

# MODELLING THE PERFORMANCE OF ENGINEERED SOIL COVERS FOR ACID GENERATING MINE WASTE

D. A. Swanson<sup>1</sup>, S. L. Barbour<sup>2</sup>, G. W. Wilson<sup>2</sup>, and M. O'Kane<sup>3</sup>

**Abstract:** Soil covers are often used as the closure option for the decommissioning of acid generating mine waste. The objective of the cover is to reduce the influx of water and oxygen into the waste material in an attempt to limit the acid generating process. Predicting the performance of an existing soil cover or evaluating various design options is of interest to both facility owners and regulatory agencies. Mine owners must provide effective and economical decommissioning strategies, and regulatory agencies must be able to assess these decommissioning strategies to determine their effectiveness and acceptability.

Prediction of cover performance involves both field monitoring and numerical modelling efforts. Field monitoring of the responses of the in-place cover (i.e., net infiltration and variations in degree of saturation) is required as a direct evaluation of cover performance. Numerical modelling techniques can then be utilized to predict the future performance of the cover system under extreme climate conditions. However, the ability of the model to adequately describe field conditions must first be demonstrated before predictions regarding future performance can be made.

The numerical Model "SoilCover" developed under the MEND program has been used to evaluate an in-place cover system over mine waste rock at the Equity Silver Mine located in British Columbia, Canada. Examples from this analysis are used to illustrate aspects of the performance modelling process.

**Key Words:** soil covers, acid mine drainage, performance modelling, decommissioning strategies, field instrumentation, monitoring.

## Introduction

The containment of acidic drainage from sulfide bearing waste rock piles and tailings facilities is perhaps the greatest environmental problem facing the mining industry today. Sulfide bearing waste rock and tailings can produce effluent that is both low in pH and high in heavy metals.

An engineered soil cover is often used to reduce the extent of acid mine drainage by limiting the influx of rain and snow melt and oxygen into the sulfide bearing waste. The success of the cover is therefore defined by the amount of water and oxygen that is allowed to move through the base of the cover layer. The ability to predict the performance of a cover system is important as mine owners must implement decommissioning strategies for the acid mine drainage problem that are both effective and economical. At the same time regulatory agencies must be able to accurately assess these decommissioning strategies to determine their effectiveness and acceptability.

---

Paper presented at Sudbury '95, Conference on Mining and the Environment, Sudbury, Ontario, May 28th - June 1, 1995

1. Graduate Student, Department of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, S7N 0W0
2. Professor, Department of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, S7N 0W0
3. Research Engineer, Unsaturated Soils Research Group, Department of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, S7N 0W0

Predicting the performance of a cover system is a two stage process involving field monitoring and numerical modelling. Field monitoring not only provides a direct evaluation of cover performance, but it also provides the basis for numerical predictions. Before numerical predictions can be made regarding future cover performance, the ability to predict existing conditions must first be demonstrated. For example, it should be demonstrated that computed changes in water content are similar to the changes in water content measured in the field. This process is referred to as field response modelling. Once the ability of the model to describe field conditions has been demonstrated, scenarios can be simulated to predict future cover performance. This process is referred to as predictive modelling.

A numerical soil-atmosphere model called "SoilCover" (MEND, 1) is used to model the field responses of an in-place cover system. Results from the evaluation of a compacted glacial till cover system for a mine waste rock pile are used to illustrate aspects of the performance modelling process.

### Numerical Modelling Background

An accurate quantification of the surface water balance (i.e., infiltration, runoff, and evapotranspiration) and internal moisture movement in the cover is critical for the numerical prediction of cover performance.

A soil cover system is comprised of essentially three zones as illustrated in Figure 1. Included is a saturated zone, an unsaturated zone, and the soil-atmosphere interface. In the saturated zone, all of the soil pores are completely filled with water and hydraulic conductivity is constant. Early modelling of soil systems included this zone only. Such a representation left a discontinuity in the natural system as the unsaturated zone was not taken into account. In the unsaturated zone, the soil pores are only partially filled with water and the hydraulic conductivity is a function of the soil matric suction. Advances in unsaturated soil and computer technology, in recent decades, have led to comprehensive numerical analysis of saturated and unsaturated soil systems.

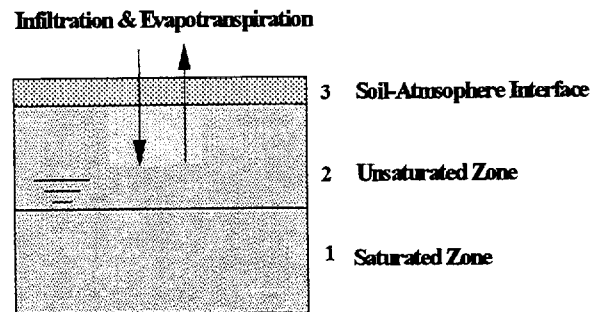


Figure 1 Components of a soil system.

However, in order to describe a fully continuous natural system one must couple the soil moisture movement to atmospheric supply and demand. The soil-atmosphere interface is a dynamic zone where moisture is supplied through rainfall and extracted through surface evaporation. The potential rate of surface evaporation is a function of atmospheric conditions. However, the actual evaporation from the soil surface is influenced by the values of soil suction and the hydraulic and thermal properties of the soil at and below the soil-atmosphere interface. Moisture is also extracted through plant root uptake.

The software used to simulate moisture movement in the cover system is based on the SoilCover model (MEND, 1) developed at the University of Saskatchewan. SoilCover is a one-dimensional heat and water transfer (liquid and vapour) model which uses a physically based method for predicting the exchange of moisture between the atmosphere and a soil surface. The theory is based on the well known principles of Darcy's, Fick's, and Fourier's laws which are used to describe the movement of liquid water, water vapour, and heat respectively, within the soil profile. The water and heat flow equations were developed by Wilson (2) within the framework of continuum mechanics as put forth by Fredlund and Dakshanamurthy (3). The

flow equations are solved using the finite element formulation developed by Joshi (4). The coupling of the soil profile to the atmosphere is accomplished using a modified Penman formulation developed by Wilson (2) and implemented by Machibroda (5) which allows for the calculation of evaporation from a saturated or an unsaturated soil surface. The extraction of water from plant roots is quantified using methods described by Tratch (6). The development of the program for use on a personal computer was carried out by Cook (7). The SoilCover model was modified by Swanson (8) to include the daily calculation of oxygen diffusion through a cover layer using Fick's law and assuming steady state conditions apply.

The model provides a daily quantification of the surface water balance that is coupled to the soil profile. The system is referred to as coupled because the actual evaporation from the soil is dependent on the matric suction of the soil surface. Similarly, runoff is a function of surface infiltration conditions. Daily climatic information is required for the calculation of potential evaporation (i.e., maximum and minimum air temperature, maximum and minimum relative humidity, average wind speed, and net radiation). Air temperature, relative humidity, and net radiation are distributed throughout the day in such a way as to represent diurnal variations. The hydraulic and thermal properties of the soil are required for the analysis and include the soil water characteristic curve, the hydraulic conductivity function, the thermal conductivity versus gravimetric water content, and the specific heat versus gravimetric water content functions. In addition, parameters that describe the oxygen diffusion coefficient versus degree of saturation function are also required for the daily calculation of oxygen flux.

### **Performance Modelling**

Performance modelling consists of a field response modelling stage and a predictive modelling stage (Swanson, 8). Results of a cover instrumentation and modelling research program carried out at Equity Silver Mine, are used to illustrate the process of performance modelling. The Equity cover system consists of 50 cm of compacted glacial till overlain by 30 cm of loose glacial till.

### **Field Response Modelling**

Field responses refer to conditions that develop within the cover such as changes in water content, changes in soil matric suction, changes in soil temperature, water and oxygen flow through the cover, actual evapotranspiration, and runoff. The objective of a field monitoring program for a cover system is to measure atmospheric conditions for the site and to quantify field responses for the cover system. O'Kane (9) and O'Kane et al (10) describe details with regard to the instrumentation and monitoring of the Equity cover system. Site climatic conditions were measured with a fully automated weather station. Neutron probe access tubes were installed for the measurement of water content and thermal conductivity sensors were installed for measurement of soil temperature and matric suction. This quantitative description of atmospheric conditions and field responses allows for the evaluation of computed field responses. Predictive modelling of future cover performance can proceed if it can be demonstrated that computed field responses are similar to measured field responses.

Figure 2 shows the computed water content profiles compared to measured water content profiles for one of the neutron probes locations. The figure also shows computed and measured changes in moisture storage for the cover. The measured water content profiles show there were substantial changes in water content in the loose till layer with only minor changes in water content for the compacted till layer. Computed water content profiles revealed a similar trend as shown in Figure 2. Daily computed changes in storage were also similar to measured changes in storage based on five sample dates for a five month period.

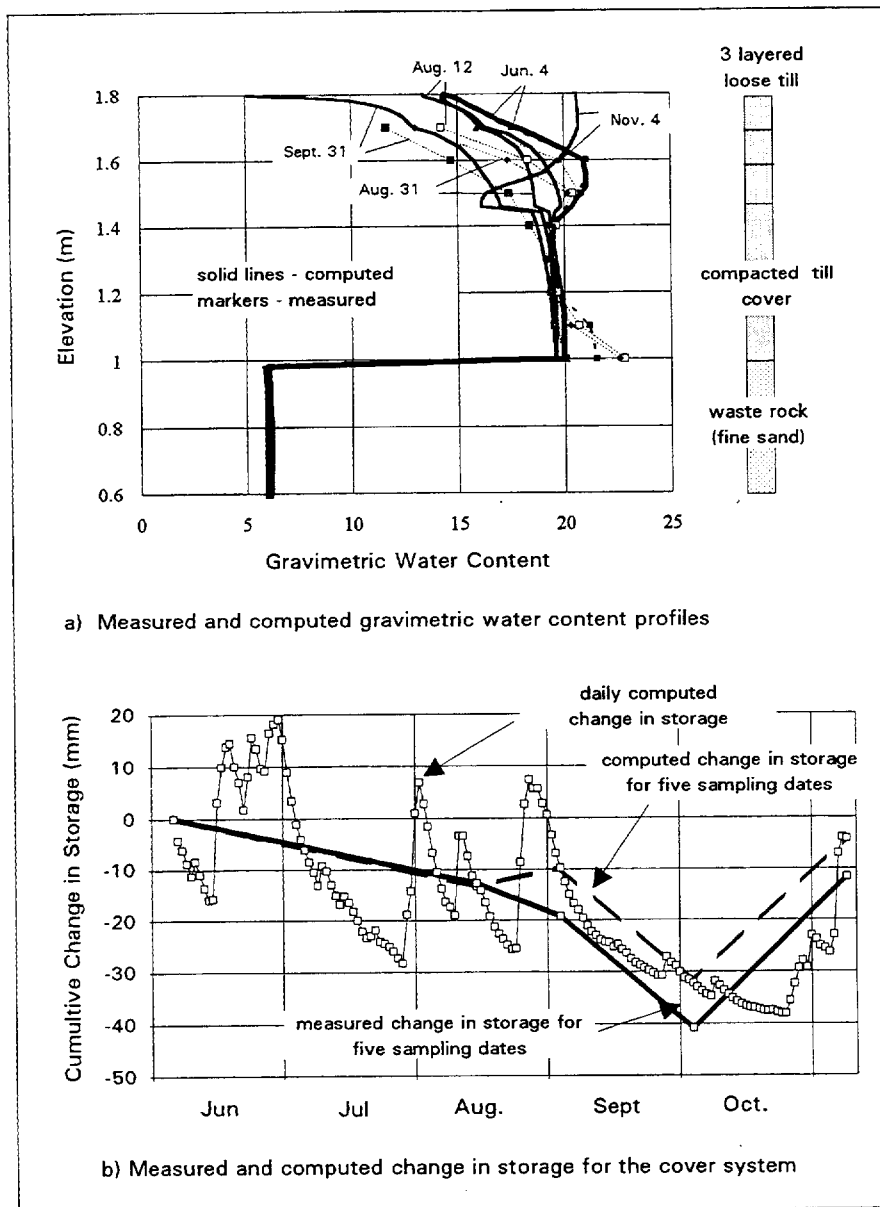


Figure 2 Calibrated model results showing a comparison between measured and computed water content profiles and moisture storage changes for the Equity cover system (from Swanson, 8).

Calibration is required for field response modelling. Laboratory soil water characteristic curves, determined by O'Kane (9), were calibrated to field measurements of water content and matric suction. In addition, laboratory tested saturated hydraulic conductivity of the loose and the compacted till layers determined by SENES (11) and O'Kane (9) were calibrated to changes in matric suction within the cover. For example, the saturated hydraulic conductivity within the loose till was modified so that computed peaks in matric suction throughout a five month period corresponded to measured peaks as illustrated in Figure 3. A three layered system in which saturated hydraulic conductivity of the loose till decreased with depth was used to obtain the matches shown in Figure 3.

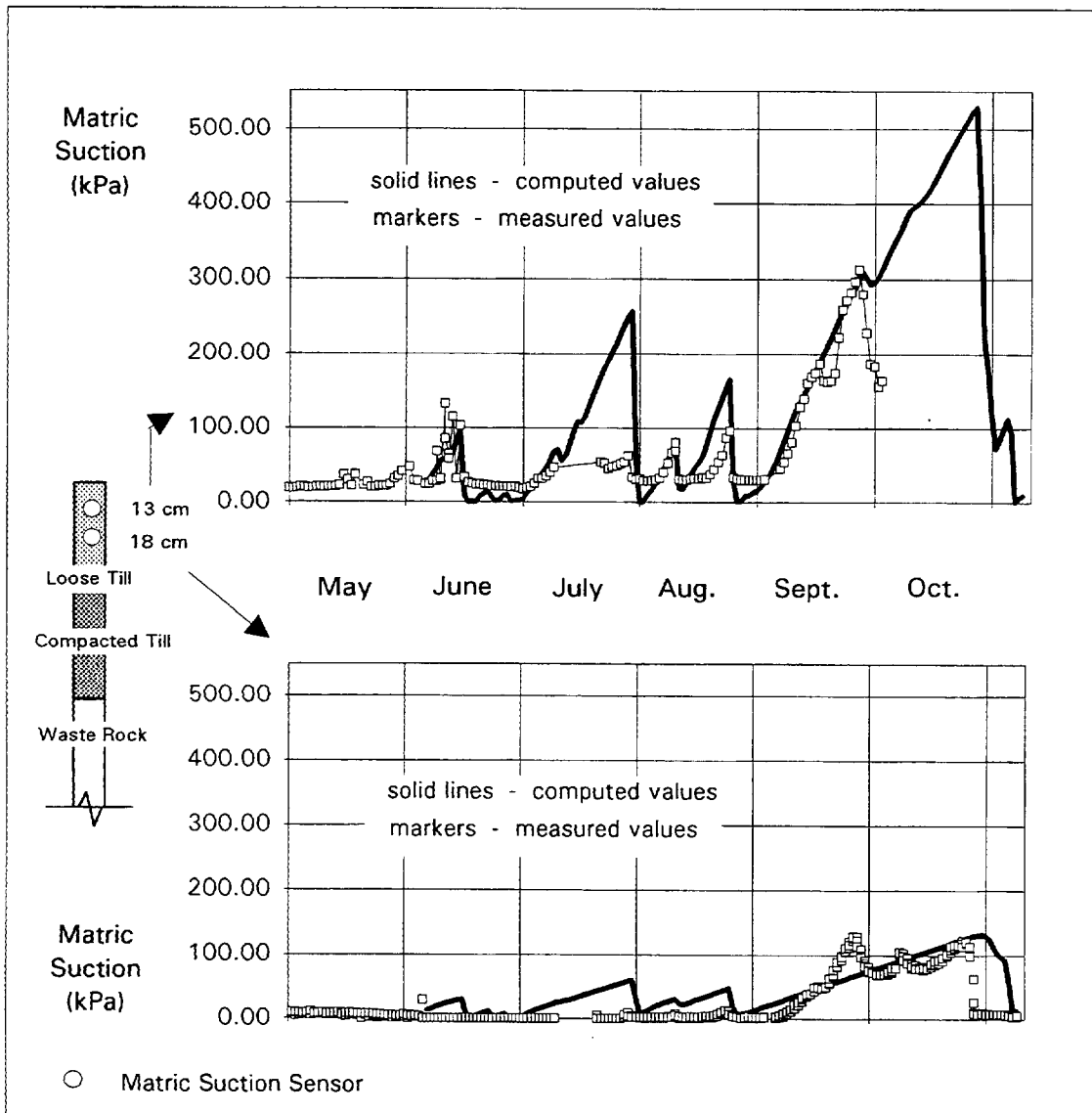


Figure 3 Calibrated model results showing a comparison between measured and computed matric suction at two depths for the Equity cover system (from Swanson, 8).

Comparisons were also made between computed and measured soil temperature response within the cover. Figure 4 shows measured soil temperatures at three depths with the cover system. The computed changes in temperature show adequate agreement with the values measured by the thermal conductivity sensors.

The previous paragraphs illustrate only some of the field response comparisons that can be made. Other comparisons can, and should, be made for field responses such as surface runoff and percolation through the cover. The field response comparisons help to build a confidence base for the ability to make

predictions. Calibration is often required for the comparisons to detailed field data sets. If adequate comparisons are achieved using a reasonable degree of calibration, one can be confident in the ability of the model to make accurate predictions regarding future cover performance.

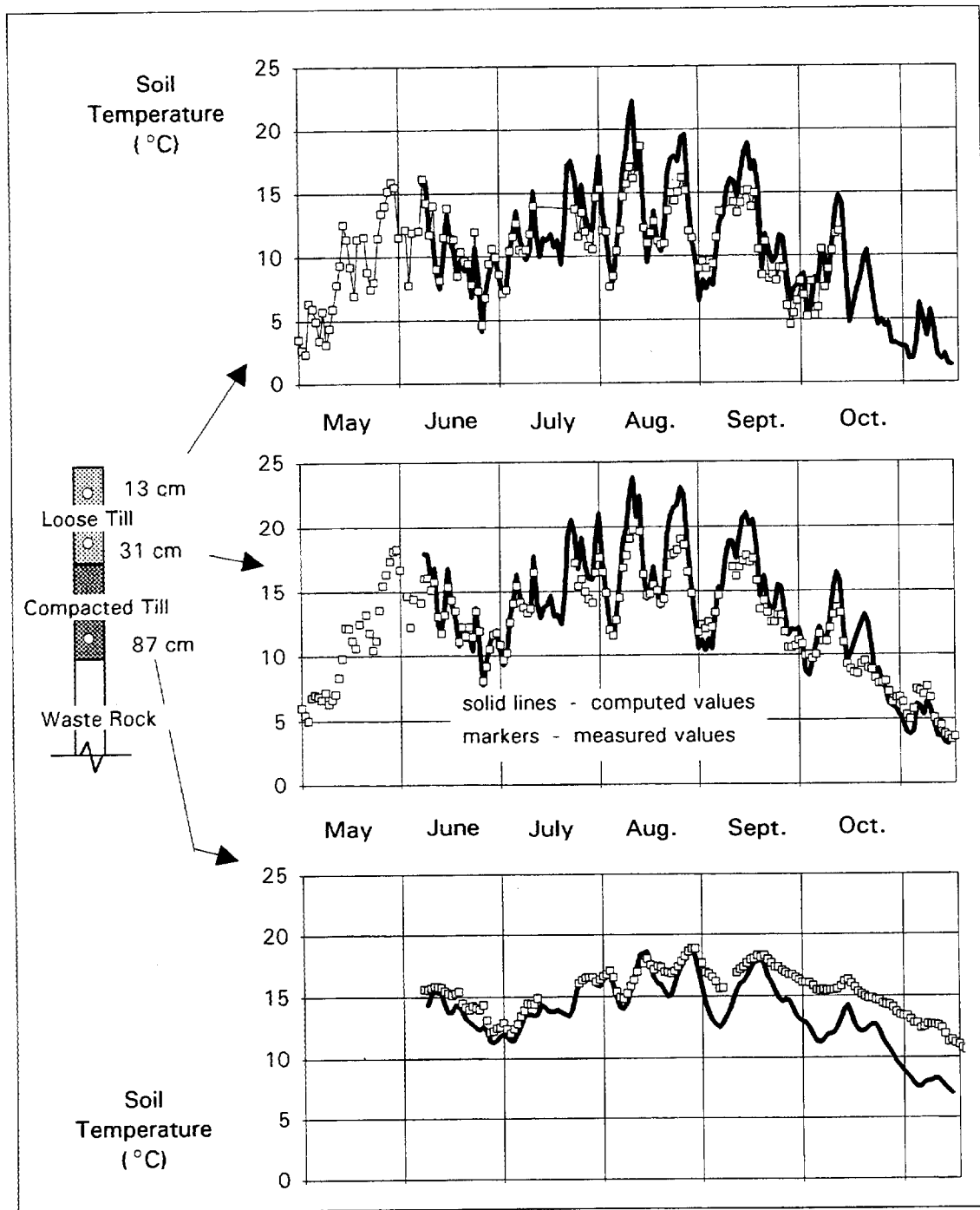


Figure 4 Calibrated model results showing a comparison between measured and computed soil temperatures at three depths for the Equity cover system (from Swanson, 8).

## **Predictive Modelling**

The evaluation of a cover system designed to limit acid mine drainage, involves the prediction of the amount of water and oxygen that is expected to move through the cover layer. The glacial till cover system, considered in this paper, relies on low hydraulic conductivity and high moisture retention characteristics to restrict water and oxygen movement into the waste. To evaluate future cover performance, various climate and cover conditions should be considered. Predictive modelling for the Equity site is currently in progress and is not included in this paper. However, the approach used for the predictive modelling program is summarized below.

For predictive modelling, extreme wet and dry as well as mean years should be identified for the site where the cover is located. For the Equity cover system, a 50 year daily precipitation data base was compiled for the region. An extreme wet year was defined as the year with the most infiltration through the cover layer. This conditions was represented by the year with the highest annual precipitation. Alternatively, the extreme dry year was defined as the year with the most oxygen movement through the cover. This condition was represented by the year with the lowest non-winter precipitation. A dry summer would result in the lowest degree of saturation in the cover system which in turn would result in the highest potential for oxygen movement through the cover. The climate parameters required for the daily calculation of potential evaporation were based on regional monthly climate normals.

Various cover conditions that are anticipated should be identified and considered in the predictive modelling analysis. This includes such aspects as anticipated ranges in saturated hydraulic conductivity and vegetation thickness. For the Equity analysis, scenarios were developed which considered a range of saturated hydraulic conductivity and vegetation cover thickness. These scenarios were considered for both the extreme wet and dry years.

Ranges should also be considered for other aspects of the analysis which are uncertain. The SoilCover version 1.0 model does not simulate freezing conditions. Simulations for the Equity analysis were therefore run for the non-winter months only. Precipitation occurring during the winter was accumulated and distributed as snow melt in the spring. The amount of water that infiltrated during the spring was sensitive to the duration of the spring snow melt. A range of snow melt durations was therefore considered in the analysis.

Reasonable conclusions can made regarding overall future cover performance by considering a range of scenarios for various climatic, cover, and vegetative conditions. Performance such as cumulative water and oxygen flux through the cover, and the variation in degree of saturation and oxygen diffusion coefficients within the cover are among the most important. The predictive modelling program for the Equity cover system is ongoing at this time and will be subsequently reported.

## **Summary**

Performance modelling of cover systems require both field monitoring and numerical modelling efforts. Field response modelling is the first step in performance modelling. The objective of field response modelling is to demonstrate an ability to adequately predict existing conditions. Key components of this stage are the measurement of site atmospheric conditions and cover responses. Calibration of hydraulic properties determined by laboratory tests is often required for this step. The ability to predict existing conditions is demonstrated if adequate comparisons between computed and measured field responses have been achieved and if the calibrations made are reasonable. Predictive modelling is the second step and involves the identification of extreme climatic conditions and the layout of scenarios that cover a range of

saturated hydraulic conductivity, vegetative cover thickness and other aspects which are felt to be uncertain.

The use of a soil-atmosphere modelling approach represents a move toward a more physically based methodology in the analysis and design of engineered soil systems.

### Acknowledgments

Funding for this research program was provided by Placer Dome Canada and the National Sciences and Engineering Research Council of Canada. The keen interest and support shown in this research program by Mr. Keith Ferguson of Placer Dome Canada is greatly appreciated. The assistance of Mr. Mike Aziz with the collection of site data for the study is also appreciated.

### References

- (1) MEND, 1993 "SoilCover", User's Manual for an evaporative flux model. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (2) Wilson, G.W., 1990. Soil evaporative fluxes for geotechnical engineering problems. Ph.D Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (3) Fredlund, D.G., and Dakshanamurthy, V., 1982 Predicting moisture flow and related swelling or shrinking in unsaturated soils. Geotechnical Engineering, Vol. 13, p 15 - 49.
- (4) Joshi, B., 1993. A finite element model for the coupled flow of moisture and heat in soils under atmospheric forcing. M. Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (5) Machibroda, R. T., 1994. Evaluation of evaporative fluxes from mine tailings using a modified Penman formulation. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (6) Tratch, D., 1994 Moisture uptake within the root zone. M.Sc. Thesis; in progress, Department of Civil Engineering. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (7) Cook, D., 1994 Modification of a finite element soil-atmosphere model. B.Sc. Thesis, Department of Civil Engineering. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (8) Swanson, D.A., 1994 Predictive modelling of moisture movement in engineered soil covers for acid generating mine waste. M.Sc. Thesis; in progress, Department of Civil Engineering. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (9) O'Kane, M., 1994 Instrumentation and monitoring of engineered soil covers for acid generating mine waste. M.Sc. Thesis; in progress, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- (10) O'Kane, M., Wilson G.W., Barbour, S.L., and Swanson, D.A., 1995 Aspects on the performance of the till cover system at Equity Silver Mines Ltd. . In Sudbury '95, Conference on Mining and the Environment, Sudbury, Ontario, these proceedings.
- (11) SENES, 1991 Acid generation modelling: Equity Silver waste rock dumps. Report No. 30938, December, 1991.