Measuring Net Percolation Rates for Waste Storage Facility Cover Systems

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ABSTRACT
The design of cover systems for the storage of mine waste are a key component of mine closure plans. The net percolation from the base of the cover system into the underlying waste material is a key measure of cover system performance. It can be estimated from: 1) direct measurements, 2) water balance and/or 3) simulations using soil-atmosphere numerical models calibrated to measured field performance. This paper discusses aspects of each of the aforementioned methods for evaluating cover system performance with respect to net percolation. Cover system field performance monitoring data is presented to illustrate the principles and methods described in the paper.

RÉSUMÉ
Les systèmes de couverture des installations de stockage des déchets provenant des mines sont généralement une composante clé des plans de fermeture de mines. La vitesse nette de percolation à partir de la base du système de couverture jusqu'aux déchets sous-jacents est une mesure importante de la performance d'un système de couverture. Qui peut être estimée par: 1) déterminations directes, 2) balance hydrique et/ou, 3) simulations utilisant des modèles numériques sol-atmosphère calibrés à la performance d'exploitation. Ce document discute des aspects de chacune des méthodes mentionnées plus haut pour évaluer les systèmes de couverture en ce qui a trait à la vitesse nette de percolation. Les données sur la performance d'exploitation du système de couverture sont présentées afin d'illustrer les principes et méthodes décrits dans le document.

1 INTRODUCTION

The primary purpose of soil cover systems is to minimize any deleterious impact of the mine waste on the receiving environment in the short term and to facilitate recovery of the environment disturbed by mining over the long term. The impact of a waste storage facility on the receiving environment will depend on the nature of the site, climate, characteristics of the waste, local hydrogeology, and the ability of the cover system design to limit the release of contaminants of concern from the underlying waste. As a result, one of the primary design objectives of a cover system for waste storage facilities is to limit the percolation of water into the underlying waste. This is generally achieved through the use of a low permeability layer and/or a moisture store-and-release layer (MEND 2004).

There are a variety of ways of estimating net percolation (NP) depending on the range of data that is available for the site. NP can be measured directly through the use of lysimeters, estimated utilizing measured components of the water balance and *in situ* hydraulic gradients, and can be simulated using soil-atmosphere numerical models that have been calibrated to measured performance monitoring data.

This paper discusses aspects of the various methods of estimating NP. The discussion illustrates how a full understanding of NP rates and cover performance is developed utilizing a methodology that incorporates multiple approaches. Cover system field performance monitoring data from existing sites is presented to illustrate the principles and methods described in the paper. This paper also presents the fundamental design variables that should be considered and a methodology for lysimeter design.

2 DIRECT MEASUREMENTS OF NP

The use of collection lysimeters is often considered to be the most straightforward approach for estimating NP values across a site. Different types of lysimeters have been used to collect and measure NP across the cover / waste material interface. In general, lysimeters range in size from small-scale barrels and shallow pans to large-scale tanks and monolithic structures constructed of liner material. The volume of collected NP is measured through a variety of methods that may include collection ports from which collected water can be pumped out at specified intervals, a piezometer to measure levels within the lysimeter collection vessel, and automatic drainage collection systems to record net flow out of the lysimeter.

Monitoring of NP with lysimeters is advantageous in that it provides an immediate measurement of the volume of NP at each location. In addition, stakeholders place significant emphasis on performance derived through these direct measurements because water is physically being collected and the systems are conceptually simple to understand, which adds to the importance of obtaining representative NP values.

It should be noted, however, that a lysimeter requires proper design, installation, and operation, with the latter two being potentially problematic, due to the physics of water flow through unsaturated soil systems. The design of lysimeters for cover system monitoring programs have typically not considered fundamental aspects of unsaturated flow. A fundamental design feature of a lysimeter installed to measure NP for unsaturated conditions is that the presence of the lysimeter must not influence the NP being measured.

The key parameters for the design of a lysimeter are the depth of the lysimeter base below the cover / waste material interface and the lysimeter wall height. Bews *et al.*, (1997) reported that the wall height should be sufficient to create the same suction levels at the top of the lysimeter as those that exist within the waste outside of the lysimeter in order to prevent wicking of water out of the lysimeter.

In addition to these design criteria, the selected lysimeter must accommodate any spatial variability in the cover system which might lead to spatially variable NP. Meiers *et al* (2009) found that NP volumes measured in a 2.5 m diameter lysimeter were not representative of overall cover performance due to site-specific localized runoff and focused recharge. Hence, not only should simulation models be used for evaluating the appropriate geometry of the lysimeter under one-dimensional (1D) conditions but one may want to consider any topographic or material variability that might produce spatial variability in NP. In addition, sufficient numbers of lysimeters should be used to identify the range of NP when spatial variability in NP is anticipated. This allows the performance measured with any one lysimeter to be evaluated relative to other lysimeters positioned within different materials or topographic locations across the cover system, should differences exist.

Selection of an appropriate lysimeter to monitor NP should be based on design criteria developed through numerical model simulations and anticipated and/or observed water dynamics of the as-built or proposed cover system.

2.1 Lysimeter Design

Proper functioning of the lysimeter requires that flow conditions inside and outside the lysimeter collection area are identical even though a phreatic surface is located at the base of the lysimeter. This requires that the wall height is sufficient to allow the same suction conditions to develop at the top of the lysimeter as those that would occur in the surrounding waste material (Bews *et al.* 1997, O'Kane and Barbour 2003).

The initial lysimeter design would consist of estimating the required depth of the lysimeter using simulation models of unsaturated flow through the cover / waste rock system under a range of anticipated NP rates.

2.1.1 Estimation of Lysimeter Depth

The following methodology is provided for estimating the depth of the lysimeter required for accurately measuring NP under steady state flux conditions.

Figure 1 shows the pressure head profile within a waste storage facility and two lysimeters under a steady state NP rate. If the NP rate across the cover / waste material interface is some value less than the saturated hydraulic conductivity of the waste material, then a break from hydrostatic pressure will occur at some elevation above the water table, or phreatic surface, and the vertical hydraulic gradient will become equal to one (Barbour 1990).

In scenario (i) of Figure 1, the break from hydrostatic pressure does not occur within the lysimeter, which results in a different pressure head condition inside the lysimeter (P_{in}) as compared to outside the lysimeter (P_{out}). The consequence of this condition is that flow will be diverted around the lysimeter, and the lysimeter will not measure the 'true' NP. Within the 'deep lysimeter' (scenario (ii) of Figure 1), the break from hydrostatic pressure occurs within the confines of the lysimeter. In this scenario the pressure head at the top of the lysimeter within the confines of the lysimeter is equal to that outside the confines of the lysimeter, and the lysimeter depth is sufficiently deep so the phreatic surface at the base of the lysimeter does not influence the measured NP.

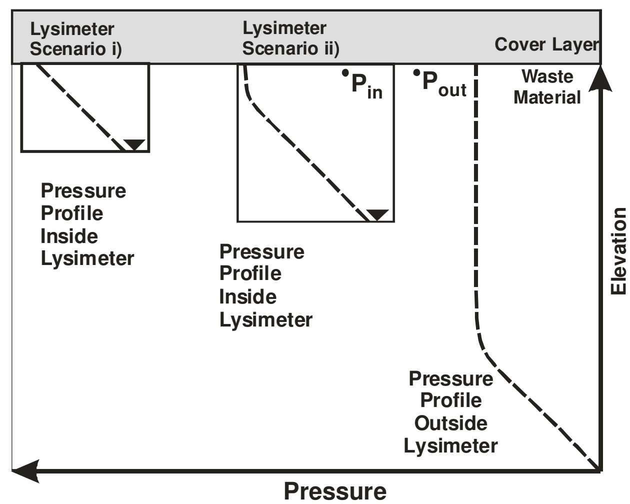

Figure 1. Pressure head profile for two lysimeter depths compared to the *in situ* material (after O'Kane and Barbour 2003)

The elevation at which the break from hydrostatic pressure occurs and the hydraulic gradient becomes equal to one, is a function of the applied percolation rate and the hydraulic conductivity function of the waste material. Figure 2 shows the hydraulic conductivity function for a waste material and two percolation rates (q_{low} of 1 x 10^{-7} and q_{high} of 1 x 10^{-5} cm/s), which are assumed to represent the range in anticipated NP rates based on numerical simulations of cover system performance under site-specific climatic conditions.

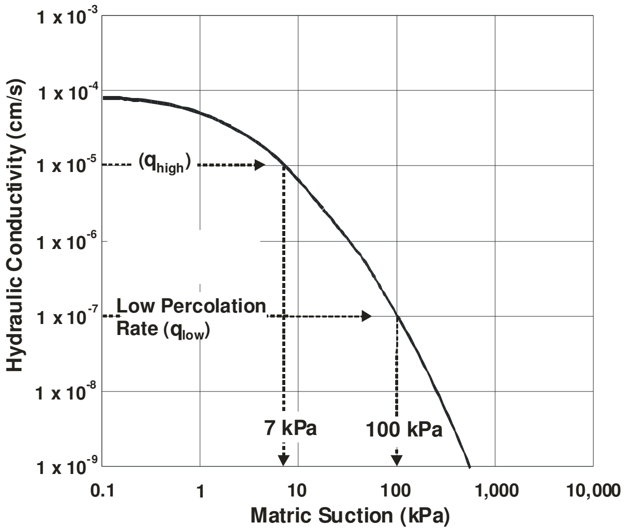

Figure 2. Hydraulic conductivity function of waste material underlying the cover system.

The break from the hydrostatic pressure will occur when the percolation rate is equal to the hydraulic conductivity. At the q_{high} flux condition shown in Figure 2, the break from hydrostatic pressure would occur at 0.7 m (i.e. 7 kPa) above the base of the lysimeter, while at the q_{low} flow rate the break from hydrostatic pressure would occur at 10 m. Hence a lysimeter with walls extending >0.7 m would be sufficient to accurately monitor the q_{high} percolation rate, and incrementally higher walls would be required to accurately measure increasingly lower percolation rates.

A simple analyses such as this may demonstrate that a standard tank lysimeter may not be practical because it is either not technically feasible nor safe to construct and install a lysimeter with the required dimensions. However, in most cases, the analysis will estimate the range of NP rates which can be reliably collected for any specific design. In the case illustrated by Figure 2, a lysimeter base located 3 m below the cover / waste material interface should accurately measure percolation rates greater than approximately 1 x 10^{-6} cm/s. However, the actual 'performance' of the lysimeter cannot be ascertained because the duration and frequency of the appropriate flux conditions cannot be simulated through this type of analysis. Transient numerical simulations are required in order to develop an understanding of lysimeter 'performance' under a wide range of percolation rates reflective of field conditions.

2.1.2 Numerical Simulations of Lysimeter Performance

O'Kane and Barbour (2003) evaluated the performance and functionality of different types of lysimeters and the role of associated monitoring systems through simulation models. The concept of the lysimeter collection ratio (LCR) was introduced, defined as the ratio of the NP that would be measured by a lysimeter, as predicted through numerical simulations, to the NP predicted outside the confines of the lysimeter.

Figure 3 shows the LCR developed for a 45 gallon short barrel lysimeter, measuring 1 m in height, utilizing a specific climatic database and material properties. Simulations were completed assuming that NP was collected and removed from the lysimeter on a continuous and monthly basis.

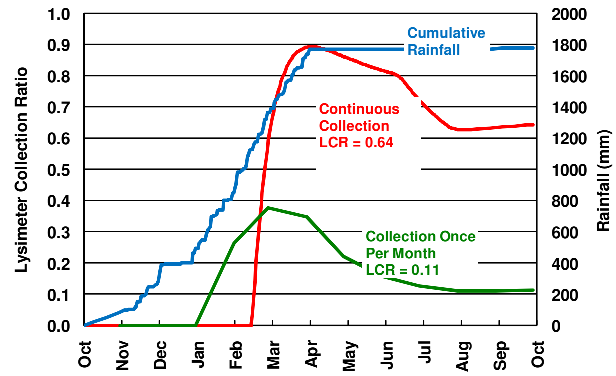

Figure 3. Lysimeter performance illustrated through the collection ratio for short barrel lysimeter simulated with continuous and monthly collection and monitoring (after O'Kane and Barbour 2003).

The NP measured using continuous collection was approximately 58 mm over a twelve month simulation period, while approximately 91 mm of NP was predicted for the cover as a whole. The LCR of the short barrel lysimeter for the continuous simulation was approximately 0.64 (i.e. the ratio of 58 mm to 91 mm). An LCR of 0.64 indicates that the lysimeter does not accurately measure the NP through the cover system since the base of the lysimeter was not sufficiently deep to allow for the break from hydrostatic pressure to occur within the confines of the lysimeter over a range of flux conditions. Figure 3 shows that the LCR fluctuates between 0 and 0.89 over the monitoring period, in response to the range in flux conditions from the base of the cover system.

The LCR was even lower for the lysimeter which is pumped out once per month. This is due to rise in the phreatic surface within the lysimeter between collection dates which effectively reduces the effective lysimeter wall height. The lysimeter is too shallow and water collected at the base of the lysimeter is free to wick up and over the lysimeter walls in between sampling intervals.

2.1.3 Lysimeter Field Performance Monitoring

Waste material, will exhibit heterogeneity due to differences in material texture and *in situ* density conditions. Simulations of lysimeter performance should be conducted on a range of material properties to simulate the range of expected *in situ* conditions. Figure 4 shows the change in the hydraulic conductivity function for a backfill waste material for a range of texture and density conditions. The illustration demonstrates how differences in material texture and or *in situ* density can influence lysimeter design. It is important that the backfill material is placed in a manner such that the stratigraphy and density conditions inside and outside the lysimeter are the same.

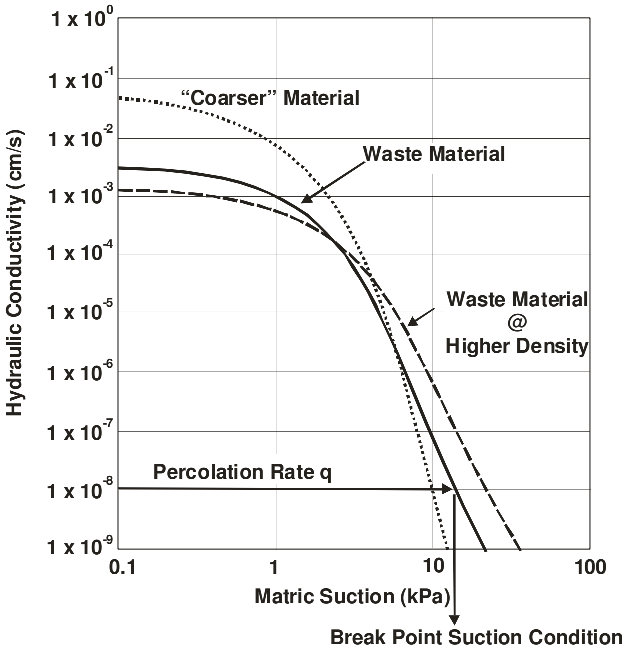

Figure 4. Hydraulic conductivity functions illustrating the influence of material texture and *in situ* density on the break from hydrostatic pressure.

Numerical simulations can be used as a tool to compare the performance of different lysimeter designs, given the variability in material properties and *in situ* conditions that may be encountered. However, the simulated performance of the various simulated cases should be considered as relative until validated through field performance monitoring. This monitoring can consist of monitoring water content and suction conditions inside and outside the confines of the lysimeter. Should the field data indicate that the pressure conditions below the cover system inside and outside the confined of the lysimeter are not similar, numerical simulations calibrated to measured *in situ* conditions should be used to estimate the actual NP.

2.2 Alternate Lysimeter Installation

If the initial assessment suggests that the required lysimeter geometry might be impractical to construct then alternative lysimeter installation techniques may be required. If it is not technically feasible to install the required lysimeter within the waste material the top edge of the lysimeter should be raised to the cover system surface, creating a lysimeter isolated from the surrounding cover system. The lysimeter would encapsulate the full thickness of the cover system and one to two metres of the underlying waste material. However, a lysimeter that extends to the cover system surface will not measure the actual NP rate because the phreatic surface at the base of the lysimeter will influence the NP measured.

To address this issue, suction and water content conditions inside and outside the lysimeter must be measured and used along with numerical simulations to correct the measured NP rates. The simulations are calibrated to the NP measured by the lysimeter and the moisture conditions measured within the lysimeter during the field performance monitoring program. After calibration of the numerical model to field conditions (i.e. field based hydraulic properties are developed), the actual lower boundary condition, as measured with instrumentation outside the lysimeter (installed at the same depth as the base of the lysimeter), is substituted into the model to determine the "true" NP from the cover system to the underlying tailings material.

3 ANALYTICAL METHOD

A simple water balance can be completed for a cover system using the performance monitoring data collected at the site. The water balance for a sloping cover system consists of the following components:

$$PPT = R + AET + NP + \Delta S + LP \qquad [1]$$

where: PPT is precipitation, R is surface runoff, ΔS is the change in water storage within the cover material, AET is the actual evapotranspiration, and LP is lateral percolation or interflow. NP is then estimated as the residual based on measurements or estimates of the other components of the water balance.

Since the value of NP is often a small component of the water balance it is essential that as many components of the water balance are measured as possible. Measurements of AET are relatively expensive and the monitoring system requires frequent servicing in order to obtain representative data. As a result AET is usually back calculated from the water balance equation with the remaining parameters measured. However, in this case either measurements or analytical estimates of AET and subsequently NP have to be developed based on components of the water balance and hydraulic gradients.

Soil suction sensors can be thought of as a piezometer of the vadose zone. Hence, the hydraulic gradient, or direction of water movement, can be evaluated based on matric suction measurements obtained with a nest of sensors throughout the thickness of the cover profile and into the underlying waste material.

Changes in storage that occur in the absence of PPT, R, and LP can be considered to occur as a result of NP and/or AET. At any specific time the cover profile can be subdivided into relative layers of upward and downward flow conditions. The decrease in water storage that occurs within the layer of upward water movement can be thought of as AET. These estimates of AET are then used to develop different ratios of AET to PE over a range of negative pore-water pressures measured at the cover surface. Immediately following rainfall when surface conditions are wet the AET/PE ratio would be at its highest level and continuously decrease as the surface dries.

NP from the base of the cover system only occurs when the hydraulic gradient across the cover / waste material interface is downward. During periods of downward flow NP can be estimated in a similar manner, or through the application of Darcy's Law:

$$q = -ki \qquad [2]$$

where: q is the NP, k is the unsaturated hydraulic conductivity based on the hydraulic conductivity function, and i is the hydraulic gradient.

It is important to note; however, that Darcy's law should not be used on its own to estimate NP. The hydraulic conductivity function is extremely non-linear so that even small incremental changes in matric suction can lead to large changes in hydraulic conductivity and this uncertainty is further extended by the limited accuracy of matric suction sensors at the high and low end of the suction range. In order to assess the validity of the applied AET/PE ratio and the estimated values of NP the water balance equation can be reorganized ($\Delta S = R - SR - NP - AET - LP$) and the changes in water storage calculated from the estimated NP and AET can be compared to actual changes in storage.

4 NUMERICAL MODEL SIMULATIONS

Field monitoring of the performance of cover systems provides a direct method of verifying the cover design and also provides a data set for calibration of simulation models (MEND 2004).

The minimum level of field monitoring required for calibration of the numerical model includes meteorological monitoring of precipitation along with sufficient monitoring to estimate potential evaporation (i.e. net radiation, air temperature, relative humidity, and wind speed), changes in water storage, and surface runoff. It is important to monitor over multiple years in order to observe cover performance for a range of climatic conditions.

In general, numerical models used in cover design are one 1D or 2D finite element or finite difference models that predict pressure head (suction) and temperature profiles in the cover profile in response to climatic forcing (such as evaporation). A key feature of these models is the ability to predict AET based on potential evaporation (PE), vegetation parameters and soil suction.

Parameters required by the model include climate data to characterize the soil-atmosphere boundary condition, material properties (particularly the functional relationships between volumetric water content and hydraulic conductivity as a function of suction), and vegetation characteristics (rooting depth/distribution and leaf area).

5 CASE HISTORY

Two case histories are provided to illustrate the various methods of determining NP. In the first case history a lysimeter was used to provide a direct measurement of NP. In the second case history numerical and analytical models are used. The NP was simulated using a numerical model that was calibrated to performance monitoring data. A simpler analytical model was developed and compared to the more rigorous numerical model. It was hoped that the simpler analytical model could then be used to estimate NP during ongoing monitoring.

5.1 First Case History – Direct Measurements

Field trials of potential cover system designs for a waste rock dump storage facility located in Western Australia were evaluated. Based on available climate data mean rainfall and PE was determined to be 724 and 1,950 mm, respectively.

The alternate cover designs were developed using the 1D numerical model, SoilCover (GeoAnalysis 2000 Ltd. 2000). The model was based on laboratory characterization of available cover materials. Two water balance covers were constructed on a horizontal surface of the waste rock storage facility in 2005 in order to verify cover performance and calibrate simulation models.

2D numerical modelling was used to evaluate the technical feasibility of utilizing large-scale lysimeter tanks to measure NP. This modelling was done using the soil-atmosphere model, VADOSE/W (Krahn, 2004). These simulations indicated that a lysimeter tank measuring 2.5 m in diameter and 2.5 m in height, with a continuous collection and monitoring system, placed below a nominally 2.0 m thick coarse-textured 'water balance' cover system could be expected to operate properly and provide an accurate measurement of NP. The analysis showed that there should be similar pressure profiles and NP rates inside and outside the lysimeter tank.

5.1.1 Direct Measurements of Net Percolation

A lysimeter with the aforementioned specifications was constructed and installed within the prepared waste rock surface. An underdrain system was installed to transfer NP via gravity to an automated monitoring system. Following the lysimeter installation a nominally 2.0 m thick water balance cover system constructed of coarse-textured material was placed over the waste rock surface. Suction and temperature profiles inside and outside the lysimeter were monitored using CSI model 229-L thermal conductivity sensors (indirect measurement of matric suction).

Figure 5 shows that the matric suction measured at the base of a cover system inside the lysimeter tank was similar to that measured outside. This indicates that the NP measured during the monitoring period should also be similar inside and outside of the lysimeter. There was approximately 765 mm of rainfall in 2006, with 628 mm occurring during the first three months. The lysimeter began to collect NP at its base on April 2, 2006 and collected 139 mm of NP over the monitoring period, equivalent to 18% of the annual rainfall.

The high variability in annual rainfall at the site along with the development of vegetation led to the expectation that NP rates would be lower during subsequent monitoring periods. However, with lower NP rates the break from hydrostatic pressure within the lysimeter would occur at higher elevations and continued monitoring would be required to ensure the lysimeter continues to accurately monitoring NP from the base of the cover system.

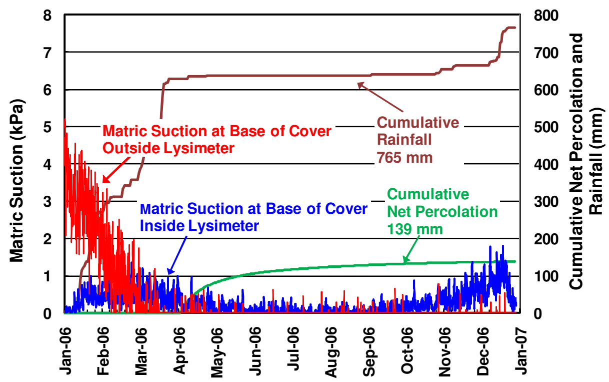

Figure 5. Matric suction measured at the base of the cover system inside and outside the confines of the lysimeter and cumulative rainfall and NP.

5.2 Second Case History – Numerical Simulation and Analytical Method

The performance of water balance cover systems were evaluated for waste rock storage facilities in a semi-arid location of Western Australia. Two cover system field trials were constructed in 2003 to evaluate the hydraulic performance of the alternate cover system designs. The design of the cover system field trials was based on a laboratory characterization of material properties and numerical simulations.

The climate in the area is strongly seasonal and highly variable, ranging from heavy rainfall to drought conditions. Mean annual rainfall is approximately 360 mm and 80% of this occurs from December to April. The mean annual PE for the site is 2,412 mm.

The cover profile in Test Plot #1 (TP1) is a nominally 4 m thick coarse-textured material placed on the waste rock surface. In Test Plot #2 (TP2) the cover is nominally 2 m thick and consists of a finer textured material. TP1 consists of approximately 55% gravel, 30% sand, and 15% silt with limited clay sized particles. The particle size distribution of TP2 contained an additional 5% of silt sized particles with an equal reduction in the gravel and sand component.

Instrumentation was installed in each test plot at the cover trial area to monitor moisture conditions within the cover material and the underlying waste. 229-L thermal conductivity sensors were installed to measure matric suction and temperature. EnviroSCAN® water content sensors were utilized to monitor the volumetric water content. An automated weather station located at the mine site measures temperature, relative humidity, wind speed, solar radiation, and rainfall. In addition, a net radiometer and tipping bucket rain gauge were installed at the field trial area.

5.2.1 Developing the Simulation Model

The material properties used to represent the waste rock and cover material are critical elements for the calibration of the simulation model. The material properties required for each layer in VADOSE/W are as follows:

- moisture retention curve, MRC (volumetric water content as a function of suction);
- hydraulic conductivity function (hydraulic conductivity as a function of suction);
- thermal conductivity function (volumetric water content versus thermal conductivity); and
- volumetric specific heat function (volumetric water content versus volumetric specific heat).

The moisture retention characteristics of the cover materials were estimated by creating a field moisture retention curve (MRC) from the monitored matric suction and water content measurements. Figure 6 shows the field MRC for the TP2 cover material and the MRC function used in the VADOSE/W simulation model.

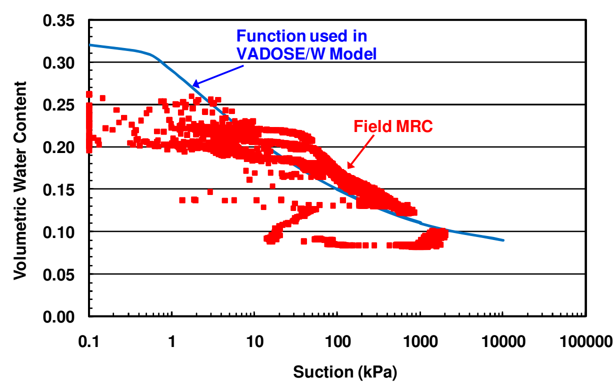

Figure 6. Comparison of the field-measured MRC data at TP2 and the MRC used in VADOSE/W.

The VADOSE/W function is similar to the cross plotted field data but does not exactly follow the shape of the field data. The field data appeared to have a lower porosity and higher air entry value (AEV) than the model simulation function. The porosity used in the simulation function was based on laboratory measurements of the cover material. The AEV which is in the range of 10 – 20 kPa, is higher than expected for the TP2 cover material as it does not have a high percentage of fines. The AEV of the ceramic tips for the thermal conductivity sensors is in the range of 5 – 15 kPa. Therefore, the sensors provide poor resolution at matric suctions below 15 kPa. Given that the AEV of the TP2 cover material is likely in the order of 1 – 2 kPa, and the MRC function was adjusted accordingly.

The hydraulic conductivity function was developed from field measurements of saturated hydraulic conductivity and the estimation method of van Genucten (1980).

The thermal conductivity and volumetric specific heat functions were estimated using modules within the VADOSE/W program. For both relationships, coefficients for a well-graded granular soil taken from the VADOSE/W library were input to the estimation equation.

5.2.2 Simulation of Field Performance

Simulated water contents and suctions were compared to conditions at each measurement depth throughout the cover and waste rock profile. Figure 7 compares the simulated and measured matric suction at depths of 190 and 220 cm. These depths are a key consideration in the simulation because these sensors are located on either side of the cover / waste rock interface. The simulated and measured values are in good agreement indicating that the simulation provides a good estimation of the moisture conditions and water movement across the cover / waste material interface.

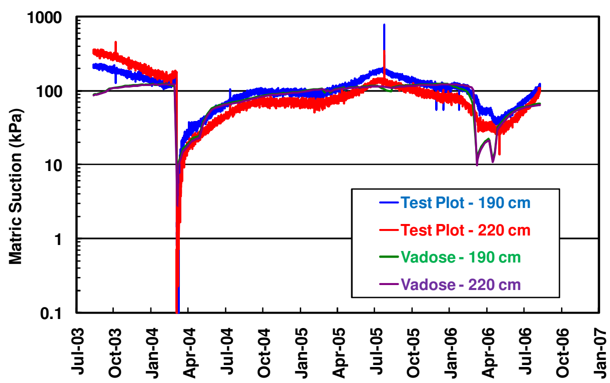

Figure 7. Comparison of the simulated and measured matric suction at depths of 190 cm and 220 cm for TP2.

Figure 8 summarizes the cumulative rainfall and simulated NP over a number of years. During the August 2003 to August 2004 monitoring period the total rainfall and NP were 522 and 161 mm, respectively. The NP as a percentage of rainfall for this period is 31%. The NP for the August 2004 to August 2005 period was 24 mm, which was 11% of the total rainfall during the period. The final year of the monitoring period included both high rainfall (790 mm) and NP (195 mm). The NP as a percentage of rainfall was 25%. For the entire three-year monitoring period the total NP was 380 mm, or 25% of the total rainfall recorded. In comparison 455 mm of NP was simulated for TP1.

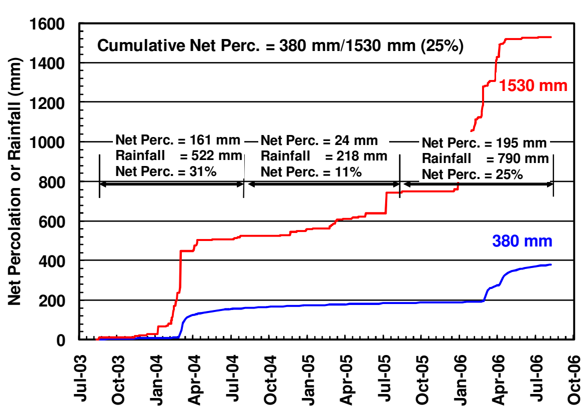

Figure 8. Comparison of the NP predicted for TP2 and rainfall measured at the cover trial area.

5.2.3 Analytical Method

The NP simulated by the calibrated numerical model was compared to a simpler analytical method with the objective of verifying that the analytical method could be used to estimate NP.

Rainfall onto the cover system either reports as runoff or infiltrates into the cover surface. A portion of the water that infiltrates within the cover profile will be removed by evapotranspiration. A small component of the infiltrating water may migrate beyond the influence of atmospheric forcing (i.e. evaporation) and drain from the cover as NP.

Surface runoff did not occur in the cover system field trials due to the presence of berms located around the perimeter of the plots. AET and NP were estimated based on the changes in storage and hydraulic gradients. AET/PE ratios were developed as a function of moisture conditions over the monitoring period. PE was estimated from monitored meteorological conditions.

The NP estimated for TP1 and TP2 by the analytical method from January to July 2005 was 8 and 9 mm, respectively. In comparison, the simulation model estimated 5 and 6 mm of NP during the same period. These data suggest that both methods predict similar NP values and that, in conjunction with other methods, the analytical method may be used to accurately estimate performance of the cover system field trials during subsequent monitoring periods.

The NP calculated for the 2008 monitoring period using the analytical method was approximately 45 mm for TP1, 11% of the total rainfall. The estimated NP and AET for TP1 are shown in Figure 9. In addition the change in water storage calculated from the water balance, utilizing the estimated NP and AET, is compared to the measured change in storage.

The calculated change in water storage closely replicates the measured performance, indicating that the estimated NP is reasonable. NP was not observed at TP2 during the 2008 monitoring period.

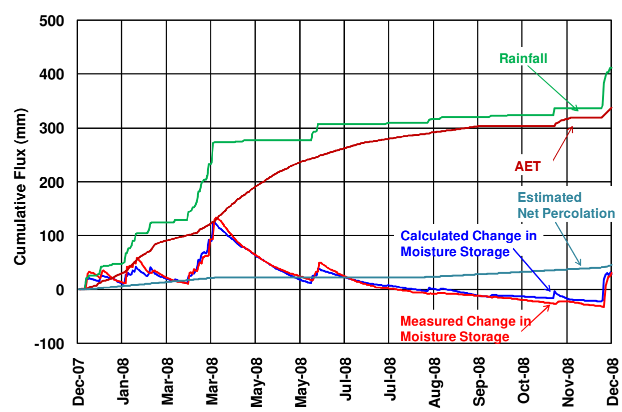

Figure 9. Water balance completed utilizing the analytical method for TP1.

6 SUMMARY

This paper summarizes three methods for evaluating net percolation rates through cover systems on waste rock. These methods include direct measurement using a lysimeter, analytical methods based on a water balance, and numerical simulations of soil-atmosphere fluxes. Direct measurements of net percolation, through the use of lysimeters is advantageous in that performance is obtained immediately upon the collection of seepage waters. In addition, these measurements are often given heightened significance because they are a direct measurement and the systems are conceptually simple to understand. However, in order to ensure that accurate net percolation volumes are being collected the proper design and installation of a lysimeter is required. In addition, the installation of a performance monitoring system is required to ensure the lysimeter is functioning as intended.

Analytical methods of estimating net percolation through changes in water storage and the use of hydraulic gradients also provide an immediate measurement of cover system performance. Ideally, the analytical method would be used in conjunction with direct measurements. Utilizing both methods provides an increased level of confidence and can also provide insight in evaluating the role of spatial heterogeneity in cover system performance should it exist.

Numerical simulations of net percolation can be developed following the establishment of an accurate set of cover system field performance monitoring data. In general, a minimum of two years of performance monitoring data is required to calibrate simulation models. The calibrated simulation model could then be used to predict net percolation or cover system performance under long-term climate variability.

A methodology that incorporates several of the approaches is advantageous in that a more comprehensive understanding of net percolation or cover system performance is developed.

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