Performance of Cover System Field Trials for Waste Rock at Myra Falls Operations

B Ayres¹, G Dirom², D Christensen¹, S Januszewski³ and M O’Kane¹

ABSTRACT

Four field test plots were constructed in 1998 on a sloped waste rock surface at the Myra Falls Operations of Boliden Westmin (Canada) Limited to evaluate hydraulic performance of alternate cover system designs. The field test plot cover systems were designed to control oxygen ingress and water infiltration to the underlying waste rock while providing a medium for a grass and legume vegetation cover. The test plots consisted of a bare waste rock surface (control plot), and three additional plots consisting of native compacted till placed directly on the waste rock surface, overlain by non-compacted till. Two of the test plots included a compacted till layer ameliorated with flyash and bentonite, respectively, to improve moisture retention and reduce permeability. The third test plot consisted of a compacted layer of native till overlain by non-compacted till. A performance monitoring system was installed in each test plot to evaluate net percolation and oxygen ingress to the underlying waste rock. In addition, each test plot has profiles of matric suction, water content, and temperature sensors installed at up-slope and down slope locations.

A review of four years of monitoring data shows that the compacted till/bentonite cover system has been most successful in limiting the infiltration of meteoric waters and oxygen ingress to the underlying waste rock material. The compacted till/flyash and compacted till cover systems have produced similar net percolation results and neither have functioned well in maintaining an oxygen ingress layer throughout the year. The amelioration of bentonite with till to produce a compacted barrier layer shows promise in reducing water and oxygen ingress at the MFO site, while the incorporation of flyash with the till did not result in a significant increase in performance. The field performance data clearly demonstrates the need for developing field trials prior to full-scale construction, as opposed to relying solely on an un-calibrated numerical modelling to design the full-scale cover system.

DESCRIPTION OF THE TEST PLOTS

As built construction

Construction of the test plots was completed in October 1998. The surface of the existing waste rock pile at the test plot area was prepared to a uniform 10:1 slope (≈5°). O’Kane et al (1995, 1996, 1997, and 1998) provide a detailed description of the design of the test plots, as well as the supporting laboratory and modelling work completed for the design.

Figure 1 shows the physical layout and materials of each test plot. Test Plot No 1 (TP-1) is a control test plot with a bare waste rock surface. All three of the remaining test plots were constructed in a similar manner. That is, each test plot had approximately 50 cm of compacted material placed directly on the waste rock platform surface, overlain with 30 cm of non-compacted native till. MFO personnel applied a seed mix of grasses and legumes to the three test plots.

Table: Test Plot Layout

<table>
<thead>
<tr>
<th>Test Plot 1 (control)</th>
<th>Test Plot 2 (flyash)</th>
<th>Test Plot 3 (native till)</th>
<th>Test Plot 4 (bentonite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm</td>
<td>30 cm</td>
<td>30 cm</td>
<td>30 cm</td>
</tr>
<tr>
<td>Till (non-compacted)</td>
<td>Till (non-compacted)</td>
<td>Native Till (compacted)</td>
<td>Tilk (non-compacted)</td>
</tr>
<tr>
<td>50 cm</td>
<td>50 cm</td>
<td>25 cm</td>
<td>25 cm</td>
</tr>
<tr>
<td>Flyash + Till (compacted)</td>
<td></td>
<td>Bentonic + Till (compacted)</td>
<td></td>
</tr>
</tbody>
</table>

Waste Rock

Waste Rock

Fig 1 - Schematic of the Myra Falls Operations waste rock test plot layout.
Test Plot No 2 (TP-2) and Test Plot No 3 (TP-3) were constructed with two 25 cm lifts of compacted material. The TP-2 compacted layer consisted of a mixture of flyash and native till. The flyash was supplied by Centralia Coal and added to the native till on a 25 per cent mass basis. The flyash was dry mixed with the native till using a pulvi-mixer. The flyash-till mixture was moisture conditioned using the pulvi-mixer, and then mixed repeatedly until consistent moisture conditions were achieved throughout the depth of the lift. Each lift was compacted using a smooth drum vibratory roller. The TP-3 compacted layer was constructed from native till only.

The Test Plot No 4 (TP-4) compacted layer was also placed in two lifts. However, the two lifts were constructed from different material. The lower lift placed directly on the waste rock platform surface consisted of a mixture of bentonite and native till. The bentonite was supplied by Wyo-Ben Incorporated located in Montana, USA and mixed on an eight per cent by mass basis using the same procedure as described above for the flyash and native till in TP-2. The upper compacted lift of TP-4 was constructed from native till without the addition of fine textured ameliorating material.

Materials

O’Kane et al (1997) summarised the physical properties of the cover and waste materials. The till cover material was a sandy, non-plastic silt matrix till with a trace of clay. It was oxidised with angular cobbles and boulders up to 15 cm with a specific gravity of 2.82. The maximum dry density was approximately 2.1 Mg/m³ for a standard Proctor compaction effort and the corresponding optimum moulding water content was ten per cent. The oxidised waste rock was well graded with coarse angular rock and a significant portion of silty material as a result of physical, chemical, and biological weathering. The saturated hydraulic conductivity of each sample was measured using a falling head apparatus during consolidation testing. The samples were prepared using material less than 4.75 mm (ie passing the No 4 sieve). The laboratory saturated hydraulic conductivity of a sample of compacted native till cover material varied between $1 \times 10^{-6}$ cm/s and $1 \times 10^{-7}$ cm/s. The laboratory saturated hydraulic conductivity of the waste rock samples varied between $1 \times 10^{-5}$ cm/s and $1 \times 10^{-7}$ cm/s because the coarse particles were screened out. In addition, significant silt size material was present in the waste rock within the upper few metres of the waste rock pile at the location where the sample was collected.

A key component of the laboratory program was the measurement of the soil water characteristic curve (SWCC). The SWCC is a continuous function relating energy and the state of water, and hence describes the water content of a soil as a function of soil suction, or negative pore-water pressure. The SWCC is central to the design of an unsaturated soil system and the most fundamental characterisation required for design. The saturated hydraulic conductivity and the relationship between the effective diffusion coefficient for oxygen and the degree of saturation were also key parameters for test plot cover design.

The soil water characteristic curves (SWCC) of the waste rock, compacted till, non-compacted till, compacted till/bentonite, and compacted till/flyash are shown in Figure 2. The SWCC’s of the non-compacted and compacted till samples illustrate the coarse but well graded nature of the potential cover material. The non-compacted till possesses a low air entry value (ie ≈ 1 kPa) with a gradual slope at suctions greater than the air entry value. The air entry value increased to approximately 10 kPa as a result of compaction and the porosity decreased from 0.34 to 0.31, although the slope of the SWCC was similar. The small percentage of clay and clay-sized material within the till sample, and as a result the non-plastic behaviour of the till, led to the relatively small increase in the air entry value following compaction. The SWCC of the waste rock is bi-modal as a result of the presence of coarse material as well silty material ‘created’ by physical, chemical, and biological weathering of the waste rock. The waste rock is gap graded with two distinct air entry values, as shown in Figure 2. The first occurring at a suction near zero and the second at approximately 7 kPa.
Soil-atmosphere modelling for test plot cover system design

The test plot cover system alternatives were modelled using the one-dimensional coupled soil-atmosphere SoilCover model (MEND, 1996). The alternatives were evaluated on the basis of their ability to perform as oxygen diffusion and water infiltration barriers. Initially, a cover system consisting of a compacted native till layer overlain by a non-compacted native till layer was considered. However, the computed degree of saturation of the compacted native till layer was less than the desired minimum of 85 per cent during the simulation period. In general, the oxygen flux across the soil cover system is limited if the degree of saturation of the compacted layer is greater than 85 per cent.

The soil-atmosphere numerical modelling showed that a compacted layer of till, ameliorated with bentonite or flyash, and placed between an upper non-compacted layer of till and the underlying waste rock provided an oxygen ingress and water infiltration barrier for the waste rock material (O’Kane et al., 1997). The model predicted that the ameliorated compacted till layer remained at a degree of saturation greater than 95 per cent during the historical ‘dry’ year growing season. The predicted net percolation from the base of the compacted layer into the underlying waste rock was approximately one per cent of the historical ‘wet’ year modelled precipitation.

The addition of 25 per cent flyash by mass increased the air entry value of the compacted till to approximately 100 kPa, although little change in the porosity of the sample was observed. The air entry value of the compacted till sample ameliorated with eight per cent bentonite by mass was approximately 30 kPa. However, the porosity of the compacted till ameliorated with eight per cent bentonite increased by 20 per cent as compared to that measured for the native compacted till sample.

DESCRIPTION OF THE FIELD PERFORMANCE MONITORING SYSTEM

Net percolation

Four lysimeters were installed at MFO in October 1997 following completion of the waste rock test plot platform. The original construction schedule called for the test plots to be constructed and instrumented following installation of the lysimeters. However, construction was postponed to the following summer (ie 1998) due to poor weather conditions. Pressure transducers to measure the depth of water within each lysimeter were installed in October 1998.

Each lysimeter was installed using the same procedure and materials, and is shown schematically in Figure 3. The pressure transducer in each lysimeter is located at the base of the lysimeter inside the centrally located piezometer. The TP-1 and TP-2 lysimeter pressure transducers are connected to the TP1/TP2 data acquisition system (DAS). The pressure transducers installed in the TP-3 and TP-4 lysimeters are connected to the TP3/TP4 DAS.

Moisture storage and transport

Moisture storage and transport are monitored using matric suction sensors and volumetric water content sensors. Nests of eight suction sensors were installed up-gradient and down-gradient of the TP-2, TP-3, and TP-4 lysimeters. A sensor was installed in the underlying waste rock at each location, followed by four sensors in the compacted layers, and three sensors in the overlying non-compacted layer. Single nests of eight volumetric water content sensors were installed at the up-gradient location of TP-2, TP-3, and TP-4. The TP-2 sensors are connected to the TP1/TP2 DAS, and the TP-3 and TP-4 sensors are connected to the TP3/TP4 DAS.

Temperature

In situ temperature was measured using the matric suction sensors. These sensors are actual thermal conductivity sensors operating under the principal of heat dissipation. Therefore, the initial temperature obtained before heating the sensor can be used to measure in situ temperature.

PRESENTATION OF FIELD PERFORMANCE MONITORING DATA

Net percolation

The test plot net percolation values shown in Table 1 are for a ‘monitoring period’ basis (ie October to September) because precipitation occurring in the late fall and winter contributes to percolation during the following spring.
The highest measured net percolation occurs at the bare surface control plot (TP-1). Net percolation was approximately seven per cent of the annual precipitation for the October 1998 to September 1999 monitoring period and increased to 18 per cent of the annual precipitation in the 1999 - 2000 monitoring period. The increase in net percolation is likely due to the wetter soil moisture conditions produced by the increased precipitation (2140 mm in 1999 - 2000 as compared to 1320 mm in 1998 - 1999). Net percolation decreased to two per cent of the annual precipitation in the 2000 - 2001 monitoring period. A negative net percolation, or upward movement of moisture, occurred in the 2001 - 2002 monitoring period. The 2001 - 2002 climate year at the MFO site featured average snowfall in the winter and below average rainfall in the summer. The upward net percolation measured at TP-1 is likely a result of the bare surface control plot responding to the dry conditions experienced from May to September at the site.

The performance of the TP-3 compacted till cover system was similar to TP-1. Net percolation was four per cent of the annual precipitation during the 1998 - 1999 monitoring period and net percolation increased to approximately five per cent in the 1999 - 2000 monitoring period. In the October 2000 to September 2001 monitoring period, net percolation was four per cent of the 1960 mm of recorded precipitation for the period. An upward net percolation was also measured at TP-3 for the 2001 - 2002 monitoring period.

The net percolation measured at TP-2 was fairly consistent throughout the four-year monitoring period with net percolation ranging from 3.1 per cent to 4.5 per cent of the annual precipitation. It is possible that there is a significant lag time between precipitation falling on the TP-2 cover system and collection of the percolation within the lysimeter. Net percolation was slightly less during the 1999 - 2000 monitoring period as compared to the 1998 - 1999 period even though approximately 800 mm more precipitation occurred in 1999 - 2000. The highest net percolation of the four years was recorded during the subsequent monitoring period, suggesting that response of the lysimeters is approximately six months to one year after the incidence of precipitation.

The net percolation recorded at the TP-4 lysimeter below the compacted till/bentonite cover system is lower than the other three test plots. Net percolation was 2.3 per cent of the annual precipitation in 1998 - 1999, a negative (upward) net percolation was recorded in 1999 - 2000, and net percolation was 1.8 per cent and 4.0 per cent for the 2000 - 2001 and 2001 - 2002 periods, respectively. It is likely that there is a lag time between the incidence of precipitation and collection in the lysimeter at TP-4 as upward net percolation was measured in the lysimeter in 1999 - 2000, one year after only 1323 mm of precipitation was recorded. The response of the lysimeter to the dry conditions measured in the summer of 2002 will not be apparent until the spring or summer of 2003.

The response of the till/flyash cover system was not as anticipated based on the test plot design soil-atmosphere modelling, which leads to concerns with its use as an ameliorating agent. The performance of the TP-2 compacted till/flyash cover system was not significantly better than the TP-3 compacted till cover system. However, the use of bentonite as an ameliorating agent at TP-4 did result in lower recorded net percolation values than the remainder of the test plots.

**Table 1**

<table>
<thead>
<tr>
<th>Time Frame</th>
<th>TP-1</th>
<th>TP-2</th>
<th>TP-3</th>
<th>TP-4</th>
</tr>
</thead>
</table>
| October 1998 - September 1999  
Precipitation = 1323 mm    | 6.6% | 3.8% | 3.9% | 2.3% |
| October 1999 - September 2000  
Precipitation = 2140 mm    | 17.6%| 3.7% | 4.7% | upward |
| October 2000 - September 2001  
Precipitation = 1960 mm    | 2.0% | 4.5% | 3.9% | 1.8% |
| October 2001 - September 2002  
Precipitation = 1743 mm    | upward | 3.1% | upward | 4.0% |

**Concerns with the test plot lysimeter measurements**

The lysimeters installed at the MFO site are not functioning exactly as designed because the water levels within the tanks are above the sand layer at the base of the tanks. Instead, the water levels have climbed into the waste rock backfill material. The original lysimeter design required regular pumping to collect percolated water. However, the delay of test plot construction from 1997 to 1998 after installation of the lysimeter tanks allowed percolation into the uncovered lysimeters. A reduction in available mine site personnel for test plot maintenance limited the pumping of the lysimeters to a bi-annual basis. The increased water levels have altered the performance of the test plot lysimeters.

In essence, a lysimeter creates an artificial, or ‘perched’, water table condition within the underlying waste rock material. The water table in this paper is defined as the depth below which the soil profile has a positive pore-water pressure. The material above the water table is unsaturated and possesses a negative pore-water pressure or suction. In an unsaturated system, suction generally increases with height above the water table. The elevation of the water table within the lysimeter determines the suction condition found at the top of the lysimeter tank directly below the test cover layer. The suction at the top of the lysimeter will be greater for a water table within the base sand layer than if the water table is within the waste rock layer. An elevated water table reduces the suction at the top of the tank to a condition lower than the material outside the confines of the lysimeter. This creates a tendency for water percolating above the lysimeter to bypass around the lysimeter tank as the increased suction outside the tank ‘pulls’ the infiltrating water away.

Figure 4 conceptually depicts the likely flow path of infiltrating water in the vicinity of the lysimeter tanks below the test plot covers. The schematic on the left represents a water table near the base of the lysimeter. The suction condition at the top of the tank is close to the suction condition outside the confines of the tank causing the water to flow vertically and producing representative net percolation results. The second schematic shows a much higher water table. The decreased suction condition at the top of the tank as compared to the surrounding material results in some lateral flow bypassing the lysimeter.

The influence of the elevated water table on net percolation depends on the rate of water infiltrating through the cover layer and the size of the lysimeter tank. At low infiltration rates, the
suction condition around the lysimeter tank will be higher, creating a larger disparity between conditions within and outside the tank. The percentage of bypass flow will be higher at low infiltration rates than higher infiltration rates. The size of the lysimeter tank also influences the percentage of bypass flow around the lysimeter. If the lysimeter is small, a higher proportion of infiltrating water will bypass the tank than for a large tank. In the case of the 2.0 m diameter lysimeter tanks installed at MFO, water directly above the middle of the tank is likely not affected by the soil suction condition outside the tank. The amount of water percolating through the MFO test plot covers is considered a moderate infiltration rate due to the high levels of precipitation experienced at the site. The lysimeter tanks are of adequate size to reduce the proportion of water bypassing the tank due to the decreased suction condition outside the tank. The net percolation rate measured in the test plot lysimeters is likely less than the ‘true’ percolation rate. The ‘true’ net percolation through the test plot covers can be evaluated with numerical modelling. The same numerical model used in the design of the lysimeter tank can be used to determine the ‘true’ net percolation. The numerical model would be calibrated to the conditions measured during the four-year monitoring period for each test plot, with the lower boundary condition set to simulate the elevated water table. The calibration variables would be the unsaturated hydraulic material properties for the cover and waste materials. The model would then be re-run with the correct lower boundary condition set to simulate the designed low water table height, and the ‘true’ percolation rate would be determined.

Moisture storage and transport

Conditions measured with volumetric water content sensors

The change in moisture storage of the test plots over the monitoring period was defined by calculating the volume of water within the test plot profile. The volume of water is an estimation of the ‘depth’ of water if the soil, air, and water components of the test plot profile were separated. For example, if a volumetric water content of 0.20 or 20 per cent was measured in a 1.0 m thick waste rock cover material profile with a porosity of 0.3, the ‘depths’ of soil, air, and water would be 70 cm, 10 cm, and 20 cm, respectively. Figure 5 summarises the change in volume of water within Test Plot Nos 2, 3, and 4 from installation to the end of September 2002. TP-1 is not shown in Figure 5 as it had only one water content sensor installed near the waste rock surface.

The response of the Test Plot Nos 2, 3, and 4 cover systems over the monitoring period is similar. The cooler, wetter months (October to April) show an increase in the volume of water stored in the cover system while the volume of stored water decreases in the warmer, drier summer months. The lowest values of water stored within the cover profiles occurred in August of 1999 and 2002. This was expected as the 1998-1999 monitoring period had a low annual precipitation (1323 mm) and during the summer of 2002 at the MFO site it was extremely dry.

Conditions measured with matric suction sensors

The average degree of saturation of the compacted till/flyash layer in TP-2, the compacted till layer at TP-3, and the compacted till/bentonite layer at TP-4 are shown in Figure 6. The data shown in Figure 6 is calculated by averaging the response of the individual sensors in each layer that were installed across the thickness of the layer. For example, the average degree of saturation values calculated for the compacted till/flyash layer is based on the response of four sensors. The TP-2 cover system featuring a compacted till/flyash layer does not maintain tension saturation conditions during the hot dry summer months at the site. The average degree of saturation of the compacted till/flyash layer dropped to approximately 50 - 60 per cent during the summers of 1999, 2000, and 2002 in response to the demand for moisture from the atmosphere. This is not a desirable performance characteristic because it implies an increase in oxygen diffusion coefficients and ultimately an increase in oxygen ingress during these hot dry periods. However, it should be noted that in each case the degree of saturation of the compacted till/flyash layer ‘recovers’ to tension saturated conditions during wet climate conditions.

There are three key reasons for the performance of the compacted till/flyash layer shown in Figure 6, all of which contribute to the measured performance. First, the till/flyash material itself does not possess sufficient moisture retention to ‘oppose’ the demand for moisture and thus significantly limit the reduction in moisture content. Second, the overlying non-compacted growth medium does not possess sufficient moisture storage and retention such that this layer alone satisfies all of the atmospheric demand for moisture. The simplest solution to this issue is to increase the thickness of the non-compacted layer, which would also be more consistent with rooting depths of undisturbed areas at the site. Finally, the hot, dry summers that are prevalent at the site contribute to the decrease in moisture conditions of the compacted till/flyash layer. This is important to note because it is a common mistake during cover system design to assume that if there is a moisture surplus on an annual basis, then limiting oxygen ingress will be
Fig 5 - Moisture storage within the test plot cover systems.

Fig 6 - Degree of saturation of compacted layers within the test plot cover systems.
possible. However, the data shown for the past three years at this site clearly demonstrates that performance of a cover system should be based on at least a seasonal basis, if not a monthly or daily basis. There are essentially two prevalent climate ‘regimes’ at the site; namely, wet conditions during the fall, winter, and spring, followed by hot, dry summers. It is important to note that these climate characteristics are very common at mine sites, which is an issue that should be addressed as part of the cover system design.

The till-flyash cover system did not perform as anticipated based on the soil-atmosphere cover system design modelling conducted prior to construction of the field trials. The variability and reduction in moisture retention characteristics of the flyash material resulted in the difference between the as-built material properties and those measured in the laboratory and input to the pre-field trial construction soil-atmosphere model. Flyash is a by-product and waste product of coal fired power stations as well as pulp and paper mills. Hence, quality control on its material properties will not be consistent, and the results reported in this paper illustrate the impact of the variability of a typical flyash product from the initiation of a project to the field implementation stages. While the results reported in this paper should viewed as being indicative of all situations regarding the use of flyash as a cover system ameliorating agent, they do strongly demonstrate the caution required with using flyash as an ameliorating agent due to the variability with the material that can be encountered during the time-frame for a typical cover system design project.

The TP-3 cover system with the compacted till layer did not maintain tension-saturated conditions throughout the monitoring period. The degree of saturation was only slightly greater than 85 per cent during the winter months at the site and reached lows of 40 - 50 per cent during the summer months. It is likely that the cover system does not perform as an adequate barrier to oxygen ingress. Note that this condition was anticipated as a result of the soil-atmosphere modelling noted earlier in this paper. However, it was decided to construct this cover system design field trial for a variety of site-specific reasons.

Figure 6 shows the average degree of saturation for the compacted till/bentonite layer within the TP-4 cover system. The performance of the compacted till/bentonite layer is better than the till/flyash layer discussed earlier. The compacted layer appears to maintain a tension-saturated condition throughout the year, even though there is a reduction in the degree of saturation during the summer months. The compacted till/bentonite material possesses significantly more moisture retention as suction increases, and therefore the average degree of saturation of the compacted till/bentonite layer during the summer remains above 85 per cent. This is a positive performance result, as is the ability of this layer to ‘recover’ and increase in moisture content in response to wet climate conditions.

**Temperature**

The temperature data collected during the monitoring period illustrates that the overlying snow pack and non-compacted layer provided insulation for the compacted layers at each of the test plots.

**SUMMARY**

Four test plots were constructed at Myra Falls Operations in 1998 and instrumented with volumetric water content and matric suction sensors. To date, four years of performance monitoring data has been collected. This paper presented net percolation rates as measured with large lysimeter tanks, moisture storage within the cover system layers, and the degree of saturation of the compacted layers within the cover systems. The collected data shows that the compacted till/bentonite cover system has been most successful in limiting the infiltration of meteoric waters and oxygen ingress to the underlying waste rock material. The compacted till/flyash and compacted till cover systems have produced similar net percolation results and neither have functioned well in maintaining an oxygen ingress layer throughout the year. The amelioration of bentonite with till to produce a compacted barrier layer shows promise in reducing water and oxygen ingress at the MFO site, while the incorporation of flyash with the till did not result in a significant increase in performance.

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