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Closure considerations while operating a tailings management facility in northern Ontario, Canada

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Abstract

Vale Canada Limited (Vale) owns mining and mineral processing facilities in the City of Greater Sudbury that have been operating since the late 1800s. Central operations include mining, milling, smelting and refining of sulphidic ore to produce principally nickel and copper metal. In 1989, milling was consolidated to the Clarabelle Mill that uses the Central Tailings Area (CTA) to manage tailings.

The CTA has been in operation since the late 1930s and closure is not expected for several decades. The CTA covers approximately 28 km^2, making it one of the largest and oldest operating tailings management facilities in North America. Given the sulphide bearing ores and net surplus precipitation climate of the Sudbury area, the CTA ponds are a key to managing Acid Rock Drainage and flow control within the central operations. Waste water and runoff from most of the central operations is also pumped to the CTA ponds. These additional sites add 25 km^2 to the area serviced by Vale's Copper Cliff Water Management System. This water management system will be required for the current life of operations (until approximately year 2050) and possibly for many decades following closure.

Mine closure planning became mandatory under Ontario law in 1991. The original CTA closure plan was submitted to the Ontario Ministry of Northern Development and Mines in 1998 and was updated in 2001 and 2006. Ongoing review of the CTA operations and associated capital projects typically includes operational and/or project evaluation in the context of the CTA's closure objectives to ensure sustainable use of the facility while meeting operational needs.

A case study of Vale's CTA is presented illustrating how tailings management operational aspects incorporate the facility's fundamental closure objectives. The operational aspects discussed in this paper are minimised acid rock drainage, surface water management, tailings filling planning, static and seismic stability and progressive reclamation. The aspects of tailings management discussed in this paper are offered as an example of best practice, in particular to operators of large, upstream constructed tailings management facilities when closure is not anticipated for many decades. This paper also illustrates the merits of considering facility closure objectives on a continual and consistent basis during operations.

1 Introduction

Vale Canada Limited (Vale) owns a number of mining facilities within the City of Greater Sudbury, Ontario, some of which have been operating since the late 1800s. The subject facility of this paper is the Central Tailings Area (CTA). Other plants considered peripheral to the CTA are also discussed in general terms as they share a common overall water management strategy with the CTA during operations and throughout closure. For the purpose of this paper all references to Vale's central operations include the following plants; Copper Cliff, Creighton and Stobie Mines, Clarabelle Mill, the CTA, Smelter Complex, Nickel Refinery, Copper Cliff Waste Water Treatment Plant (CCWWTP) and Nolin Creek Waste Water Treatment Plant (NCWWTP). In 1989, milling was consolidated at the Clarabelle Mill that uses the CTA to manage tailings. The facility has been in operation as a tailings management facility since the late 1930s and closure is not expected for several decades.

Figure 1 includes a Google Earth inset showing the City of Greater Sudbury location within central Canada. The figure also presents a plan view of the CTA, surrounding urban setting and Vale's central mining and mineral processing plants and the areas serviced by the Copper Cliff and Nolin Creek Water Management Systems. The CTA comprises several discrete active and inactive tailings management areas. The inactive areas commonly referred to as the "Old Stack" include A, CD, M, M1, P, Q and the Inactive Pyrrhotite

Storage (IPS) Areas. The active R Area comprises the R1, R2, R3, and R4 Areas. The R Area cells are now managed as one basin with a common central pond. Topographically, the CTA forms a plateau that is confined by bedrock outcrops and perimeter dams.

The CTA's urban setting is between the communities of Copper Cliff to the east and Lively to the west. To the north is White Water Lake and to the south is Regional Road 55 (RR 55), a major arterial divided highway. The CTA covers approximately 28 km^2, making it one of the largest and oldest operating tailings management facilities in North America. Typically the ores are sulphidic and the region has a net surplus precipitation climate. As such, the CTA ponds are a key to managing acid rock drainage (ARD) and flow control within the central operations. Waste water and runoff from most of the central operations is also pumped to the CTA ponds. The central operations sites beyond the CTA add 25 km^2 resulting in a total area of approximately 53 km^2 that is serviced by Vale's Copper Cliff Water Management System (CCWMS). This water management system will be required for the entire life of facility plan (LOFP) at Vale's central operations in the City of Greater Sudbury (until approximately year 2050) and will remain in service throughout closure until active water management is no longer required.

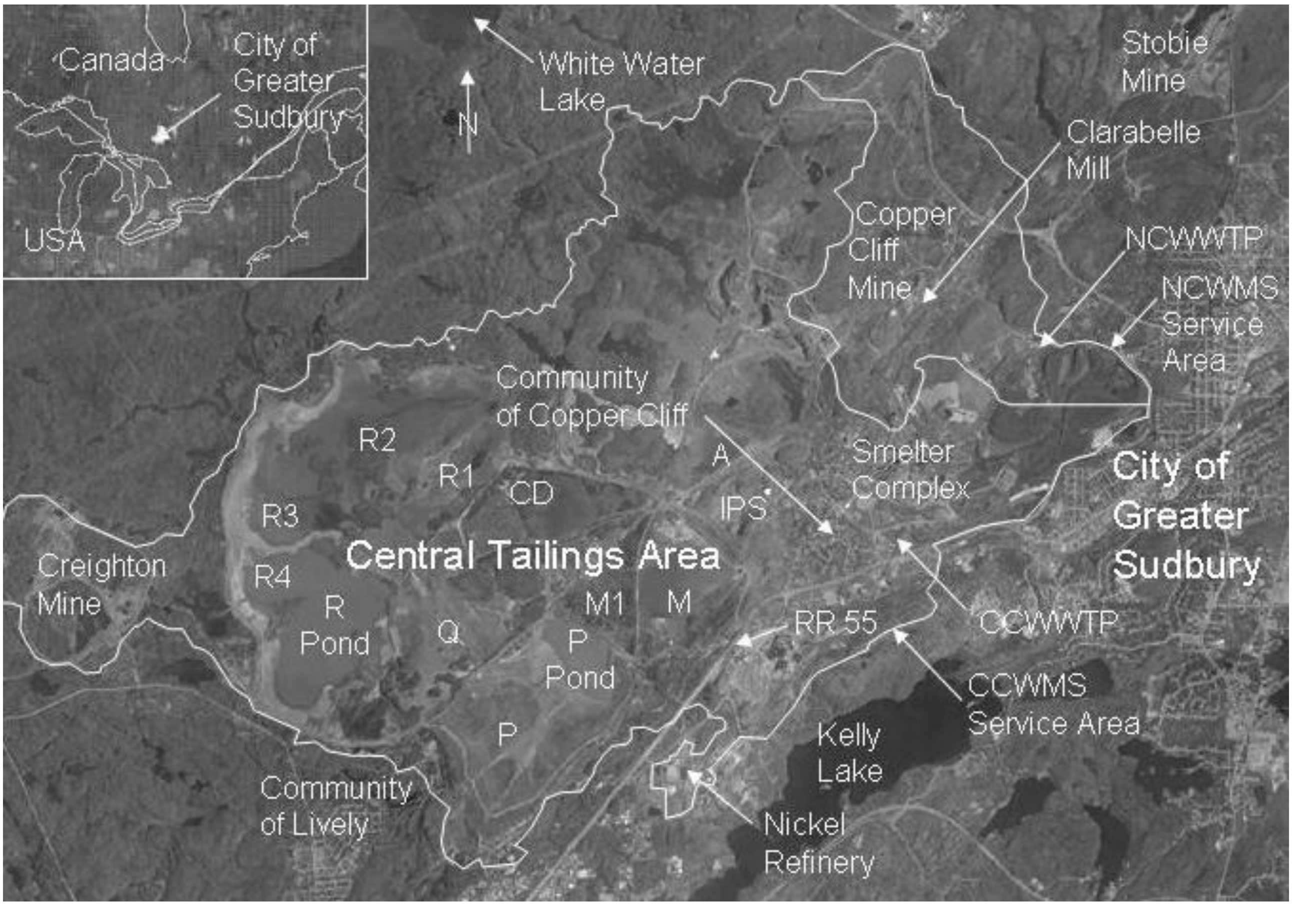

Figure 1 Vale's CTA and central operations in the City of Greater Sudbury and Google Earth inset illustrating Sudbury's location within central Canada (Source: Google Earth)

2 CTA closure objectives and plan

Under Ontario law, mine closure planning became mandatory in 1991. The original CTA closure plan was submitted to the Ontario Ministry of Northern Development and Mines in 1998 and was updated in 2001 and 2006. The general objective of the CTA closure plan is to provide a decommissioning strategy reflecting current site conditions should the site close unexpectedly. However, based on the current LOFP and approximate production rates, the CTA-R Area is expected to receive tailings until the year 2035. Beyond 2035, tailings will be placed in A Area following expansion to accommodate tailings production for at least another two decades. As the closure plan must address present conditions, regardless of the LOFP, the CTA closure plan has been prepared for both current and final operating conditions.

Future land use and aesthetic requirements following CTA closure is expected to be consistent with land use to the north. This area forms part of the White Water Lake watershed headwaters and is characterised primarily as bush-land with low density habitation. Land use surrounding White Water Lake (approximately 3 km north) is recreational and residential. Implementation of the proposed CTA reclamation measures is expected to satisfy the following objectives:

- Minimised ARD.
- Surface and seepage water management.
- Physical stability.
- Improved site aesthetics.

The CTA reclamation measures and closure objectives were established based on detailed site characterisation studies conducted between 1993 and 1998, and in order to limit the potential adverse environmental impacts identified by these studies. Table 1 summarises such measures and objectives for the Old Stack, R Area at the end of operations, and for R Area in its current state. Measures for the potential A Area expansion are not included herein as engineering and permitting requirements are not expected to enter the planning stage for another five to ten years.

Since the original closure plan submission, the operation of the CTA and associated capital projects typically includes evaluation in the context of the CTA's closure objectives. This is done to ensure continued operation of the facility while avoiding additional reclamation measures which could otherwise result without due consideration of the facility closure objectives.

The remainder of this paper presents a case study of the CTA and associated water management system illustrating the extent to which various operational aspects consider the facility's fundamental closure objectives. The operational aspects discussed is this paper are; minimised ARD, tailings filling planning, surface water and seepage management, static and seismic stability and progressive reclamation.

3 Minimised ARD

Clarabelle Mill is designed to process approximately 32,000 tonnes per day of sulphide ore. During the milling process, approximately 15% (by mass) is processed into nickel-copper concentrate. The mill circuit also generates two tailings streams, rock and pyrrhotite. Of the remaining 85%, 15% is used to backfill mined out underground voids. The remaining 70% is pumped as slurry to the CTA. The pyrrhotite and rock tailings have considerably different gradations and sulphur contents and therefore are managed differently.

The sulphur content of pyrrhotite tailings is generally 16–22% while that of rock tailings is 1.5–2%. Consequently, pyrrhotite tailings have a high potential for ARD if not managed appropriately. The pyrrhotite particle size distribution (PSD) is also considerably finer at approximately 85% passing the 0.074 mm particle size, versus 50% with rock. The PSD difference results in important differences in geotechnical characteristics between these materials. This is most readily illustrated in terms of construction trafficability. The rock tailings drain rapidly and can support a 28 tonne bulldozer within hours (up to 150 m from the deposition point), whereas pyrrhotite tailings will not support construction traffic despite allowing several months for drainage.

Given the high ARD potential of the pyrrhotite, the fundamental strategy to minimise ARD involves saturating pyrrhotite as soon as practicable during operations and permanently at closure. The underlying tailings management strategy to accomplish this uses rock tailings to construct perimeter containment with sufficient freeboard to centrally deposit and saturate/submerge pyrrhotite. This is illustrated schematically in Figure 2. There are other key filling plan objectives, some with competing interests. As such, tailings filling planning is a critical element in meeting operating objectives without compromising those for closure.

Table 1 CTA reclamation measures and closure objectives summary

CTA Area	Reclamation Measures	Closure Objectives			
		Minimised ARD	**Surface and Seepage Water Management**	**Physical Stability**	**Improved Site Aesthetics**
Old Stack	Upgrade perimeter tailings dams (A, M, and P Area)	X	X	X	X
	Construct upper A Area pond and dams	X	X	X	X
	Construct P Area spillway(s)		X	X	
	Operate and maintain existing P Area seepage control system	X	X		
	Engineered cover over IPS Area and raise dam	X	X	X	X
	Maintain existing vegetation and vegetate exposed tailings (CD, M, P and Q Area)			X	X
Final R Area	Construct spillway	X	X	X	
	Operate and maintain existing perimeter seepage control system	X	X		
	Vegetate exposed tailings beaches and slopes			X	X
	Tailings filling plan and water cover while allowing for flood control (with R perimeter level approximately 20 m higher than current)	X	X	X	
Current R Area	As above except as noted below				
	Engineered cover over R1	X	X	X	X
	Tailings filling plan and water cover while allowing for flood control at current R perimeter level.	X	X	X	

Note: "X" Indicates the closure objective(s) each reclamation measure is intended to satisfy.

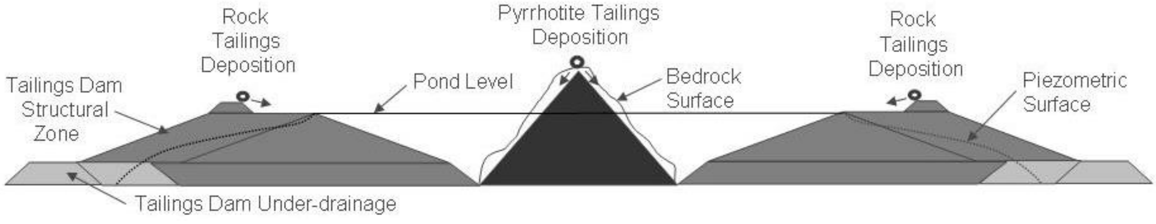

Figure 2 Schematic of R Area tailings management strategy and perimeter dam construction (not to scale)

4 Tailings filling planning

In general, the tailings filling plan calls for spigotting rock tailings from a perimeter pipeline around R Area while a separate pumping system end-discharges pyrrhotite inside. Segregation of rock tailings occurs as the tailings slurry flows over the beach (typically 90 to 150 m wide) towards the centrally located R Pond. The resulting tailings gradation within 90 m of the perimeter contains less than 30% passing the 0.074 mm particle size. The 90 m wide beach is compacted to achieve at least 95% of the material's Standard Proctor Density. The segregation and compaction results in a well-drained, dense structural zone that is required for static and seismic stability. The perimeter crest is then raised about 1 m high in the upstream direction using bulldozers to scrape tailings from the structural zone towards the perimeter forming a raised crest about 9 m wide. Pyrrhotite discharge locations are selected to minimise line movements and avoid infringing on the 90 m wide rock tailings structural zone. Figure 2 provides a schematic illustration of the perimeter rock tailings deposition, central pyrrhotite deposition and perimeter dam construction/design. Several key objectives drive the filling plan:

- Provision of a sufficient freeboard allowance for environmental and dam safety flood water management.
- Provision of sufficient storage for pyrrhotite and rock tailings.
- Provision of a sufficient process water reserve.
- Controlled tailings beach lengths to maximise water cover for ARD mitigation, provide dust control and maximise tailings solids retention on the beach while maintaining a minimum 90 m wide beach for dam stability.

Updating the filling plan typically begins with establishing a current digital terrain model (DTM) of the R Area tailings beach and R Pond bathymetry. In order to predict future R Area DTMs, rock and pyrrhotite tailings deposition is modelled over the original DTM incorporating pipeline arrangements, measured deposition slopes, and measured or estimated densities. Deposition modelling is typically run according to deposition time steps, quantity increments, or elevation targets. Interpreted modelling results are used to provide: tailings line operating requirements, dam crest and beach raising targets, water management plan and capital construction requirements.

Filling plans for the CTA are usually updated every two to three years or sooner as required by operational adjustments in milling rate and/or potential variances in deposition strategy. Normally, one year time-steps are modelled over the first five years of the plan to establish the detailed filling plan and confirm the timing of previously forecasted capital construction requirements. Then, one year time steps are run for another five to ten years, primarily to identify capital construction requirements and check for fatal flaws against the general filling plan and closure objectives. Lastly, modelling is taken to the final permitted R Area crest elevation (335 m) to again check for filling plan fatal flaws against the operating and closure objectives, one of the most important being surface water management.

5 Surface and seepage water management

Mining in the Sudbury basin for more than a century has resulted in the excavation and storage of rock (much of it with ARD potential). Within Vale's central operations considerable volumes of waste rock (approximately 40 million cubic metres total) have been stockpiled over some relatively large areas (approximately 6.3 km^2 total). Long before awareness of the potential adverse environmental effects of ARD, waste rock was used as a construction material for mine yards, roads and stockpiles. The Sudbury landscape is typically characterised by highly irregular bedrock topography protruding through moderately undulating overburden. Shallow organic and/or granular soils partially cover bedrock outcrops. Relatively deep lacustrine and/or alluvial deposits overlie bedrock valleys and glaciation has resulted in many lakes and streams. These terrain characteristics and the lack of ARD knowledge have led to waste rock being used for mine construction and operations over multiple drainage basins that now require drainage control and water quality management.

Since 1972, surface water over areas potentially affected by ARD has been managed using two systems; the CCWMS and Nolin Creek Water Management Systems (NCWMS). The CCWMS comprises seven sub-watersheds covering approximately 53 km^2 and containing 22 reservoirs. Flows are either treated at the CCWWTP or re-cycled for mill process water. The NCWMS comprises a single, three reservoir, catchment covering approximately 9 km^2 and associated flows are treated at the NCWWTP. The approximate service areas for each system are shown on Figure 1.

During the 1990s closure planning studies for the central operations, one of the most significant objectives was long term management of ARD runoff and seepage from tailings stacks, and waste rock yards, roads and stockpiles. As the CCWMS already serviced the majority of the central operations, the strategy adopted was long term collection and treatment over the CCWMS watershed. Over time, potentially ARD generating materials within the NCWMS watershed would be relocated within the CCWMS sub-watersheds so drainage can be collected and treated and the NCWWTP eventually decommissioned.

In 1999, Vale embarked on a 10 year, C$ 100 million campaign to upgrade the CCWMS at several sites within the central operations. While several conceptual strategies were considered, upstream flow attenuation using reservoirs was selected for both economic and technical reasons.

> *The development of the CCWMS was guided by: Vale's Environmental Policy, Provisions and requirements under Provincial and Federal Law, Compatibility with Closure for Sudbury Area operations dependant on the CCWWTP, Relevant dam safety guidelines (i.e. CDA, 1999; MNR, 1999) and compatibility with filling plans and tailings management best practice (MAC 1998, 2003) (as cited in Noack et al., 2007).*

The upgrades have resulted in vastly improved operational efficiency and environmental performance at Vale's central operations. In 2009, the success of the CCWMS upgrades was recognised with an Environmental Award of Merit from Consulting Engineers Ontario and has been the recent subject of various articles and presentations. However, discussion of the system's compatibility with the central operations closure strategy for ARD and surface water management was not included. The expected benefits to the CCWMS are worthy of further discussion.

There are various technical aspects of the CCWMS which are expected to complement the surface water management closure strategy for the central operations. At closure, the large R and P Area ponds in the CTA will provide an existing reservoir system that will continue attenuating direct runoff and pumped flows from several of the central operations plants and seepage stations. The current system has the capacity to manage a 1:10 year, 30 day rain plus snow melt event. However, once Clarabelle Mill is no longer in operation, the R and P Area ponds can be operated to manage larger storm events. The reservoir systems and control structures outside the CTA can also be modified to increase environmental flood management capacity for closure. Given the net surplus precipitation climate of the Sudbury area, the R Pond will also complement the CTA closure plan objective to minimise pyrrhotite ARD potential by maintaining a permanent water cover.

The design of the control structures integrates operational flow control with capability to pass extreme floods into a single appurtenance that will contribute to cost effective, post closure monitoring. Key features include gravity driven flow control structures that drain to the CCWWTP, relatively simple design and construction and remote state-of-the-art flow control linked to the CCWWTP, normally staffed by a sole operator. The simplicity of the design and construction have to date required relatively little maintenance and the gravity based design will allow the flow attenuation system to function as long as required with little energy input.

The CCWMS is also compatible with existing CTA seepage control measures which are expected to remain in operation well into closure. Seepage from the CTA perimeter dams is either collected in engineered ponds and return pumped to the CTA R and P ponds or is diverted to the CCWWTP by gravity. There are three seepage stations to service 6.5 km along the R Area perimeter and another four to service 3.7 km along the Old Stack perimeter. A photo of an Old Stack seepage pond is included in Figure 3.

6 Physical (static and seismic) stability

Given the sand/silt gradation and upstream construction method of the CTA tailings dams together with the large ponds, controlled dam toe seepage is critical to the CTA's perimeter stability. This concept is widely recognised in modern geotechnical engineering practice and has been appropriately considered in the design and construction of the R Area perimeter dams. Under drainage systems have been incorporated to intercept and direct seepage originating from the tailings pond and migrating through the structural zone so that seepage reports to the downstream toe in a controlled manner (Figure 2). The R Area perimeter structural zone is also designed to withstand earthquake design ground motions (EDGM) by assuming all the tailings contained behind the structural zone would liquefy under the design earthquake leaving the contained tailings with negligible residual shear strength. Given inevitable increases in seismic design loading, this design assumption will remain valid over the operation of R Area as well as in post closure conditions.

During the early construction eras of the Old Stack tailings areas, geotechnical engineering as applied to tailings or earth embankment dams was generally not widely established. Consequently, the Old Stack perimeter containment dams constructed in the upstream direction did not include under drainage, compacted structural zones and/or QA/QC observations. In addition, the tailings deposition methods did not typically consider where deposition occurs in ponds near the facility perimeter, increased loose, low permeability zones tend to accumulate that can lead to perimeter stability concerns. Recently, the requirement for seismic upgrades in response to recently increased EDGMs has been confirmed for some of the Old Stack dams.

In response, Vale has embarked on a multi-year campaign to upgrade the Old Stack perimeter tailings dams. Kallio Dam was completed in year 2010 and the Cecchetto Dam is scheduled to be completed in 2012. During feasibility design engineering it was recognised the current (and recently increased) EDGMs are likely to increase at some point and tailings zones predicted not to liquefy under current loading criteria would eventually be prone to liquefaction. Accordingly, and given the CTA and associated ponds are likely to remain a permanent feature well into closure, a key design assumption was that tailings below the predicted long term piezometric levels would liquefy. However, unlike the R Area perimeter design, residual tailings strength characteristics were considered in the design of the recent seismic stabilisation improvements. These were configured such that the seismic resistance could be incrementally increased by adding onto the previously constructed stabilisation buttresses, if and when required.

7 Progressive reclamation

In the context of the CTA and other central operations closure plans, closure measures fully or partially completed during operations prior to plant closure are considered to be progressive reclamation. While some of the topics previously discussed such as upgrades to the CCWMS and Old Stack dams could be considered examples of progressive reclamation, this discussion will focus on continuous tailings slope and beach vegetation efforts as part of normal operations.

Vegetation along the 8 km long Old Stack perimeter slopes and extensive beach areas has been underway for at least three decades. The bulk of these efforts began after active tailings deposition terminated and have been complete for more than ten years. Currently only maintenance work is required from time to time. Vegetation work on the Old Stack slopes included placement of a silt-clay layer varying from 15 to 60 cm thick over the existing tailings slopes (four to five horizontal to one vertical) and cultivation of native grasses and shrubs and planted coniferous trees. The tailings beaches were treated with lime, seeded and also planted with coniferous trees. These efforts have been largely successful as evidenced by extensive slope and beach areas covered with thick grasses and shrubs and trees up to 8 m high, see Figure 3.

Progressive vegetation along the 21 km long R Area perimeter slopes began in year 2006, with the application of a silt-clay layer and cultivation of native grasses and shrubs over a portion the perimeter near the Lively community. While these efforts have been successful some significant challenges remain. Some of the recent vegetation has been damaged by tailings slope erosion during heavy rain events and from routine pipeline maintenance along the dam slopes. Consequently, Vale is considering a service road/bench along the entire R Area perimeter to control slope runoff and capture slurry drainage during line maintenance.

In addition, there is doubt whether there is sufficient quantity of natural low permeability material available locally to cover the R Area tailings dam slopes. Although Vale has stockpiled some silt-clay overburden excavated during upgrades to the CCWMS and Old Stack upgrades, the volume is believed to be well short of required. In addition, local by-laws have restricted transporting silt-clay materials which were already in short supply and in high demand due to other current Vale reclamation efforts. Vale is exploring other non-traditional cover materials such as by-products from the pulp and paper industry as well as mixtures of Vale mineral wastes. Vale is also planning exploratory efforts to establish vegetation on the existing tailings slopes with the objective of minimising or eliminating the need of off-site silt-clay fill.

Figure 3 Photo showing vegetation on an Old Stack tailings beach and dam slope and a seepage pond with P Area Pond in the background

Probable expansion into A Area will share a portion of the current R Area exterior, the extent of which is not yet known. Consequently, reclamation along this portion of the perimeter will be deferred until the A Area expansion limits have been determined, likely within the next ten years.

8 Closing remarks

This paper presents an operator's perspective on closure considerations when operations are ongoing and expected to continue for several decades. In the context of fulfilling the facility closure objectives, the aspects of tailings management discussed in this paper are offered as an example of best practice, in particular to operators of large, upstream constructed tailings management facilities.

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