



Dams with Frozen Components: Fit For Purpose Tailings Management Solutions

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SMA Environmental Forum 2018
Saskatoon, Saskatchewan
October 17–18, 2018



Outline

- Introduction
- Foundation & Design Considerations
- Frozen Foundation vs. Frozen Core Dam
- Instrumentation
- Tailings Deposition
- Closure

Project Introduction



Image Source: <https://jsis.washington.edu/archive/canada/file/archive/taskforce09/maps.shtml>

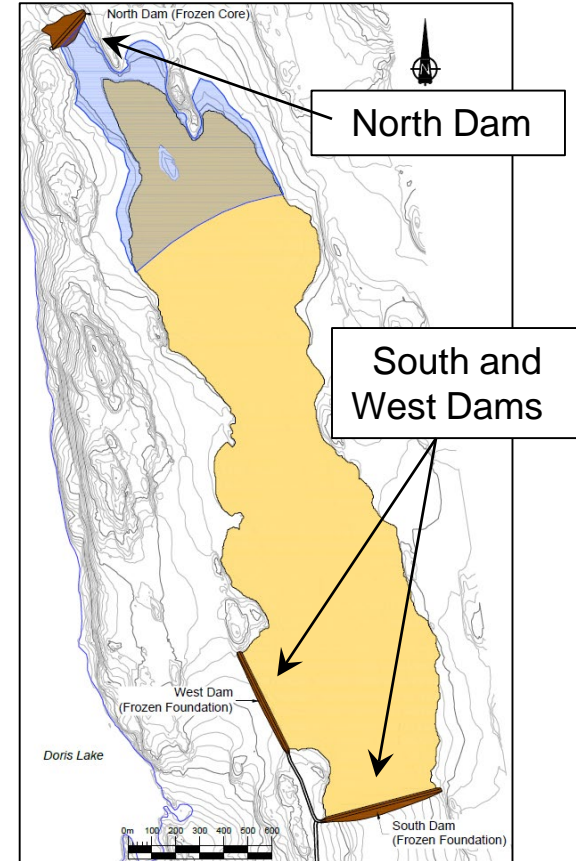
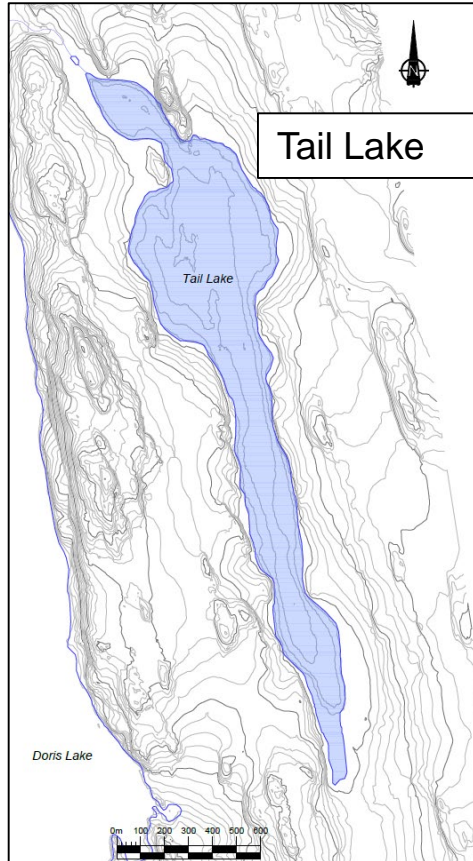
Geographic location of mine



Mine Site

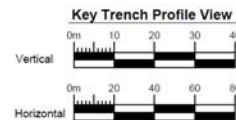
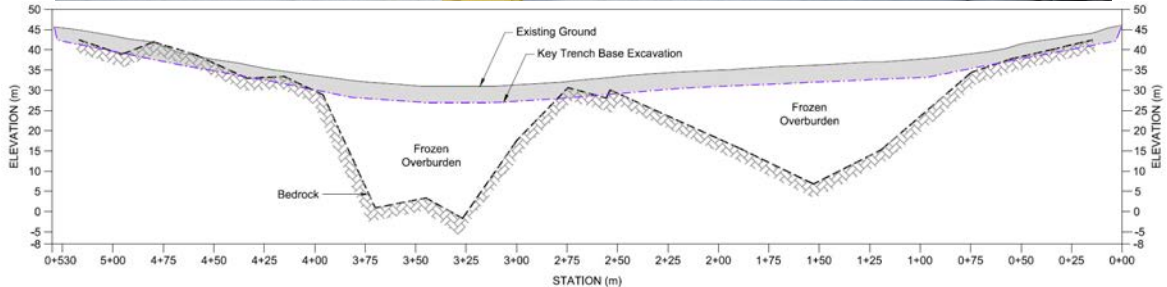
Tailings Impoundment Area (TIA)

- Former lake listed as Schedule II
- Sub-aerial deposition of tailings slurry
- Environmental containment
- High degree of safety



Foundation Conditions

- Continuous cold (-8°C) permafrost
- Bedrock – basalt outcrops
- Thick deposits (>15m) of ice-rich sand and marine silts/clays
- Saline porewater



Example section beneath the TIA

Design Considerations

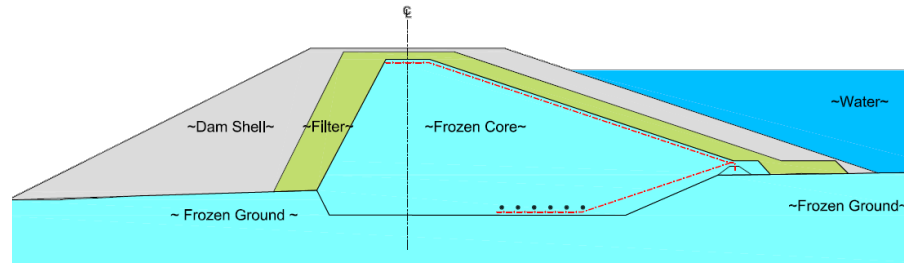


Ice-rich material present
beneath the TIA

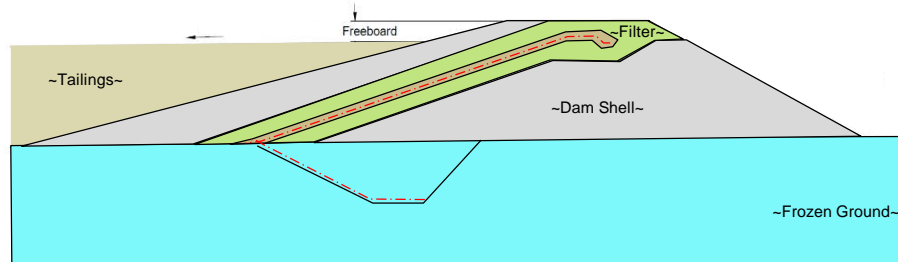
- Challenging foundation
 - Thick permafrost soils
 - Porewater salinity / depressed freezing point
 - Creep susceptible
 - Low strength soils when thawed
- Lack of borrow materials
 - Material with low permeability not available, or not suitable
- Climate and construction timing
- Project location

Definitions

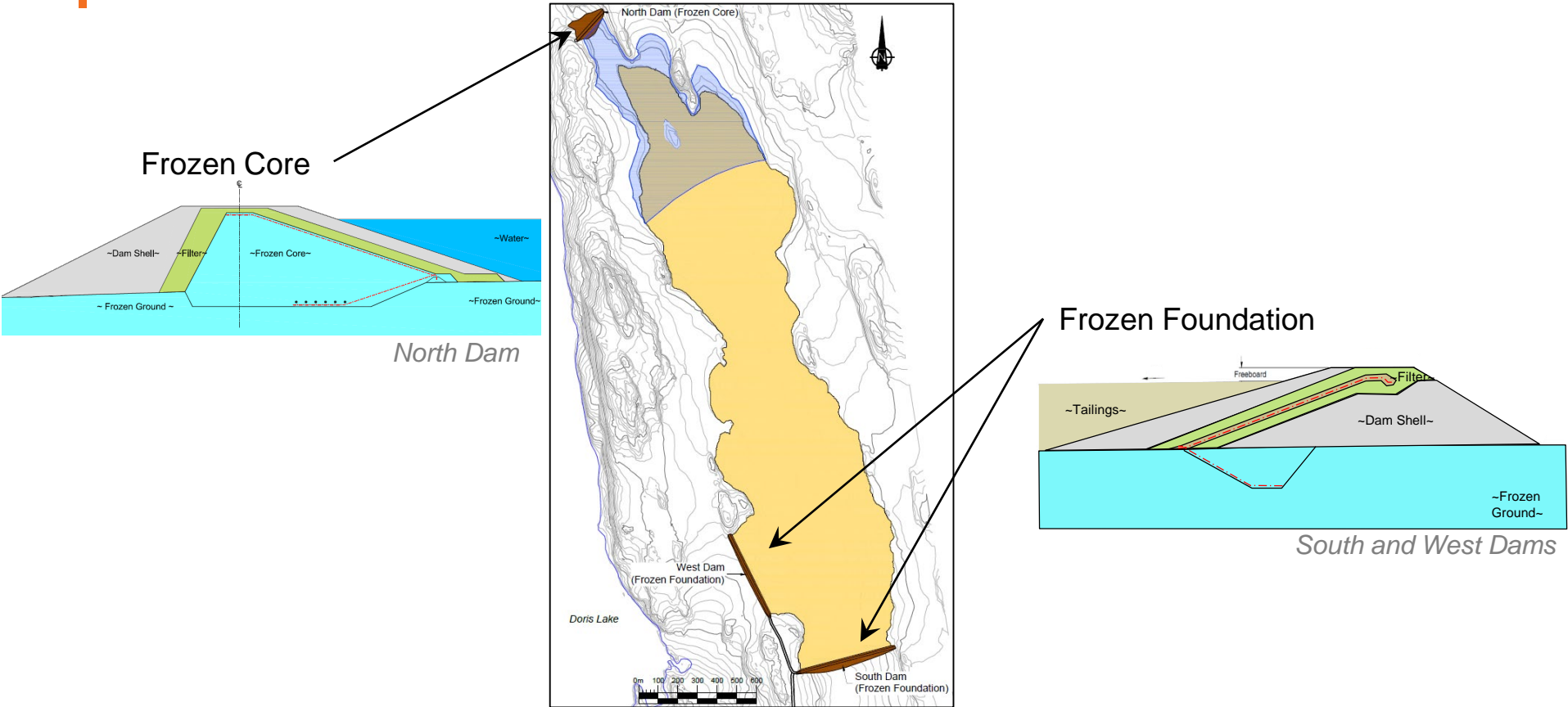
- **Frozen Core Dam:** The water retaining structure is an impermeable frozen mass consisting of the dam core and foundation



- **Frozen Foundation Dam:** A more classical (thawed) above ground structure that is bonded to a frozen (impermeable) foundation

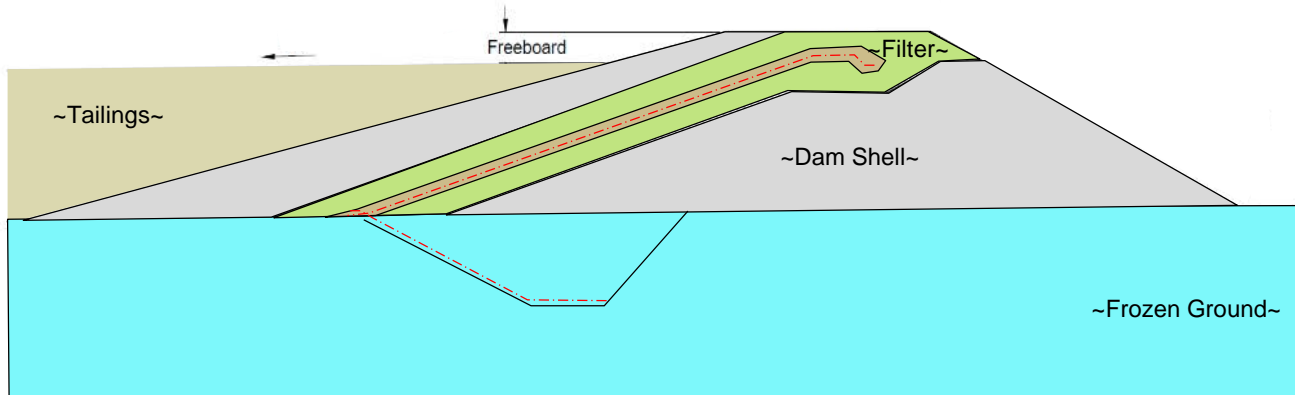


Tailings Impoundment Area (TIA)



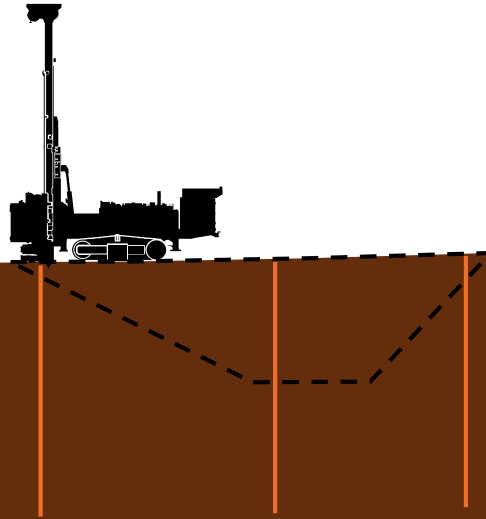
Frozen Foundation Dam

- Key that tailings (solids) deposited upstream
- Upstream geosynthetic clay liner (GCL) system keyed into the frozen foundation as a water retaining element for the unlikely case of foundation thawing / seepage



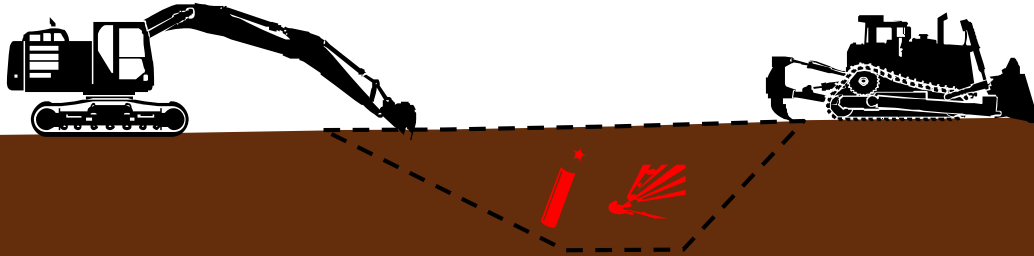
Frozen Foundation Dam

- Percolation testing
- Foundation confirmation
- Key trench depth optimization
- Depth is a function of thermal modelling



Frozen Foundation Dam

- Ripping in frozen overburden
- Drill/blast in bedrock
- 3 to 4 m depth





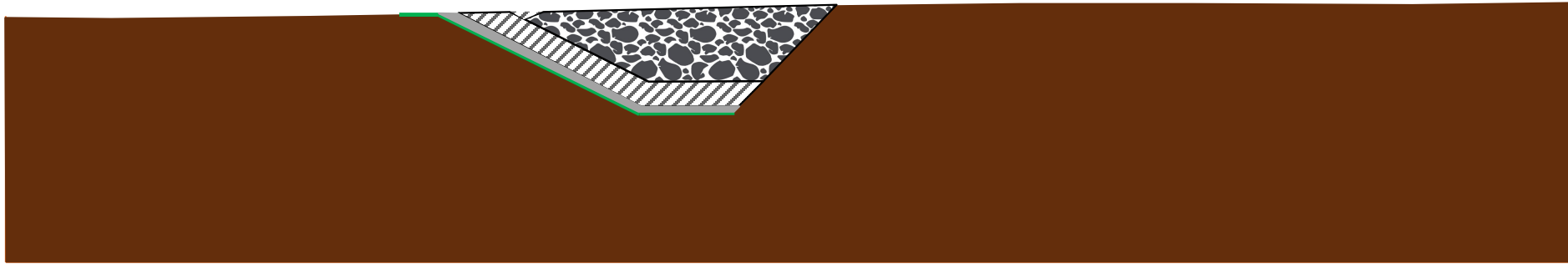
Foreground: Drilling of blast holes
Background: Key trench excavation



Near complete section of key trench

Frozen Foundation Dam

- Liner keyed into frozen foundation
- Winter construction



Run of Quarry Material



Transition Material



Bedding Material



GCL Liner



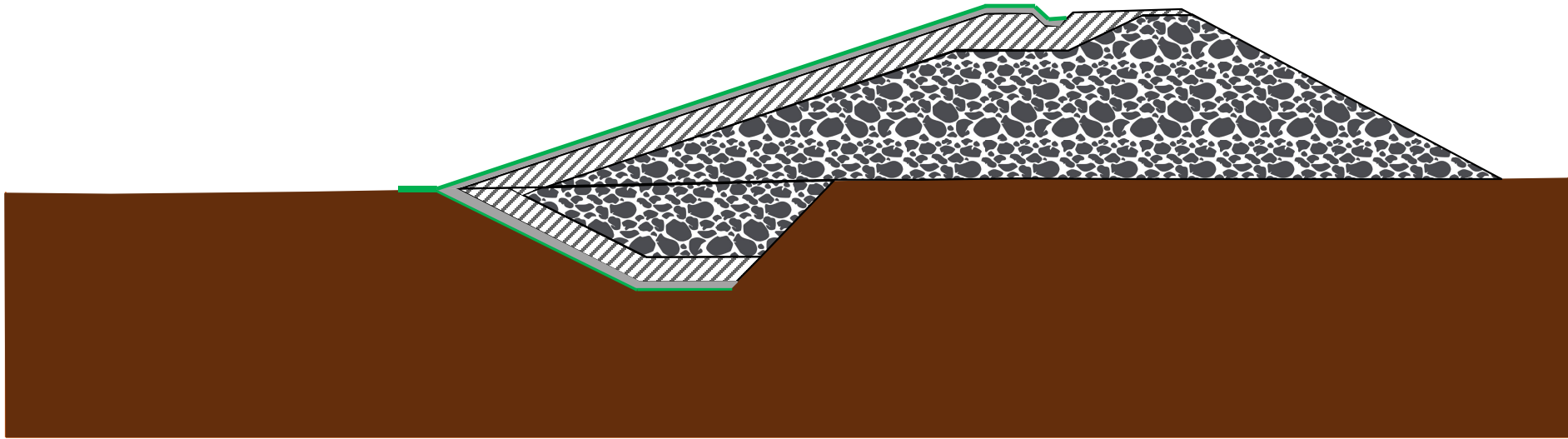
Deployment of liner on upstream slope of key trench



Backfilling of key trench above liner

Frozen Foundation Dam

- Thermal protection
- Minimum cover section



Run of Quarry Material



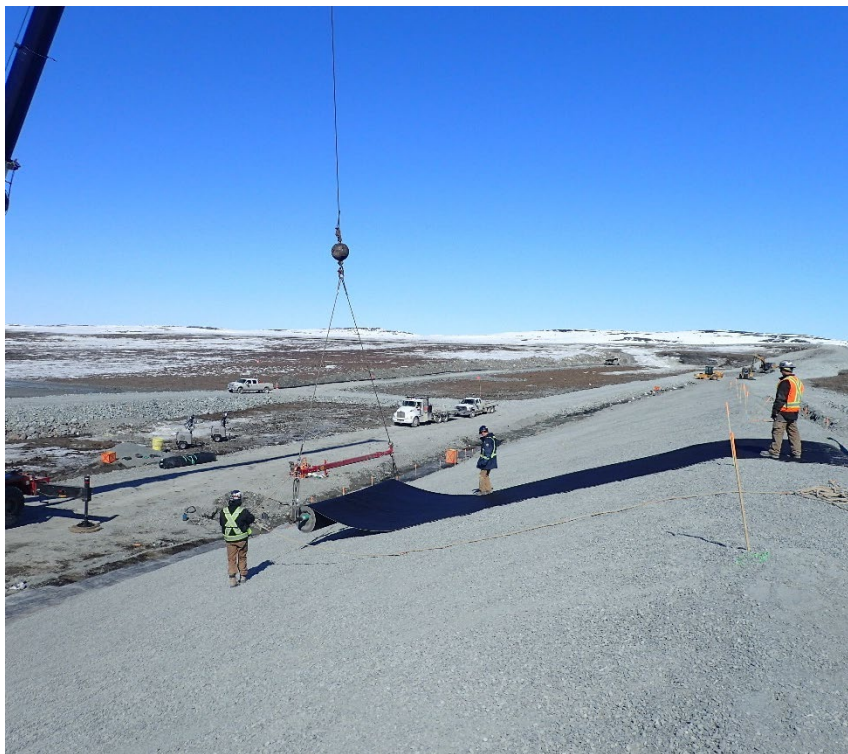
Transition Material



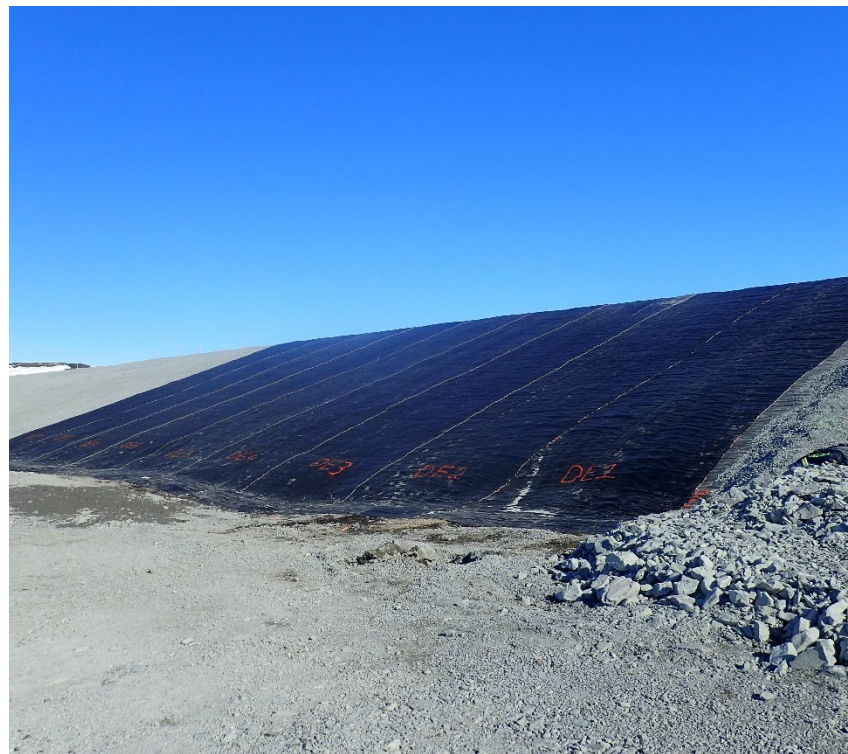
Bedding Material



GCL Liner

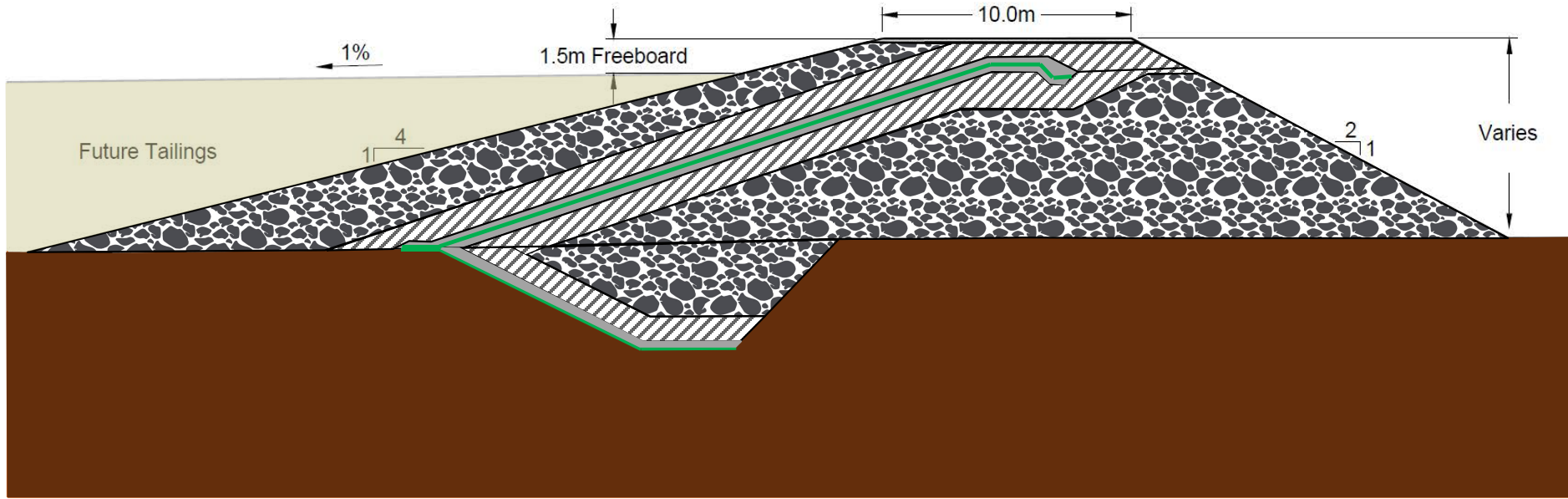


Deployment of liner on upstream slope of above ground fill



Deployed liner on upstream slope of above ground fill

Frozen Foundation Dam



Run of Quarry Material



Transition Material



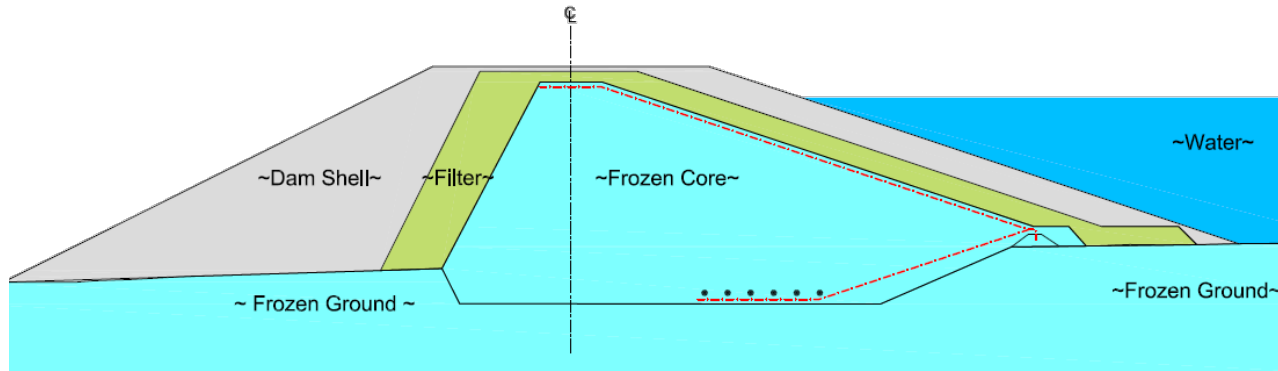
Bedding Material



GCL Liner

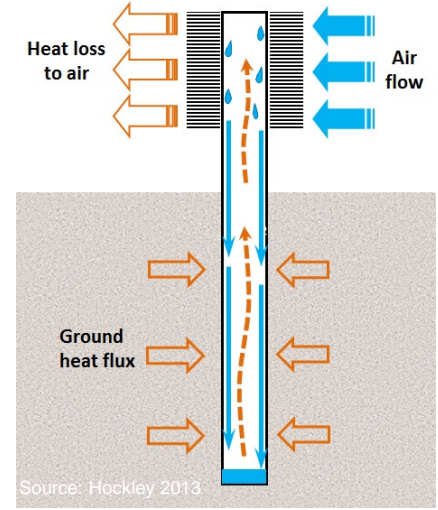
Frozen Core Dam


- Water retaining structure
- Thermosyphon evaporator pipes provide passive cooling during the winter



Frozen Core Dam

- Passive refrigeration system
- Pressurized sealed pipes charged with a two-phase working gas (CO_2)
- Radiators help heat exchange



 Frozen Core Material ● Evaporator Pipe



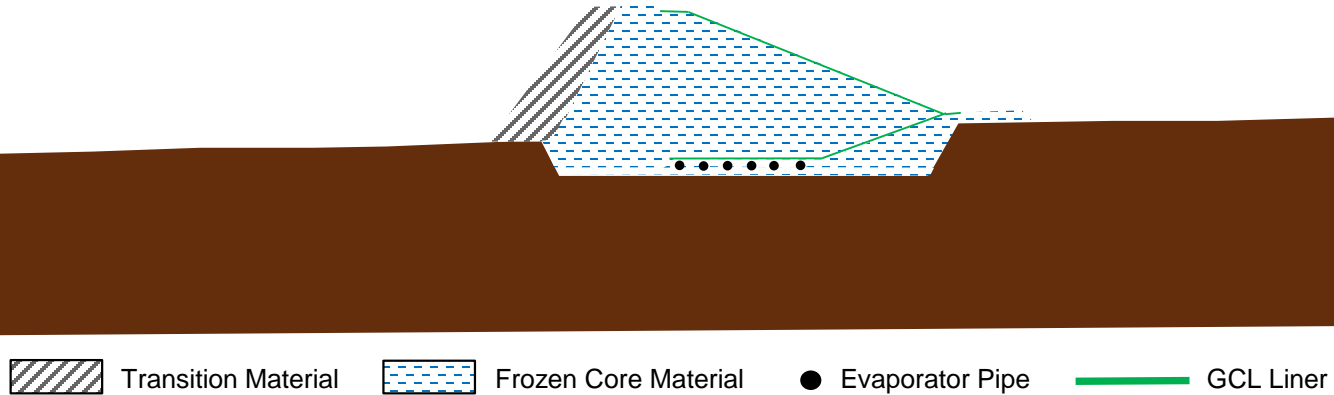
Thermosyphon evaporator pipes
connected to radiator



Thermosyphon evaporator pipes
installed along the key trench base

Frozen Core Dam

- Saturated crushed rock
- Placed in thin lifts
- Freeze back prior to next lift



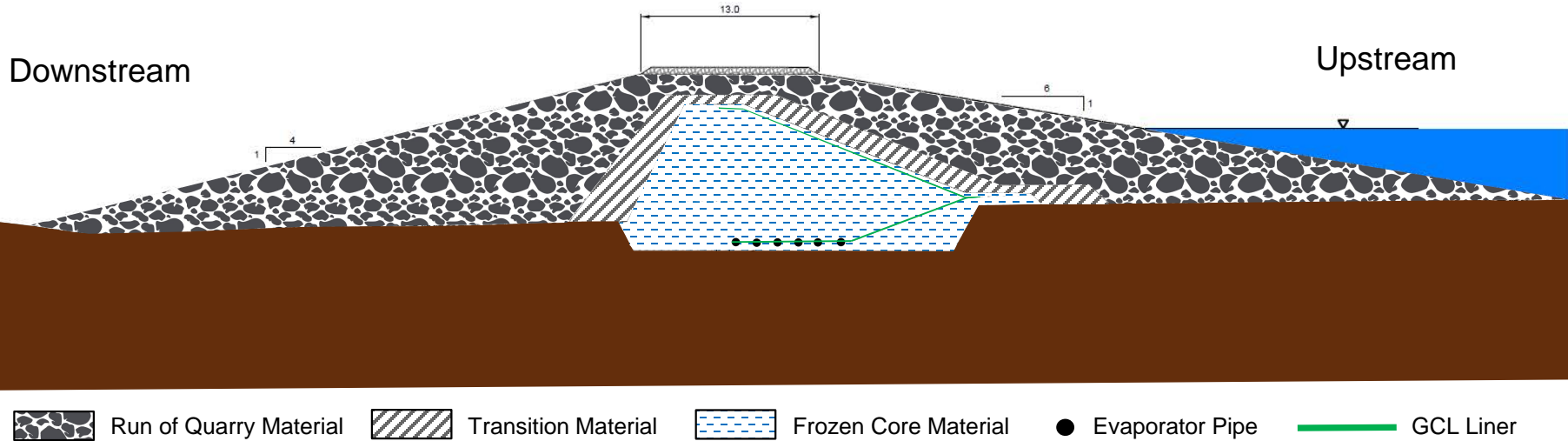


Frozen core construction



Liner installation in key trench

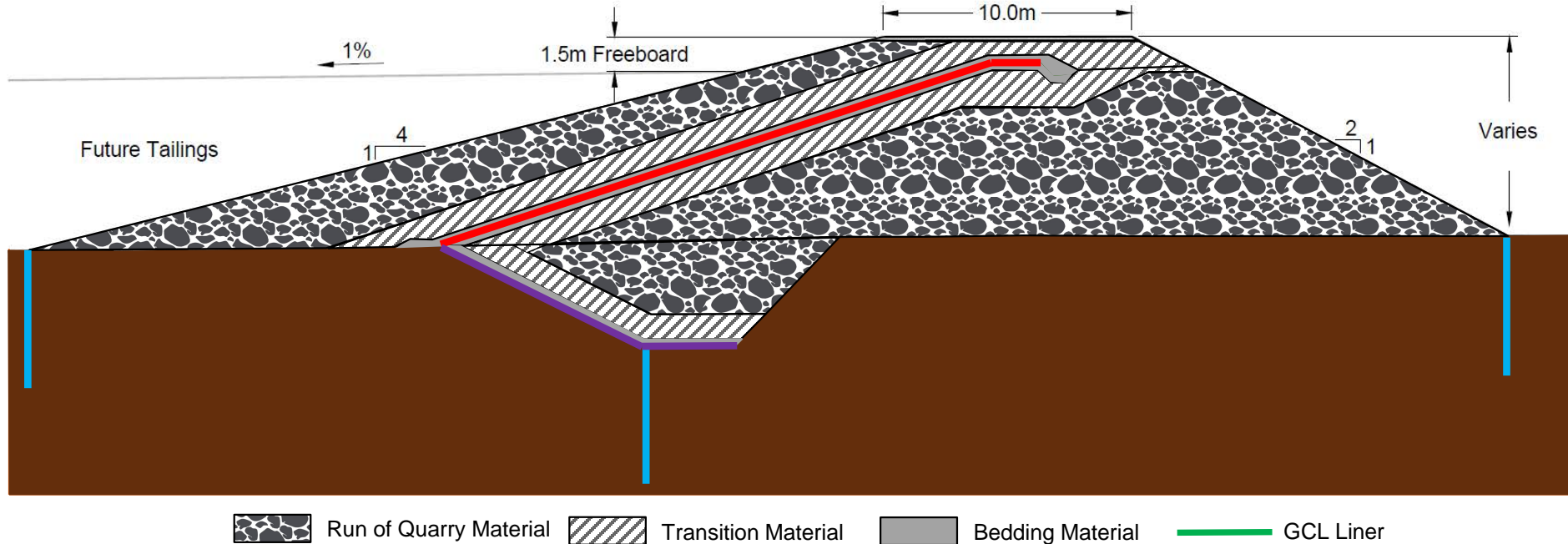
Frozen Core Dam



Instrumentation

Ground Temperature Cables

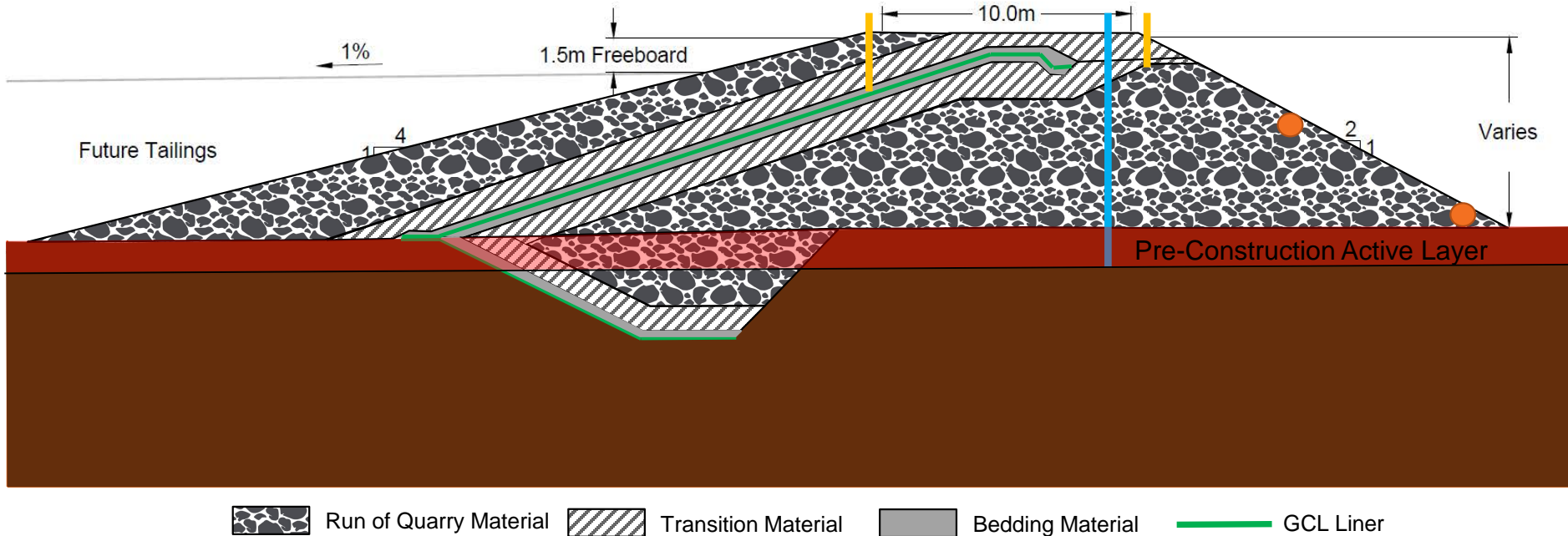
- Ground temperature cables monitor the thermal regime of the foundation and overall deformation performance



Instrumentation

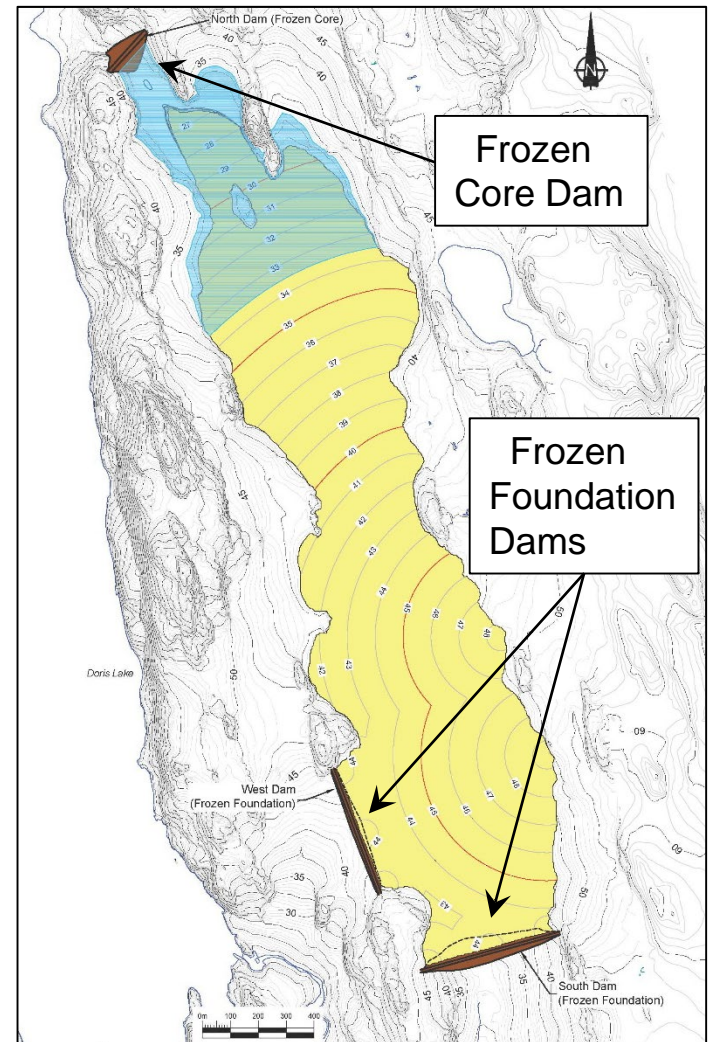
Settlement Monitoring

- Surficial, shallow, and deep settlement surveillance to monitor deformation



Tailings Deposition

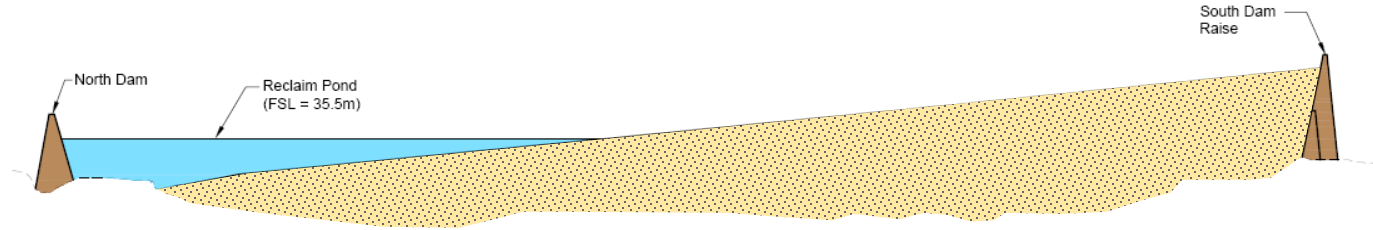
- Development of substantive tailings beaches from the Frozen Foundation Dams (West and South Dams)
- No tailings deposition against the Frozen Core Dam (North Dam)
- Least amount of environmental risk
- Tailings freeze back



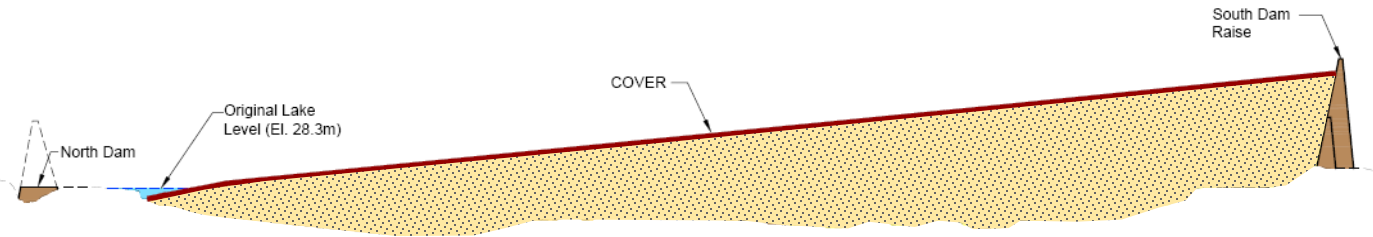
Closure of the TIA



Closure of the TIA



End of Mine



Post Closure

LEGEND

- Existing Ground Surface
- Deposited Tailings

Conclusions

- Imperative to maintain the frozen state of the core and foundation of these containment structures to:
 - Retain primary element of impermeable functionality
 - Mitigate long term deformation
- Unique and innovative containment designs were required to overcome site-specific challenges
- Tailings management designs need to be adapted to account for local conditions to ensure the design is appropriate and will provide a high degree of safety in environmental containment

Questions?

 **srk** consulting



 **TMAC**
RESOURCES