Cover System Design and Testing for Pierina Mine, Ancash, Peru

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Abstract

Minera Barrick Misquichilca S.A., a Peruvian subsidiary of Barrick Gold Corporation, operates the Pierina open pit gold mine near Huaraz in the Department of Ancash, Peru. Pierina has been in production since 1998; closure planning is a continuing process that started before mine construction and has been refined during the life of the operation.

Closure cover design for the waste dump and spent leach pad facilities at the Pierina mine is a great technical challenge because the annual precipitation exceeds annual pan evaporation, and almost all of the annual precipitation occurs within seven months. The basic cover system design includes the use of a low permeability clay/silt layer overlain by a topsoil (evapotranspirative) cover. An unusual design concept (suction break) is also being evaluated. The suction break depressurizes the topsoil material during the rainy season by diverting lateral flow between the topsoil and clay/silt materials.

In order to test the cover system design, two large-scale test panels were constructed at the heap leach facility. In one panel, clay/silt material was placed and roller compacted to approximately 90% of maximum density with an approximate thickness of 35 cm. In the other panel, clay/silt material was placed and compacted only by equipment traffic resulting in an approximate thickness of 55 cm. Approximately 30 cm of topsoil was then placed over the clay/silt in both test panels to serve as growth media.

The performance of the cover systems in both panels is currently being evaluated with a network of monitoring stations containing water content, oxygen content and matric potential sensors. In addition, deep percolation, surface water runoff and erosion rates are also monitored. In this paper, the efficiency of the suction breaks and difference between the compacted and non-compacted clay/silt sub-layer are examined.

1 Introduction

1.1 Project location

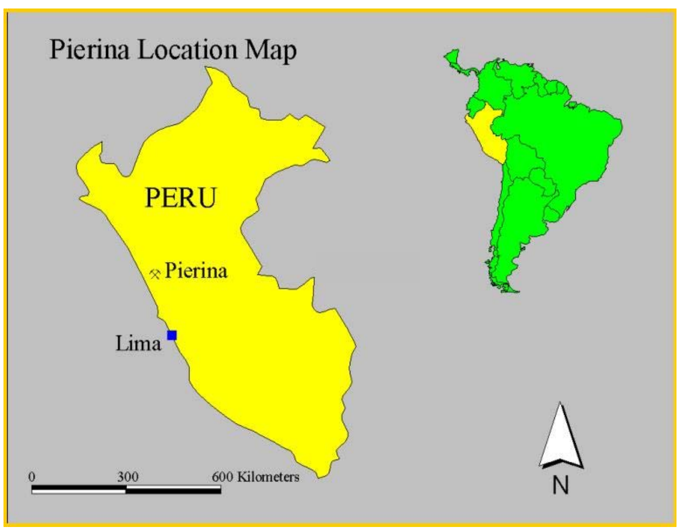

Figure 1 Pierina location map

The Minera Barrick Misquichilca Pierina mine (Pierina) is located on the eastern flank of the Cordillera Negara, about 10 km northwest of the City of Huaraz in the Ancash Department, Peru (Figure 1). The Pierina mine is an open pit operation consisting of an open pit, a valley-fill heap leach facility, a waste rock facility, a Merrill-Crowe processing plant, and ancillary mine infrastructure. The elevations of the mine facilities range between 3800 meters (m) and 4200 m above sea level. The project construction began in 1996 and production began in 1998. At Pierina, closure planning is a continuing process that started before mine construction and has been refined during the life of the operation.

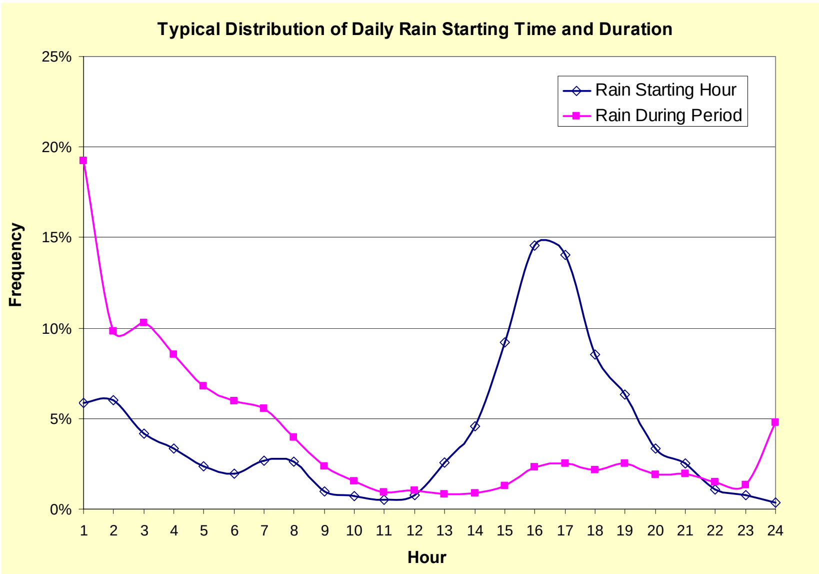

Figure 2 Daily precipitation patterns

1.2 Climate

Climate data have been recorded at the mine site since January 1997. The climate at the site is characterized by a bi-modal precipitation pattern with wet (October – April) and dry (May – September) seasons (Table 1). Temperatures at the site rarely fall below zero and do not change significantly month by month; the average annual temperature is about 6.0°C. Average annual precipitation is about 1200 mm with most precipitation received as afternoon thunderstorms (Figure 2).

Average precipitation far exceeds the pan evaporation during the rainy season; the recorded annual pan evaporation is approximately 1060 mm.

Table 1 Average monthly climate data, Pierina (January 1997 – April 2007)

Month	Precipitation (mm)	Pan Evaporation (mm)	Daily Temperature (Degree C)	Daily Relative Humidity (%)	Daily Wind Speed (m/s)	Daily Net Solar Radiation (w/m2)
Jan	156.3	74.8	6.0	82.5	2.6	141.4
Feb	187.8	55.0	6.1	85.6	2.5	143.7
Mar	243.7	52.0	5.9	87.8	2.4	116.2
Apr	145.0	53.1	6.4	85.1	2.4	117.4
May	32.1	91.7	6.6	75.2	2.5	90.4
Jun	9.1	86.3	6.1	66.2	2.6	76.0
Jul	3.5	122.5	6.1	58.6	2.8	87.3
Aug	9.2	142.9	6.4	57.5	2.9	97.8
Sep	48.6	111.1	6.3	68.2	2.7	104.6
Oct	103.7	106.6	6.2	74.3	2.7	119.3
Nov	109.2	99.0	6.1	72.6	2.7	131.8
Dec	162.5	62.0	5.9	82.1	2.6	130.2
Total/Average	**1210.7**	**1057.0**	**6.2**	**74.6**	**2.6**	**113.0**

1.3 Test panels

The authors of this paper have been working on the behaviours of cover systems for many years, analyzing their response under a variety of conditions using experimental, numerical, and in situ monitoring tools (e.g. Zhan et al., 2000, 2001a, 2001b, 2006). Because the precipitation exceeds the potential evapotranspiration, the Pierina cover system design cannot relay solely on an evapotranspirative cover. However, recent studies have shown that the geometry of a cover system will affect its performance to limit water and oxygen fluxes (Aubertin et al., 1997, 2006; Bussière et al., 2002, 2003). Moisture that builds up above an interface between coarse- (topsoil) and fine-grained (clay/silt) materials could flow along a sloped interface. Studies on the effect of slope on cover system performance are rare. Most analyses on the slope effect have been conducted using analytical approaches. These solutions are generally based on steady-state conditions, and assume infinite thickness and no evapotranspiration (ET). Bussière et al. (2002) conducted a laboratory study on the cover inclination behaviours which showed significant differences compared with results from analytical solutions and from one-dimensional modelling results.

The basic cover system design consists of a clay/silt layer emplaced on top of the waste with a topsoil cover to support vegetation. An unusual and innovative design component of the Pierina cover system is the use of "suction breaks". The suction breaks consist of a network of drainage pipes that are placed at regular intervals within the topsoil layer. These drains serve to reduce the pore pressure in the topsoil material, thereby increasing topsoil stability and also reducing the potential for deep percolation. They also block lateral flow along the sloped interface between the topsoil and clay/silt layer.

Figure 3 Heap leach facility test panel location (in green)

In order to test the efficacy of the cover system design, two test panels have been installed at the heap leach facility with a standard 10 m suction break spacing but different clay/silt thicknesses and degree of clay/silt compaction.

The test panels were installed in December, 2005 with subsequent seeding of native grasses (Figure 3). In addition, a cover performance monitoring system was installed to develop a better understanding of the capability of the cover systems to minimize deep percolation into the heap leach facility after closure. The cover performance monitoring system consists of four instrument nests within each test panel to monitor deep flux, water content, soil matric potential and gaseous oxygen.

2 Cover system performance test

A cover system performance test was designed to:

- Determine the hydraulic properties of available clay/silt and topsoil borrow source materials
- Evaluate the constructability of the cover system design on 2.5(H):1(V) side-slopes
- Evaluate the performance of roller compacted vs equipment compacted clay/silt
- Determine the cover system water budget consisting of precipitation minus:
    - surface water runoff
    - surface evaporation and plant transpiration
    - drainage from the suction breaks
    - deep percolation flux
- Monitor for long-term erosion

2.1 Borrow material hydraulic property characteristics

Table 2 Summary of hydraulic property measurements

Material Type	Field Saturated Hydraulic Conductivity (cm/sec)	Laboratory Saturated Hydraulic Conductivity (cm/sec)	Number of Samples
Previously reclaimed area:			
Fat Clay	2.2E-06		2
Topsoil	2.2E-04		4
Borrow Material			
Compacted clay/silt		2.7E-06	5
Topsoil		1.5E-04	5
Test Panel			
Uncompacted clay/silt	1.3E-05		4
Compacted clay/silt	4.9E-06		6
Leach ore		4.5E-02	2

Both laboratory and field hydraulic properties were measured for borrow and leach ore materials to assist in design planning and predictive modelling of the cover system performance. Laboratory measurements consisted of determining saturated (K_{sat}) and unsaturated (K_{unsat}) hydraulic conductivity and the moisture retention curves (MRC) of cover and underlying mine waste materials. In addition, sixteen single-ring cylinder infiltrometer tests (Bouwer et al., 1999) were conducted to determine in-situ K_{sat} values of topsoil and clay/silt materials at a previously reclaimed site and equipment and roller-compacted clay/silt layers and topsoil layer at the test panels. Table 2 summarizes the laboratory and field K_{sat} values; moisture retention and unsaturated hydraulic conductivity characteristics are described in Section 3.

2.2 Test panel construction overview

Two test panels, each approximately 20 meters by 55 meters were constructed on the northern corner of the heap leach facility. Each test panel had clay/silt borrow material placed over the 2.5:1 slope heap leach material, overlain with topsoil material for vegetative growth. The clay/silt material in Panel 3 was roller compacted to approximately 90% of maximum density after placement to a final thickness of 35 cm. In Panel 4, only equipment traffic compaction occurred on the clay/silt material resulting in a final approximate thickness of 55 cm. Approximately 30 cm of topsoil was then placed over the clay/silt layer in both test panels. The western-most portion of the test panels extended onto a relatively flat bench (2% slope), whereas the rest of the panels were on side-slope. In both panels, four series of suction breaks were placed at approximately 10 meter spacings in the topsoil material along slope contours.

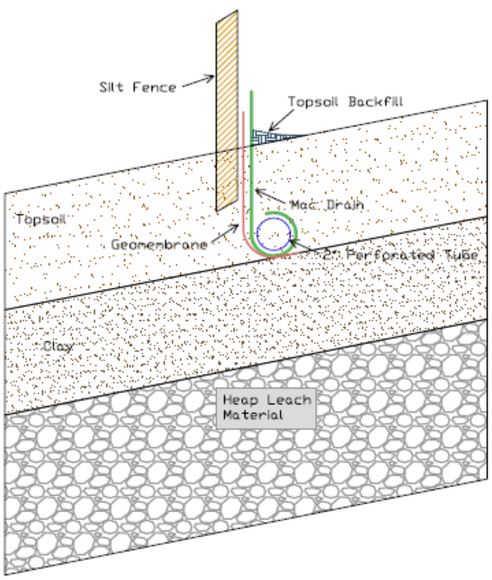

Figure 4 Cross-section of suction break design

A geomembrane lined “break” with a 2-inch diameter perforated drainage pipe was placed within the topsoil to collect water from the cover system. Figure 4 shows a cross-sectional schematic of the suction break construction. The removal of soil water via suction breaks should reduce water flux into the clay/silt and underlying leach ore or waste rock materials. In addition, the suction breaks should provide additional geotechnical stability by reducing saturation that may be occurring at the interface.

2.3 Monitoring system installation

A monitoring system was installed to evaluate long-term cover performance in the two test panels at two different topographic locations (flat areas vs. sloped areas) and above and below the suction breaks. Four sites were selected for each panel (Figure 5). One site was on an upper bench (west side) and the other three sites were on the side slope located between the second and third suction breaks. “Major” monitoring nests (with letter T) are located in the upper flat area and in the middle of the side-slope panel area between the suction breaks, “minor” sensor nests (with letter M), are located directly above and below a suction break.

Sensor Type	Abbreviation
Tensiometer	AT
Water Content	WC
Oxygen	O2
Heat Dissipation	HDS
Flux Meter	WFM
Flow Level	PT

Station Name	Number of Sensors					
	AT	HDS	WFM	WC	O2	PT
P3-S1-T	3	3	1	3	2	
P3-L1-T	3	3	1	3	2	
P3-L1-M	2		1	2		
P3-L2-M	2		1	2		
P4-S1-T	3	3	1	3	2	
P4-L1-T	3	3	1	3	2	
P4-L1-M	2		1	2		
P4-L-2M	2		1	2		
P3-PT1, P4-PT1						2
Total Number	20	12	8	20	8	2

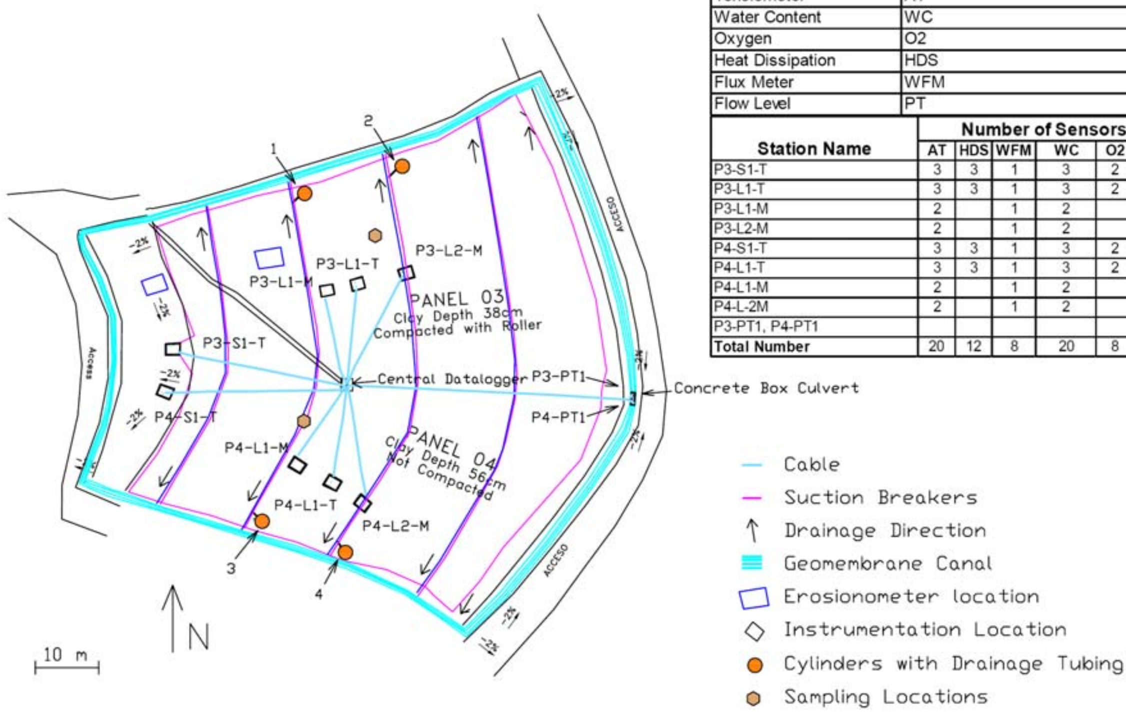

Figure 5 Plan view of the cover system test panels

Monitoring system sensor types include:

1) Soil matric potential sensors:
   a. Heat dissipation sensors (HDS)
   b. Advanced tensiometers (AT)
2) Soil moisture content sensors: ECH2O probes
3) Water flux meters (WFM)
4) Oxygen content sensors: Figaro KE50
5) Surface water monitoring:
   a. 015 cm H-Type flume
   b. 0-140 cm H_2O pressure transducer

The soil matric potential (HDS and AT) and water content (ECH2O) sensors monitor the wetness of the soil cover and the removal of water through drainage and evapotranspiration. The water flux meter (WFM) measurements provide a small scale point measurement of deep flux at each location. The oxygen sensors monitor how efficient the clay/silt layer is in minimizing oxygen flux into the leach ore. Finally, the H-flumes provide a very precise measurement of surface water flow rates.

For all major sensor nests, two sets of HDS, AT, and ECH2O sensors were placed approximately in the middle of the topsoil and clay/silt layers with a third set of sensors generally placed 30 cm below the clay/silt-leach ore contact (Figure 6). Both ATs and HDS were used in the major sensor nests in order to accurately capture the full range of soil moisture matric potential. Figaro oxygen sensors were placed at the same depths as the AT sensors in the ore and clay/silt. WFMs (Gee et al, 2002) were placed below all other sensors at depths of 1.5 to 1.9 meters below the ground surface in order to measure deep infiltration. The minor nest monitoring stations consisted of AT and ECH2O sensors in the clay/silt and topsoil, and a flux meter in the leach ore.

To install the sensors, 2 by 3 meter pits were hand dug to a depth of about 2 meters. Timbers were placed around the walls of the pit for worker protection. A smaller hole was then dug another 1.0 meter for installation of the WFM. Clay/silt, topsoil and leach ore materials were separated by placing on plastic sheets to prevent mixing of materials during backfilling.

The WFMs were installed first followed by backfilling with leach ore placed by hand and spread with shovels in 0.5 meter lifts to the depth of the first sensors. HDS and ECH2O sensors were placed horizontally and bedded in the soil, advanced tensiometers and oxygen sensors were installed vertically and are designed to be replaceable in case of sensor failure.

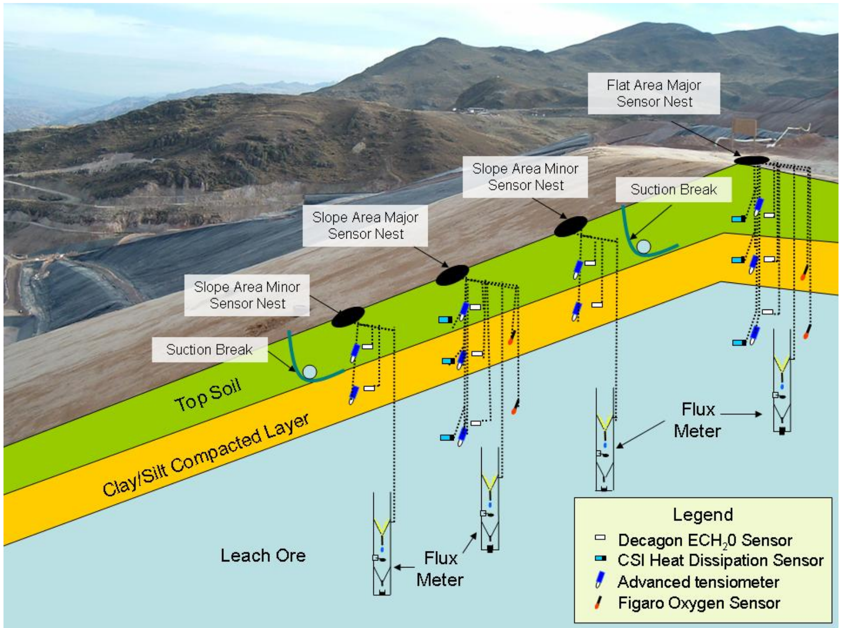

Figure 6 Cross-section of monitoring nest installation

At the interface between the clay/silt and topsoil, bentonite was placed between the pit wall and the undisturbed clay/silt in order to eliminate preferential flow created by the excavation of the pit. The clay/silt on Panel 3 was placed in 15 cm layers and compacted with a plate compactor. All other materials were placed in 15 cm layers and compacted by foot. After backfilling, sensor cables were bundled into protective polyethylene conduit to the data logger. Data from the sensor nests are collected hourly.

Stormwater runoff from the panels is collected in side-slope and down-stream drainage channels (Figure 5) and routed to two H type flumes located at the foot of the panels. During a storm event, the depth of water in the flume is measured with a pressure transducer at 6 minute intervals. In addition, drainage from the pipes located in the suction break is measured on a daily basis in two cisterns (cylinders) per panel located where the suction breaks meet the side-slope channels (Figure 5).

2.4 Monitoring system results

The monitoring system was fully operational as of February 15, 2006. Consequently, this manuscript only evaluates the cover system performance evaluation with the first 14 months of observed data. Numerical simulation using a 2D unsaturated flow model will also be performed to investigate the slope effects on cover performance and effectiveness of the suction break. These results will be published separately.

2.4.1 Precipitation and surface water runoff

Stormwater runoff rates generated from the two panels were similar. During the first rainy season after cover installation stormwater runoff averaged approximately 40% of the total precipitation whereas by the second rainy season, it had decreased to approximately 15% of precipitation with a total average of 25% (Figure 7). It was observed that in the second rainy season the amount of siltation (from erosion) that was observed in the flumes decreased significantly compared to the first rainy season due to the emergence of mature vegetation on the test panels.

As indicated on Figure 7, the observed stormwater runoff was well simulated by Soil Conservation Service (SCS) model (SCS, 1986). The SCS curve number (CN) method is a simple and widely used method for determining the approximate amount of runoff from a rainfall event in a defined area. Curve number values of 97 and 90 for the first and second rainy seasons were observed to provide the best fits. The lower curve number during the second rainy season is due to the development of more mature vegetation on the test panels. Both curve numbers are much greater than listed using standard assumptions for soil type and vegetative cover (SCS, 1986). Consequently, these data indicate that SCS curve numbers should be adjusted upwards to account for steep slopes.

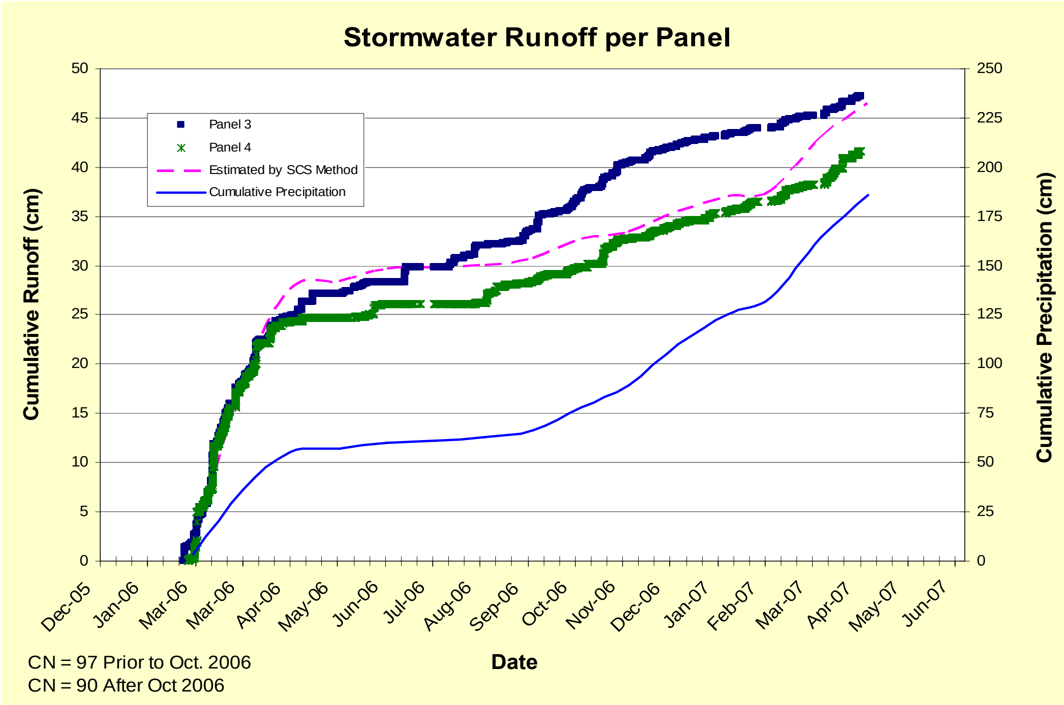

Figure 7 Cumulative precipitation and simulated/observed stormwater runoff

2.4.2 Cover and leach ore moisture and oxygen content status

The monitoring data indicate that the flat areas received unrealistic amount of recharge. This is most likely due to ground settlement and the drainage of water towards the sensor nests. This expectation was confirmed by the observations of surface water ponding near the nests. Consequently, the observed data from the sensor nests installed in the flat area will be not discussed due to the biased monitoring results.

Figure 8 shows the topsoil, clay/silt and leach ore water content status for the major sensor nests located in the middle of the side-slope panels between the suction breaks. The topsoil material held up to 45% (volumetric) water content; with the Panel 3 (compacted clay/silt) topsoil typically holding slightly less water content than Panel 4 topsoil. Water contents in the leach ore remained less than 5% during the first rainy season and only rose above 5% in Panel 3 during the second rainy season. In addition, it was found that increased clay/silt water contents were observed almost one month later in Panel 4 than in Panel 3. This may be due to the greater water holding capacity of the uncompacted clay/silt layer in Panel 4, which is the product of difference of the maximum and minimum water contents multiplied by the layer thickness.

The above and below suction break monitoring locations (minor sensor nests) also showed similar behaviour. Figure 9 indicates that the clay/silt in both panels showed similar behaviour during the first rainy season. In the second rainy season, the Panel 3 compacted clay/silt became wetter much earlier than the Panel 4 uncompacted clay/silt. In addition, the above suction break Panel 3 compacted clay/silt sensor showed wetting one month earlier than the below suction break sensor, indicating that a seepage face was forming above the suction break. However, in the Panel 4 un-compacted clay/silt, these trends were not observed which suggests that the moisture retention in the topsoil was sufficient to store infiltrated precipitation. Finally, once the clay/silt water content exceeded 20%, drainage into the leach ore material is observed in both panels.

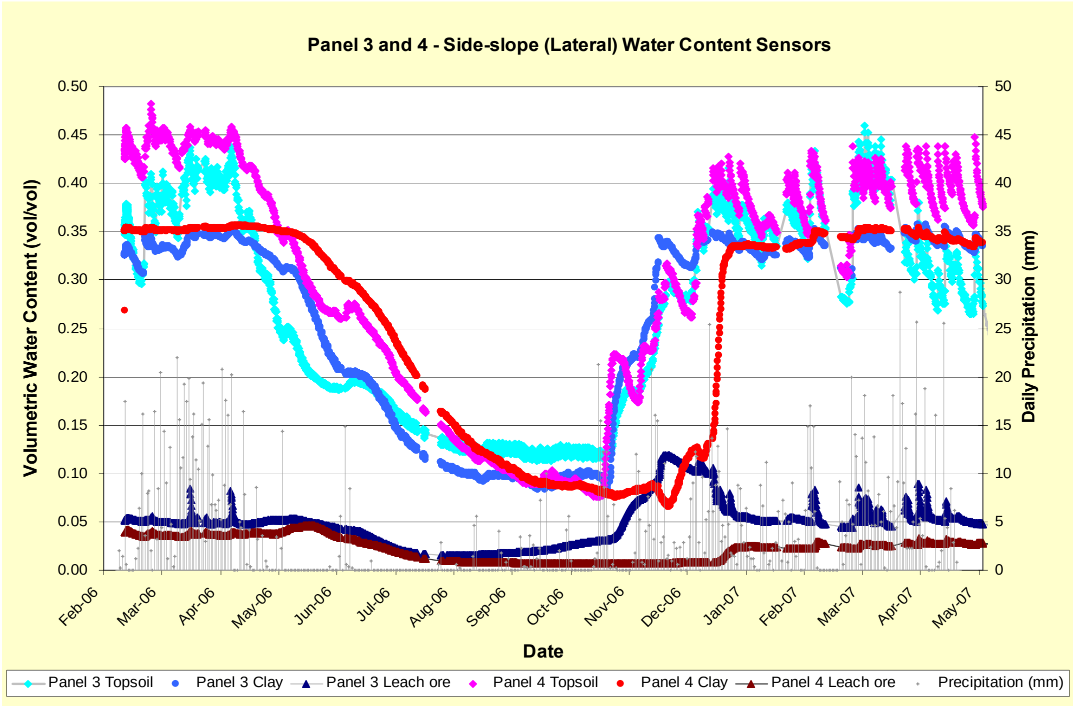

Figure 8 Water content of topsoil, clay/silt and leach ore in the middle of side-slopes

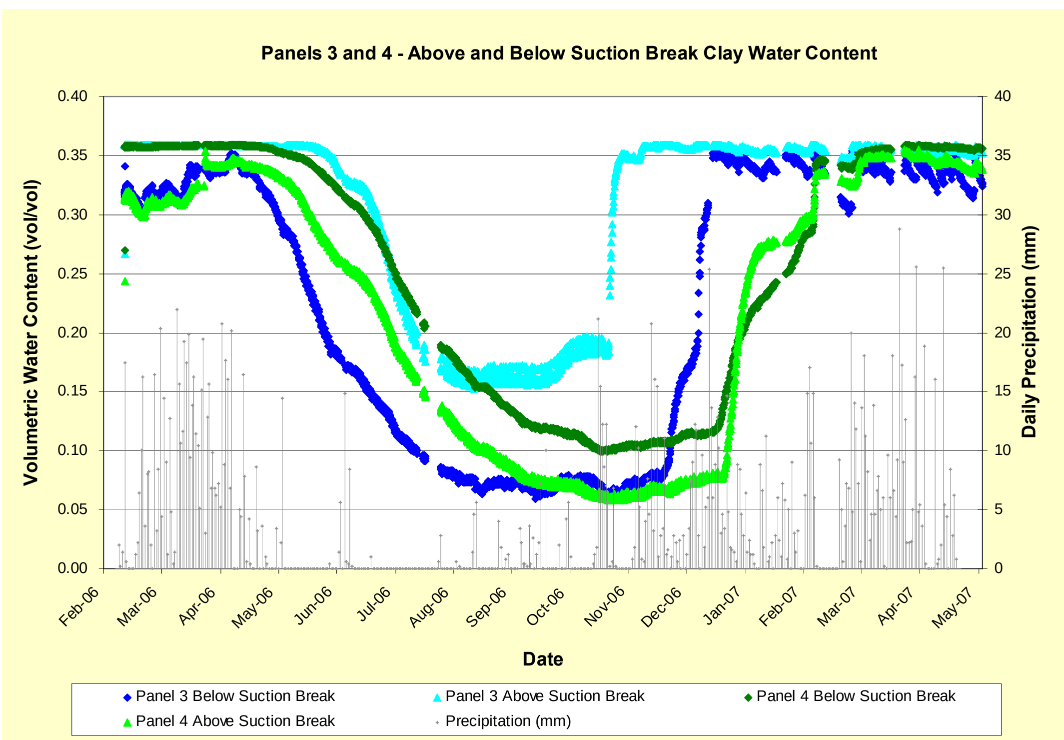

Figure 9 Water content in clay/silt above and below suction breaks

The gaseous oxygen content in the clay/silt and leach ore materials typically ranged from 65% to 85% of atmospheric levels (data not shown). Oxygen contents were consistently lower in the Panel 3 compacted clay/silt and varied slightly between the rainy and dry seasons. These data are consistent with the higher water content status of the Panel 3 clay/silt, but also indicate that oxygen transfer through the clay/silt into the leach ore is not greatly impeded.

2.4.3 Estimated downward flux

Downward flux through the cover system was estimated from both direct flux (WFM) and water content measurements. The leach ore water content sensor data were used to approximate downward flux rates by assuming a downward unit gradient and applying the closed-form analytical solution by van Genuchten et al. (1991) to solve Darcy's law. Laboratory and field observed K_{sat}, water content and matric potential relationships were combined to estimate van Genuchten parameters via best fit (Table 3) and calculate the corresponding hydraulic conductivities from the leach ore water content data. Under a unit gradient assumption, the unsaturated hydraulic conductivity is equivalent to the downward flux rate. In actuality, the side-slope sensors showed an upward gradient from around May 15 to November 15, 2006 (Panel 3) and December 30 2006 (Panel 4). In addition, the WFM is located approximately 1 meter below the leach ore water content sensor such that water content predicted and WFM measured fluxes may not exactly coincide.

Table 3 Estimated van Genuchten parameters for leach ore

Parameter	Θr	Θs	α (1/cm)	n	m	L	Ks (cm/sec)
Lab- field combined data estimates	0.001	0.26	0.029	1.73	0.70	4.65	0.045

The water content estimated downward flux rates for the Panel 3 and 4 side-slope areas are shown on Figure 10. In addition, Table 4 compares the estimated water content downward flux and flux meter results. Due to data logger issues, some WFM data was lost during the second rainy season, so only the periods with both WFM and water content data are compared. The Panel 3 side-slope showed higher WFM flux rates (9% to 15% of precipitation) than the Panel 4, which showed 6% to 11% of precipitation. The predicted "water content flux" was significantly lower during the same period, possibly due to the different depths between the sensor types. The WFM data from both panels indicate that the least flux occurred below the suction break, followed by the intermediate station and the greatest flux occurring above the suction break. This is consistent with water accumulating above the clay layer and draining laterally via gravity through the topsoil material. Finally, the water content and WFM data are consistent and indicate that the Panel 4 uncompacted clay/silt cover design is performing better than the Panel 3 compacted clay/silt cover design.

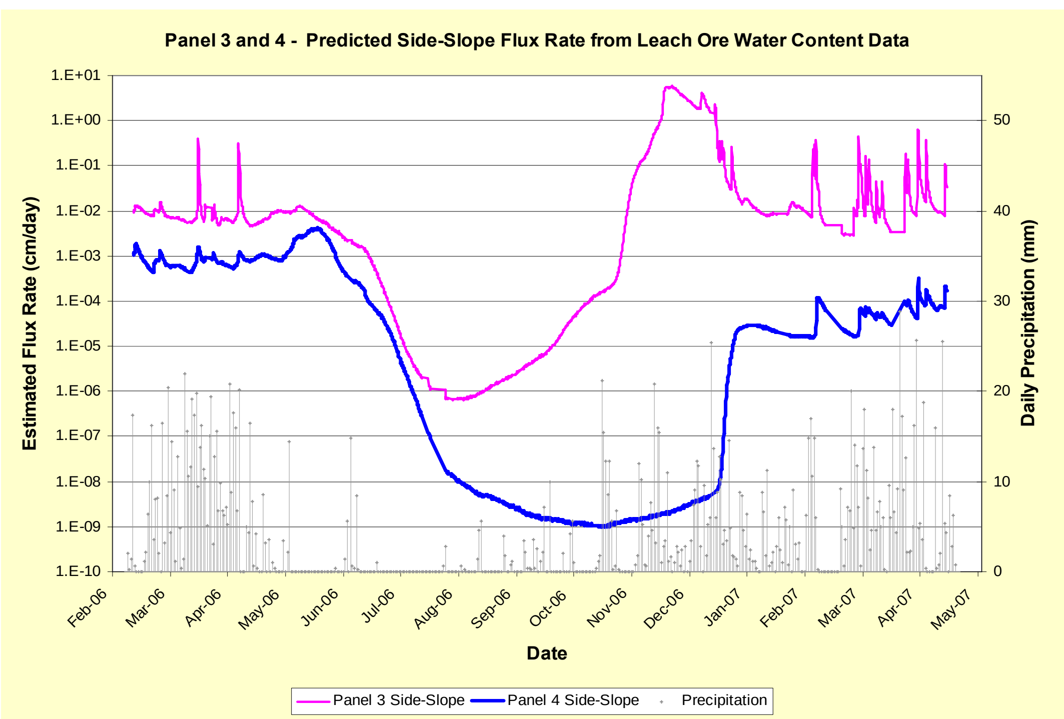

Figure 10 Predicted downward flux from leach ore water content data

Table 4 Comparison of predicted downward flux (in cm) from water content and WFM data

Dates	Precip-itation (cm)	Panel 3 Downward Flux (cm)				Panel 4 Downward Flux (cm)			
		Side-slope (Major Nest)		Side-slope (Minor Nest - WFM)		Side-slope (Major Nest)		Side-slope (Minor Nest - WFM)	
		Water Content Estimated	WFM	Below Suction Break	Above Suction Break	Water Content Estimated	WFM	Below Suction Break	Above Suction Break
2/12/06 - 6/20/06	66.2	1.23	12.73	8.70	13.4	0.14	6.80	5.74	7.6
12/22/06 - 2/15/07	26.06	2.7	0.0	0.0	0.0	0.0012	-	0.0	2.7
Total	**92.26**	**3.93**	**12.73**	**8.70**	**13.4**	**0.14**	**6.80**	**5.74**	**10.3**
Percent of Precipitation		**4.3%**	**13.8%**	**9.4%**	**14.5%**	**0.2%**	**7.4%**	**6.2%**	**11.2%**

3 Discussion and conclusions

The test panel construction and monitoring system installation was completed successfully and has been functioning adequately to assess the cover system performance. Monitoring data to date indicate that:

1. Measured downward flux rates range from 6% to 15% of the measured precipitation. Considering that precipitation far exceeds the pan evaporation during the rainy season, the cover systems are greatly reducing the potential flux.
2. The uncompacted clay/silt cover (Panel 4) is performing much better than the compacted clay/silt (Panel 3) in reducing downward flux. This is most likely due to the thicker clay/silt layer in Panel 4.
3. The suction breaks are as effective as expected. They significantly reduce the pore pressure in the topsoil material, thereby increasing topsoil stability and also reducing deep percolation between the above and below the suction break in both panels (Table 4).
4. Significant downward flux was observed in the flat area monitoring locations primarily due to surface water ponding. Consequently, flat areas should be avoided in cover design if at all possible in these types of climates.
5. Oxygen contents in the clay/silt layer and leach ore were only slightly decreased from atmospheric levels, and oxygen transport does not appear to be greatly impeded by the clay/silt layer.
6. Established vegetation was observed to significantly decrease runoff and erosion. Significant differences in deep downward flux attributable to vegetation were not observed.

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References

Aubertin, M., Cifuentes, E., Martin, V., Apithy, S., Bussière, B., Molson, J., Chapuis, R.P. and Maqsoud, A. (2006) An investigation of factors that influence the water diversion capacity of inclined covers with capillary barrier effects. Proceedings of the 4th International Conference on Unsaturated Soils, UNSAT 2006, April 2-6, Carefree, Arizona, Geotechnical Special Publication No. 147, ASCE, GEO Institute, G. A. Miller, Zapata, C.E., Houston, S.L. & Fredlund, D.G. (eds). Vol.2, pp. 613-624.

Aubertin, M., Chapuis, R.P., Bouchentouf, A. and Bussière, B. (1997) Unsaturated flow modeling of inclined layers for the analysis of covers. Proceedings of the 4thICARD, Vancouver, B.C., 2: pp. 731-746.

Bouwer, H., Back, J.T. and Oliver, J.M. (1999) Predicting Infiltration and Ground Water Mounds for Artificial Recharge, J Hydro Eng, ASCE, (4) pp. 350-357.
Bussière, B., Apithy, S. A., Aubertin, M. and Chapuis, R.P. (2003) Diversion capacity of sloping covers with capillary barrier effects. 56th Annual Canadian Geotechnical Conference and 4th Joint IAH-CNC and CGS Groundwater Specialty Conference, Winnipeg, Manitoba, September 29 - October 1, 2003. Comptes-Rendus sur CD-ROM, 8p.
Bussière, B., Aubertin, M. and Chapuis, R.P. (2002) A laboratory set up to evaluate the hydraulic behavior of inclined capillary barriers. Proceedings of the International Conference on Physical Modelling in Geotechnics, St.Jonh's, Newfoundland, pp. 391-396.
Gee, G. W., Ward, A. L., Caldwell, T. G. and Ritter, J. C. (2002) A vadose-zone water fluxmeter with divergence control. Water Resour. Res. 38(8)10.1029/2001WR00816.
U.S. Soil Conservation Service (1986) Urban hydrology for small watersheds, Tech. Release 55, Washington, D.C. SCS See U.S. Soil Conservation Service
van Genuchten, M. Th., Leij, F.J. and Yates, S.R. (1991) The RETC code for quantifying the hydraulic functions of unsaturated soils. U.S. Salinity Laboratory, U.S. Dept. of Agriculture, Agriculture Research Service, Riverside, CA. p. 83.
Zhan, G., Schafer, W., Milczarek, M., Myers, K., Giraudo, J. and Espell, R. (2006) The evolution of evapotranspiration cover system at Barrick Goldstrike Mines, 7th ICARD, March 26-30, 2006, St. Louis, MO.
Zhan, G., Aubertin, M., Mayer, A., Burke, K. and McMullen, J. (2001a) Capillary cover design for leach pad closure, SME Transaction 2001, 1: pp. 104-110.
Zhan, G., Mayer, A., McMullen, J. and Aubertin, M. (2001b). Slope effect study on the capillary cover design for a spent leach pad, Tailings and Mine Waste'01, Balkema, Rotterdam (ISBN 90 5809 182 1), pp.179-187.
Zhan, G., Mayer, A., McMullen, J. and Aubertin, M. (2000), Capillary cover design for a spent leach pad, Proceedings of International Symposium on Hydrology and the Environment, October 17 –21, Wuhan, Hubei, China, pp.144-150.