

Linking Tailings Seepage Geochemistry to the Performance of Cover System Field Trials for a Tailings Storage Facility at Peak Gold Mine Operations

Meiers, P. Greg. Shaw, Shannon. Overdeest, Noëlle. O’Kane, Mike

E-mail: gmeiers@okc-sk.com

Keywords: Cover system field trial, tailings seepage

ABSTRACT

The Goldcorp Inc. Peak Gold Mining Operation is an underground gold operation located near Cobar in New South Wales, Australia. Two cover system field trials were constructed in 2002 to evaluate the hydraulic performance of alternate cover system designs for closure of the Peak Gold Mine tailings storage facility. The cover system field trials utilize the “moisture store-and-release” concept to limit the infiltration of meteoric waters to the underlying tailings as a means of controlling acid rock drainage and contaminant release from the tailings storage facility.

The first field trial consists of a nominal 1.5 m thick layer of oxidised waste rock material, while the second field trial consists of a nominal 2.0 m thick layer. State-of-the-art monitoring systems were installed to assess the field performance of the field trials during all seasons of the year. Lysimeter collection and monitoring systems are being used to automatically record the quantity of net percolation through each of the cover system field trials. A review of monitoring data shows that the 2.0 m cover system field trial has been most successful in limiting the migration of dissolved elements within the tailings storage facility.

INTRODUCTION

Peak Gold Mine (PGM) located near Cobar NSW, Australia commenced operations in 1992, and is expected to continue operating until 2012. The tailings storage facility (TSF) contains potentially acid forming tailings material and, at closure, the impoundment is expected to contain approximately 14.2 million tonnes of tailings. Preliminary closure planning for the mine site identified that research of suitable cover system options is required to control acid rock drainage (ARD) and metal leaching from the TSF over the long-term.

Dry cover systems can be simple or complex, ranging from a single layer of earthen material to several layers of different material types, including native soils, non-reactive tailings and / or waste rock, geosynthetic materials, and oxygen consuming organic materials. The two principal objectives of a cover system designed for managing potentially acid forming mine waste, are to control the ingress of oxygen and / or to control the infiltration of meteoric waters to the underlying reactive waste material.

The characteristics of acid rock drainage that develop, such as low pH and elevated concentrations of dissolved elements, are influenced by, but not limited to, the *in situ* moisture content and the ingress of meteoric water and oxygen to the waste material. Each of these parameters will vary in association with different cover system designs and subsequently influence the characteristics of the mine seepage. The mass or load of contaminants released from the waste storage facility to the environment is a function of the net percolation and the concentration of elements within the seepage.

Two cover system field trials were constructed at the PGM to evaluate the performance of alternate designs. The objective of this paper is to assess the relative performance of the alternate designs on the basis of tailings seepage quality and quantity.

BACKGROUND

Tailings Storage Facility

The PGM TSF, which is operated using a central thickened discharge technique, covers an area of approximately 80 ha. Since operations commenced at PGM, the tailings have been discharged from a single spigot producing a tailings stack with an average beach slope of 1.7%. However, PGM completed modifications to the spigot discharge point in 2002, converting it to a multi-spigot discharge point system to increase the capacity of the TSF. The use of the multi-spigot system reduced the discharge velocity, which increased the average beach slope to 3.5%. The TSF currently contains approximately 9.5 million tonnes of tailings and will contain approximately 14.2 million tonnes at the end of mine life (2012), based on the current and anticipated future tailings production rates of 660,000 and 750,000 t/yr, respectively.

Cover System Field Trials

Peak Gold Mine is located within a semi-arid region of Australia. The mean annual rainfall and potential evaporation are approximately 415 mm and 2550 mm, respectively. It is difficult and usually not feasible in arid and semi-arid climates such as this to construct a cover system that maintains a high saturation layer, thereby reducing oxygen ingress. The cover system will be subjected to extended dry periods and therefore the effect of evaporation will be significant. However, subjecting the cover system to evaporative demands can be beneficial

in arid and semi-arid climates. For this reason, the “moisture store-and-release” cover system was investigated to limit the infiltration of meteoric waters to the underlying tailings material as a means of minimizing the migration of contaminants from the TSF to the receiving environment.

The design of the cover system field trials was based on a geotechnical characterization and numerical modelling programme. Completely oxidized waste rock from the upper horizon of the New Cobar open-cut operation was deemed the most promising potential cover material on site. This material, as well as the tailings material, was sampled for physical property characterization in April 2001. The geotechnical characterization programme consisted of measuring the particle size distribution (PSD) of all potential cover and tailings material samples. The PSD results were then used as a screening tool for categorizing the material and selecting samples for detailed physical and hydraulic characterization, which consisted of specific gravity, saturated hydraulic conductivity, and moisture retention testing. The test results obtained provided the various hydraulic and physical parameters required for the numerical modelling programme. The methodology used for developing the cover system field trial design at PGM can be found in Ayres *et al.* (2003).

Soil-atmosphere cover system design modelling was completed using the one-dimensional SoilCover model (GeoAnalysis 2000 Ltd., 2000) to evaluate alternate designs on the basis of predicting net percolation to the underlying waste. The modelling programme indicated that a minimum of two meters of the oxidized New Cobar waste rock was required to minimize the infiltration of meteoric waters to the underlying tailings material. The complete details of the material characterization and numerical modelling programme can be found in OKC (2001).

Two cover system field trials were constructed on the surface of the PGM thickened tailings pile during April 2002. Each cover system field trial covers an area of approximately 0.12 ha (35 m by 35 m). Test Plot #1 (TP1) consists of a 1.5 m thick layer of waste rock from the New Cobar open pit project, while Test Plot #2 (TP2) consists of a 2.0 m thick layer of New Cobar waste rock.

Two “control” plots were also instrumented, one on the bare tailings surface, and one in a naturally vegetated area. The purpose for the control plots was to provide a basis for comparison of the 1.5 m and 2.0 m field trials to an uncovered tailings condition and for assessing the actual transpiration rates for the native vegetation, which is required for assessing the long-term performance of the cover system field trials. However, for the purpose of this paper, data collected from the control plots was not included for discussion.

The cover system field trials were constructed for the calibration and validation of the soil-atmosphere numerical models developed for the design of the field trials. The models will be calibrated to the measured *in situ* cover system material properties and field performance monitoring data. Prediction of long-term cover system performance due to varying climatic conditions, geometry, and material properties would then be completed using the field calibrated model.

Construction of the cover system field trials for the PGM TSF closure programme and installation of the various components of the monitoring system are described in detail in OKC (2002), and are briefly described in this document.

Cover System Field Trial Performance Monitoring

State-of-the-art monitoring systems were installed to assess the field performance of the cover system field trials during all seasons of the year. Rainfall is being recorded by an automated weather station, which also records various other climatic parameters that are required for calculating potential evaporation and conducting field response numerical modelling. Lysimeter collection and monitoring systems are being used to automatically record the quantity of net percolation through each of the cover system field trials. *In situ* moisture and temperature conditions at each field trial are automatically measured by EnviroSCAN[®] water content sensors (indirect measurement of volumetric water content) and thermal conductivity (TC) sensors (indirect measurement of matric suction). An automated surface runoff collection and monitoring system was installed on the two field trials. A portable gas analyser is being used to record oxygen and carbon dioxide concentrations within the cover profile and underlying tailings.

Additional monitoring of *in situ* moisture conditions is being conducted at each field trial using the Diviner 2000[®] (D2K) portable moisture content probe. Six D2K access tubes were installed into the soil profile spatially across each field trial (TP1 and TP2). Monitoring of *in situ* moisture conditions spatially across the field trials provides an indication of the variability in cover system performance attributed to material heterogeneity and *in situ* density conditions.

Figure 1 is a schematic of the TP1 field performance monitoring system (excluding the runoff monitoring system). The TP2 field performance monitoring system is similar to TP1, with the exception of an increased cover profile thickness.

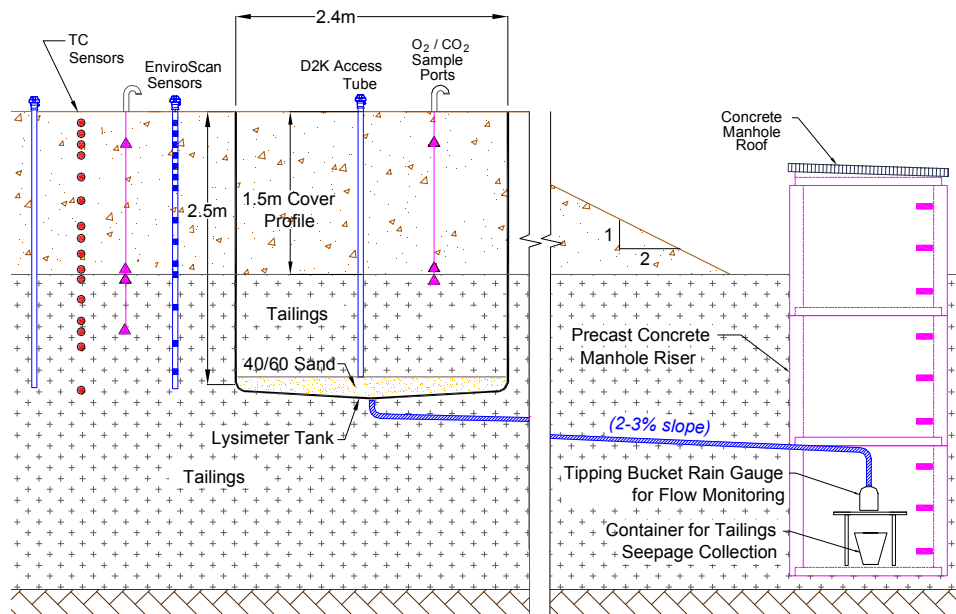


Figure 1: Schematic of the TP1 field performance monitoring system. Lysimeter Design Programme

A fundamental design feature of a lysimeter installed to measure net percolation for unsaturated conditions is that the presence of the lysimeter must not influence the net percolation being measured. A key design parameter of a lysimeter is the depth of the lysimeter base below the cover / waste material interface and the lysimeter wall height. In general, the lysimeter wall height should be the same as the depth of the base of the lysimeter below the cover / waste material interface in order to prevent wicking of moisture out of the lysimeter, which has percolated to the base of the lysimeter (Bews *et al.*, 1997).

The presence of a lysimeter base creates an “artificial” zero pressure condition, or a “false” phreatic surface, at the base of the lysimeter below the cover / waste material interface, which typically does not exist outside the confines of the lysimeter. The pressure head profile at the top of the lysimeter within the confines of the lysimeter must be the same as that measured outside the confines of the lysimeter to prevent the divergence of flow around the lysimeter tank.

The following is a “back-of-the-envelope” methodology which was used to estimate the depth of the lysimeter base below the cover / tailings interface required for measuring representative net percolation rates. The estimated depth of the lysimeter base was used as a starting point for the numerical modelling lysimeter design programme at PGM in order to evaluate the performance under a range of percolation rates.

The suction and water content profile can be predicted through an unsaturated porous material under a steady state infiltration rate applied to the surface (Barbour 1990). Darcy’s Law governs the flow of water through a column:

$$q = -k i \quad (1),$$

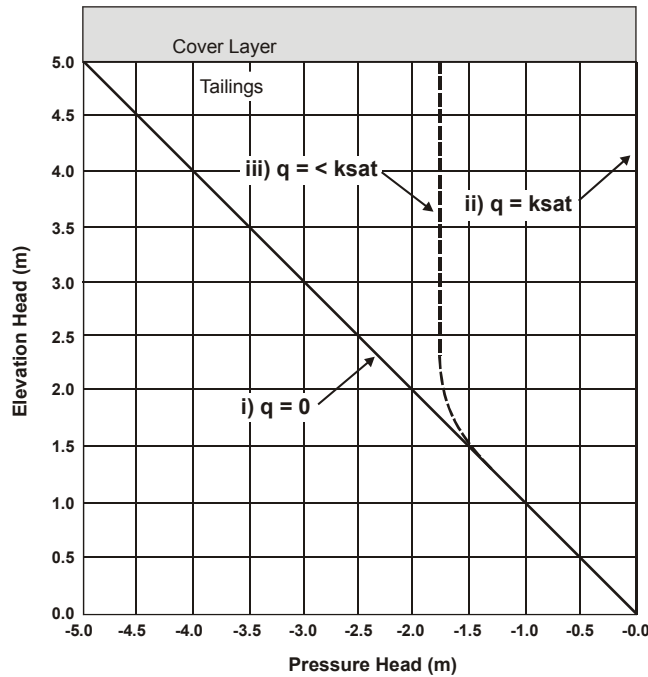
where:

- q is the Darcy flux (L/T),
- k is the hydraulic conductivity (L/T), and
- i is the hydraulic gradient.

The hydraulic gradient consists of the elevation gradient, which is equal to one in the case of vertical flow, and the pressure gradient. Darcy’s Law was developed for saturated flow, where the hydraulic gradient is a constant value (i.e. the saturated hydraulic conductivity); however, the hydraulic conductivity of an unsaturated porous material is a function of the negative pressure head of the material.

Three percolation scenarios are presented in Figure 2 to illustrate the pressure profile developed as a function of the percolation rate from the base of a cover system to the underlying tailings material. If the percolation rate across the cover / tailings interface is zero (i.e. scenario (i) in Figure 2), the pressure head will decrease hydrostatically for each increment of elevation above a point within the TSF where a zero pressure head has developed (i.e. water table condition). The pressure head remains zero, as shown in Figure 2 (Scenario (ii)), if the flux across the cover / tailings interface is equal to the saturated hydraulic conductivity of the tailings material.

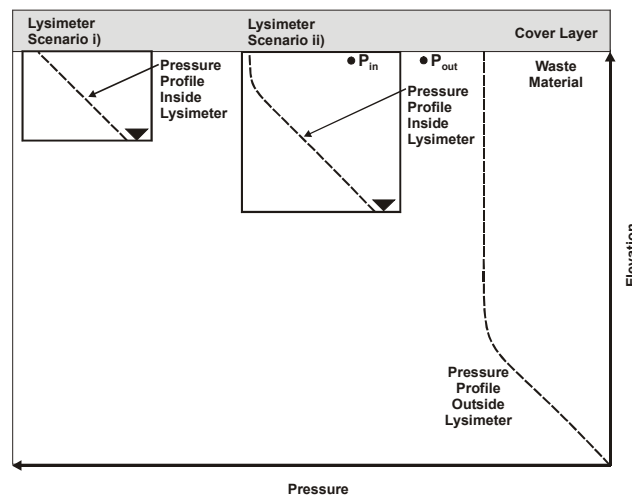
Figure 2: Relationship between pressure and elevation head for three different percolation rates (after O’Kane and Barbour 2003).



If the steady state percolation rate across the cover / tailings interface is some value less than the saturated hydraulic conductivity of the tailings, then the vertical hydraulic gradient will become equal to one at some elevation above the water table, as shown in Figure 2 with scenario (iii). The elevation at which the pressure head gradient becomes equal to zero and the hydraulic gradient is equal to one, is a function of the applied percolation rate and the hydraulic conductivity function of the tailings material. For percolation rates higher than that illustrated for scenario (iii) in Figure 2, but still less than the saturated hydraulic conductivity of the tailings, the “break” from the hydrostatic line will occur at a more negative pressure head; and vice versa for higher percolation rates. Under these conditions the unsaturated hydraulic conductivity in the upper portion of the profile is equal to the percolation rate (i.e. $q = -k$).

Figure 3 shows the pressure head profile for the tailings material underlying the cover layer for a steady state infiltration rate from the base of the cover material, similar to that presented in Figure 2, however, now with the addition of two lysimeters. Within the “shallow lysimeter” (scenario (i) of Figure 3), the break in the pressure head profile does not occur within the backfilled lysimeter, which results in a different pressure head condition inside the lysimeter (i.e. P_{in}) as compared to outside the lysimeter (i.e. P_{out}). The impact of this condition is that preferential flow will occur, and the lysimeter will not measure the “true” net percolation condition due to flow bypassing around the lysimeter.

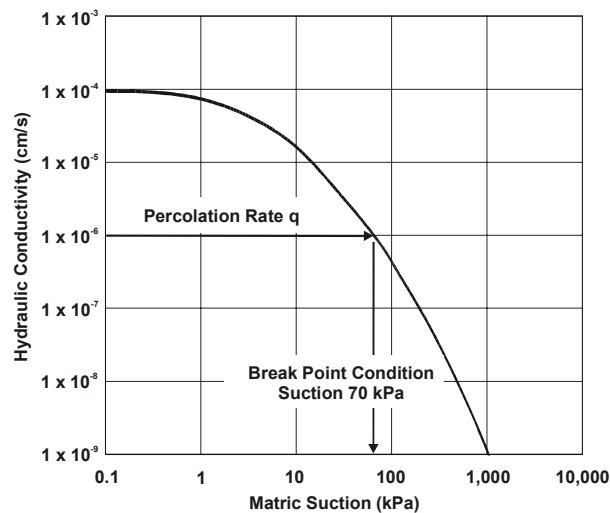
Figure 3: Pressure head profile for two lysimeter depths compared to the *in situ* material (after O’Kane and Barbour 2003).



Within the “deep lysimeter” (scenario (ii) of Figure 3), the break in the pressure head profile occurs within the confines of the lysimeter because the base of the lysimeter (i.e. the depth of the artificial water table) is at a depth that allows for this condition to develop within the lysimeter backfill. In this scenario the pressure head at the top of the lysimeter within the confines of the lysimeter is equal to that outside the confines of the lysimeter, and the lysimeter depth is sufficiently deep so the presence of the water table condition at the base of the lysimeter does not influence the net percolation condition. The pressure head developed is a function of the net percolation rate from the base of the cover layer and the hydraulic conductivity function of the tailings material.

Figure 4 shows the hydraulic conductivity as a function of matric suction for the PGM tailings material and a steady state percolation rate of 1×10^{-6} cm/s from the base of the cover layer. The steady state percolation rate of 1×10^{-6} cm/s corresponds to a net percolation of 12% (50 mm) of the mean annual rainfall for PGM, assuming a porosity of 0.5 and the percolation occurs during a four-month period. The break from the hydrostatic conditions of the pressure head profile will occur when the percolation rate is equal to the hydraulic conductivity. The pressure head developed under a steady state infiltration rate of 1×10^{-6} cm/s would be approximately 7 m (i.e. 70 kPa suction). In order for the break in pressure head to occur within the confines of the lysimeter, the base of the lysimeter below the cover / tailings interface would have to be greater than 7 m for a steady state infiltration rate of 1×10^{-6} cm/s. Assuming that the base of the lysimeter was placed 7 m below the cover / tailings interface there would be a divergence of flow, to some degree, around the lysimeter tank for all percolation rates less than 1×10^{-6} cm/s (i.e. 12.5 mm per month).

Figure 4: Hydraulic conductivity function of the PGM tailings material.



It was not economically nor technically feasible to construct a 7 m deep lysimeter extending from the base of the cover system, or realistically speaking even a 4 m lysimeter tank, which would cause divergence through a greater range of percolation rates. Results from the PGM lysimeter design numerical modelling programme indicated that field data collected from a lysimeter extending < 7 m down from the base of the cover / tailings interface would be inaccurate and would not provide the field data required for calibrating the numerical model and predicting long-term performance. In order to obtain meaningful net percolation field performance monitoring data for the PGM cover system field trials, the alternative was to raise the wall of the lysimeter to the cover system surface, creating a lysimeter isolated from the surrounding cover system. However, a lysimeter that extends to the cover system surface will not measure the actual net percolation rate because the artificial water table created at the base of the lysimeter will influence the net percolation measured. The percolation measured through a lysimeter with walls that extend to the surface is likely greater than the “true” percolation rate.

To address this issue, moisture conditions inside and outside the confines of the lysimeter are measured. A numerical model is calibrated to the net percolation measured by the lysimeter and the moisture conditions measured within the lysimeter during the field performance monitoring programme. After calibration of the numerical model to field conditions (i.e. field hydraulic properties are developed), the actual lower boundary condition, as measured with instrumentation outside the lysimeter, is substituted into the model to determine the “true” net percolation from the cover system to the underlying tailings material.

Lysimeter Collection and Monitoring System

Large-scale lysimeters are being used in this study to monitor the quantity and quality of water that percolates through each cover system field trial. The lysimeters consist of a large plastic tank, buried in the centre of each cover trial, and an underdrain system to transfer collected water / tailings seepage via gravity to a collection and monitoring system. The base of the lysimeter tank within each of the cover system field trials is placed 1.0 m below the cover / tailings interface with the walls extended to the field trial surface. The lysimeter tanks have a diameter of 2.4 m and a height of 2.5 m and 3.0 m for TP1 (Figure 1) and TP2, respectively.

The lysimeter tanks were backfilled in a manner such that the stratigraphy and density / moisture conditions inside and outside the tanks were the same. Plastic containers are situated beneath each tipping bucket gauge to facilitate collection of tailings seepage for geochemical analysis. The tipping bucket gauges and sample containers are at the bottom of concrete manholes located immediately outside the perimeter of each cover system field trial.

Tailings Geochemical Characterization

A geochemical testing programme for the tailings material was carried out by Environmental Geochemistry International (EGi) in July 2000. The field sampling programme consisted of sampling tailings material as a function of depth at 1 m intervals throughout the tailings profile at three sample locations. The sample locations were associated with crest, mid slope, and toe locations of the thickened tailings slope profile. Samples obtained within a continuous tailings lithology at a specific sample location were combined into a bulk sample, resulting in a total of nine samples. In addition, one sample was taken from the tailings discharge spigot and one from the thickener plant. The resulting eleven samples were tested for paste pH, paste electrical conductivity (EC), net acid producing potential (NAPP), and static net acid generation (NAG). Three of the samples were flushed with distilled water and then reanalysed using the NAG test to determine the neutralizing capacity of process lime additions to the thickened tailings following an extended period of placement.

Table 1 summarises the paste pH, paste EC, net acid producing potential (acid potential minus neutralization capacity), and the NAG test results. The tailings paste pH values ranged from a low of approximately 6.1 to as high as 8.8, while the paste EC values ranged from 0.9 to 5.8 mS/cm. The highest paste pH and lowest paste EC values were measured for sample numbers 1 and 2, representative of the discharge pipe and thickener plant, respectively. The pH and EC values of the fresh tailings (i.e. samples 1 and 2) would seem to suggest that a portion of the buffering offered by the lime treatment has been consumed or leached from the thickened tailings pile. The net producing potential indicates that the geochemical composition of the tailings material will provide little acid neutralization capacity (ANC) and the NAPP ranges from approximately 50 to 140 kg H₂SO₄/t, consistently reporting net acid potential.

Table 1: Acid forming characteristics of tailings material (after EGi, 2000).

Sample No.	Paste pH	Paste EC (mS/cm)	Acid-base Analysis				NAG Test		
			Total S (%)	MPA	ANC (kg H ₂ SO ₄ /t)	NAPP	NAG _{pH}	Titre (pH 4.5)	Titre (pH 7.0)
								(kg H ₂ SO ₄ /t)	
1	8.7	0.9	2.3	70	8	62	2.5 (2.5)	17 (16)	27 (26)
2	8.8	1.1	2.0	62	12	50	2.6	14	23
3	6.1	5.8	2.0	62	6	56	2.5	17	25
4	7.4	2.9	2.5	76	7	69	2.4	24	34
5	7.8	2.8	4.8	145	6	139	2.3	27	44
6	8.2	1.6	3.2	99	8	91	2.3 (2.4)	27 (25)	41 (42)
7	6.3	3.6	2.0	62	4	58	2.4	19	28
8	7.4	2.8	2.0	60	6	54	2.4	18	26
9	7.6	2.8	3.7	114	6	108	2.4 (2.4)	23 (22)	42 (39)
10	7.8	2.6	2.2	67	6	61	2.3	23	34
11	6.5	2.4	2.3	70	4	66	2.4	18	27

Note: NAG test values reported in parenthesis were conducted on water flushed samples.

Results from the NAG test analysis show that all samples have final NAG_{pH} values less than 4.5 supporting the classification as potentially acid forming (PAF). The results of NAG tests conducted on flushed samples are relatively unchanged indicating that the process water alkalinity will have limited buffering capacity.

Figure 5 shows the final NAG_{pH} and NAPP values for the tailings material samples. The final NAG_{pH} values range from 2.3 to 2.6 while all of the NAPP values are positive, indicating that all tailings samples are considered PAF.

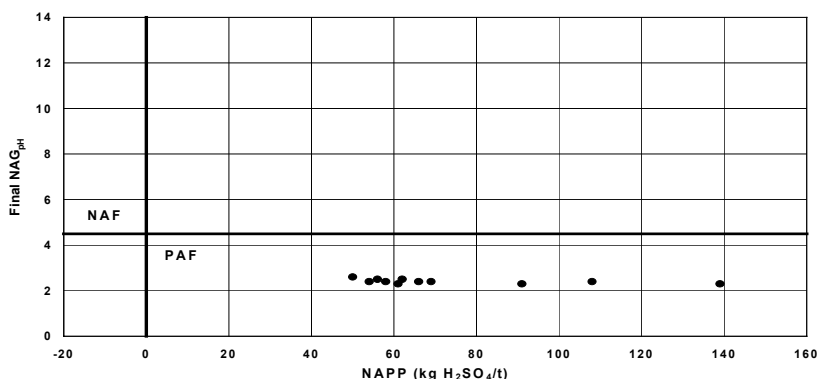


Figure 5: Final NAG_{pH} as a function of NAPP (after EGi, 2000) showing zones considered non-acid forming (NAF) versus potentially acid forming (PAF).

Multi-element analyses of the solids and water extracts were conducted on three tailings samples. An analysis of the solids indicated elevated levels of Ag, As, Bi, Cd, Cu, Pb, S, Sb, Se, and Zn (EGi, 2000). The results of water extracts on the same samples generally showed elevated levels of soluble Ca, Cd, Cl, Co, Mg, Mn, Na, Pb, SO_4 and Zn (potentially as cyanide-metal complexes). Note that the water extraction tests were conducted at neutral pH conditions. It is anticipated that concentrations of these elements would differ under acidic conditions.

Table 2: Chemical composition of the tailings water extraction (after EGi, 2000).

	Sample No. 3	Sample No. 4	Sample No. 5
pH	6.0	7.3	7.5
EC (mS/cm)	6.6	2.9	2.7
<i>Dissolved Elements (mg/l)</i>			
As	0.004	0.001	0.001
Ca	254	198	191
Cd	0.4	0.07	0.03
Cl	410	290	450
Co	0.4	0.02	0.007
Cu	0.03	0.02	0.01
Fe	0.04	0.01	<0.01
Mg	279	54	40
Mn	36	4	1.5
Na	867	349	334
Pb	1.7	0.3	0.2
SO_4	3378	1411	1474
Zn	63	11	3

Note: The full elemental sweep is not summarized in this table.

While the sample set used for this characterization is not statistically representative of the 6.4 million tonnes of tailings in place during the sampling programme, it can be assumed that the tailings material is generally PAF with limited buffering capacity, and elevated levels of elements may occur within the tailings seepage from near neutral through to acidic conditions.

INTERPRETATION OF COVER SYSTEM PERFORMANCE

For the purpose of this paper, the discussion of cover system field trial performance does not include *in situ* matric suction / temperature and runoff data.

Net Percolation

Table 3 summarizes the annual net percolation for the cover system field trials and rainfall measured during the monitoring period. The lowest net percolation was measured at TP2. Net percolation was relatively unchanged ranging from ~0% to 0.5% during the 2002 to 2005 monitoring period. The net percolation measured at TP1 was considerably higher, ranging from ~0% to 32%.

Table 3: Summary of the TP1 and TP2 net percolation and rainfall.

Monitoring Period	Rainfall (mm)	TP1 (1.5 m)		TP2 (2.0 m)	
		(mm)	(%)	(mm)	(%)
2002 (252 days)	70	0.04	~0.0	0.12	~0
2003	384	123 ⁽¹⁾	32 ⁽¹⁾	0.18	~0
2004	262	24.2	9.3	0.66	0.3
2005 (136 days)	10	0.24	2.5	0.05	0.5
Total:	726	148⁽¹⁾	20⁽¹⁾	1.01	~0

Note: The net percolation values reported herein require soil-atmosphere numerical modelling for correction due to the boundary condition imposed by the lysimeter base.

¹ Values are in error due to cover system subsidence.

In 2003, 384 mm of rainfall occurred, which is approximately the mean annual average (415 mm); however, rainfall was considerably lower during the other monitoring periods. It is anticipated that measured net percolation reported in Table 3 would be greater assuming that near mean annual rainfall levels occurred throughout the entire monitoring period.

Net percolation measured at TP1 during the 2003 monitoring period is considerably higher than that predicted during the cover system design numerical modelling programme; however, it is anticipated that these values are in error and not reflective of the TP1 performance. It is hypothesized that the higher net percolation is a result of the fact that the “artificial” phreatic surface at the base of the lysimeters has reduced moisture storage capacity in the cover and tailings materials within the lysimeters (and also increased the *in situ* hydraulic conductivity as a result of lower suction conditions). The result is an increase in the net percolation at the depth of tailings corresponding to the base of the tailings. Although not within the scope of this paper, it must be emphasized that until field response modelling of the TP1 lysimeter is completed, the net percolation at TP1 is expected to be higher than the “true” net percolation. Alternatively, some settlement of the TP1 cover material has occurred during / following significant rainfall events, and has possibly resulted in preferential flow paths in the cover material, thus leading to higher net percolation conditions.

Figure 6 summarizes the change in the total volume of water measured within the TP1 cover profile and cumulative net percolation. The volume of water is an estimation of the “depth” of water if the solids (mineral soil), air, and water components of the cover system profile were separated. The volume of solids remains constant while that of water changes in response to atmospheric forcing (i.e. rainfall and evaporation).

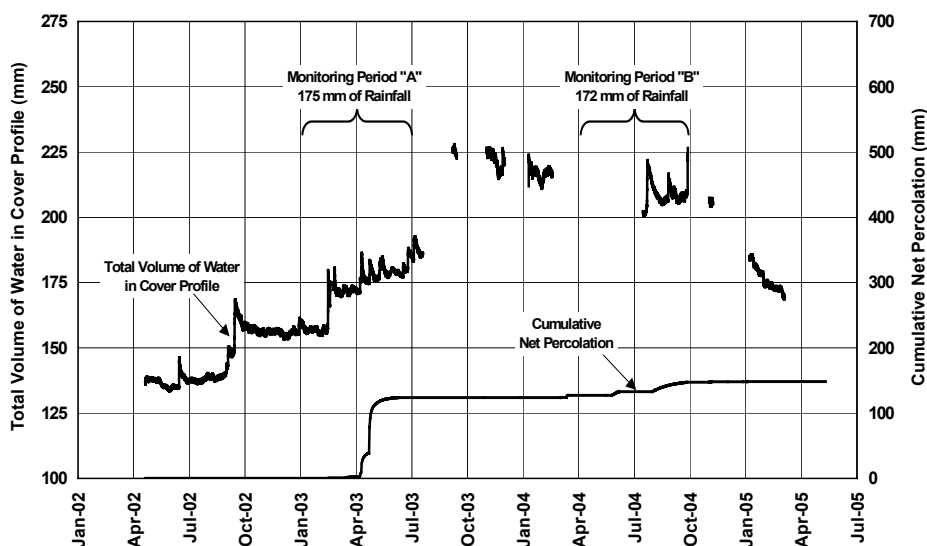


Figure 6: Change in the total volume of water within the cover profile and cumulative net percolation measured at TP1.

Two six-month field performance monitoring periods are shown in Figure 6 as “A”, January 2003 to July 2003, and “B”, April 2004 to October 2004. During monitoring period A the total volume of water increased within the TP1 cover profile by approximately 28 mm in response to the 175 mm of rainfall that occurred, as shown in Figure 6. During monitoring period B, approximately 172 mm of rainfall occurred, which is similar to that recorded during monitoring period A. Starting on February 15, 2004, corrupt data was output by the EnviroSCAN[®] moisture content sensors thus the total volume of water measured within the cover profile at the onset of monitoring period B is unknown. However, with reasonable confidence, it can be assumed that the total volume of water measured within the TP1 cover profile throughout the B monitoring period was greater than that measured during the A monitoring period.

During the A and B monitoring periods, approximately 124 mm and 20 mm of net percolation were measured, respectively. The net percolation values reported for the two six-month monitoring periods are counter-intuitive to what would be expected based on the *in situ* moisture conditions and cumulative rainfall. During the B monitoring period the total volume of water measured within the cover profile was greater than that measured during the A monitoring period. This indicates that there would be reduced storage capacity within the cover profile during the B monitoring period, resulting in a reduction in the capacity of the cover profile to buffer / store rainfall events and subsequently minimize net percolation.

The subsidence of “freshly placed” cover material can occur over a relatively short period in response to rainfall, which increases the *in situ* moisture content and subsequently changes the overburden pressure and shear strength within the cover material profile. Cover system field trials constructed at the Rio Tinto, Tom Price mine located in Western Australia, of a similar textured cover material to that at PGM for example, subsided approximately 10 cm in less than 10 hrs in response to a 210 mm rainfall event (OKC, 2004). Due to the rapid subsidence, cracks developed throughout the cover profile, which functioned as preferential flow paths during high intensity rainfall events. This resulted in meteoric water bypassing the cover profile.

The TP1 cover profile subsided approximately 5 to 10 cm, which was determined based on a change in the D2K moisture content access tubes in relation to the field trial surface. The exact date is unknown, however, based on maintenance of the field trials conducted by PGM personnel, it was concluded that it occurred during February 2003. The weather station recorded approximately 50 mm of rainfall on February 17, 2005 and then 25 mm February 21, 2003. Of the 124 mm of net percolation that occurred at PGM during monitoring period A, approximately 60 mm was measured over a 24 hr period, with a considerable amount also occurring prior to and following the 24 hr period. Field performance monitoring data (not presented in this paper) suggest that a portion of the rainfall took advantage of the surface cracks and thus bypassed the cover profile, which is reflected in the net percolation rate. This behaviour was exacerbated as the cover profile subsidence created a surface depression over the TP1 lysimeter tank, which was subsequently brought back up to grade during the latter part of the 2003 monitoring period.

Sufficient information is available to put the volume of net percolation collected during the 2003 monitoring period in question. As a result, when comparing the net percolation of the respective cover systems, only the 2004 and 2005 data have been used.

Figure 7 summarizes the cumulative net percolation measured from January 2004 to the end of the 2005 monitoring period for TP1 and TP2. Daily rainfall is included to assist with interpretation of the data. In response to atmospheric forcing (i.e. rainfall and evaporation), the net percolation of TP1 fluctuates. From March 2004 to November 2004, there are three net percolation “events” measured for TP1, while the percolation rate is near steady state for TP2 during the same monitoring period. The net percolation of TP2 is less responsive to atmospheric forcing due to the thicker cover profile and subsequent increased storage capacity. Approximately 25 mm and 0.7 mm of net percolation were measured at TP1 and TP2, respectively.

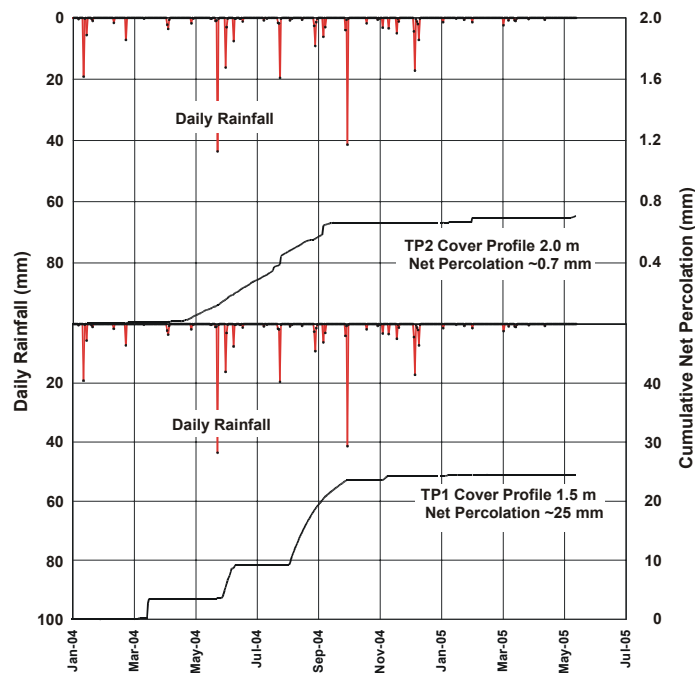


Figure 7: Cumulative net percolation and daily rainfall measured at TP1 and TP2.

Pore-Gas Concentrations

In situ O₂ gas concentrations within the cover material and underlying tailings are monitored using a portable gas analyser. Figure 8 displays the O₂ pore-gas concentrations measured within the TP1 and TP2 cover profile and underlying tailings on November 12, 2002, which is approximately six months from field trial construction. Oxygen

concentrations within the TP1 cover profile decreases significantly with depth from 19% at a depth of 25 cm to 10.5% at a depth of 145 cm, while oxygen concentrations within the TP2 profile decreased from 20% at a depth of 30 cm to 16 % at the base of the cover profile (195 cm). For comparison purposes, O₂ gas concentrations for ambient air conditions are approximately 20.9%. The oxygen concentration decreases from 10.5% to 7.5% and from 16% to 13% across the cover / tailings interface for TP1 and TP2, respectively. The pore-gas concentrations fluctuate in response to changes in the cover profile *in situ* moisture content and subsequently the coefficient of oxygen diffusion; however, the trend shown in Figure 8 remains prevalent.

The oxygen gradients measured across the cover / tailings interface, shown in Figure 8, indicate that the tailings material underlying the TP1 and TP2 field trials is consuming oxygen. The oxygen concentration is lower at the TP1 cover / tailings material interface as compared to the TP2 cover / tailings interface, which indicates that the oxygen consumption within TP1 may be somewhat higher than in TP2.

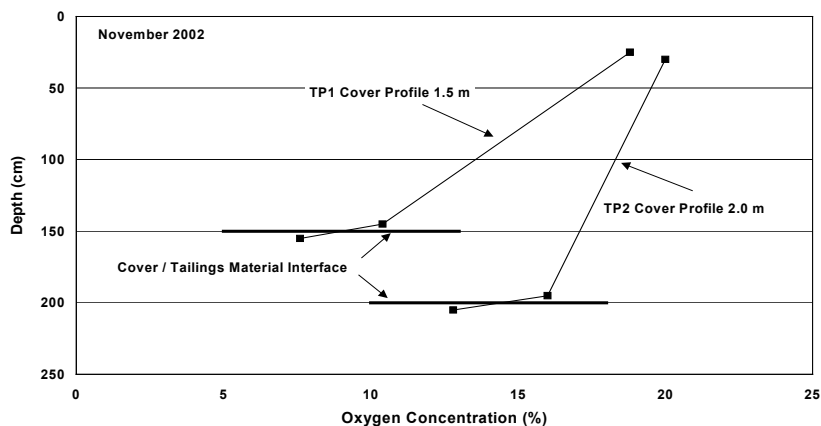


Figure 8: *In situ* O₂ gas concentrations measured within the TP1 and TP2 cover profiles.

Tailings Seepage Analysis

Tailings material placed within the lysimeter tank is PAF and metal leaching. Cover system field trial construction has isolated these tailings from the surrounding or subsequent future overlying tailings material and associated process water. Isolation of the tailings material within the lysimeter tank simulates the *in situ* conditions that will likely occur once tailings deposition ceases within the TSF and an appropriate cover system has been placed to manage the percolation of meteoric waters to the underlying tailings material. An analysis of the tailings seepage collected to date at TP1 and TP2 provides an indication of the solubility of the elements within the tailings material underlying the respective field trials, and is summarized in Table 4.

Table 4: Chemical composition of the tailings seepage collected to date.

	TP1					TP2
	Feb 03	Mar 03	Oct 03	July 04	April 05	July 04
pH	4.3	3.1	2.8	2.5	2.7	6.0
EC (mS/cm)	13.5	16.4	8.0	7.9	5.5	-
<i>Dissolved Elements (mg/l)</i>						
As	0.02	0.01	0.01	0.004	0.008	0.01
Ca	-	444	392	481	475	-
Cd	3.8	3.3	1.7	1.3	1.9	0.04
Cl	-	820	455	182	-	-
Cu	4.1	1.9	0.6	1.7	1.4	1.1
Fe	63	103	174	409	235	-
Mg	-	406	216	469	434	-
Mn	91	154	49	31	27	2
Na	-	2000	423	513	254	-
Pb	2.3	2.4	0.8	0.09	0.01	0.4
SO ₄	-	10700	4430	3930	-	-
Zn	1850	2170	1040	930	620	19

Note: The limited elemental analysis conducted on the TP2 sample is due to restricted sample volume reporting to the collection system.

Figure 9 shows the TP1 and TP2 tailings seepage analysis of Zn, Cu, and SO₄; pH is also included on a secondary Y-axis. The TP1 February 2003 and TP2 July 2004 samples correspond to the date when sufficient tailings seepage was first available for analysis. The pH of the TP1 seepage sampled February 2003 and March 2003 are 4.3 and 3.1, respectively. This indicates that approximately one year following cover system placement, acidic conditions have developed within the tailings underlying TP1. The chemistry of the seepage collected in

TP1 over time has gradually changed from a process water dominated chemistry particularly high in Cl, Na and metals, potentially in cyanide complexes, such as As, Cd, Cu, Pb and Zn to a water quality more indicative of ARD with elevated Ca, Mg, Fe and associated metals and SO₄.

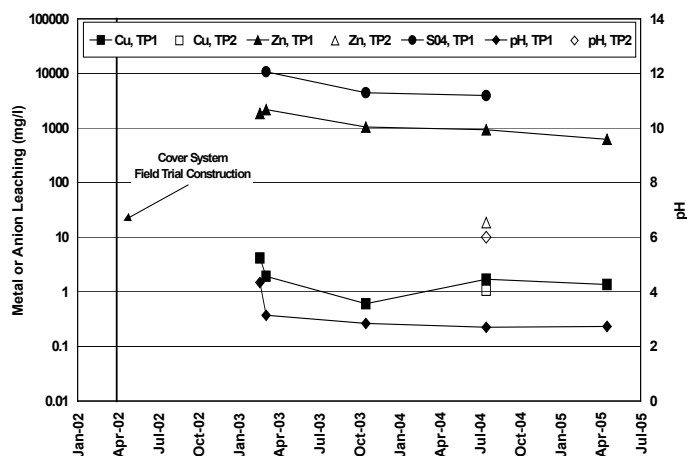


Figure 9: Elemental analysis and pH of tailing seepage collected to date.

The water quality in TP2 has conversely remained near neutral (pH 6.0) based on the sample collected July 2004. The pH of the tailings placed within the lysimeter tanks during construction was not measured; however, due to the relative homogeneity of the tailings and the proximity (~35 m) of the source tailings for each lysimeter, it was assumed that the pH of the bulk tailings placed within each lysimeter was relatively similar at the time of construction and at least similar to that recently measured in TP2 (i.e. > 6.0).

This would suggest that either the tailings still contain enough neutralization capacity in TP2 to buffer acidity as it migrates downward, or that the water reporting at the base of the 1.0 m tailings profile in TP2 is still dominated by draining alkaline process water. The quality of the TP2 seepage sample with a near neutral pH and relatively elevated levels of metals typically complexed with cyanide (e.g. As, Cu, Pb) is more indicative of a gold tailings process water than of a buffered ARD leachate. This supports the hypothesis that the TP2 seepage being collected is still largely comprised of process water. The lag time in the seepage migration in TP2 as compared to TP1 is largely an effect of the thicker cover profile. Due to the lower rate of percolation of meteoric water and subsequent flushing / draindown of alkaline process water from the 1.0 m tailings profile in the TP2 lysimeter tank, acid seepage has not yet reported to the collection facility. Whether acidic pore-waters within the TP2 profile have not developed to the extent of those reporting out the bottom of TP1 is uncertain at this stage of the monitoring. The rate of seepage and contaminant migration from TP2 is, however, considerably slower than that from TP1. Monitoring the variations in the chemistry of leachate reporting from below the respective cover systems will provide the basis for predicting the time it may take for contaminants to migrate through the TSF to the point of seepage or contact with groundwater under different cover type scenarios.

Tailings Seepage Load

Concentrations in seepage can increase, decrease, or stay the same with reduced contact with water (reduced net percolation) as a result of complex geochemical processes occurring along the flow paths within the waste facility (e.g. changing pH or redox conditions, precipitation, dissolution reactions, attenuation processes, etc.) Therefore, to link the cover system performance to tailings seepage, the mass or "load" of potential elements rather than the volume-dependent concentrations have been used to provide a basis of comparison between the two cover system scenarios.

The annual net percolation rates for TP1 and TP2 of 17.8 mm/yr and 0.5 mm/yr respectively were applied over the surface area of the 2.4 m diameter tanks holding the tailings from which seepage is collected. These relative 'flows' on an annual basis were multiplied by the water qualities collected from each field trial in July 2004 (assumed to be representative of the 'annual' concentrations). These calculated loads of dissolved elements under each cover system are summarized in Table 5.

Table 5: The calculated annual load from the cover system field trials.

Dissolved Elements	Elemental Load (g/yr)	
	TP1 (1.5 m cover)	TP2 (2.0 m cover)
As	0.0003	0.00002
Cd	0.1	0.0001
Cu	0.1	0.002
Mn	2	0.005
Pb	0.01	0.001
Zn	75	0.04

Note: Annual load and net percolations are based on 2004 and 2005 field data.

Figure 10 shows the calculated annual load for As, Cd, Cu, Mn, Pb and Zn from the two field trials. The relative differences in the calculated loads are a coupled effect of the difference in net percolations (and therefore volume of water) through the cover profile and the differences in concentrations of the pore-water in each lysimeter. TP1 seepage is now dominated by an ARD signature quality while the seepage from TP2 is still dominated by a process water quality. The change in concentration from one water type to another differs for each element due to differing solubilities at different pH conditions, complexation, attenuation, precipitation and dissolution processes that occur within the tailings profile. Therefore, the relative difference from one lysimeter to another is not consistent across the suite of elements. The calculated loads at TP1 are consistently much higher than that from TP2, in the order of one to three orders of magnitude depending on the element. This is a function of differences in both net percolation and pore-water chemistry.

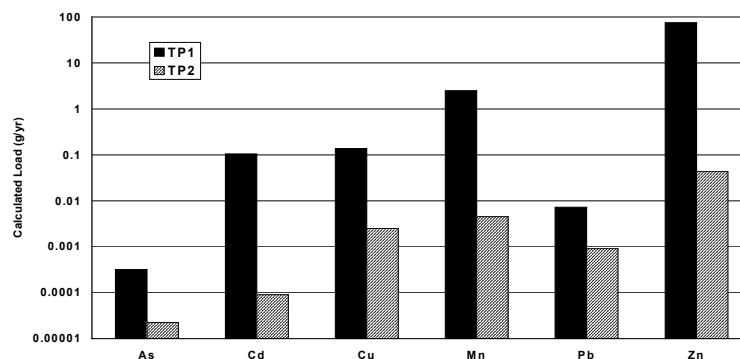


Figure 10: Annual mass or load calculated for TP1 and TP2.

It is anticipated that the pore-water chemistry within the 1.0 m tailings profile in each field trial will evolve to relatively similar 'steady state' water qualities over time (i.e. an ARD signature water quality). As a result, the relative difference in performance of the two cover system field trials will also change. Continued monitoring of the field trials and tailings seepage will provide the information required for predicting the long-term elemental release to the environment.

SUMMARY

Two cover system field trials were constructed at the Peak Gold Mines in April 2002. The cover system field trials utilize the "moisture store-and-release" concept to limit the infiltration of meteoric waters to the underlying tailings as a means of controlling mine drainage from the tailings storage facility. State-of-the-art monitoring systems were installed to evaluate the cover system field trial performance during all seasons of the year. Large-scale lysimeter tanks were installed for monitoring net percolation and collecting tailings seepage.

Field data show that the 2.0 m thick cover system field trial has performed better than the 1.5 m field trial at limiting the infiltration of meteoric waters to the underlying tailings. The geochemistry of the tailings seepage reporting to the 1.5 m field trial collection system is characteristic of acid rock drainage while that of the 2.0 m field trial is near neutral with elemental levels characteristic of the process water.

The load of various elements reporting to the 1.5 m field trial collection system are on average one to three orders of magnitude greater than that from the 2.0 m field trial, which is reflective of the tailings seepage geochemistry of the respective field trials and the difference in infiltration through the two covers.

On-going monitoring of the physical properties, seepage water quality and pore-gas environment through two alternate covers and into the tailings below will provide a unique dataset for the assessment of cover performance on acid generating tailings.

REFERENCES

Ayres, B, Silveira C, Ellice, C, Christensen, D, and O'Kane, M. 2003. Development of a cover system design for potentially acid-forming tailings at Peak Gold, NSW, Australia. Proceedings Sixth International Conference on Acid Rock Drainage, pp 957-963 (Cairns).

Barbour, S L, 1990. Reduction of acid generation in mine tailings through the use of moisture-retaining layers as oxygen barriers: Discussion, Canadian Geotechnical Journal, 27:398-401.

Bews, B E, Barbour, S L, Wilson, G W, and O'Kane, M, 1997. The design of lysimeters for low flux cover system over acid generating waste, Canadian Geotechnical Golden Jubilee Conference, Pre-print Vol 1, pp 26-33 (The Canadian Geotechnical Society: Alliston).

Environmental Chemistry International (EGi), 2000. Acid forming characteristics of tailings samples from the Peak Gold Mine, memorandum to Peak Gold Mines from EGi, 18 July.

GeoAnalysis 2000 Ltd., 2000. SoilCover Version 5.1.

O'Kane Consultants Inc. (OKC), 2001. Development of a cover system design for the Peak Gold Mines tailing dam, Phase One final report: Potential cover and tailings dam material characterization and cover system design soil-atmosphere modelling, report #661-08 prepared for Peak Gold Mines, December.

O'Kane Consultants Inc. (OKC), 2002. As-built report for the Peak Gold Mine tailings dam cover system field trials, report #661-12 prepared for Peak Gold Mines, October.

O'Kane, M, and Barbour S L, 2003. Predicting field performance of Lysimeters used to evaluate cover systems for mine waste. Proceedings Sixth International Conference on Acid Rock Drainage, pp 327-339 (Cairns).

O'Kane Consultants Inc. (OKC), 2004. Rio Tinto, Hamersley Iron Pty. Ltd., Tom Price Operations, Acid rock drainage control field test plots, Monitoring report No.2 for Year One, report #662/3-02 prepared for Pilbara Iron, October.