Mine Closure 2024 – AB Fourie, M Tibbett & G Boggs (eds)

doi:10.36487/ACG_repo/2415_61

Design constraints of a closure design basis and cover options assessment for a gold mine tailings facility in the Canadian Shield

Aileen Cash [a,*], Dawn Paszkowski [a]

[a] *BGC Engineering Inc, Canada*

Abstract

A design basis was developed to guide closure design decisions for a tailings facility at an operating underground gold mine in the Canadian Shield of Ontario, Canada. An interdisciplinary design team made up of subject matter experts in geotechnical engineering, groundwater and surface water hydrology, geochemistry and ecology collaborated with site personnel through a series of workshops to develop the design basis, which was subsequently used to inform a structured screening-level options assessment for alternate closure cover scenarios. Various end land uses were considered in developing the design basis, which resulted in 19 site-specific closure goals organised within six overarching focus areas: 1) geotechnical performance; 2) geochemical performance; 3) surface water; 4) groundwater; 5) land use and ecology; and 6) earthworks, landform design and active care. Design constraints identified in the design basis included a limited appetite for disturbing new areas for borrow material, a preference for a dry landform, and the desire to limit net percolation in a humid continental climate, lower groundwater levels in the tailings and curtail degradation of groundwater quality. Regulatory guidelines, the expectations of local communities and First Nations people, economic feasibility and land capability were also recognised as potential constraints. A range of conceptual cover designs were developed within the identified constraints, incorporating modelling of projected post-closure ecosystems. A qualitative options assessment framework was used to provide relative rating of the cover options based on their technical merits in relation to the design goals set out in the closure design basis. The screening-level options assessment highlighted the need for the closure design to balance the potentially competing demands of a low-permeability cover system with the desire to minimise land disturbance and use of borrow materials.

Keywords: *tailings management area, closure goals, end land use, cover systems, options assessment, boreal ecosystem, Ontario*

1 Introduction

The development of a closure design basis has become a standard practice for closure planning and the landform design of mine facilities. A vision, end land use, goals, objectives and criteria can be developed at the mining landscape scale, or at the scale of an individual landform, to align expectations for the performance of reclaimed areas with land use goals (Landform Design Institute [LDI], n.d.). A closure design basis was developed for a tailings facility in the Canadian Shield of northern Ontario, Canada, and was subsequently used to guide a structured screening-level assessment of alternative closure cover options.

The mine site is an underground gold mine located in the warm-summer humid continental climate region (Köppen-Geiger classification Dfb; Kottek et al. 2006). The site receives approximately 800 mm mean annual precipitation, most of which falls between May and October. The site's tailings facility is contained by five earthfill dams, each less than 14 m high, resulting in a facility that is primarily formed by containment structures with a pond at the centre of the facility. Four of the five dams used upstream construction methods with a

[*] Corresponding author. Email address: acash@bgcengineering.ca

low-permeability compacted clay blanket and the downstream supported by a waste rock buttress. The remaining dam was constructed with a compacted clay core with sand and gravel filters and a downstream waste rock buttress. The average downstream slope angle of the dams ranges from 3H:1V to 10.5H:1V. It has been the location for tailings discharge since it was commissioned in the mid 1980s and is progressing towards the end of its operational life. The total current reservoir storage is approximately 3 Mm^3.

Based on current tailings production rates, the tailings facility is anticipated to reach capacity in the next two years. Current activities to prepare the facility for closure include covering tailings beaches with waste rock to control dust generation, constructing stabilisation berms along the dams to meet dam stability requirements through closure, and developing a preliminary tailings infill management plan and closure plan for the facility.

The closure plan identifies high-level objectives for closure of the tailings facility: namely, eliminating surface water storage, limiting surface water infiltration into the underlying tailings, protecting the dams from erosion and placement of an engineered cover system on the tailings surface. As the facility progresses towards closure, the need for a more detailed road map for progressive reclamation and closure of the facility was identified. The first step in the process was to develop a closure design basis and a screening-level options assessment for a closure cover system.

2 Closure vision and design basis development

The closure design basis was developed to link the closure design of the tailings facility to performance requirements at closure. In addition to supporting the qualitative closure cover options assessment discussed in this paper, it is expected that the design basis will be used to support subsequent analyses, phases of design and the planning of trial covers.

The closure design basis was developed via an interactive workshop with an interdisciplinary project team having expertise in geotechnical engineering, groundwater and surface water hydrology, geochemistry, landform design and ecology (Figure 1). As part of the closure design basis process, the closure vision and end land use for the site were refined in collaboration with the mine staff. The closure vision is the big picture idea of the post-mining end land use to be achieved through mine closure (McKenna & Pollard 2021). A range of end land uses were considered for the tailings facility, including a boreal ecosystem, an area for walking trails and outdoor recreation activities, and industrial use, and also took into account regulatory guidelines, the expectations of local communities and Indigenous groups, economic feasibility and land capability. The target end land use defined in the design basis is a locally common boreal ecosystem to provide habitat for focal animals. To support the development of a boreal ecosystem, and to meet regulatory requirements, a cover system was identified as the primary closure construction requirement for the facility.

Figure 1 Project team development at a closure vision and design basis workshop

The design basis documented closure principles, regulatory requirements, corporate commitments, established closure goals, objectives and supporting criteria, defined as follows after McKenna & Pollard (2021):

- goals — overarching design or performance requirements in support of the closure vision
- objectives — design requirements in support of a goal
- criteria — specific and measurable outcomes that determine if the objective has been fulfilled.

The closure design basis was summarised as a table, with the intent that it be a 'living document' that is updated as needed based on changes to goals, regulations, the mine plan and tailings deposition, as well as new findings regarding performance observations and material properties. The project is currently at the conceptual design stage and relied on criteria outlined in the current closure plan.

2.1 Closure design principles and goals

Six broad governing closure principles were at the core of the design basis: geotechnical performance and physical stability; geochemical performance; surface water and surface water quality; groundwater and groundwater quality; land use and ecology; and earthworks, landform design and active care (Table 1). Nineteen goals were developed across the six closure principles as part of the design basis workshop. Subsequently, the project team developed the associated objectives and criteria for each goal. In instances where criteria (i.e. measurable outcomes) could not be defined due to insufficient data, gaps in knowledge were identified (Section 2.3).

Table 1 Closure design principles and goals for the tailings facility

Closure principles	Closure goals
Geotechnical performance and physical stability	Long-term physical stability of the landform Declassify the facility tailings dams
Geochemical performance	Maintain metal(loid) attenuation along groundwater flow paths (minimise potential for desaturation of peat horizon) Maximise chemical stability of autoclave tailings (minimise degree of tailings saturation above peat horizon) Protect soil cover from adverse geochemical reactions
Surface water and surface water quality	Protect receiving water bodies (runoff/surface water management) Limit need for active management of surface water
Groundwater and groundwater quality	Reduce contaminant loading to surface water receptors via identified groundwater pathways Limit active management of groundwater
Land use and ecology	Establish boreal ecosites and habitat for focal animals Support Indigenous people, communities, and relevant stakeholder land use Establish recreational features Improve site appearance and aesthetics
Earthworks, landform design and active care	Protect and maintain the health and safety of all parties involved throughout the design lifetime of the facility Plan for, but minimise, the need for long-term monitoring and maintenance time and effort Manage cost Ensure landform design is constructable Minimise land disturbance for borrow materials Ensure landform design fits into site/region and design is socially acceptable

2.2 Closure design constraints

To facilitate closure of the tailings facility, the construction of a soil cover over the facility will be necessary to meet regulatory requirements and achieve the closure design objectives (e.g. control net percolation, enhance trafficability, maintain a dry landform, provide a growth medium for boreal ecosystems). During the design basis process, several important constraints were identified. These are discussed below.

2.2.1 Spatial constraints

The tailings facility is constrained spatially on all sides by infrastructure, other mine facilities or natural features. The site is adjacent to infrastructure including a highway, an airport and the adjacent community. Current and historic mine infrastructure and landforms are also present, including underground mine infrastructure, historic tailings and waste rock stockpiles, and mine water treatment infrastructure. Natural features include a nearby lake. The facility also has associated diversion ditches which are intended for use at closure. As a result, regrading of the landform as part of the design is not anticipated. As no culturally significant sites have been identified in the area, there is no spatial constraint on the landform and water management structures' closure design.

In addition to the spatial constraints outlined above, the following key design constraints were identified as part of the design basis and were taken into consideration when developing conceptual cover system designs.

2.2.2 Dam declassification

The intent for the facility to be a dry landform at closure was a key geotechnical design constraint, necessary to achieve the goal of declassifying the containment dams. It is expected that considerations related to surface water management, hydrology of the facility, and long-term geotechnical stability and settlement will need to be addressed prior to dam decommissioning. The closure design for the facility will require both effective surface water management to direct water to the closure spillway, and prediction (and potentially mitigation) of settlement in the tailings basin. Studies to characterise the tailings properties and develop preliminary plans for tailings infilling and shaping of the basin have been completed, though it is expected that additional studies to support dam decommissioning will be required as the closure design advances beyond this conceptual design phase.

2.2.3 Borrow material availability

A cover system for the facility may require multiple material types in varying quantities. Limited stripping of borrow material has occurred to date at the site due to the underground operation and, as a result, limited volumes of stockpiled material are available for closure construction. The tailings facility is approximately 140 ha, necessitating 140,000 m^3 per 0.1 m thickness of cover material(s), without accounting for shrinkage factors or wastage. Existing stockpiles onsite are expected to be insufficient for cover construction (i.e. < 40,000 m^3 estimated), and large disturbances to adjacent areas are undesirable. Therefore, availability (both location and quantity) of materials may affect the selection of the cover system type and material thickness(es).

Surficial deposits in the area have glacial origins and generally consist of glaciolacustrine materials overlying interlayered silts and sands, overlying glacial till and bedrock (Section 3.1). A desktop borrow assessment was conducted using terrain mapping techniques, however, field investigations to ground truth available materials are required. Future planned ground disturbance for the expansion of an existing tailings facility may present an opportunistic borrow source that could appreciably reduce cost and the amount of new disturbance, especially for organic materials.

2.2.4 Net percolation, geochemical stability and groundwater quality

A portion of the water that accumulates in the tailings facility infiltrates the subsurface and travels southward, below the containment dam and along an identified groundwater flow path. Groundwater on this flow path carries mine-related water quality signatures associated with process water and remobilisation of metals from tailings solids. A seepage pump-back remediation system was installed at the toe of the containment dam to intercept process-affected groundwater flowing along the flow path and return it to the facility. It is anticipated that removal of the pond from the facility and construction of a cover system intended to reduce net percolation into the facility will reduce the hydraulic gradient driving groundwater flow, and ultimately reduce the potential for mass loading reporting downstream. Future decommissioning of the pump-back system after closure of the facility is a key closure goal, currently estimated to occur 30 years after closure.

Due to the humid continental climate in the area, the optimal cover design will require a detailed understanding of the water balance. Design elements will be required to promote evapotranspiration and manage overland flow and runoff to limit net percolation. The optimal net percolation for the closed tailings facility is expected to be constrained by two factors:

- limiting saturation in autoclave tailings. Although the tailings are primarily flotation tailings there are minor amounts of autoclave wastes where low levels of arsenic are presumed to be sustained through co-precipitation with ferric iron produced within the autoclave. Reductive dissolution of arsenic-bearing iron oxides from autoclave (and roaster) products results in higher concentrations of arsenic and iron in porewater within suboxic and saturated (anoxic) zones. As a result, it is advantageous to maintain oxidising conditions in the autoclave tailings materials to maximise their chemical stability
- maintaining saturation in the peat horizon. A saturated layer of organic peat material is present below the footprint of the facility. The peat layer provides a zone of sulphate reduction where dissolved arsenic, iron and other trace elements show pronounced decreases in concentration, predicted to result from removal as secondary sulphide precipitates.

The closure cover design will ideally reduce net percolation to lower the water table in the facility and maintain oxidising conditions in the tailings while minimising desaturation of the underlying peat to maintain the zone of sulphate reduction. This constraint would require that the water table in the facility after closure be at or above the pre-disturbance water level, interpreted to be near the pre-disturbance ground surface or in the peat horizon.

2.2.5 End land use

The desired end land use defined in the design basis is a locally common boreal ecosystem that provides habitat for focal animals and recreational opportunities for the community. To inform the scoping-level closure cover design options, a quantitative ecohydrological analysis (QEA) model was used to determine the types of ecosites that could be supported on a cover system with materials available in the area. The model uses site-specific inputs such as climate, topography (e.g. slope, aspect, position), and the material properties of both underlying substrates and cover materials. With this information the model projected the post-closure ecosystems that would most likely occur on the facility given different cover designs. A detailed description of the QEA model is provided by Baker et al. (2020).

The QEA model was used to project ecosites for post-closure landforms and cover systems based on the relative soil moisture regime (RSMR) and soil nutrient regime (SNR) of the rooting zone (defined as the upper 1 m), which may include both the cover material and the underlying mine substrate (e.g. mine rock, tailings). Results of the modelling indicated that a growth medium composed of an organic-mineral soil mix (85% by volume of an equal mix of glaciofluvial and glaciolacustrine mineral soils; 15% by volume of organics or peat soils) would have the balance of properties to make it a suitable option for closure cover revegetation. Organic-mineral mixes are a superior growth media for covers relative to either organic or mineral overburden alone. The advantages include increased water retention and nutrient supply from the organics to the mineral soil, reduced density, less erosion of mineral soil with the addition of organics and the coarser fragments in the glaciofluvial material, and efficiencies from the mixing of materials during handling. An additional benefit of using a material mix for a growth medium is that the QEA model results indicated the overall volume of peat, organics, and/or glaciolacustrine material needed for cover construction would be reduced when compared to glaciofluvial material with organics or glaciolacustrine material with organics as a growth media.

Results of the QEA modelling also indicated that multiple ecosites could be supported due to the range in RSMR and SNR conditions created by the driest and wettest combinations of materials available for cover construction. The model projected regimes that correspond to local ecosites that would achieve end land use objectives (i.e. locally common boreal ecosystems found in areas adjacent to the mine site), with some novel ecosite conditions expected. The operational feasibility of mixing and placing the proposed growth medium requires further investigation, as does confirmation of the available quantity of these material types.

2.3 Knowledge gaps

Gaps in knowledge at the design basis phase may affect design decisions in future project phases or at subsequent levels of design. As noted previously, in instances where criteria (i.e. measurable outcomes) could not be defined for goals associated with closure of the tailings facility, due to insufficient data or information, gaps in knowledge were identified. These knowledge gaps were documented in the design basis, and include the following:

- water quality criteria. It is anticipated that criteria for acceptable water quality at closure will align with site-specific water quality targets that have not yet been defined. As a result, closure water quality targets for the receiving surface water bodies and mixing zones, if allowed, are noted as a knowledge gap
- focal wildlife species. The selection of one or more focal wildlife species from the known species at risk in the project area has not yet occurred, which may affect the ecosite type or vegetation species selection at closure
- land use requirements. Indigenous, community, and stakeholder land use requirements may also alter the end land use or ecosite requirements carried forward as further consultation and phases of design are completed
- borrow material availability and properties. A preliminary desktop borrow assessment was completed, however, ground truthing for location and volume and geotechnical/soils testing of materials have not occurred. Availability of borrow material will affect the type of cover that can be constructed and its ability to meet the design goals.

The knowledge gaps identified at this conceptual stage of closure design are expected to guide further studies. For example, field investigations to identify borrow areas and available materials with subsequent laboratory testing will clarify material availability and properties for construction. Future Indigenous, stakeholder and community engagement efforts are needed to clarify land use requirements, and engagement with regulatory agencies will clarify water quality criteria and focal wildlife species.

3 Conceptual cover system design

The cover system for the tailings basin of the facility is anticipated to require a design with a higher degree of technical complexity to meet the range of performance goals and objectives relative to the waste rock embankments. A series of conceptual cover systems were developed considering both the materials available as well as the ability of those materials to support target ecosites.

3.1 Available materials

The types of overburden materials available in the area were considered as part of the development of closure cover design options. Materials identified through terrain mapping included organics, beach deposits, glaciolacustrine material, glaciofluvial material and till, described as:

- organics — material is composed largely of partially decomposed vegetative matter, usually present within wetlands. Typically, organic material is found overlying either glaciolacustrine material or till, and can include topsoil organic horizons and peat soil
- beach deposits —typically sandy and uniform deposits that may accumulate from a variety of sources (e.g. deposition from glacial lakes, wind and water erosion)
- glaciolacustrine — materials typically consist of massive to laminated clay and silt to fine sand deposited in glacial lakes
- glaciofluvial — materials typically consist of coarse- to medium-grained sand and gravel, with the possibility of cobbles, boulders and lenses of till intermixed
- till — material that has been deposited by glacial ice and can range from highly compact to very dense deposits consisting of poorly sorted clasts, usually matrix-supported subangular or subrounded, in a clay-silt-sand matrix; to unconsolidated, hummocky and very poorly sorted material. It is frequently mixed with glaciofluvial or glaciolacustrine material.

Additional materials available onsite, such as mine waste rock, were also considered in the development of closure cover design options, as well as mixtures of material types. The materials were evaluated with respect to their suitability for design elements in a cover system and their ability to support desired ecosites.

3.2 Closure cover design options

Cover system types can range from simple protection covers (e.g. for erosion protection, isolation and/or revegetation) to multi-layered systems (e.g. store-and-release or capillary break covers) and barrier covers with engineered layers (e.g. compacted clay, geosynthetic). The Global Cover System Design Technical Guidance Document (International Network for Acid Prevention [INAP] 2017) provides a comprehensive description of the range of cover types.

For this tailings facility, eight conceptual cover systems were developed within the range of cover system types. The conceptual cover system options were developed considering both available borrow material types for construction of design elements, as well as the ability of the materials to support target ecosites. The range of materials proposed in the conceptual covers included run-of-mine waste rock, glaciolacustrine clay, a low-permeability synthetic liner and a growth medium to support vegetation (i.e. organic-mineral soil mix, Section 2.2.5). The current operational practice at the site is to cover the tailings beaches with a layer of waste rock approximately 0.3 m thick for dust control. This configuration was included in the options assessment (Section 4.1) for comparison to the eight conceptual covers outlined above.

The cover system options considered were as follows:

1. reclamation cover with thin growth medium
2. revegetation evapotranspiration cover — growth medium to support target boreal forest ecosite
3. revegetation evapotranspiration cover — growth medium to support target boreal forest ecosite planted with a dense deciduous forest
4. single capillary break store-and-release cover with thin growth medium
5. single capillary break store-and-release cover with thick growth medium
6. double capillary break store-and-release cover with thick growth medium
7. compacted clay layer barrier cover with very thick growth medium
8. low-permeability synthetic liner barrier cover with thick growth medium.

A 'thin' growth medium is defined as 0.3 to 0.5 m, 'thick' is defined as 0.6 to 0.8 m and 'very thick' is defined as 1.0 to 1.2 m. The total thickness of each cover option is not presented herein as they were developed based on site-specific climate and material properties. Given the current conceptual stage of design they are only preliminary. Growth medium thicknesses are also preliminary and based on initial QEA modelling from limited sample data available from the site.

It is anticipated that the reclamation and revegetation covers would not significantly reduce net percolation as a fraction of precipitation (NP/P) to the underlying tailings (i.e. NP/P ≈ 50%). In contrast, capillary break covers are expected to have a moderate effect on net percolation (i.e. 30% < NP/P < 50%), while barrier covers with a compacted clay layer or other low-permeability liner (e.g. geomembrane, geosynthetic, composite, etc.) are expected to yield the greatest reductions in net percolation (i.e. 10% < NP/P < 30%). These results are in general agreement with INAP (2017). It is further anticipated that cover options with a thick or very thick growth medium would support boreal ecosites that would increase evapotranspiration and limit overland flow. As an option to maximise evapotranspiration, cover option 3 included installation of a dense deciduous aspen forest to enhance water removal from the cover.

4 Cover systems options assessment and results

A qualitative options assessment framework was developed as a tool to provide screening-level ratings of the eight closure cover options. The goal of the qualitative options assessment was to rate the cover system options based on their technical merits in relation to the design goals set out in the closure design basis. The closure design basis identified 19 goals across the six closure principles. Three goals were excluded from the qualitative options assessment: supporting Indigenous, communities and relevant stakeholder land use; cost management; and maintenance of health and safety. The cover system options were rated against the remaining 16 goals with respect to their likelihood of achieving each goal. The likelihood of each cover system supporting Indigenous, community and stakeholder land uses requires further input from these groups, which is ongoing in community consultations. Feedback from the consultations will be integrated as the project advances, including updating the design basis document, and in future weighted options assessments as goals related to land use are clarified. Rough order of magnitude costs for the cover system options were prepared but not considered during the options assessment workshop so as to maintain focus on the technical differences and merits of each option. Finally, the ongoing health and safety of all parties during the design lifetime of each cover system option proposed is considered a non-negotiable design requirement. Therefore, this goal did not require rating.

The qualitative options assessment framework considered the following four ratings:

- unacceptable — highly unlikely to achieve goal
- poor — lower likelihood to achieve goal
- fair — likely to achieve goal
- good — highest likelihood to achieve goal.

A qualitative system was chosen for this assessment where relative weighting of a given goal's importance was not considered because the closure of the tailings facility is currently at the conceptual phase of design. Additional studies which could support a weighted options assessment are planned or in progress, and a supplemental quantitative options assessment is anticipated in future design phases. The options assessment framework was tailored to consider and rate the cover system options based on their ability to meet goals and objectives for the tailings basin specifically (i.e. not embankment areas). The tailings basin comprises most of the total facility surface area and is expected to have higher design complexity with respect to water management, geochemistry, settlement and constructability. In comparison, embankment area footprints are not expected to change as stabilising berms were constructed during the final design stages of the facility.

4.1 Options assessment results

Qualitative ratings for each cover system were determined by the design team in a collaborative workshop where the merits of each goal rating were discussed from the perspective of each technical discipline. In addition to the rating, extra commentary was also recorded to provide context for the discussion.

Table 2 provides the ratings for each cover system option with respect to the likelihood it will achieve each design goal laid out in the design basis.

The current condition (i.e. covering tailings beaches with waste rock) was determined to have unacceptable ratings for establishing boreal ecosites and protection of receiving water bodies, and surface water runoff would require management. In general, revegetation covers had lower ratings with respect to their ability to meet geochemical and groundwater-related goals due to an expected higher net percolation relative to capillary break or barrier layer covers.

Capillary break store-and-release covers would require more material for construction than revegetation covers as a coarser-textured material would be required below the growth medium. It is anticipated that run-of-mine waste rock would be used as it is readily available at the mine site and may provide some operational benefits (e.g. reduce waste rock stockpile sizes); however, testing is required to determine if the grain size distribution meets coarse-texture material requirements. A capillary break is also advantageous to hydraulically separate the tailings from the reclamation growth medium and limit upward diffusion due to low saturation in the coarse-textured material. Further study is required to determine if capillary break covers would adequately reduce net percolation into the tailings to achieve a water table that maintains saturation in the peat horizon and maintain oxidising conditions in the tailings.

Barrier layer covers (i.e. a compacted clay layer or low-permeability synthetic liner) present a higher degree of confidence that the pump-back system may be decommissioned post-closure, which would reduce long-term operational and water treatment costs. A compacted clay layer would need to consider upward diffusion to protect the growth media from adverse geochemistry. Upward diffusion may be counteracted by the water balance (e.g. upward diffusion of solutes is balanced by, or overcome by, the rate of advective flushing through the overlying growth medium), which will require detailed understanding of the water balance. A very thick growth media was considered for this scenario to limit root ingress into the barrier layer. A low-permeability synthetic liner and compacted clay layer were rated lower with respect to constructability as these covers would necessitate more complex construction methods.

The screening-level options assessment highlighted the need for the closure design to balance the potentially competing demands of a low-permeability cover system to reduce net percolation with the desire to minimise land disturbance and use of borrow materials. It also highlighted the importance of understanding the water balance as this is crucial to many of the design goals (e.g. maintaining geochemical stability of the tailings, limiting active surface water and groundwater management, and maintaining a dry landform). Quantifying the net percolation into the facility with different cover system options will be important in future design phases to estimate the position of the water table after closure, as this will influence the chemical stability of the autoclave tailings and the anoxic conditions in the peat layer that promote sulphide reduction. In addition, management of surface water in the tailings basin through surface grading and landform design will be required to maintain a dry landform to progress towards the goal of dam declassification.

With consideration of required and available materials and the technical performance ratings determined in the screening-level options assessment, four cover system options were selected to be carried forward into further design phases: options 1, 5, 7 and 8. These design options provide end members that are expected to help the design team understand the effects of different cover systems on the tailings facility water balance and illustrate the spectrum from simple to complex construction requirements.

Table 2 Results of screening-level cover system options assessment

		Cover options								
		Current condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Closure principles	**Closure goals**	***Waste rock***	***Thin growth medium***	***Thick growth medium***	***Thick growth medium, dense vegetation***	***Capillary break, thin growth medium***	***Capillary break, thick growth medium***	***Double capillary break***	***Compacted clay liner***	***Low-K liner***
Geotechnical performance	Long-term physical stability of the landform	Fair	Fair	Fair	Fair	Fair	Fair	**Good**	**Good**	**Good**
	Dam declassification	Poor	Poor	Poor	Fair	Fair	Fair	**Good**	**Good**	**Good**
Geochemical performance	Maintain metal(loid) attenuation	**Good**	**Good**	**Good**	**Good**	Fair	Fair	Poor	Poor	Poor
	Maximise chemical stability of autoclave tails	Poor	Poor	Poor	Fair	Fair	Fair	**Good**	**Good**	**Good**
	Protect soil cover from adverse geochemistry	N/A	Poor	Fair	Fair	**Good**	**Good**	**Good**	**Good**	**Good**
Surface water and surface water quality	Protect receiving water bodies	U/A	Fair	Fair	Fair	**Good**	**Good**	**Good**	**Good**	**Good**
	Limit active surface water management	Poor	Fair	Fair	Fair	**Good**	**Good**	**Good**	**Good**	**Good**
Groundwater and groundwater quality	Reduce contaminant loading via groundwater pathways	Poor	Poor	Poor	Fair	Fair	Fair	**Good**	**Good**	**Good**
	Limit active management of groundwater	Poor	Poor	Poor	Poor	Fair	Fair	**Good**	**Good**	**Good**
Land use and ecology	Establish boreal ecosites for focal animals	U/A	Poor	Fair	Fair	**Good**	**Good**	**Good**	**Good**	**Good**
	Establish recreational features	Poor	Poor	Fair	Fair	Fair	**Good**	**Good**	**Good**	**Good**
	Improve site appearance and aesthetics	Poor	Fair	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**
Earthworks, landform design and active care	Minimise monitoring and maintenance	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
	Ensure landform design is constructable	**Good**	**Good**	Fair	Fair	**Good**	Fair	Poor	Poor	Poor
	Minimise land disturbance for borrow	Fair	Poor	Poor	Poor	**Good**	**Good**	Fair	Fair	Poor
	Design fits into the site/region, socially acceptable	Poor	Fair	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**

N/A — Not Applicable, U/A — Unacceptable, Low-K — Low hydraulic conductivity or permeability

4.2 Additional phases of work

Future phases of work are anticipated to address gaps identified in the design basis and advance the overall closure cover design for the facility. Hydrologic modelling of preliminary cover designs coupled with 3D groundwater flow modelling of the facility was completed, and conceptual design for a closure cover trial is in progress. Additional future phases of work may include: a borrow investigation to ground truth the terrain mapping and quantify available materials; collection of seeds from local species to grow supplemental planting stock for reclamation; trafficability and construction trials; and additional laboratory hydrologic and geotechnical testing of construction and in situ materials.

5 Conclusion

The closure of a tailings facility is complex and requires input from an interdisciplinary team to establish the key technical, regulatory and societal requirements that must be met. The development of a locally common boreal ecosite was the desired end land use for this tailings facility and this concept was used to develop a design basis with 19 goals across six closure principles. Several constraints were identified in the design basis that will affect the closure design of the facility, including the preference of a dry landform, the limited availability of borrow material, and the need to maintain an optimal water table condition for the geochemical stability of the autoclave tailings and attenuation of metal(loids) in the underlying saturated organics layer.

Eight conceptual closure cover options were developed for evaluation in a collaborative qualitative screening-level options assessment. The options assessment provided qualitative ratings against each of the design basis goals to assess the technical merits of each cover design option. Four cover options — reclamation, capillary break store-and-release, a compacted clay liner barrier and a low-permeability liner — were selected for further assessments. The gaps identified in the design basis and options assessment highlighted the need for additional studies to better quantify the ability of the cover systems to meet the design objectives and criteria. A detailed understanding of the water balance for the facility and, specifically, the quantification of net percolation and overland flow, is required to optimise the location of the water table in the post-closure period. Sufficient volumes of material to meet the construction and reclamation needs, and to establish the target end land use, must also be identified.

Acknowledgement

The authors would like to thank the collaborative efforts of the design team, including mine staff, partner consultants and the Engineer of Record. Special thanks to Dr Carl Mendoza for his valuable insights and support on this paper.

References

Baker, T, Straker, J, Ryan, MG 2020, 'Development of a soil water balance-based model for predicting ecosystem occurrence on post-closure landforms', *British Columbia Mine Reclamation Symposium*, University of British Columbia, Vancouver http://dx.doi.org/10.14288/1.0402425.

International Network for Acid Prevention (INAP) 2017, *Global Cover System Design Technical Guidance Document*, International Network for Acid Prevention, https://www.inap.com.au/wp-content/uploads/global-cover-system-design.pdf

Kottek, M, Grieser, J, Beck, C, Rudolf, B, and Rubel, F 2006, 'World Map of the Köppen-Geiger climate classification updated', *Meteorologische Zeitschrift*, vol. 15, pp. 259–263.

Landform Design Institute (LDI) n.d., *Developing a design basis memorandum for landform design and closure planning'*, in D Wylynko & G McKenna (eds), *LDI How-To Guide*, Landform Design Institute, Delta. In press.

McKenna, G & Pollard, J 2021, '*Mining with the end in mind: Landform design for sustainable mining'*, Landform Design Institute, Delta, viewed 25 April 2024, https://landformdesign.ca/pdf/LDI-PositionPaper2021.pdf