

Whistle Mine Backfilled Pit Dry Cover Case Study – Performance Based on Six Years of Field Monitoring

B.K. Ayres¹, L. Lanteigne², M. O’Kane³, and G. Meiers⁴

¹O’Kane Consultants Inc., Saskatoon, SK, CANADA, bayres@okc-sk.com

²Vale Ontario Operations, Copper Cliff, ON, CANADA, llanteigne@vale.com

³O’Kane Consultants Inc., Calgary, AB, CANADA, mokane@okc-sk.com

⁴O’Kane Consultants Inc., Fredericton, NB, CANADA, gmeiers@okc-sk.com

Abstract

Decommissioning of the Whistle Mine property near Sudbury, Ontario included backfilling an open pit with acid-generating waste rock stored on the site. A multi-layer dry cover system was constructed over the backfilled pit between June 2004 and November 2005. The primary design objective of the pit cover system is to limit the influx of atmospheric oxygen to the underlying waste rock by maintaining the barrier layer at or near saturation at all times, thereby creating an oxygen ingress barrier. Instrumentation was installed during construction of the cover system to facilitate evaluation of its performance over time under site-specific climate conditions. The pit cover system is performing as expected based on field data collected over the past six years. The influx of atmospheric oxygen and meteoric water to the waste rock backfill has been substantially reduced since construction of the cover system. The cover system is geomorphically stable and supports the growth of various native plant species.

Key Words: acidic drainage, compacted clay layer, oxygen ingress barrier, landform design

Introduction

Vale, Ontario Division (Vale) has completed decommissioning the Whistle Mine property, which was a satellite ore deposit for their Copper Cliff Canada operations. Over the life of the mine approximately 7 million tonnes of waste rock was generated and stockpiled in two waste rock dumps (WRDs) adjacent to the open pit. The Whistle Mine waste rock is composed of approximately 80% mafic norite, which has an average sulphide content of 3% (MEND, 1997). After considering a number of closure options, Vale decided to relocate all waste rock to the open pit and cover it with a multi-layer soil cover system. The rationale for relocating the waste rock to the open pit is detailed in Ayres *et al.* (2007). This paper reviews the design and construction of the pit cover system, but focuses on performance of the pit cover system based on six years of field monitoring data.

Site Background

The Whistle Mine site is located approximately 30 km north of Sudbury, ON. The climate in the area is semi-humid, characterized by wetter conditions in the fall, winter, and spring and drier conditions during the hot summer months. The site has a mean annual precipitation and potential evaporation of 900 mm and 520 mm, respectively. Approximately 30% of the annual precipitation occurs as snow.

The Whistle Mine nickel / copper orebody, originally discovered in 1897, was developed as an open pit mine in 1988. The open pit covered an area of 9.7 ha and due to natural relief in the area, sloped an average of 13% from the north to south perimeter. Mining and production of waste rock at Whistle Mine occurred between 1988-1991 and 1994-1998. All waste rock stockpiled on surface was relocated to the open pit between July 2000 and December 2001. Lime was added during waste rock backfilling to mitigate the effect of stored acidity on seepage waters discharged from the site. The collection and subsequent treatment of contaminated seepage water emanating from the former waste rock storage areas and backfilled pit is on-going.

Design of the Backfilled Pit Cover System

Geochemical modelling was conducted to assess the effectiveness of various cover system options on long-term water quality of the backfilled pit (SENES, 2003). Based on modelling predictions, the design objectives for the backfilled pit cover system are to:

1. Reduce ingress of atmospheric oxygen to the underlying waste material to the minimum acceptable level as determined by geochemical modelling;
2. Reduce entry of meteoric water to the underlying waste material to less than 5% of annual precipitation at the site; and
3. Provide a medium for establishing a sustainable vegetation cover that is consistent with the final land use of the area.

The first two design objectives can be achieved by incorporating a layer of fine-textured material in the cover system (MEND, 2004). The objective is to utilize the capillary barrier concept to assist with maintaining near saturation within the fine-textured layer under all anticipated climatic conditions, which in turn limits the ingress of oxygen due to low oxygen diffusion conditions. In addition, the lower hydraulic conductivity of the fine-textured soil layer (usually compacted), combined with the lower capillary barrier, provides a control on net percolation to the underlying waste material. A multi-layer system incorporating a fine-textured soil layer, hereafter referred to as a 'barrier layer', was selected as the preferred type of cover system for the backfilled pit at Whistle Mine.

Cover system trials were constructed at Whistle Mine in 2000 to obtain site-specific information on construction feasibility and potential performance of alternate cover systems. Three experimental cover systems were constructed over acid-generating waste rock, with each cover having a different barrier layer overlain by 0.9 m of sand and gravel. The trialed barrier layers included compacted silty-clay, compacted sand-bentonite, and a geosynthetic clay liner (GCL). Instrumentation was installed to monitor climatic parameters, gaseous O₂ and CO₂ concentrations as well as moisture and temperature conditions within the cover and waste materials, and finally, net percolation. Further details on the cover trials can be found in Ayres *et al.* (2002) and Adu-Wusu *et al.* (2002).

Based on estimated construction costs and requirement for an adequate oxygen barrier, a source of local clay was chosen as the material for the pit cover barrier layer. Laboratory testing of the borrow material revealed the clay has low to medium plasticity and a saturated hydraulic conductivity of 5×10^{-8} cm/s when compacted to 95% of standard Proctor maximum dry density.

Cover design soil-plant-atmosphere numerical modelling

The two-dimensional (2-D) soil-plant-atmosphere model VADOSE/W (Krahn, 2004) was used to evaluate performance of several multi-layer cover system alternatives. Field response simulations were completed prior to a preliminary and detailed cover design modelling program, to develop a calibrated model based on data collected from the Whistle Mine cover system field trials. The preliminary modelling program consisted of one-dimensional simulations to determine the optimal thickness for each cover layer, based on maintaining a barrier layer degree of saturation above 85% after three consecutive dry years. Results from preliminary modelling indicated that the preferred cover system design with respect to oxygen ingress was a 0.45 m thick compacted clay barrier layer and a 1.2 m thick growth medium layer.

Two-dimensional simulations of the longest cross-section through the backfilled pit surface were required to confirm suitability of the preliminary cover design in terms of reducing both oxygen ingress and net percolation. The predicted barrier layer degree of saturation remained above 96%, and oxygen diffusion coefficients for the barrier layer at every point along the modelled section were lower than the minimum required value (see Figure 1). The predicted cumulative net percolation was <2% of precipitation for the preferred cover design with most occurring in the runoff collection and sedimentation pond area. Additional details on the soil-plant-atmosphere modelling program are provided in Ayres *et al.* (2005).

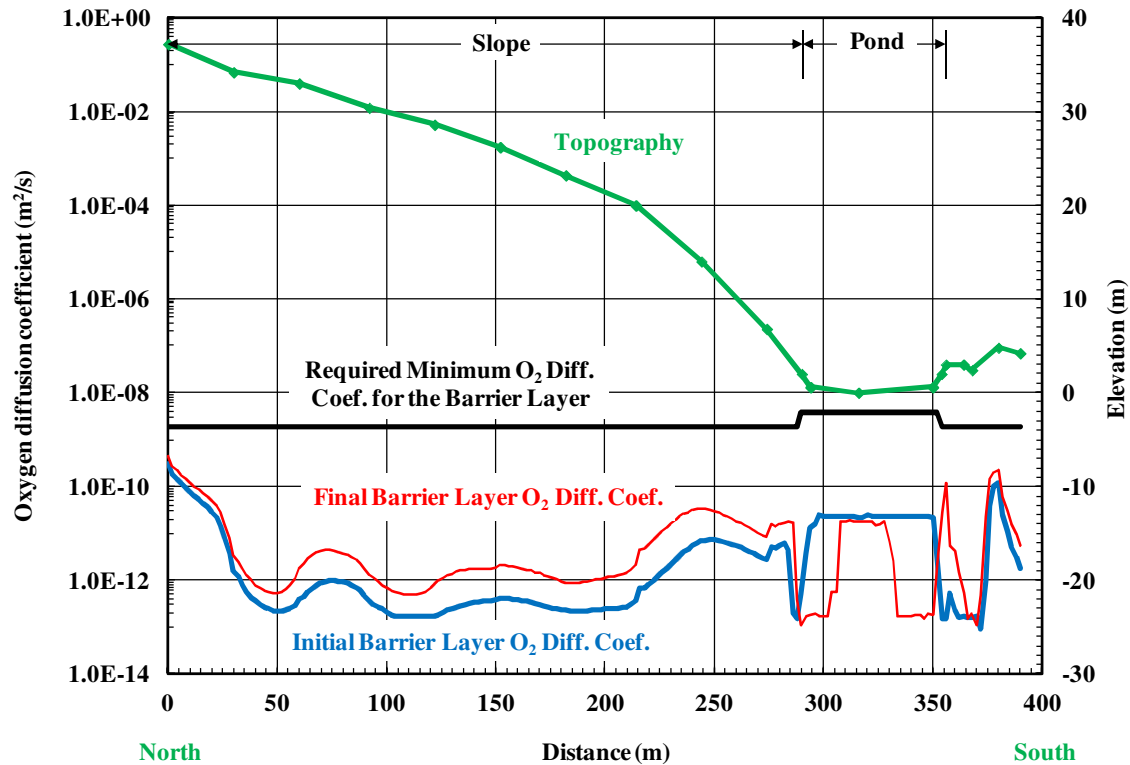


Figure 1. Initial and final predicted oxygen diffusion coefficients for the barrier layer for the driest climate year on record (from OKC-MDH, 2004).

Final cover system design

Based largely on results of soil-plant-atmosphere modelling, the final cover system design for the backfilled pit consists of a 0.1 m sand and gravel levelling layer, a geosynthetic separation fabric (geotextile), a 0.45 m barrier layer comprised of compacted clay, and a minimum of 1.2 m of sand and gravel for a protective / growth medium layer. The primary purpose of the levelling layer is to provide a suitable foundation for the geotextile, but it also acts as a capillary break layer. A thin layer of topsoil was admixed to the cover surface to assist with growth of a seeded mixture of native grass and legume species.

Design of the Pit Cover Landform

Erosion and landform evolution numerical modelling was conducted to assist in designing a runoff management system and final landform for the pit cover system. The WEPP model (Flanagan and Livingston 1995) was used to estimate erosion rates from the cover system, while the SIBERIA model (Willgoose *et al.* 1991) was used to predict long-term landform evolution. A 100-year climate database was developed using available data from the Sudbury Airport Environment Canada weather station and extrapolation from equivalent areas in the region. The surface of the cover system was assumed to be bare of vegetation for all WEPP simulations, which was felt to be reasonable over the short term and conservative over the long term. WEPP output data were used to generate parameters for the SIBERIA landform evolution model. Two final landform alternatives were evaluated for the pit cover system.

The first landform alternative that was examined consisted of a highly engineered system to manage runoff generated from spring snowmelt and rainfall events. This landform has lateral diversion berms to capture runoff water and divert it laterally to one of two collection channels oriented parallel to the slope. Output from the SIBERIA model (see Figure 2) shows breaching of the lateral berms, development of gullies and rills, and overall failure of the landform over a 100-year period.

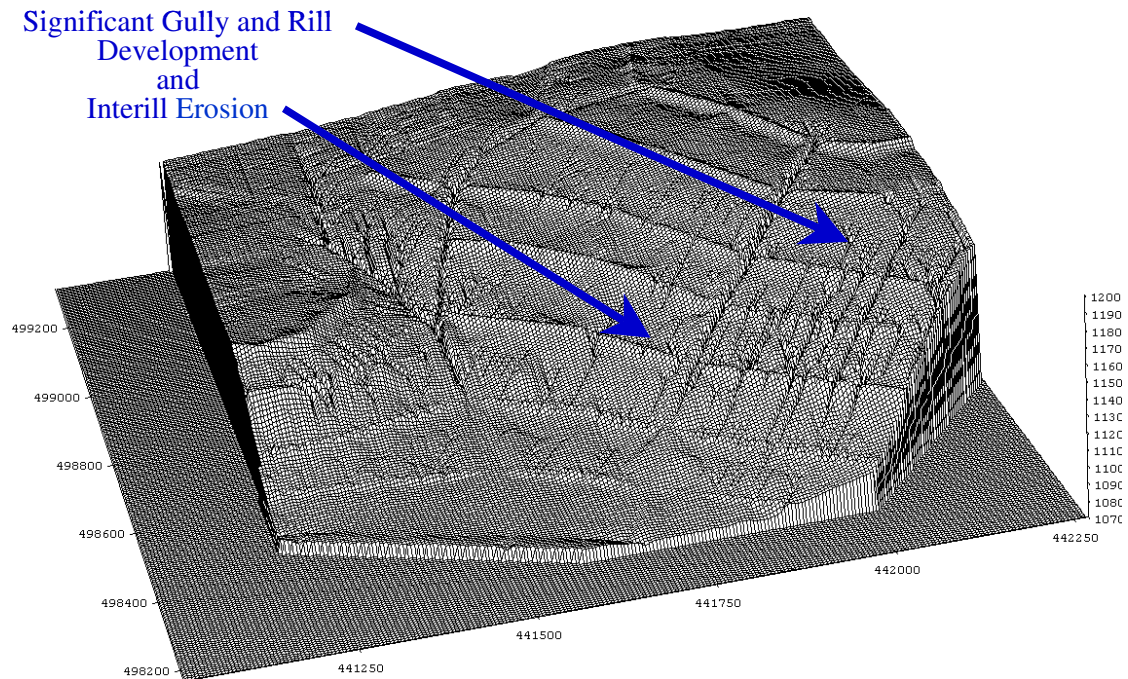


Figure 2. Predicted landform evolution of the first landform alternative for the pit cover system after 100 years (from OKC-MDH, 2004).

The second alternative and ultimately constructed final landform consists of a number of catchments oriented parallel to the slope in a pattern of crests and troughs (see Figure 3). To achieve this topography, an additional 0.6 m of sand and gravel was placed in the crests. This micro-topography is beneficial for revegetation efforts because snow accumulates in the troughs, thereby increasing soil moisture levels; wind velocities are also reduced across the ground surface, thus reducing potential erosion of topsoil and grass seeds. The objective was to develop a landform with catchments more analogous to natural systems.



Figure 3. Constructed final landform over the backfilled pit at Whistle Mine as of mid-2006; also shows the cleared waste rock storage areas (top left and right) and water treatment facility (bottom centre).

In conjunction with design of a sustainable final landform, a system was required to minimize erosional damage to the pit cover and manage suspended sediment in runoff waters over the short and long terms. Progressively higher levels of erosion protection were used in hillslope channels as contributing area and associated design flow velocities increased towards the south. A series of three containment ponds were designed at the south end of the backfilled pit for management of suspended sediments in the pit cover runoff water. The base of each pond consists of a minimum 0.6 m layer of compacted clay and slopes gradually east to west, towards individual hydraulic control structures (overshot gates) and the final discharge point (Post Creek wetlands). It is anticipated that the runoff ponds will be decommissioned in the near future given a mature grass cover has established itself and soil loss from the cover is minimal. A wetland habitat has already established in the area of the ponds (see bottom photo in Figure 4), which will provide long-term attenuation of peak surface flows and diversified habitat for wildlife.

Construction of the Pit Cover System

Construction of the pit cover system was completed during snow-free periods of 2004 and 2005. A portable soil testing laboratory was on-site for duration of construction to routinely check that borrow materials conformed to specifications. Testing of completed work areas, particularly the barrier layer, consisted of *in situ* density, water content and permeability measurements, as well as surveying to verify that the specified minimum layer thickness was achieved. Figure 4 shows different views of pit cover construction. Based on inspections by the engineer and records of construction, the Whistle Mine pit cover system and ancillary infrastructure were constructed in general accordance to the design and specifications.



Figure 4. Photos showing cleaning of the pit perimeter prior to barrier layer construction (top left), cross-slope ripping of topsoil into the granular cover material (top right), and the finished pit cover in July 2008 with the Collection Pond overshoot gate in the foreground (bottom left).

Cover System Performance Monitoring

A performance monitoring system was installed for the Whistle Mine pit cover to achieve the following objectives:

1. Obtain a water balance for the site;
2. Develop confidence with all stakeholders with respect to cover system performance from a micro- and macro-scale perspective;
3. Enhance understanding of key characteristics and processes that control cover system performance; and
4. Track evolution of the cover system in response to various site-specific physical, chemical, and biological processes.

The system includes a meteorological station, two weirs for measuring runoff flows, two automated stations for monitoring net percolation rates and *in situ* moisture and pore-gas concentrations within and below the cover system, 13 secondary stations to monitor spatial performance, and four groundwater monitoring wells. Collection of data from all monitoring sites, shown in Figure 5, has been on-going since the fall of 2005. Key data collected over the past six years are presented below to illustrate performance of the pit cover system.

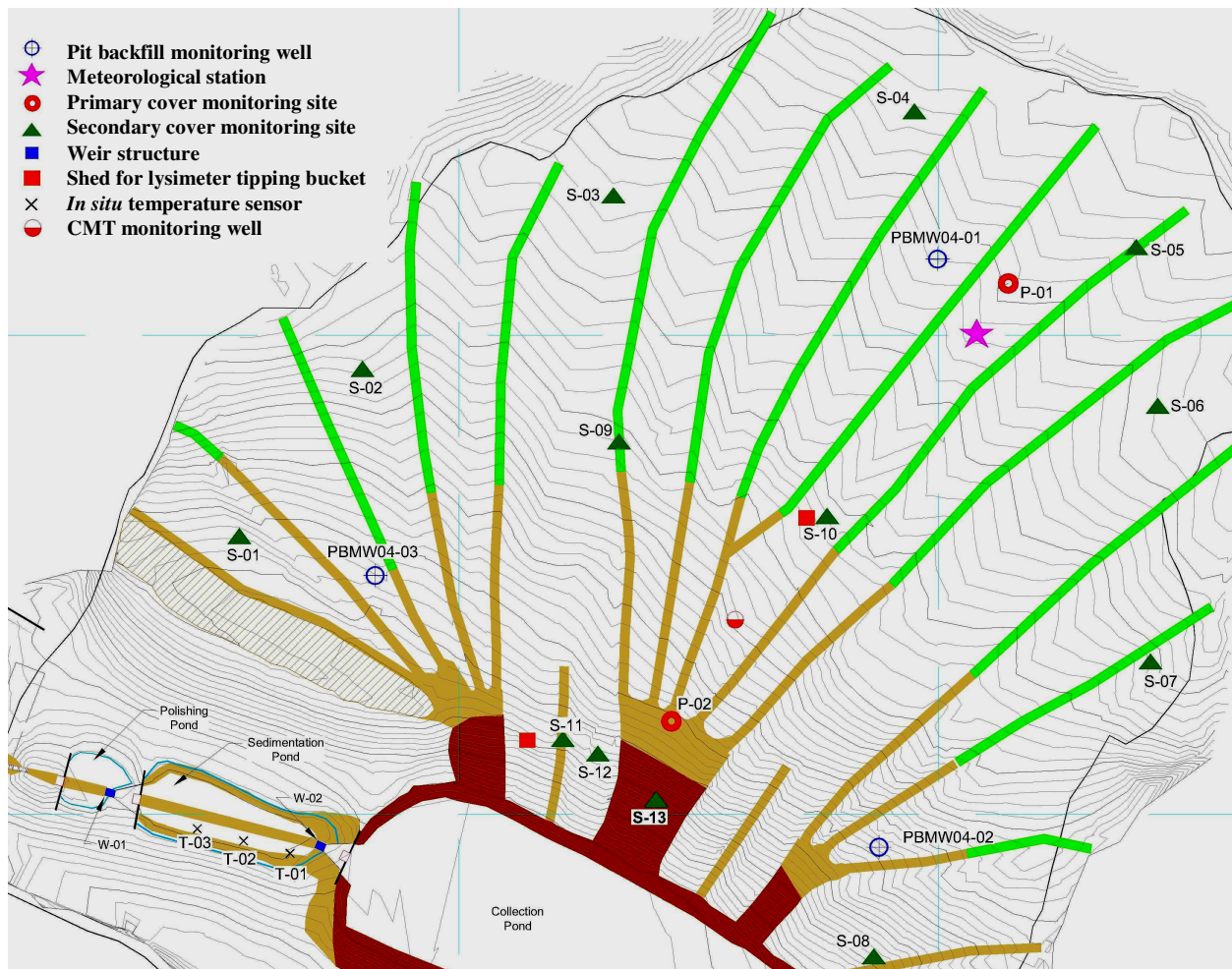


Figure 5. Location of monitoring stations on the pit cover system (from OKC-MDH, 2006).

Oxygen ingress to the backfilled waste rock

The primary design objective of the Whistle Mine pit cover is to limit oxygen diffusion into the underlying reactive waste rock by maintaining the compacted clay layer at or near saturation at all times, thereby creating an oxygen ingress barrier. The diffusion of oxygen through a soil layer will be minimized if the degree of saturation remains greater than 85% to 90% (Nicholson *et al.* 1989; Mbonimpa *et al.* 2003). Volumetric water content values measured at the P-01 upslope, crest location, and the P-02 downslope, drainage channel location allow for the calculation of the degree of saturation in the top and bottom of the barrier layer (see Figure 6). Degrees of saturation in the barrier layer at these two monitoring locations have remained above 94% since 2006. Maintenance of near-saturated conditions in the barrier layer confirms what was predicted during the cover design modelling program.

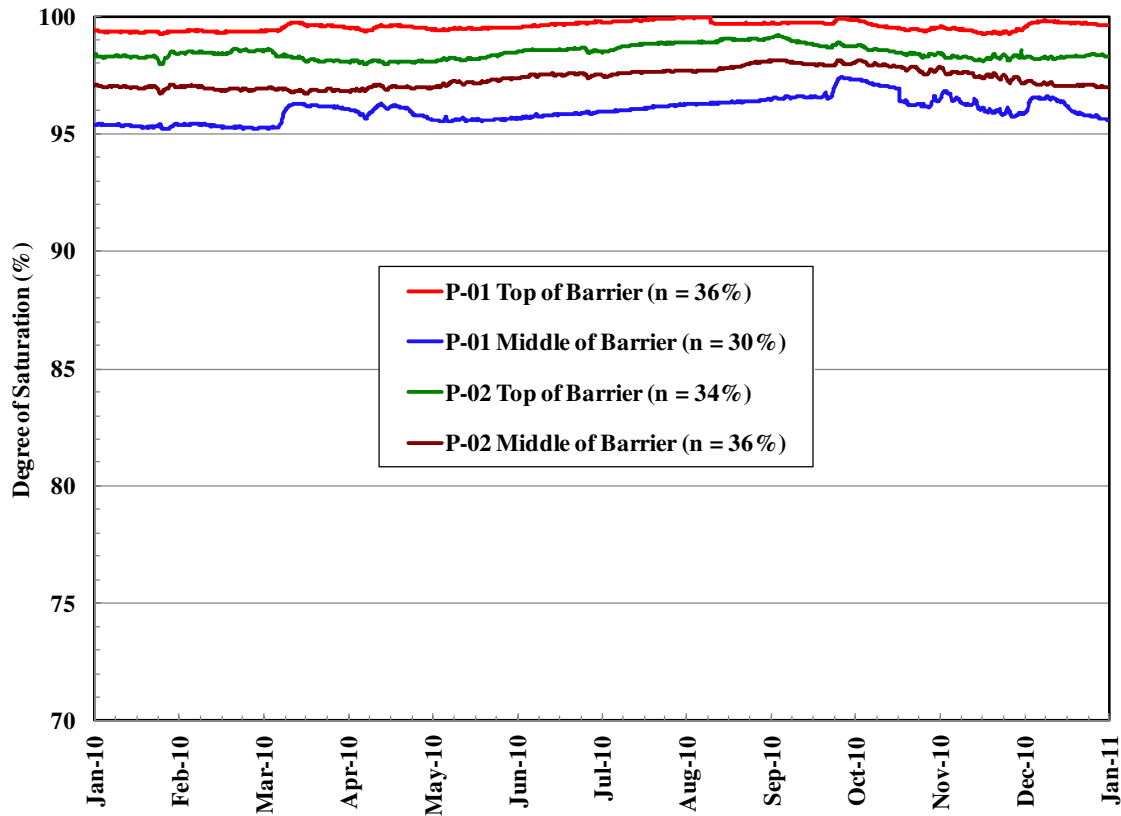


Figure 6. Degrees of saturation in the pit cover barrier layer at stations P-01 and P-02 in 2010 (from OKC, 2011).

Geochemical modelling determined that the desired oxygen diffusion coefficient (D_e) for the barrier layer is $3.8 \times 10^{-9} \text{ m}^2/\text{s}$ or lower, based on predicted long-term solute concentrations in the backfilled pit. Table 1 shows average D_e values for the barrier layer at stations P-01 and P-02 from 2006 to 2010; they were calculated based on the method outlined in Aachib *et al.* (2004) and measured *in situ* volumetric water contents. The D_e values have been an order of magnitude lower than the minimum required for closure except for the P-01 location in 2009. Based on degrees of saturation for the barrier layer at stations P-01 and P-02 it is reasonable to assume that oxygen diffusion into the backfilled waste rock has been adequately limited since cover construction.

Table 1. Mean D_e values calculated for the compacted clay barrier layer at P-01 and P-02 for 2006 to 2010 compared to the minimum required based on geochemical modelling (from OKC, 2011).

	P-01 D_e ($10^{-11} \text{ m}^2/\text{s}$)	P-02 D_e ($10^{-11} \text{ m}^2/\text{s}$)
2006	42	17
2007	36	3.9
2008	14	1.8
2009	231	1.8
2010	14	1.8
Minimum required	376	

Pore-gas concentration measurements

Concentrations of O_2 and CO_2 are measured at the primary and secondary monitoring sites on top and at the base of the barrier layer, as well as 90 cm below the barrier layer, using a portable gas analyzer. This monitoring is needed to check that atmospheric O_2 is not being advectively transported into the waste rock along the backfilled pit perimeter or through imperfections in the cover system. As shown in Figure 7, O_2 pore-gas concentrations below the barrier layer are less than 2–3%, particularly for sampling ports located 90 cm below the barrier layer. Many of the gas sampling ports above and immediately below the barrier layer have become plugged or contain excessive amounts of pore-water, preventing the collection of pore-gas samples. Nonetheless, pore-gas concentration data collected to-date confirms that the cover system is functioning as an effective oxygen ingress barrier.

Although not shown, relatively high CO_2 concentrations are being recorded at most sampling stations. This is generally associated with high sulphide oxidation rates and resulting high CO_2 production rates from carbonate buffering. This scenario was assumed improbable for the Whistle pit cover system given the low O_2 concentrations immediately below the barrier layer in the waste rock backfill. The relatively high CO_2 concentrations at some sampling locations below the barrier layer is attributed to the ‘trapping’ effect of the barrier layer in which CO_2 produced at a low rate below the barrier layer diffuses through the barrier layer very slowly.

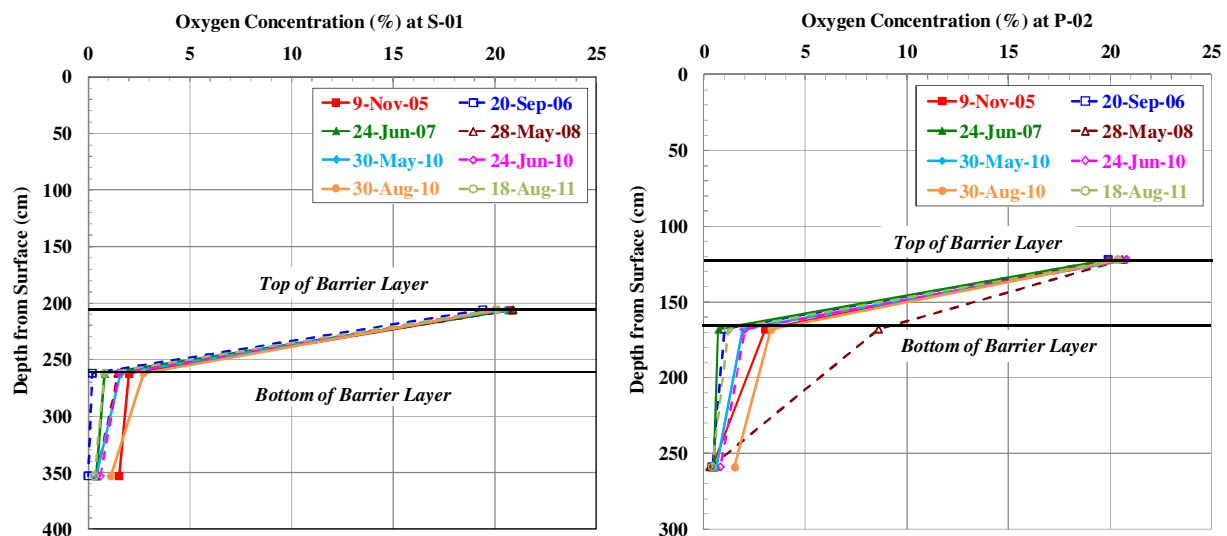


Figure 7. O_2 pore-gas concentrations measured across the barrier layer and within the underlying backfill waste rock at stations S-01 and P-02 (from OKC, 2011).

Net percolation to the backfilled waste rock

Net infiltration of meteoric water across the cover system and into the backfill waste rock (i.e. net percolation) is continually monitored with tank lysimeters at stations P-01 and P-02. Cumulative net percolation measured at station P-01 in 2010 was 4 mm (see Figure 8), which equates to ~1% of total precipitation measured at the site. Net percolation recorded in 2006 and 2007 corresponds to ~3% of annual total precipitation, while net percolation comprised ~1% of total precipitation in 2008 and 2009. It is hypothesized that net percolation rates have decreased as the vegetation cover develops and ‘pumps out’ additional water stored in the growth medium layer, comparing well to rates predicted from the cover design modelling program.

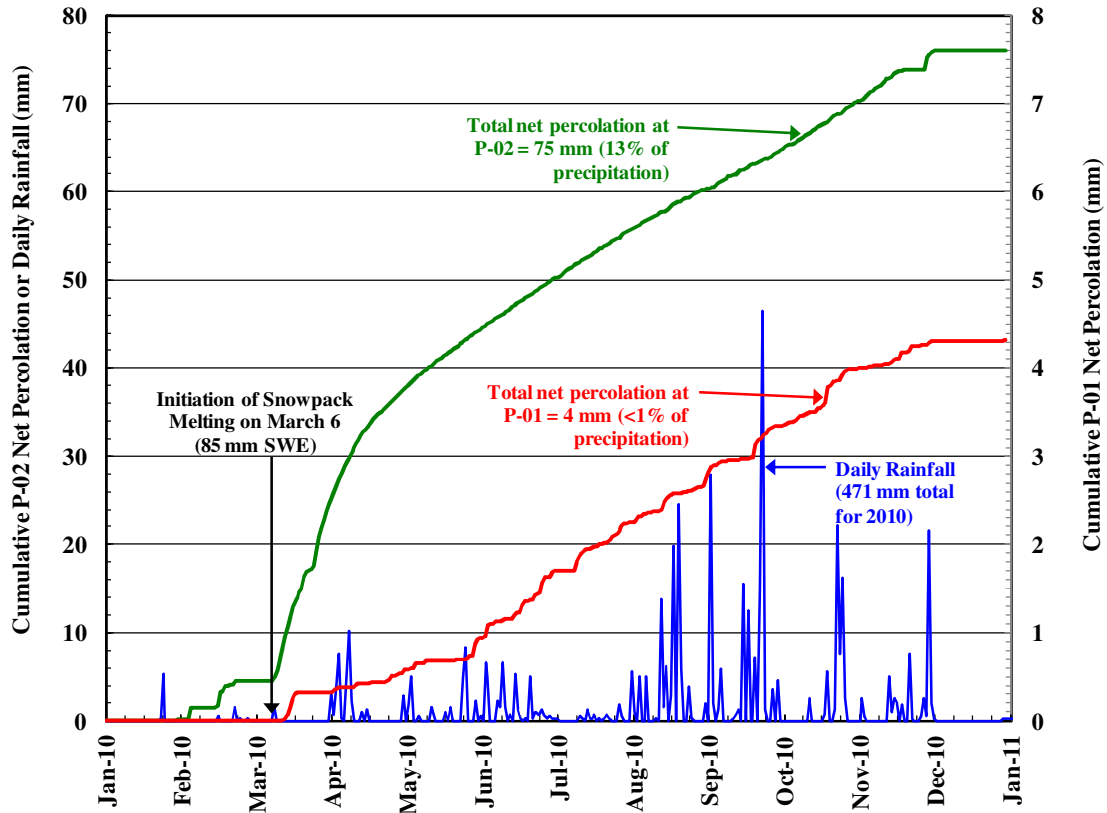


Figure 8. Cumulative net percolation measured at station P-01 and P-02 for 2010. Daily rainfall and initiation of the snowpack melt is also included (from OKC, 2011).

The pit cover is performing as expected at the P-01 location with limited net percolation. However, net percolation at the P-02 location might suggest that the barrier layer is not limiting the infiltration of meteoric waters to the same extent as the P-01 location. As discussed below, wet/dry and freeze/thaw cycles have not occurred within the barrier layer at P-02 and as such, it is believed the integrity of the barrier has not been altered from as-built conditions.

Higher net percolation rates further downslope and towards the runoff collection ponds is consistent with predictions from the 2-D cover design modelling program. The modelling showed the barrier layer has a limited capacity to laterally divert subsurface (interflow) waters. It is believed the P-02 lysimeter is showing the effects of breakthrough of interflow waters, plus precipitation incident to the area above the lysimeter tank. Another factor contributing to higher net percolation rates is the lack of vegetation above the P-02 lysimeter tank, which results in lower evapotranspiration rates. The coarse rip-rap layer on the cover surface at this location possesses a very high hydraulic conductivity, which leads to rapid infiltration

rates and very low evaporation rates. It is believed, however, that net percolation rates measured at the P-01 monitoring location are more indicative of the overall performance of the Whistle Mine pit cover system compared to those measured at the P-02 station.

Extent of freezing and drying with depth

The extent and magnitude of temperature and water content variations in the cover system, particularly for the barrier layer, are important for tracking the evolution of the cover system and its performance over time. Seasonal freeze/thaw and wet/dry cycling can diminish barrier layer performance over time as a result of a macro-pore structure developing in the compacted clay material (INAP, 2003).

In situ temperature and water content throughout the pit cover and upper waste rock profile are recorded at station P-01 and P-02. The freezing front extended to a maximum depth of 60 cm at P-01 and 100 cm at P-02 in February. The minimum temperature recorded in the barrier layer at P-01 and P-02 in 2010 was 4.2 °C and 1.5 °C, respectively. Based on *in situ* temperature data collected to-date, the growth medium layer along with the annual snow cover at the site is sufficient to prevent the pit cover barrier layer from freezing.

Volumetric water content in the pit cover and upper waste rock profile is continuously monitored at stations P-01 and P-02 using calibrated Sentek EnviroSCAN® capacitance sensors. Figure 9 is 2-D contours of the volumetric water content profile measured at these stations in 2010. The *in situ* water content of the P-01 and P-02 cover profiles increased in response to melting of the snowpack in early March and intense rainfall events from August through November. Throughout the summer period, slight differences exist in wetting and drying of the P-01 and P-02 cover profiles. In general, a greater proportion of rainfall events trigger wetting through the entire depth of the cover profile at P-02 as compared to P-01. The variation in profile wetting at these two locations is attributed to differences in moisture storage capacity (i.e. higher at P-01 due to thicker cover), surface treatment (i.e. vegetation at P-01 versus riprap at P-02), and position along the slope profile (i.e. run-on is greater at P-02 compared to P-01). There is no evidence of wet/dry cycling in the barrier layer based on data collected to-date at stations P-01 and P-02.

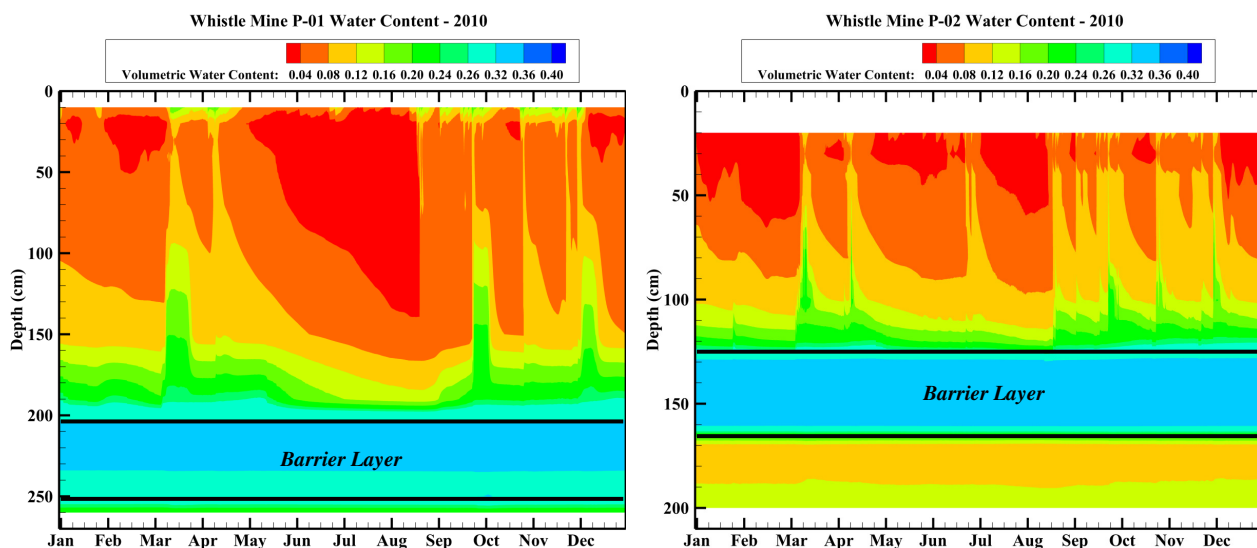


Figure 9. Water content contours measured in the cover and waste rock profile in 2010 at P-01 and P-02 (from OKC, 2011).

Water balance

An annual water balance has been developed for the pit cover system since the onset of monitoring. Precipitation (PPT) is comprised of both rainfall and water content of the snowpack measured at the site. Net percolation (NP) through the pit cover system is based on lysimeter measurements. Change in moisture storage (ΔS) is calculated based on the volume of water in the cover profile at the start and end of the monitoring period. Lateral drainage and surface runoff (R) from the pit cover system can be estimated based on data collected by the weirs. Finally, actual evapotranspiration (AET) from the cover system is not directly measured at the site, but can be back-calculated from the water balance equation ($AET = PPT - R - \Delta S - NP$).

Table 2 presents annual water balance fluxes for the pit cover system. A water balance could not be completed for the 2008 monitoring period due to malfunctioning of a datalogger. A total AET of 377 mm (68% of total precipitation) was calculated for the pit cover in 2010 using the water balance equation. The amount of potential evaporation (PE) in 2010, which is a theoretical maximum assuming free water on the surface at all times, was 655 mm based on the Penman (1948) method and climate data collected at the site. The estimated AET was 58% of the calculated PE, which is reasonable given the site climatic and vegetation conditions.

Table 2. Annual water balance fluxes for the pit cover system from 2006 to 2010 (from OKC, 2011).

	% of Precipitation			
	2006	2007	2009	2010
<i>Precipitation (mm)</i>	765	584	809	556
Runoff and interflow	62	39	40	34
Evapotranspiration	35	57	54	68
Change in storage	0	1	5	-2
Net percolation	3	3	1	1

Pit overflow water quality

A high water level drain was installed along the south perimeter of the backfilled pit to prevent any uplift pressures from developing on the underside of the pit cover system. The drain also serves as a single point of discharge from the pit, thus allowing for easier control and monitoring of flows. Figure 10 shows the geometric annual mean of various chemical parameters for pit overflow waters since 2002. Recall that backfilling of the pit occurred in 2000-2001, while construction of the pit cover system was completed between June 2004 and November 2005. All water chemistry parameters presented in Figure 10 are trending in a positive direction since construction of the pit cover system.

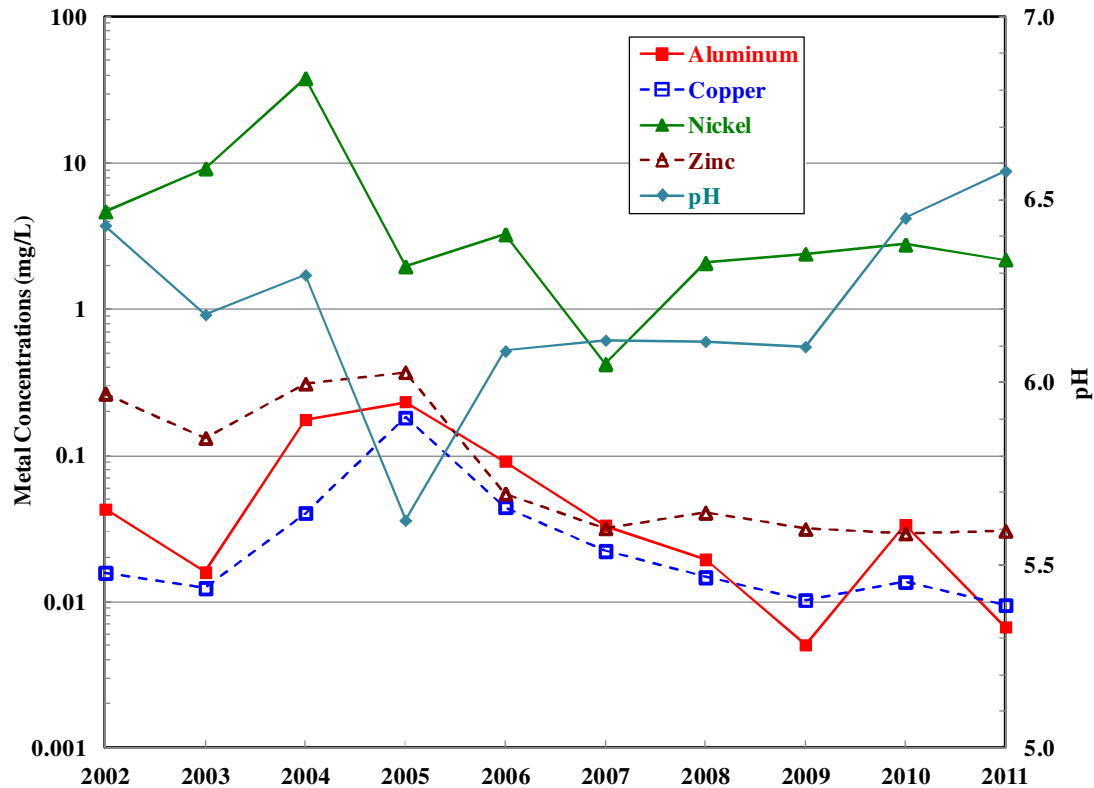


Figure 10. Annual mean quality of pit overflow waters since 2002.

Summary

A multi-layer dry cover system was designed for closure of the Whistle Mine backfilled pit with input from geochemical, soil-plant-atmosphere, erosion and landform evolution numerical modelling, as well as monitoring data from cover system field trials. Potential impacts resulting from site-specific physical, chemical and biological processes were also considered in the design of the pit cover from a sustainable performance perspective.

The Whistle Mine pit cover system is performing as expected based on field data collected over the past six years. The influx of atmospheric oxygen and meteoric water to the waste rock backfill has been substantially reduced since construction of the cover system. The cover system is geomorphically stable and supports the growth of various native plant species.

References

- Aachib, M., Mbonimpa, M., and Aubertin, M. (2004) Measurement and prediction of the oxygen diffusion coefficient in unsaturated media, with applications to soil covers. *Water, Air and Soil Pollution*, Vol. 156, pp. 163-193.
- Adu-Wusu, C., Renken, K., Yanful, E.K. and Lanteigne, L. (2002) Engineered covers on acid-generating waste rock at Whistle Mine, Ontario. In *Proc. of 55th Canadian Geotechnical Conference*, Niagara Falls, ON, Canada, October 20-23, 2002, pp. 131-138.
- Ayres, B., Lanteigne, L., and O'Kane, M. (2005) Design and construction of the backfilled pit cover system at Whistle Mine, Canada: a case study. In *Proc. of Securing the Future 2005, International Conference on Mining and the Environment*, June 27-July 1, 2005, Skelleftea, Sweden.

- Ayres, B., Lanteigne, L., Smith, Q., and O'Kane, M. (2007) Closure planning and implementation at CVRD Inco's Whistle Mine, Ontario, Canada. In Proc. of Mine Closure 2007, October 16-19, 2007, Santiago, Chile.
- Ayres, B.K., O'Kane M., Lanteigne, L., and Christensen, D. (2002) Construction and instrumentation of waste rock test covers at Whistle Mine, Ontario, Canada. In Proc. the 9th International Conference on Tailings and Mine Waste, January 27-30, 2002, Fort Collins, CO, USA.
- Flanagan, D.C. and Livingston, S.J. (1995) Water Erosion Prediction Project (WEPP) version 95.7 user summary. In (Flanagan and Livingston, editors) 'WEPP user summary', NSERL Report No 11, July.
- INAP (International Network for Acid Prevention). (2003) Evaluation of the long-term performance of dry cover systems, final report. Prepared by O'Kane Consultants Inc., Report no. 684-02, March.
- Krahn, J. (2004) Vadose zone modeling with VADOSE/W – An engineering methodology, First Edition, GEO-SLOPE International Ltd., May.
- Mbonimpa, M., Aubertin, M., Aachib, M., and Bussière, B. (2003) Diffusion and consumption of oxygen in unsaturated cover materials. Canadian Geotechnical Journal, Vol. 40, pp. 916-932.
- MEND (Mine Environment Neutral Drainage). (1997) Whistle Mine waste rock study: Volume I and II. Canadian MEND Program, Project 1.41.4, December.
- MEND (Mine Environment Neutral Drainage). (2004) Design, construction and performance monitoring of cover systems for waste rock and tailings. Canadian MEND Program, Project 2.21.4, July.
- Nicholson, R.V., Gillham, R.W., Cherry, J.A., and Reardon, E.J. (1989) Reduction of acid generation in mine tailings through use of moisture-retaining cover layers as oxygen barriers. Canadian Geotechnical Journal, Vol. 26, pp. 1-8.
- OKC-MDH (O'Kane Consultants Inc. – MDH Engineered Solutions Corp.). (2004) Whistle Mine reclamation project: final design report for the backfilled pit cover system. Report no. 707/3-01 prepared for Inco Ltd., April.
- OKC-MDH (O'Kane Consultants Inc. – MDH Engineered Solutions Corp.). (2006) Whistle Mine backfilled pit cover system – record of construction quality control and assurance. Report no. 707/3-02 prepared for Inco Ltd., May.
- OKC (O'Kane Consultants Inc.). (2011) Whistle Mine pit cover system 2010 performance monitoring report. Report no. 707/4-05 prepared for Vale, May.
- Penman, H.L. (1948) Natural evaporation from open water, bare soil and grass. In Proceedings of the Royal Society. (London) Part A, Vol. 193, pp. 120-145.
- SENES (SENES Consultants Ltd.). (2003) Draft report on: geochemical modelling of cover options for the Whistle Mine backfilled pit. Prepared for Inco Ltd., May.
- Willgoose, G.R., Bras, R.L., and Rodriguez-Iturbe, I. (1991). A physically based coupled network growth and hillslope evolution model: 1 Theory. Water Resources Research, Vol. 27, pp. 1671–1684.