TAILINGS IMPOUNDMENT CLOSURE ENHANCEMENT

Amy Adams, PhD., P.Eng., P.E., Knight Piésold Ltd., North Bay, Ontario, Canada
Craig Hall, P.Eng., Knight Piésold Ltd., North Bay, Ontario, Canada
Ken Brouwer, P.Eng. P.E., Knight Piésold Ltd., Vancouver, British Columbia, Canada

ABSTRACT

Many tailings impoundments provide long-term storage for saturated, semi-fluid fine grained materials. Closure of these tailings impoundments represents an ongoing priority and a potential challenge for owners and professionals due to the potentially fluid nature of the impounded tailings in the event of a hypothetical dam breach.

One solution is to cap and shape the impoundment surface using waste rock or other materials to promote surface runoff, minimize dusting, and densify the underlying tailings through consolidation. Poor surface trafficability can hinder capping operations, and the cap itself may not fully mitigate the potential for deeper saturated tailings to fluidize and flow in the event of a dam breach.

This paper provides a case study for the decommissioning of the Nye Tailings Impoundment at the Stillwater Mine. The closure plan includes capping the loose saturated tailings with waste rock along with a cover of surface soils to reclaim the impoundment and create a stable landform. Initial staged construction of the closure cap will be accomplished using a geotextile to improve trafficability during placement of the initial rockfill capping layer.

A potential opportunity to enhance the closure of the impoundment can be achieved through the progressive development of a large waste rock storage area over the capped tailings surface. This closure enhancement would provide significant storage capacity for waste rock and reduce additional site disturbance during ongoing mine operations. As an added benefit, the waste rock load would promote consolidation, densification, and dewatering of the underlying tailings, further reducing the potential for the impounded tailings to fluidize and flow in the event of a hypothetical dam breach. This integrated waste management strategy for the Stillwater Mine will provide operational benefits for ongoing waste rock management while concurrently developing a stable reclaimed post closure landform to enhance the reclamation objectives for the mine site.

RÉSUMÉ

Plusieurs parcs de résidus permettent le stockage à long terme de matériaux à grain fin saturés et semi-fluides. La fermeture de ces bassins de retenue des résidus représente une priorité constante et un défi potentiel pour les propriétaires et les professionnels en raison de la nature potentiellement fluide des résidus enfermés dans l'éventualité d'une rupture hypothétique du barrage.

Une solution consiste à recouvrir et à façonner la surface du bassin de retenue à l'aide de roches stériles ou d'autres matériaux afin de favoriser le ruissellement de surface, de minimiser la formation de poussière, et de densifier les résidus sous-jacents par la consolidation. La faible aptitude à la circulation en surface peut nuire aux opérations de recouvrement, et la couverture elle-même pourrait ne pas atténuer complètement le risque que des résidus saturés plus profonds se fluidifient et s'écoulent en cas de rupture d'un barrage.

Cet article fournit une étude de cas pour la fermeture du parc de résidus de Nye à la mine Stillwater. Le plan de fermeture comprend le recouvrement des résidus saturés et lâches avec des roches stériles ainsi qu'une couverture de sols en surface pour réhabiliter le bassin de retenue et créer un relief stable. La construction en phase initiale de la

couverture de fermeture sera réalisée à l'aide d'un géotextile pour améliorer l'aptitude à la circulation lors de la mise en place de la couche de couverture initiale en enrochement.

Une possibilité d'améliorer la fermeture du bassin de retenue peut être atteinte grâce au développement progressif d'une vaste zone de stockage de stériles sur la couverture de la surface des résidus. Cette amélioration de la fermeture fournirait une capacité de stockage importante pour les stériles et réduirait la perturbation supplémentaire du site lors des opérations minières en cours. Comme avantage supplémentaire, la charge de roche stérile favoriserait la consolidation, la densification et la déshydratation des résidus sous-jacents, réduisant davantage le potentiel de fluidification et d'écoulement des résidus enfermés en cas de rupture hypothétique d'un barrage. Cette stratégie intégrée de gestion des déchets miniers pour la mine Stillwater apportera des avantages opérationnels à la gestion continue des stériles, tout en développant simultanément un relief stable après la fermeture pour améliorer les objectifs de remise en état du site minier.

1 INTRODUCTION

Tailings impoundments store fine grained materials that remain from mining operations after the economic minerals have been extracted from the ore during processing. The stored tailings often comprise fine-grained sand, silt, and clay sized rock fragments mixed with water which facilitates slurry transport and deposition into the tailings impoundment. The settled tailings deposit may consist of soft, saturated, semi-fluid tailings in a lined impoundment. Storage of soft, saturated tailings is associated with increased physical risks because of the potential mobility of the material. These risks must be managed throughout the life of the mine and at closure.

Many tailings impoundments have historically been constructed in natural valleys or lakes that were filled and then abandoned when mine operations ceased or the storage area reached its ultimate capacity. These abandoned tailings impoundments may present a long term risk to public safety and to the environment if conditions exist to emit dust, seep, or become physically unstable following an earthquake or storm event.

Mine closure, and correspondingly the closure of tailings impoundments, is increasingly becoming a key component that must be addressed in the early stages of planning, even before the first economic ore is extracted. International organizations such as the International Commission on Large Dams (ICOLD), the Canadian Dam Association (CDA), and the Mining association of Canada (MAC) have introduced guidelines and best practices for tailings impoundment design and closure (ICOLD, 2011 and 2013; CDA, 2014; MAC, 2008). In addition, many jurisdictions are codifying the need to address closure at all stages of mine planning and development (e.g. State of Montana, 2017; Province of Ontario, 2012). The ultimate goal of successful closure design is to provide for long term public safety and protect the environment including air, surface water, and groundwater resources.

Modern tailings impoundments are commonly closed in phases (CDA, 2014). The active closure phase begins once the impoundment reaches the ultimate capacity or the mine ceases production, and typically involves the construction of a closure cap to form a stable landform and minimize dusting. The capped tailings impoundment can then be reclaimed to other desirable land uses such as recreational or natural areas. The impoundment is closely monitored for a number of years during the active closure phase and will transition to passive closure once the long term physical and chemical stability of the impoundment has been demonstrated.

Demonstrating long term stability during closure for time periods ranging from decades to centuries is challenging given the complexity and uncertainty associated with future performance predictions. During the closure period, there is the potential for changes in the local environment, land use, meteoric conditions, topography, geology and state of practice. Increasing the density and reducing the flowability of the settled tailings within a tailings impoundment can reduce the consequence of a hypothetical dam breach and de-risk the tailings impoundment following closure.

This paper presents a case history for the tailings characterization, closure design, and proposed closure enhancement for the Nye Tailings Impoundment at the Stillwater Mine. The closure design involves the construction of a closure cap to stabilize the tailings surface and limit dusting. The closure cap will be constructed in stages to allow time for consolidation and strength gain while providing the mine with operational flexibility and capital cost distribution.

There is an opportunity to enhance the closure of the Nye Tailings Impoundment by placing additional waste rock over the capped tailings. Placement and storage of waste rock at the closed tailings impoundment will cause additional consolidation, dewatering, and densification of the underlying tailings. This will further stabilize and de-risk the closed tailings impoundment by reducing the potential for the tailings to flow in the event of a hypothetical dam breach event. Additional storage capacity for waste rock within areas that are already affected by the mine operations will reduce the need for additional disturbance and reduce the overall environmental impact of the ongoing mining operations. These improvements will lead to a reduction in the risks associated with the project, in both the operations and closure phases.

2 PROJECT OVERVIEW

The Stillwater Mine is an underground platinum and palladium mine located approximately 5 miles southwest of Nye, Montana (MT) (Figure 1). The mine in owned and operated by Sibanye Stillwater.

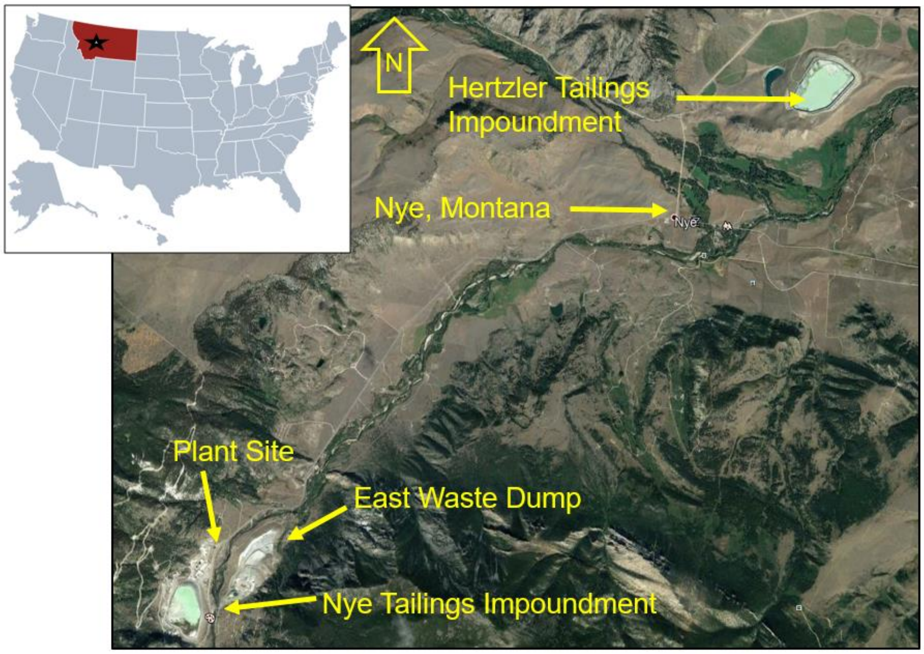

Figure 1 Stillwater Mine Location Map

The Stillwater Mine comprises a 3,000 tpd concentrator, the Nye Tailings Impoundment, the Hertzler Tailings Impoundment, the East Waste Dump and other ancillary facilities to support the operation. The mine site layout, including the Nye Tailings Impoundment and the East Waste Dump, is illustrated on Figure 2.

Waste rock from the mine operations is stored at the East Waste Dump. The coarse (sand) fraction of the tailings was historically pumped underground for cemented paste backfill to support the underground mining operations, while the finer tailings slimes were deposited into the Nye Tailings Impoundment located adjacent to the Stillwater River. A paste plant was commissioned in 1999 to produce paste using the whole tailings for underground backfill when required. During regular operations, the coarse (sand) fraction of tailings is pumped underground for sand backfill and the remaining tailings slimes slurry is pumped to the Hertzler Tailings Impoundment for storage. Occasionally whole tailings are used underground for paste backfill.

The Nye Tailings Impoundment was commissioned in 1987 and operated as the primary tailings impoundment until 2001. Tailings have only been intermittently deposited to the Nye Tailings Impoundment since the Hertzler Tailings Impoundment was commissioned in 2002. The Nye Tailings

Impoundment is near capacity and is currently utilized for operational management of water and tailings. The supernatant pond generally covers the northern half of the tailings impoundment, though the volume and surface area vary with meteoric conditions and the mine operations.

Figure 2 The Nye Tailings Impoundment (looking East)

The Nye Tailings Impoundment consists of an earthfill and rockfill embankment constructed using the downstream construction method to a maximum embankment height of approximately 136 ft (42 m). A typical cross section is shown on Figure 3. The minimum crest elevation is approximately El. 5,108 ft. (El. 1,557 m) and the maximum operating pond level is El. 5,104 ft. (El. 1556 m). The minimum crest width is approximately 30 ft. (9.1 m). The downstream slopes vary from 1.7H:1V to 2H:1V. The impoundment is lined with a 100 mil HDPE geomembrane liner to minimize seepage from the basin.

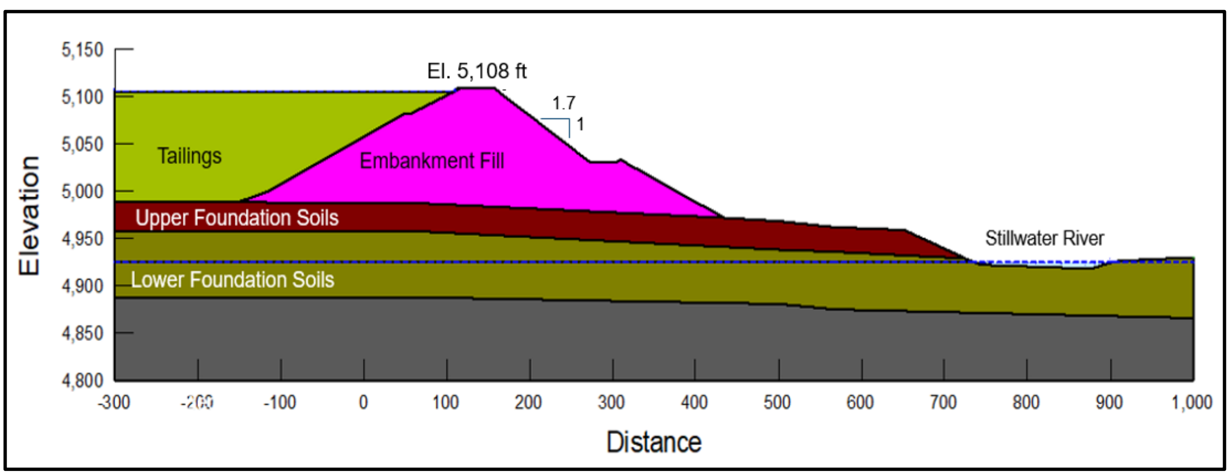

Figure 3 Typical Embankment Cross Section

3 SITE INVESTIGATIONS

The Nye Tailings Impoundment contains predominately fine grained tailings consisting of fine sands, silts, and clay sized rock fragments. Site investigations including geotechnical drilling and sampling, Cone Penetration Testing (CPT), and the installation of vibrating wire piezometers were completed to characterize the tailings to support the closure design. The site investigations were completed by ConeTec and included a total of 24 CPT soundings, 12 geotechnical drillholes, and two vibrating wire piezometer (VWP) installations. The site investigations locations are shown on Figure 4.

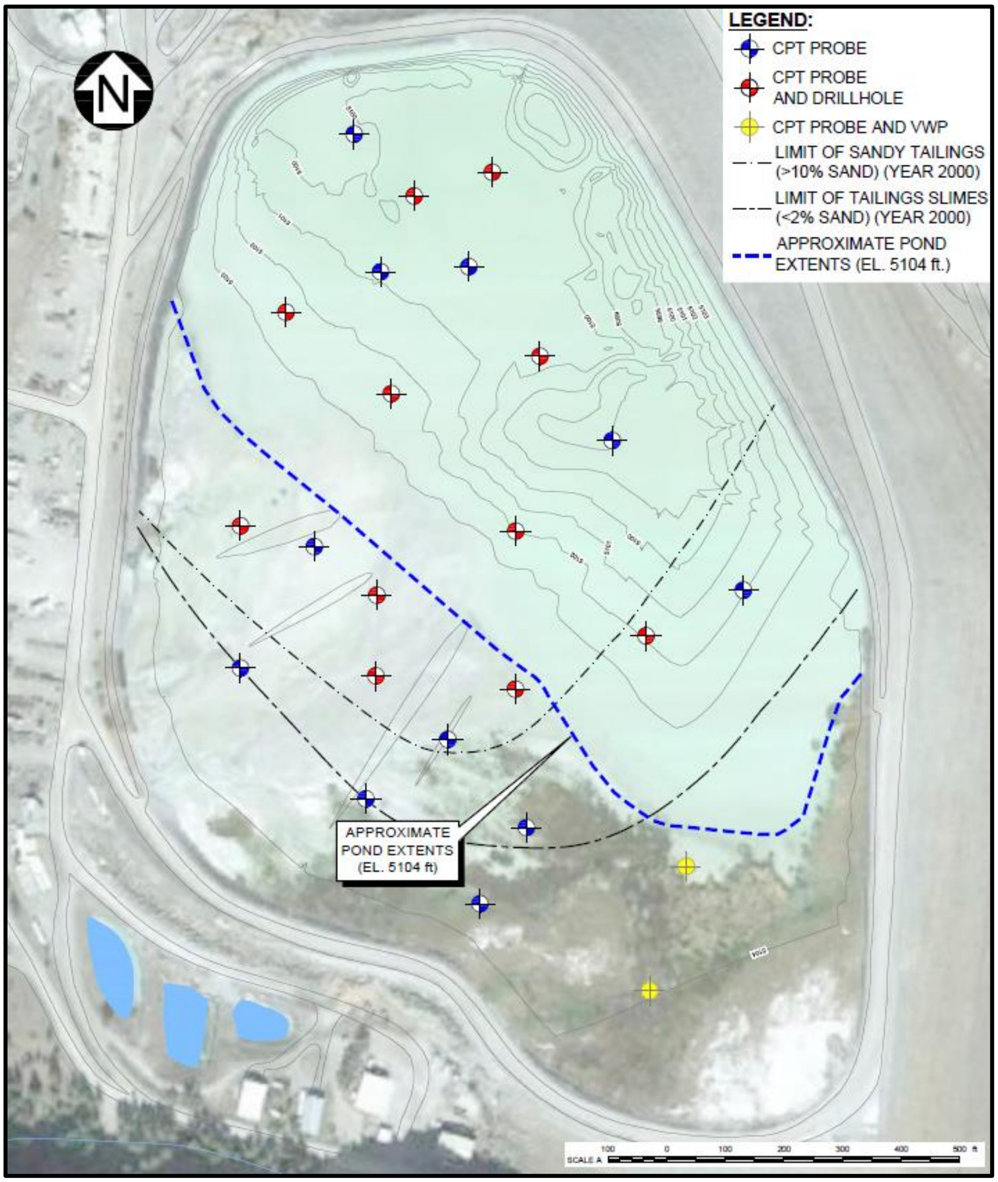

Figure 4 2016 and 2018 CPT Site Investigation Locations

Two separate site investigations were completed to characterize the tailings on the exposed tailings beach and below the supernatant pond as follows:

- **2016 Site Investigations** – Amphibious vehicle mounted equipment was used to complete site investigations over the exposed tailings surface at the southern end of the tailings impoundment. Freezing temperatures improved accessibility for the site investigations that were completed in December.
- **2018 Site Investigations** – Barge mounted equipment was used to complete the site investigations over the northern area of the tailings surface covered by the supernatant pond.

Pore Pressure Dissipation (PPD) testing and seismic response testing were completed at the majority of the CPT locations to measure the in situ pore water profile and the shear wave velocity profile. Drillholes were advanced to collect tailings samples and to complete shear vane testing using ConeTec's electronic Vane Shear Test (eVST) system. Undisturbed samples were collected in Shelby Tubes using a piston sampler to improve recovery in the soft tailings. Disturbed samples were collected to support rheological testing using an aqua lock sampler. Two vibrating wire piezometers (VWPs) were installed in the beach area during the 2016 site investigations to monitor pore water pressures within the tailings and during construction of the closure cap.

Laboratory index, strength, and deformation testing was completed on samples collected during the 2016 site investigation and is in progress for samples collected during the 2018 site investigation. The following laboratory testing was completed:

- Index testing was completed to characterize the in situ tailings including moisture content, particle size analysis, Atterberg limits (plasticity), specific gravity, and bulk unit weight
- Direct Simple Shear (DSS) testing was completed on 6 samples to evaluate the strength ratio under static loading conditions and the variation in strength with increasing effective stress.
- Constant Rate of Strain (CRS) consolidation testing was completed to measure the compressibility of the tailings, including the compression index, coefficient of consolidation, and hydraulic conductivity.
- Cyclic Direct Simple Shear (CDSS) testing was completed to evaluate the deformation during cyclic loading (i.e. earthquakes) as well as the post-cyclic strength ratio and potential for strength loss following liquefaction.
- Rheology testing including Vane Yield Stress, Boger Slump, and Transportable Moisture Limit (TML) testing was completed to evaluate the yield stress and flowability of the tailings at different moisture contents.

4 TAILINGS CHARACTERIZATION

The tailings in the Nye Tailings Impoundment are generally coarser at the south end of the impoundment and finer towards the north end of the impoundment. Sensitive fines were observed in the northern and north eastern areas of the impoundment while sandy silt and clayey silt was observed in the southern and south western areas of the impoundment. A generalized stratigraphic cross section trending south to north through the impoundment is illustrated on Figure 5. The phreatic surface within the tailings was observed at surface and the tailings are fully saturated and hydrostatic, consistent with normally consolidated tailings contained within a fully lined tailings impoundment.

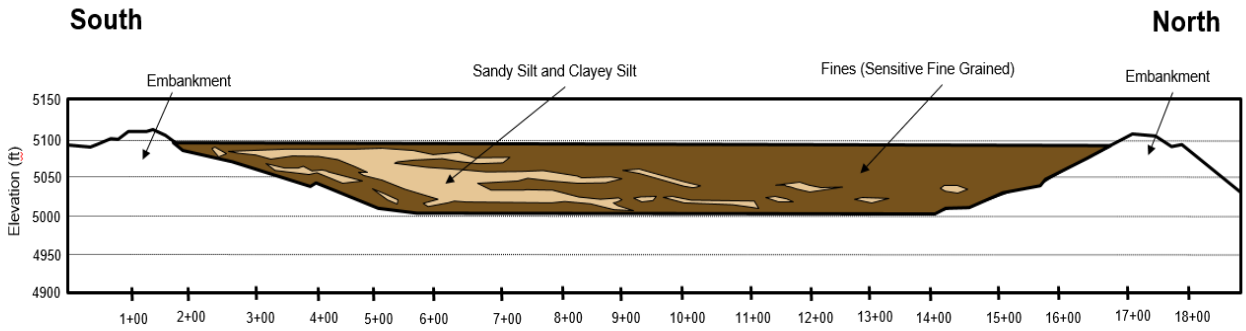

Figure 5 **Typical South-North Stratigraphic Section through the Nye Tailings Impoundment**

The dry unit weight increases with depth and ranges from approximately 35 pcf in the near surface loose sensitive fines to 85 pcf at depth within the sandy and clayey silt units. The tailings are low plasticity to non plastic and generally contain greater than 80% silt and clay sized particles. The specific gravity of the solids varies from 2.8 to 2.9.

The CPT data were interpreted using the commercial software CPeT-IT and CLiq (Geologismiki, 2014a and 2014b). Typical CPT results including measured tip resistance, sleeve friction, pore pressure, and interpreted undrained shear strength profiles are provided in Figure 6 for two CPT soundings. SCPT18-06 (light line) is characteristic of the sensitive fine grained tailing slimes that were observed predominately in the northern area of the impoundment (dark brown shading on Figure 5), while SCPT18-11 (dark line) is located approximately in the middle of the impoundment and is characteristic of the coarser tailings including sandy and clayey silt that was observed in the centre and southern area of the impoundment (lighter tan coloured zones on Figure 5).

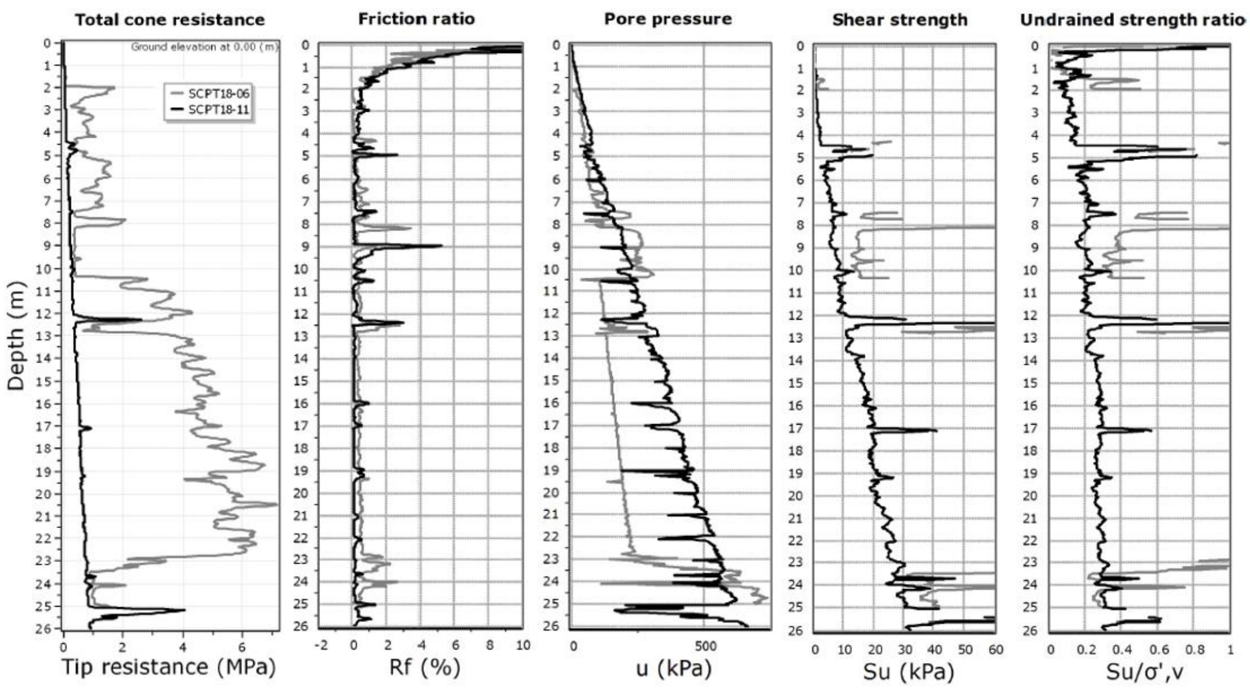

Figure 6 **Typical CPT Results**

The shear strength was interpreted from the CPT results based on correlations with field vane measurements and an estimated cone factor (N_{kt}) of 16. The undrained shear strength at surface ranges from less than 5 kPa to greater than 10 kPa and increases with depth consistent with a normally consolidated tailings deposit. The undrained shear strength ratio (Su/σ'_v) is in general agreement with the laboratory results from the 2016 site investigations suggesting a value of 0.21 at low effective stresses, reducing to 0.15 at stresses greater than 200 kPa. The tailings are sensitive and liquefiable as indicated by the low friction ratios. The liquefied undrained shear strength estimated from the CPT measurements is approximately 0.05. The interpreted liquefied undrained shear strength will be confirmed through ongoing laboratory CDSS testing.

5 CLOSURE PLAN

The closure plan for the Nye Tailings Impoundment has been developed to provide for long term public safety and to protect air, surface water, and groundwater resources at the site and on adjacent lands. The permitted closure plan includes construction of a closure cap over the tailings surface. The configuration of the closure cap during operations is illustrated on Figure 7.

The closure cap will include the following components:

- Placement of a geomembrane protection layer to maintain the integrity of the exposed geomembrane along the upstream slope of the embankment, and widen the crest by approximately 18 ft. (5.5 m) to improve accessibility for construction equipment.
- Reduction and ultimate removal of the supernatant pond.
- Placement of a closure cap to stabilize the tailings surface. The closure cap will consist of a 4 ft. (1.2 m) thick waste rock cap placed over a Mirafi 440 geotextile to improve trafficability. The waste rock will be placed in 2 ft. (0.6 m) thick lifts using a low ground pressure dozer.
- Installation of a sump and overflow spillway within the closure cap for surface water management during mine operations. Water that is collected in the sump during operations will be used to supplement process water in the concentrator or will be transferred to the Hertzler Tailings Impoundment.

Placing the closure cap over soft, saturated tailings may present challenging construction conditions. The closure cap will be constructed in 4 stages over 4 or more years to allow time for removal of the supernatant pond and corresponding consolidation and strengthening of the tailings surface. The stability of the tailings will be closely monitored during and following construction of the closure cap. Monitoring will include piezometers to measure the pore pressures in the tailings, and survey monuments and inclinometers to confirm the stability of the embankments. The closure process will be complete once the closure cap is constructed and the monitoring data suggests that the impoundment is stable.

Once completed, the closure cap will stabilize the upper layer of the tailings, create a trafficable surface, provide long term water management, and minimize dusting. The reclaimed impoundment embankments and the capped and closed tailings impoundment surface will form a stable landform.

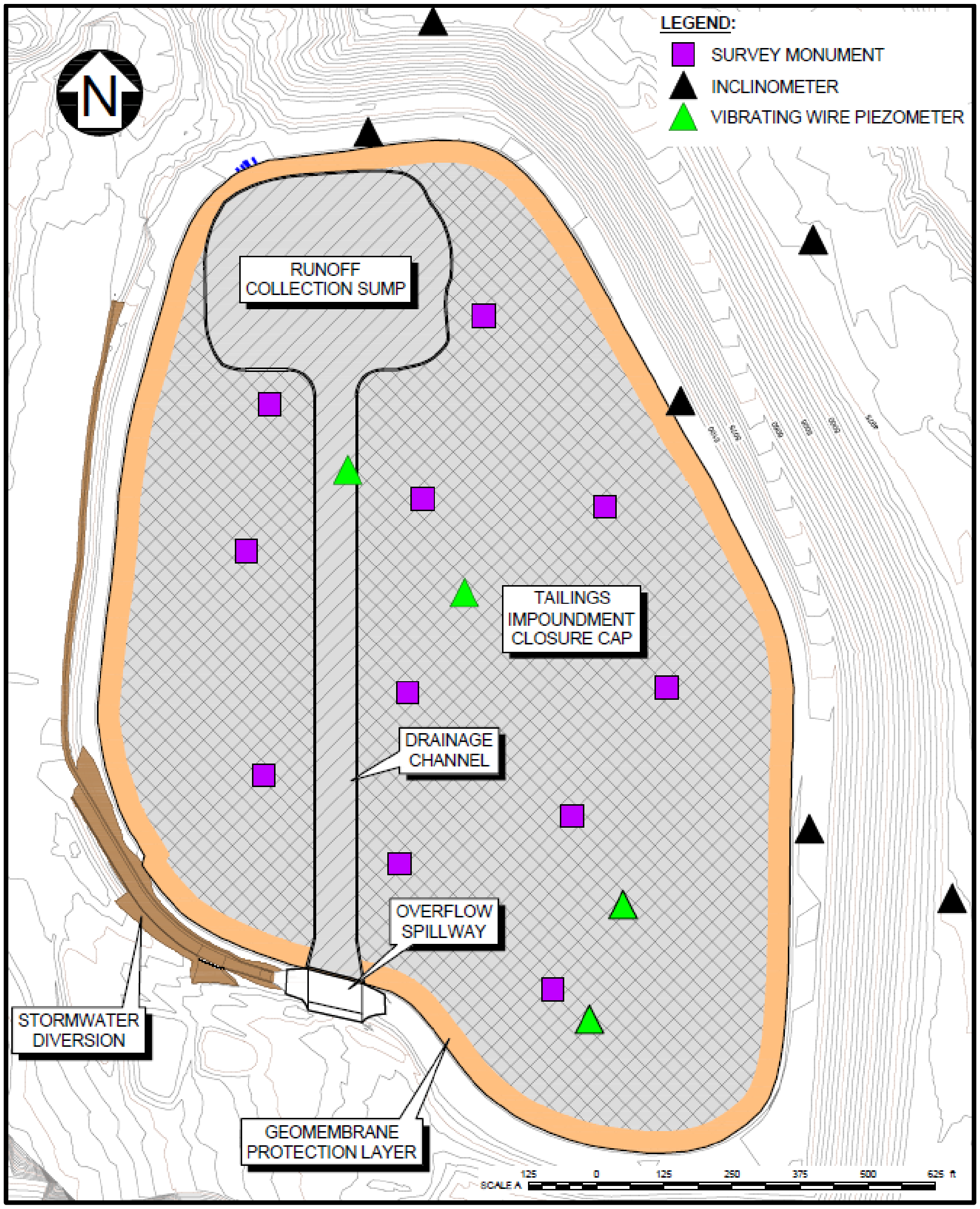

Figure 7 Closure Cap during Operations

6 CLOSURE ENHANCEMENT

6.1 Tailings Densification

The behaviour of settled tailings varies significantly with water content and density as illustrated by the Boger Slump rheological tests shown in Figure 8. The rheological testwork was completed on similar tailings material collected from a different mine site. As the water content of the tailings decreases from left to right, the density increases and the tailings become less flowable under static stresses.

Figure 8 Tailings Flowability

The testwork shown in Figure 8 was completed on the same tailings sample and illustrates the effects of changing the moisture content and density of the settled tailings. A similar relationship has been noted between strength at a given moisture content, and the tailings grain size and clay content (i.e. Adams, et al, 2017a). Finer grained tailings with higher percentages of clay are more stable than coarser, sandy tailings at the same water content.

The ground improvement technologies commonly used on large civil engineering projects can also be effectively applied to tailings impoundments to improve the performance of the settled tailings. Ground improvement technologies can be used to increase the density, reduce the water content, increase the shear strength, reduce the permeability, or induce other beneficial changes in the soil characteristics and behaviour.

Many different ground improvement technologies are available. A commonly used and effective ground improvement technology involves constructing a compressive load to induce consolidation in the underlying soil as illustrated on Figure 9. As the soil consolidates, the density will increase and the water content will decrease. This process may require long time periods to achieve the desired effect depending on the characteristics of the soil. Wick drains can be installed to enhance the soil drainage and accelerate the consolidation process. Adams et al (2017b) demonstrated the effectiveness of applying a consolidation load accelerated with wick drains to densify, dewater, and reduce the flowability of tailings through an instrumented test program installed at a mine site in central British Columbia.

The weight of the waste rock closure cap overtop of the Nye Tailings Impoundment will result in consolidation of the near surface tailings which will in turn increase the density and reduce the water content and flowability of the near surface tailings. This will create a stable landmass for the expected loading conditions. A portion of the settled tailings within the landmass may remain in a semi-fluid state and may have the potential to flow during a hypothetical dam breach event. Although the probability of a hypothetical dam breach is very low, additional tailings consolidation could be induced by increasing the thickness of the waste rock overtop of the closed tailings impoundment. The additional tailings consolidation would increase the density and reduce the flowability of the settled tailings. This will further reduce the consequences of a hypothetical dam breach and will de-risk the tailings impoundment following closure.

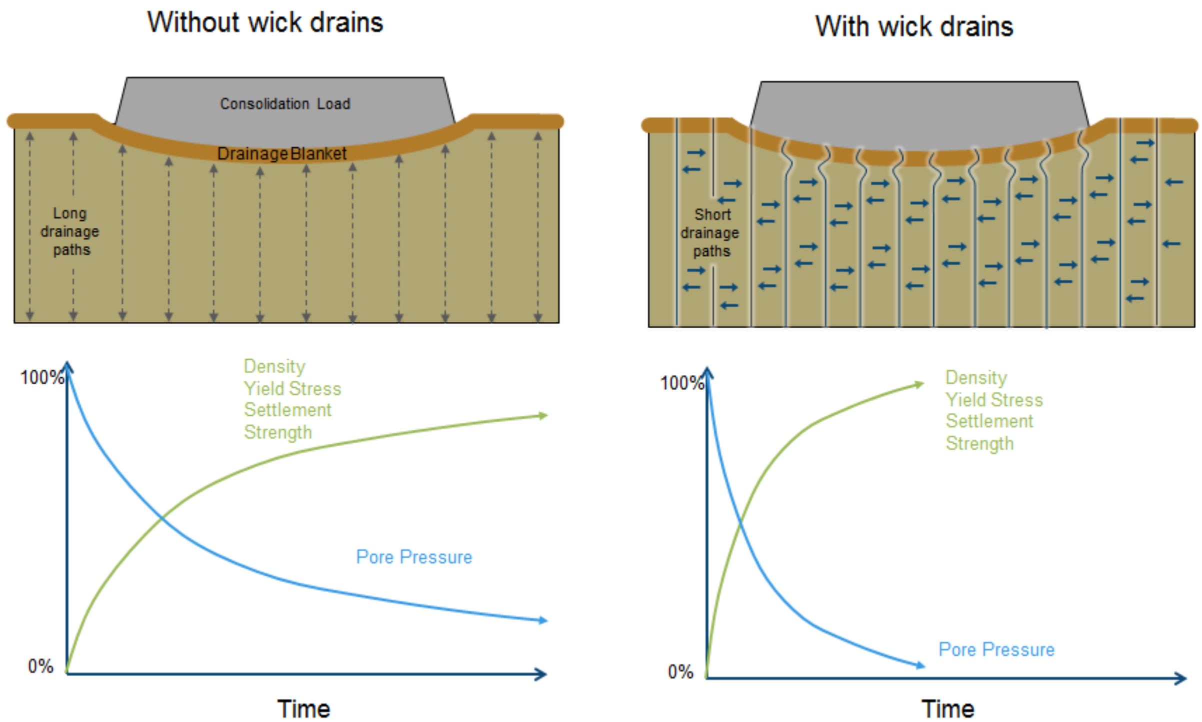

Figure 9 **Schematic ground improvement technology consisting of a compressive load constructed over tailings amended with wick drains.**

A preliminary consolidation analyses was completed to evaluate the potential effect of placing additional waste rock over the tailings impoundment closure cap. The analysis was based on the measured dry density, specific gravity, and assumed a compression index (Cc) of 0.5. The results summarized in Table 1 and indicate that significant additional settlement and dewatering (up to 6 times greater) may be realized if the waste rock thickness was increased to 50 ft (15 m) compared to the 4 ft. (1.2 m) thick closure cap. The estimated settlement and dewatering would increase by an additional 50% if the thickness of the waste rock were increased to 110 ft. (34 m).

Table 1 **Magnitude of Consolidation Settlement and Dewatering**

		Waste Rock Thickness		
Quantity	**Unit**	**4 ft (1.2 m)**	**50 ft (15 m)**	**110 ft (34 m)**
Vertical Settlement	ft.	2	12	17
	m	0.6	3.7	5.2
Volume of Interstitial Water Released	M gal	15	100	140
	m^3	57,000	380,000	530,000

The results of the analysis suggest that additional consolidation will increase the density and reduce the water content of the tailings, thus reducing the flowability of the settled tailings during a hypothetical dam breach event. Reducing the potential for the tailings to flow also reduces the potential consequences of a future event that may de-stabilize the tailings impoundment. This effectively reduces the long term risk associated with the closed impoundment. Additional work including consolidation testing, rheological testing, and 2D deformation modelling is in progress to confirm the preliminary estimates.

6.2 Future Waste Rock Storage

The proximity of the Nye Tailings Impoundment to the underground mine makes it an ideal location for future waste rock storage for the ongoing operations at Stillwater Mine. Re-purposing the closed Nye Tailings Impoundment as a Waste Rock Storage Area (WRSA) will achieve the following objectives:

- Reduces the overall disturbance area required to support ongoing mine operations
- Provides a new waste rock storage area located within a short haul distance from the shaft and underground portals
- Enhances the closure of the Nye Tailings Impoundment by further consolidating, densifying, and dewatering the tailings contained within the closed impoundment to further reduce the flowability of the settled tailings during a hypothetical dam breach event.

A conceptual section illustrating the potential waste rock storage arrangement overtop of the Nye Tailings Impoundment and on the adjacent valley slope is illustrated on Figure 10.

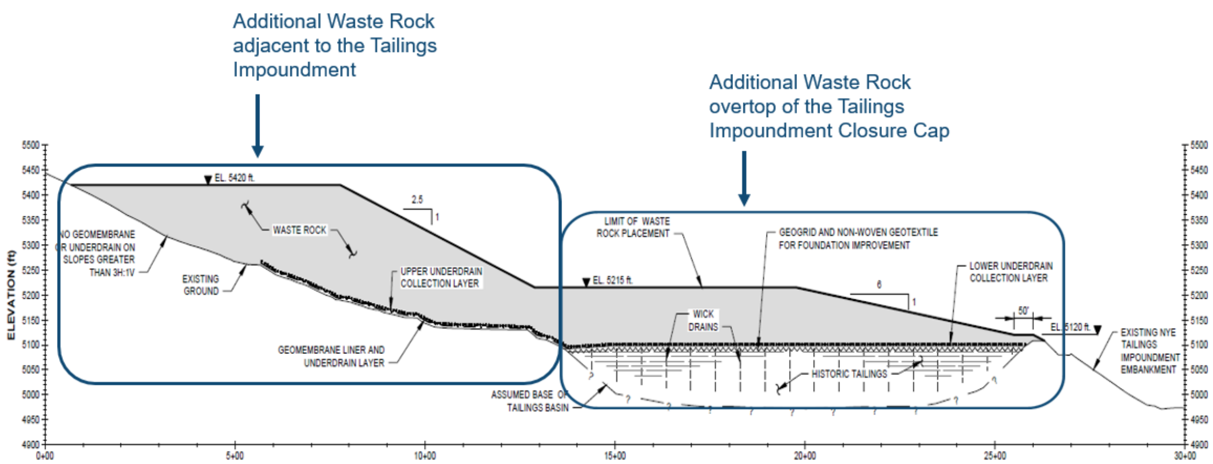

Figure 10 **Conceptual Closure Enhancement – Waste Rock Storage Area**

The total mass and placement geometry of waste rock that could potentially be stored over the closed Nye Tailings Impoundment will depend on the strength, deformability, and drainage characteristics of the tailings, the rate of waste rock placement, and the ability of the impoundment embankment to support the additional load. The waste rock placement schedule will need to allow time for pore pressures that develop in the underlying tailings to dissipate. Wick drains may be necessary to enhance drainage and accelerate pore pressure dissipation.

An example of the potential consequence of loading settled tailings too quickly is the Pinto Valley Tailings Impoundment failure that occurred in 1997 (Hansen and LaFronz, 2000). Waste rock was being placed over a decommissioned tailings impoundment in 50 ft. (17 m) thick lifts. The dam failed during placement of the second lift. The failure resulted in the release of tailings and waste rock which flowed viscously and intercepted Pinto Creek located approximately 2,000 ft downstream of the impoundment. The failure was potentially related to rapid, undrained loading caused by the placement of waste rock over the saturated tailings.

The potential response in the tailings as a result of the closure cap construction, and further placement of waste rock over the closed tailings impoundment is conceptually illustrated on Figure 11. Currently, the tailings at depth are consolidated under self weight and hydrostatic pore pressures and have a soft to firm consistency. Construction of the closure cap is expected to substantially increase the density and decrease the water content in the near surface tailings, but may have a much lesser impact on the deeper, denser tailings. The placement of additional waste rock over the capped tailings impoundment will result in additional loading over the entire tailings volume and will induce further consolidation, densification, and dewatering at depth. Reducing the water content of the tailings will result in an increase in yield strength and a reduction in the potential to flow, as illustrated in Figure 8 based on rheological testing completed on similar tailings.

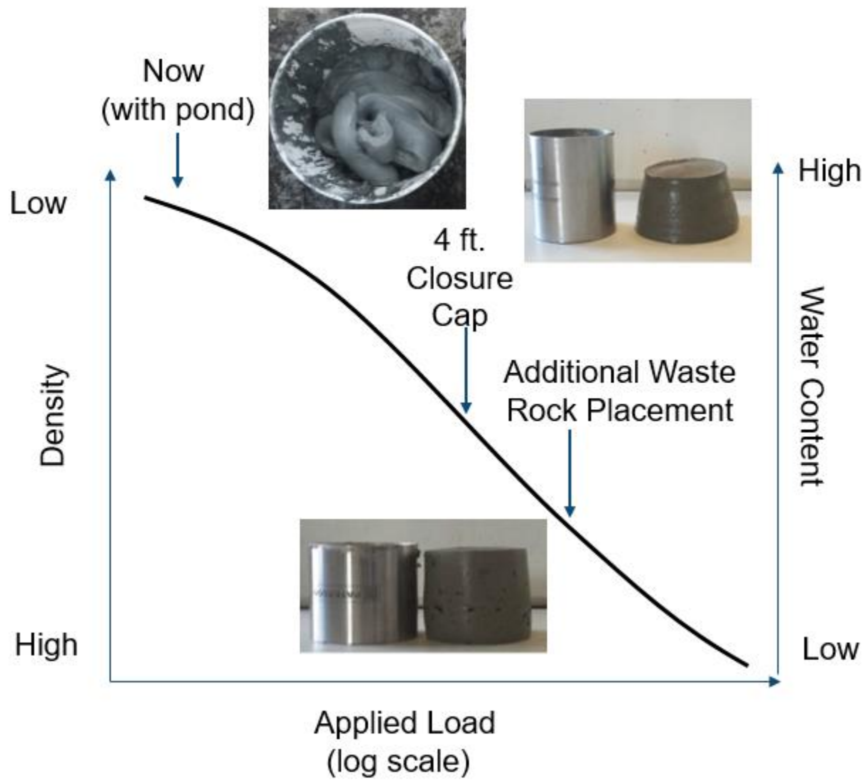

Figure 11 **Tailings Rheology Continuum at Closure**

It is important to note that the tailings will remain normally consolidated despite placement of additional waste rock. Over long periods of time the tailings may become slightly over consolidated due to ongoing creep (secondary compression). However, the tailings void ratio is expected to remain above the critical state line. As a result, there will still be potential for the tailings to contract and liquefy in response to a triggering event. Reducing the volume of water stored within the tailings mass will significantly reduce the potential for the tailings to flow.

Analyses are being completed to evaluate the stable waste rock storage configuration and to estimate the deformations that may occur within the tailings mass as a result of placement of additional waste rock over the Nye Tailings Impoundment closure cap. The additional waste rock will be placed in stages and the observational approach will be implemented to carefully monitor the performance of the facility. The waste rock will be placed in a controlled manner and at a rate to allow time for pore pressure dissipation and strength gain, thus mitigating the potential for undrained failures. Instrumentation and monitoring including vibrating wire piezometers, settlement monuments, slope inclinometers, and regular surveying will be used to monitor the tailings response and embankment performance. The construction staging and waste rock placement rate placement rate will be adjusted as necessary to manage pore pressures within the tailings and to provide for a stable storage facility during operations and closure. Consolidation and deformation within the underlying tailings mass will enhance the overall stability and lower the long-term consequences associated with a hypothetical dam breach event, effectively de-risking the tailings impoundment post closure.

7 SUMMARY AND CONCLUSIONS

The Nye Tailings Impoundment is near capacity and is currently being used to provide operational flexibility for process water and tailings management at the Stillwater Mine. The tailings are contained by a 136 ft (42 m) high embankment located adjacent to the Stillwater River. The closure plan for the Nye Tailings Impoundment has been developed to provide for long term public safety and to protect air, surface water, and groundwater resources at the site and on adjacent lands. The permitted closure plan includes construction of a closure cap over the surface of the tailings. Following construction of the closure cap, it is envisioned that the Nye Tailings Impoundment will provide storage for waste rock generated from the ongoing mining operations.

The closure concept for the impoundment will include the construction of a 4 ft. (1.2 m) thick rockfill cap to provide a cover to control erosion, provide surface water management, and provide a surface that is suitable for future use of the land. A sump and overflow spillway will be established within the closure cap to provide water management during the ongoing mine operations. A closure spillway will be installed for long-term water management at final closure. Water that is collected in the sump during operations will be used to supplement process water in the concentrator or will be transferred to the Hertzler Tailings Impoundment.

Construction of the closure cap over soft, saturated tailings may be challenging. The construction schedule will be staged to allow time for removal of the existing supernatant pond and corresponding consolidation and strengthening of the tailings surface. A high strength woven geotextile will be placed over the tailings surface to provide trafficability during initial construction of the closure cap. The settled tailings and impoundment will be closely monitored during and following construction of the closure cap.

The Stillwater Mine will continue to operate following construction of the Nye Tailings Impoundment closure cap. The proximity of the Tailings Impoundment to the underground mine makes it an ideal location for future waste rock storage. The placement of additional waste rock is expected to cause ongoing consolidation, dewatering, densification and strengthening of the tailings which will enhance the closure for the Nye Tailings Impoundment by further consolidating the tailings and reducing the flowability of the settled tailings during a hypothetical dam breach event. Analyses are currently underway to identify the stable waste rock storage area configuration and to evaluate the expected deformations under static and cyclic loading conditions. This integrated waste management strategy for the Stillwater Mine will provide operational benefits for ongoing waste rock management while concurrently developing a stable reclaimed post closure landform to enhance the reclamation objectives for the mine site.

8 REFERENCES

Adams, A., Brouwer, K., Davidson, S., 2017b. *Best Available Technologies to Stabilize a Historical Tailings Impoundment.* Proceedings of the Tailings and Mine Waste Conference, Banff, Alberta. November 2017.

Adams, A., Friedman, D., Brouwer, K., and Davidson, S., 2017a. *Novel Application of Proven Best Available Technologies to Stabilize a Historical Tailings Impoundment.* Canadian Dam Association Annual Conference, Kelowna, British Columbia. October 16 to 18.

Canadian Dam Association (CDA), 2014. *Technical Bulletin - Application of Dam Safety Guidelines to Mining Dams.*

Geologismiki Geotechnical Software (Geologismiki). 2014a. CLiq2. Version 2. Serres, Greece.

Geologismiki Geotechnical Software (Geologismiki). 2014b. CPeT-IT. Version 2. Serres, Greece.

Hansen, L.A. and LaFronz, N.J., 2000. *Stabilization of the Pinto Valley Tailings Impoundment Slide.* Tailings and Mine Waste 2000.

International Commission on Large Dams (ICOLD), 2011. "Improving Tailings Dam Safety – Critical aspects of management, design, operation, and closure". Bulletin 139.

International Commission on Large Dams (ICOLD), 2013. "Sustainable design and post-closure performance of tailings dams". Bulletin 153.

Mining Association of Canada (MAC), 2008. "Towards Sustainable Mining – Mine Closure Framework". November 19.

Province of Ontario (ON), 2012. Mine Development and Closure under Part VII of the Mining Act, R.S.O 1990, Chapter M.14.

State of Montana (MT), 2017. Montana Code Annotated (MCA) Title 82. Minerals, Oil, and Gas Chapter 4. Reclamation. Part 3. Metal Mine Reclamation.