The Design and Implementation of the Field Test Plots
at
BHP Iron Ore, Mt. Whaleback - a Cover System for an Arid Climate

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ABSTRACT

BHP Iron Ore initiated research programs in January of 1995 to develop long term plans for decommissioning of the waste rock material at their Mt. Whaleback operation. More than 2 billion tonnes of waste rock were deposited during the past 30 years. Ultimately, the operators will deposit a total of approximately 5 billion tonnes in waste rock dumps constructed near the open pit. The Mt. Whaleback operation is located in a semi-arid climate adjacent to Newman, Western Australia, approximately 1200km north-northeast of Perth, Western Australia.

The primary research program includes the development of technology for the long term performance of the waste rock dumps with respect to vegetation, slope stability, surface runoff, erosion, and water infiltration. This paper focuses on the design and implementation of a cover system to prevent water infiltration to the underlying waste rock. A laboratory program and the soil-atmosphere modelling completed to design the horizontal field test plots are described. The construction of the horizontal surface field test plots are discussed together with the field instruments installed to monitor performance. The key components of the instrumentation program are the design and installation of large scale field lysimeters to measure the unsaturated flow of moisture into the waste rock from the base of the cover layer.

The cover system is designed to maximize infiltration during wet periods for subsequent evapotranspiration while minimizing surface runoff. The result is a near zero net infiltration to the underlying waste material. A key feature of the design is the use of pit run waste material as the cover material. Monitoring is in progress and will continue for at least two annual wet/dry cycles. The optimum cover system should minimize the net infiltration of water to the underlying waste rock while maintaining physical and ecological integrity for long term performance.

BACKGROUND

The Mt. Whaleback iron ore mine is located in the Hamersley Iron Province in the northwestern corner of Australia and situated adjacent to Newman, WA approximately 1200km north-northeast of Perth, WA. Development of the mine started in 1968. The mine currently produces approximately 23 million tonnes of iron ore and moves 90 million tonnes of waste material annually.

Mt. Whaleback is the largest known continuous high grade iron ore deposit in the world and originally contained over 1.7 billion tonnes of iron ore (van der Hayden, 1993). The ore consists mainly of the mineral hematite, an iron oxide containing approximately 70% iron. The texture of the ore varies from hard and massive, through banded and slabby, to soft and powdery. Shale, strongly weathered as well as "un-oxidized", is a common type of waste rock. Pyrite is the most common iron sulphide in the shale of the area, with average sulphide values less than 0.5%. The exception is the Mt. McRae Shale unit, which averages 3% sulphides, but locally has concentrations up to 20%. Pyrite in these zones appears visibly as bands and nodules (van der Hayden, 1993). Additional waste material includes a commonly occurring Banded Iron Formation, or BIF, as well as small amounts of Chert and Dolerite.

The oxidized waste rock materials at Mt. Whaleback are geochemically similar and deficient in pyrite as well as carbonates (Graeme Campbell & Associates, 1996). These materials possess little capacity to produce or consume acid. The "un-oxidized" waste rock has varying acid generating potential. The nodular unit of the Mt. McRae Shale contains sulphide-S concentrations ranging from 1.7% to 20% and has a deficiency of carbonates. This unit is capable of producing up to one tonne of H_2SO_4 per tonne of waste rock (Graeme Campbell & Associates, 1996). The disseminated unit of the Mt. McRae Shale, as well as additional shale units have the potential to produce in the range of 50 to 100kg of H_2SO_4 per tonne of waste rock (Graeme Campbell & Associates, 1996). The disseminated and nodular Mt. McRae Shale units may oxidize rapidly once exposed to the atmosphere. The non-acid forming materials typically have low concentrations of pyrite and a low to moderate capacity to consume acid.

The mine site is located in a semi-arid tropical region with a mean annual rainfall of approximately 320mm. It is common for rainfall to occur over short periods and with high intensity. Annual potential evaporation typically exceeds 3000mm.

Acid rock drainage (ARD) is a major environmental problem facing the mining industry today. ARD is the result of the combined chemical and biological oxidation of sulphide minerals and the release of associated metals, such as iron, aluminum, manganese, and other heavy metals. Mine waste rock and tailings that contain sulphide minerals will react with atmospheric oxygen and water to produce sulphuric acid. Waste rock and tailings materials often 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.

It is common practice to construct single or multi-layered engineered cover systems to control ARD from mine waste rock and tailings. 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.

The Mt. Whaleback Cover System Design Philosophy

It is not feasible to limit the ingress of oxygen to the potentially acid generating material at the Mt. Whaleback operation. In addition, it is not practical to attempt to control the bacteriological activity within the waste material. The most promising closure option to control ARD at the Mt. Whaleback operation is the utilization of a moisture “store and release” cover system which takes advantage of the high evaporative conditions at the site. The Mt. Whaleback cover system is designed to accept as much rainfall as possible, while minimizing runoff and associated erosion, with all infiltration remaining within the cover material. The cover system is constructed using suitable pit run waste material to minimize closure costs. The moisture is subsequently released to the atmosphere as evapotranspiration creating a “net zero moisture transfer” from the cover material to the underlying waste rock. The objective is to control acid rock drainage as a result of preventing moisture movement into and through the waste rock material.

The principles applied to the design of the Mt. Whaleback cover system are well developed and 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 heat and 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.

The methodology for the water infiltration aspect of the cover research project includes:

1. field sampling of waste rock and pit run potential cover materials,
2. procurement of historical regional and site climate data,
3. physical laboratory characterization of waste rock and cover materials,
4. design of alternate soil cover systems using a one-dimensional (1-D) soil-atmosphere model,
5. design of the field instrumentation program,
6. construction of alternate 1-D cover systems and installation of field monitoring instruments,
7. design of a cover system for a sloped waste rock surface,
8. construction of a cover system on a sloped waste rock surface and installation of field monitoring instruments,
9. a minimum of two years (two wet/dry climate cycles) of field monitoring, and
10. field response and predictive modelling of the alternate cover systems.

PHYSICAL CHARACTERIZATION OF WASTE AND COVER MATERIALS

A key design component is the use of pit run waste material placed in small lifts by end dumping with a little to no subsequent movement of material by tracked dozers. Therefore, a field sampling program was completed in October, 1996 by BHP Iron Ore personnel. Large metal drums (≈ 200 litre volume) were used to collect potential cover materials and waste rock samples for grain size analysis at the Centre for Land Rehabilitation, University of Western Australia. The potential cover materials sampled were chosen so as to represent pit run oxidized waste. The grain size analysis for 27 bulk samples were completed in December, 1996.

Typical grain size distribution curves for the pit run potential cover material as well as the Mt. McRae Shale waste rock sampled from an existing waste rock dump are shown in Figure 1. The materials are generally coarse in texture and relatively well graded, and while being physically similar are clearly geochemically dissimilar.

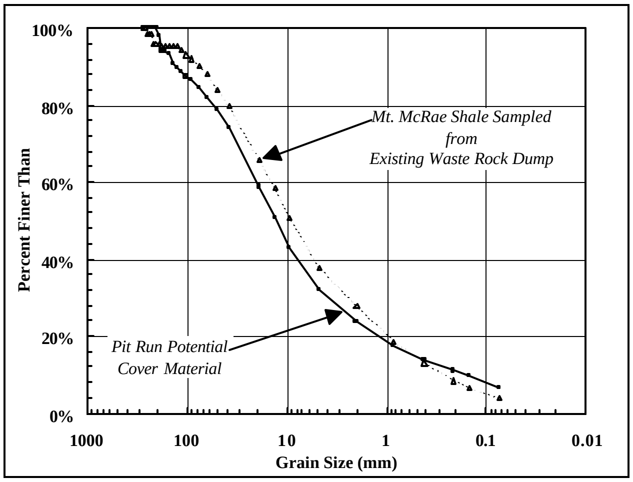

Figure 1. Typical Grain Size Distributions for the Mt. Whaleback Pit Run Potential Cover Material and the Mt. McRae Shale Waste Rock (from Jasper, 1996).

A total of thirteen 20 litre plastic containers were received from the Centre for Land Rehabilitation, University of Western Australia by O’Kane Consultants Inc. in Saskatoon for detailed laboratory characterization. The 13 plastic containers had potential cover materials and waste rock samples representative of the material originally sampled.

A key component of the laboratory program is the measurement of the soil water characteristic curve (SWCC). The SWCC is a continuous function relating energy and the state of water, and hence describes the water content of a soil as a function of soil suction, or negative pore-water pressure. The SWCC is central to the design of an unsaturated soil system and the most fundamental characterization required for design. The SWCC test apparatus employs the axis translation technique to apply matric suction to samples across a saturated high air entry ceramic disk. The SWCC test apparatus is constructed from stainless steel, is approximately 30cm in diameter and 60cm in height, and capable of measuring the SWCC of material passing 75mm.

The SWCC test samples were prepared in the test apparatus to represent *insitu* moisture and density conditions that were measured prior to and during construction of the 1-D test plots. The samples were then saturated under atmospheric conditions by attaching a water column head to the apparatus and allowing water to enter the sample from the base of the sample through the saturated ceramic disk. The matric suction applied to each sample was increased incrementally from 0kPa to 100kPa using the Buchner-Haines Funnel method (i.e. a “hanging” water column) as well as the axis translation technique. The test was halted while small samples were obtained from the SWCC apparatus for subsequent vapour equilibrium testing using saturated salt solutions at suctions ranging from approximately 4000kPa to 300,000kPa. The SWCC test was re-started as matric suction was subsequently decreased (in order to measure hysteresis of the SWCC and determine a representative porosity) using the same increments while allowing the sample access to a water supply at atmospheric pressure.

The wetting (i.e. decrease in matric suction) component of the SWCC test is in progress, however the drying portion (i.e. increasing matric suction) of the SWCC curve was estimated based on the available laboratory data and is shown in Figure 2. The pit run potential cover material had a distinctive low air entry value with gradual decrease in the slope of the SWCC near the residual suction, as shown in Figure 2.

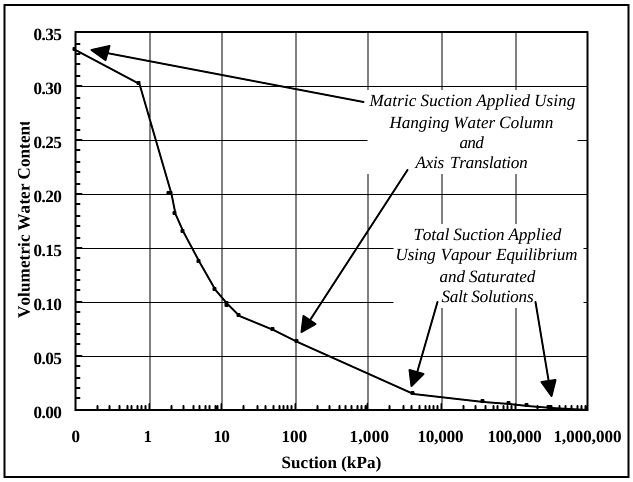

Figure 2. Drying Portion of the Soil Water Characteristic Curve for the Mt. Whaleback Pit Run Potential Cover Material.

The saturated hydraulic conductivity of all materials was measured using the SWCC apparatus by replacing the SWCC test lid with a falling head apparatus lid and conducting a falling head test prior to and subsequent to the SWCC test. A best fit curve to the drying portion of the SWCC shown in Figure 2 was developed using methods suggested by Fredlund and Xing (1994) in order to develop a hydraulic conductivity function based on the SWCC and the saturated hydraulic conductivity. The hydraulic conductivity function representative of the pit run potential cover material is presented in Figure 3.

DESIGN, CONSTRUCTION, AND MONITORING OF THE TEST PLOTS FOR A HORIZONTAL SURFACE AT THE TOP OF THE WASTE ROCK DUMP

Two alternate field test plots were constructed in February, 1997 on the top of an existing waste rock dump in order to verify the design suggested by preliminary soil-atmosphere modelling results. A monitoring program was designed and instruments were installed in each test plot in August, 1997.

One-Dimensional Soil-Atmosphere Modelling

The objective of the final cover system for the waste rock dumps will be to achieve a zero net infiltrative flux. The test plot cover systems were designed to accept as much surface infiltration as possible. The soil profile of the cover material was designed to store or “harvest” rainfall to aid in sustaining plant growth during dry climate periods. The water in the soil profile would subsequently evapotranspirate before reaching the base of the cover layer and result in a net zero infiltrative flux.

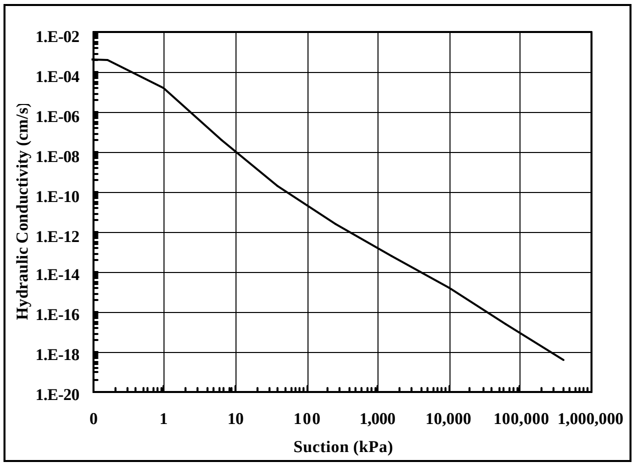

Figure 3. Hydraulic Conductivity Function of the Mt. Whaleback Pit Run Potential Cover Material Based on Methods Suggested by Fredlund *et al.* (1994).

The Soil-Atmosphere Model: A soil-atmosphere modelling program was completed using the finite element 1-D model SoilCover (MEND, 1996). 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.

Climate Input: The SoilCover model requires input of daily rainfall, net radiation, air temperature, relative humidity, and wind speed. The thirty year historical rainfall data base for Newman, WA was evaluated to determine the maximum rainfall for a 365 day period from October 1 to September 30. The period from October 1 to September 30 was chosen since the lowest monthly rainfall was recorded during the months of September and October during the period of record. This historically dry climate period was chosen since it allowed for the use of an initially dry soil profile for the model.

The maximum total rainfall for the one year period was approximately 500mm and occurred from October 1, 1994 to September 30, 1995. Daily air temperature, relative humidity, and wind speed recorded at the Newman meteorological station for the same period was used for the soil-atmosphere modelling. The Newman, WA climate data was supplemented with daily global radiation for the same period as well as sunshine data recorded at Meekathara, WA from 1971 to 1987. The sunshine data was averaged for each day of the year. The average daily data was used to calculate the net radiation for each day of the period modelled using the equations suggested by Maidment (1993). Meekathara is located approximately 400 km south-southwest of Newman and is similar in terms of climate. The potential evaporation as predicted by the Penman (1948) method was approximately 3300mm.

Material Properties: The field and laboratory characterization information described were used as material properties for the soil-atmosphere modelling.

Soil-Atmosphere Modelling Results: The physical model consisted of 2m of cover material over 3m of waste rock and assumed a poorly vegetated cover system, as opposed to good or excellent. A 2m cover thickness was modelled since it was estimated that the thickness of a single lift of material placed by haul trucks on a level surface was approximately 2 meters. The soil-atmosphere numerical modelling predicted the net flux of water entering the waste rock from the base of the 2m cover layer was less than 1% of the 30 year maximum annual rainfall record (≈ 500mm).

SoilCover predicted a cumulative net upward flux (primarily liquid water flow) of moisture would occur over the period modelled that was less than 0.1% of the applied rainfall. The predicted cumulative net surface fluxes for the model are shown in Figure 4. A cumulative net upward flux of approximately 10mm was predicted at the surface of the soil cover system. The cumulative local runoff was approximately 60% of the total rainfall and occurred primarily during significant rainfall events. However, the model also predicted that some runoff occurred during smaller rainfall events that took place immediately following the major rainstorms.

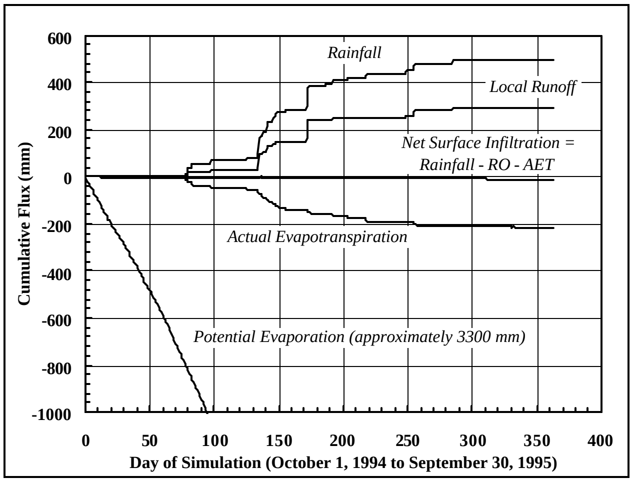

Figure 4. Cumulative Surface Fluxes for a 2m Soil Cover Model with Poor Vegetation.

The predicted cumulative actual evapotranspiration was approximately 215mm. Therefore the ratio of actual evapotranspiration to potential evaporation (AET/PE) was approximately 0.07 for the period modelled. The majority of evapotranspiration occurred during the middle 150 days (January, 1995 to May, 1995 inclusive) of the simulation. No appreciable evapotranspiration occurred during the first 100 and last 100 days of the period modelled. Rainfall that infiltrated during the period modelled was stored in the upper 25 to 50 cm of the soil profile, as shown in Figure 5, and subsequently evapotranspirated. SoilCover predicted that the rainfall events were buffered by the presence of the cover material and essentially no moisture infiltrated to the underlying waste rock.

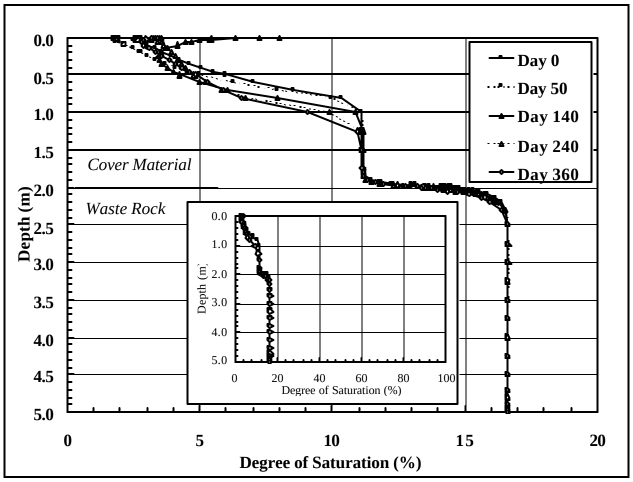

Figure 5. Degree of Saturation as a Function of Depth for the Modelled 2m Cover Layer Over Waste Rock with Poor Vegetation.

Construction of the Horizontal Surface Test Plots

Two 1ha field test plots were constructed in February, 1997 to verify the results predicted by the soil-atmosphere model. The test plots were constructed with common operational considerations. Test Plot No.1 had a cover thickness of 2m since this consisted of a single lift of material placed on the original waste rock surface by 240tonne capacity haul trucks. Two lifts of material were placed during construction of Test Plot No.2 to achieve a 4m cover layer thickness. The undulating surface created by the "paddock" dumping was not leveled off in order to maintain short surface runoff paths. A cover surface topography created by end dumping each haul truck load will inhibit severe surface erosion associated with accumulated surface runoff over the relatively short term life of the field test plots. The topography can also "store runoff" for subsequent evaporation, or for infiltration followed by evapotranspiration. The short runoff paths to the "troughs" will limit surface erosion. In addition, the stored runoff or "run-on" to these low areas will enhance vegetation establishment. The potential vegetation development at these low areas will lead to an improved cover design since potential transpiration from the soil profile will increase should the stored runoff infiltrate. This practical consideration for physical stability during the life of the test plots will achieve the objective of minimizing accumulated surface runoff which could lead to erosion.

Performance Monitoring - Horizontal Surface Test Plots

Field performance of the two test plots is monitored by a system designed to measure infiltration to the underlying waste rock, changes in moisture conditions within the cover layers, and climate conditions. Large scale lysimeters to measure infiltration into the underlying waste rock were installed in January, 1997 prior to construction of the test plots. The remaining components of the monitoring system were installed in August, 1997. All field monitoring instruments are controlled by remote data acquisition systems.

The field performance monitoring program was designed to measure the components of:

$$FWR = \Delta S + NSF, \text{ and} \qquad (1)$$

$$NSF = R - AET - RO \qquad (2)$$

where:

- FWR is the net flux into the underlying waste rock from the base of the cover material,
- ΔS is the change in storage within the cover layers,
- NSF is the net surface flux,
- R is the rainfall,
- AET is the actual evaporative flux, and
- RO is runoff.

Actual evaporation is measured using a fully automated Bowen Ratio System. A schematic representation of Equations 1 and 2 is shown in Figure 6. A fully automated meteorological station measures rainfall, net radiation, air temperature, relative humidity, wind speed, and wind direction.

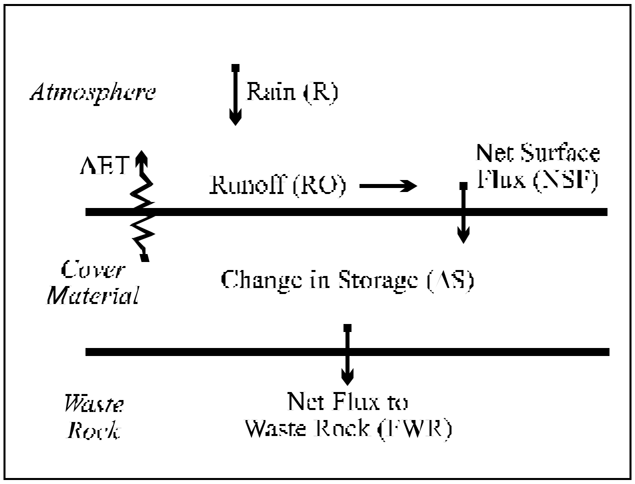

Figure 6. Schematic Representation of the Horizontal Surface Field Test Plot Monitoring Program.

Change in Storage: Changes in storage are measured using soil suction sensors and water content sensors installed laterally into the cover layers and underlying waste rock profiles of each test plot from instrumentation access boxes installed prior to construction of the test plots. Soil suction is measured using a thermal conductivity sensor that indirectly measures matric suction while also providing an *insitu* temperature measurement. A soil suction sensor can be thought of as the piezometer of the unsaturated zone. Hence, measurement of matric suction is a fundamental component of the monitoring program since matric suction describes the stress state of the cover system. In other words, a change in the degree of saturation or water content of the cover system is caused by a change in matric suction within the cover material. Therefore, field measurements of matric suction describe the performance of the cover system. Field matric suction values also provide a means of verifying field water content measurements. In addition, the hydraulic conductivity of the unsaturated cover material can be determined based on the response time of the matric suction sensor. Finally, the hydraulic gradient, or direction of moisture flow can be evaluated based on matric suction measurements. The hydraulic gradient cannot be determined from water content measurements, particularly in layered systems which describes most natural and engineered systems.

Net Flux into the Waste Rock: 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. In general, the design and installation of lysimeters to monitor evaporative fluxes as well as net infiltration is well understood and implemented in the soil science discipline. However, the design of field lysimeters for cover system monitoring programs have typically not included fundamental lysimeter design aspects established in the soil science discipline. Therefore, a two-dimensional (2-D) saturated-unsaturated modelling program was completed using SEEP/W (Geo-Slope International Ltd., 1995) to aid with the design of the field lysimeters for the Mt. Whaleback cover research program.

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 Mt. Whaleback 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 lysimeter 2.4m in diameter and 2.3m deep was modelled since it represented the dimensions of a commercially available high density polyethylene (HDPE) tank. The objective of the steady state model was to determine if the given lysimeter geometry was capable of measuring the flux from the base of the cover system.

Sand was included in the model since it will be easier to monitor 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 2-D modelling illustrated that in order to reduce the influence of the sand, the base of the lysimeter must be at least 2 to 2.5m from 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. Waste rock from the excavation in which the lysimeter was placed was backfilled into the lysimeter above the sand in order to simulate *insitu* conditions below the cover layer.

In excess of 150 steady state simulations were completed while varying the flux applied at the surface from 1 x 10^{-5} m/s (k_{sat} of the cover material) to 1 x 10^{-10} (1% of maximum annual rainfall), the lower boundary condition of the model, and the type and depth of sand placed in the lysimeter.

The flow vectors predicted by the model were vertical, as shown in Figure 7, indicating that flow was not drawn into the lysimeter, did not diverge around the lysimeter, or was not drawn out of the lysimeter. The flow was uniform and vertical since the predicted pressure head profile within the lysimeter geometry was the same as that outside the confines of the lysimeter. Therefore, the presence of the sand and collected water at the base of the lysimeter did not influence the flux of water into the lysimeter. The applied flux, q, for the model shown in Figure 7 was 1 x 10^{-9} m/s. The width of the entire model was 15m. Therefore, the flow, Q, across the entire width of the model was 15m multiplied by 1 x 10^{-9} m/s, or 1.5 x 10^{-8} m^2/s, as shown in Figure 7. The lysimeter should measure the equivalent flow applied across the width of the model, if the lysimeter is designed properly. The width of the lysimeter (2.4m) multiplied by the applied surface flux (1 x 10^{-9} m/s) is equal to 2.4 x 10^{-9} m^2/s. Figure 7 shows that SEEP/W predicted that the correct flux reported to the base of the lysimeter.

The 2-D steady state modelling demonstrated a 2.4m diameter by 2.3m deep lysimeter would measure the actual flux from the base of the cover system to the underlying waste rock. The proper design and installation of the field lysimeters was a key component of the field monitoring program. The measured net flux from the base of the cover system as a percentage of rainfall is a value that is simple to understand and provides the foremost measure of the performance of a cover system designed to store and release moisture for the long term. Measurement of moisture and temperature conditions in the cover material and waste rock will serve as a tool to verify the performance of the field lysimeters.

Two field lysimeters were installed under each field test plot prior to placement of cover material. Two PVC pipes and a third aluminum pipe was installed within each field lysimeter, as shown schematically in Figure 8. The central PVC pipe was installed to the base of the lysimeter into the sand in order to manually measure, from the surface, the water head within the lysimeter and ultimately determine the flux of water into the lysimeter. Water content sensors connected to a datalogger system were installed inside the second PVC pipe to monitor qualitative changes in moisture conditions within and above each field lysimeter. The third access pipe was an aluminum pipe installed to qualitatively measure moisture conditions using a neutron moisture probe, should the need arise. The qualitative water content measurements will provide a means of verifying the measured flux as well as evaluate changes in storage as a result of infiltration and exfiltration within the lysimeter.

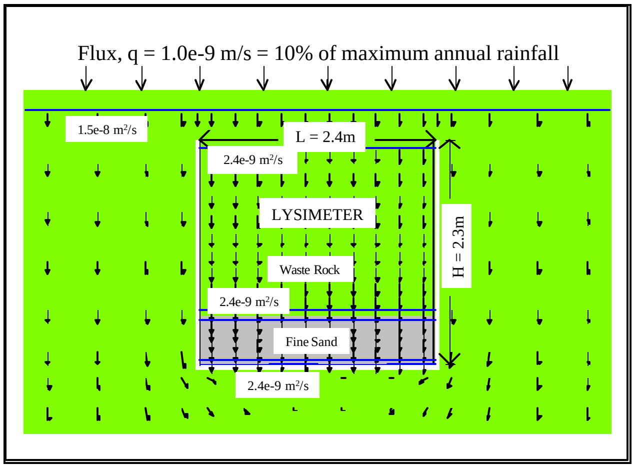

Figure 7. 2-D Steady State Modelling Results Illustrating that the Field lysimeter is Measuring the Proper Flux from the Base of the Cover System into the Waste Rock.

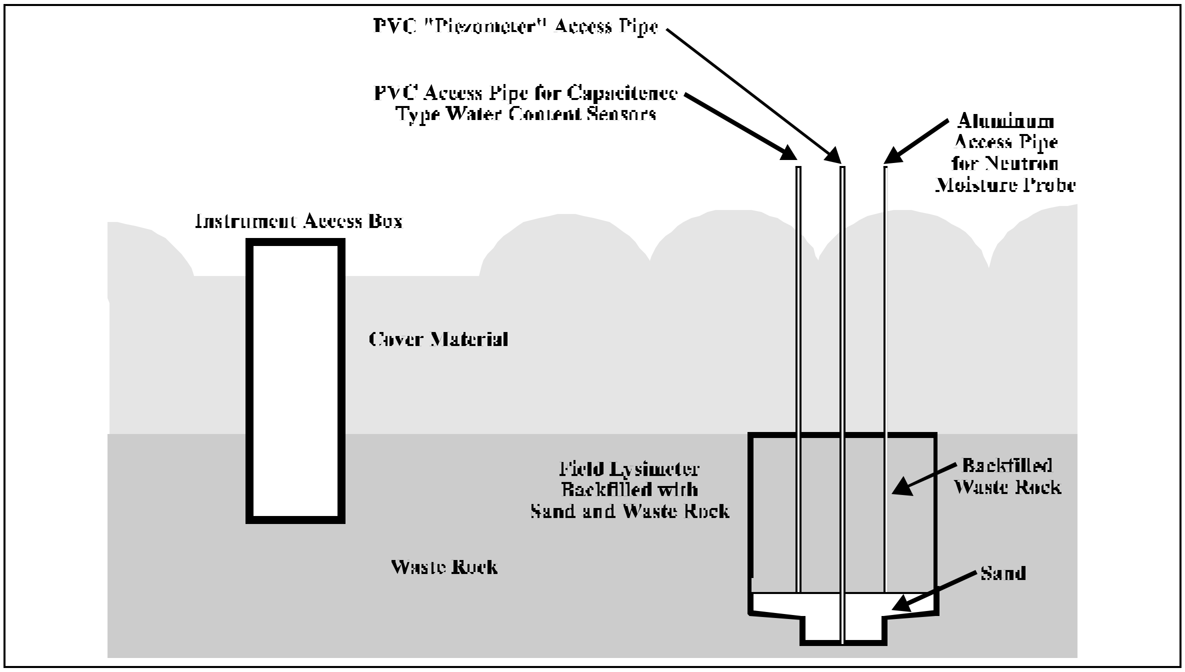

Figure 8. Schematic Diagram Illustrating the Field Lysimeter and Instrument Access Box Installed into the Underlying Waste Rock and Overlying Cover Material.

DESIGN, CONSTRUCTION, AND MONITORING OF THE SLOPED WASTE ROCK SURFACE TEST PLOT

Field performance monitoring of the test plots constructed in February, 1997 will provide a quantitative measure of the performance of the moisture storage and release cover design on a horizontal surface. The investigation deals with vertical flow of heat and moisture in horizontal layers, using numerical models as well as field scale physical models. The study will establish a good understanding of cover system behaviour. The effect on cover performance as a result of evapotranspiration, infiltration, cover and waste material properties, and layer thickness will be understood for vertical, or one-dimensional, conditions.

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. 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 Mt. Whaleback site and a cover system placed on these slopes will clearly not be horizontal. Hence, the hydraulic performance of the cover system and its ability to function as a moisture store and release system to control water infiltration to the underlying waste rock will be much different than that predicted by idealized one-dimensional numerical models.

A study concurrent to the 1-D cover performance study is in progress to evaluate the performance of a moisture store and release cover system placed on a sloped waste rock surface. The study includes a total of four distinct segments, or phases, some of which are conducted concurrently. The investigation includes a literature review to document state of the art practice and review the level of current research for designing cover systems for sloped surfaces. The literature search would also include a search and evaluation for a suitable numerical model, or more likely numerical models, that will be used to evaluate the performance of the multi-axial cover system.

The second phase of the 2-D investigation consists of numerical modelling of a cover system constructed on a sloped waste rock surface. The objective of the 2-D cover system modelling would be the same as for a horizontal waste rock surface. That is, determine the thickness of cover material required to create a moisture store and release system such that a net zero flux of moisture enters the underlying waste rock. The modelling approach would likely involve coupling the results from soil-atmosphere modelling with that of two-dimensional saturated-unsaturated modelling to predict the performance of a cover system constructed on a sloped surface.

The third phase of the study is a field evaluation of the 2-D performance of a moisture store and release cover system placed on a sloped waste rock surface. Three primary instrument nests to monitor hydraulic head (i.e. suction), temperature, and water content within the unsaturated cover system and the waste rock just below the cover layers would be installed at the top, base, and at a mid-slope location down a cross section of the slope. Each primary instrument nest will consist of a profile of approximately 8 to 12 sensors installed in the waste rock and cover material. The results from the numerical modelling completed as part of the second phase will help determine the optimum location and spacing for the primary instrument nests. Secondary instrument nests will be installed laterally from each primary instrument nest to replicate the monitoring at each location down the slope. The secondary instrument nests would be placed approximately 30 to 50m from the primary instrument nests and include sensors to monitor suction and temperature. Variability of the cover material down the slope will occur as a result of segregation during placement of the material. The objective of the patterned instrument nests is to replicate monitoring laterally and longitudinally to the sloped surface. A tipping bucket rainfall gauge will be installed at the sloped test plot area. Surface runoff and erosion monitoring systems will be constructed. Results from the phase two modelling will also determine the viability of installing the large HDPE lysimeter tanks for measuring infiltration to the underlying waste rock. All field monitoring instruments will be connected to a fully automated data acquisition system.

The period of monitoring will ensure a complete understanding of the 2-D hydraulic performance of the cover system is established. The final phase of the study will include an evaluation of the field monitoring data as well as field response modelling of the collected field data. The phase 2 preliminary modelling methodology will be verified and modified as required such that a methodology based on measured performance can be established. The verified methodology can then be used as a predictive tool for future cover system designs. Key material properties and processes that influence performance will be established and documented as a result of the literature search, the preliminary numerical modelling, the field performance monitoring, and the field response modelling completed during the final phase.

The literature review and 2-D modelling was in progress during preparation of this paper and results will be presented in subsequent publications. Construction of the cover system on the sloped waste rock surface is scheduled for January, 1998.

OBSERVATIONS AND CONCLUSIONS

The research program may also include an evaluation of physical stability, vegetation development, and soil evolution during the test plot monitoring period. The data obtained from each test plot will permit the assessment of field performance with respect to net infiltration. Numerical modelling will be carried out to simulate observed performance and calibrate the model. The results of this exercise will permit accurate predictions regarding the long term performance of the field test plots under alternative atmospheric conditions which are associated with climate extremes. The objective of the research project is to design a cover system for the waste rock piles at Mt. Whaleback that will provide long term prevention of acid rock drainage.

Progress to date demonstrates that a moisture store and release cover system constructed with pit run waste material has good potential as a final ARD cover system at the Mt. Whaleback site. The cover system design takes advantage of the high evaporative conditions at the mine site. Construction of the final cover system design will need to be integrated into the mine plan to minimize closure costs. The optimum cover system should minimize the net infiltration of water to the underlying waste rock while maintaining physical and ecological integrity for long term performance.

The 1-D cover system test plots were constructed in February, 1997. Two significant rainfall events occurred during construction which afforded the opportunity to observe moisture conditions prior to and following each event. Approximately 100mm of rainfall occurred over a 3 day period which was followed 12 hours later by a second 100mm event over a 2 hour period. Infiltration as a result of the rainfall led to an increase in the moisture content of material from the surface to a depth of approximately 0.75m. A significant decrease in moisture content of this material was observed immediately following the rainfall events. The observed qualitative performance of the cover system during and subsequent to the rainfall events provided a measure of confidence to the preliminary soil-atmosphere modelling results. However, field performance monitoring over a number of complete wet-dry climate cycles is a key component to understanding the processes that describe performance as well as to confirming the effectiveness of this system. The measured performance will verify the preliminary soil-atmosphere modelling and provide a quantitative measure of the moisture store and release cover system at the Mt. Whaleback operation.

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