

DESIGN OF FIELD TEST PLOTS FOR A SLOPED WASTE ROCK SURFACE¹

by:

M. O'Kane², J. Stoicescu³, S. Januszewski⁴, D.M. Mchaina⁵, and M.D. Haug⁶

Abstract. Westmin Resources Limited is a Western Canadian mining company with producing interests in base and precious metals and coals. Westmin's Myra Falls Operations produce copper, zinc, and gold concentrates. The Myra Falls Operations are located in the central interior of Vancouver Island in a hanging glacial valley. Mean annual precipitation is approximately 3,000mm with more than 75% occurring during the months of October to April. Historic surface deposition of waste rock has resulted in acid rock drainage (ARD). An applied research program was initiated to develop a cover system for the waste rock material at the Myra Falls site. The objective is to develop a cover system which controls the ingress of oxygen and infiltration of water, while providing a medium for sustainable vegetation that is consistent with the end land use of the area. Progress to date suggests that modified local till materials (amended with either fly ash or bentonite) can be used in soil cover construction. Four test plots were designed using two-dimensional saturated-unsaturated modelling tools to ensure that the performance of each test plot was representative of a full scale ARD cover system. This paper summarizes the design philosophy and principles of the cover system as well as the methodology for the two-dimensional numerical modelling program. Conclusions and results from the numerical modelling program are presented with a focus on implications for construction of the field test plots and installation of the performance monitoring instruments. The numerical modelling demonstrated that the hydraulic performance of a soil cover system placed on a sloped waste rock surface will be much different than that predicted by idealized one-dimensional numerical models, and in general current design methodologies. The modelling clearly demonstrated that the design of small scale field test plots was not a simple task. The physical dimensions of the field test plots had a significant impact on the ideal location for monitoring instruments and incorrect placement of instruments would lead to an erroneous measure of test plot performance.

Additional Key Words: acid rock drainage, soil cover systems, field test plots

Introduction

The design of a cover system for long term closure of the waste rock and tailings facilities at the Westmin Resources Ltd., Myra Falls Operations is part of the closure plan for the copper, zinc, gold, and silver mine.

A field study to evaluate alternative soil cover systems was initiated following a two year study that focused on the development of alternatives. Required for the field study was the design of four field test plots. The design objective was to ensure the actual potential of the cover system alternatives was measured during the performance monitoring phase of the field study.

¹Paper presented at the 1998 National Meeting of the American Society for Surface Mining and Reclamation, St. Louis, Missouri, May 16-21, 1998.

²Mike O'Kane, P.Eng., Principal, O'Kane Consultants Inc., Saskatoon, SK.

³Jeffrey Stoicescu, Project Engineer, M.D. Haug and Associates Ltd., Saskatoon, SK.

⁴Steve Januszewski, P.Eng., Environmental Engineer, Myra Falls Operations, Westmin Resources Ltd., Campbell River, B.C.

⁵David Mchaina, P.Eng., Environmental Engineer, Westmin Resources Ltd., Vancouver, B.C.

⁶Moir Haug, P.Eng., President, M.D. Haug and Associates Ltd., Saskatoon, SK.

Numerical modelling of the field test plots demonstrated the complexity of designing small scale field test plots. The physical dimensions of the test plot as well as the slope of the waste rock surface on which the cover system will be constructed had a significant impact on hydraulic performance. It was not possible to design the field test plots as idealized one-dimensional systems. The design and placement of the monitoring system instruments was also influenced by the field test plot orientation and dimensions. The numerical modelling demonstrated the need to monitor each field test plot as a two-dimensional system.

Background information on the Myra Falls Operations is presented. The design of the field test plots for a

sloped waste rock surface is also presented through a discussion on the cover system design philosophy and project methodology, and a review of material properties, the one-dimensional soil-atmosphere modelling, and the two-dimensional saturated-unsaturated modelling.

Background

The Myra Falls Operations are located in a hanging glacial valley in the central region of Vancouver Island, B.C. (Figure 1). Mean annual precipitation at the mine site is approximately 3000mm, with less than 25% of the total precipitation occurring during the months of April to September.

The site is in an active seismic zone with a 475 year return period acceleration of 0.51g (Hallam *et al.*, 1991). The tailings and waste rock at the Myra Falls Operations have the potential to generate acid rock drainage (ARD). Open pit and underground mining started at the Myra Falls Operations in the mid 1960's at a nominal 1,000tpd of ore. The waste rock was placed in a side-hill and ridge configuration using primarily end dumping methods along the north slope of the valley above the alluvial plain. The coarse fraction of the tailings went to underground backfill while the fine tailings were discharged via a gravity pipeline for subaqueous deposition.

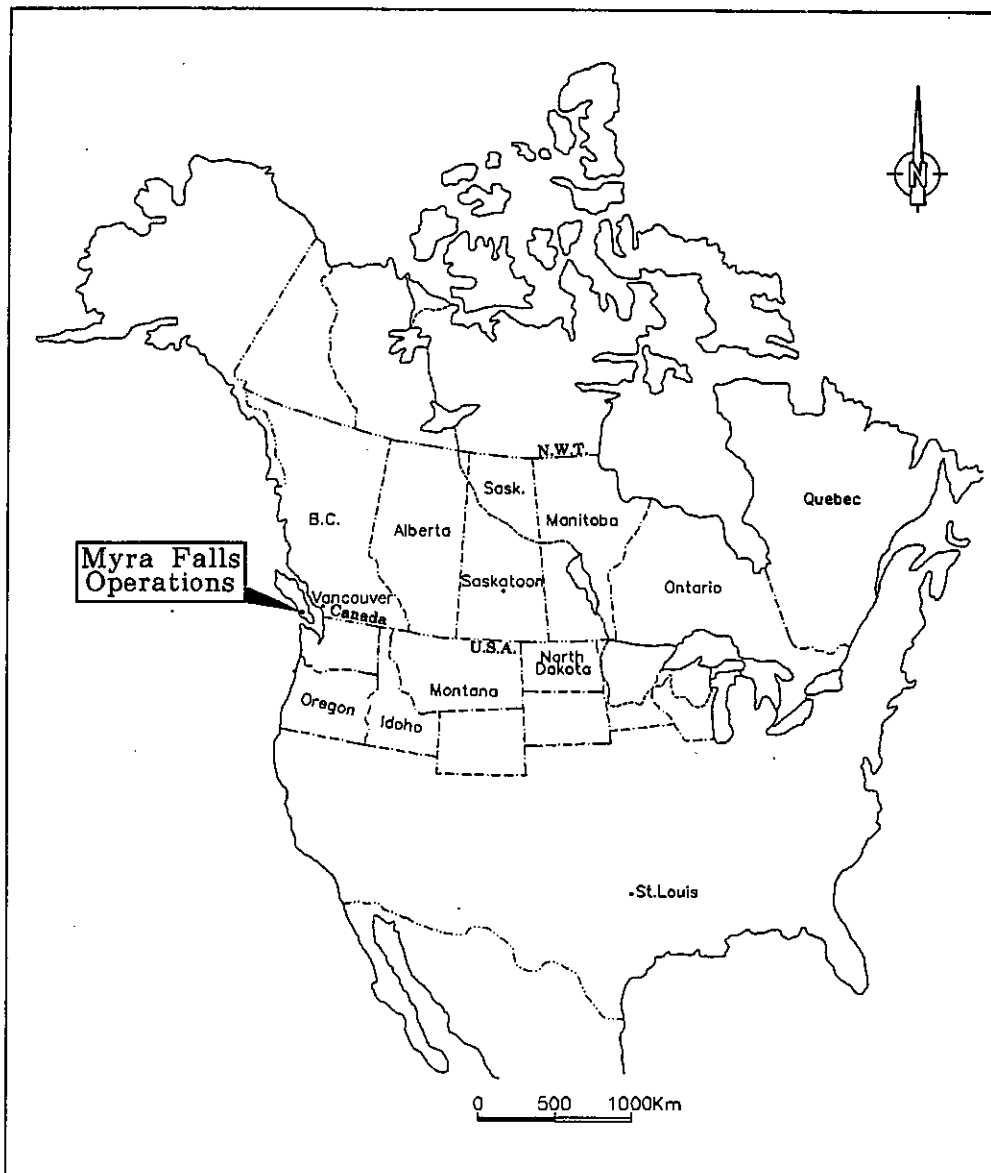


Figure 1 Location of Myra Falls Operations.

Mill throughput was increased to 3,000tpd in the early 1980's following the discovery of a new copper-gold porphyry deposit containing up to 300 million tonnes of ore grade material (Hallam *et al.*, 1991). Expansion of the mine required surface deposition of the tailings and a sub-aerial system for placing the tailings in the valley was designed and implemented.

Konasewich *et al.* (1990) completed hydrogeological studies of the waste rock dump and installed groundwater monitoring systems. Hallam *et al.* (1991) stated that acid base accounting and hydrogeological modelling indicated active oxidation was occurring in the upper 10m of the waste rock dumps and in deeper zones of high content sulphide materials. The mean net neutralization potential (based on acid-base accounting) for all waste rock samples tested was -88.1t CaCO₃ per 1,000t of waste and varied from +25.7t to -423.6t CaCO₃ per 1,000t of waste. Broughton and Ferguson (1990) completed a field testing program on an area of the tailings beach which had been continuously exposed for a period of 30 months. Oxidation was clearly evident to a maximum depth of 1m in coarse sandy areas, although the presence of thin saturated silty layers hindered oxidation at some locations. Thirteen tailings samples had between 8% and 34% sulphur and net neutralization potential between -196t and -1,070t CaCO₃ per 1,000t of tailings (neutralization potential varied between 1t and 63t CaCO₃ per 1,000t of tailings). The sub-aerial tailings are drained by an under drainage collection system (located within the valley alluvium) that is also designed to intercept and collect acidic groundwater from the waste rock dump (van Dyk, 1987). Figure 2 shows the general arrangement of the waste rock dump and tailings facility.

The Cover System Design Philosophy

The net infiltrative flux through a cover system is an important consideration in the design of a closure system for a mine waste disposal facility. The objective is to control/limit the quantity of water that flows downward through the cover to the underlying waste material, since the infiltrating water ultimately contributes to subsequent production of acid rock drainage. The net infiltrative flux is a function of the total precipitation, evaporative flux, change in soil moisture storage, and runoff. Each of these factors are in turn influenced by a variety of conditions. For example, runoff and infiltration rates are a function of rainfall intensity, surface topography, vegetation, soil properties, and soil moisture conditions (Wilson *et al.*, 1994). Evaporation and/or evapotranspiration from the

cover surface is a strongly coupled process that depends on atmospheric conditions, soil/waste properties, and soil/waste conditions. In addition, it is clear that runoff, as well as run-on, are site specific considerations.

Controlling the ingress of atmospheric oxygen to mine waste material is also a key component of the design of a closure system for a mine waste disposal facility, in addition to limiting water infiltration. Soil cover systems can function as oxygen diffusion barriers, although the mining industry has little experience regarding their ability to function as permanent oxygen barriers. Water covers have generally been accepted as the most suitable method of limiting atmospheric oxygen to sulphide bearing mine waste in semi-humid to humid climates. However, it is clear that water covers are not feasible at all locations due to technical, social, and economic factors.

Soil cover systems that maintain a continuously high degree of saturation can be utilized to control the ingress of atmospheric oxygen to the underlying waste material since they create a "blanket" of water, or a "water cover" over the sulphide bearing waste. Factors that control the economic and technical feasibility of a soil cover system for a particular site include, but are certainly not limited to: site climate conditions; vegetation conditions; soil properties and conditions; waste material properties and conditions; soil and waste material evolution; and surface topography.

The design philosophy described above attempts to integrate the waste material with the natural ecosystem, rather than attempting to isolate the waste from the environment in order to reduce ARD. A design philosophy that attempts to isolate potentially acid generating mine waste from the environment is based on viewing an engineered soil cover system as an "upside down liner" and tends to increase the cost of decommissioning and lead to long term performance problems (Barbour *et al.*, 1996).

The principles applied to the design of the Myra Falls Operations cover system were established by researchers and practitioners around the world. The key design principle is the utilization of unsaturated soil mechanics (Fredlund and Rahardjo, 1993) to describe the flow and storage of moisture. Additional design principles as described by Wilson *et al.* (1994); Bews *et al.* (1997); and Wilson *et al.* (1997), were employed to couple the performance of the cover system to site climate conditions.

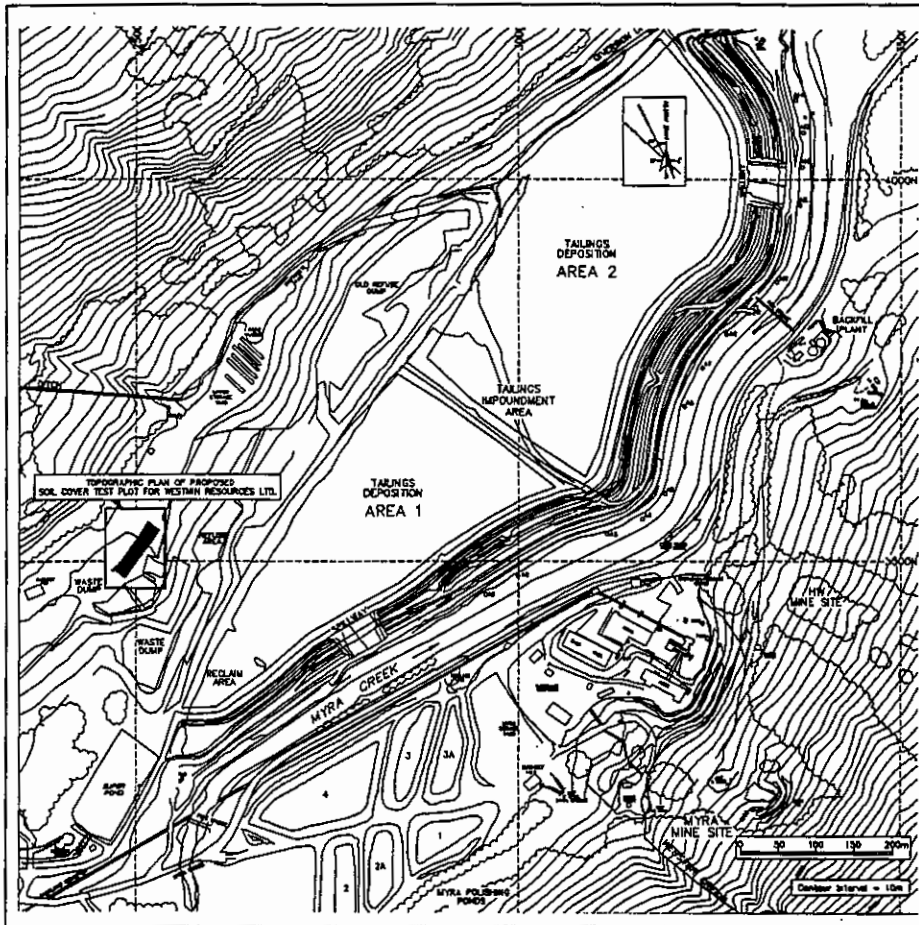


Figure 2 General arrangement of tailings area and waste rock dump at the Myra Falls Operations.

In summary, the three principal objectives of cover systems 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 cover system, thereby minimizing the effective oxygen diffusion coefficient and ultimately controlling the flow of oxygen across the 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/or 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.

Methodology

The development of a cover system design at the Myra Falls Operations was initiated by Westmin Resources Ltd. and the Unsaturated Soils Research Group (USG) at the University of Saskatchewan in 1994. A review of

relevant literature and site specific reports was followed by representative sampling and physical testing of waste and potential cover materials. A soil-atmosphere modelling program was completed to determine the viability of using local till as the cover material over the waste rock and tailings. The laboratory program was refined to evaluate ameliorated local till as the cover material, since the initial soil-atmosphere modelling indicated the local till by itself was not suitable. Subsequent soil-atmosphere modelling using the ameliorated till properties demonstrated the potential of using the ameliorated till as a cover material.

Physical Characterization of the Cover and Waste 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 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 2.1Mg/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. 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 varied between $1 \times 10^{-5}\text{cm/s}$ and $1 \times 10^{-7}\text{cm/s}$ since 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. The saturated hydraulic conductivity of the tailings sample was approximately $1 \times 10^{-5}\text{cm/s}$.

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.

SWCCs of the waste rock, tailings, compacted till, and non-compacted till are shown in Figure 3 and represent the materials evaluated during the initial soil-atmosphere modelling. The SWCCs 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. $\approx 1\text{kPa}$) with a gradual slope at suctions greater than the air entry value. The air entry value increased to approximately 10kPa 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.

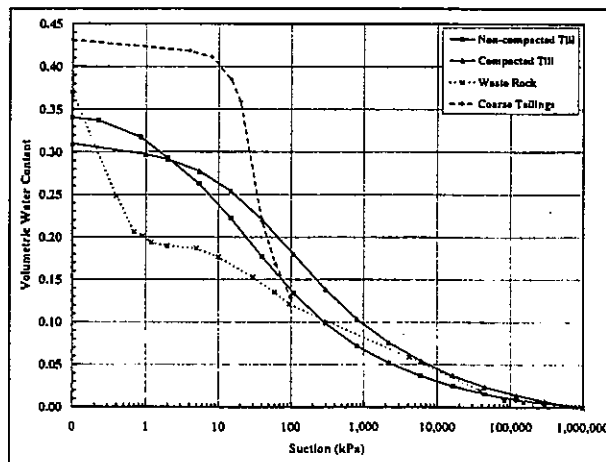


Figure 3 Soil water characteristic curves for the till cover material and waste material (after O'Kane *et al.*, 1995).

The shape of the SWCC for the waste rock was bimodal, as a result of the presence of coarse material as well as 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 3. The first occurring at a suction very near zero and the second at approximately 7kPa . The coarse tailings were uniform with an air entry value equal to 10kPa .

Additional SWCC tests were completed using compacted till ameliorated with varying percentages of top ash, bottom ash, and precipitate catch obtained from a pulp and paper mill. 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 SWCCs 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 4 compares the SWCCs 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 100kPa , although little change in the porosity of the sample was observed, as shown in Figure 4. 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 natural compacted till sample.

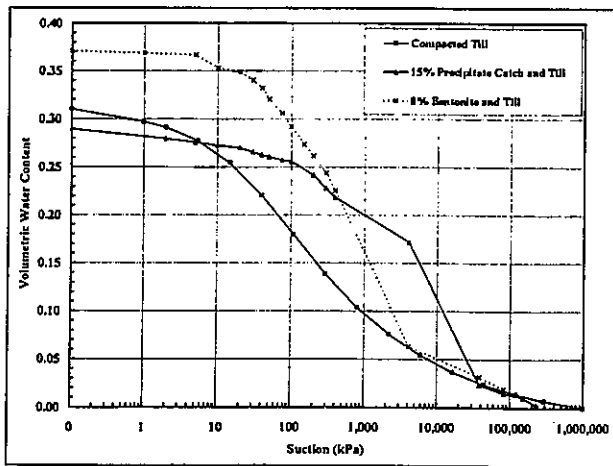


Figure 4 Soil water characteristic curves for the compacted natural till material and the ameliorated compacted till materials (after O'Kane *et al.*, 1996).

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

Design of the Field Test Plots for a Sloped Waste Rock Surface

The design of the field test plots for the sloped waste rock surface included soil-atmosphere modelling, evaluation of the optimum dimensions (foot print) of each test plot, design of the lysimeter to monitor the net infiltration from the base of each test plot, and determining the proper orientation and location of the performance monitoring sensors within the test plot profile.

Soil-Atmosphere Modelling

The soil-atmosphere modelling study was completed by the USG over a two year period and included:

1. collection of potential cover materials and waste materials during a January, 1995 site visit,
2. laboratory characterization of the potential cover materials and waste materials,
3. preliminary numerical modelling of several soil cover systems,
4. measurement of the soil water characteristic curve when the compacted till material was ameliorated with a fine grained material,

5. evaluating the ability of the ameliorated compacted till to function as an oxygen ingress and water infiltration barrier to the underlying waste rock, and
6. appraising the effect of placing a capillary break layer above and below the compacted till layer on the performance of the entire soil cover system.

The soil-atmosphere model. The soil-atmosphere modelling was completed using the finite element 1-D model SoilCover (1997). SoilCover predicts pressure head and temperature profiles in the soil profile in response to climatic forcing and lower boundary conditions. A key feature of SoilCover is the ability of the model to predict actual evaporation and transpiration based on potential evaporation and predicted soil suction (Wilson *et al.*, 1997), as opposed to the user being required to input these surface flux boundary conditions. The actual evapotranspiration rate is generally well below the potential rate during prolonged dry periods since the suction, or negative water pressure, in the soil profile increases as the surface desiccates. In addition, SoilCover is a fully coupled (through the vapour pressure term) heat and mass transfer model which is capable of predicting water vapour movement as well as oxygen flux across a cover system. Machibroda (1994) demonstrated that SoilCover correctly predicted the surface flux boundary conditions of a mine tailings facility. The performance predicted by SoilCover was verified with field performance monitoring of an oxygen ingress and water infiltration limiting till cover system (placed on waste rock at a semi-humid site), and a water infiltration limiting oxidized cap rock cover system (placed on waste rock at a semi-arid site) by Swanson (1995).

Summary of soil-atmosphere modelling study - Phase 1.

The soil cover system alternatives proposed for the Myra Falls Operations 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 layer overlain by a non-compacted layer was considered. However, the computed degree of saturation of the compacted 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%. The degree of saturation of the soil cover system was predicted to remain greater than 85% only if the material properties of the lower compacted layer were improved. To achieve this result, the air entry value of the lower compacted layer was arbitrarily increased from the measured value of approximately 10kPa to 50kPa, and the saturated hydraulic conductivity was decreased from $1 \times 10^{-6}\text{cm/s}$

to 1×10^{-3} cm/s in order to represent a compacted till layer ameliorated with a fine grained material.

The results of the Phase 1 numerical modelling showed that the degree of saturation in the compacted/non-compacted cover without soil modification decreased to less than 75% during the summer of the historical dry year (with respect to precipitation) growing season (O'Kane *et al.*, 1997). Repeating the analysis for the dry year with the modified soil properties increased the minimum degree of saturation in the compacted layer to 85% during the growing season. The laboratory program to evaluate alternative ameliorated till mixtures was initiated, based on the Phase 1 modelling results.

Summary of soil-atmosphere modelling study - Phase 2.

The phase 2 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). SoilCover predicted that the ameliorated compacted till layer remained at a degree of saturation greater than 95% during the historical dry year growing season, as shown in Figure 5. 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.

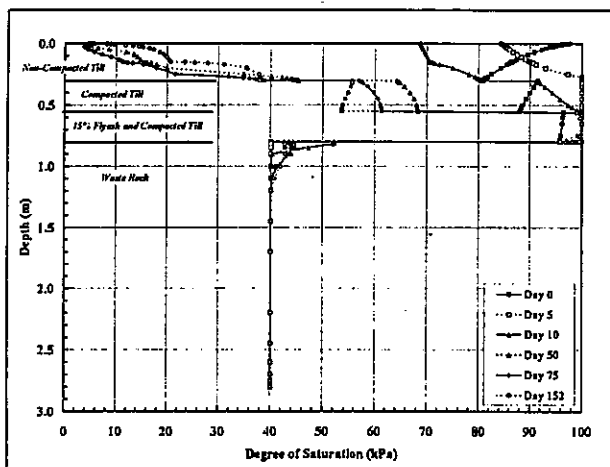


Figure 5 Degree of saturation of the cover system versus depth for the dry year model and a 0.25m ameliorated compacted till layer (from O'Kane *et al.*, 1996).

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. The predicted net flux from the base of the cover into the waste rock was approximately 10% of the growing season precipitation. The majority of infiltration occurred during the spring freshet.

Design of the Field Test Plots Using Saturated-Unsaturated Two-Dimensional Modelling

The hydraulic performance of waste rock piles found in the mining industry is dependent upon geometry, or configuration, and method of placement. The configuration can be classified into valley filled, cross valley filled, side valley filled, ridge dumped, or heaped (Taylor and Greenwood, 1985). The two methods used to construct waste rock dumps are end dumping and lift dumping (terraced). In many cases a particular waste rock dump is built with a combination of the configurations listed and with both construction methods. There are sloped waste rock surfaces at the Myra Falls Operations, therefore a cover system placed on these slopes will clearly not be horizontal. Hence, the hydraulic performance of the cover system and its ability to control water infiltration and oxygen ingress to the underlying waste rock will be much different than that predicted by idealized one-dimensional numerical models.

The two-dimensional modelling test plot design program was developed to determine the effect of a sloping cover and waste rock surface on the flow regime through and around the cover system. The objective was to ensure that the true potential of the field test plots was measured by the monitoring system. The computer package SEEP/W (Geo-Slope International Ltd., 1995) was used to model the flow regime in two dimensions within the model. SEEP/W is a two-dimensional finite element saturated-unsaturated flow model. The objectives of the investigation were to:

1. determine the optimum (with respect to cost and performance) test plot dimensions,
2. determine the optimum location of the instrument access boxes based on the cover dimensions,
3. determine the optimum direction and distance that the monitoring instruments should be located from the instrument access box,
4. determine the dimensions and position of the zero-tension lysimeter underlying the test plot, in three-dimensions, and
5. provide a detailed assessment of the effect of the sloping waste rock surface on the optimum position for the lysimeter and instrument access boxes.

The physical model. Figure 6 shows the modelled cross-sections of the cover systems with a 17.5m x 17.5m foot print. It was fundamental to model a series of sections to determine the three-dimensional flow regime within the cover system since SEEP/W is a two-dimensional modelling system. The multiple seepage models used in the analysis were necessary to locate the optimum position for the lysimeter and monitoring instruments from a three-dimensional point of view. The stratigraphic components of the model consisted of a multiple layer soil cover system over waste rock, as shown in Figure 7. The various soil cover options modelled in the analysis were based on the soil-atmosphere modelling results.

Surface flux boundary conditions. The surface boundary conditions were predicted by SoilCover. The results of the modelling revealed that the average flux into the waste rock was 2.4×10^{-9} cm/sec. A surface flux approximately 2 orders of magnitude greater (4.7×10^{-7} cm/sec) was specified for the waste rock outside of the test plot foot print to represent a heavy rainfall event during the wet season. The high flux for the waste rock surface was chosen to determine if flow around the cover would influence flow of pore water into or out of the lysimeter.

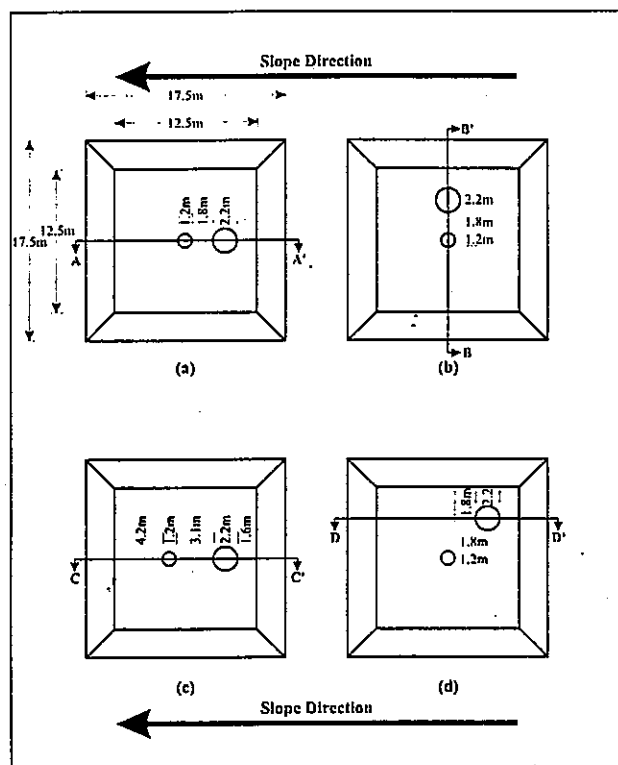


Figure 6 Modelled cross sections of the field test plots.

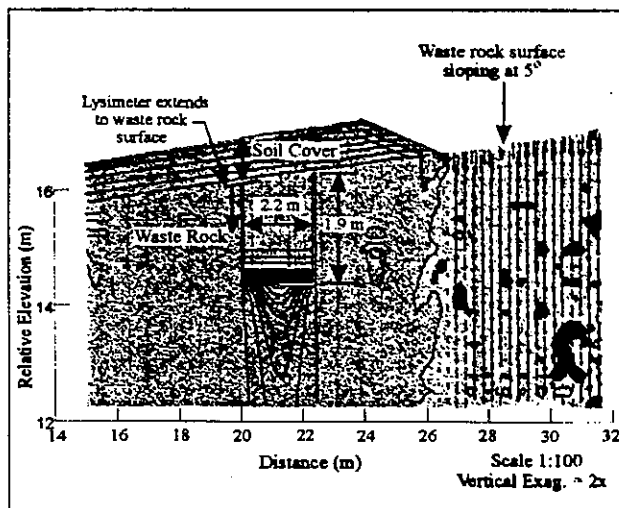


Figure 7 Cross section showing the lysimeter and test plot configuration.

Optimum location of instrumentation in the cover. The model for sections A-A' and C-C' (Figure 6) demonstrated that pore pressures were reduced up-slope of the access box. The cause for this reduction in pore pressure was related to the two-dimensional flow which dominates within the sloping cover system. The model showed that precipitation which infiltrates, flows down the slope within the upper till layer. That is, groundwater will flow through the cover along the path of least resistance. In the cover system, the lower compacted till layer possesses a saturated hydraulic conductivity which is two orders of magnitude lower than that of the upper till layer. The effect of gravity allowed the groundwater to flow downslope through the upper till layer which was the path of least resistance for the scenario modelled. The model showed that the groundwater flow down the slope was impeded by the access box.

Groundwater "built up" behind the access box causing a decrease in pore pressures. The model predicted that the influence of this decrease in pore pressure extended approximately 3.3m up-slope from the access box. The area downslope of the access box was also affected. The model predicted that the area 3.3m downslope of the access box had higher pore pressures than other locations within the cover since groundwater was deflected around the access box. Thus, the area immediately up-slope and downslope of the access box would not indicate the actual conditions within the cover system as a result of the presence of the access boxes. For this reason, the soil cover monitoring instruments should not be installed in a direction up-slope or downslope of the access box. The magnitude of the zone of pore pressure influence was a function of

the surface flux boundary conditions modelled, the slope of the cover system, and the properties of the cover and underlying waste material.

Figure 6, section B-B' shows a seepage model that was perpendicular to the sloping waste rock surface at a distance half way along the slope. Pressure head contours for section B-B' (Figure 8) illustrated that the monitoring instruments should be located approximately 1.8m from the access box. This separation distance was important, since the model showed that flow around the access box may influence the readings in the sensors if they are positioned less than 1.8m from the instrumentation access box. In summary, the instrumentation should be installed 1.8m from the access box in a direction perpendicular to the slope direction.

Zero-tension lysimeter location and design. Measurement of the net flux from the base of the cover layer into the underlying waste material is likely the most important component of a cover system monitoring program. Kohnke *et al.* (1940) concluded that zero-tension lysimeters are typically designed and installed incorrectly. Therefore, numerical two-dimensional saturated-unsaturated modelling was completed to design the zero-tension lysimeters proposed for the field test plot performance monitoring system. A lysimeter installed to monitor net infiltration from the base of a cover system is part of an unsaturated system. Flow into the lysimeter may occur during saturated conditions, however flow will primarily occur during unsaturated conditions. The flux through the cover is a function of the properties of not only the cover material but also the material underlying the cover, which in turn controls the suction at the base of the cover. In addition, the lysimeter establishes an artificial water table boundary condition below the cover that is different than outside the lysimeter. The design of the Myra Falls Operations field lysimeters required that the geometry of the lysimeter (cross sectional area and depth), hydraulic properties of the backfill (SWCC and k_{sat}), and the cover response (flux) be integrated so that the suction at the cover layer-waste rock interface was the same both inside and outside of the confines of the field lysimeter. A series of zero-tension lysimeters with varying geometry and shape were evaluated during a preliminary modelling review process. A lysimeter 2.2m in diameter and 1.9m deep was chosen for further evaluation, since it demonstrated potential during the preliminary review process and represented the dimensions of a commercially available high density polyethylene (HDPE) tank. The objective of the steady state modelling was to determine if the

given lysimeter geometry was capable of measuring the flux from the base of the cover system.

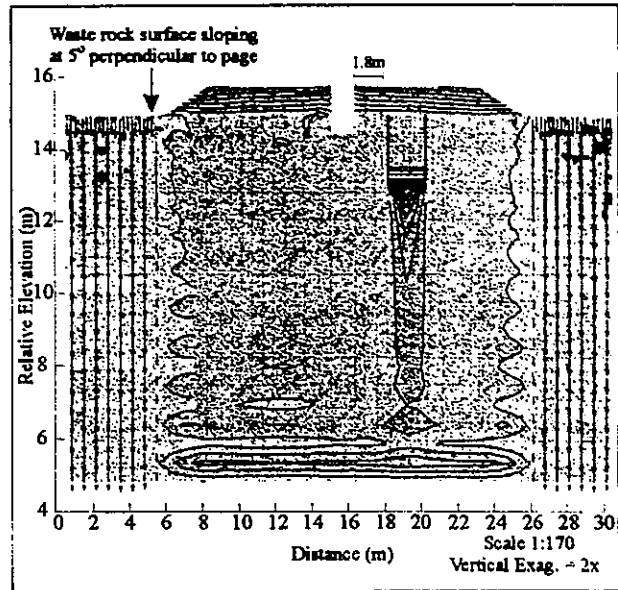


Figure 8 Pressure head profile for model cross section B-B' (see Figure 6).

Sand was included in the lower 0.3m of the lysimeter modelled. It will facilitate monitoring the net infiltration from the base of the cover system (that ultimately reports to the base of the field lysimeter) if the material at the base of the lysimeter is uniform and relatively simple to characterize. The two-dimensional modelling illustrated that in order to reduce the influence of the sand, the base of the lysimeter must be located at least 2 to 2.5m below the waste rock-cover layer interface. The material properties of the sand were estimated from a grain size curve for a commercially available sand. The general design criteria for the sand was that the material should have an air entry value greater than the waste rock. This will ensure that a capillary barrier to downward flow is not created at the sand-waste rock interface during unsaturated conditions. In addition, the saturated hydraulic conductivity of the sand should be greater than the anticipated flux from the base of the cover system.

The results of the models for section A-A' and C-C', as shown in Figure 6, demonstrated that the flow of pore water into the waste rock was influenced by the location of the instrument access box. The area directly up-slope and downslope of the access box may influence the flow into the lysimeter. Therefore, the lysimeter should be located at least 3.3m directly up-slope or downslope from the access box, based on the model results from sections A-A' and C-C'. Figure 9 shows

the predicted pressure head profiles inside and outside of the confines of the lysimeter for the model D-D', shown in Figure 6. The model results showed that a zero-tension lysimeter located in this position will accurately monitor the net infiltration across the cover system.

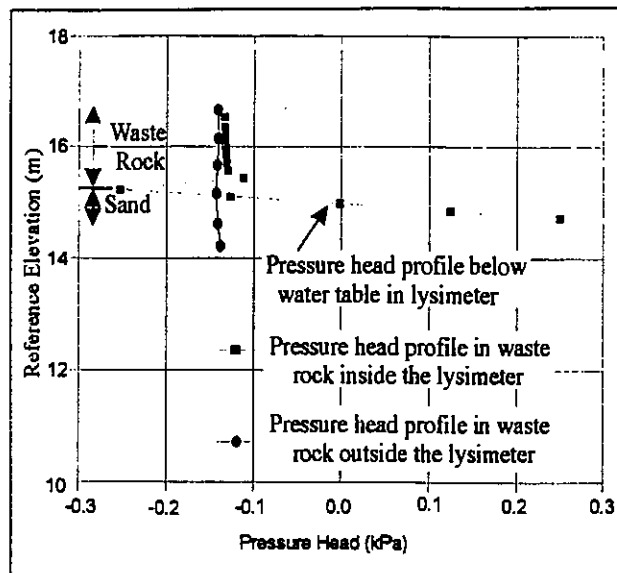


Figure 9 Pressure head profile inside and outside the lysimeter for cross section D-D' (see Figure 6).

The proper design and installation of the zero-tension field lysimeters is a key component of the field performance monitoring program. The measured net flux from the base of the cover system as a percentage of precipitation is a value that is simple to understand and provides the foremost measure of the performance of a cover system designed to limit water infiltration for the long term. Field measurement of moisture and temperature conditions in the cover material and waste rock will serve as a tool to verify the performance of the zero-tension lysimeters.

Performance monitoring

Performance monitoring methodology was developed as part of the field test plot design since it was anticipated the size of the test plots would influence the location and type of monitoring instruments. The performance of each test plot will be monitored by:

1. measuring net infiltration (and associated water quality) from the base of the cover into the underlying waste rock using a zero-tension lysimeter,
2. evaluating the development of the vegetation cover,

3. measuring surface runoff and sediment transport,
4. measuring gaseous oxygen concentration just below each cover layer interface, as well as just below the interface of the waste rock and lower compacted layer,
5. measuring oxygen consumption from the surface of the test plots as described by Tibble and Nicholson (1997), and
6. measuring soil suction, soil temperature, and soil water content profiles (8 sensors for each profile).

Summary

The results of the laboratory characterization program and the soil-atmosphere modelling demonstrated the potential of using local till ameliorated with either flyash or bentonite as a component of the Myra Falls Operations cover system. Two-dimensional saturated-unsaturated modelling was used to design the field test plots and monitoring system to ensure that the true potential of the proposed cover system alternatives are measured.

The design of small scale field test plots and zero-tension lysimeters to measure infiltration seems conceptually simple. However, once the saturated/unsaturated flow system is analyzed using a range of surface flux boundary conditions, it is clear that it can be seen as somewhat more complex. Discontinuities at boundaries increase the potential for flow to be diverted away from the desired simple one-dimensional case. The two dimensional geometry of the field test plot and lysimeter led to a two dimensional flow system. The potential for two-dimensional flow within the cover system was increased, as a result of modelling the field test plots on a sloped waste rock surface. The key conclusion arising from the modelling was to ensure that the field test plots are designed and monitored as two-dimensional systems, rather than idealized one-dimensional systems.

Acknowledgments

The authors would like to thank the manuscript reviewers for their time and guidance in helping focus this paper.

Literature Cited

Barbour, S.L., Vanapalli, S., and O'Kane, M., 1996. A critical review of the Waite Amulet and Heath Steele Cover Systems. A MEND project report.

- Bews, B.E., O'Kane, M.A., Wilson, G.W., Williams, D., and N. Currey, The design of a low flux cover system, including lysimeters, for acid generating waste rock in semi-arid environments, Proceedings of the 4th Intl. Conf. on Acid Rock Drainage, Vancouver, B.C., May 31-June 6, 1997, pp.747-762.
- Broughton, L.M. and Ferguson, K.D., 1990. The geochemistry of Westmin resources Ltd., Myra Creek Mine tailings, after thirty months of exposure of sub-aerial tailings, Regional Program Report 94-04. For: Environment Canada, Environmental Protection, Pacific and Yukon Region.
- Fredlund, D.G. and Rahardjo, H., 1993. Soil Mechanics for Unsaturated Soils. John Wiley and Sons Inc., New York, N.Y.
- Geo-Slope International Ltd., 1995. SEEP/W User's Manual. Geo-Slope International Ltd., Calgary, AB.
- Hallam, R.L., Haile, J.P., and Brouwer, K.J., 1991. Waste disposal practices for control of acidic drainage, Proceedings, Second International Conference on the Abatement of Acidic Drainage, Montréal, PQ., September 16-18, 1991, pp. 85-107.
- Kohnke, H., Dreibelbis, F.R., Davidson, J.M., 1940. A survey and discussion of lysimeters and a bibliography on their construction and performance. USDA Misc. Publ. 372. U.S. Gov. Print Office, Washington, D.C.
- Konasewich, D., Jones, C., Morin, K., and Gerencher, E., 1990. Hydrogeological assessment and development of AMD control technical for Myra Falls Waste Rock, For: British Columbia Acid Mine Drainage Task Force.
- Machibroda, R., 1994. Evaluation of evaporative fluxes from mine tailings using the modified Penman method. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- O'Kane, M., Bews, B., Newman G., and Wilson, G.W., 1995. Final Report for Phase I of a cover research program at Westmin Resources Ltd., Myra Falls Operation - Progress Report No. 2. Unsaturated Soils Research Group, Department of Civil Engineering, University of Saskatchewan, December, 1995.
- O'Kane, M., Wilson, G.W., and Haug, M.D., 1996. Final Report for Phase II of a Cover Research Program at Westmin Resources Ltd., Myra Falls Operation. Unsaturated Soils Research Group, Department of Civil Engineering, University of Saskatchewan, September, 1996.
- O'Kane, M., Mchaina, D.M., Stoicescu, J., Januszewski, S., Haug, M.D., and Bews, B.E., 1997. Managing for closure at the Myra Falls Operation - The design of a soil cover system for long term ecological and physical stability, Proceedings of the 21st Annual BC Mine Reclamation Symposium/22nd Annual Meeting of the Canadian Land Reclamation Association, September 22-25, 1997, Cranbrook, B.C.
- SoilCover, 1997. Unsaturated Soils Research Group, Department of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- Swanson, D.R., 1995. Predictive Modelling of Moisture Movement in Engineered Soil Covers for Acid Generating Mine Waste. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- Taylor, M.J. and Greenwood, R.J., 1985. Classification and surface water control. In Design of non-impounding mine waste dumps. Edited by M.K. Carter. American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, pp. 1-13.
- Tibble, P.A. and Nicholson, R.V., 1997. Oxygen consumption on sulphide tailings and tailings covers: measured rates and applications. Fourth International Conference on Acid Rock Drainage, Vancouver, B.C., May 31-June 6, 1997, pp. 647-661.
- van Dyk, R.P., 1987. Environmental control and reclamation at Westmin Myra Falls Operations. Proc. of the 11th Annual B.C. Mine Rec. Symp., Campbell River, B.C., May 4-7, 1987, pp. 227-234.
- Wilson, G.W., Fredlund, D.G., and Barbour, S.L., 1994. Coupled soil-atmosphere modelling for soil evaporation, Can. Geo. J., Volume 31, 1994, pp. 151-161.
<https://doi.org/10.1139/t94-021>
- Wilson, G.W., Fredlund, D.G., and Barbour, S.L., 1997. The effect of soil suction on evaporative fluxes from soil surfaces, Can. Geo. J., Volume 34, No.1, pp. 145-155.
<https://doi.org/10.1139/t96-078>