



Design of Back Forty Tailings Management Facility

BACK FORTY PROJECT, MICHIGAN

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Mine Waste Material Balance

The mine will generate the following waste streams over the Life-of-Mine

- Tailings 8.95M t (4.90M m³ / 6.41M yd³)
- Waste Rock 48.81M t (24.96M m³/ 32.65M yd³)

As per the mine permit commitment, backfilling the open pit at the end of operation will require 19.05M m³ of waste rock

The TMF is therefore designed to deposit the following waste streams that will remain on surface:

- Remaining waste rock 5.91M m³
- Total tailings 4.90M m³

The TMF is a zoned co-disposal facility



TMF General Arrangement Plan



• Footprint area of TMF is 50.2 ha (124 acres)



TMF General Arrangement Plan Cont..





TMF Cross-Section



The TMF has:

- A gently sloped base (~1%)
- A free draining waste rock perimeter wall (4.5M m³)
- A double liner system that extends under the perimeter wall
- A waste rock crown at top of the facility (1.4M m³)
- An overburden separator from the NWRF (10 m wide)

The TMF is Designed to High Standard

- Tailings, dewatered to 65-76% solids content, is discharged in the facility
- Perimeter structure contain three waste rock dykes (each dyke is about 10 m high, 36 m crest width, 3H:1V side slopes)
- The perimeter dyke is competent frictional waste rock material
- A granular drainage is provided under the entire footprint of the facility
- Supernatant water will be pumped out actively
- Most of the tailings will be unsaturated except just below the pond area, phreatic surface will be only under the pond
- The facility will have an emergency spillway
- The wide waste rock perimeter structure and lower phreatic surface significantly increase the factor of safety for stability



TMF Base Grade



Cut and fill



- The base of the facility is graded to the northwest to convey seepage and any leakage by gravity into an external sump
 - The base grade of the facility will be prepared by cut and fill
 - The subsurface soil is silty sand, sand to sand and gravel – strong foundation soil

Base Grade



TMF Base Liner System



- The double liner system of the facility includes the following, from top to bottom:
 - 0.3 m (1.0 ft) thick random overburden soil protection layer
 - 330 g/m² (10 oz/yd²) Non-woven filter geotextile
 - 0.3 m (1.0 ft) thick 9.5 mm (0.37 in) aggregate (MDOT-29A) leachate collection layer
 - 542 g/m² (16 oz/yd²) Non-woven cushion geotextile
 - 1.5 mm (60-mil) HDPE primary liner (textured below perimeter wall and below tailings)
 - 4.5 kg/m² (0.92 lb/ft²) Geosynthetic Clay Liner (GCL)
 - Geocomposite leak detection and collection layer
 - 1.0 mm (40-mil) HDPE secondary liner (textured below perimeter wall and below tailings)
 - 150 mm (5.9 in) compacted < 9.5 mm (0.37 in) overburden soil

TMF Top of Liner Grade



Top of protection layer

- Top of the liner is approximately 0.6 m above the base grade, containing 0.3 m drainage layer and 0.3 m overburden protection layer
- The drainage layer will limit the head of leachate over the liner, reducing risk to groundwater contamination

Leachate and Leak Collection Systems



- The Leachate Collection System includes a blanket of coarse aggregate, two interior perforated pipelines, and two perimeter pipelines
- The Leak Collection System includes a geocomposite, two interior perforated pipelines, and one perimeter pipeline



TMF Perimeter Liner Anchor Berm



- A 1 m (3.3 ft) high perimeter berm is proposed for anchoring the base liner system of the facility and also for creating a perimeter ditch
- The perimeter ditch is designed to convey the 100-year, 24-hour storm event
- The ditch will discharge into the external sump
- A thermal cap is provided to protect the perimeter seepage and leak collection pipelines against freezing
- Pipe boots will be provided where the perimeter seepage and leak collection pipes penetrate the liner system to convey flow to the external sump
- The pipelines that penetrate the liner system will be insulated



Leachate and Leak Collection System



• Thermal cover is provided over the seepage and leak collection pipelines discharging into the external sump



• The external sump will have a double liner system

TMF Perimeter Dyke



- Perimeter wall is free draining constructed of waste rock to a maximum elevation of 262 m (859.6 ft), maximum height of about 35 m (115 ft)
- The wall will have about 36 m (118 ft) wide crest and 3H:1V side slopes
- Upstream face of the wall will have crushed rock transition and overburden filter
- A 542 g/m² (16 oz/yd²) non-woven geotextile will be used as a filter between the raises
- Tailings foundation will be in-situ tested (e.g. CPTu) prior to dyke raise
- VWPs will be installed to monitor tailings foundation performance
- After the 10 m high start-up dyke, the perimeter wall will be raised in 2 m lifts



TMF Emergency Spillway



- Emergency spillway is provided to convey storm events up to PMP to the open pit via LLCS 1
- The emergency spillway will eliminate the risk of overtopping
- Emergency spillway includes riprap lined channels and pipe culverts



TMF Distribution and Decant System



- Tailings will be discharged from perimeter spigot points, located about 50 m (164 ft) apart
- Floating pump barge will be used to pump the water accumulated at the top of the facility



TMF Water Management

- Supernatant and consolidation tailings water will be drained through the perimeter wall, bottom leachate collection system and floating pump barge
- Tailings thickening to 65-76% solids content in the mill will eliminate about 3.04M m³ of water from coming to the TMF



TMF Stage Developmental Plan



END OF START-UP CONSTRUCTION

STAGE 1 CONFIGURATION AT 10 MONTHS



TMF Stage Developmental Plan Cont...



STAGE 2 CONFIGURATION AT 16 MONTHS

STAGE 3 CONFIGURATION AT 24 MONTHS



TMF Stage Developmental Plan Cont...



STAGE 4 CONFIGURATION AT 50 MONTHS

STAGE 5 CONFIGURATION AT 78 MONTHS



TMF Stage Developmental Plan Cont...



STAGE 6 CONFIGURATION AT ULTIMATE

CLOSURE CONFIGURATION



TMF Closure

- Waste rock will be removed from the NWRF and placed on top of the TMF to form a stable post-closure landform that will easily shed-off runoff water
- The remaining material on the NWRF and the SWRF will be used for backfilling the open pit





TMF Closure Cont...

- Closure cover on benches and crown of the TMF will include a multilayer composite liner system containing the following, from top to bottom:
 - 0.6 m transition layer
 - 0.3 m liner bedding
 - 3.5 kg/m² (0.92 lb/ft²) Geosynthetic Clay Liner (GCL)
 - 1.5 mm (60-mil) LLDPE liner
 - 0.3 m (1.0 ft) thick 9.5 mm (0.37 in) aggregate (MDOT-29A) drainage layer
 - 330 g/m² (10 oz/yd²) non-woven filter geotextile
 - 450 mm (17.7 in) growth layer
 - 150 mm (5.9 in) topsoil
- Closure cover on side slopes (3H:1V) will include all the multilayers above except for GCL



TMF Closure Cont...

• Chutes and drainage ditches (designed for PMP) will be provided to manage the post closure drainage





Design Analyses Completed

The following analyses have been completed to support the design of the TMF:

- Material balance
- Monthly water balance for various climatic conditions
- Staged tailings deposition plan (Goldtail and AutoCAD Civil 3D)
- Thermal analysis (TEMP/W)
- Filter compatibility analysis (NRCS 2017)
- Liquefaction analyses
 - Static (Sadrekarimi 2014 and 2016)
 - Seismic (SHAKE2000 and Boulanger and Idriss 2014)
- Consolidation analysis (CONDES0)
- Seepage analysis (SEEP/W)

Design Analyses Completed Cont...

• Stability (static and pseudo-static) analysis (SLOPE/W): e.g.:



Design Analyses Completed Cont...

• Liner tests

- GCL chemical compatibility (Swell Index, ASTM D5890, and Fluid Loss, ASTM D5891)
- Geomembrane hydrostatic puncture test (ASTM D5514)
- Closure Analyses
 - Veneer stability analyses (static unsaturated, static saturated, pseudo-static unsaturated, and static unsaturated & low ground pressure)
 - Cover infiltration (HELP model)
 - Post-closure drawdown seepage (SEEP/W transient)
 - Hydraulic analysis of chutes and spillway PMP



Detailed Design

The following will be completed per the conditions in the Part 632 Permit:

- Detailed design
- IFC drawings
- Technical specifications
- CQC/CQA plan
- Operations, Maintenance and Surveillance (OMS) Manual
- Instrumentation and monitoring plan



GOLDER



Traditional Upstream Tailings Management Facilities vs Zoned Tailings and Waste Rock Co-Disposal Facilities

CONCEPTS AND EXAMPLES

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Zoned Co-disposal vs Traditional Upstream Raised TMF



Traditional Upstream Raised TMFs

The following are characteristics of typical upstream TMFs:

- Starts with a free draining low starter dyke
- Tailings discharged at around 30% solids content by weight
- Tailings segregate during deposition
- Coarse tailings and high specific gravity tailings settle near discharge location
- Fine tailings and low specific gravity slimes settle away from discharge location
- Coarse tailings excavated from tailings beach are used to construct the subsequent dam raises



Zoned Co-disposal vs Traditional Upstream Raised TMF Cont..

The following photos show how a typical upstream TMF is constructed:



Coarse starter dyke



Tailings excavation during upstream dyke raise



After upstream dyke raise is complete



Zoned Co-disposal vs Traditional Upstream Raised TMF Cont...



Back Forty Zoned Co-disposal TMF

The Back Forty TMF design mitigated the known risks of traditional upstream TMFs:

- Perimeter dyke Constructed of waste rock 36 m wide crest (strong, free draining, non-liquefiable and erosion resistant)
- Transition and filter zones of dyke Allow tailings consolidation water to easily drain out of the facility while eliminating the risk of tailings migration into the perimeter wall
- Underdrain system A granular drainage layer beneath the entire base of the tailings facility which is graded for gravity drainage
- Tailings solids content Tailings will be thickened to 65-76% solids content in the mill reducing 3M m³ of water from coming to the TMF



Zoned Co-disposal vs Traditional Upstream Raised TMF Cont...

- Phreatic surface Free draining underdrain and perimeter wall as well as pumping of bleed water from decant area will result a very low phreatic surface
- Dyke raise foundation The dyke will be raised over high density and high strength consolidated thickened tailings
- Emergency spillway It will safely convey extreme storm events up to the Probable Maximum Precipitation, thus preventing overtopping
- Slope stability analysis Placement of very wide competent frictional waste rock material as perimeter structure and placement of a drainage layer at the bottom of the facility that lowers the phreatic surface within the facility significantly increase the factor of safety for stability
- Liquefaction analysis Conservative seismic and static liquefaction analyses carried out assuming elevated water table confirmed the stability of the facility
- Performance review The facility will be monitored closely during construction and operations to ensure that the design intent is being satisfied



Operating TMFs with Similar Features to Back Forty TMF

1. Canadian Malartic Mine, Quebec



- Open pit gold mine
- The perimeter waste rock fill berms are raised by the upstream method
- Tailings are deposited at 60% to 68% solids content









Operating TMFs with Similar Features to Back Forty TMF Cont...

2. Musselwhite Mine, Ontario



Underground gold mine



Sand and gravel over soft tailings

Thickened tailings at 63% to 68% solids content) deposited over previously slurry tailings facility



0+000

RIGINAL GROUND

0+100

0+120



Sand and gravel over thickened tailings





Operating TMFs with Similar Features to Back Forty TMF Cont...

3. Neves Corvo Mine, Portugal



- Underground copper and zinc mine
- Thickened tailings disposed over subaqueous slurry tailings
- Interior of the facility partitioned using waste rock berms









