

WASTE ROCK COVER SYSTEM FIELD TRIALS AT THE MYRA FALLS OPERATIONS - A SUMMARY OF THREE YEARS OF PERFORMANCE MONITORING

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ABSTRACT

Four field test plots were constructed in 1997 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 moisture retention, water content, and temperature sensors installed at up-slope and down slope locations.

The field data collected to date demonstrates that infiltration to the underlying waste rock has been reduced to as little as 1% of precipitation for the compacted till-bentonite ameliorated cover system, and less than 10% for the compacted till-flyash ameliorated cover system as well as the compacted native till cover system. The presence of the overlying non-compacted till and associated vegetation significantly impacts infiltration to the waste rock during the summer and fall. Precipitation occurring as rainfall is stored in the non-compacted growth medium overlying the compacted layer, and subsequently "released" back to the atmosphere as evapotranspiration. The presence of the compacted layer limits water infiltration to the underlying waste rock during wet fall, winter, and spring conditions.

The native till and flyash ameliorated cover systems have not functioned as oxygen ingress barriers during the period monitored. The poorer performance of the native till cover system was expected, but this was not the case for the flyash ameliorated system. The reduction of moisture conditions in the compacted till-flyash layer and the compacted native till layer was a result of atmospheric demand for moisture during the summer. A reduction in the moisture conditions within the compacted till-bentonite layer was also observed, although to a much less extent. Increasing the thickness of the overlying non-compacted layer should significantly reduce the demand for moisture from the compacted layers, and thus prevent de-saturation and eventually an increase in oxygen ingress.

The optimum cover system design will be determined after all field data is used to calibrate a soil-atmosphere model, and this model's output used as input for a site specific hydrogeologic model. Then the relative technical and economic advantages of each cover system option can be evaluated to select the optimum waste rock cover system for the Myra Falls site.

INTRODUCTION

The design of a soil cover system for long term closure of the waste rock and tailings facilities at the Myra Falls Operations mine site is part of the closure plan for the copper, zinc, gold, and silver mine. The Myra Falls Operation (MFO) is located in a hanging glacial valley in the central region of Vancouver Island, B.C. Mean annual precipitation at the mine site is approximately 2,500 mm, with less than 25% of the total precipitation occurring during the months of April to September. There is net acid generating waste rock at the site, which can lead to acid rock drainage (ARD).

Implementing a dry cover system is a common ARD prevention and control technique used at numerous sites around the world. The primary purpose of placing dry cover systems over reactive waste material is to minimize further degradation of the receiving environment following closure of the waste impoundment. The objectives of a dry cover system are to minimize the influx of water and provide an oxygen diffusion barrier to minimize the influx of oxygen. Apart from these functions, dry covers are should be resistant to erosion and provide support for vegetation. Dry covers 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. Inhibiting oxygen ingress requires that a "blanket" of water (i.e. a tension saturated layer of cover material) over the reactive waste material be maintained, which reduces the influx of atmospheric oxygen and subsequent production of acidic drainage.

DESCRIPTION OF THE TEST PLOTS

As-Built Construction:

The test plots were constructed in October 1998. 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. This section summarizes key aspects of the design and supporting work.

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

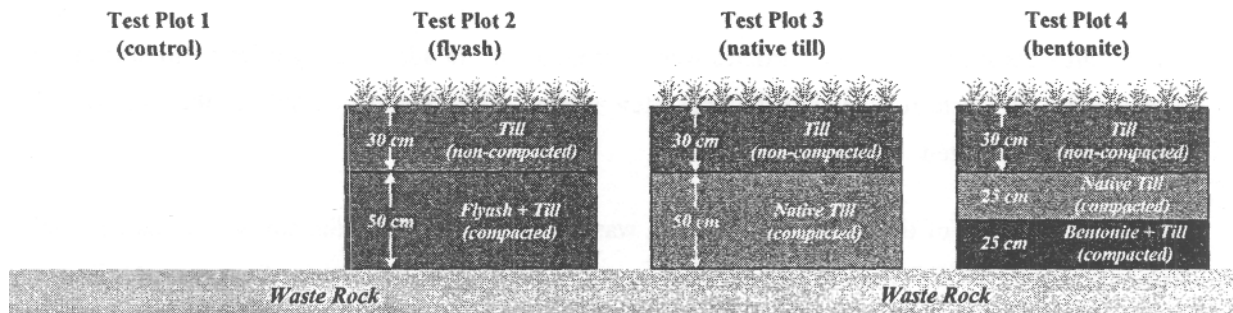


Figure 1 Schematic of the Myra Fall Operations waste rock test plot layout.

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% 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 8% 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) summarized the physical properties of the cover and waste materials. However, the information is repeated here for clarity. The till cover material was a sandy, non-plastic silt matrix till with a trace of clay. It was oxidized with angular cobbles and boulders up to 15cm with a specific gravity of 2.82. The maximum dry density was approximately 2.1 Mg/m^3 for a standard Proctor compaction effort and the corresponding optimum moulding water content was 10%. The oxidized 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 4.75mm (i.e. passing the No.4 sieve). The laboratory saturated hydraulic conductivity of a sample of compacted native till cover material varied between $1 \times 10^{-6} \text{ cm/s}$ and $1 \times 10^{-7} \text{ cm/s}$. The laboratory saturated hydraulic conductivity of the waste rock samples varied between $1 \times 10^{-5} \text{ cm/s}$ 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 meters 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 saturated hydraulic conductivity and the relationship between the effective diffusion coefficient for oxygen and the degree of saturation are also key parameters for soil cover design. The SWCC is central to the design of an unsaturated soil system and the most fundamental characterization required for 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 and represent the materials evaluated during the soil-atmosphere modelling conducted to design the test plots. A SWCC of a compacted till-flyash sample collected after construction of the test plots is also 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 (i.e. ≈ 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 fine textured 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 alternative designs modelled 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% 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%.

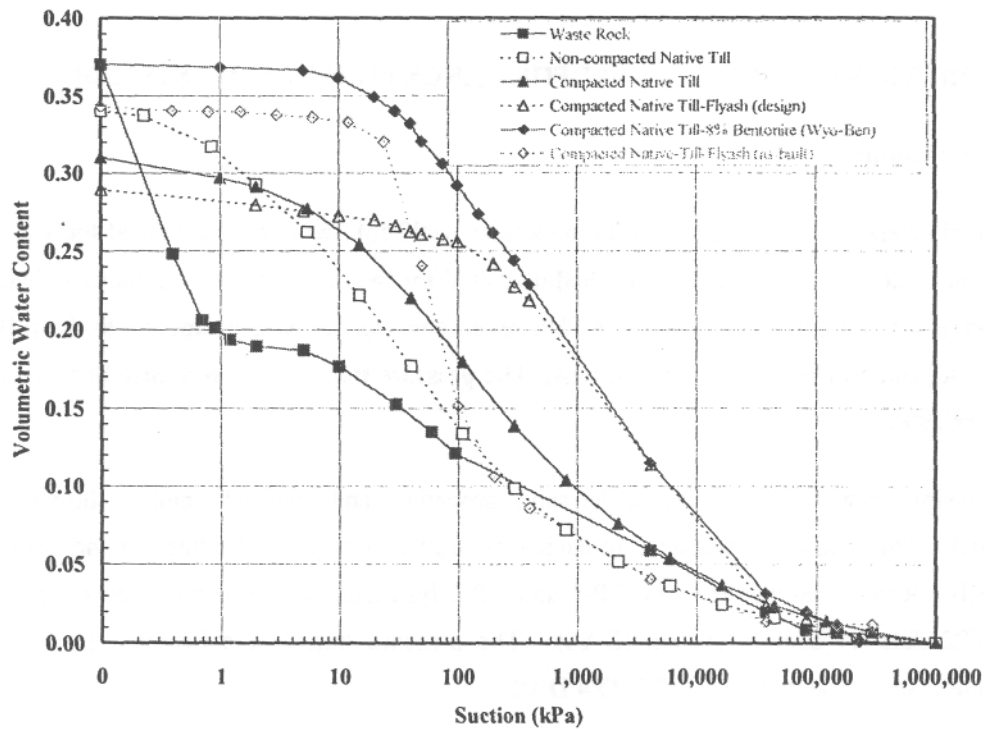


Figure 2 Soil water characteristic curves of the cover and waste rock materials.

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% 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 1% of the historical "wet" year modelled precipitation.

The addition of 15% by mass of precipitate catch increased the air entry value of the compacted till to approximately 100kPa, although little change in the porosity of the sample was observed, as shown in Figure 2. The air entry value of the compacted till sample ameliorated with 8% bentonite was approximately 30kPa. However, the porosity of the compacted till ameliorated with 8% bentonite by mass increased by 20% 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 (Le. 1998) due to poor weather conditions. The pressure transducers were installed in each lysimeter 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.

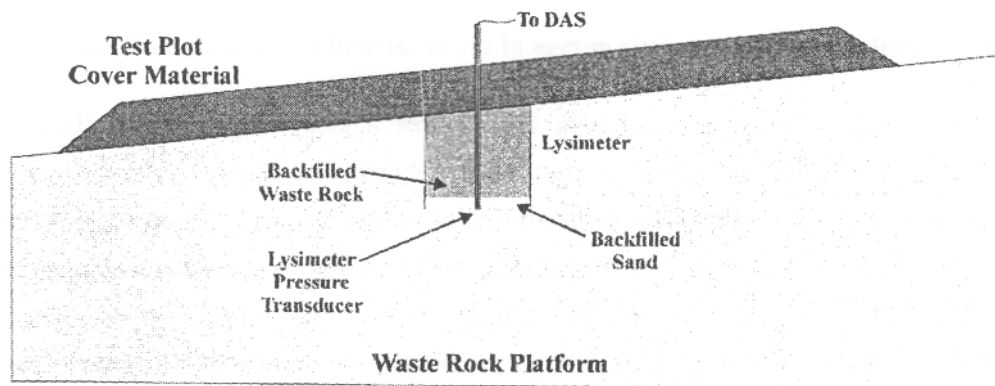


Figure 3 Schematic of the Myra Fall Operations lysimeter configuration.

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-1 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 actually 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.

Oxygen Concentration:

Gas sampling ports were installed at the down-gradient nest location just below the material layer interface of each test plot. For example, at TP-2, gas-sampling ports were installed just below the interface of the non-compacted till material and the compacted till-flyash material, as well as just below the interface of the compacted till-flyash material and the waste rock material. All of the gas-sampling ports were connected to small diameter flexible tubing that extended to a sequencer and analyzer that are controlled by the TP3-TP4 DAS. The setup allowed for automated measurements of oxygen concentrations at TP-2, TP-3, and TP-4, although the system is shut down during the winter.

FIELD PERFORMANCE MONITORING - PRESENTATION AND DISCUSSION OF DATA

Net Percolation:

The test plot net percolation values shown in Tables 1 and 2 are for a "monitoring period" basis (i.e. October to September) because precipitation occurring in the late fall and winter contributes to percolation during the following spring. A negative value implies that gradients within the lysimeter were upward and no percolation reported to the lysimeter.

Table 1

Summary of test plot net percolation as a percentage of precipitation.

Time Frame	TP-2	TP-3	TP-4
October 98 – September 99 Precipitation = 1,323 mm	< 1%	5%	< 1%
October 99 – September 00 Precipitation = 2,140 mm	26%	3%	< 1%
October 00 – August 15, 01 Precipitation = 1,650 mm	not available	not available	not available

The response of the TP-1 and TP-2 test plots during the 1999-2000 monitoring period is significantly different than the previous monitoring period and could be argued to be counter-intuitive. However, until monitoring data is available for additional years, the response of the TP-2 and TP-3 lysimeters during the 1999-2000 monitoring period should not be considered anomalous. The primary reason for difference in response is likely the significantly higher precipitation recorded during the 1999-2000 monitoring period. Approximately 1,323 mm was recorded during the 1998-1999 monitoring period, as compared to 2,140 mm recorded during the 1999-2000 monitoring period. This led to higher percolation values in TP-2 during the latter monitoring period. The key information generated from the lysimeters is that the bentonite-till cover system and the native till cover system are performing as anticipated.

The response of the flyash-till cover system is not as anticipated based on the test plot design soil-atmosphere modelling, which leads to concerns with its use as an ameliorating agent. For example, the SWCC of the compacted till-flyash material used for the soil-atmosphere cover design modeling is significantly different than that measured on material used during construction of the test plots. The key difference is the air entry value, which is significantly lower and thus not able to maintain tension saturated conditions to the same extent. In addition, it is likely that the saturated permeability of the till-flyash mixture used for the design would be lower than the mixture used during construction. The key point is that the quality of the flyash can be inconsistent and careful consideration must be given due to the potential difference between the product from its use during the design stage to its use during full-scale implementation of a cover system.

Moisture Storage and Transport:

The average degree of saturation of the compacted till-flyash layer and the non-compacted layer at TP-2 is shown in Figure 4. The data shown in Figure 4 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. Note that the data shown is based on the response of both the suction sensors and the volumetric water content sensors. The non-compacted material has lower moisture conditions than the compacted till-flyash layer, which is to be expected as it is exposed to the atmosphere. In addition, the response to the demand for moisture during the summer is more significant. The till-flyash compacted 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% during the summers of 1999 and 2000 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.

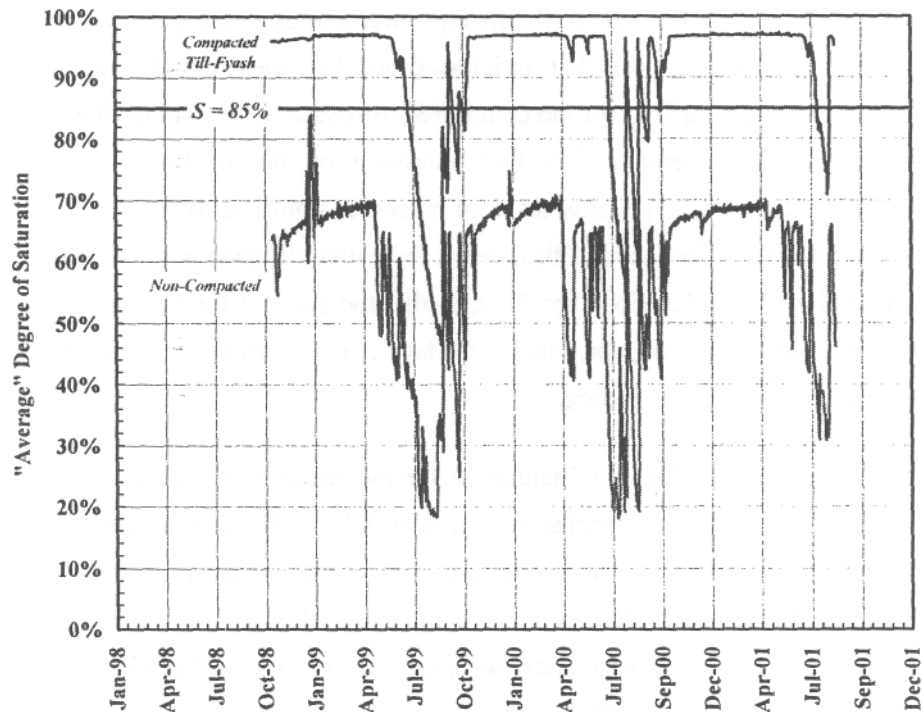


Figure 4 Average degree of saturation of the compacted till-flyash and non-compacted native till at Test Plot 2.

There are three key reasons for the performance of the compacted till-flyash layer shown in Figure 4, 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. This simplest solution for this problem 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 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 falls, winters, and springs, followed by hot dry summers. It is important to note that these climate

characteristics are very common at mine sites across Canada, which is an issue that should be addressed as part of the cover system design.

The performance of the compacted till-flyash layer was not as designed. The primary reason for the difference in performance between that anticipated and that measured during the past three years is illustrated in Figure 2. The SWCC of the compacted till-flyash layer used during the design stage of the project is significantly different than that measured on the till-flyash mixture obtained during construction of the test plots. The latter material possesses significantly less ability to retain moisture as suction increases. The performance of the compacted native till layer and the non-compacted native till at TP-3 was similar to that described for TP-2, in that the demand for atmospheric moisture during the summer was satisfied by the compacted native till layer. This performance was anticipated based on the soil-atmosphere cover design modelling.

Figure 5 shows the average degree of saturation for the compacted till-bentonite layer, the compacted native till layer, and the non-compacted till layer at TP-4. The performance of the compacted till-bentonite layer is characteristic to that discussed earlier for the till-flyash and native till compacted layers at TP-2 and TP-3, respectively. However, the compacted till-bentonite material possesses significantly more moisture retention as suction increases (see Figure 2), and therefore the average degree of saturation of the compacted till-bentonite layer during the summer remains above or just below 85%. 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. Figure 6 clearly shows that the decrease in moisture content within the compacted till-bentonite layer is a function of the demand for atmospheric moisture during the summer. The sensor installed near the upper interface of the compacted till-bentonite layer decreases in moisture content during the summer, while the sensor at the base of the layer maintains tension saturated conditions throughout the summer.

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.

Oxygen Concentration:

The oxygen concentration data collected during the monitoring period agrees with the moisture content data presented earlier. Gaseous oxygen concentration measured below the compacted till-bentonite layer was consistently near zero, while the measurements below the compacted layers at TP-2 and TP-3 were variable in response to the seasonal change in moisture conditions of the compacted layers.

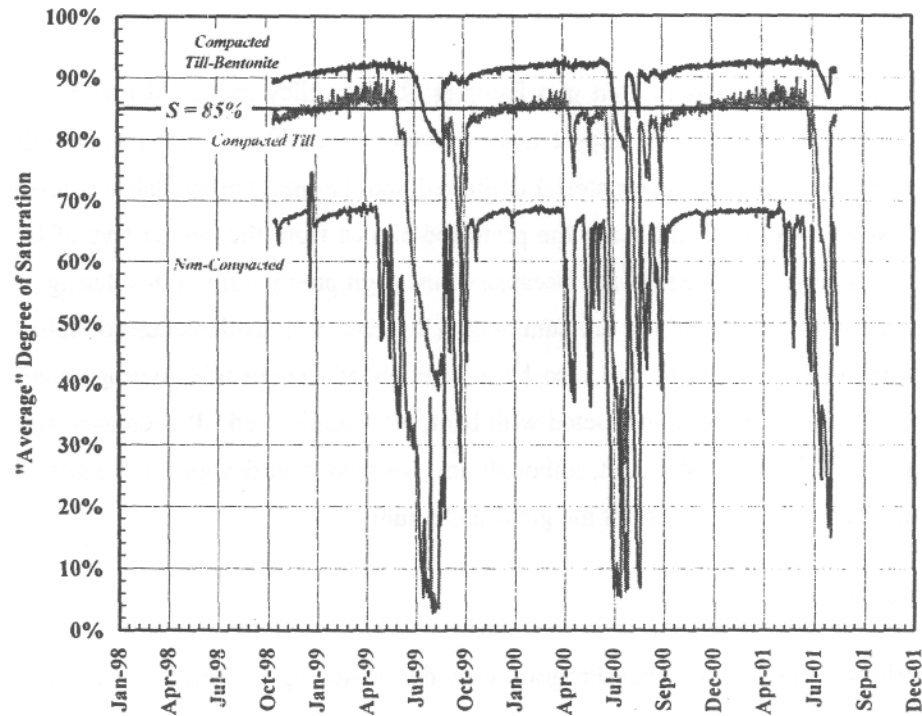


Figure 5 Average degree of saturation of the compacted till-flyash and non-compacted native till at Test Plot 4.

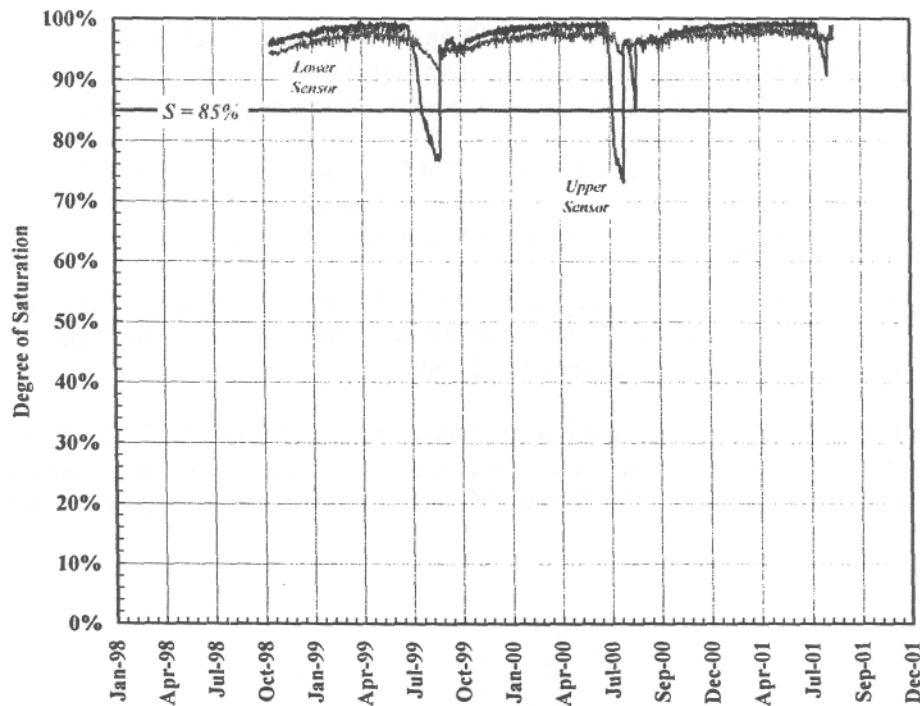


Figure 6 Degree of saturation of the upper and lower sensors installed in the compacted till-flyash layer at Test Plot 4.

SUMMARY

The Myra Falls Operation is located in a hanging glacial valley in an old growth area of a provincial park. This presents issues with respect to developing a suitable closure plan for the waste rock and tailings material. Potential cover material is limited and the material available is relatively coarse. The use of the native cover material is not the preferred choice from the perspective of limiting oxygen and water to the underlying waste material because of the high precipitation rates during the fall, winter, and spring coupled with the typical hot dry summers. However, it is fundamental to realize that the optimum cover system for the MFO site will also be a function of site-specific hydrogeologic and cost-benefit considerations. The test plot constructed with bentonite ameliorated till decreased water infiltration and oxygen ingress to the greatest extent, although any cover system design for the site should consider the benefit of increasing the thickness of the growth medium.

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