to modify performance if approved by the MPCA and DNR. Options include:

- increased or decreased thickness of the geomembrane material to modify the potential for defects to be created during installation and to modify the life of the geomembrane

- increased or decreased soil cover thickness above the geomembrane material to modify water storage capacity

- increased or decreased soil hydraulic conductivity of the granular drainage layer above the geomembrane to modify lateral drainage capacity
- increased or decreased uninterrupted slope length to modify lateral drainage capacity
- modified soil type and/or thickness below the geomembrane to modify leakage rate through potential geomembrane defects
- including a geosynthetic clay liner below the geomembrane to modify leakage rate through potential geomembrane defects

After installation, the installed geomembrane cover system can be adjusted to modify performance if approved by MPCA and DNR. Options include:

- overseeding and/or fertilizer application to improve vegetation density
- organic matter addition to rooting zone layer to improve vegetation density
- increased or decreased thickness of rooting zone layer to modify vegetation density and soil moisture storage
- increased or decreased frequency of cover system maintenance to modify vegetation density and erosion of the cover system
- long-term conversion to engineered vegetated store and release evapotranspiration cover system

3.5 Reclamation, Closure, and Postclosure Maintenance

The cover system will be implemented progressively starting in Mine Year 14 and is expected to be fully implemented by the end of Mine Year 21. Construction sequencing is shown on Figure 3-8. The cover system will be required to function until constituents have been depleted from the stockpile or the release rates of constituents from the stockpile have decreased to the point where West Pit lake concentrations result in achieving water resource objectives without limiting drainage. The 200-year model does not show that the sulfur in the waste rock has been depleted or that constituent release rates have decreased.

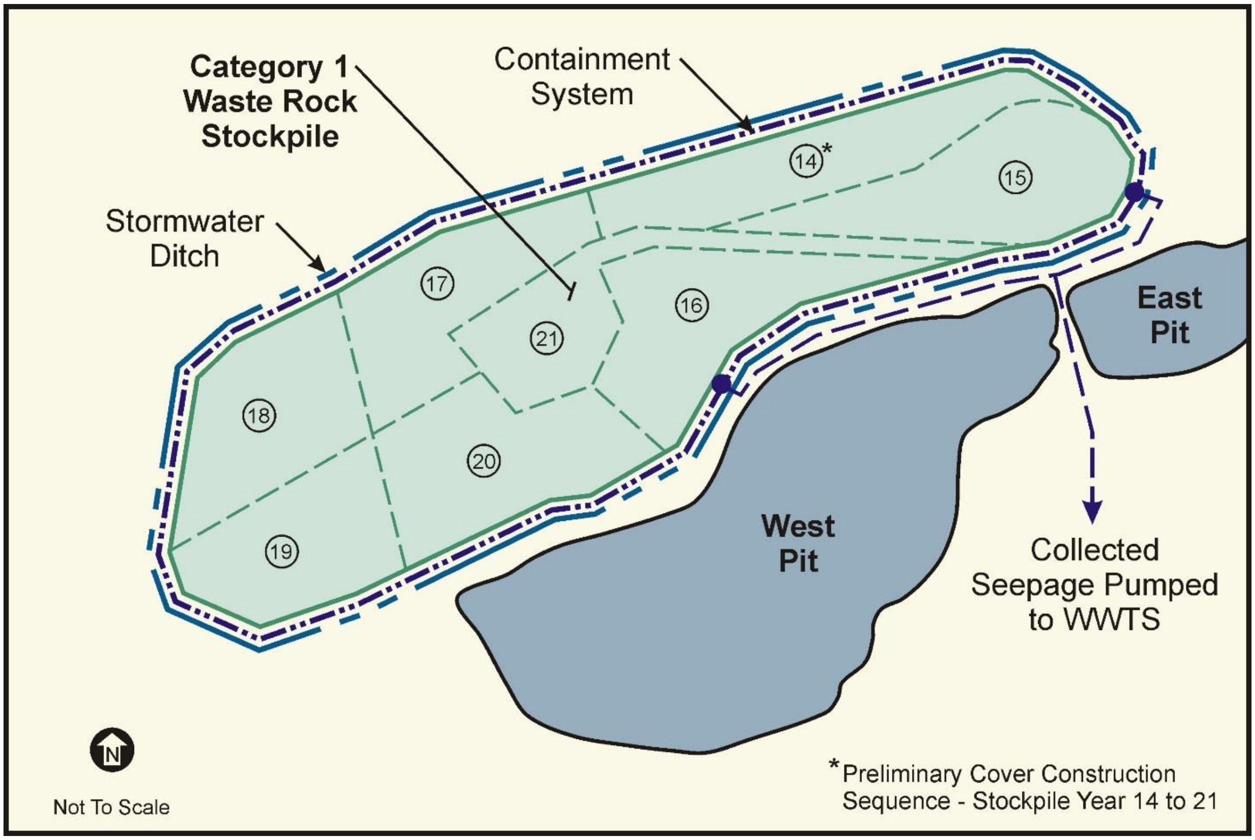


Figure 3-8 Category 1 Waste Rock Stockpile Cover Construction Sequencing

4.0 Plant Site Adaptive Water Management

4.1 Overview

4.1.1 Plant Site Water Management Systems

Water management systems at the Plant Site include fixed engineering controls (Reference (2)) and adaptive engineering controls. Adaptive water management features at the Plant Site include the WWTS and the FTB Pond Bottom Cover System (Section 5.0). The design of the WWTS is adaptive because treatment components can be modified and plant capacity can be adjusted to accommodate varying influent streams and discharge requirements. The design of the FTB Pond Bottom Cover System is adaptive because it can be modified to achieve the desired hydraulic conductivity based on operational experience, field monitoring, test projects, or availability of new construction materials or techniques.

Overviews of water management during the different phases of the Project are provided on Large Figure 2 through Large Figure 7. A timeline showing the variations in Plant Site water management through the various phases of the Project is provided on Figure 4-1.

During operations (Large Figure 2 and Large Figure 3), the FTB Pond will be the primary collection and distribution point for water used in the beneficiation process. The primary sources of water to the FTB Pond will include water from the Beneficiation Plant used to transport Flotation Tailings to the FTB, direct precipitation, stormwater run-on, construction mine water, Overburden Storage and Laydown Area runoff, treated mine water from the WWTS, and water collected by the FTB Seepage Containment System and the FTB South Seepage Management System (referred to collectively as the FTB seepage capture systems). Some of the water collected by the FTB seepage capture systems will be routed to the WWTS and some will be returned to the FTB Pond (Section 2.1 of Reference (2)). Sufficient flow will be routed to the WWTS, treated, and discharged off-site to meet stream augmentation requirements. The WWTS will discharge to the Second Creek, Unnamed Creek, and Trimble Creek watersheds just downstream of the FTB seepage capture systems. Starting in approximately Mine Year 11, when the Project will no longer be generating construction mine water and when East Pit flooding will begin, OSLA runoff will be routed to the East Pit, rather than the FTB Pond, and some treated mine water will be routed from the WWTS to the East Pit to accelerate flooding (Large Figure 3).

Concentrate and solids management in the WWTS will include secondary membrane separation followed by chemical precipitation, with the residual solids disposed in a permitted solid waste facility or in the Hydrometallurgical Residue Facility (HRF).

During reclamation (Large Figure 4) while the FTB is being reclaimed, the WWTS will continue to treat tailings basin seepage and mine water. It will also treat water from the HRF to facilitate HRF reclamation, including decanted HRF pond water, water from the HRF Drainage Collection System, and water from the HRF Leakage Collection System. WWTS discharge will continue to be conveyed to Second Creek, Unnamed Creek, and Trimble Creek in quantities sufficient to meet stream augmentation requirements. Some WWTS discharge will also be blended with untreated, collected tailings basin seepage and pumped to the Mine Site to flood the West Pit. A small portion of WWTS discharge may also be used to maintain the designed water volume within the FTB Pond. During reclamation, the WWTS will also facilitate East Pit flushing by treating mine water from the East Pit, then returning treated mine water to the pit (Section 2.2.2.2).

During closure (Large Figure 5), the WWTS will treat tailings basin seepage, decanted HRF pond water, water from the HRF Drainage Collection System, and water from the HRF Leakage Collection System. The only influent to the WWTS from the Mine Site during this phase would be the water from the Category 1 Stockpile Groundwater Containment System, a very low volume of flow of water that could be discharged directly to the West Pit, with agency approval (Section 2.1.1. and 2.2.2.2), or treatment of the water from the groundwater containment system could transition to non-mechanical treatment with gravity discharge to the West Pit as further described in Section 6.2, after the non-mechanical system has been proven to provide appropriate treatment. Also, in closure, the bottom of the FTB Pond will be augmented with bentonite around Mine Year 30 (Section 5.0). The FTB Pond Bottom Cover System will reduce the percolation from the FTB Pond, maintaining a permanent pond that will, in combination with the bentonite amended soil covers for the beaches and exterior slopes of FTB dams, provide an oxygen barrier around the Flotation Tailings to reduce oxidation and resultant production of chemical constituents. After placement of the FTB Pond Bottom Cover System, FTB pond water will be pumped to the WWTS, as necessary, to prevent any overflow from the pond.

The ultimate goals for postclosure maintenance are to transition from the mechanical treatment provided by the WWTS to non-mechanical treatment and to allow overflow of the FTB Pond by demonstrating that water in the FTB Pond can be directly discharged as stormwater. Because non-mechanical treatment designs are very site-specific and very dependent on the quality of the water to be treated, it is assumed that the WWTS will operate in the long-term (Large Figure 6) and the transition to non-mechanical treatment (Large Figure 7) will only occur after the design for a non-mechanical system has been proven. Water from the FTB Pond will continue to be pumped to the WWTS to prevent pond overflow until the pond water has been demonstrated to meet the applicable water quality standards.

During postclosure maintenance (after the FTB is reclaimed and hydrology has stabilized), tailings basin seepage and water collected by the HRF Leakage Collection System will continue to be collected and discharged via the WWTS until non-mechanical treatment has been demonstrated to provide appropriate treatment. FTB pond water will be pumped to the WWTS, as necessary, to prevent any overflow, until it can be demonstrated that the pond water is stormwater and meets all applicable surface water quality standards. The WWTS will also treat water mine water as needed to prevent the West Pit from overflowing, and discharge treated water to Unnamed (West Pit Outlet) Creek, which flows into the Partridge River, as described in Section 2.2.2.3. The WWTS will operate as long as necessary and will be financially assured.

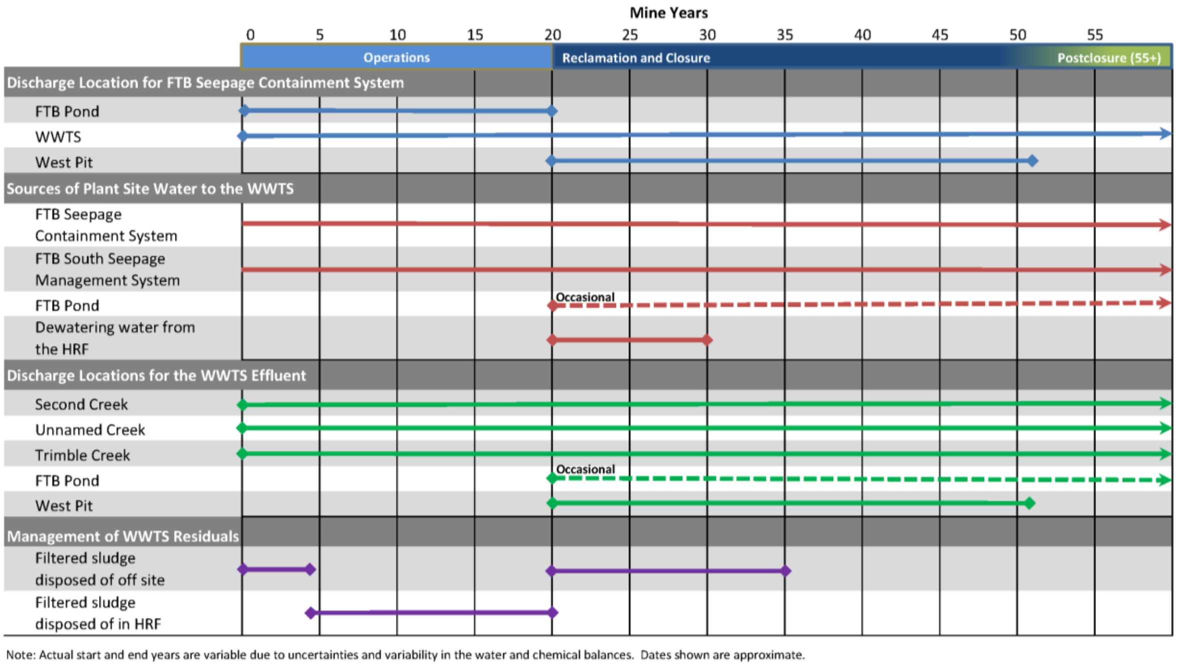


Figure 4-1 Plant Site Water Management Timeline with Mechanical Treatment

4.1.2 Water Resource Objectives

The water resource objectives at the Plant Site are to:

- meet the applicable surface water standards, to be defined by the MPCA as part of the NPDES/SDS process, in three Embarrass River tributaries (Trimble Creek, Unnamed (Mud Lake) Creek, and Unnamed Creek) and one Partridge River tributary (Second Creek) at their headwaters near the FTB

- meet the applicable groundwater, to be defined by the MPCA as part of the NPDES/SDS process, at points of compliance at the Plant Site

- meet NPDES/SDS permit conditions with regard to discharge limits

- maintain streamflow in Trimble Creek, Unnamed Creek, Unnamed (Mud Lake) Creek, and Second Creek within $\pm$ 20% of the existing annual average flow (i.e., before Cliff Erie's implementation of short-term mitigation measures at the former LTVSMC tailings basin under its Consent Decree with MPCA) for purposes of maintaining hydrology and existing aquatic ecology (Section 9.5 of Reference (39))

Meeting these objectives requires the integrated operation of all the fixed engineering controls described in Section 2 of Reference (2) and the adaptive engineering controls described in Sections 2.0, 4.0, and 5.0 of this document.

4.1.3 Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in NPDES/SDS and Water Appropriation permitting. Water quantity monitoring will also be conducted in accordance with the Water Appropriation permitting requirements, while water qualtity monitoring will be conducted in accordance with the NPDES/SDS permitting requirements. The program includes monitoring the flow and/or water quality of water from Plant Site project features, stormwater, groundwater, and surface water. See Section 5 of Reference (2) for details.

4.2 Plant Site Water Treatment

4.2.1 Purpose and Overview

During the operations, reclamation, closure, and postclosure maintenance phases, the WWTS will treat Plant Site water to provide water that:

- meets the needs of the Project when the water is being treated for recycling or re-use
- meets water resources requirements (quality and quantity) for discharge to the environment

Water quality standards and NPDES/SDS permit conditions will be used as a basis for defining the specific treatment targets needed for discharge, which are listed in Table 4-1. Treatment targets are the same for these four phases of the Project, because treated tailings basin seepage will be discharged to the environment.

Table 4-1 WWTS Discharge Proposed Water Quality Targets (PWQTs)

Parameter(1)	PWQT	Basis
Metals/Inorganics (µg/L, except where noted)		
Aluminum	125	M.R., part 7050.0222 Class 2B (chronic standard)
Antimony	31	M.R., part 7050.0222 Class 2B (chronic standard)
Arsenic	10	M.R., part 7050.0221 Class 1 (Primary MCLs)
Barium	2,000	MN Groundwater (HRL, HBV, or RAA)
Beryllium	4	M.R., part 7050.0221 Class 1 (Primary MCLs)
Boron	500	M.R., part 7050.0224 Class 4A (chronic standard)
Cadmium(3)	2.5	M.R., part 7052.0100 Class 2B (chronic standard)
Chromium(2)	11	M.R., part 7052.0100 Class 2B (chronic standard)
Cobalt	5	M.R., part 7050.0222 Class 2B (chronic standard)
Copper(3)	9.3	M.R., part 7052.0100 Class 2B (chronic standard)
Iron	300	M.R., part 7050.0221 Class 1 (Secondary MCLs)

Parameter(1)	PWQT	Basis
Lead(3)	3.2	M.R., part 7050.0222 Class 2B (chronic standard)
Manganese	50	M.R., part 7050.0221 Class 1 (Secondary MCLs)
Nickel(3)	52	M.R., part 7052.0100 Class 2B (chronic standard)
Selenium	5	M.R., part 7052.0100 Class 2B (chronic standard)
Silver	1	M.R., part 7050.0222 Class 2B (chronic standard)
Thallium	0.56	M.R., part 7050.0222 Class 2B (chronic standard)
Zinc(3)	120	M.R., part 7052.0100 Class 2B (chronic standard)
General Parameters (µg/L, except where noted)		
Chloride (mg/L)	230	M.R., part 7050.0222 Class 2B (chronic standard)
Fluoride (mg/L)	2	M.R., part 7050.0221 Class 1 (Primary MCLs)
Hardness (mg/L)(4)	100	Hardness PWQT chosen to establish PWQTs for metals with a hardness based standard
Sodium	60% of cations	M.R., part 7050.0224 Class 4A (chronic standard)
Sulfate (mg/L)	10	M.R., part 7050.0224 Class 4A (chronic standard)

M.R. = M.R., MCLs = Maximum Contaminant Levels, PWQT = Preliminary Water Quality Targets
(1) The Proposed Water Quality Targets parameter list has been updated from RS29T to include only the parameters modeled in GoldSim.
(2) The Chromium (+6) standard of 11 µg/L is used rather than the total Chromium standard to be conservative.
(3) Standard based on hardness.
(4) M.R., part 7050.0223 Class 3C standard for hardness is 500 mg/l.

Large Table 7 shows the potentially applicable water quality standards, the PWQTs selected from those potential standards, and the effluent concentrations used as inputs to the GoldSim model used to assess potential impact the receiving waters. This table may be updated depending on the discharge limits listed in the Project NPDES/SDS Permit, once issued.

The reverse osmosis (RO) membrane separation pilot-plant test (Reference (40)) demonstrated that the planned design is capable of achieving the effluent concentrations used in the GoldSim model and the PWQTs.

The WWTS will be designed to have the performance needed to achieve the treatment targets using the treatment processes described in Section 4.3. Additional details on the modeling and sizing of the treatment processes have been developed for NPDES/SDS permitting using the Plant Site water modeling results and are documented in the Waste Water Treatment System: Design and Operation Report (Reference (41)), which also includes the Waste Water Treatment System Permit Application Support Drawings. In addition, the treatment processes and the operation of the WWTS can be adapted, as necessary, throughout each Project phase, to meet water resource objectives and the needs of the Project.

The Project phases are described below in terms of the sources of Plant Site water to the WWTS, the discharge location of the treated water, and the purpose of treatment. The transition from reclamation to closure and then to postclosure maintenance may be implemented in stages, with deployment of postclosure maintenance features timed to adaptively manage Project needs, water resource objectives, and site-specific conditions.

4.2.1.1 Operations

During operations, the WWTS tailings basin seepage treatment train will treat water collected by the FTB seepage capture systems that is to be discharged for stream augmentation. The primary purpose of treatment will be to meet the appropriate water quality discharge limits. In addition, the WWTS mine water treatment trains will treat mine water for discharge to the FTB Pond as described in Section 2.

4.2.1.2 Reclamation and Closure

At the start of reclamation, the volume of water treated by the WWTS tailing basin seepage treatment train will increase relative to operations. Influent sources during reclamation will include water collected by the FTB seepage capture systems, excess FTB pond water, decanted HRF pond water, water from the HRF Drainage Collection System, and water from the HRF Leakage Collection System. Mine water will also continue to be treated at the WWTS, as described in Section 2. The purpose of water treatment during the reclamation phase will be to meet the appropriate discharge limits for water discharged to the environment and to provide a source of clean water to flush the East Pit and to flood the West Pit. Treatment will be designed to achieve constituent concentrations within the flooded West Pit that will not result in exceedance of appropriate groundwater and surface water standards at appropriate compliance points downstream of the West Pit during postclosure maintenance.

4.2.1.3 Postclosure Maintenance

During postclosure maintenance, the WWTS will continue to treat water collected by the FTB seepage capture systems as well as excess water from the FTB Pond as needed to prevent overflow (until pond water meets water quality standards, as described in Section 6.5). Overflow from the West Pit will also be treated for discharge to the environment. The primary purpose of water treatment at the WWTS during postclosure maintenance will be to meet the appropriate water quality discharge requirements.

The ultimate water management and treatment goal is to transition from the mechanical treatment provided by the WWTS to non-mechanical treatment systems at both the Mine Site and the Plant Site. A potential non-mechanical treatment system for the Plant Site, the FTB Non-Mechanical Treatment System, is described in Section 6.4. For financial assurance calculations, it is assumed that the WWTS will continue to operate during postclosure maintenance until the transition to non-mechanical treatment occurs. The transition from mechanical to non-mechanical water treatment will occur only after the site-specific design for the non-mechanical system has been proven and approved by the appropriate regulatory agencies.

4.2.2 Design Basis for Plant Site Water Treatment

The design of the required processes for treatment of Plant Site water at the WWTS will be based upon the following factors:

- the quantity and quality of water collected by the FTB seepage capture systems requiring treatment during various phases of the Project
- the quantity and quality of the FTB Pond requiring treatment to prevent overflow during the various phases of the Project
- the quantity and quality of the HRF Pond as the pond is drained during reclamation
- the results of pilot-testing of the primary and secondary treatment unit operations as described in the Final Pilot-Testing Report (Reference (40))
- the purpose of treatment for each phase of the Project as described in Section 4.2.1

The quantity and quality of the Plant Site water that will be delivered to the WWTS will be estimated using the Plant Site water quality modeling results (Reference (4)) prepared for NPDES/SDS and Water Appropriation permitting. The following subsections provide a summary of the expected influent water quantity and quality for the Plant Site water inflows to the WWTS.

4.2.2.1 Plant Site WWTS Influent Quantities

The estimated water quantities of Plant Site water that will be conveyed to the WWTS from the FTB seepage capture systems, the FTB Pond, and the HRF, which includes the HRF Pond, the HRF Drainage Collection System, and water from the HRF Leakage Collection System during the three phases of the Project are summarized in Table 4-2. The Plant Site water quantity estimates summarized in Table 4-2 are the annual average of the 90th percentile flow rates from the FTB seepage capture systems from the Plant Site water modeling (Reference (4)).

Table 4-2 Plant Site Water Flows to the WWTS

Source	90th Percentile Estimated Average Annual Flow (gpm)(1)		
	Operations(2)	Reclamation and Closure(3)	Postclosure Maintenance(4)
FTB Seepage Capture Systems	3900	3150	2180
HRF	0	150	0(5)
FTB Pond	0	830	740

(1) The 90th Percentile flows from each source do not occur in the same year and therefore are not additive.
(2) Estimate based on Reference (4) for Mine Year 10 (Design Year), 90th Percentile.
(3) Estimate based on Reference (4) for Mine Year 25, 90th Percentile.
(4) Estimate based on Reference (4) for Mine Year 75, 90th Percentile.
(5) Flow from the HRF Leakage Collection System will be collected in postclosure maintenance, but the volume is negligible, and was not included in the water modeling.

Actual flow rates from the FTB seepage capture systems will vary throughout the 20-year operating phase of the Project. Generally the flow to the FTB seepage capture systems will increase throughout the Project as the FTB is built up. In addition, significant changes in flow could occur when the two FTB Ponds are combined in approximately Mine Year 7. While the tailings basin seepage flows to the WWTS will gradually trend upward, the volume of water discharged from the Project will be determined by the minimum hydrologic requirements of receiving streams and the capacity of the FTB Pond. These two parameters will help to bracket the hydraulic operating range for the WWTS as described below.

In addition to long-term variations in flows over the operating life of the Plant Site, the influent flows to the WWTS from the Plant Site are anticipated to fluctuate seasonally. The seasonal inflow variations, including the average summer and average winter flow rates are summarized in Table 4-3.

Table 4-3 Seasonal Variations in Plant Site Water Inflows to the WWTS

Source	Estimated Inflow (gpm)(1)(2)								
	Operations(3)			Reclamation and Closure(4)			Postclosure Maintenance(5)		
	1-Month Maximum	Average Summer	Average Winter	1-Month Maximum	Average Summer	Average Winter	1-Month Maximum	Average Summer	Average Winter
FTB Seepage Capture Systems	4000	3960	3840	3350	3120	3190	2540	2400	1950
HRF	0	0	0	150	150	150	0(6)	0(6)	0(6)
FTB Pond	0	0	0	1570	1210	450	1180	1120	350

(1) The 90th Percentile flows from each source do not occur in the same year and therefore are not additive.
(2) For this table summer is May through October; winter November through April.
(3) Estimate based on Reference (4) for Mine Year 10 (Design Year), 90th Percentile.
(4) Estimate based on Reference (4) for Mine Year 25, 90th Percentile.
(5) Estimate based on Reference (4) for Mine Year 75, 90th Percentile.
(6) Flow from the HRF Leakage Collection System will be collected in postclosure maintenance, but the volume is negligible, and was not included in the water modeling.

The maximum flow of tailings basin seepage to the WWTS is expected during reclamation and closure. From this maximum flow rate, the flow to the FTB seepage capture systems is expected to decline as the water stored in the FTB drains out and the FTB Pond Bottom Cover System is constructed, decreasing the seepage rate (Section 5.0). The discharge from the WWTS during reclamation will be used to maintain the hydrologic conditions of the receiving streams and, when possible, to augment West Pit flooding. A small portion of the WWTS discharge may also be used during reclamation to maintain the designed water volume within the FTB Pond.

HRF pond water and HRF Drainage Collection System water will also be directed to the WWTS during reclamation. This flow will represent a relatively small volume of water compared to other Plant Site flows to the WWTS. The temporary cover over the HRF during reclamation and ultimately the final cover over the HRF is expected to reduce the flow rate from the HRF from an initial value of 150 gpm to virtually 0 gpm by the end of the reclamation and closure phase of the Project.

During postclosure maintenance, it is expected that the flow to the WWTS from the FTB seepage capture systems will be relatively stable.

4.2.2.2 Plant Site Influent Water Quality

The average quality of Plant Site water that reports to the WWTS is expected to change gradually during the operations, reclamation and closure, and postclosure maintenance phases of the Project (Large Table 8). Estimated influent water quality is based on the quantity and quality of water from the FTB seepage capture systems and the FTB Pond. During reclamation, HRF drainage will be blended with the primary membrane concentrate and sent directly to the secondary membrane (VSEP) unit.

The initial quality of water that will be captured by the FTB seepage capture systems during operations is known based on the results from ongoing groundwater monitoring activities. The Project will result in changes in the quality of water leaving the toes of the Tailings Basin, but it will take several years for these effects to be observed given the slow travel time for water through the Tailings Basin. The seepage water concentration for each constituent will respond uniquely to changes in operation of the FTB during operations and reclamation and closure (Attachment M of Reference (4)). During postclosure maintenance, the concentrations of most constituents in the water collected by the FTB seepage capture systems and in the FTB Pond will approach their long-term equilibrium values.

4.3 WWTS Unit Process Design

4.3.1 WWTS Design Overview

The unit treatment processes that have been designed for use in the WWTS are based on the expected influent quantity and quality and on delivering the desired effluent quantity and quality, which have been described for the mine water flows from the Mine Site and the Plant Site flows in Sections 2.2 and 4.2, respectively.

Schematic diagrams of the of the WWTS unit processes during operations, reclamation and closure, and postclosure maintenance are shown on Large Figure 8 through Large Figure 10.

4.3.1.1 WWTS Influent Flows

Inflows to the WWTS will include the tailings basin seepage as well as the high concentration and low concentration mine water flows, which will be pumped from the Equalization Basin Area to the WWTS as described in Section 2. During operations, the WWTS process units will be designed to accommodate the summer average flow of tailings basin seepage as presented in Table 4-3 and the mine water flows summarized in Table 2-3. As noted in Table 4-3 the plant water flows to the WWTS are not expected to fluctuate as much, on a seasonal basis, as the mine water inflows (See Section 2.2.2.3.2), because the primary source of the plant water inflows to the WWTS is the tailings basin seepage. While storage and equalization of mine water flows is included in the design at the Mine Site (Section 2.2.4), any storage and equalization that may be required for tailings basin seepage will be provided by returning water to the FTB Pond as shown on Large Figure 8. The WWTS will be also be designed to accommodate the influent water quality shown in Large Table 4 for the tailings basin seepage and the blended high and low concentration mine water sources.

Initially, three separate flows will feed into the WWTS: the high and low concentration mine water flows and the tailings basin seepage flow. The three separate treatment processes that will be used to treat these flows are described separately in the following paragraphs. After the initial start-up and operation of the WWTS, it may be possible to optimize system performance by combining treatment of the low concentration streams – the tailings basin seepage and the low concentration mine water. This is an example of potential adaptive engineering controls that could be evaluated for the design of the WWTS.

4.3.1.2 Process Unit Design Inputs

Several of the proposed treatment processes have been pilot-tested using available water from the tailings basin. The results of these testing activities have been submitted to the MPCA for review (Reference (40)). For the unit operations that were included in the pilot-testing, the sections below provide limited information related to the pilot-test results.

The design of the treatment system components, including the sizing of units to accommodate the desired flow-rates, the chemical addition requirements, potential sludge generation and recycle rates was developed using the pilot-test results as well as other resources, including:

- additional information from process equipment vendors related to hydraulic and chemical treatment performance
- modeling of the overall WWTS unit operations using an integrated GoldSim and PHREEQC model

Design details and modeling results are provided in the WWTS Design and Operation Report (Reference (41)). The following subsections describe each of the components of the WWTS. Universal (common) elements of the WWTS are described in the initial paragraphs followed by descriptions of process units specific to the three influent flows to the WWTS – tailings basin seepage, low concentration mine water, and high concentration mine water.

4.3.2 Universal Design Elements

4.3.2.1 Site Layout

The WWTS will be located immediately south of the Tailings Basin, as shown on Large Figure 11. The location of the WWTS will need to accommodate trucks for the delivery of treatment chemicals (e.g., lime, calcite, and carbon dioxide) and for the removal of solids, during the phases of the Project when the HRF is not available for disposal.

4.3.2.2 WWTS Building

The proposed design for the WWTS building envisions construction using a pre-engineered steel structure. The foundations for the WWTS building and the process units will be cast-in-place, reinforced-concrete. A back-up power supply sufficient to operate critical WWTS equipment during a power outage will be required. A small volume of treated water will be stored at the site and used for chemical feed systems, back-washing, and general site housekeeping. Potable water for hygiene purposes will be delivered to the site from the Plant Site Potable Water Treatment System. The building will meet appropriate State and local building codes.

4.3.3 Tailings Basin Seepage Treatment Train

Tailings basin seepage will be treated at the WWTS for discharge to the designated streams using the treatment processes described below.

4.3.3.1 Collection

Tailings basin seepage will be collected using the FTB seepage capture systems described in Section 2.1 of Reference (2). In reclamation, additional water will also be collected from the FTB Pond, decanted from the HRF Pond, from the HRF Drainage Collection System, and from the HRF Leakage Collection System as described in Section 4.2.1.2.

4.3.3.2 Headworks

Tailings basin seepage flows into the WWTS will be pumped to the headworks, which will be used to control the flow through to the WWTS. The headworks will include chemical addition and a basin with capacity to store the WWTS influent design flow for up to 24 hours.

4.3.3.3 Filter Pretreatment

In the event that influent iron and manganese concentrations in the tailings basin seepage are greater than those estimated by Reference (4), pretreatment may be necessary ahead of the greensand filters to reduce loading, reduce backwash frequency, and optimize greensand filtration operations. Pretreatment (ahead of the greensand filter) will consist of a settling pond to remove iron solids that oxidize and precipitate when the water is pumped from the FTB seepage capture systems. Allowing for this potential pretreatment option is an example of the adaptive engineering controls available at the WWTS.

4.3.3.4 Greensand Filtration

Greensand filtration was evaluated in the pilot-test and will be used as pretreatment to the membrane separation system for the tailings basin seepage to remove particulate matter that could irreversibly foul the membranes. Pretreatment to remove particulate matter is needed because of anticipated elevated iron and manganese concentrations in the tailings basin seepage.

To reduce the elevated concentrations of dissolved iron and manganese, sodium permanganate will be added to the greensand filter influent so that iron and manganese can be removed by contact oxidation and filtration. The addition of sodium permanganate will also serve to continuously regenerate the manganese oxide coating on the greensand media. Periodically, the filters will be backwashed – based either on head-loss across the filters and/or filter runtime – to maintain their filtration capacity. Filter backwash water will be conveyed to the FTB Pond, and the filtrate will proceed on to the membrane separation unit. The greensand filters will be installed as modular pressure filters to provide adaptability.

4.3.3.5 Primary Membrane Separation

Membrane separation, including RO or similar membrane technologies, is a well-established technology for water treatment. Commercial scale membrane separation systems typically use spiral-wound membranes to remove dissolved constituents from water. Membrane separation technologies are employed for desalination, for the production of drinking water from seawater, and for industrial applications such as boiler feed water and water reuse. Under pressures greater than the natural osmotic pressure, water will pass through the membrane pores and the dissolved solids will be retained on the feed side of the membrane (Reference (42)). The retained constituents are contained in a concentrate stream. The performance of a pilot-scale RO membrane separation system for treating tailings basin seepage was recently evaluated and the results have been reported in the Final Pilot-Testing Report (Reference (40)).

The rejection of constituents by the membranes depends on the membrane materials, membrane pore size, and the overall composition of the water. A variety of membrane types are available in the marketplace from several manufacturers, including membranes for general brackish water treatment or general desalting to more specialized membranes for boron removal or specific industrial applications. Most commonly, the membrane modules from these manufacturers are standardized as 4-inch or 8-inch diameter modules that can be readily be interchanged. The selection of membranes for each phase of the Project is another example of an adaptive engineering control available for the WWTS.

The primary membrane separation system for treatment of the tailings basin seepage will have high-pressure feed pumps; cartridge filtration on each skid for additional particulate removal; and skid-mounted membrane housings, membrane modules, and chemical feed systems. It will be equipped with a control package that will integrate the membrane separation system with the overall WWTS control system.

4.3.3.5.1 Chemical Pretreatment

Antiscalants will be used for chemical pretreatment of water entering the WWTS membrane separation system to minimize the formation of insoluble salts such as calcium carbonate, barium sulfate, and calcium sulfate or other constituents such as silica that may otherwise accumulate and foul the membrane. Antiscalants are commonly dosed immediately ahead of the membrane separation system and improve the recovery of the membrane system by minimizing the natural tendency for solids accumulation on the membranes, which increases pressures and reduces throughput (capacity). Antiscalants interfere with crystallization and deposition on the membrane, slow the crystallization process, or otherwise create conditions to maintain solubility of the salts (e.g., by lowering pH). Antiscalants used in the pilot-testing are reported in Reference (40).

4.3.3.5.2 Residuals Management

The membrane separation system will generate two main classes of residuals: cleaning waste and primary membrane concentrate.

The membranes will need to be cleaned periodically to remove accumulated scale and/or foulants. Cleaning will be accomplished by a clean-in-place (CIP) process in which chemical solutions are circulated through the membrane system. The CIP process will consist of two-steps: an acid clean and a base/alkaline clean. Each step will use chemicals to remove a different class of foulants (e.g., acid to remove metals or carbonates and base to remove silica or biofilm). The CIP waste will be routed to the FTB Pond.

Primary membrane concentrate management is described in Section 4.3.3.7.

4.3.3.6 Primary Membrane Permeate Stabilization

The primary membrane permeate will require stabilization prior to discharge. The primary membrane permeate will have a very low concentration of dissolved solids, an elevated concentration of dissolved carbon dioxide, and a depressed pH. Due to these conditions, the primary membrane permeate, prior to stabilization, is expected to be acidic and corrosive.

The permeate will be stabilized using pressure vessel contactors filled with calcite, followed by dissolved gas stripping towers for removing excess carbon dioxide. Bench tests of stabilization methods were conducted as part of its pilot-testing program (Reference (40)). The goals of the stabilization bench tests were to identify methods and chemicals to adjust pH, restore buffering capacity, reduce corrosiveness, and ultimately to meet the discharge water quality requirements. The results of this work showed that the effluent could be stabilized using either hydrated lime or crushed limestone to achieve dissolved solids concentrations that were within the required discharge limits while also producing a stable (non-corrosive) and non-toxic effluent.

4.3.3.7 Concentrate Management

The concentrate from the primary membrane separation unit will be treated to reduce the volume using a secondary membrane system. VSEP (vibratory shear enhanced processing), a trade-marked process developed by New Logic Research, was the secondary membrane system evaluated during the pilot-testing (Reference (40)). The VSEP system consists of vertical stacks of circular flat sheet membranes mounted on a vibrating base. The shear introduced at the membrane surface due to high frequency vibration of the stack reduces fouling and allows higher recoveries than can be achieved with a spiral-wound membrane. The VSEP system has the ability to operate either in continuous flow or batch mode. The VSEP system evaluated in the pilot-test was able to reduce the primary membrane concentrate volume and further concentrate sulfate prior to chemical precipitation. The VSEP system will have hydraulic capacity equal to the design flow rate for the primary membrane concentrate.

The VSEP system shares a number of general similarities with the primary membrane system:

- A number of membrane types are available for selection and use in the VSEP system. These membranes are modified flat sheet membranes that are commonly available from the large membrane suppliers such as Dow or Hydranautics.

- The VSEP system will require chemical pretreatment. It is expected that acid and an antiscalant will be used for pretreatment.

- The VSEP membranes will require regular chemical cleaning to maintain their capacity. The cleaning process will likely require at least two chemicals (acid and base, generally).

As with the primary membrane system, the VSEP system will be equipped with a high-pressure pump that will pump the water across membrane. The VSEP permeate will be recycled to the front of the primary membrane unit for additional treatment. The VSEP concentrate (reject concentrate) will be conveyed to the chemical precipitation treatment process as described in Section 4.3.5.

The results from the pilot-test of the VSEP technology have been used to determine the values of key design parameters for the system (operating pressure, influent pH, and cleaning frequency) and select a membrane type for the operations phase of the Project.

4.3.3.8 Discharge Works

WWTS discharge will be conveyed to the permitted outfalls along the west, northwest, and north perimeter of the FTB – beyond the FTB Seepage Containment System – to augment streamflow in Trimble Creek, Unnamed Creek, and Second Creek.

4.3.4 Low Concentration Mine Water Treatment Train

Low concentration mine water will be treated at the WWTS. During operations, this stream will be treated, then blended with effluent from the high concentration mine water treatment train (Section 4.3.5) prior to being routed to the FTB Pond for reuse in the beneficiation process. During reclamation and closure, this stream will be treated and routed to either the East Pit (for flushing) or the West Pit (flooding). Finally, during postclosure maintenance, after treatment, this stream will be discharged to the Partridge River via Unnamed (West Pit Outlet) Creek. The PWQTs for each of these phases are listed in Table 2-1.

The process units used to treat low concentration mine water will include:

- greensand filtration for pre-treatment and removal of fine particulate matter that would reduce the life of the membrane separation process components

- reverse osmosis using nanofiltration (NF) membranes

- VSEP for secondary membrane separation of the NF concentrate prior to chemical precipitation, and “second-pass” processing of chemical precipitation effluent, as needed

Additional details on the process units that will be used to treat low concentration mine water at the WWTS are described below.

4.3.4.1 Headworks

The headworks for the low concentration mine water treatment train will be located at the CPS in the Equalization Basin Area at the Mine Site and will include a lift station with variable frequency drive (VFD) pumps and an in-line strainer. The primary purpose of the strainer will be to remove relatively large objects that may damage the membrane separation system components. A flow splitter will be located within the WWTS building to allow recirculation of membrane separation effluent and blending with the inflow from the LCEQ Basins.

4.3.4.2 Greensand Filtration

The filtration system that will be used ahead of the membrane separation units will be a parallel (modular) configuration of pressurized greensand filter vessels, similar to the configuration used for the FTB Seepage treatment train. The greensand filters will be used to remove particulate matter that could irreversibly foul the membranes. Greensand filtration will also remove metals ahead of the primary membrane separation system. The greensand equipment was shown to be effective for both pretreatment and metals removal during pilot-testing.

The greensand filtration vessels will require periodic backwashing. This backwash will be routed to a backwash recovery tank. Decant will be routed back to the headworks. Settled solids will be routed into the chemical precipitation train. The media filtration system will discharge to the primary membrane separation system.

4.3.4.3 Primary Membrane Separation

The primary membrane separation units for the low concentration mine water treatment train will have a similar arrangement to the primary membrane units for the tailings basin seepage system, but will use a different type of membrane.

For the low concentration mine water, NF membranes will be used for treatment because these membranes have a high selectivity for multivalent ions such as sulfate and calcium over monovalent ions such as chloride and sodium. This is important to the overall design of the WWTS because excess retention of monovalent ions in the primary membrane concentrate will limit the performance of the chemical precipitation treatment train used to treat the high concentration mine water flows. Commercial scale NF systems typically use spiral-wound membranes with pore sizes of 1 to 10 nm to remove dissolved constituents from water and are typically used for removing sulfate from seawater and for other industrial applications.

The primary membrane separation system will be equipped with a high-pressure pump that will pump the water across spiral-wound NF membranes. Under pressures greater than the natural osmotic pressure, water will pass through the membrane pores and the dissolved solids will be retained on the feed side of the membrane (Reference (42)). The retained constituents are contained in a membrane concentrate stream. With NF, most of the multivalent ions (metals and sulfate) are retained by the membrane, while a portion of the monovalent ions (e.g., chloride and sodium) are allowed to pass through. This results in a membrane separation concentrate that has a relatively high concentration of metals and sulfate, but lower conductivity. The lower conductivity (activity) of the membrane separation concentrate allows a greater amount of sulfate to be subsequently precipitated in the chemical precipitation units described in Section 4.3.5.

The low concentration mine water primary membrane separation treatment system will require the additional of pretreatment chemicals, similar to those described in Section 4.3.3.5.1. The membrane separation system will also require periodic cleaning. The membrane separation system cleaning solutions will be routed to the secondary membrane feed for the low concentration mine water.

4.3.4.4 Secondary Membrane System

A secondary membrane (VSEP) separation system is included in the design of the low concentration mine water treatment train. Similar to the secondary membrane system for the tailings basin seepage, the VSEP process will be used to reduce the volume of the membrane separation concentrate prior to chemical precipitation. This unit will also to provide operational flexibility to achieve additional sulfate removal from recycling of the chemical precipitation effluent. The percentage of chemical precipitation train recycle will be varied to accommodate flow and water quality requirements.

The VSEP concentrate will be fed into the chemical precipitation system using head available from the membrane filtration machines, and directed to the applicable precipitation train via a splitter box.

4.3.4.5 Discharge Works

Permeate from the low concentration mine water primary membrane separation system will discharge through a permeate blending tank that will allow for the addition of chemical precipitation effluent, secondary VSEP permeate, or other chemicals (lime) to be added before the blended water is discharged to the FTB Pond or to the East Pit or the West Pit during reclamation and closure.

4.3.5 High Concentration Mine Water (Chemical Precipitation) Treatment Train

The chemical precipitation treatment train will be used to remove metals and sulfate from the high concentration mine water and from the reject concentrate from the secondary membrane separation units in the WWTS. The chemical precipitation treatment train will consist of three chemical reactor-clarifier systems that will be operated in series to precipitate metals, sulfate, and excess calcium as solid residuals. Metals will be removed via a high density sludge (HDS) process. Sulfate will be removed via high lime treatment. Excess calcium removal and final pH adjustment are achieved by recarbonation. The solid materials created from these processes will be separated by gravity, dewatered via pressing, and managed at the HRF (Reference (7)) during operations or disposed at a permitted solid waste facility. During reclamation and closure and postclosure maintenance, these solid materials will also be disposed at a permitted solid waste facility.

Hydraulic loading to the chemical precipitation train will be equalized via the HCEQ Basin and, indirectly, via the LCEQ Basin (which equalizes flow to the membrane separation train). Overall hydraulic capacity of the chemical precipitation system will be based on summation of the following flow components:

- the design reject concentrate flow rate from the tailings basin seepage membrane separation train
- the design reject concentrate flow rate from the low concentration mine water membrane separation train resulting from membrane treatment of the flow required to prevent overfilling of the LCEQ Basin following the spring flood event in Mine Year 10
- the flow rate required to contain the one month spring flood event in Mine Year 10 to prevent overfilling of the HCEQ Basin

Process equipment for the chemical precipitation treatment train will be constructed in two phases. Phase 1 will be constructed in Mine Year 1 when flows and required capacity are low. Phase 2 is expected to be constructed prior to Mine Year 5, depending on the observed flows and the treatment performance of the Phase 1 units. For Phase 1, 100% of the overall hydraulic design capacity will be installed, consisting of one train (50% of the overall hydraulic design capacity each). Redundancy and peak flow capacity in the Phase 1 equipment will be achieved by using the excess storage capacity in the equalization basins in the early years of operation.

For Phase 2, when higher inflow rates are expected, a second parallel treatment train will be installed to support the full hydraulic capacity needed for the project during operations.

4.3.5.1 Headworks

The chemical precipitation treatment train headworks will include a lift station at the CPS in the Equalization Basin Area at the Mine Site that will draw from the HCEQ Basin. The lift station will be equipped with two VFD pumps. A splitter box will also be located within the WWTS building to allow blending of the secondary membrane concentrate with the HCEQ Basin effluent.

4.3.5.2 High-Density Metals Precipitation

Removal of metals, including nickel, copper, and cobalt, will be accomplished in an HDS metals precipitation system. This system will comprise rapid-mix tanks, high-density sludge reactors, and clarifiers. Lime will be added to adjust the pH to the desired set-point (approximately pH 10.5). The system will be able to recycle settled sludge from the clarifier back to the reactor to maintain a high sludge concentration to facilitate the co-precipitation of iron and metals. The design includes provisions for the addition of ferric chloride (to supplement iron concentration in the reactor) and polymer coagulant (to achieve the desired solids settling in the clarifiers), if necessary. Metals will be removed from the system as sludge.

4.3.5.3 Gypsum Precipitation

Sulfate removal will be achieved through the addition of lime to precipitate gypsum. This system will comprise rapid mix tanks, HDS reactors, and clarifiers. Lime will be added to adjust the pH to 12 to 12.5. The system will be able to recycle settled sludge from the clarifier back to the reactor to provide nucleation sites for gypsum precipitation, thereby enhancing precipitation kinetics. The design includes provisions for the addition of polymer coagulant to assist with solids removal in the clarifiers, if necessary. Sulfate will be removed from the system as gypsum sludge.

4.3.5.4 Recarbonation/Calcite Precipitation System

Effluent from the gypsum precipitation system will have a high pH and a high concentration of calcium, both of which are undesirable during transmission of the effluent to the FTB Pond. A recarbonation/calcite precipitation system comprising a rapid mix tank with carbon dioxide injection and a solids-contact clarifier will provide for excess calcium removal. Carbon dioxide (CO_2) will be stored on-site in outdoor, liquid CO_2 tanks. Liquid CO_2 from the tanks will be converted to a gas in a vaporizer unit, then dissolved into a water feed stream in the equilibration system. The resulting carbonic acid will then be added to the rapid mix tank to achieve a pH set-point of 10 to 10.5. This will facilitate the precipitation of calcium carbonate which is removed from the waste water in the solids contact clarifier. The excess calcium will be removed from the system as calcite sludge.

4.3.5.5 Effluent Neutralization

An in-line carbonic acid injection point downstream of the solids contact clarifier will provide final neutralization of the chemical precipitation effluent to pH 8 or less.

4.3.5.6 Discharge Works

Discharge works for the chemical precipitation treatment train system will consist of a clear well. The clear well will include a pump for transferring chemical precipitation effluent to the VSEP unit (Section 4.3.4.4) for further treatment, if necessary, to achieve desired water quality targets. The clear well will also have a gravity outlet for blending with membrane permeate and subsequent pumping to the FTB Pond.

4.3.5.7 Sludge Storage and Dewatering

The chemical precipitation treatment train processes will produce solid residuals in the form of chemical sludges, including a metal/iron sludge, gypsum sludge, and calcite sludge. These sludges will be conveyed within the treatment plant by means of sludge pumps and piping. In the case of the metals and gypsum precipitation processes, some fraction of the sludge collected in the clarifiers will be recycled to the precipitation reactors to maintain the necessary solids content in the reactors. Any excess sludge from these processes and the sludge collected in the calcite clarifiers will be pumped to sludge storage tanks. The sludge storage tanks will be equipped with agitators to prevent clogging of the cone with solids. Sludge accumulated in the sludge storage tanks will be dewatered by plate-and-frame filter presses over the course of one eight-hour shift each day. Filtered sludge will be transferred from the filter presses into trailers for hauling to a permitted solid waste facility for disposal or, after the Hydrometallurgical Plant is operational, to the Hydrometallurgical Plant to recover metals or to the HRF for disposal.

4.4 Engineering Control Performance

4.4.1 Description with Basis

The overall performance of the WWTS will represent a compilation of the performance of each individual treatment unit. The performance of each individual component has been determined during the permitting level design activities, including sizing of units to accommodate the desired flow-rates, defining the chemical addition requirements, and calculating the potential sludge generation and recycle rates (Reference (41)). The design calculations used to determine the construction and operating specifics for treatment units were based upon:

- analytical results from the pilot-testing program to evaluate primary and secondary membrane separation treatment along with chemical stabilization of the discharge water as well as chemical precipitation of the VSEP Concentrate (Reference (40))
- additional information from process equipment vendors related to hydraulic and chemical treatment performance

4.4.2 Modeling of Engineering Controls

Modeling of the overall performance of the WWTS unit operations was completed using an integrated GoldSim and PHREEQC model for the WWTS during operations, reclamation and closure, and postclosure maintenance. The modeling has been used to define the specific requirements for each treatment unit that will be needed to achieve the PWQTs as listed in Table 2-1 and Table 4-1. The integrated GoldSim/PHREEQC modeling results are included with the WWTS Design and Operation Report (Reference (41)).

4.5 Adaptive Management

To meet the specific treatment targets for each of the Project phases, the operating configuration and the operating requirements of individual process units within the WWTS or the capacity of the WWTS may need to be modified. Thus, the WWTS is considered an adaptive engineering control. The WWTS treatment processes can be adapted, as necessary, in response to the actual conditions encountered during the Project, the monitoring results, and the conditions estimated by continued model updating.

4.5.1 Reporting and Model Update

The Project includes a comprehensive water quality and quantity monitoring and reporting program (Section 5 of Reference (2)). The program includes annual comparison of actual monitoring to modeled results for the WWTS. This comparison will be used to refine the model. See Section 6 of Reference (2) for details.

4.5.2 Circumstances Triggering Modification

Circumstances that could trigger the need for one or more modifications to the WWTS operating configuration include:

- variation in influent water quantity, which could result in the need for more or less treatment system capacity
- variation of the influent water quality from the modeled water quality, which could result in a change in the operating performance of one or more of the treatment processes

4.5.3 Options for Modified Performance

Variations of either influent water quantity or quality will be addressed within the overall concept for the design, construction, and operation of the WWTS. Because the plan for construction of the WWTS envisions a phased build-out of the capacity that will be needed when the maximum flow occurs, variations in quantity can easily be addressed by either accelerating or delaying the installation of the additional equipment that is planned for the expansion of the WWTS. Treatment performance issues that could occur from changes in influent water quality can be addressed by making adjustments to operating conditions.

In addition to operational changes, the treatment systems could also be modified to improve performance, if necessary. Any modifications to the operation of the WWTS would be completed in accordance with the applicable permit requirements, including review and approval of any treatment system modifications by the MPCA, if necessary. Examples of how the WWTS may be adapted during the Project to modify treatment performance include:

- use of alternative membranes for either the primary or secondary membrane separation process units to modify the removal efficiencies of selected parameters across these systems
- treatment system modifications to improve metals removal (including mercury) (Section 4.5.3.1)
- softening pretreatment (Section 4.5.3.2)
- treatment system modifications to improve mine water treatment (Section 4.5.3.3)

4.5.3.1 Modifications to Improve Metals Removal

If removal rates for metals (including mercury) are less than projected, several treatment system modifications are possible to improve performance and achieve water resource objectives:

- pretreatment modifications such as addition of a chemical scavenger ahead of the greensand filter units to obtain additional metals removal
- addition of polishing treatment units for removal of trace metals (e.g., ion exchange) from the primary membrane permeate

4.5.3.2 Softening Pretreatment

One potential performance issue that has been identified in relation to treatment performance is related to the uncertainty in influent quality and the potential need to for additional pre-treatment. Uncertainty in the influent quality is due to the un-balanced ionic charge that is included in the water quality modeling and a paucity of silica data collected during the environmental review process. Because RO membranes reject virtually all ions in solution, while NF membranes would allow a portion of the monovalent ions to pass through, the potential for silica fouling increases when the percentage of RO membranes increases to meet the discharge performance requirements.

Softening pretreatment could be added at the WWTS if operational experience indicates precipitation on the forward side of the membranes is reducing the life of membranes in either the primary or secondary membrane separation systems to a level that is not acceptable for the overall operating cost of the treatment systems. The need for pretreatment will be determined during the operations phase of the Project using measured water quality data in combination with operational experience and modeling results.

Softening pretreatment could include adding a chemical reaction, coagulation, and precipitation unit similar to the HDS or sulfate removal units in the chemical precipitation train. Chemical feed systems for the addition of lime and soda ash could also be needed and additional solid wastes will be generated that will need to be filter-pressed and disposed along with the solids from the chemical precipitation treatment train. Potential ripple effects on other environmental aspects of the Project due to the addition of softening pre-treatment at the WWTS could include increased fugitive emissions, increased point source emissions, and increased solid waste. Generally, ripple effects from this adaptive management strategy will be small compared to current impacts and could be effectively mitigated.

4.5.3.3 Modifications to Improve Mine Water Treatment

Variations of either influent mine water quantity or quality can be addressed within the overall concept for the design, construction, and operation of the WWTS. The plan for construction of the WWTS already envisions a phased build-out of the capacity that will be needed prior to when the maximum flow of mine water occurs. Variations in quantity can easily be addressed by either accelerating or delaying the installation of the additional equipment that is planned for later phases of the WWTS. Treatment performance issues that could occur from changes in influent water quality can be addressed by making adjustments to operating conditions.

At most times throughout the year, it is expected that the WWTS will have excess hydraulic capacity for the treatment of mine water. This additional capacity could be used to modify treatment performance, for example by adjusting the recovery rates for the membrane separation processes or increasing the hydraulic retention times in the chemical precipitation processes. This additional capacity can also be used on an annual average basis to maintain treatment performance.

Softening or other pretreatment will not be needed for mine water because the use of NF membranes in the primary membrane separation unit (Section 4) will allow enough ionic constituents to pass that the potential for scaling is sufficiently reduced.

In addition to operational changes, the treatment systems could also be modified to improve performance, if necessary. Any modifications to the operation of the WWTS would be completed in accordance with the applicable permit requirements, including review and approval of any treatment system modifications by the MPCA, if necessary. If treatment system performance is less than projected, several additional treatment system modifications are also possible to improve performance and achieve water resource objectives, including:

- pretreatment modifications such as addition of a chemical scavenger ahead of the greensand filter units to obtain additional metals removal (including mercury)
- use of alternative membranes in either the primary or secondary membrane separation units to improve the performance for one or more specific parameters
- addition of polishing treatment units for removal of trace metals (e.g., ion exchange)

5.0 Flotation Tailings Basin (FTB) Pond Bottom Cover System

5.1 Project Feature

The reclamation plan for the FTB includes bentonite amendment to the upper layer of Flotation Tailings below the FTB Pond. The FTB Pond Bottom Cover System has been designed to maintain a permanent pond that will act as an oxygen barrier, reducing oxidation of the Flotation Tailings and resultant products of oxidation. It will also reduce seepage through the Flotation Tailings, thereby reducing the amount of flow to be collected via the FTB seepage capture systems and treated at the WWTS. When the FTB hydrology stabilizes, following installation of the pond bottom cover, it is likely that the FTB Pond will be perched. FTB dam exterior slopes and Flotation Tailings beaches will also be amended with bentonite to reduce the oxygen diffusion and precipitation percolation into the tailings (Section 7.2 of Reference (6)).

5.2 Planned Engineering Control

5.2.1 Purpose

The purpose of the FTB Pond Bottom Cover System is to 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.

5.2.2 Design

The FTB final reclamation plan includes bentonite amendment of the FTB pond bottom to reduce percolation. The FTB final reclamation system will be designed and constructed in accordance with applicable requirements of Minnesota Rules, part 6132.2500, subpart 2. The proposed method of adding bentonite to the pond bottom is by broadcasting (Figure 5-1). Bentonite injection, or placement of a geosynthetic clay liner, are alternate methods. With broadcasting, granular or pelletized bentonite will be systematically fed through a broadcast spreader system to uniformly distribute the bentonite across the area of the pond (Figure 5-1). Typical global positioning system survey and path tracking equipment will be utilized to track and confirm uniform spreading of the bentonite. The 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.

An alternate to the proposed broadcasting method is to inject bentonite into the pond bottom, then mix the Flotation Tailings at the pond bottom with the injected bentonite. This is shown schematically on Figure 5-2, and is similar to the method used in agriculture to inject manure and fertilizers below the ground surface, but with the addition of a mixing apparatus just behind the point of injection.

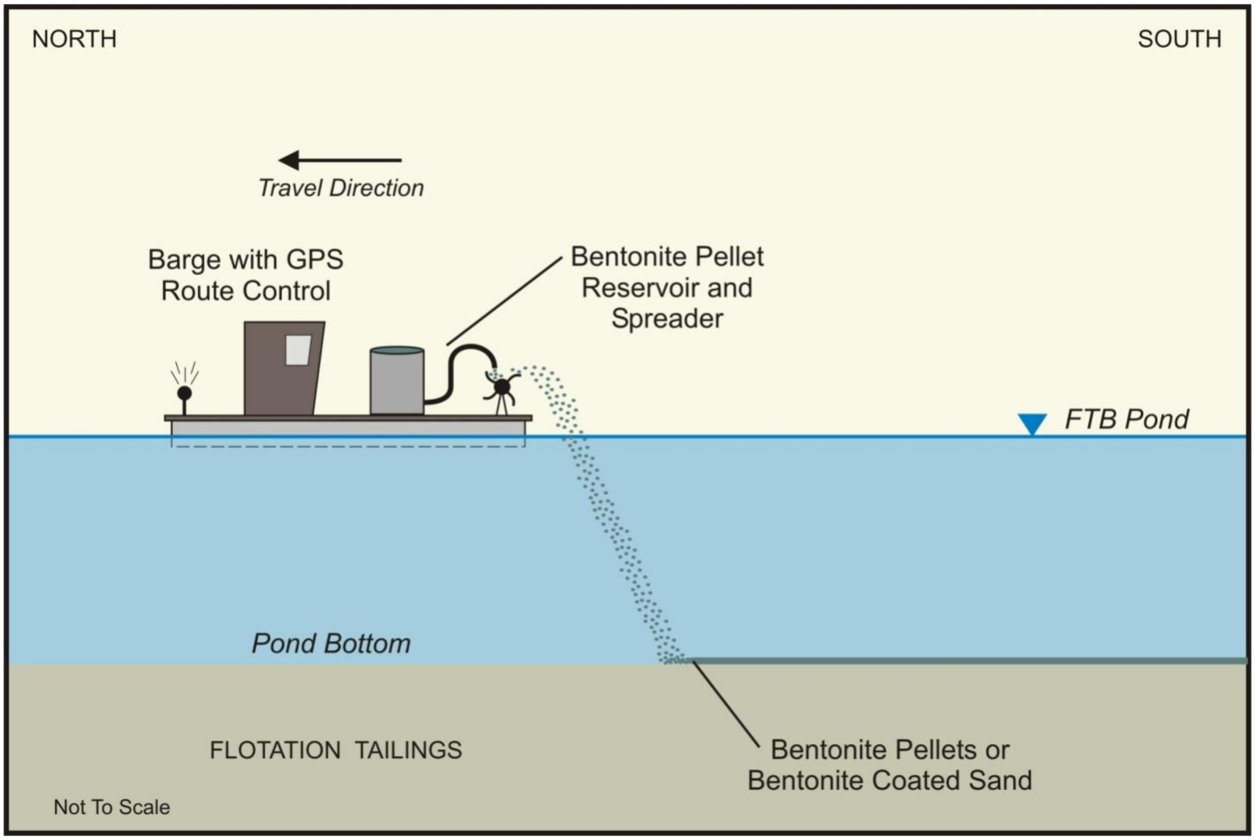


Figure 5-1 Bentonite Broadcasting

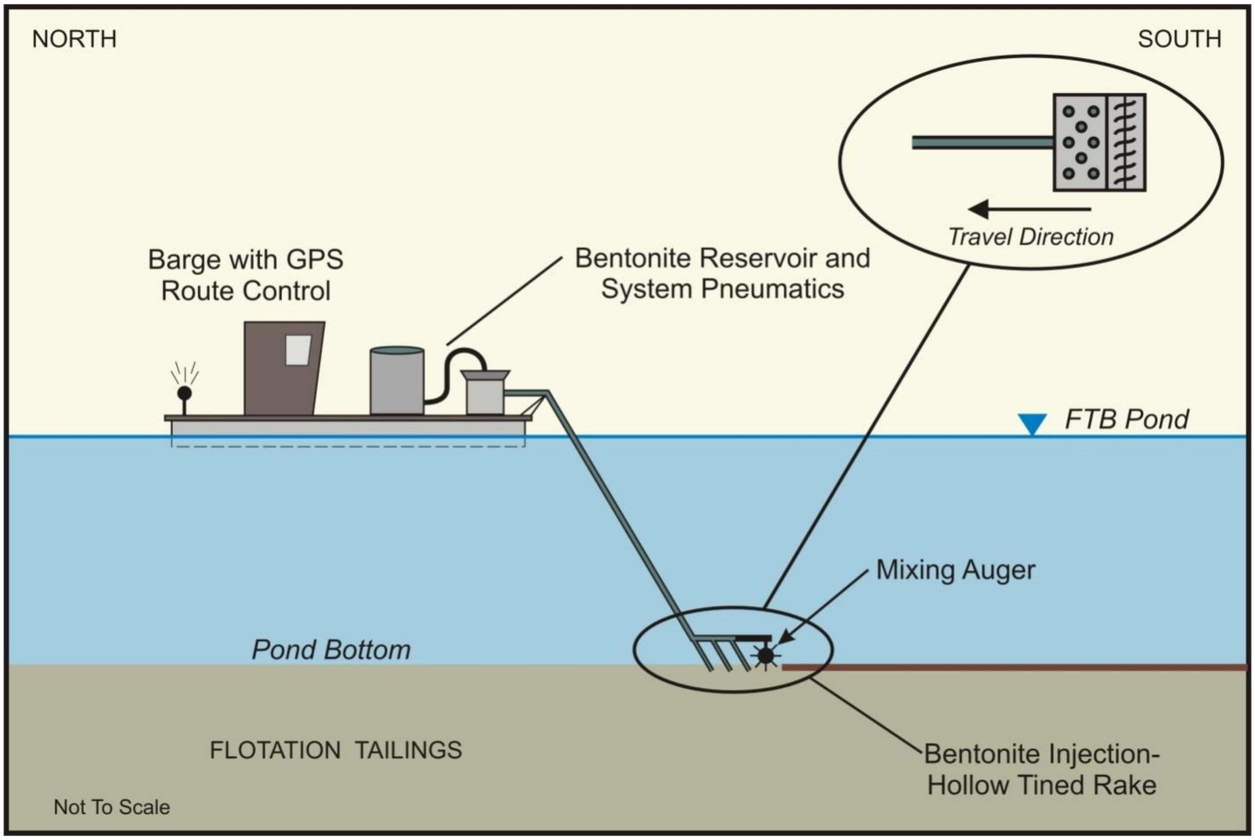


Figure 5-2 Bentonite Injection

A second alternative to the proposed broadcasting method is placement of a geosynthetic clay liner (GCL) on the pond bottom. This is shown schematically on Figure 5-3, and is similar to the method used on some sediment remediation sites where sediment in bays or rivers is covered in place.

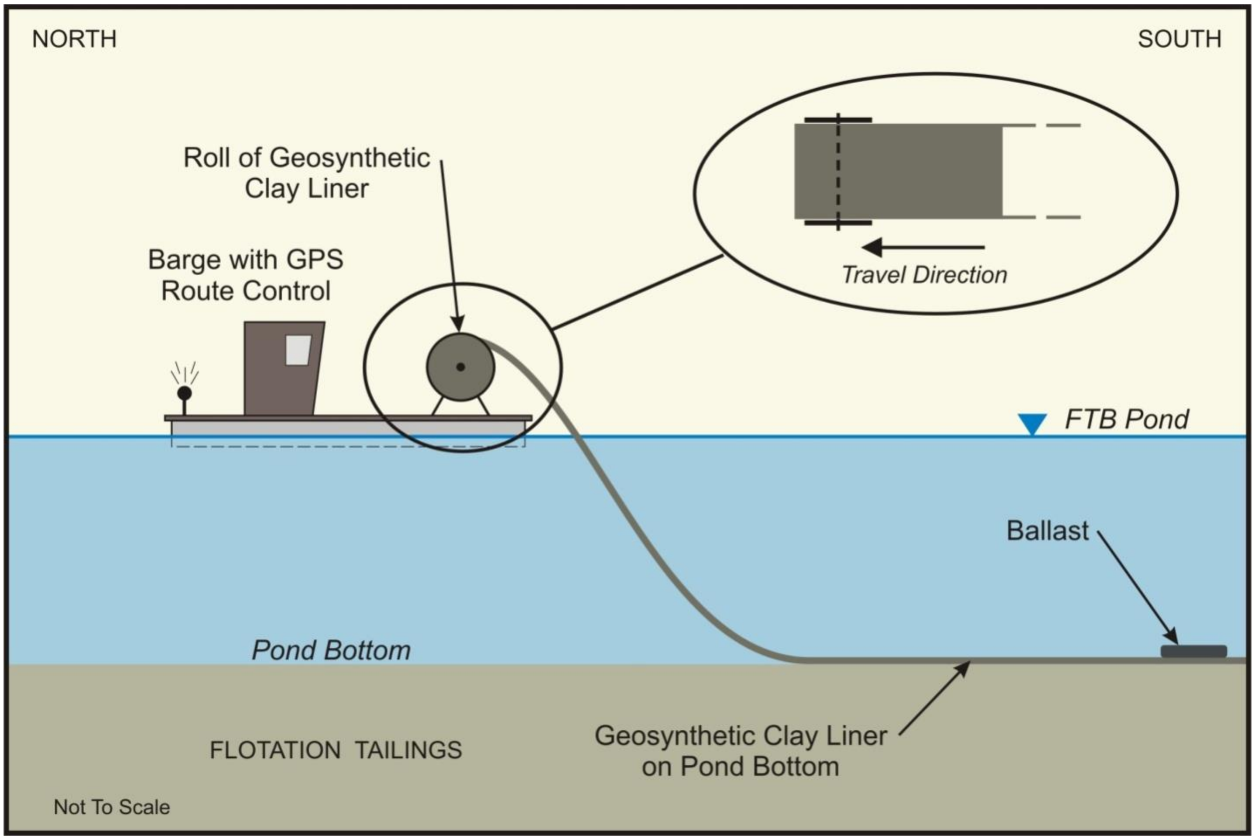


Figure 5-3 Geosynthetic Clay Liner

The application rate (most likely in pounds per acre) will be determined at the time of implementation on the basis of the percolation rate that must be achieved. A field testing and demonstration program will be conducted to evaluate the efficacy of the proposed method and to select a method that is effective, efficient, and economical (Attachment I of Reference (6)). By this test method the hydraulic conductivity of the bentonite amended Flotation Tailings can first be estimated in the laboratory and the 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. A systematic construction method will be used to achieve a uniform rate and distribution of bentonite application as dictated by pre-application laboratory test results.

As part of initial FTB Pond reclamation work, the selected construction contractor will be required to demonstrate that the means and methods selected for bentonite application to the pond bottom will yield the desired uniformity of bentonite application to result in a completed reclamation pond bottom having the specified mean hydraulic conductivity. The contractor will also be required to demonstrate that the bentonite application can be accomplished without going over the air quality permit requirements for fugitive dust emissions.

It is important to note that the required percolation rate is a mean percolation rate; not a maximum percolation rate. Therefore, there can and will be portions of the pond bottom where percolation rates greater than the mean exist due to the less than perfectly uniform application of bentonite. There will be other portions of the pond bottom where percolation rates lower than the mean result from placement of an excess amount of bentonite.

During bentonite amendment of the FTB beaches (described in Section 7.2 of Reference (6)) and pond bottom, pond water level will be managed to facilitate construction of an overlap zone; a zone where the bentonite amendment of the pond bottom overlaps the bentonite amendment of the FTB beaches. This will create the required continuity in the overall bentonite amended Flotation Tailings system. Riprap will be placed along the edge of the pond, in the zone subject to wave action and the associated potential for erosion. The riprap will be hauled in by truck and spread by dozer in the winter, when the FTB surface and pond is frozen. The riprap will settle into place as the ice thaws in the spring. Riprap rock types, size, and gradation will be specified on the basis of pond fetch and wave run-up computations completed just prior to the time that riprap placement is required.

5.2.3 Degree of Use in Industry

Bentonite is a highly plastic (can be deformed without cracking), swelling (volume increases with increasing moisture content), naturally occurring clay (usually forms from weathering of volcanic ash) consisting mostly of the clay mineral montmorillonite. Montmorillonite swells appreciably when it absorbs water if the predominant cation on the clay surface is monovalent (commonly sodium). Chemically, montmorillonite is a hydrated sodium calcium aluminum magnesium silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\bullet}nH_2O$. Potassium, iron, and other cations commonly substitute isomorphically within the crystal structure; the exact ratio of cations varies with source.

Bentonite has been used for many geotechnical, hydrogeological, and petroleum applications for more than a century. Bentonite is used in the geotechnical exploration and oil drilling industry as a component of drilling mud. Bentonite is also used as a soil additive to hold soil water in drought prone soils, in the construction of earthen dams and levees to prevent the seepage of fluids, as an additive to water to create liquid slurry for groundwater flow cutoff walls, (a.k.a. slurry walls) and to facilitate construction within excavations below groundwater elevations. Bentonite is also used as the primary hydraulic barrier in geosynthetic clay liners (GCLs, which are factory-manufactured clay liners) and as a soil admixture to produce hydraulic barriers for pond liners, earthen dams, and liners and covers for waste containment systems.

Bentonite amended soil cover systems have been used for many years in a wide variety of applications including closure of municipal and industrial solid waste disposal facilities, mine tailings facilities and for related components such as for groundwater flow cutoff walls and as hydraulic barriers in earthen dams.

Use of bentonite amended soils is typically dictated by the lack of other suitable nearby construction materials such as a high quality local clay source, by limitations in construction season and time available for placement of other natural soil types, and by the need for a hydraulic barrier of lower hydraulic conductivity than might be available from other clay sources.

CETCO (a manufacturer and distributor of powdered and granulated bentonite and manufactured geosynthetic clay liners world-wide) is one of several companies with a long history of providing bentonite-based products and associated research and specifications for use by design engineers, facility owners and construction contractors involved in the design and construction of bentonite-amended soils for hydraulic barriers and other applications. Wyo-Ben is another manufacturer and worldwide distributer of bentonite products used in the construction industry for projects such as bentonite amended cover systems.

5.3 Engineering Control Performance Parameters

5.3.1 Description with Basis

The performance parameter for the bentonite amended Flotation Tailings is hydraulic conductivity (a.k.a. permeability). The hydraulic conductivity and the layer thickness of bentonite amendment and the overlying hydraulic head are the basis for computing flow through the bentonite amended layer. Flow through the layer is expressed by Darcy's Law as:

$$Q=KiA, \text{ where } i = \Delta h/L \qquad \textbf{Equation 5-1}$$

where:

- Q = the rate of flow in units of volume per time such as gallons per day
- K = the measured hydraulic conductivity of the bentonite amended layer; in units of length per time such as centimeters per second
- i = the hydraulic head driving flow through the bentonite amended layer, computed as $\Delta h/L$ (unitless)
- Δh = the hydraulic head above the bentonite amended layer (soil suction below the amended layer is assumed to be negligible relative to hydraulic head above the amended layer)
- L = the saturated thickness of bentonite amended layer
- A = the area over which flow is being computed

The desired limitations on flow will be achieved by specifying and constructing the desired bentonite amended layer and by controlling the hydraulic head above the bentonite amended layer. Pond elevation will be controlled by pumping any excess FTB pond water to the WWTS. The FTB emergency overflow acts as a backup means of controlling pond elevation, but discharge from the emergency overflow is not expected. The emergency overflow is provided for protection of the dams in the rare event that freeboard within the FTB is not sufficient to contain 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 of Reference (6), PMP rainfall events are rare and such an event has a low likelihood of being experienced during the life of the basin. The PMP does not have an assigned return period, but it is usually assumed by hydrologists to be on the order of 100 million to 10 billion years. Based on extrapolation of 72-hour rainfall depth data from US Weather Bureau-Office of Hydrology Technical Paper TP 49, and the assumed return period of the PMP of 100 million years, a 1/3 PMP event could occur roughly once in 1,000 years and a 2/3 PMP could occur once in 500,000 years. On this basis, even though there is a low likelihood of overflow, it is standard practice in dam design to accommodate overflows in a manner that protects the integrity of the dams.

5.3.2 Maintenance Program

The planned FTB Pond Bottom Cover System requires very little maintenance to remain effective. Along the pond perimeter where wave action and freeze-thaw cycles occur, the bentonite layer will require protection from wave erosion and some confinement to resist freeze-thaw impacts. This protective layer will require periodic inspection early in the life of the reclaimed pond to confirm that the selected erosion control and freeze-thaw protection method (typically well graded riprap) is effective and to repair and upgrade riprap in any areas showing signs of erosion and/or freeze-thaw impacts.

5.3.3 Modeling of Engineering Controls

The FTB Pond Bottom Cover System is modeled in the water quality model with a mean percolation rate of 6.5 in/yr (percolation rate from the Tailings Basin MODFLOW model, Section 6 of Reference (4)). The three-dimensional flow model previously established for computing seepage rate from the entire FTB will continue to be used to model performance of the bentonite-amended pond bottom. This model relies on Darcy's Law (Equation 5-1) for computation of seepage using defined as-built conditions (hydraulic conductivity, layer thickness, hydraulic head) in discrete areas of the FTB. Seepage from the discrete areas is aggregated by the model to obtain the total seepage rate from the FTB.

For illustration of the seepage calculation, consider the modified version of Darcy's Law (shown in Equation 5-2) normalized to a unit area [A], where q is the flow through a unit area.

$$\frac{Q}{A} = q = K\frac{\Delta h}{L}$$

Equation 5-2

Using this equation, if the average pond depth is 5.0 feet [Δh] and the average bentonite amended layer thickness is 0.2 feet [L], the average hydraulic conductivity of the bentonite amended layer [K] required to achieve a mean percolation rate of 6.5 inches/year [q] can be calculate as follows:

$$6.5\frac{in}{yr} = K\frac{5.0ft}{0.2ft}$$

Equation 5-3

Solving for K, the average hydraulic conductivity required will be 0.26 inches/year or 2.1 x 10^{-8} cm/sec. For comparison, GSE, Inc. (www.gseworld.com) and CETCO (www.cetco.com) produce geosynthetic clay liners that are roughly one-quarter inch in thickness and have a manufactured maximum hydraulic conductivity of 5.0 x 10^{-9} cm/sec under 2.2 feet of hydraulic head.

5.3.4 Impact on Transition to Non-Mechanical Treatment

The WWTS is the engineering control that will provide compliance with water resource objectives. The FTB Pond Bottom Cover System has no direct impact on compliance because its function is to reduce the volume of water that must be treated by the WWTS.

However, the performance of the FTB Pond Bottom Cover System will impact the likelihood of achieving long-term non-mechanical treatment (Section 6.4). The pond bottom cover reduces both constituent loading and flow to the toes of the Tailings Basin. A change in the amount of water that needs to be treated results in a change in the required size of the non-mechanical treatment system. Figure 5-4 shows the relationship between the amount of percolation from the FTB Pond and the required volume of the non-mechanical treatment system, assuming a 5-day residence time. At the end of operations, the average percolation rate from the FTB Pond with no cover is approximately 25 inches/year (this seepage rate reflects conditions during operations when additional water is added to the pond). With this seepage rate, the non-mechanical treatment system will need a volume of approximately 45,000 cubic yards. The design percolation rate of 6.5 in/yr will require a 20,000 cubic yard system.

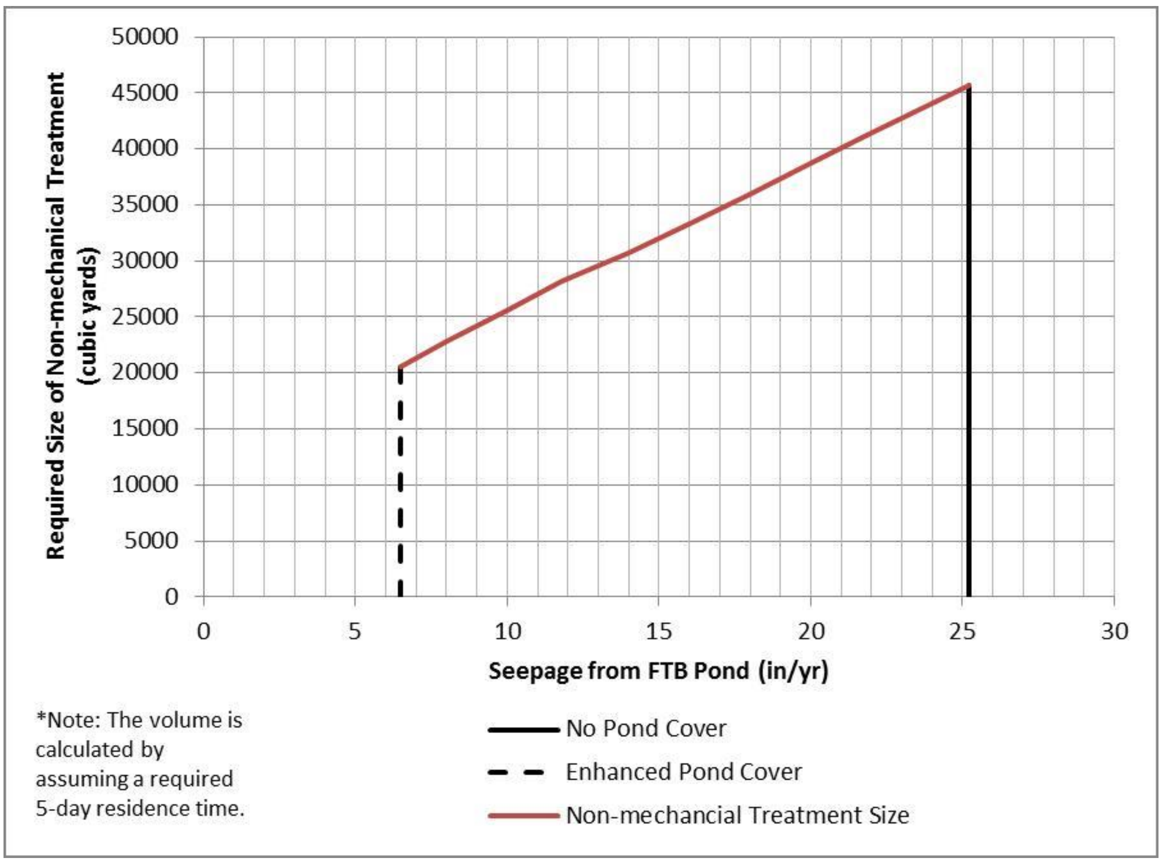


Figure 5-4 Relationship Between FTB Pond Percolation and Required Size of Non-Mechanical Treatment

5.4 Adaptive Management

5.4.1 Test Projects

A field demonstration project will be conducted in conjunction with construction of the bentonite layer to confirm that the construction methodology will achieve the required reduction in percolation. This demonstration project will be developed based on the state of practice existing when the pond bottom cover system is to be implemented. Prior to implementation of the demonstration project, a demonstration project plan will be submitted to the DNR for review and approval. In addition to providing a description of the demonstration project approach, the plan will include criteria and methods for evaluating demonstration project outcomes.

5.4.2 Reporting and Model Update

The Project includes a comprehensive water quality and quantity monitoring and reporting program that will be finalized in NPDES/SDS and Water Appropriation permitting. The program includes performance monitoring for the FTB seepage capture systems (quantity and quality of the water collected by the seepage capture systems), which will provide an indication of cover system performance. See Section 5 of Reference (2)) for details. The program will include annual comparison of actual monitoring to modeled results for the water collected by the FTB seepage capture systems, the FTB Pond, and in groundwater. This comparison will be used to refine the model. See Section 6 of Reference (2) for details.

5.4.3 Modified Design

If the monitored quantity or quality of water collected by the seepage capture systems, or annual updates to the model indicate that modifications are needed to meet water resource objectives, modifications could be made to the FTB Pond Bottom Cover System, the FTB Seepage Containment System, or the WWTS. This section describes potential adaptive management actions for the FTB Pond Bottom Cover System. Potential adaptive management actions for the FTB Seepage Containment System are described in Section 2.1.3.2 of Reference (5), and potential adaptive management aspects of the WWTS are described in Section 4.5. Additional potential adaptive management actions for water quality at the Plant Site are described in Sections 6.5 and 6.6 of Reference (2).

The pond bottom cover design can be modified up to the point of installation. The current version of this document will determine the design to be implemented. After installation, post installation adjustments can be made.

5.4.3.1 Circumstances Triggering Modification

Circumstances that could trigger a request for design modification approval include:

- New construction materials or techniques are developed that would achieve the required limits on percolation.

- Field monitoring confirms that the actual percolation rate differs from that planned. Actual percolation could differ from plan for various reasons:
    - Average pond depth differs from plan.
    - Actual performance of the bentonite amendment differs from plan.
- Field monitoring and model updating demonstrate that the required limits on percolation have changed and that a modified design can achieve that performance. The required amount could change for various reasons:
    - Modeled performance of other adaptive engineering controls (FTB Seepage Containment System or WWTS) could change.
    - Modeled constituent load from FTB could change.

5.4.3.2 Options for Modified Performance

Prior to installation, the design of the pond bottom cover system can be adjusted to modify performance if approved by MPCA and DNR. Options include:

- increased or decreased thickness of the bentonite amendment (decreases/increases flow [Q] by decreasing/increasing hydraulic conductivity [K] in Equation 5-1)
- increased percent of bentonite (decreases Q by decreasing K in Equation 5-1)
- combination of increased/decreased thickness and increased/decreased percent bentonite

After installation, the design of the installed pond bottom cover system can be adjusted to modify performance if approved by MPCA and DNR. Modified performance after installation can be achieved by the same methods listed for initial installation, and/or:

- the bentonite amended layer could be excavated from portions of the pond bottom

5.5 Reclamation, Closure, and Postclosure Maintenance

The FTB Pond Bottom Cover System will be implemented during reclamation and will be required to function until constituents have been depleted from the portion of the FTB that is subject to oxidation, and/or the release rates of constituents from the FTB have decreased to the point where water resource objectives can be achieved without the cover system. The 200-year model does not show that the sulfur in the tailings has been depleted or that constituent release rates have decreased.

The bentonite, as a naturally occurring by-product of volcanic activity, is expected to perform its intended function for a very long time in this subaqueous application. The performance of the bentonite can be expected to be supplemented by the build-up of organic matter on the pond bottom that will occur over time. As noted in Section 5.3.2, some inspection and possibly some maintenance will be required to establish a pond bottom cover system that will achieve the required long-term performance.

6.0 Non-Mechanical Treatment Systems

6.1 Overview

6.1.1 Purpose

The purpose of the Non-Mechanical Treatment Systems is to replace mechanical water treatment at the WWTS with low-maintenance, low-energy, non-mechanical treatment systems during the postclosure maintenance phase of the Project. Non-mechanical treatment systems will be designed and tested to treat water from the Category 1 Stockpile Groundwater Containment System, the West Pit overflow, the HRF, and the FTB seepage capture systems.

6.1.2 Conceptual Design

The non-mechanical treatment systems are expected to include constructed wetlands or Permeable Reactive Barriers (PRBs) to remove sulfate, metals, and other dissolved or suspended constituents from water. Constructed wetlands and PRBs are flow-through treatment systems containing a porous medium (or multiple porous media) that remove constituent mass through physical, chemical, and/or biological treatment processes. The mechanisms of treatment for constructed wetlands and PRBs are described further in Section 6.1.3.1.

Non-mechanical treatment systems for the West Pit overflow and the seepage capture systems will also use Permeable Sorptive Barriers (PSBs) to provide a contingency system for additional metals removal downstream of the constructed wetlands, if needed. The fundamental operation of a PSB is described in Section 6.1.3.2.

6.1.2.1 Permeable Reactive Barriers

A PRB is a flow-through treatment system containing a porous medium (or multiple porous media) that removes constituent mass through physical, chemical, and/or biological treatment processes. The water to be treated in a PRB can be directed either horizontally or vertically, and vertical flows may be directed either upward or downward, depending on the treatment requirements. The portion of the PRB that treats the water is the treatment unit. Within the treatment unit, native soils will be supplemented with: 1) materials to induce the chemical and/or biological conditions desired for constituent mass removal, such as solid or liquid phase organic substrate, nutrients, or chemical amendments; and 2) coarse materials (sand and gravel) to promote even distribution of the flow within the treatment unit.

The basic design factors for PRBs include:

- Sufficient hydraulic retention time in the treatment unit to achieve required treatment. Hydraulic retention time on the order of 5 days is typically required in colder climates (Reference (43)).
- A hydraulic design that provides an even distribution of flow through the treatment unit. This is typically accomplished by using gravel media and drain tile to evenly

distribute the flow into and out of the treatment unit (Reference (44)) and incorporating coarse materials into the treatment unit.

- A drain field or other access points to allow the replacement/replenishment of organic substrate and any supplemental material in the treatment unit, if necessary.

Additional basic PRB design guidance is available from numerous sources, including the Interstate Technology and Regulatory Council (Reference (45)).

6.1.2.2 Constructed Wetlands

A constructed wetland is a flow-through treatment system that removes constituent mass through physical, chemical, and/or biological treatment processes. This is similar to a PRB, but the constructed wetland also includes actively growing wetland vegetation to further support microbial communities and to facilitate other biologically-based chemical transformations. The water to be treated in a constructed wetland may be directed either horizontally or vertically, and vertical flows may be directed either upward or downward, depending on the treatment requirements. The portion of the constructed wetland that treats the water is the treatment unit. Within the treatment unit, native soils and wetland plant communities may be supplemented with: 1) materials such as slowly degradable organic matter to promote biological activity, and 2) coarse materials (sand and gravel) to promote even distribution of the flow within the treatment unit.

The basic design factors for a constructed wetland include:

- Sufficient hydraulic retention time in the treatment unit to achieve required treatment. Hydraulic retention time on the order of 2 to 5 days may be required in colder climates (Reference (43)).

- A hydraulic design that provides an even distribution of flow through the treatment unit. This is typically accomplished by using gravel media and drain tile to evenly distribute the flow into the treatment unit (Reference (44)), by installing control structures to manage the flow of surface water away from the top of the treatment unit, and by adding some coarse materials within the treatment unit.

To provide the proper hydraulic configuration, constructed wetland design includes water delivery and collection systems above and below the treatment unit to distribute flow evenly. The sub-surface delivery system typically consists of a gravel filled layer with distribution piping. The surface water management system is designed to promote the free flow of water onto or off the top of the treatment unit while maintaining saturated conditions in the treatment unit. Additional basic constructed wetland design guidance is available from numerous sources, including the USEPA (Reference (46) and Reference (47)).

The gradual increase in contaminants within the sediment of the constructed wetland is not expected to result in adverse effects to wildlife. Sequestration of metals by wetlands occurs naturally and has been ongoing for centuries through many processes including plant uptake, adsorption (binding to soil or organic matter) and precipitation (formation of solid compounds) (Reference (48), Reference (49)). Natural and constructed wetlands accumulate metal oxides and metal sulfides in their sediment. When sediments remain saturated with water and anaerobic, re-mobilization of the most metals and sulfur back into the water column is not expected (Reference (50); Reference (51)). The precipitation of oxides and sulfides and uptake by organic matter (dissolved organic carbon) has been shown to occur fairly rapidly in constructed wetlands (Reference (52)) and in natural wetlands (Reference (50); Reference (51)). Biota and plants have adapted to elevated and sulfide concentrations in wetland sediments (Reference (50); Reference (53); Reference (51)) such that long-term functioning of wetlands and removal of metals and sulfur has been demonstrated in a number of locations and climate regimes (Reference (50), Reference (52), Reference (51), Reference (48)). Because of the longevity of natural wetlands to maintain their functionality (e.g., biota and vegetation) and sequester metals and sulfur (Reference (50), Reference (51), Reference (48)), constructed wetlands also have the potential to maintain functionality and sequester metals and sulfur on a long-term basis.

6.1.2.3 Permeable Sorptive Barriers (PSB)

A PSB is a treatment unit containing a solid-phase media with an affinity for sorption of metals. Because they are chemical/physical removal mechanisms, PSBs have a finite capacity, however, that capacity can provide significant duration of treatment if sized properly. The purpose of the PSB is to provide a contingency system that will be in place, if needed. The PSB media will be placed at the downgradient end of the constructed wetland or PRB so that water can flow by gravity through the sorptive media.

Generally, an empty bed (the volume of the media is not typically considered in the design of sorption systems) contact time of greater than 30 minutes is adequate for sorption systems.

6.1.3 Basis of Treatment

6.1.3.1 Permeable Reactive Barriers (PRBs) and Constructed Wetlands

PRBs and constructed wetlands rely on the same combination of processes acting in concert to facilitate the removal of sulfate, trace metals and other dissolved or suspended constituents from water including:

- biochemical reduction of sulfate to sulfide using sulfate reducing bacteria (SRB)
- sorption to solid phase surfaces such as iron oxides or organic matter
- chemical precipitation to convert dissolved phase constituents to solid phase particles
- physical filtering of solid phase particles

Within PRBs and constructed wetlands, sulfate can be reduced to sulfide by SRB (Reference (54)). This process occurs in anaerobic environments and has the benefit of precipitating dissolved metals as insoluble metal sulfides. The reduction of sulfate is enhanced in situ by the addition of a degradable organic substrate (Reference (55)). The organic substrate maintains biologic activity. Supplemental materials can also be added including nutrients (nitrogen and phosphorous) and zero-valent iron (ZVI). The ZVI promotes abiotic chemical reduction, providing conditions favorable for SRB (Reference (56)). The ZVI also provides dissolved iron to the solution that helps to precipitate any excess sulfide generated during the process.

Effective biological sulfate reduction in PRBs and constructed wetlands requires an organic substrate and a matched microbial community that will maintain anoxic conditions. The submerged sediments of most natural wetlands in Minnesota contain all of the components necessary to promote sulfate reduction and metal precipitation; however, they may not have the appropriate hydraulic configuration to provide the needed hydraulic retention times and the even flow distribution.

Sorption of metals on to solid phases has been studied extensively. For example, the USEPA recently published a literature review of sorption coefficients for dissolved chemicals to soil, sediment and other solid phases (Reference (57)). Historical work on the sorption of metals onto peat was also reported by the DNR (Reference (58)), among others.

Chemical precipitation of metal sulfides is a well-established process that is considered to occur instantaneously when metal cations and sulfide anions are both present in solution (Reference (59)). A recent review of metal sulfide precipitation (Reference (60)) summarizes the significant elements of the body of knowledge associated with metal sulfide precipitation. It also provides additional support for the fundamental processes involved in the removal of metals from water within PRBs and constructed wetlands that rely on SRB. For example, a laboratory study performed by Lindsay, et al. (Reference (61)), reported removal efficiencies of greater than 99.9% for cobalt, nickel and zinc, primarily due to the formation of metal sulfides. Lower removal efficiencies could occur when influent concentrations are lower or when inadequate retention time is provided for the biological generation of sulfide (Reference (55)).

The final treatment mechanism observed in PRBs and constructed wetlands is physical filtering of particulates. This process has been reported in both natural and constructed wetlands for many years (Reference (62)). Physical removal mechanisms rely on very slow water velocities over a large cross-sectional area which allows for laminar flow and intimate contact between the water phase and solid surfaces within the wetland matrix.

6.1.3.2 Permeable Sorptive Barrier (PSB)

Copper and many other metals in solution preferentially sorb onto various solid phase media. Sorption of metals onto solid surfaces has been well documented in a literature review of numerous sorption tests completed by the USEPA (Reference (57)). In addition, site-specific testing with unconsolidated soil from the Mine Site demonstrated that copper sorption to soils from the site was likely near the high end of the reported range (Reference (63)). The basis for the higher than average sorption capacity for copper in site soils may be due to the above average iron content or to other factors that were not evaluated. Given these results, a sorptive barrier for the reduction of copper concentrations in solution is a viable method of achieving the water resource objectives.

Sorption is a finite process for a defined volume of solids. While site soils will provide an excellent sorptive material, other media specifically designed for metal sorption are available, if necessary. One such material, which is produced from peat in Minnesota, is APTsorb. This material is manufactured by American Peat Technology, Inc. of Aitkin, MN has been demonstrated to sorb copper and cobalt in studies by the DNR using mining influenced water from the Soudan Mine State Park (Reference (64)).

6.1.4 Degree of Use in Industry

6.1.4.1 PRBs

The development and use of PRBs to treat groundwater was initiated in the 1990s (Reference (45)). Recently, PRBs have been applied extensively at sites with groundwater impacts. This has resulted in refinement of the techniques needed to design PRB systems to achieve required site-specific performance. PRB technology was developed as a method to enhance natural processes that contribute to the transformation/degradation of organic compounds or the transformation of dissolved inorganic constituents into insoluble products (Reference (45)). Most PRB systems have been installed below ground for the treatment of groundwater, which facilitates year-round operation and relatively stable operating temperatures. Over 200 full-scale PRBs have been installed to treat groundwater at a variety of sites. A recent guidance document on PRB systems provides 13 specific case histories of PRB implementation (Reference (45)). The development of PRBs specific to mine water drainage also originated in the 1990s (Reference (55)); building on earlier work on non-mechanical treatment of acid mine drainage in a variety of configurations that all have similar operating characteristics (Reference (65)).

Of particular interest to the Project is a treatment system that was installed in northern Quebec at the Cadillac Molybdenum Mining site and was operated successfully through winter conditions as reported by Kuyucak, et al. (Reference (66)). In this system, a solid-phase organic medium was used to generate favorable conditions for SRB. The following concentration reductions (calculated from influent and effluent values in Table 2 of Reference (66)) were reported for this full-scale system:

- the treatment system reduced copper concentrations from 300 μg/L to an average effluent concentration of 8 μg/L, which is a removal efficiency of 97%
- the treatment system reduced nickel concentrations from 0.6 mg/L to an average effluent concentration of 0.01 mg/L, which is a removal efficiency of 98%
- the treatment system reduced zinc concentrations from 1.35 mg/L to an average effluent concentration of 0.012 mg/L, which is a removal efficiency of 99%

- the treatment system reduced sulfate concentrations from 887 mg/L to an average effluent concentration of 360 mg/L, which is a removal efficiency of 59%

This successful operation of a PRB at an industrial site where the climate and the constituents of concern are similar to the Project site demonstrates that a PRB has the potential to significantly reduce the load of metals and sulfate in the water collected during postclosure maintenance at the Mine Site and Plant Site.

6.1.4.2 Constructed Wetlands

The ability of wetlands and other flow-through systems to improve water quality has been studied and documented for many years (Reference (62); Reference (46); Reference (47)). Numerous guidance documents for the development of constructed wetlands have been published by both State and Federal governments (Reference (67); Reference (68); Reference (65); Reference (47)).

Data from analog sites on potential performance of a non-mechanical system for the removal of copper, cobalt, nickel, lead, boron, and sulfate is presented below.

- Copper: A constructed wetland treatment system at the Savannah River Site was designed specifically to remove copper by the formation of a solid-phase copper-sulfide precipitate that would remain sequestered within the wetland sediments (Reference (69)). The constructed wetland covers 8.8 acres (including perimeter access areas and multiple locations for hydraulic control) and was designed to treat flows ranging from 0.25 to 2.6 MGD (170 to 1,740 gpm), with an average flow of approximately 1 MGD (690 gpm). The system was installed in 2000 and has been monitored since the spring of 2001. During the first year of performance monitoring (March 2001 to April 2002) influent copper concentrations ranged from 10 to 47 µg/L and effluent concentrations ranged from 3 to 11 µg/L with an average effluent copper concentration of 6 µg/L (Section 3 and Figure 4 of Reference (69)). Additional monitoring of the system through 2005 showed that the system performance continued with minimal maintenance (Reference (70)). The performance of this full-scale system provides a realistic analog for removal of dissolved metals, particularly copper, to a consistent effluent value. The constructed wetland at the Savannah River Site is designed to allow the growth of plants to provide all of the substrate necessary to support microbial activity by SRB and, ultimately, to sequester copper as copper sulfides, subaqueously, within the wetland soil matrix.

- Cobalt: Cobalt was monitored in the performance of a full-scale constructed wetland treatment system for the treatment of leachate from a Coal Ash Landfill (Reference (71)). This work demonstrated that cobalt was effectively removed from an influent concentration of approximately 5 to 20 µg/L to effluent concentrations consistently less than 2 µg/L in the second year of operation (Figure 3 of Reference (71)).

- Nickel: Nickel was present at high concentrations in the leachate from a nickel sulfide tailings operation in Norway and was effectively removed using a constructed wetland treatment system (Reference (72)). Although this treatment system only had an 8.5 hour hydraulic retention time and was treating water with influent nickel concentrations ranging from 1.75 to 5.61 mg/L, effluent concentrations below the detection limit of 10 µg/L were achieved once consistent anaerobic conditions were established (Table 1 of Reference (72)). Removal of nickel in this system occurred within the anaerobic section of a multi-cell system and was most effective in the summer months.

- Lead: Removal of lead from waste water to low concentrations has been reported in a constructed wetland treatment system by Hawkins, et al. (Reference (73)). This constructed wetland system, which treated refinery waste water, reported removal of lead from an average influent concentration of 10.5 µg/L to an average effluent concentration of 2.2 µg/L (Table 5 of Reference (73)).

- Boron: Boron exists in the environment as a weak acid. The primary attenuation mechanism for boron is adsorption. Sartaj (Reference (74)) demonstrated that the adsorption of boron is negatively impacted by lower pH. Adsorption is optimal at a pH of approximately 9 and drops off by 70% as pH is reduced to 7.5. This is likely related to the weak acid characteristics of the borate acid. The pKa of boric acid is 9.24. Thus, at lower pH most of the boric acid will be protonated and less strongly adsorbed. However, the degree of adsorption also depends on the strength of the adsorption bond. However, Sartaj (Reference (74)) demonstrated that peat can effectively remove boron from landfill leachate that has near neutral pH. In a two year field demonstration at the Huneault Waste Management landfill near Ottawa, Canada, a 1.4 meter (4.6 feet) thick bed of peat removed boron from the leachate, with influent concentrations averaging 14 mg/l boron, and the effluent averaging 1.1mg/l. The pH of the influent pond and in the peat ranged from 6.5 to 7.6. This pH range is consistent with the expected conditions. Sartaj (Reference (74)) also demonstrated that temperature impacts the adsorption of boron, with slightly higher sorption at lower temperatures.

- Sulfate: As noted in Section 6.1.3.1, sulfate is reduced in the subsurface to sulfide by SRB (Reference (54)). The rate of this reaction is dependent on many factors including influent concentration, temperature, pH, organic carbon availability, and redox potential within the treatment system. Long-term concentration reductions of approximately 50 mg/L per day of retention time have been reported in the literature and observed in site-specific bench testing of sulfate removal processes from tailings basin groundwater (Reference (75)). Additional testing of sulfate removal will be completed as part of the development plan described in the following section.

6.1.4.3 PSBs

The use of sorptive media is a demonstrated technique to address water quality and reduce concentrations of dissolved copper, cobalt, and other metals. The sorptive capacity of APTsorb for metals, particularly copper and cobalt, has been demonstrated in field testing conducted in cooperation with the DNR at the former Soudan Underground Mine, which is now the Soudan Mine State Park (Reference (64)). Copper concentrations were decreased by 90% from an average influent concentration of 80 µg/L to an effluent copper concentration of generally less than 8 µg/L. Similarly, cobalt influent concentrations of approximately 6 to 20 µg/L were consistently decreased to below 5 µg/L.

6.1.5 Adaptive Management

The Non-mechanical treatment systems are adaptive engineering controls because they will be designed and operated based on site-specific conditions using the knowledge that is gained during the operating and reclamation phases of the Project. The specific adaptive management approach for each non-mechanical system is outlined in the development plans (Sections 6.2.3, 6.3.3, and 6.4.3).

6.2 Category 1 Stockpile Non-Mechanical Treatment System

6.2.1 Purpose

The purpose of the Category 1 Stockpile Non-Mechanical Treatment System is to replace mechanical treatment of the water collected by the groundwater containment system with a low-maintenance, low-energy, non-mechanical treatment system.

6.2.2 Conceptual Design

The Category 1 Stockpile Non-Mechanical Treatment System is expected to include two permeable reactive barriers (PRBs) for metal precipitation and solids removal.

For the Category 1 Stockpile Non-Mechanical Treatment System, the modeled mean flow is approximately 4 gpm, based on modeling of the Category 1 Waste Rock Stockpile geomembrane cover discussed in Section 3.3.3. Using the design flow rate of 4 gpm, a design hydraulic retention time of 5 days, and an effective porosity of 30%, the required volume of a treatment unit can be calculated using Equation 6-1:

$$\text{Volume} = \frac{4\ gal}{min} \times 5\ day \times \frac{1{,}440\ min}{day} \times \frac{1\ ft^3}{7.48\ gal}\ x\ \frac{1}{0.3} \qquad \textbf{Equation 6-1}$$

The design volume is 12,800 cubic feet. Assuming a minimum working treatment depth of three feet results in a 0.1 acre treatment unit or two 0.05 acre treatment units. Potential locations for PRBs are shown on Figure 6-1. These locations could vary, depending on the final hydraulic plan for discharge from the Category 1 Stockpile Groundwater Containment System into the West Pit. Using a PRB at each of these locations could take advantage of gravity flow.

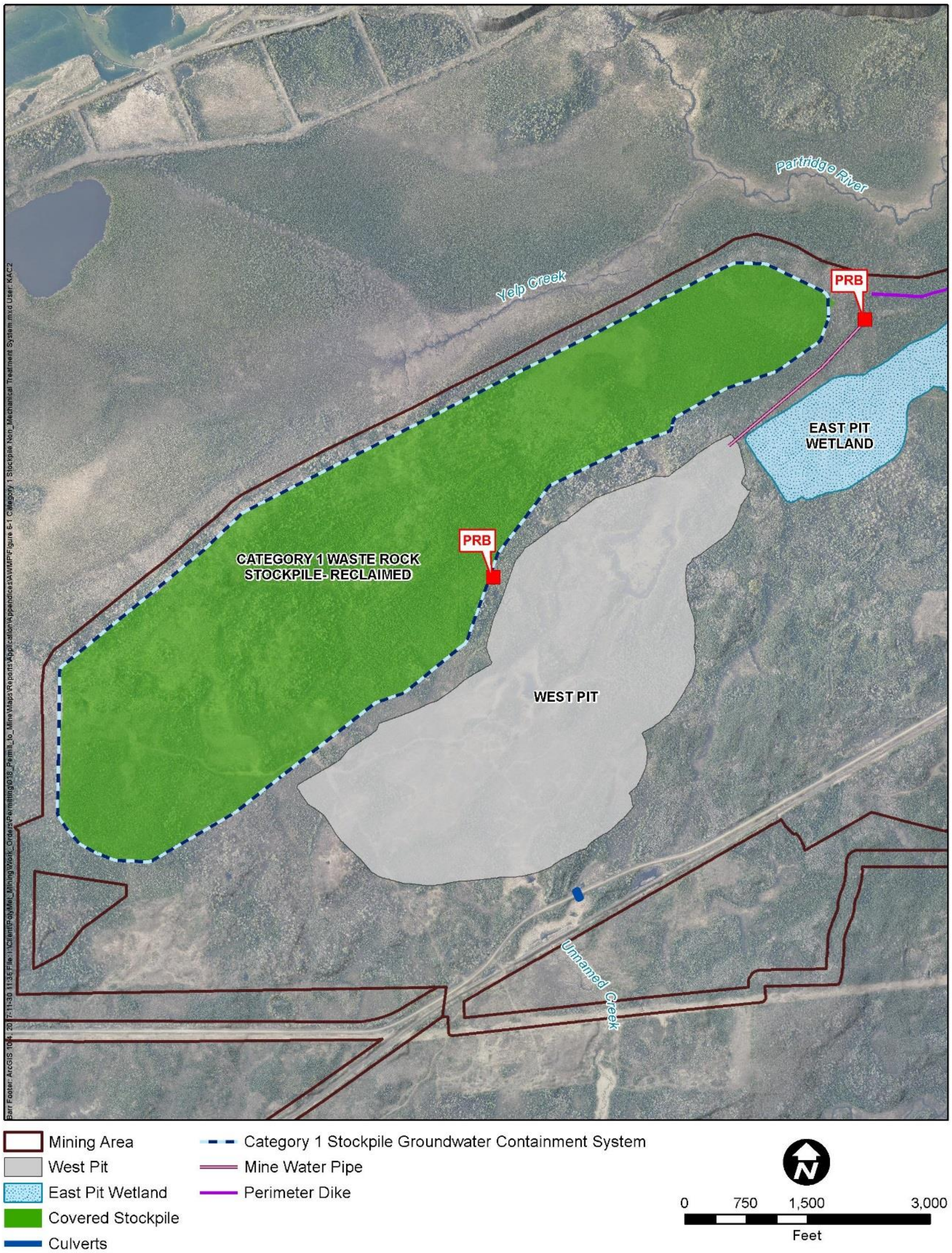


Figure 6-1 Conceptual Plan View: Category 1 Stockpile Non-Mechanical Treatment System

6.2.3 Development Plan

The performance of a PRB system will depend on site-specific conditions and the actual water being treated. The site-specific design of a PRB system for the water collected by the Category 1 Stockpile Groundwater Containment System must be pilot-tested to prove its performance before one or more PRBs could be installed and operated to replace mechanical treatment. A pilot-scale PRB will be designed, installed, and monitored after the Category 1 Stockpile Groundwater Containment System has been completed and the water quality of the seepage is comparable to that expected during postclosure maintenance. Based on current modeling, water quality is estimated to stabilize at levels comparable to the long-term water quality that could be directed to the PRB system after approximately Mine Year 22, when the stockpile is completely reclaimed (several more years may be needed in order for previously-accumulated water within the stockpile and the surficial deposit to completely reach the groundwater containment system). Monitoring of the actual seepage quality during operations will be used to evaluate when the PRB testing could be initiated.

The pilot-scale non-mechanical treatment system will be constructed at the Mine Site and use a slip stream of the water from the groundwater containment system as inflow. It is anticipated that several years of pilot-testing will be required to obtain the data needed to understand the effects of seasonal variations in temperature and other factors on the performance of the PRB. After the pilot-testing has been completed and the results of the work have been accepted by the DNR and MPCA, the design and installation of a full-scale PRB system can be initiated if the proven performance is sufficient to allow replacement of mechanical treatment.

Another important factor in consideration of non-mechanical treatment is the useful life of the system. This will depend on the design configuration as well as site-specific factors and will be evaluated during the pilot-testing program.

The design and timing of the pilot-testing program will be developed during operations and provided to the DNR for review.

6.3 West Pit Overflow Non-Mechanical Treatment System

6.3.1 Purpose

The purpose of the West Pit Overflow Non-Mechanical Treatment System is to replace mechanical treatment of the West Pit overflow water with a low-maintenance, low-energy, non-mechanical treatment system during the postclosure maintenance phase of the Project.

6.3.2 Conceptual Design

The West Pit Overflow Non-Mechanical Treatment System is expected to be a multistage system consisting of the following:

- a constructed wetland for metal (copper, cobalt, nickel and lead) precipitation and solids removal

- a permeable sorptive barrier (PSB) for polishing
- an aeration pond

On an annual basis, the mean flow rate from the West Pit to the Partridge River via Unnamed (West Pit Outlet) Creek is expected to be 320 gpm (Section 6 of Reference (3)). The proposed design and operation of any non-mechanical system at the Mine Site will be adapted as necessary to effectively treat actual flows and to meet applicable regulatory requirements and standards.

Figure 6-2 shows a conceptual layout for the West Pit Overflow Non-Mechanical Treatment System and Figure 6-3 shows a conceptual cross-section of the proposed system, showing each of the three stages. For this system it is likely that the flow will be directed vertically upward through the treatment unit as shown on Figure 6-3. Each of these stages is described briefly in the following paragraphs.

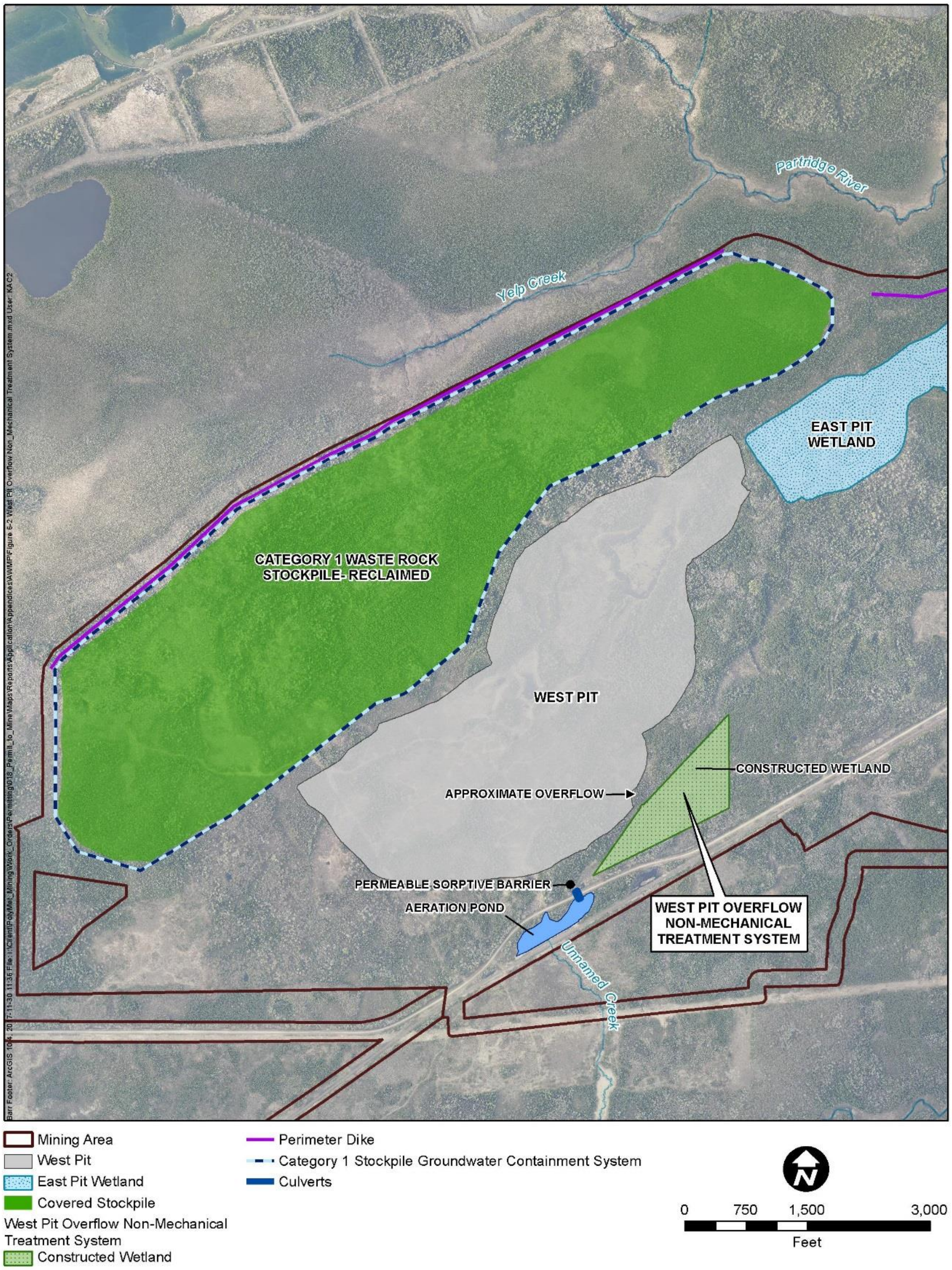


Figure 6-2 Conceptual Plan View: West Pit Overflow Non-Mechanical Treatment System

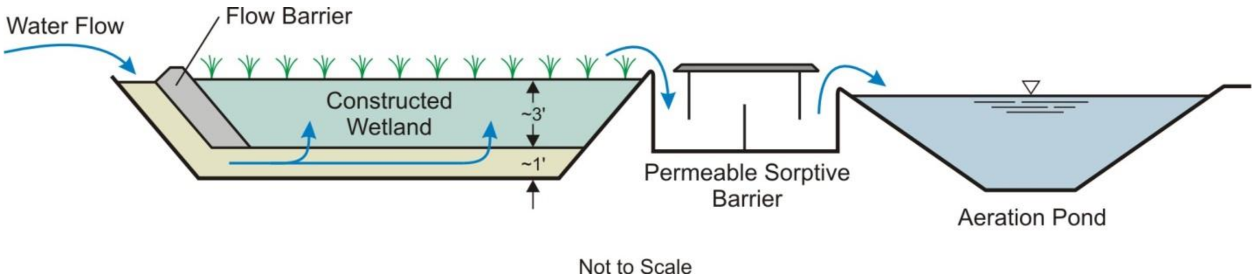


Figure 6-3 Conceptual Cross-Section: West Pit Overflow Non-Mechanical Treatment System

6.3.2.1 Constructed Wetland

Using the design discharge rate of 1,920 gpm, a design hydraulic retention time of 48 hours for summer and early fall operation, effective porosity of 30%, and a design depth of three feet, the required area for the constructed wetland, calculated in **Equation 6-2**, is approximately 18.9 acres (not including access roads).

$$Area = \frac{1{,}920\ gal}{min} \times 2\ day \times \frac{1{,}440\ min}{day} \times \frac{1\ ft^3}{7.48\ gal} \times \frac{1}{0.3} \times \frac{1\ Acre}{43{,}560\ ft^2} \times \frac{1}{3 ft} \qquad \textbf{Equation 6-2}$$

Additional volume, which would increase retention time, could be created, if necessary, by increasing the area or depth of the constructed wetland. For example, a 5-day retention time would increase the area of the system to 47 acres, if the depth remained constant.

It may be beneficial to adjust the pH of the West Pit water before it enters the wetland system. If this is needed, pH adjustments could be made to the West Pit overflow with lime treatment upstream of the wetland or to the West Pit lake during flooding as part of contingency mitigation (Section 6.6 of Reference (1) presents contingency mitigation options for the West Pit).

Because the treatment system would be designed for a 2-month discharge period, the system has a larger footprint than a system designed for year-round discharge, but it also has several advantages compared to a system that would operate year-round, including:

- avoiding the need for winter operation and potential complications due to freezing
- allowing the discharge to occur during a period when the water will still be relatively warm which would increase SRB activity and reduce the design hydraulic retention time, as noted in Equation 6-2
- allowing the wetland vegetation to build up a supply of degradable carbon within the wetland during the growing season that can be consumed by SRB and other microorganisms to support biological sulfate reduction in the fall when plant activity and the diffusion of oxygen into the subsurface decreases

During non-discharge periods, the wetland will need to be maintained in a saturated condition. This will be accomplished by limiting the outflow from the wetland and realizing inflows from direct precipitation and clean stormwater from surrounding areas entering the wetland. If necessary, the inflow to the wetland could also be supplemented with a small volume of gravity discharge from the West Pit to maintain saturated conditions. Any flow from the West Pit would only be used to re-supply water lost to evapotranspiration during the growing season. These operations will make the wetland system self-sustaining in support of biological sulfate reduction and metal sulfide precipitation.

The constructed wetland will potentially be located within the previously disturbed areas (Overburden Storage and Laydown Area) of the Mine Site to the southeast of the proposed West Pit overflow. The overflow from the West Pit would flow by gravity to the constructed wetland and then by gravity out of the wetland into the PSB.

6.3.2.2 Permeable Sorptive Barrier (PSB)

PSBs will be constructed to provide a contingency system for additional removal of metals, if needed. Using the design discharge rate of 1,920 gpm and a design contact time of one hour (twice the typical design time to be conservative), the required minimum volume for the PSB at the outfall of the constructed wetland, calculated using Equation 6-3, is 15,400 cubic feet of sorptive media.

$$Volume = \frac{1{,}920\ gal}{min} \times 1\ hr \times \frac{60\ min}{hr} \times \frac{1\ ft^3}{7.48\ gal}$$ **Equation 6-3**

The PSB media will be placed at the downgradient end of the constructed wetland so that water can flow by gravity through the sorptive media and into an aeration pond as described in the following section. Increasing the volume of the media within the sorptive barrier would decrease the required frequency for replacement of the media.

6.3.2.3 Aeration Pond

An aeration pond will provide time for water exiting the PSB to re-equilibrate with the atmosphere, and in particular to increase the concentration of dissolved oxygen before the water is discharged to an Unnamed (West Pit Outlet) Creek, which flows into the Partridge River. The design time for retention in an aeration pond is one day. However, a cascade spillway or other design components could reduce the time required to reach equilibrium with the atmosphere. Again, the proposed limited discharge period will eliminate the need to operate when the aeration pond would be covered with ice or snow, thus eliminating a potential limiting factor for aeration.

Using the design discharge rate of 1,920 gpm, a design hydraulic retention time of one day, and a pond depth of at least 3 feet, the maximum surface area required for the aeration pond, calculated in Equation 6-4, is approximately 2.8 acres.

$$Area = \frac{1{,}920\ gal}{min} \times 1\ day \times \frac{1{,}440\ min}{day} \times \frac{1\ ft^3}{7.48\ gal} \times \frac{1\ Acre}{43{,}560\ ft^2} \times \frac{1}{3\ ft}$$ **Equation 6-4**

A potential location for the aeration pond (shown in Figure 6-2) is in an area where a stormwater pond will exist during mining operations.

6.3.3 Development Plan

The performance of a multi-stage (constructed wetland/PSB/aeration pond) treatment system will depend on site-specific conditions and the actual water being treated. The site-specific design of a treatment system for West Pit overflow water must be pilot-tested to prove its performance before it could be installed and operated to replace mechanical treatment. A pilot-scale treatment system will be designed, installed, and monitored after the water quality of the West Pit is comparable to that expected during postclosure maintenance. Based on current modeling, water quality is estimated to stabilize at levels comparable to the long-term water quality that could be directed to the constructed wetland system after approximately Mine Year 55 (although concentrations for many constituents trend downward over the long-term). Monitoring of the actual West Pit overflow quality during operations and reclamation will be used to evaluate when the constructed wetland testing could be initiated.

The pilot-scale non-mechanical treatment system will be constructed at the Mine Site and use water from the West Pit as inflow. It is anticipated that several years of pilot-testing will be required to obtain the data needed to understand the effects of seasonal variations in temperature or other factors on the performance of the treatment system. After the pilot-testing has been completed and the results of the work have been accepted by the DNR and MPCA, the design and installation of a full-scale treatment system can be initiated if the proven performance is sufficient to allow replacement of mechanical treatment.

Another important factor in consideration of non-mechanical treatment is the useful life of the system. This will depend on the design configuration as well as site-specific factors and will be evaluated during the pilot-testing program.

The design and timing of the pilot-testing program will be developed during operations and provided to the DNR for review.

6.4 Flotation Tailings Basin (FTB) Non-Mechanical Treatment System

6.4.1 Purpose

The purpose of the FTB Non-Mechanical Treatment System is to replace mechanical treatment of the water draining through the Tailings Basin and collected in the FTB seepage capture systems with a low-maintenance, low-energy, non-mechanical treatment system during the postclosure maintenance phase of the Project. During postclosure maintenance, any water collected by the HRF Leakage Collection System (Section 2.2.2 of Reference (7)) would also be routed to this system.

6.4.2 Conceptual Design

The FTB Non-Mechanical Treatment System is expected to be a multistage system consisting of the following:

- a constructed wetland for metal precipitation and solids removal
- permeable sorptive barriers (PSBs) for polishing

For the FTB Non-Mechanical Treatment System, the total flow is expected to be approximately 1,730 gpm (Section 6.4.1 of Reference (4)) for the combined flows modeled at the north, northwest, west, and south toes. In postclosure maintenance, seepage flow to the east will be less than 1 gpm. Provisions to adaptively manage this low-volume flow from the eastern segment of the FTB Seepage Containment System will be included in the development of the FTB Non-Mechanical Treatment System (Section 6.4.3).

The conceptual plan includes re-building the natural wetlands between the FTB and the FTB Seepage Containment System as a vertical, upflow constructed wetland system with PSB systems at the outer perimeter within the access road. Figure 6-4 shows a conceptual layout for the FTB Non-Mechanical Treatment System. Figure 6-5 shows a conceptual cross-section of the proposed system. Water collected by the FTB South Seepage Management System is expected to be pumped to the non-mechanical treatment system.

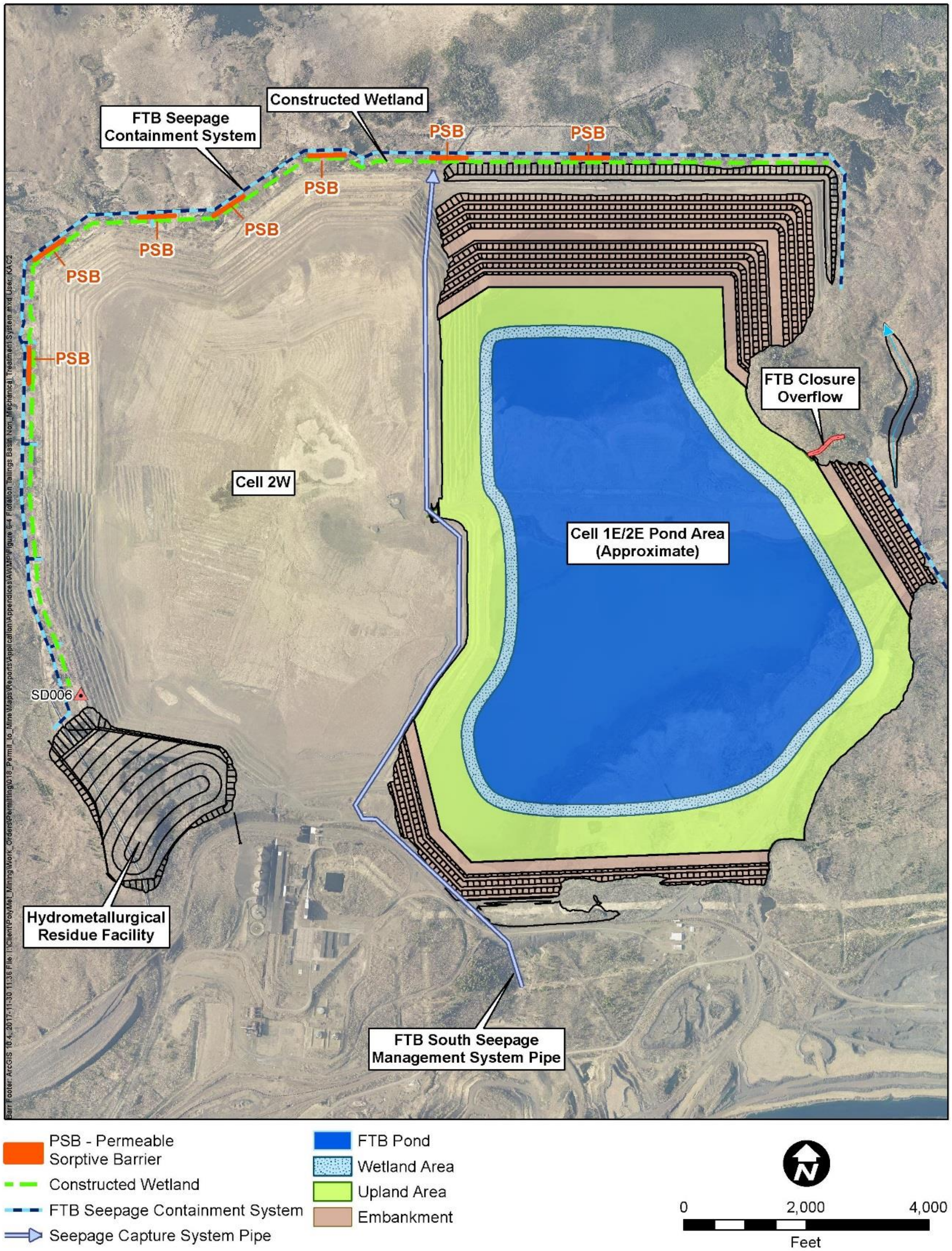


Figure 6-4 Conceptual Plan View: FTB Non-Mechanical Treatment System

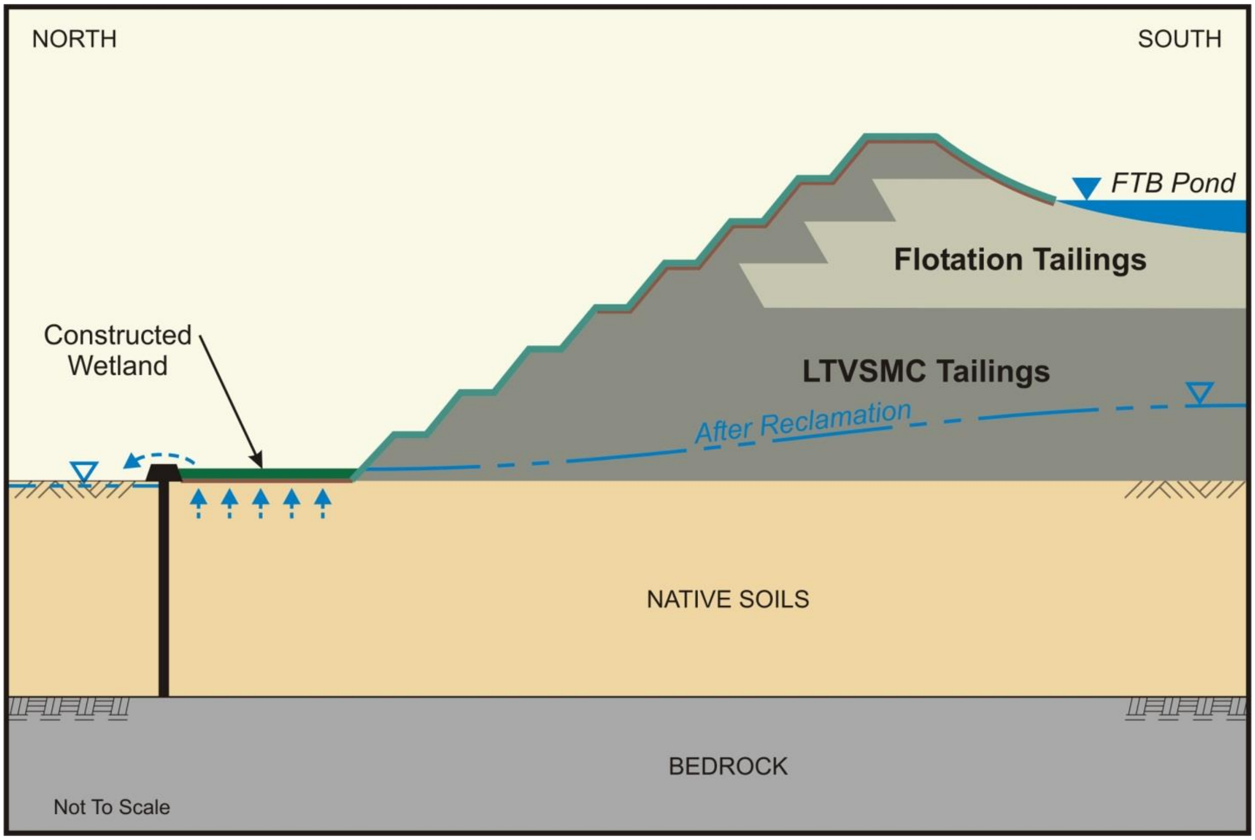


Figure 6-5 Conceptual Cross-Section: FTB Non-Mechanical Treatment System

6.4.2.1 Constructed Wetland

The constructed wetland will be designed to remove metals and reduce the load of sulfate. The hydraulic retention time will be 5 days (Section 6.1.2.2) to provide for year-round operation at a wide range of temperatures. In addition, an extra foot of open water will be maintained above the volume required for the 5-day retention time, to allow for ice formation while maintaining an open water layer in winter months (Reference (70)).

Using the design flow rate of 1,730 gpm, a hydraulic retention time of 5 days, an average working treatment depth of approximately three feet, and an effective porosity of 30%, the minimum required area for a constructed wetland, calculated in **Equation 6-5**, is approximately 42 acres.

Equation 6-5

$$Area = \frac{1{,}730\ gal}{min} \times 5\ day \times \frac{1{,}440\ min}{day} \frac{1\ ft^3}{7.48\ gal} \times \frac{1}{0.3} \times \frac{1\ Acre}{43{,}560\ ft^2} \times \frac{1}{3\ ft}$$

Constructed wetlands will be implemented at various suitable locations (within existing wetland areas) between the toe of the FTB dams and the FTB Seepage Containment System. They will discharge via outlet structures at multiple locations along the outer access road of the FTB

Seepage Containment System as shown conceptually on Figure 6-4. Assuming that the treatment system can be constructed outside the toe of the FTB, this represents a minimum width of approximately 66 feet around the north and west perimeter of the FTB. The actual distance between the FTB toe and the groundwater containment system will be greater to provide adequate area for wetland construction based on groundwater modeling and the extent of existing wetlands.

6.4.2.2 Permeable Sorptive Barrier (PSB)

PSBs will be constructed to provide a contingency system for additional removal of metals, if needed. Using an empty bed contact time of one hour, and a discharge rate of 1,730 gpm, the required minimum volume for the PSB at the outfall of the constructed wetland, calculated using Equation 6-6, is 14,000 cubic feet of sorptive media.

Equation 6-6

$$Volume = \frac{1{,}730\ gal}{min} \times 1\ hr \times \frac{60\ min}{hr} \times \frac{1\ ft^3}{7.48\ gal}$$

PSBs will be designed to be incorporated into the outlet structures from the constructed wetland at multiple locations along the outer access road of the FTB Seepage Containment System as shown in Figure 6-4. PSBs may be incorporated into the construction of the access road around the outer perimeter or into other outlet structures, sometimes referred to as cassettes that would be designed specifically to house these units and facilitate periodic removal and replacement.

6.4.3 Development Plan

The performance of a constructed wetland/PSB treatment system will depend on site-specific conditions and the actual water being treated. The site-specific design of a treatment system for tailings basin seepage must be pilot-tested to prove its performance before a treatment system could be installed and operated to replace mechanical treatment.

Prior to closure, a pilot-scale treatment system will be designed, installed, operated, and monitored using actual water collected by the FTB seepage capture systems so that it will be comparable to that expected during postclosure maintenance. Based on current modeling, water quality is estimated to stabilize at levels comparable to the long-term water quality that could be directed to the constructed wetland system after approximately Mine Year 45. The pilot-scale non-mechanical treatment system will be constructed at the FTB and use a slipstream of water from the FTB seepage capture systems as inflow. It is anticipated that several years of pilot-testing will be required to obtain the data needed to understand the effects of seasonal variations in temperature and other factors on the performance of the treatment system. After the pilot-testing has been completed and the results of the work have been accepted by the DNR and MPCA, the design and installation of a full-scale treatment system can be initiated if the proven performance is sufficient to allow replacement of mechanical treatment during closure and postclosure of the Project.

In addition, to assess the potential for implementation of non-mechanical treatment of the tailings basin seepage in the event of a contingency closure of the Project, a pilot-test work plan has been developed and submitted to the MPCA and the DNR for review and approval. In accordance with the approved work plan, pilot-testing of non-mechanical treatment for tailings basin seepage will be initiated using the existing water quality conditions. The testing will include multiple phases with changing water quality, preceding the anticipated changes to the actual water quality for the Project. When the Project proceeds to completion, the results of this work will be used to inform any modifications or improvements to the proposed pilot-testing and full-scale installation of non-mechanical treatment for the tailings basin seepage during closure and postclosure maintenance, as described above.

Another important factor in consideration of non-mechanical treatment is the useful life of the system. This will depend on the design configuration as well as site-specific factors and will be evaluated during the pilot-testing program.

The design and timing of the pilot-testing program initiated by the work plan described above will continue to evolve and adapt during operations with review and input provided by the MPCA and DNR.

6.5 FTB Pond Overflow Post-Mechanical Treatment Options

6.5.1 Purpose

The ultimate goal is to allow overflow of the FTB Pond after demonstrating that water in the FTB Pond is stormwater and that it complies with applicable standards. Once this is demonstrated, pond water could be allowed to overflow. The transition from preventing pond overflow to allowing it will occur only after the pond water has been demonstrated to be stormwater meeting applicable standards, and after this demonstration has been approved by the appropriate regulatory agencies.

6.5.2 Conceptual Design

The FTB Closure Overflow (Attachment A Drawing FTB-024 of Reference (6)) will be embedded into bedrock of the hillside east of Cell 2E during reclamation (Section 7.4 of Reference (6)). It is expected that this structure would be modified to serve as a stormwater overflow. Figure 6-4 shows the location of the FTB Closure Overflow. Water discharged via this overflow structure would enter the Unnamed (Mud Lake) Creek watershed.

6.5.3 Development Plan

During the initial portion of the postclosure maintenance phase, while FTB pond water is pumped to the WWTS to prevent overflow, a monitoring program will document changes in pond water levels and water quality over time (Section 5.1 of Reference (2)). This data will be used to evaluate options for demonstrating that the pond water can be classified as stormwater. It will also be used to evaluate potential stormwater overflow outlet elevations.

Revision History

Date	Version	Description
6/11/12	1	Initial release
7/10/12	2	Responses to comments on Version 1 Section 5 - eliminated expanded WWTF and added antimony and lead treatment Section 6 – added lead treatment Section 8 – moved enhanced bentonite for beach to contingency mitigation Section 9 – moved to contingency mitigation section
9/28/12	3	Significant changes in response to comments on Version 2 and because of long-term mechanical treatment
10/31/12	4	Numerous changes in response to comments on Version 3. Figure 2-4 was corrected to show Cat 1 cover construction sequence. A few instances of corrections were made to provide for internal consistency.

Date	Version	Description
3/6/13	5	Major reorganization The Category 1 Stockpile Groundwater Containment System description (Section 3 of AWMP v4) has been moved to the NorthMet Project Rock and Overburden management Plan v5 The Flotation Tailings Basin Containment System (Section 7 of AWMP v4) has been moved to the NorthMet Project Flotation Tailings Management Plan v2 Section 2 - Mine Site Adaptive Water Management has been added. It combines the overview of Mine Site water managements (Section 1.4 of AWMP v4) with the Waste Water Treatment Facility design. Section 4 - Plant Site Adaptive Water Management has been added. It combines the overview of Plant Site water managements (Section 1.5 of AWMP v4) with the Waste Water Treatment Plant design. Non-mechanical treatment systems for the Category 1 Waste Rock Stockpile, the West Pit Overflow and the Flotation Tailings Basin (AWMP v4 Sections 4, 6, and 9 respectively) are consolidated in Section 6 of this document All information relating to the modeling of the Category 1 Waste Rock Stockpile has been consolidated in Section 3.4.3 (Previously in Sections 2.1 and 2.4.3 of AWMP v4) Section 2.2.1.1 During operations WWTF effluent sent to the East Pit will bypass the WWTF neutralization unit in order to deliver high alkalinity water that will help maintain circumneutral pH in the East Pit In long-term closure, FTB pond water will be pumped to the WWTP and treated only to the extent necessary to prevent overflow of the FTB Pond. Reducing the constituent load in the FTB Pond is no longer part of the WWTP plan in long-term closure. An ultimate goal of long-term closure is to allow overflow of the FTB Pond by demonstrating that water in the FTB Pond can be directly discharged as stormwater. Information on the FTB seepage flow that is assumed to bypass the FTB Containment System in the water quality model is described in Section 6.4.1 of the Water Modeling Data Package Volume 2 - Plant Site v9. The description of the FTB Containment System has been moved to the Water Management Plan - Plant v2. Additional information on the groundwater modeling that informs the design of the FTB Containment System is found in Attachment C of the Water Management Plan - Plant v2. Information formerly found in Table 7-1 regarding Tailings Basin Modflow model parameter values has been moved to Attachment C of the Water Management Plan - Plant (v2).
1/15/15	6	Changes in response to Agency comments, updated water modeling, and Project changes for the FEIS. Adaptive management options added for water management during reclamation if East Pit treatment is completed before the West Pit is fully flooded. Long-term mechanical treatment systems at the WWTF and WWTP include the option of chemical precipitation for primary membrane volume reduction.

Date	Version	Description
2/24/15	7	Revised to address agency comments on v6.
3/25/15	8	Revised to address agency comments on v7.
4/30/2015	9	Edits to Table 2-3
8/4/2015	10	Certification page added; minor changes made to Large Figures 1, 4, and 5 to account for changes to the WWTF footprint and discharge; reference to the design basis report for the waste water treatment systems was added; water terminology was updated to conform with the NPDES/SDS application.
8/23/2017	11	Updated to describe WWTS relocations, with the treatment components under one roof at the Plant Site and the Equalization Basin Area located south of Dunka Road. Descriptions of financial assurance were removed because it is now contained in the Permit to Mine Application.
12/08/2017	12	Revised to address DNR comments on v11.

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Large Table 1 Mine Water Quality - Operations

EQ Basin	Source	Percentile	Ag	Al	Alkalinity	As	B	Ba	Be	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	K	Mg	Mn	Na	Ni	Pb	Sb	Se	SO4	Tl	V	Zn
East EQ Basin	East Pit	10	2.00E-04	1.41E-04	9.56E+00	1.00E-01	1.00E-01	9.65E-03	4.00E-04	5.69E+02	1.61E-03	2.48E+01	2.63E-01	1.00E-02	1.97E-01	1.32E+00	4.92E-02	4.43E+01	3.89E+01	1.05E+00	1.62E+02	2.92E+00	2.00E-03	1.75E-02	3.36E-02	2.06E+03	2.00E-04	1.00E-02	1.84E-01
		90	2.00E-04	1.74E-03	4.54E+01	1.00E-01	1.00E-01	1.17E-02	4.00E-04	7.39E+02	4.37E-02	7.12E+01	2.79E+00	1.00E-02	1.28E+01	1.50E+00	2.09E-01	5.85E+01	3.98E+02	3.70E+00	3.71E+02	5.80E+01	2.00E-03	9.08E-02	1.23E-01	3.80E+03	2.00E-04	1.00E-02	1.96E+00
	Central Pit	10	1.80E-04	1.41E-04	9.33E+00	1.68E-02	3.01E-02	1.41E-02	3.42E-04	8.00E+01	1.07E-03	3.43E-01	4.34E-02	1.53E-03	1.77E-01	2.09E-01	4.92E-02	6.29E+00	1.42E+01	2.87E-01	1.83E+01	4.50E-01	1.94E-03	5.31E-03	5.86E-04	1.16E+02	7.48E-05	7.34E-03	1.28E-01
		90	1.99E-04	1.74E-03	3.09E+01	6.40E-02	5.68E-02	2.92E-02	4.00E-04	1.37E+02	7.29E-03	5.95E-01	1.73E-01	2.35E-03	2.48E+00	3.68E-01	2.09E-01	1.15E+01	5.50E+01	4.66E-01	4.78E+01	1.66E+00	2.00E-03	1.76E-02	6.27E-03	4.46E+02	1.12E-04	9.57E-03	7.08E-01
	West Pit	10	1.66E-04	9.30E-04	2.51E+01	2.68E-02	5.48E-02	1.90E-02	2.65E-04	1.16E+02	1.05E-03	4.91E+00	5.67E-02	2.07E-03	1.17E-01	4.24E-01	4.58E-02	1.14E+01	2.07E+01	1.56E-01	3.20E+01	1.12E+00	2.92E-03	9.48E-03	2.55E-04	2.53E+02	8.30E-05	8.52E-03	8.01E-02
		90	1.79E-04	2.15E-03	4.31E+01	5.72E-02	8.72E-02	2.53E-02	3.49E-04	2.76E+02	5.34E-03	1.05E+02	2.38E-01	4.13E-03	6.15E-01	1.01E+00	1.99E-01	2.79E+01	7.78E+01	3.70E-01	7.99E+01	4.46E+00	6.61E-03	3.20E-02	1.40E-02	6.12E+02	1.18E-04	9.25E-03	2.90E-01
	Haul Roads	10	2.21E-09	9.30E-04	3.48E+01	8.57E-03	4.05E-02	2.60E-02	1.39E-05	1.36E+02	7.98E-04	0.00E+00	6.08E-02	5.50E-03	1.19E-01	1.77E+00	4.58E-02	2.13E+01	2.56E+01	1.36E-01	2.39E+01	9.89E-01	3.20E-04	1.16E-02	1.64E-05	1.36E+02	4.50E-07	6.18E-03	4.51E-02
		90	6.71E-05	2.15E-03	5.11E+01	6.57E-02	1.00E-01	3.08E-02	4.00E-04	3.47E+02	3.56E-03	0.00E+00	2.57E-01	1.00E-02	6.57E-01	3.29E+00	1.99E-01	4.92E+01	1.28E+02	3.36E-01	1.59E+02	2.60E+00	2.79E-03	7.39E-02	4.62E-03	2.27E+02	1.59E-04	1.00E-02	1.66E-01
	Rail Transfer Hopper	10	2.00E-04	1.41E-04	9.56E+00	1.00E-01	1.00E-01	1.28E-02	4.00E-04	2.84E+02	1.61E-03	0.00E+00	2.63E-01	8.82E-03	1.97E-01	1.60E+00	4.92E-02	3.27E+01	3.73E+01	1.05E+00	4.56E+01	2.92E+00	2.00E-03	1.75E-02	3.25E-02	1.17E+03	2.00E-04	1.00E-02	1.84E-01
		90	2.00E-04	1.74E-03	4.54E+01	1.00E-01	1.00E-01	1.51E-02	4.00E-04	4.35E+02	1.44E-02	0.00E+00	2.46E+00	1.00E-02	1.28E+01	2.18E+00	2.09E-01	4.75E+01	1.42E+02	3.66E+00	2.39E+02	5.73E+01	2.00E-03	8.70E-02	7.99E-02	1.93E+03	2.00E-04	1.00E-02	1.53E+00
	Category 1 Stockpile	10	1.90E-08	9.30E-04	3.48E+01	6.06E-02	1.00E-01	1.09E-02	1.12E-04	6.34E+02	1.68E-03	2.23E-02	6.17E-02	1.00E-02	1.19E-01	1.34E+00	4.58E-02	4.35E+01	7.58E+01	1.91E-01	1.15E+02	1.29E+00	1.90E-03	1.72E-02	1.23E-04	5.63E+02	2.95E-06	1.00E-02	9.18E-02
		90	2.00E-04	2.15E-03	5.11E+01	1.00E-01	1.00E-01	1.97E-02	4.00E-04	7.23E+02	7.67E-03	7.27E-01	3.19E-01	1.00E-02	6.57E-01	1.43E+00	1.99E-01	5.38E+01	3.73E+02	4.97E-01	2.97E+02	6.61E+00	2.88E-02	9.05E-02	3.71E-02	2.72E+03	2.00E-04	1.00E-02	3.83E-01
	Cumulative	**10**	1.38E-04	5.58E-04	1.89E+01	7.46E-02	8.59E-02	1.31E-02	3.16E-04	3.44E+02	1.96E-03	2.67E+00	1.94E-01	7.17E-03	2.06E-01	1.18E+00	5.24E-02	3.75E+01	5.87E+01	5.94E-01	7.33E+01	2.38E+00	1.91E-03	2.17E-02	1.14E-02	1.28E+03	1.22E-04	9.37E-03	1.55E-01
		90	1.90E-04	1.69E-03	4.21E+01	8.74E-02	9.43E-02	1.71E-02	3.87E-04	5.92E+02	2.58E-02	2.89E+01	1.66E+00	8.63E-03	7.41E+00	1.60E+00	1.88E-01	4.73E+01	2.27E+02	2.23E+00	1.99E+02	2.46E+01	5.84E-03	6.74E-02	5.72E-02	2.45E+03	1.75E-04	9.77E-03	1.22E+00
West EQ Basin	Category 2/3 Stockpile	10	2.09E-02	7.86E+01	3.80E+00	9.97E-02	1.05E-01	8.45E-03	5.87E-03	4.06E+02	1.67E-02	5.54E-22	1.59E+00	1.30E-02	7.75E+01	1.54E+00	1.81E+01	3.00E+01	1.60E+02	2.26E+00	6.46E+01	2.54E+01	1.05E-01	4.47E-01	5.25E-02	2.09E+03	1.20E-03	3.35E-02	1.78E+00
		90	2.91E-02	4.91E+02	1.84E+01	9.98E-02	2.54E-01	1.28E-02	1.30E-02	5.63E+02	1.45E-01	4.51E-21	1.94E+01	1.41E-02	1.03E+02	1.88E+00	1.04E+02	4.66E+01	8.97E+02	3.93E+01	2.18E+02	3.01E+02	3.32E-01	1.59E+00	1.14E-01	8.66E+03	9.00E-03	3.97E-02	1.47E+01
	Ore Surge Pile	10	3.51E-02	1.32E+02	6.84E-03	9.94E-02	1.08E-01	6.50E-03	8.77E-03	3.50E+02	2.11E-02	3.08E-21	6.59E+00	1.51E-02	1.30E+02	1.66E+00	3.03E+01	1.82E+01	2.12E+02	1.31E+01	3.00E+01	1.25E+02	1.74E-01	3.12E-01	9.87E-02	2.37E+03	1.88E-03	5.04E-02	3.28E+00
		90	4.78E-02	8.20E+02	5.10E-01	9.96E-02	3.58E-01	1.21E-02	2.10E-02	4.61E+02	1.76E-01	2.52E-20	3.94E+01	1.67E-02	1.64E+02	1.91E+00	1.71E+02	4.20E+01	1.33E+03	7.92E+01	1.72E+02	8.13E+02	5.46E-01	2.43E+00	9.98E-02	1.31E+04	8.63E-03	5.84E-02	2.13E+01
	Category 4 Stockpile (inactive)	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Cumulative	**10**	2.33E-02	8.99E+01	2.95E+00	9.97E-02	1.06E-01	8.27E-03	6.21E-03	3.96E+02	1.70E-02	8.85E-22	2.35E+00	1.33E-02	8.49E+01	1.56E+00	1.97E+01	2.92E+01	1.50E+02	4.18E+00	5.17E+01	3.53E+01	1.11E-01	4.03E-01	5.80E-02	1.94E+03	1.31E-03	3.61E-02	1.98E+00
		90	3.25E-02	5.26E+02	1.57E+01	9.98E-02	2.64E-01	1.33E-02	1.41E-02	5.43E+02	1.47E-01	7.67E-21	2.07E+01	1.45E-02	1.10E+02	1.88E+00	1.13E+02	4.58E+01	9.96E+02	3.95E+01	2.18E+02	4.05E+02	3.61E-01	1.72E+00	1.11E-01	9.01E+03	8.10E-03	4.23E-02	1.63E+01

1. All concentrations shown are mg/L
2. All concentrations are shown for the peak year of Operations, Mine Year 14
3. Percentiles are the 10th and 90th percentiles of the annual average concentrations
4. Category 4 stockpile has been moved to the East Pit by Year 14, therefore no concentrations are shown
5. Source: FEIS modul outputs from Water Modeling Data Package Vol 1 - Mine Site v14

Large Table 2   Mine Water Quality - Reclamation and Closure

Source	Percentile	Ag	Al	Alkalinity	As	B	Ba	Be	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	K	Mg	Mn	Na	Ni	Pb	Sb	Se	SO4	Tl	V	Zn
East Pit	10	2.00E-04	1.41E-04	9.56E+00	1.00E-01	1.00E-01	1.09E-02	4.00E-04	1.72E+02	1.61E-03	5.73E+01	2.49E-01	1.00E-02	1.97E-01	1.33E+00	4.92E-02	4.43E+01	3.46E+01	4.25E-01	1.71E+02	2.28E+00	2.00E-03	1.75E-02	9.82E-03	4.47E+02	2.00E-04	1.00E-02	1.84E-01
	90	2.00E-04	1.74E-03	4.54E+01	1.00E-01	1.00E-01	1.91E-02	4.00E-04	7.25E+02	4.14E-02	8.99E+01	1.85E+00	1.00E-02	1.28E+01	2.71E+00	2.09E-01	5.85E+01	2.84E+02	3.33E+00	4.39E+02	1.58E+01	2.00E-03	9.08E-02	9.14E-02	2.57E+03	2.00E-04	1.00E-02	1.96E+00
Category 1 Stockpile	10	1.68E-06	9.30E-04	3.48E+01	9.64E-02	1.00E-01	9.96E-03	3.72E-04	6.35E+02	1.70E-03	1.38E-15	6.17E-02	1.00E-02	1.19E-01	1.34E+00	4.58E-02	4.35E+01	7.60E+01	1.91E-01	1.75E+02	1.29E+00	6.08E-02	1.75E-02	2.26E-04	1.95E+03	1.26E-04	1.00E-02	9.22E-02
	90	2.00E-04	2.15E-03	5.11E+01	1.00E-01	1.00E-01	1.34E-02	4.00E-04	7.23E+02	7.89E-03	3.25E-04	3.19E-01	1.00E-02	6.57E-01	1.43E+00	1.99E-01	5.38E+01	3.76E+02	4.97E-01	3.02E+02	6.61E+00	1.00E-01	9.07E-02	7.39E-02	3.63E+03	2.00E-04	1.00E-02	3.90E-01
Cumulative	**10**	1.94E-04	7.68E-04	2.05E+01	1.36E-01	1.04E-01	3.72E-02	3.95E-04	4.20E+02	1.56E-03	8.39E+01	2.49E-01	9.23E-03	6.78E-01	2.37E+00	1.06E+00	8.87E+01	1.92E+02	1.45E+00	2.81E+02	2.58E+00	6.05E-02	1.68E-02	8.93E-03	9.97E+02	1.90E-04	9.65E-03	1.74E-01
	90	1.96E-04	2.29E-03	5.53E+01	1.52E-01	1.11E-01	4.55E-02	4.05E-04	9.36E+02	3.62E-02	1.15E+02	1.64E+00	9.32E-03	1.18E+01	3.62E+00	2.87E+00	1.03E+02	4.26E+02	3.93E+00	5.15E+02	1.43E+01	7.69E-02	8.04E-02	7.97E-02	2.84E+03	1.93E-04	9.73E-03	1.72E+00
Central Pit	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
West Pit	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Plant Site Concentrate	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Haul Roads	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rail Transfer Hopper	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Category 2/3 Stockpile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ore Surge Pile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Category 4 Stockpile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

trations shown are mg/L
trations are shown for Mine Year 25
; are the 10th and 90th percentiles of the annual average concentrations
EIS modul outputs from Water Modeling Data Package Vol 1 - Mine Site v14

Large Table 3 Mine Water Quality - Postclosure Maintenance

	Source	Percentile	Ag	Al	Alkalinity	As	B	Ba	Be	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	K	Mg	Mn	Na	Ni	Pb	Sb	Se	SO4	Tl	V	Zn
Active Sources	West Pit	10	2.00E-04	9.30E-04	3.48E+01	8.36E-03	1.00E-01	2.55E-02	3.00E-04	3.52E+01	9.48E-04	1.03E+01	1.24E-02	3.26E-03	1.19E-01	2.04E-01	4.58E-02	7.85E+00	1.93E+01	1.72E-01	2.62E+01	1.79E-01	4.50E-03	8.51E-03	2.35E-04	5.54E+01	1.12E-04	1.00E-02	7.30E-02
		90	2.00E-04	2.15E-03	5.11E+01	1.83E-02	1.00E-01	3.68E-02	4.00E-04	4.75E+01	3.60E-03	1.46E+01	5.95E-02	3.65E-03	6.51E-01	2.58E-01	1.99E-01	1.31E+01	2.30E+01	2.25E-01	4.48E+01	5.97E-01	8.83E-03	1.17E-02	2.85E-03	6.97E+01	1.23E-04	1.00E-02	2.15E-01
	Category 1 Stockpile	10	2.89E-05	9.30E-04	3.48E+01	1.00E-01	1.00E-01	9.49E-03	4.00E-04	6.35E+02	1.70E-03	1.59E-21	6.17E-02	1.00E-02	1.19E-01	1.34E+00	4.58E-02	4.35E+01	7.61E+01	1.91E-01	1.80E+02	1.29E+00	2.09E-02	1.75E-02	2.35E-04	2.26E+03	2.00E-04	1.00E-02	9.22E-02
		90	2.00E-04	2.15E-03	5.11E+01	1.00E-01	1.00E-01	1.14E-02	4.00E-04	7.23E+02	7.97E-03	2.50E-09	3.19E-01	1.00E-02	6.57E-01	1.42E+00	1.99E-01	5.38E+01	3.76E+02	4.97E-01	3.05E+02	6.61E+00	1.00E-01	9.08E-02	7.03E-02	4.01E+03	2.00E-04	1.00E-02	3.90E-01
	Cumulative	**10**	1.96E-04	9.30E-04	3.48E+01	8.62E-03	1.00E-01	2.68E-02	3.22E-04	3.36E+01	7.19E-04	7.17E+00	1.69E-02	2.16E-03	1.19E-01	1.87E-01	4.58E-02	7.34E+00	1.37E+01	1.22E-01	2.47E+01	2.66E-01	5.75E-03	6.00E-03	2.55E-04	5.22E+01	7.34E-05	1.00E-02	5.92E-02
		90	2.00E-04	2.15E-03	5.11E+01	1.47E-02	1.00E-01	3.93E-02	4.00E-04	5.92E+01	3.63E-03	1.32E+01	7.50E-02	2.73E-03	6.55E-01	2.97E-01	1.99E-01	1.25E+01	2.10E+01	1.90E-01	4.94E+01	8.43E-01	1.20E-02	9.48E-03	2.85E-03	1.32E+02	8.84E-05	1.00E-02	2.23E-01
Inactive Sources	Combined East/Central Pit	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Plant Site Concentrate	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Haul Roads	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Rail Transfer Hopper	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Category 2/3 Stockpile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Ore Surge Pile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Category 4 Stockpile	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

1. All concentrations shown are mg/L
2. All concentrations are shown for Mine Year 75
3. Percentiles are the 10th and 90th percentiles of the annual average concentrations
4. Source: FEIS modul outputs from Water Modeling Data Package Vol 1 - Mine Site v14

Large Table 4 WWTF Ranges of Blended Influent Water Quantity and Quality

WWTF Ranges of Blended Influent Water Quantity and Quality (µg/L unless otherwise specified)	Operations[2]						Closure[3]				Post-Closure[4]			
	East EQ Basin		West EQ Basin		FTB Seepage		Mine Water		FTB Seepage		Mine Water		FTB Seepage	
	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%	10%	90%
Flow (gpm) [1]	1280	1780	115	170	2030	3605	0[6]	1750	3500	3500	250	325	2055	2838
Ag (Silver)	0.138	0.190	23.3	32.5	0.172	0.211	0.194	0.196	0.1440	0.176	0.196	0.200	0.066	0.172
Al (Aluminum)	0.558	1.690	89900.0	526000.0	4.62	11.50	0.768	2.29	5.44	11.2	0.930	2.15	7.83	23.1
Alk (Alkalinity)	18900	42100	2950	15700	75900	114000	20500	55300	72400	109000	34800	51100	111000	159000
As (Arsenic)	74.6	87.4	99.7	99.8	22.9	40.4	136.0	152.0	36.20	44.90	8.6	14.7	11.400	15.800
B (Boron)	85.9	94.3	106	264	164	235	104	111	145	220	100	100	222	325
Ba (Barium)	13.1	17.1	8.3	13.3	24.5	26.7	37.2	45.5	18.300	21.000	26.8	39.3	16.700	21.700
Be (Beryllium)	0.316	0.387	6.210	14.100	0.415	0.483	0.395	0.405	0.347	0.459	0.322	0.400	0.221	0.569
Ca (Calcium)	344000	592000	396000	543000	90800	137000	420000	936000	133000	227000	33600	59200	67500	101000
Cd (Cadmium)	1.960	25.8	17.0	147	0.689	2.01	1.56	36.2	0.644	2.540	0.719	3.63	0.230	0.677
Cl (Chloride)	2670	28900	0	0	19700	24700	83900	115000	17800	23000	7170	13200	11200	15200
Co (Cobalt)	194	1660	2350	20700	11.2	34.4	249	1640	13.10	52.6	16.9	75.0	5.30	17.2
Cr (Chromium)	7.17	8.63	13.30	14.50	4.98	7.02	9.23	9.32	4.57	5.44	2.16	2.73	1.36	1.79
Cu (Copper)	206	7410	84900	110000	247	524	678	11800	194.0	384	119	655	67.6	145
F (Fluoride)	1180	1600	1560	1880	844	1190	2370	3620	665	825	187	297	180	296
Fe (Iron)	52	188	19700	113000	1300	2410	1060	2870	790	1840	46	199	1870	3720
K (Potassium)	37500	47300	29200	45800	20500	29500	88700	103000	25700	29300	7340	12500	10300	14200
Mg (Magnesium)	58700	227000	150000	996000	75000	98300	192000	426000	80800	114000	13700	21000	70200	121000
Mn (Manganese)	594	2230	4180	39500	563	907	1450	3930	500	813	122	190	567	929
Na (Sodium)	73300	199000	51700	218000	62400	75900	281000	515000	65300	78500	24700	49400	30600	49100
Ni (Nickel)	2380	24600	35300	405000	157	476	2580	14300	189	677	266	843	68	195
Pb (Lead)	1.91	5.84	111.00	361.00	27.80	51.20	60.50	76.90	35.30	43.50	5.75	12.00	6.68	10.00
Sb (Antimony)	21.7	67.4	403	1720	7.19	11.4	16.8	80.4	8.72	13.00	6.00	9.48	2.76	5.45
Se (Selenium)	11.4	57.2	58.0	111	1.89	2.89	8.93	79.70	2.720	4.21	0.26	2.85	0.60	1.20
SO4 (Sulfate)	1,280,000	2,450,000	1,940,000	9,010,000	282,000	337,000	997,000	2,840,000	292,000	386,000	52,200	132,000	154,000	278,000
Tl (Thallium)	0.122	0.175	1.31	8.10	0.151	0.191	0.190	0.193	0.1310	0.157	0.0734	0.0884	0.053	0.122
V (Vanadium)	9.370	9.770	36.1	42.3	6.77	9.09	9.65	9.73	6.15	7.04	10.0	10.0	2.300	3.000
Zn (Zinc)	155	1220	1980	16300	66.2	139	174.0	1720.0	61.8	159.0	59.2	223.0	17.9	41.1
TDS (Total Dissolved Solids mg/L)[5]	1820	3626	2811	12064	630	822	2092	5031	690	972	174	341	458	743

(1) Flows are shown as annual average flows (gpm), rounded to the nearest 5 gpm.

(2) Estimates based on Reference (3) non-charged balanced water for Mine Year 14

(3) Estimates based on Reference (3) non-charged balanced water for Mine Year 25

(4) Estimates based on Reference (3) non-charged balanced water for Mine Year 75

(5) TDS estimates are based on sum of all modeled constituents

(6) P10 mine water flows for Mine Year 35 are zero, because in 10% of model runs, East Pit flushing is complete by Mine Year 35.

Large Table 5 HELP Model Input Layer Summary (Preliminary)

	Vertical Percolation Layer 1	Lateral Drainage Layer 1	Geomembrane Barrier Layer	Vertical Percolation Layer 2	Selection and/or Verification Method
Material Texture Number	8	5	36	22	Selected by HELP Model User
Unified Soil Classification (Typical Description)	ML (inorganic silts, very fine sands, rock flour, silty or clayey fine sands)	SM (silty sands, sand-silt mixtures)	N/A	ML (inorganic silts, very fine sands, rock flour, silty or clayey fine sands)	Help Model Default Based on Material Texture Number - Construction Specification and Construction QA/QC
Thickness (inches)	18	12	N/A	6	Construction Specification and Construction QA/QC
Porosity (Vol/Vol)	0.463	0.457	N/A	0.419	HELP Model Default Based on Material Texture Number
Field Capacity (Vol/Vol)	0.232	0.131	N/A	0.307	HELP Model Default Based on Material Texture Number
Wilting Point (Vol/Vol)	0.116	0.058	N/A	0.180	HELP Model Default Based on Material Texture Number
Initial Soil Water Content (Vol/Vol)	Calculated by HELP Model	Calculated by HELP Model	N/A	Calculated by HELP Model	HELP Model Default Based on Material Texture Number
Saturated Hydraulic Conductivity (cm/sec)(1),(3)	3.7×10^{-4}	1.0×10^{-3}	4.0×10^{-13}	1.9×10^{-5}	HELP Model Default Based on Material Texture Number -- Construction Specification and Construction QA/QC for Lateral Drainage Layer
Root Channels(2)	Approx. 4.2	N/A	N/A	N/A	HELP Model Default Based on Vegetation Quality
Surface Slope	1% Top; 27% Side	1% Top; 27% Side	N/A	N/A	Construction Specification and Construction QA/QC
SCS Runoff Curve Number	Calculated by HELP Model	N/A	N/A	N/A	HELP Model Default Based on Surface Material Texture Number, Vegetation Quality and Surface Slope
Uninterrupted Slope Length (feet)	150' on Side Slopes; 75' on Top Slopes	150' on Side Slopes; 75' on Top Slopes	N/A	N/A	Construction Specification and Construction QA/QC
Vegetation Quality	Good Stand of Grass	N/A	N/A	N/A	Specified by HELP Model User
Fraction of Area Allowing Runoff	100%	N/A	N/A	N/A	Specified by HELP Model User on Basis of Site Geometry
Evaporative Zone Depth (inches)	12	N/A	N/A	N/A	Specified by HELP Model User
Geomembrane Installation Quality	N/A	N/A	Good	N/A	Specified by HELP Model User
Defects Frequency	N/A	N/A	Input range supported by 2.4.1.1	N/A	Specified by HELP Model User
Defect Size	N/A	N/A	$1.0\ cm^2$	N/A	HELP Model Default

(1) Saturated Hydraulic Conductivity – for cover construction projects it is standard practice to specify the saturated hydraulic conductivity of only the Lateral Drainage Layer. While default saturated hydraulic conductivity values for Vertical Percolation Layers are used to facilitate HELP Modeling; carry-over of these values to Construction Specifications and Construction QA/QC is not typical and is not proposed.

(2) Root Channels – an empirical factor utilized by the HELP Model to increase the hydraulic conductivity of the top soil layer (Vertical Percolation Layer 1) to account for the effects of root channels on soil hydraulic conductivity.

(3) Per agreement with MPCA participants in stockpile cover design review, the construction specifications will require a hydraulic conductivity of 1.0 x 10-2 cm/sec for Lateral Drainage Layer 1 on stockpile side slopes and a hydraulic conductivity of 1.0 x 10-3 cm/sec for Lateral Drainage Layer 1 on the top and benches of the stockpile. The Saturated Hydraulic Conductivity of 1.0 x 10-3 cm/sec is used for HELP modeling of the entire Category 1 Waste Rock Stockpile to yield a slightly higher estimate of percolation rate through geomembrane defects for purposes of water quality impacts modeling; Material Texture Number 5 for Lateral Drainage Layer 1 has been selected to provide the 1.0 x 10-3 cm/sec hydraulic conductivity HELP model input for Lateral Drainage Layer 1. Actual (construction specification) Lateral Drainage Layer 1 will be more reflective of the characteristics of HELP Model Default Material Texture 1 – SP (poorly graded sands and gravelly sands, little or no fines).

Large Table 6 HELP Model Input and Output Summary (Water Quality Impacts Modeling)

HELP Model - Primary Inputs and Model Outcomes	Scenario 1: Lower Defect Frequency (2 holes/acre)(1),(3)						Scenario 2: Higher Defect Frequency (10 holes/acre)(3)					
	Stockpile Top and Benches		Stockpile Sides		Stockpile Weighted Average(2)		Stockpile Top and Benches		Stockpile Sides		Stockpile Weighted Average(2)	
Slope Angle, %	1%		27%		18.3%		1%		27%		18.3%	
Drainage Length, ft.	75		150		N/A		75		150		N/A	
Hydraulic Conductivity of Granular Drainage Layer, cm/sec	1×10^{-3}		1×10^{-3}		1×10^{-3}		1×10^{-3}		1×10^{-3}		1×10^{-3}	
Average Annual Precipitation, in/yr and as % of Precipitation	27.68	100.00%	27.68	100.00%	27.68	100.00%	27.68	100.00%	27.68	100.00%	27.68	100.00%
Surface Water Runoff, in/yr and as % of Precipitation	3.21	11.60%	2.96	10.68%	3.04	10.98%	3.12	11.27%	2.96	10.68%	3.01	10.88%
Evapotranspiration, in/yr and as % of Precipitation	18.90	68.28%	18.80	67.93%	18.84	68.05%	18.86	68.14%	18.80	67.93%	18.82	68.00%
Lateral Drainage off Geomembrane, in/yr and as % of Precipitation	5.31	19.18%	5.88	21.24%	5.69	20.56%	4.67	16.87%	5.76	20.81%	5.40	19.50%
Percolation through Geomembrane, in/yr and as % of Precipitation	0.22	0.79%	0.030	0.11%	0.09	0.34%	1.01	3.65%	0.16	0.58%	0.44	1.60%

(1) Geomebrane barrier layer installation quality is "Good" per HELP Model User's Manual definition
(2) Area of Category 1 Waste Rock Stockpile - Top (acres): 175
(2) Area of Category 1 Waste Rock Stockpile - Sides (acres): 351
(2) Total Area of Category 1 Waste Rock Stockpile (acres): 526
(3) All values rounded to nearest hundreth; some rounding errors will be reflected in column totals

Large Table 7 Treated Mine Water – GoldSim Concentrations

Parameter (µg/L unless otherwise noted)	GoldSim Treated Mine Water Concentration			Surface Water							Groundwater	Drinking Water	
				M.R. 7052.0100 Class 2B (chronic standard)			M.R. 7050.0222 Class 2B (chronic standard)			M.R. 7050.0224 Class 4A (chronic standard)	Minn. Groundwater (HRL, HBV, or RAA)	Federal Standard, (Primary MCLs)	Federal Standard, (Secondary MCLs)
Metals/Inorganics													
Aluminum	125						**125**						50-200
Antimony	31						**31**				6	6.0	
Arsenic	10			53			(3)					**10.0**	
Barium	2,000										**2,000**	2,000	
Beryllium	4										0.08	**4.0**	
Boron	500									**500**	1,000		
Cadmium (1) (2)	4	4	2	**5.1**	**4.2**	**2.5**	(3)				4	5.0	
Chromium (+3)				86			(3)				20,000	100 (total)	
Chromium (+6)	11			**11**			(3)				100	100 (total)	
Cobalt	5						**5.0**						
Copper (1) (2)	30	16	9	**20**	**17**	**9.3**	(3)					1,300	1,000
Iron	300												**300**
Lead (1) (2)	19	7	3				**10.2**	**7.7**	**3.2**			15	
Manganese	50										100		**50**
Mercury				0.0013			(3)					2.0	
Nickel (1) (2)	100	90	50	**113**	**94**	**52**	(3)				100		
Selenium	5			**5.0**			(3)				30	50	
Silver	1						**1.0**				30		100
Thallium	0.56						**0.56**				0.6	2.0	
Zinc (1) (2)	388	200	100	**260**	**216**	**120**	(3)				2,000		5,000
General Parameters													
Ammonia (un-ionized)							40						
Bicarbonate (meq/L)										5			
Chloride (mg/L)	230						**230**						250
Cyanide (free)				5.2			(3)				100	200	
Dissolved Oxygen (mg/L)							>5.0						
Fluoride (mg/L)	2											4.0	**2.0**
Hardness (mg/L) (2)	250	200	100	**250**	**200**	**100**	250	200	100				
Nitrate (mg/L)											10	10	
Oil							500						
pH (su)							6.5-9.0			6.0-8.5			6.5-8.5
Sodium (% of cations)										**60**			
Specific Conductance (uhmos/cm)										1,000			
Sulfate (mg/L) (2)	250	150	9							**10**			**250**
Total Dissolved Salts (mg/L)										700			500 (total dissolved solids)
Turbidity (NTU)							25						

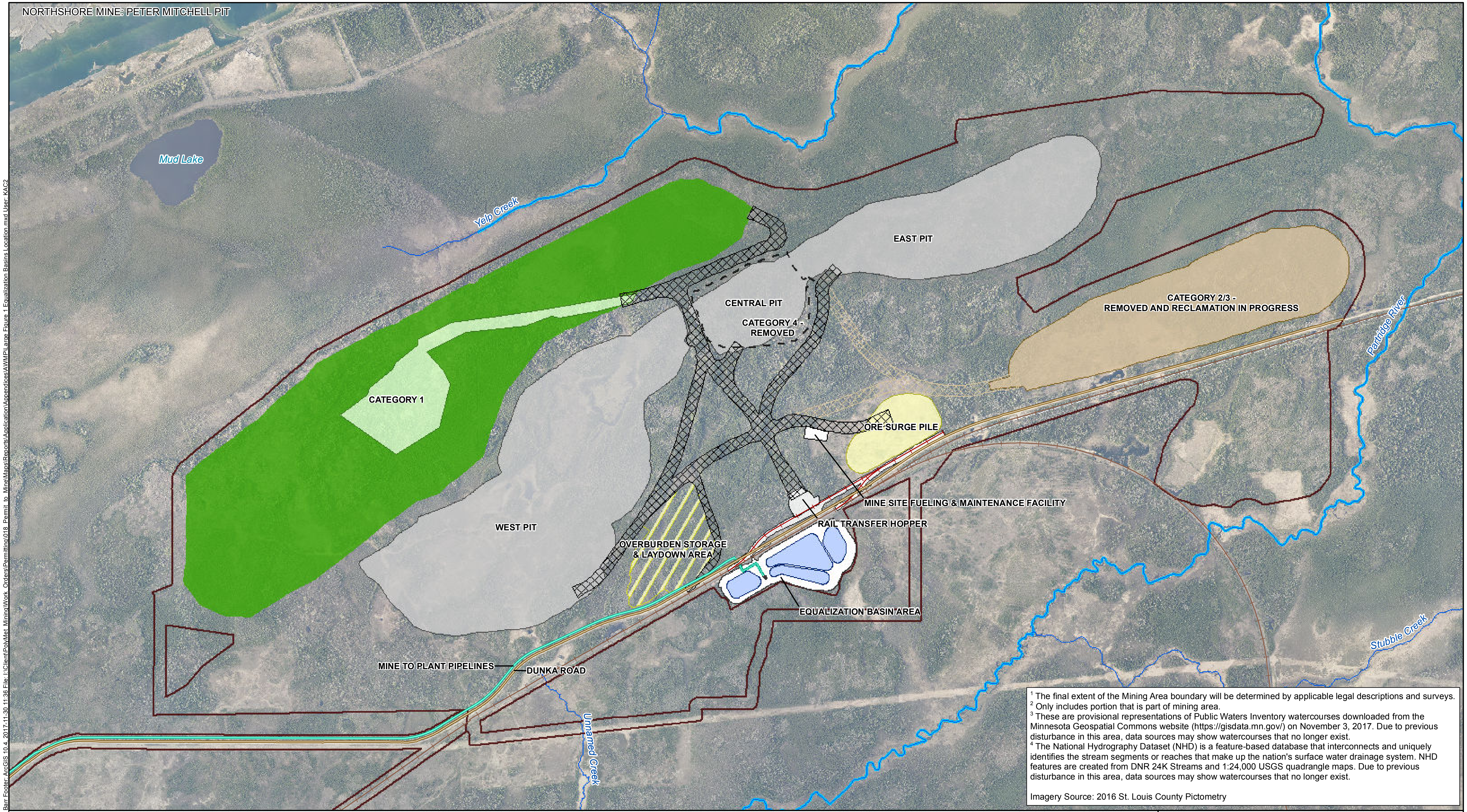
Values in **bold** font indicate value used for Preliminary Water Quality Target.
(1) Surface water standard based on Hardness.
(2) GoldSim modeled concentration for Operations, Reclamation and Closure, and Postclosure Maintenance.
(3) Standard superseded by M.Rules 7052.0100, Class 2B standard.

Large Table 8 WWTS Discharge – GoldSim Effluent Concentrations and Potential Water Quality Standards

Parameter (µg/L unless otherwise noted)	GoldSim WWTS Discharge Concentration	Surface Water			Groundwater	Drinking Water	
		M.R. 7052.0100 Class 2B (chronic standard)	M.R. 7050.0222 Class 2B (chronic standard)	M.R. 7050.0224 Class 4A (chronic standard)	Minn. Groundwater (HRL, HBV, or RAA)	Federal Standard, (Primary MCLs)	Federal Standard, (Secondary MCLs)
Metals/Inorganics							
Aluminum	125		**125**				50-200
Antimony	31		**31**		6	6.0	
Arsenic	10	53	(3)			**10.0**	
Barium	5				**2,000**	2,000	
Beryllium	4				0.08	**4.0**	
Boron	400			**500**	1,000		
Cadmium (1) (2)	2	**2.5**	(3)		4	5.0	
Chromium (+3)		86	(3)		20,000	100 (total)	
Chromium (+6)	11	**11**	(3)		100	100 (total)	
Cobalt	5		**5.0**				
Copper (1) (2)	9	**9.3**	(3)			1,300	1,000
Iron	300						**300**
Lead (1) (2)	3		**3.2**			15	
Manganese	50				100		**50**
Mercury		0.0013	(3)			2.0	
Nickel (1) (2)	50	**52**	(3)		100		
Selenium	5	**5.0**	(3)		30	50	
Silver	1		**1.0**		30		100
Thallium	0.56		**0.56**		0.6	2.0	
Zinc (1) (2)	100	**120**	(3)		2,000		5,000
General Parameters							
Ammonia (un-ionized)			40				
Bicarbonate (meq/L)				5			
Chloride (mg/L)	1.3		**230**				250
Cyanide (free)		5.2	(3)		100	200	
Dissolved Oxygen (mg/L)			>5.0				
Fluoride (mg/L)	0.05					4.0	**2.0**
Hardness (mg/L) (2)	100	**100**	100				
Nitrate (mg/L)					10	10	
Oil			500				
pH (su)			6.5-9.0	6.0-8.5			6.5-8.5
Sodium (% of cations)	2 (mg/L)			**60**			
Specific Conductance (uhmos/cm)				1,000			
Sulfate (mg/L) (2)	9			**10**			250
Total Dissolved Salts (mg/L)				700			500 (total dissolved solids)
Turbidity (NTU)			25				

Values in **bold** font indicate value used for Preliminary Water Quality Target.
(1) Surface water standard based on Hardness.
(2) GoldSim modeled concentration for Operations, Reclamation, and Long-Term Closure.
(3) Standard superseded by M.Rules 7052.0100, Class 2B standard.

Large Figures



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

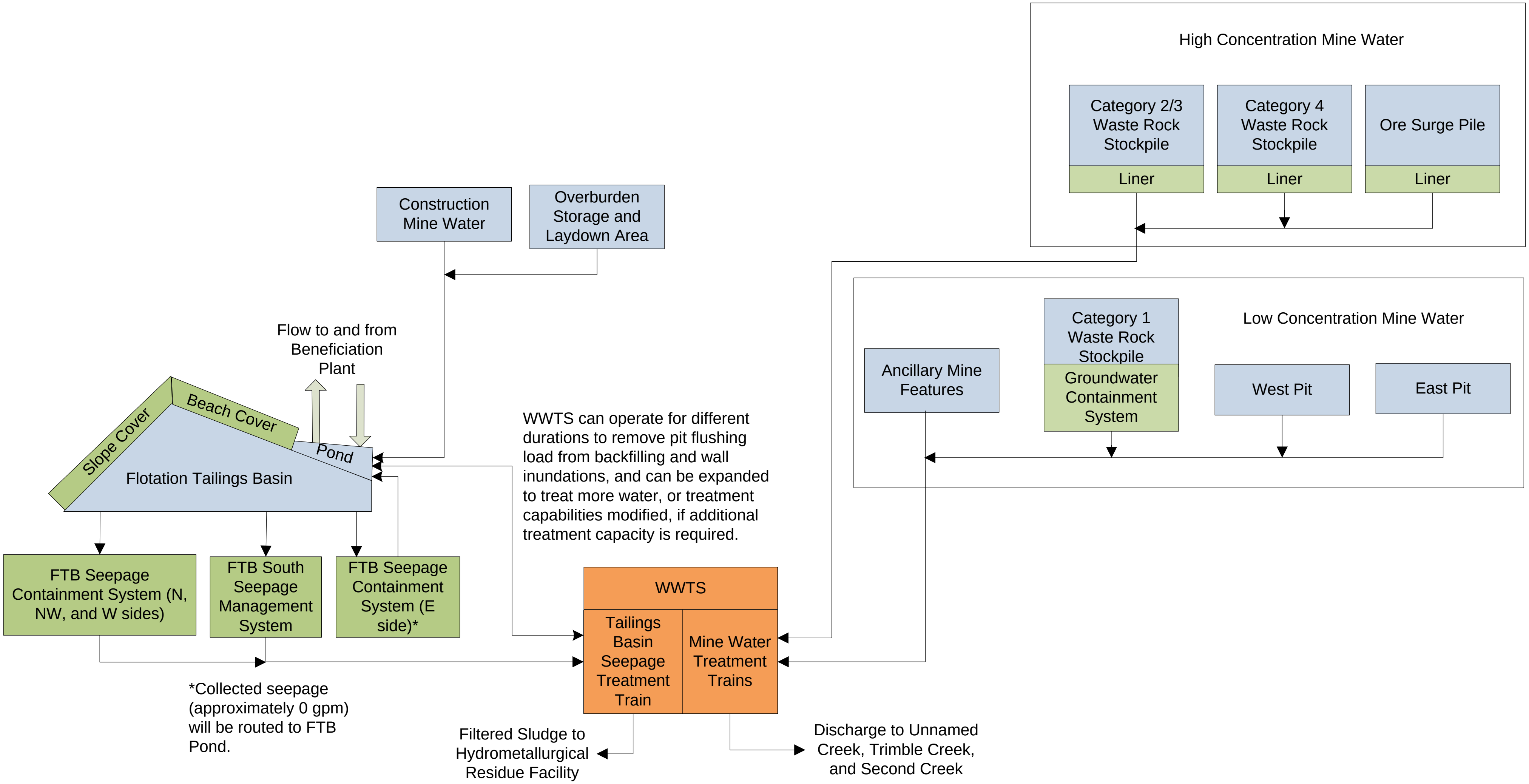
Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Dunka Road[2]
Mine Year 20 Footprints
Mine Pits
Open Stockpile
Covered Stockpile
Removed Stockpile
Active Stockpile
Storage & Laydown Area
Removed and Reclaimed Stockpiles
Existing Private Railroad
Proposed Railroad Track
Public Waters Inventory (PWI) Watercourses[3]
National Hydrography Dataset (NHD) Rivers & Streams[4]

0 750 1,500 3,000
Feet

EQUALIZATION BASINS LOCATION
NorthMet Project
Poly Met Mining, Inc.

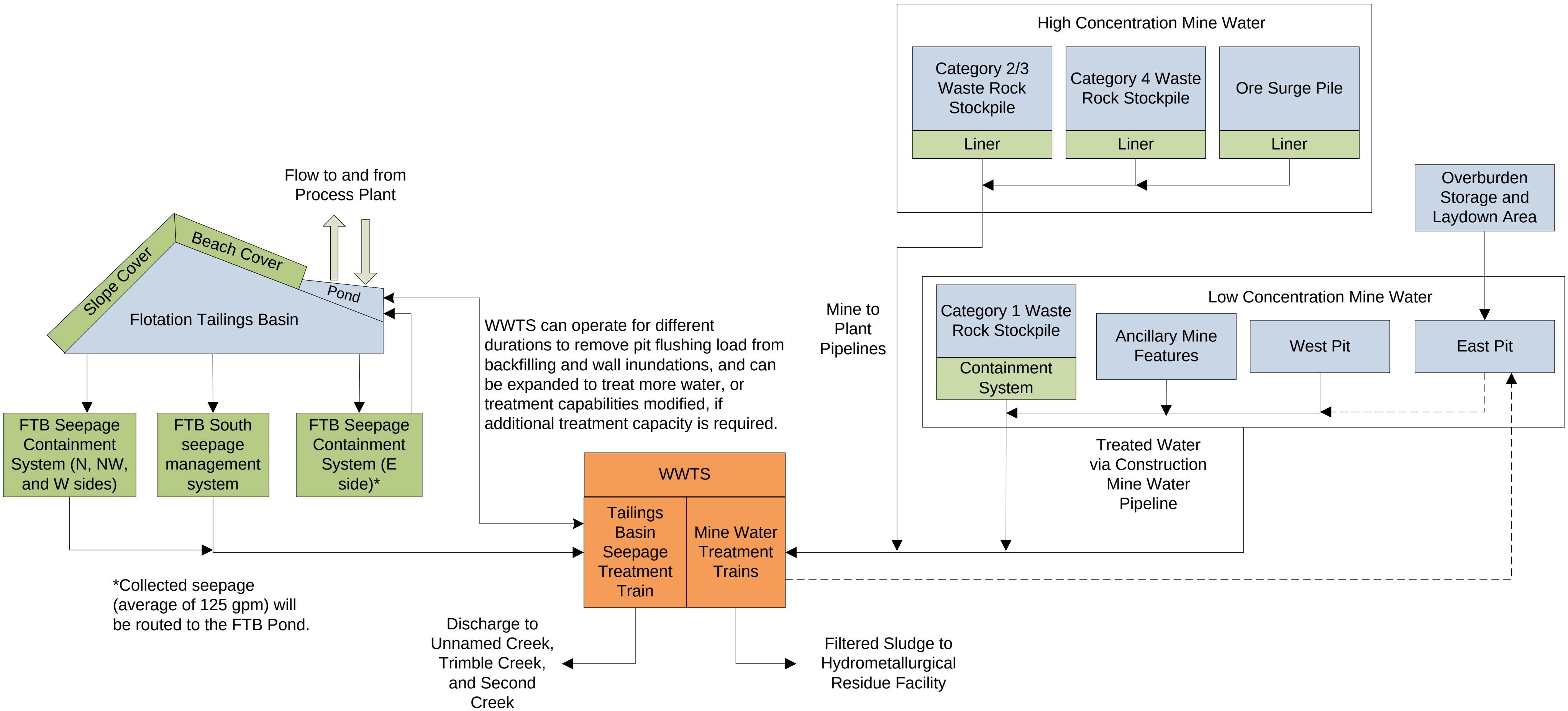
Large Figure 1
Adaptive Water Management Plan



Project Feature	
Fixed Engineering Control	Not expected to be modified during life of the project
Adaptive Engineering Control	Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – OPERATIONS (APPROXIMATELY MINE YEAR 1 THROUGH MINE YEAR 11)
NorthMet Project
Poly Met Mining, Inc.

Large Figure 2
AWMP



Dashed lines represent intermittent or occasional flow

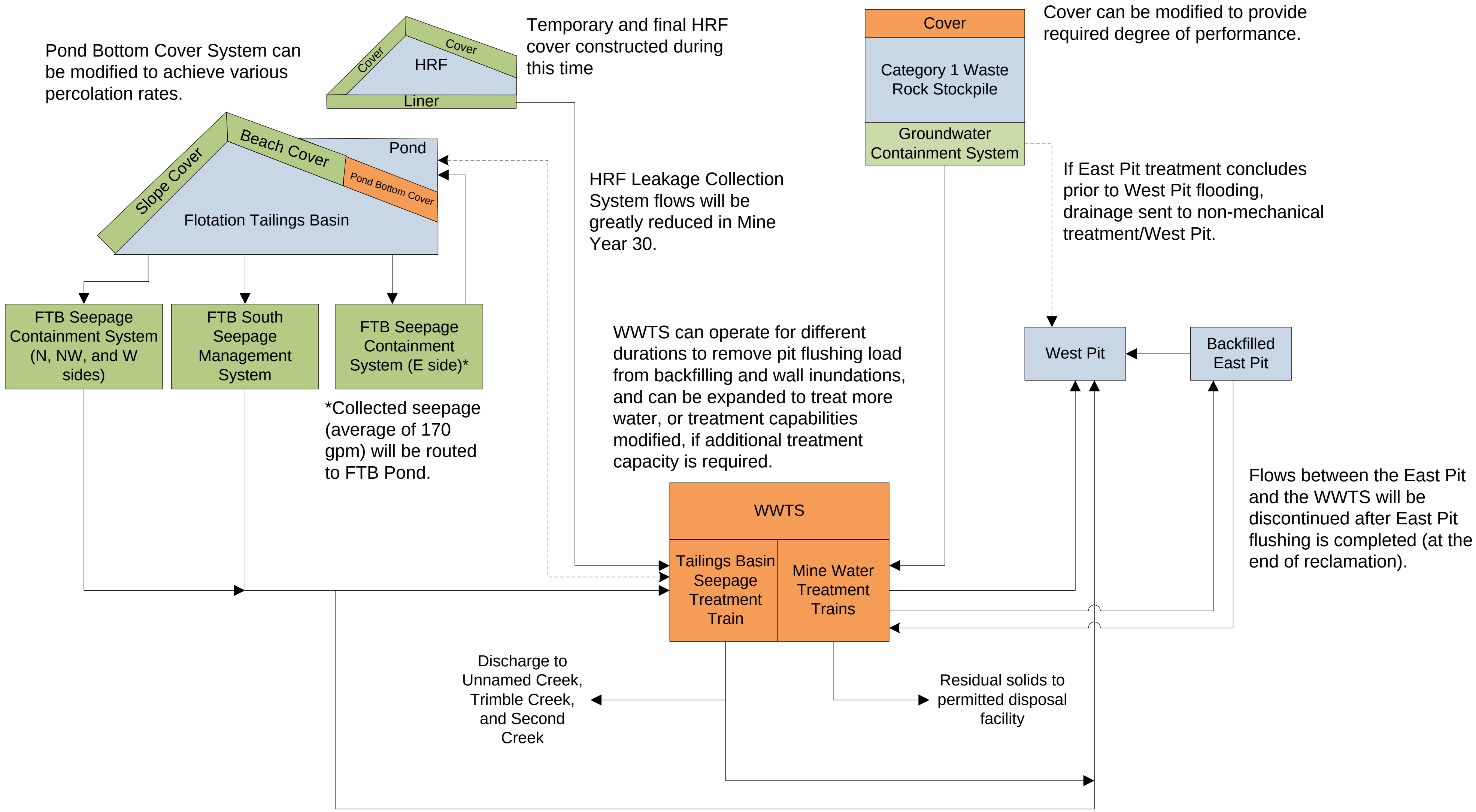
Project Feature

Fixed Engineering Control — Not expected to be modified during life of the project

Adaptive Engineering Control — Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – OPERATIONS (APPROXIMATELY MINE YEAR 11 THROUGH MINE YEAR 20)
NorthMet Project
Poly Met Mining, Inc.

Large Figure 3
AWMP



Dashed lines represent intermittent or occasional flow

Project Feature

Fixed Engineering Control — Not expected to be modified during life of the project

Adaptive Engineering Control — Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – RECLAMATION AND CLOSURE (APPROXIMATELY MINE YEAR 21 THROUGH MINE YEAR 34)
NorthMet Project
Poly Met Mining, Inc.

Large Figure 4
AWMP

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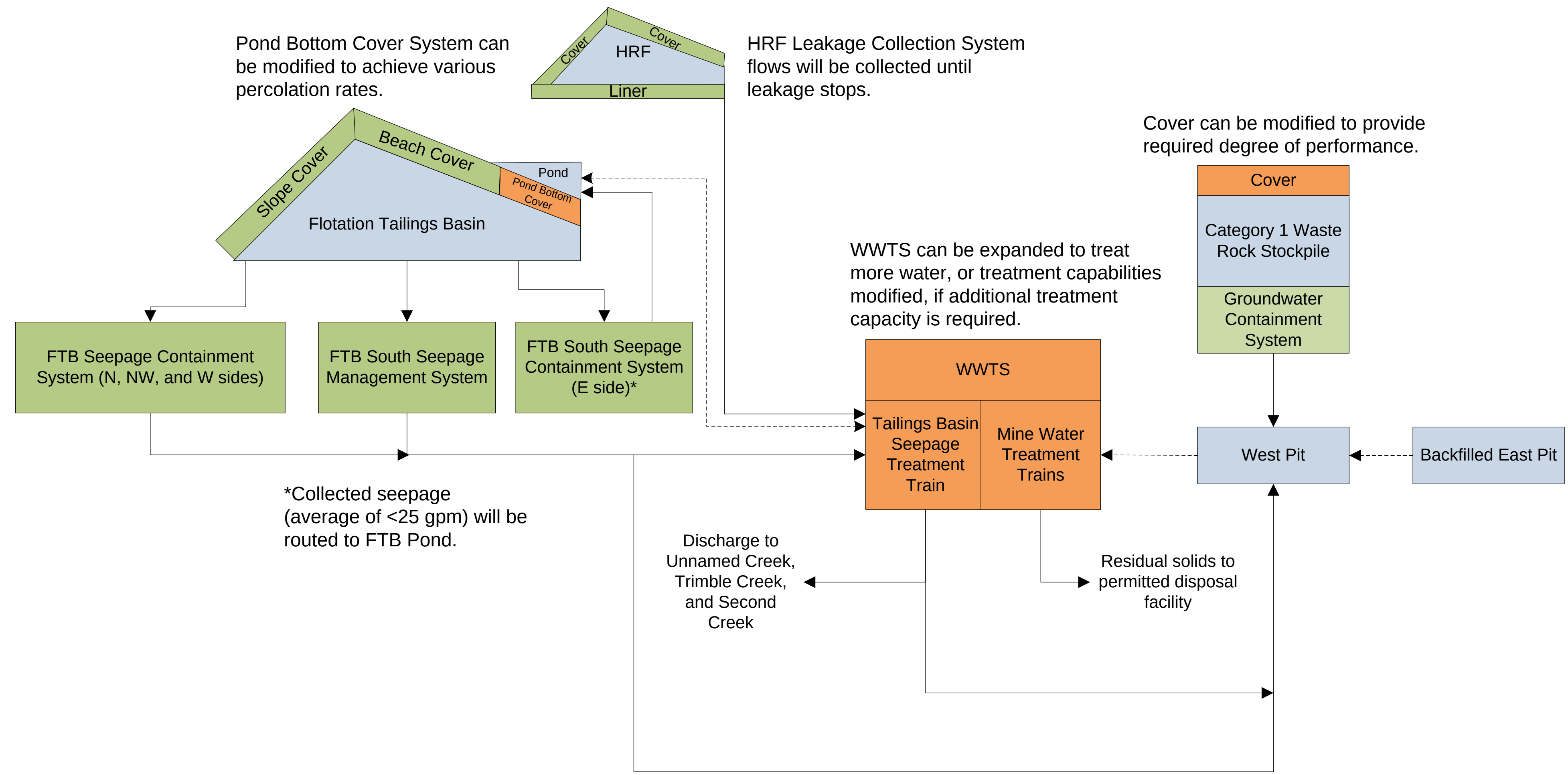
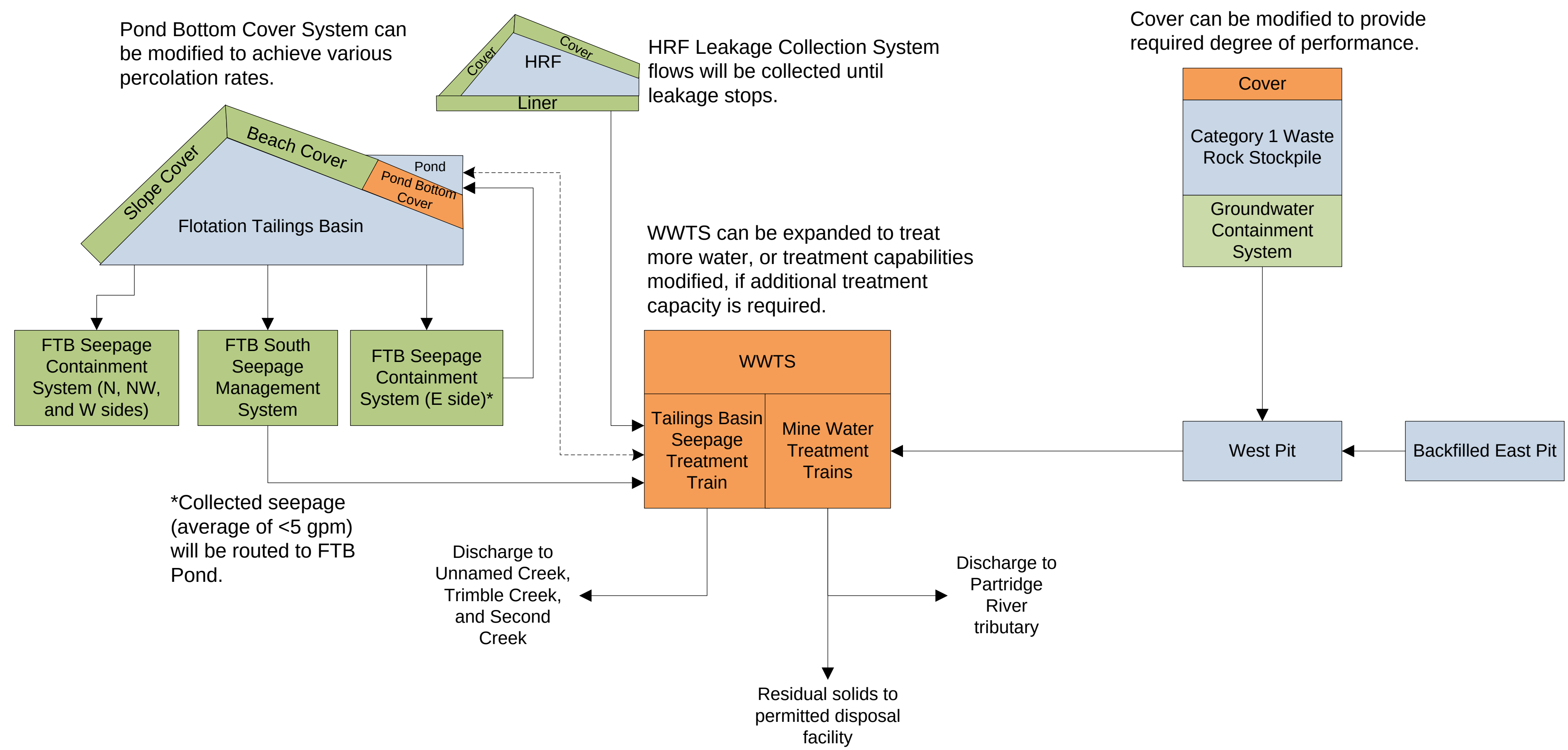


Dashed lines represent intermittent or occasional flow

Project Feature	
Fixed Engineering Control	Not expected to be modified during life of the project
Adaptive Engineering Control	Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – CLOSURE
(APPROXIMATELY MINE YEAR 35 THROUGH MINE YEAR 55)
NorthMet Project
Poly Met Mining, Inc.

Large Figure 5
AWMP



Dashed lines represent intermittent or occasional flow

Project Feature

Fixed Engineering Control — Not expected to be modified during life of the project

Adaptive Engineering Control — Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – POSTCLOSURE MAINTENANCE: LONG-TERM MECHANICAL TREATMENT
NorthMet Project
Poly Met Mining, Inc.

Large Figure 6
AWMP

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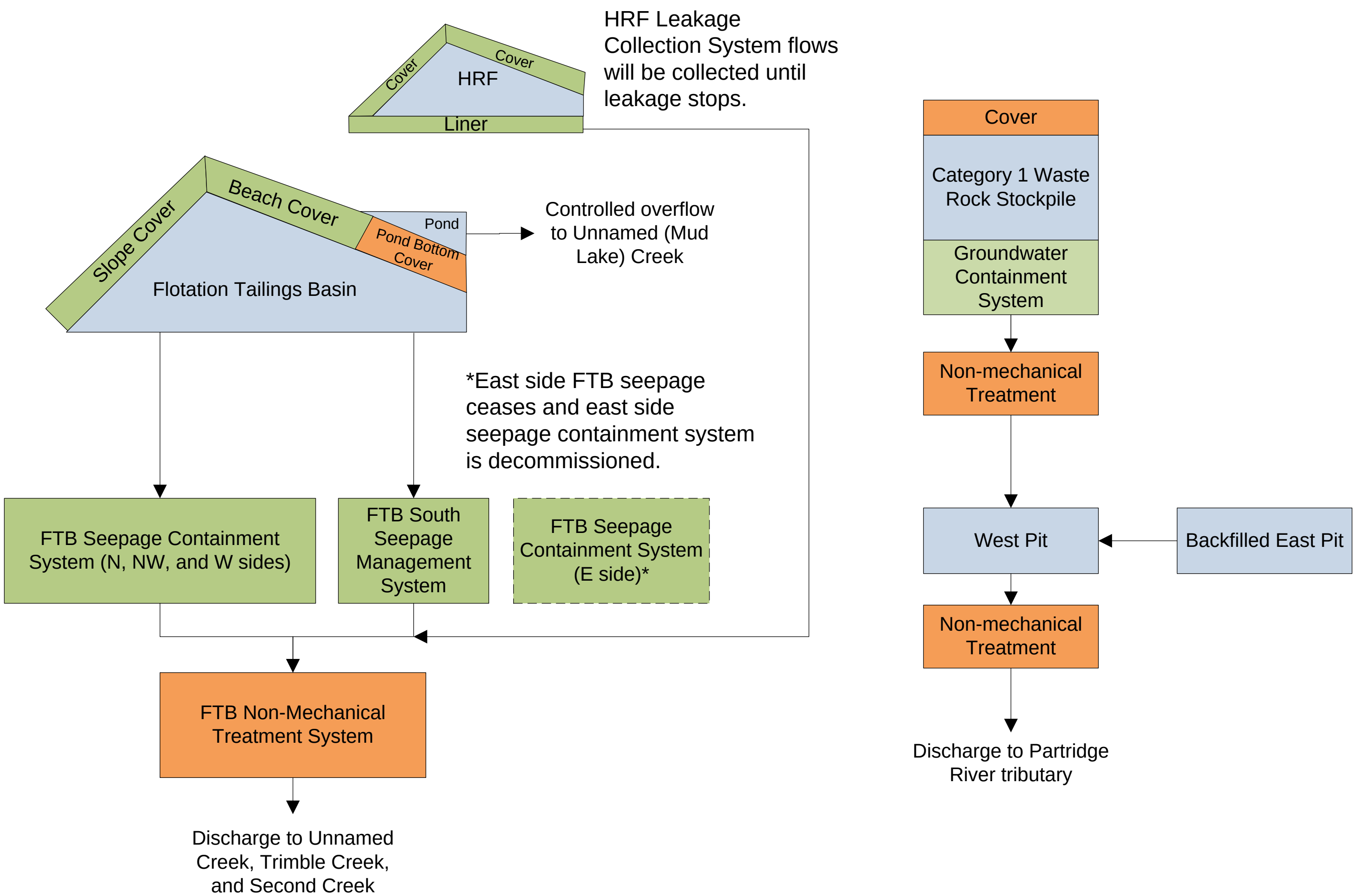


Dashed lines represent intermittent or occasional flow

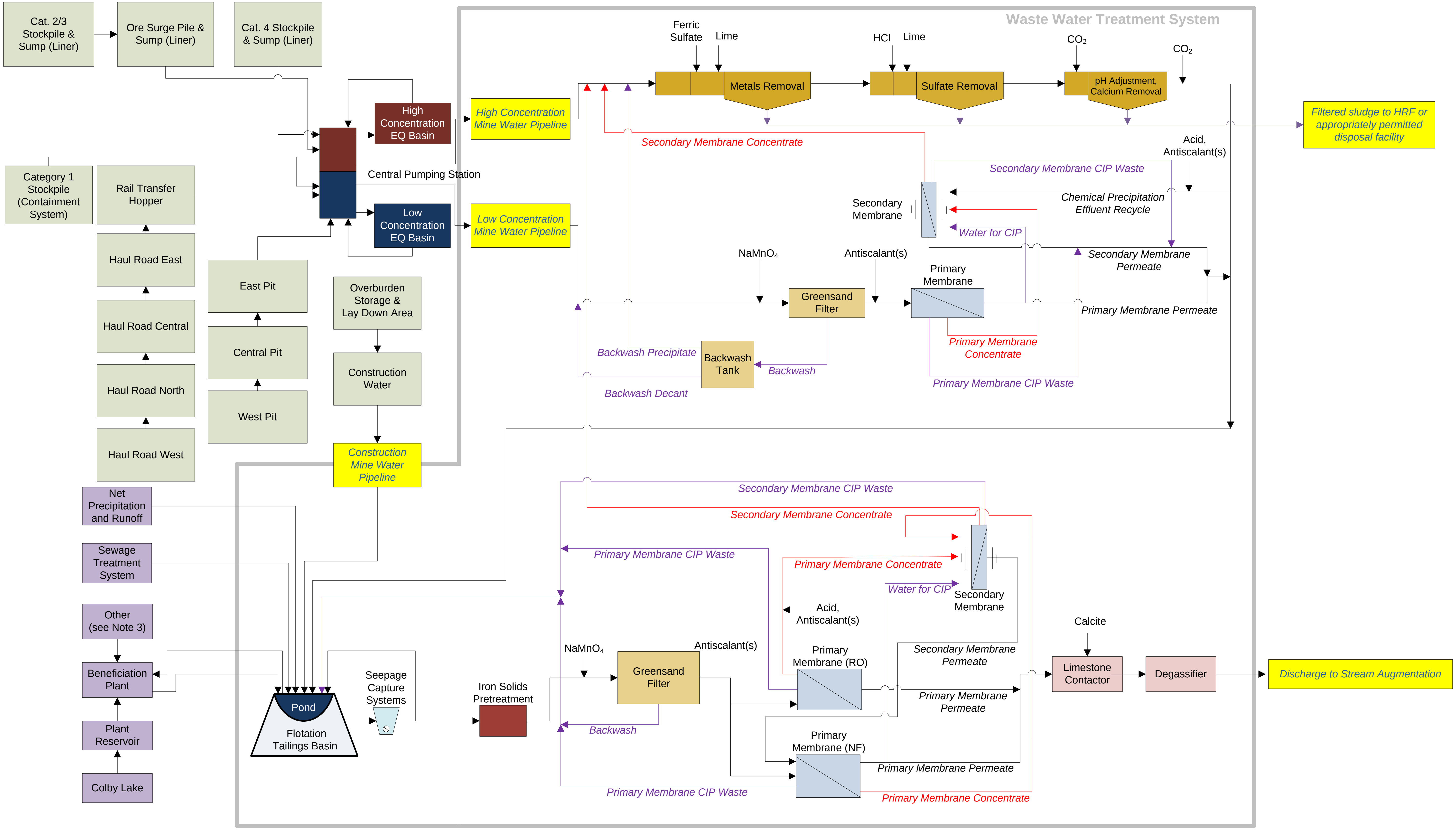
Project Feature

Fixed Engineering Control — Not expected to be modified during life of the project

Adaptive Engineering Control — Design, operation, and/or maintenance plan may change during life of project

WATER MANAGEMENT SCHEMATIC – POSTCLOSURE MAINTENANCE: LONG-TERM NON-MECHANICAL TREATMENT
NorthMet Project
Poly Met Mining, Inc.

Large Figure 7
AWMP



Notes:

(1) This figure shows the Waste Water Treatment System flow configuration at the beginning of operations. Mine Year 1 is expected to be the year of minimal discharge and minimal loading from the WWTS.

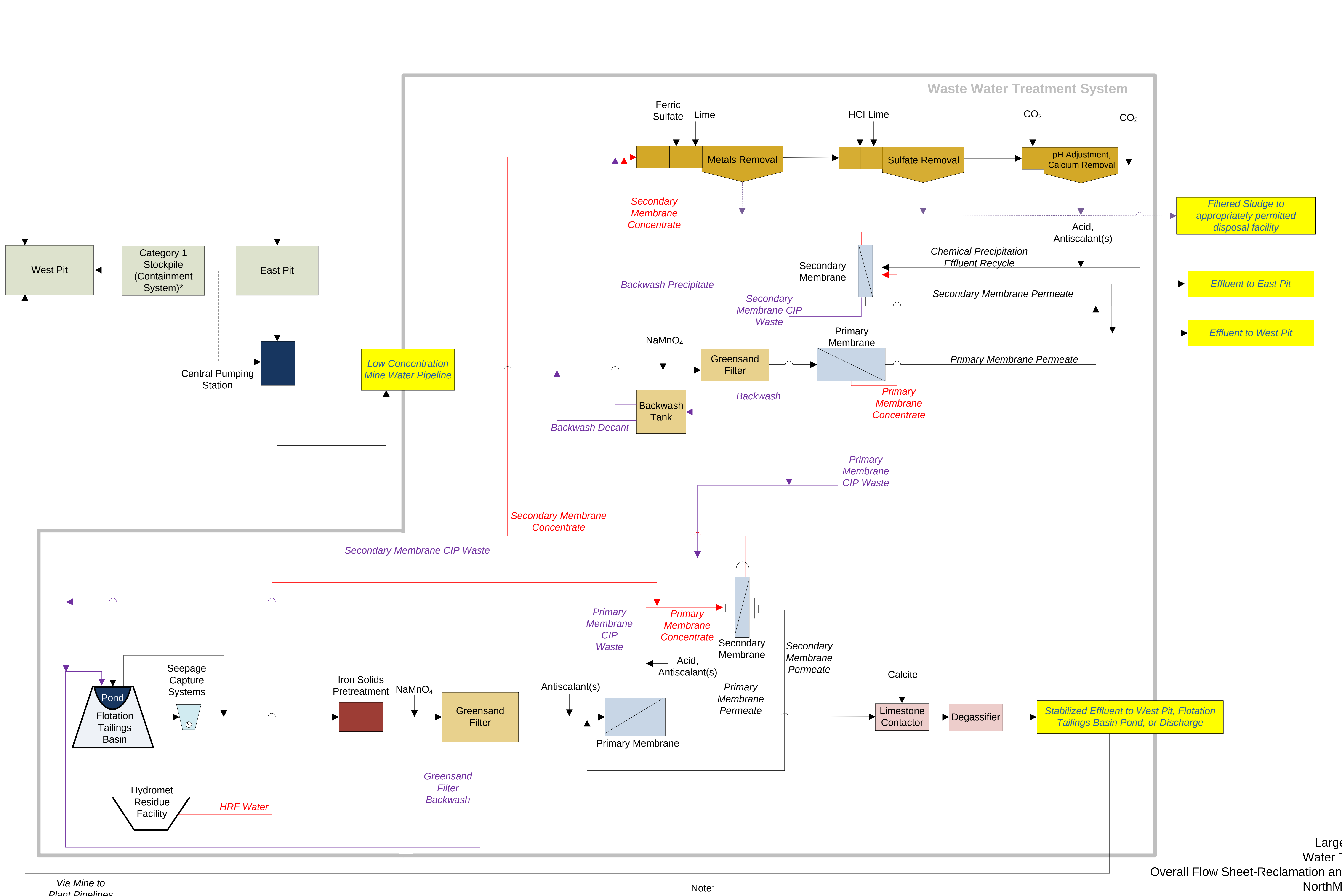
(2) This figure shows average flows from sources of intake water, operations contributing wastewater to the effluent, and treatment units within the WWTS. It does not include flows that do not contribute to the effluent, such as water entrained within tailings and water in sludge from chemical precipitation units.

(3) Other inflows to the Beneficiation Plant include water in the raw ore, reagents, and gland seals of slurry pumps.

Large Figure 8
Water Treatment
Overall Flow Sheet – Operations
NorthMet Project
Poly Met Mining, Inc.
Hoyt Lakes, MN

11-28-2017

Mpls\23 MN\69\2369C08 NorthMet WWTF\WorkFiles\Figures-Diagrams\Flow Sheets\Source Files\Large Figure-8-Operations AWMP v12.vsd

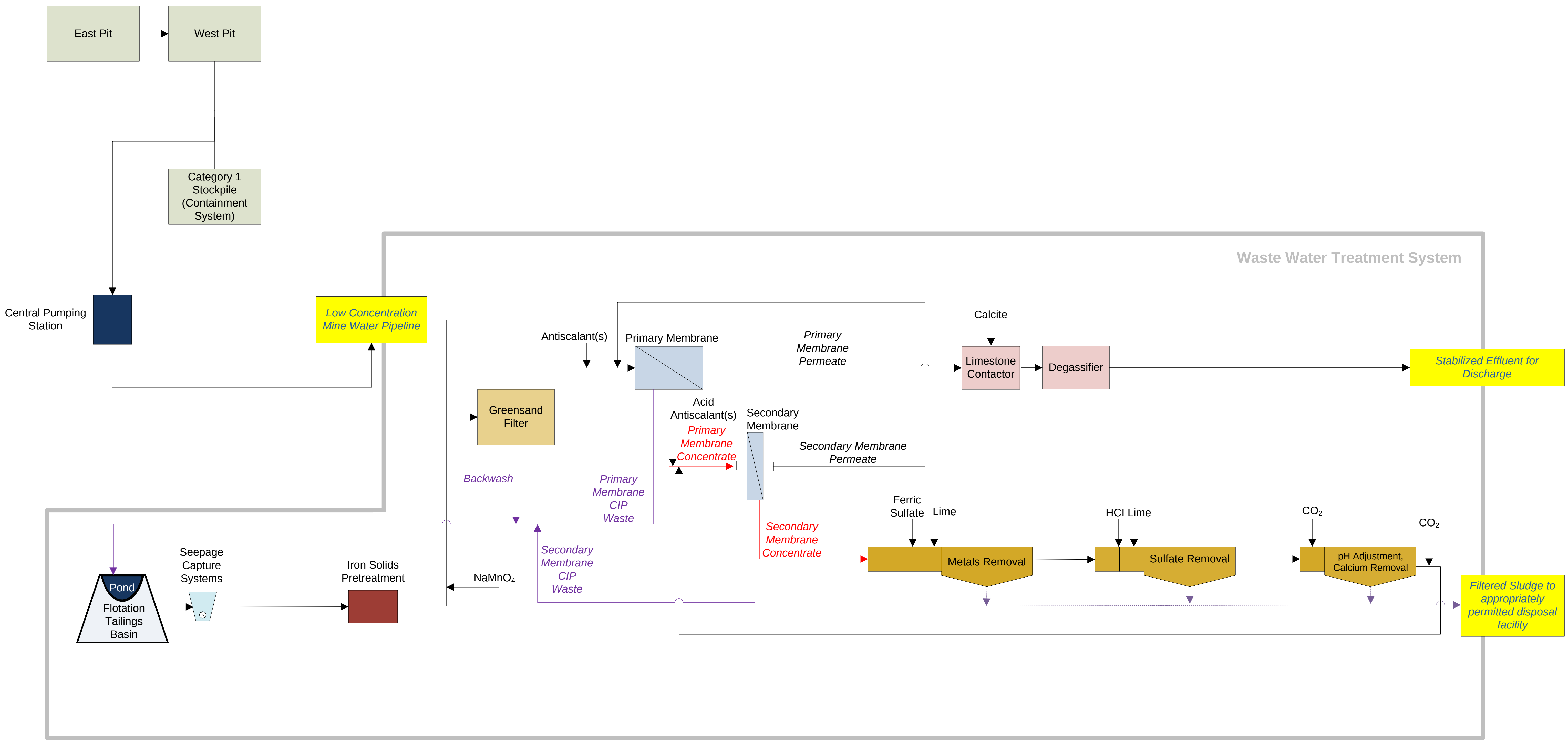


Large Figure 9
Water Treatment
Overall Flow Sheet-Reclamation and Closure
NorthMet Project
Poly Met Mining, Inc.
Hoyt Lakes, MN

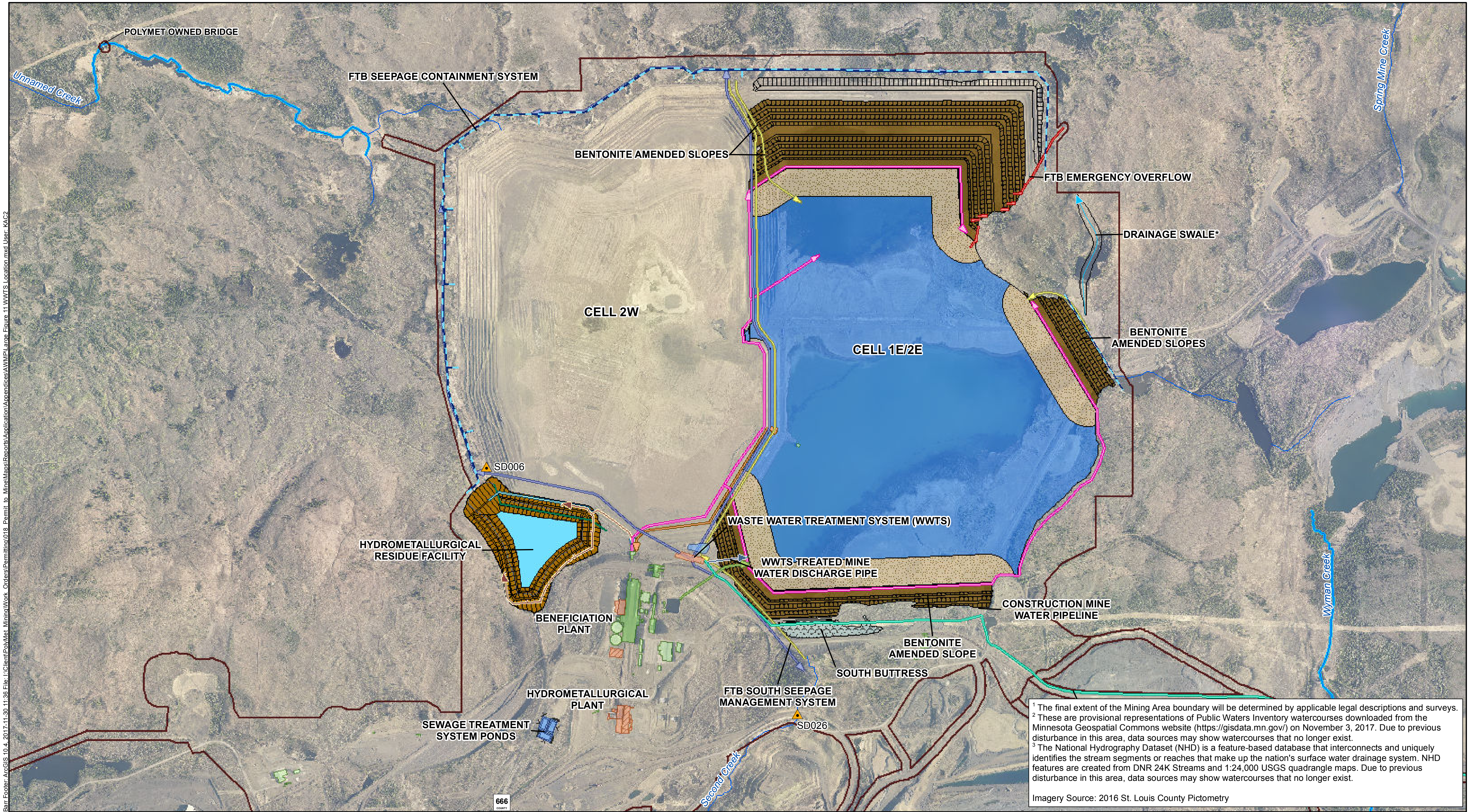
Note:
*Flows from the Category One Stockpile Containment System will be routed to the WWTS during reclamation and may be routed to the West Pit during closure

11-28-2017

Mpls\23 MN\69\2369C08 NorthMet WWTF\WorkFiles\Figures-Diagrams\Flow Sheets\Source Files\Large Figure-9-Reclamation and Closure AWMP v12.vsd



Large Figure 10
Water Treatment
Overall Flow Sheet- Postclosure
NorthMet Project
Poly Met Mining, Inc.
Hoyt Lakes, MN



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

Imagery Source: 2016 St. Louis County Pictometry

Mining Area[1]
Existing NPDES Discharge Stations
Mine Year 20 Footprints
FTB Seepage Containment System
FTB Water Return Pipe
FTB Tailings Discharge Pipe
Tailings Basin Seepage Collection Pipe
Plant Reservoir Overflow
Treated Water Pipe
Treated Mine Water Ppe
FTB Seepage Collection Drain (under HRF)
Return Water Pipe
Residue Discharge Pipe
Public Waters Inventory (PWI) Watercourses[2]
National Hydrography Dataset (NHD) Rivers & Streams[3]
Drainage Flow Direction
*The drainage swale drains stormwater away from the toe of the dam.

0 1,000 2,000 4,000
Feet

WWTS LOCATION
NorthMet Project
Poly Met Mining, Inc.

Large Figure 11
Adaptive Water Management Plan

Barr Footer: ArcGIS 10.4, 2017-11-30 11:36 File: I:\Client\PolyMet_Mining\Work_Orders\Permitting\018_Permit_to_Mine\Maps\Reports\Application\Appendices\AWMP\Large Figure 11 WWTS Location.mxd User: KAC2

Appendix A

WWTS Terminology Changes

Appendix A WWTS Terminology Changes

Some terminology associated with the WWTS has changed since the FEIS. Changes are associated with the relocation of the mine water treatment trains that were previously at the Mine Site WWTF to the Plant Site WWTS, and the relocation of the Mine Site equalization basins to south of Dunka Road. To aid review of documents prepared for the FEIS which are referenced in this plan, the following table explains WWTS terminology changes.

Former name	New name
Waste Water Treatment Plant (WWTP) and Waste Water Treatment Facility (WWTF)	Waste Water Treatment System (WWTS)[1]
Treated Water Pipeline	As a whole: • Mine to Plant Pipelines (MPP) Three individual pipes: • Construction Mine Water Pipeline • Low Concentration Mine Water Pipeline • High Concentration Mine Water Pipeline
Construction Mine Water Basin	Construction Mine Water Basin
West Equalization Basin	High Concentration Equalization Basin (HCEQ Basin)
East Equalization Basin 1	Low Concentration Equalization Basin 1 (LCEQ Basin 1)
East Equalization Basin 2	Low Concentration Equalization Basin 2 (LCEQ Basin 2)
WWTP effluent (discharged to receiving waters)	WWTS discharge
WWTF effluent (sent to the FTB via the CPS)	Treated mine water[2] (WWTS stream pumped to the FTB)
Treated mine water[3]	Treated mine water[2]
Central Pumping Station	Central Pumping Station
--	Equalization Basin Area[4]
Splitter Structure	This structure will be integrated into the Central Pumping Station.
CPS Pond	This pond no longer exists.

1. The two sets of treatment trains that were previously at two locations will now be housed under one roof at the Plant Site.
2. Formerly "treated mine water", which included WWTF effluent, OSLA runoff, and construction mine water. With reconfiguration, that mixture no longer exists, and the "treated mine water" would consist of effluent from the chemical precipitation and membrane filtration portion of the WWTS.
3. "Treated mine water" formerly included WWTF effluent, OSLA runoff, and construction mine water. With reconfiguration, that mixture no longer exists, but these flows still report to the FTB.
4. New term describing pond area south of Dunka Road