

# **MANAGING FOR CLOSURE AT THE MYRA FALLS OPERATION - THE DESIGN OF A SOIL COVER SYSTEM FOR LONG TERM ECOLOGICAL AND PHYSICAL STABILITY**

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## **ABSTRACT**

Westmin's Myra Falls Operations has the one single largest environmental problem facing the mining industry today. The tailings and waste rock materials are acid generating. A review of existing literature indicates that there are a number of technologies that can be used and developed for the prevention and control of acid generation in sulphidic mine tailings and waste rock. The majority of the ARD control technologies are centered around the curtailment of oxygen and water to the waste material. The most promising technology for Westmin's Myra Falls Operations is engineered soil covers. An initial cover design evaluation using local till materials indicated that the materials were not suitable for the proposed application. However, the soils were modified with a selection of amendments and the laboratory results showed significant improvements. The results suggest that local till materials amended with either flyash or bentonite can be used in soil cover construction. Westmin intends to conduct field trials to evaluate the performance of a short list of soil cover variations to determine the final cover system design as a result of the encouraging laboratory and soil-atmosphere modelling results.

This paper summarizes the results of the laboratory characterization of the potential cover and waste materials and presents the soil-atmosphere numerical modelling used to design the field test plots. Construction aspects, instrumentation, vegetation, two-dimensional flow and in general the scope of the project will be briefly discussed. The successful use of local till material ameliorated with a fine grained material will provide a positive impact to the mining industry. This application to the design of soil cover systems is a novel approach which offers an economic alternative for decommissioning smaller waste rock piles and tailings management facilities.

## **INTRODUCTION**

The design of a soil cover system for long term closure of the waste rock and tailings facilities at the Westmin Resources Ltd., Myra Falls Operation is part of the closure plan for the copper, zinc, gold, and silver mine. The Myra Falls Operation 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 3000 mm, with less than 25% of the total precipitation occurring during the months of April to September.

Acid rock drainage (ARD) is the single largest environmental problem facing the mining industry today. ARD is the result of the combined chemical and biological oxidation of sulphide minerals and the contaminant release of associated metals, such as iron, aluminum, manganese, and other toxic heavy

metals. Mine waste rock and tailings that contain sulphide minerals will react with the oxygen and water to produce sulphuric acid. All waste rock and tailings materials have some potential to neutralize the acid generated. The net acid released to the collection system and/or environment is defined as acid rock drainage.

The three principal objectives of the soil cover system are:

1. to function as an oxygen ingress barrier for the underlying waste material by maintaining a high degree of saturation within a layer of the soil cover system thereby minimizing the effective oxygen diffusion coefficient and ultimately controlling the flux of oxygen across the soil cover system,
2. to function as a water infiltration barrier for the underlying waste material as a result of the presence of a low permeability layer and a moisture storage and release layer, and
3. to provide a medium for establishing a sustainable vegetation cover that is consistent with the current and final land use of the area.

## **PHASE 1 LABORATORY PROGRAM AND SOIL-ATMOSPHERE MODELLING**

### Laboratory Characterization Program:

Six waste material samples and six potential cover material samples were collected for laboratory characterization as part of the first phase of a cover research program conducted by the Unsaturated Soils Research Group (USG) at the University of Saskatchewan. Initial specific gravity testing, visual classification, index testing (i.e. Atterberg limits), and grain size analysis of the material demonstrated that some of the samples could be combined as one sample. Therefore, subsequent moisture retention, or soil water characteristics testing, hydraulic conductivity testing, consolidation testing, and compaction testing was performed on four potential cover materials and five waste materials. The waste material samples consisted of three waste rock samples and two tailings samples.

The cover material with the most potential was a sandy, non-plastic silt matrix till with a trace of clay. The till was oxidized with angular cobbles and boulders up to 15cm with a specific gravity of 2.82. The maximum dry density was approximately  $2.1\text{Mg/m}^3$  for a standard Proctor compaction effort and the corresponding optimum moulding water content was 10%. The waste rock samples were collected at the base of small test pits. 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 the consolidation testing following equilibrium at a specified consolidation pressure. The samples were prepared using material less than 4.75mm (i.e. passing the No.4 sieve). The saturated hydraulic conductivity of a sample of till cover material varied between  $1 \times 10^{-6}\text{cm/s}$  and  $1 \times 10^{-7}\text{cm/s}$ . The

saturated hydraulic conductivity of the waste rock samples was between  $1 \times 10^{-5}$  cm/s and  $1 \times 10^{-7}$  cm/s since the coarse particles were screened out and since 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. The saturated hydraulic conductivity of the tailings sample was approximately  $1 \times 10^{-5}$  cm/s.

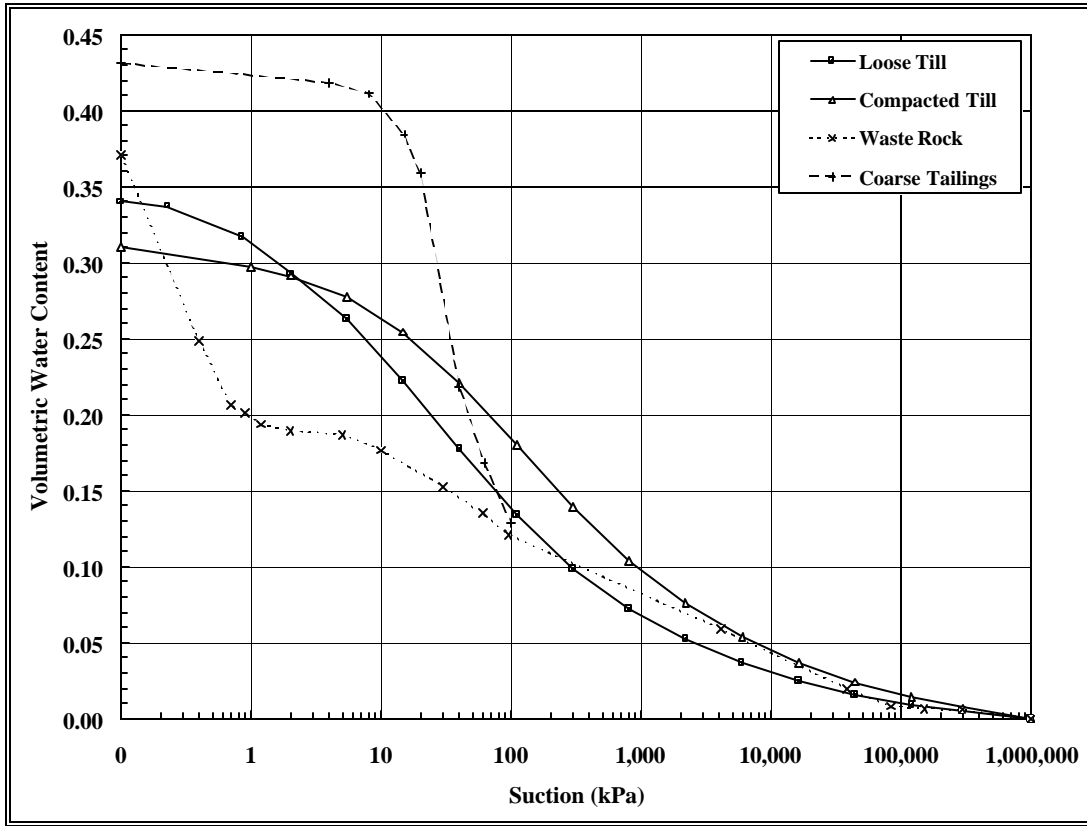
The soil water characteristic curves (SWCC) of the waste rock, tailings, compacted till, and non-compacted till are shown in Figure 1 and represent the materials evaluated during the soil-atmosphere modelling. The SWCC's of the non-compacted and compacted till samples illustrate the coarse but well graded nature of the potential cover material. The non-compacted till possesses a low air entry value (i.e.  $\approx 1$  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 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 1. The first occurring at a suction very near zero and the second at approximately 7 kPa. The coarse tailings are uniform with an air entry value equal to 10 kPa.

#### Soil-Atmosphere Modelling:

The soil atmosphere modelling was conducted to evaluate the potential of using the local till material as a cover material for the waste rock pile at the Myra Falls Operation. The 1D finite element model SoilCover (MEND, 1996) was used to evaluate the performance of the cover system as layer thickness, vegetation development, material properties, initial conditions, and boundary conditions were varied. SoilCover was developed at the University of Saskatchewan under the leadership of Dr. G.W. Wilson and was based on Wilson (1990) and Wilson et al, 1997 to address the need for predicting surface flux boundary conditions from a geotechnical perspective for problems such as soil cover design, groundwater modelling and contaminant transport, as well as heave and settlement. The key components of SoilCover are:

1. it is a coupled heat and mass transfer model which allows for the prediction of vapour water movement and
2. it couples the soil profile to the atmosphere which allows for the prediction of an actual evaporative flux rather than being required as input by the user.

The extreme dry year (1985) and the extreme wet year (1986) year, based on precipitation data collected at the site, were selected for the soil-atmosphere modelling. Climate data for the approximate growing season, from May 1 to September 29, was used as the atmospheric boundary conditions.



**Figure 1 Soil water characteristic curves for the till cover material and waste material (after O’Kane et al, 1995).**

The dry year climate data was used to evaluate the performance of the cover system as an oxygen ingress barrier while the wet year was used to predict the net flux to the underlying waste rock from the base of the cover system. A model consisting of waste rock overlain by 0.5m of compacted till and 0.3m of non-compacted till placed on the compacted layer was evaluated. The degree of saturation of the compacted layer was less than 70% during the latter half of the dry year simulation as a result of evapotranspiration to the atmosphere and drainage into the waste rock (O’Kane et al, 1995). It is generally accepted that the air phase is not continuous until the degree of saturation is less than 85% (Fredlund and Rahardjo, 1993). Therefore in general, the oxygen diffusion coefficient is minimized if the degree of saturation is greater than 85%. The months of July and August at the site can be characterized as hot and dry, even though from an annual perspective the site can be characterized as experiencing a wet climate. The inability of the non-compacted layer to satisfy atmospheric demand for moisture, and the relatively low moisture retention characteristics of the non-compacted and compacted layers, led to

desaturation of the compacted layer and ultimately failure of the cover system as an oxygen ingress barrier. The relatively low storage and high saturated hydraulic conductivity of the compacted layer led to significant drainage from the cover layers into the waste rock during snow melt and precipitation events (O’Kane et al, 1995).

The thickness of each layer was increased in an effort to increase storage and prevent desaturation of the cover during the summer as well as reduce the net flux into the underlying waste rock. These models also failed in much the same manner as described earlier, and in any event the volume of till cover material at the site is limited.

A number of models were also completed to evaluate the effect on cover performance when the compacted layer was modified such that the air entry value increased and the saturated hydraulic conductivity decreased. The model results demonstrated that increasing the air entry value of the compacted layer led to adequate saturation conditions within the compacted layer throughout the simulation as suctions approached 100kPa (O’Kane et al, 1995). This led to the second phase of the project where a laboratory program was conducted to evaluate the moisture retention of the compacted till amended with a fine grained material.

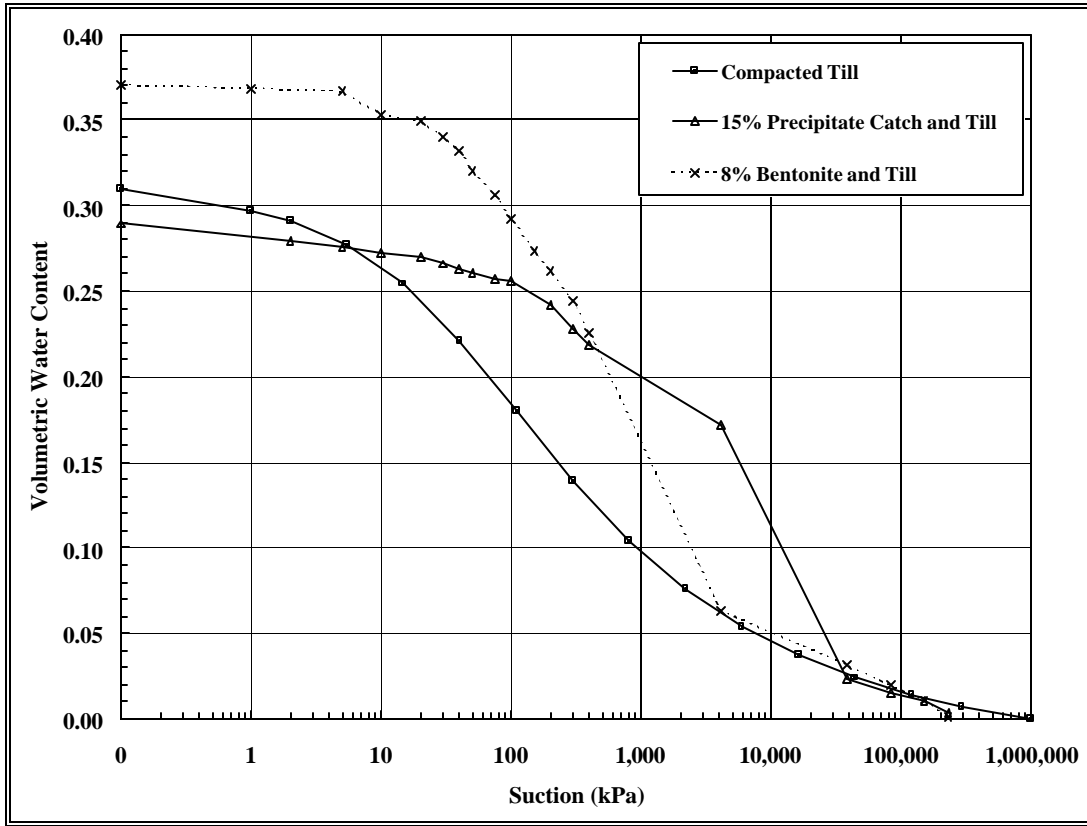
## **PHASE 2 LABORATORY PROGRAM AND SOIL-ATMOSPHERE MODELLING**

### Laboratory Characterization Program:

Soil water characteristic curve tests were completed using compacted till ameliorated with varying percentages of top ash, bottom ash, and precipitate catch obtained from Howe Sound Pulp and Paper Limited. The soil water characteristics of each of the three ash products were also measured. The effect on the SWCC was also measured as a result of the addition of varying percentages of a bentonite product supplied by Wyo-ben of Montana, USA. Nearly 20 SWCC’s and standard Proctor compaction tests were completed (O’Kane et al, 1996). Saturated hydraulic conductivity testing of each sample is in progress using a constant head triaxial permeameter.

Figure 2 compares the SWCC’s of the natural compacted till sample, the natural compacted till ameliorated with 15% precipitate catch, and the natural compacted till ameliorated with 8% bentonite. The addition of 15% by mass of precipitate catch increased the air entry value of the compacted till to approximately 100 kPa, 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 30 kPa. However, the porosity of the compacted till ameliorated with 8% bentonite by mass increased by 20% as compared to that measured for the natural compacted till sample.

The optimum moulding water content of the 8% bentonite ameliorated till was 14% at a maximum dry density of  $1.9\text{Mg/m}^3$ . The maximum dry density of the 15% precipitate catch ameliorated till was approximately  $2.0\text{Mg/m}^3$  and the corresponding optimum moulding water content was 11.5%.

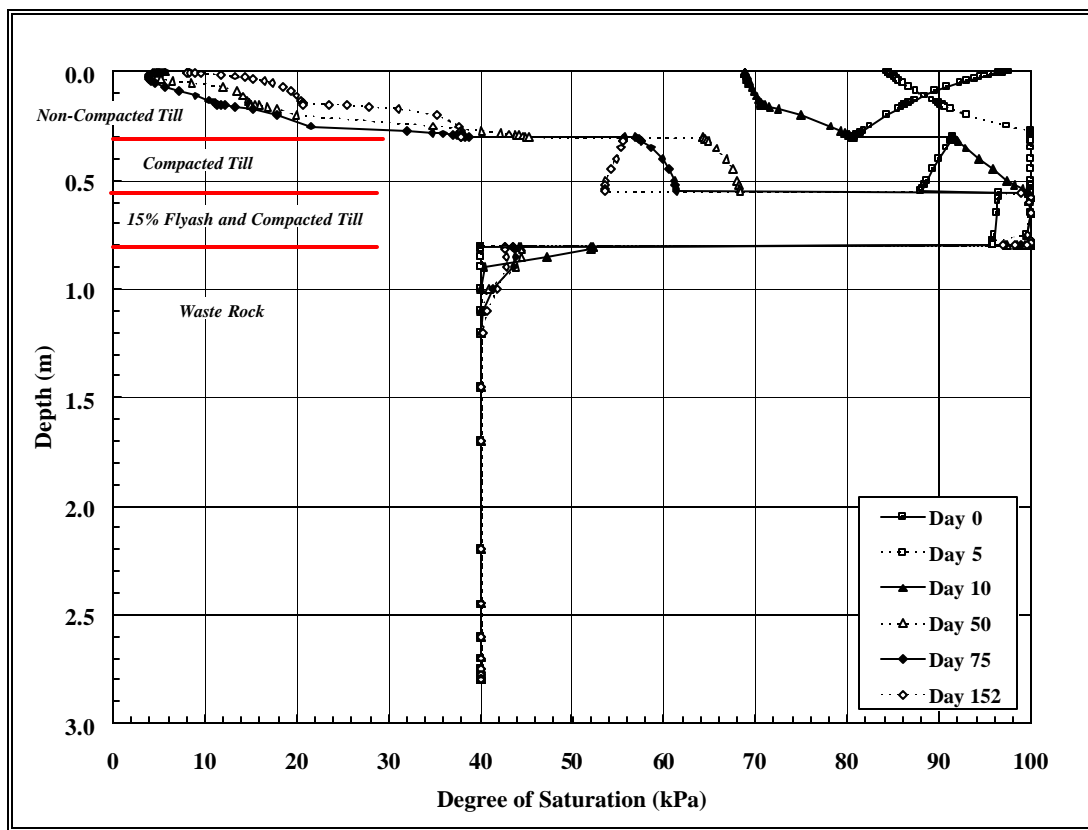


**Figure 2** Soil water characteristic curves for the compacted natural till material and the ameliorated compacted till materials (after O’Kane et al, 1996).

Soil-Atmosphere Modelling:

Additional soil-atmosphere modelling was completed using the ameliorated compacted till material properties shown in Figure 2 and the non-compacted till material properties shown in Figure 1. The models used the layer thickness and climate data as described for Phase 1. The soil-atmosphere modelling showed that a compacted layer of till, ameliorated with bentonite or precipitate catch, 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. SoilCover predicted that the degree of saturation of the ameliorated compacted till layer was greater than 95% during the historical dry year growing season (O’Kane et al, 1996). The predicted net flux from the base of the compacted layer into the underlying waste rock was approximately 1% of the growing season precipitation for the historical wet year (O’Kane et al, 1996).

Further modelling was conducted to determine the feasibility of partitioning the 0.5m compacted layer into two separate layers. A lower compacted layer consisting of 0.25m of compacted till ameliorated with either 15% precipitate catch or 8% bentonite and an upper compacted layer represented by 0.25m of natural compacted till was modelled between the overlying 0.3m non-compacted layer and the underlying waste rock. The degree of saturation of the modelled profile as a function of depth is shown in Figure 3. The lower ameliorated compacted layer maintained a level of saturation greater than 95% during the period modelled since a capillary break was created at the interface of the waste rock and ameliorated till and the material had sufficient storage and moisture retention. The predicted high level of saturation minimized the oxygen diffusion coefficient and correspondingly controlled the flux of oxygen across the soil cover system. The net flux into the underlying waste rock from the base of the ameliorated compacted till layer was less than 1% of the wet year growing season precipitation (O’Kane et al, 1996).



**Figure 3** The degree of saturation of the cover system as a function of depth for the dry year simulation and a 0.25m thick ameliorated compacted till layer (from O’Kane et al, 1996).

The potential of a compacted layer of till placed between upper and lower capillary break layers to function as an oxygen ingress and water infiltration barrier was also evaluated. The model predicted that the compacted layer would remain at a degree of saturation greater than 85% throughout the growing

season. However, the predicted net flux from the base of the cover system into the waste rock was approximately 10% of the growing season precipitation.

## **CONSTRUCTION OF THE FIELD TEST PLOTS**

The numerical modelling using the ameliorated compacted till laboratory properties indicated that the following soil cover system designs demonstrated the greatest potential for further investigation as field test plots.

1. 15% flyash added to a 0.25m thick compacted till layer overlain by 0.25m of compacted till, all overlain by 0.30m of non compacted till,
2. 8% bentonite added to a 0.25m thick compacted till layer overlain by 0.25m of compacted till, all overlain by 0.30m of non compacted till, and
3. 15% flyash added to a 0.50m thick compacted till layer overlain by a 0.30m thick non compacted layer.

The three test plots described above will be seeded with a specially formulated grass and legume seed mix. The mix was designed to provide an initial erosion control of vegetation while at the same time providing an environment that will encourage invasion by native species (Polster, 1997). A fourth test plot will be constructed to the same specifications as test plot number 1. However, the seed mix will not be applied to this fourth test plot. An automated surface runoff measurement system and sediment catchment system will be installed on these two test plots to measure the difference in performance with respect to erosion and surface runoff as a result of the presence of the grass and legumes.

Construction is scheduled to begin in mid August, 1997. The field monitoring instruments will be installed during construction as well as in September, 1997, following completion of construction. The physical dimensions, slide slopes, and in general the two-dimensional performance of each test plot was evaluated using a 2-D saturated unsaturated model. In addition, the size, shape, and location of the field lysimeter used to measure infiltration into the underlying waste rock was designed using the same model. The 2-D model results are beyond the scope of this paper and will be presented in subsequent publications.

## **SCOPE OF PROJECT**

The objective of this applied research program is to evaluate the long term performance of a final cover system design for the waste material at Westmin's Myra Falls Operation. The program includes the design and construction of four test plot cover systems as well as field instrumentation, field monitoring, and numerical modelling. Field instrumentation will monitor moisture and temperature conditions in the test plots and underlying waste material together with oxygen fluxes, vegetation development, and runoff quantities. This information will be used to ensure that the field response modelling accurately simulates field conditions for long term predictive modelling and final cover performance assessment. The monitoring period will extend to almost three years. A final design will be based on the performance of

four field test plot soil cover systems. Key performance indicators will include limiting oxygen and water to the underlying waste rock, maintaining physical integrity, and establishment of a sustainable vegetation cover. Additional work may be required to evaluate natural succession of forest growth prior to determining a final soil cover system design.

Highlights of the project schedule include construction of the field test plots during the latter two weeks of August, 1997 and installation of the field instruments in early September, 1997. A full two years of monitoring is included in the project schedule with field response modelling, predictive modelling, and decommissioning of the test plots planned subsequent to the monitoring period.

The successful use of a local till material ameliorated with a fine grained material will provide a positive impact to the mining industry. This application to the design of soil cover systems is a novel approach which requires development of optimum mixing and placement methods. The project also addresses the development of three significant areas of technology required in the mining industry in order to assess the performance of soil cover systems. The research will also focus on the importance of developing and applying technologies for:

1. monitoring, modelling, and evaluating the performance of the soil cover system in a two dimensional sense rather than in the idealized one dimensional approach,
2. evaluation of the development of vegetation and its impact on soil cover system performance,
3. quantitatively measuring the net infiltration into the underlying waste material using field lysimeters,
4. automated runoff and sediment transport instrumentation to evaluate the long term physical integrity of soil cover systems, and
5. decommissioning of field test plots and the development of analytical and field procedures to determine the development of vegetation with respect to soil cover systems and the change in physical, biological, and chemical characteristics of each cover layer.

This paper will be the first in a series regarding the development of a soil cover system for the waste material at the Myra Falls Operations. Subsequent papers will provide an overview of the project as well as focus on selected aspects as outlined in the scope of the project.

## **SUMMARY**

The Myra Falls Operation is located in an old growth area of a provincial park. The mine is situated in a hanging glacial valley which presents further 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. High precipitation during the fall, winter, and spring together with hot dry summers prevent the use of the existing cover materials as a means of limiting oxygen and water to the underlying waste material. The use of a fine grained material such as flyash to ameliorate the relatively coarse till cover material offers promise as a means of developing an economic closure plan for the waste material. The completed laboratory work and numerical modelling demonstrated that the potential of the ameliorated till as a cover material merits further investigation in the field. The successful exploit of an inexpensive fine grained additive to existing cover material will provide a positive environmental and economic impact for Westmin Resources Ltd., as well as for the Canadian mining industry as a whole, through the development and application of an ameliorated till soil cover system for minimizing acid rock drainage.

Ameliorated soils can be used as cover materials for the final closure of mine waste material, municipal landfills, and hazardous solid waste disposal areas. The key impact will be in humid locations where inadequate soil is available to create a cover system with high moisture retention and low hydraulic conductivity.

## **ACKNOWLEDGEMENT**

The Unsaturated Soils Research Group at the University of Saskatchewan completed the laboratory work and initial soil atmosphere modelling the under the direction of Dr. Ward Wilson, P.Eng. We wish to thank Dr. Wilson for encouraging the transfer of this project from a fundamental research study to one of an applied nature. This applied research is being funded by Westmin Resources Ltd. and The Industrial Research Assistance Program (IRAP).

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