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Design, Construction and Performance Monitoring of the Large-Scale Waste Rock Cover System Field Trials at the Historic Mount Morgan Mine Site in Queensland, Australia

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BACKGROUND

The Mount Morgan Mine, in central Queensland, was in operation for over a hundred years and generated 134 Mt of waste rock and tailings. The last ten years of activity at the site involved re-treatment of historic tailings.

The Mount Morgan mine site is a significant source of Acid Rock Drainage (ARD) in the Dee River catchment. The State of Queensland, Department of Natural Resources and Mines (NR&M) manages the site, and in January 2000 NR&M developed the Rehabilitation Plan for the Mount Morgan mine site, Central Queensland (Unger, 2003). The objectives of the plan are to: improve water quality downstream; avoid managing ARD interception and treatment indefinitely; manage the site in accordance with its significant mining heritage; and develop and apply best-practice rehabilitation and management at this site. A seepage interception and pump-back system is currently in place, and the amount of ARD entering the groundwater system and ultimately reaching the Dee River is being quantified.

A number of projects are in progress, or have been completed, towards achieving these objectives. One of these projects is the development of a cover system for waste rock material at the mine site. This project involved the construction of two large-scale cover system field trials in 2003 on acid-generating waste rock, as well as installation of field performance monitoring systems (site-specific meteorological conditions, net percolation, interflow, moisture content, matric suction, temperature, and surface runoff). In addition, a monitoring system was installed at a "natural" site in order to compare performance of an undisturbed area, in terms of storage and release of moisture, to the cover system field trials.

The two cover systems are designed to limit the infiltration of meteoric water to the underlying waste rock as a means of controlling long-term acidic drainage from the waste rock dump. Test Plot 1 is referred to as a "water-shedding" cover system with a nominal 1.0 m thick layer consisting of a compacted clay layer overlain by a layer of non-compacted growth medium (weathered granodiorite), while Test Plot 2 which is referred to as a "moisture store-and-release" cover system consists of a nominal 2.0 m thick layer of growth medium.

This paper will briefly describe the design and construction of the field trials, as well as the field performance monitoring system. Discussion and field performance monitoring data will be provided on the difference in performance between the two cover system field trials. Emphasis will be placed on the impact on performance of the two cover systems as a result of runoff volumes. In particular, it has been demonstrated that runoff volumes negated the intended performance of the respective water-shedding and moisture store-and-release cover design. A complete water balance for each field trial will be presented illustrating the difference in performance between the cover system field trials.

1 INTRODUCTION

The two principal design objectives of cover systems for reactive mine waste are:

- 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, thereby minimising the effective oxygen diffusion coefficient and ultimately controlling the flow of oxygen across the cover.
- 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 store-and-release layer (MEND, 2004).

Additional design objectives for cover systems placed on reactive mine waste can include:

- Prevention of mechanical weathering of the underlying waste material.
- Influence of consolidation and differential settlement.
- Oxygen consumption (i.e. organic cover materials).
- Reaction inhibition (i.e. incorporate limestone at the surface to control the rate of oxidation (does not prevent oxidation)).
- Control of upward capillary movement of process water constituents/oxidation products (MEND, 2004).

It is difficult and usually not economically feasible in arid and semi-arid climates to construct a cover system that contains a layer that remains highly saturated to reduce oxygen transport. The cover system will be subjected to extended dry periods and therefore the effect of evapotranspiration will be significant. However, subjecting the cover system to evaporative demands can be beneficial in arid and semi-arid climates and result in a reduction of infiltration to the underlying sulphidic waste material. A homogeneous upper cover surface layer with a well-graded texture and possessing sufficient storage capacity can be used to retain water during rainfall events. The storage layer releases a significant portion of pore-water back to the atmosphere by evapotranspiration during extended dry periods, thereby significantly controlling the net percolation across the cover system and into the underlying waste material. The objective is to control acidic drainage as a result of preventing moisture movement into and through the waste material. A cover system with the above objectives is often referred to as a “moisture store-and-release” cover system (MEND, 2004).

Cover systems can be simple or complex, ranging from a single layer of earthen material to several layers of different material types, including native soils, non-reactive tailings and/or waste rock, geosynthetic materials, and oxygen consuming organic materials. Factors that control the economic and technical feasibility of a cover system for a particular site include, but are certainly not limited to (MEND, 2004):

- Site climate conditions.
- Availability of cover material(s) and distance to borrow source(s).
- Cover and waste material properties and conditions.
- Surface topography.
- Soil and waste material evolution.
- Vegetation conditions.

2 BACKGROUND

The Mount Morgan mine is a historic underground and open cut mining operation located next to the town of Mount Morgan, QLD, Australia. Mining operations commenced in 1882 and operated for 108 years to recover gold and considerable quantities of silver and copper. The waste rock dumps produced from the open cut operation contain potentially acid-forming material. Preliminary closure planning for the mine site identified that research of suitable cover options for the waste rock dump was required. The Mount Morgan mine site is located on the boundary between the wet tropic to the north and subtropical east coast to the south and therefore, dry "moisture store-and-release" and "water-shedding" cover system designs have been chosen for further investigation.

Two cover system field trials (test plots) were constructed for the Queensland Department of Natural Resources and Mines (NR&M) on acid-generating waste rock at the Mount Morgan mine during January and February of 2003. Test Plot 1 is referred to as a "water-shedding" cover system, while Test Plot 2 is referred to as a "moisture store-and-release" cover system. Both covers limit the infiltration of rainfall to the underlying waste rock as a means of controlling acidic drainage from the waste rock dump. One control test plot was also established in a natural vegetated area.

The overall objective of the waste rock cover system trial project is to obtain field data on the performance of the alternate cover system designs. Monitoring the field performance of the cover system field trials for a number of annual wet-dry climate cycles will enable the short-term performance of the alternate cover system designs to be evaluated in response to varying site climatic conditions. The collection of accurate and reliable field performance data, such as in situ moisture conditions within the cover and waste materials and net percolation through the cover systems, will facilitate the calibration and subsequent validation of numerical models used for cover system design.

2.1 Climate Conditions

The climate at the site is seasonal, with average maximum daily temperatures ranging from 32°C in January to 23°C in July. The average annual rainfall is approximately 740 mm with a standard deviation of approximately 291 mm. A significant proportion of the rainfall occurs during the summer months, on average, December, January, and February receive greater than 110 mm of rainfall while July receives the least amount of rainfall on average (29 mm). The average annual potential evaporation is approximately 1840 mm.

2.2 Field Trial Cover System Design

The three main areas for design of the Mount Morgan mine cover system field trials are sample collection / field testing, material characterisation, and soil-atmosphere numerical modelling. The key findings for each area are presented below. Further details are provided in OKC (2002).

Sample Collection / Field Testing:

- Field testing and sample collection occurred in March 2002.
- Nine test pits, four in the waste rock field cover trial area and five in the potential cover material borrow area 1, were excavated ranging in depth from 1.75 m to 3.0 m. A total of 16 samples were obtained for subsequent particle size analysis.
- Approximately 100 samples were collected throughout the profile of each test pit for paste pH, paste conductivity, and moisture content samples analysis. In addition, in situ density tests were conducted.

Material Characterisation:

- The paste pH of the waste rock material was low, ranging from 2 to 3, while the majority of the paste conductivity values for the waste rock were between 4 and 13 mS/cm. Low paste pH and high paste conductivity results generally indicate a significant storage of potentially leachable oxidation products. The paste pH of the potential cover material samples ranged from a low of approximately 5 to a high of 9, with the majority of the paste conductivity values in the 0.5 mS/cm range.
- The waste rock material samples are well-graded, although they should be considered to be gap-graded due to a lower percentage of material between the 1 mm and 10 mm particle size. On average, the waste rock consists of approximately 55% cobble and gravel, 27% sand, 18% silt and clay-sized particles based on the Unified Soil Classification System. The particle size distributions (PSDs) of the potential cover materials can also be categorised as well-graded, although generally finer than and more variable than the waste rock samples. In general, the material characterization program identified two potential cover materials: a weathered granodiorite (approximately 30%

cobble and gravel, 55% sand, 15% silt and clay-sized particles) and a “grey” clay (approximately 10% cobble and gravel, 55% sand, 35% silt and clay-sized particles).

- The results of the PSD testing, along with visual observations made during the site visit, were used to select a smaller sub-set of samples for detailed physical and hydraulic characterisation. Detailed laboratory characterisation of the waste rock and potential cover material samples included specific gravity tests, compaction tests, small and large-scale permeability tests, and small and large-scale soil water characteristic curve (moisture retention) tests. These tests provide the necessary material properties required for soil-atmosphere cover design numerical modelling.
- The saturated permeability of the waste rock material ranged from approximately 1 x 10^{-4} cm/s for a low density condition to 2 x 10^{-5} cm/s for a high density condition. The saturated permeability of the potential cover material ranged from approximately 5 x 10^{-5} cm/s to 3 x 10^{-6} cm/s, while the “grey” clay potential material ranged from 2 x 10^{-6} cm/s to 4 x 10^{-8} cm/s, for low and high density conditions, respectively.

Soil-Atmosphere Cover System Design Modelling:

- The detailed soil-atmosphere modelling completed for this project examined three possible cover system designs for the Mount Morgan site. The first design was a store and release cover consisting of 2.0 m of potential cover material overlying a thin (15 cm) compacted waste rock layer and a 10 m waste rock profile. The remaining two cover designs were “water shedding” cover designs. The compacted clay cover design possessed a 0.5 m thick potential cover material overlying a 0.5 m thick compacted clay barrier layer. The compacted waste rock cover design was similar; it included a 0.5 m thick potential cover material layer overlying a 0.5 m thick compacted waste rock layer.
- The primary objective of the soil-atmosphere modelling programme was to determine the “average” net percolation through each cover system design under the same set of climate conditions.
- Numerical modelling sensitivity analyses conducted as part of this project showed that the performance of the cover system is sensitive to rainfall, saturated hydraulic conductivity, and the presence of vegetation at the surface.

2.3 Cover System Field Trial Construction

Two cover system field trials (test plots) were constructed over acid-generating waste rock at the Mount Morgan mine in January-February 2003. Figure 1 shows the two constructed field trials. One control test plot was also established in a natural vegetated area at the mine site. The two cover system field trials are immediately adjacent to each other on the Western Waste Dump located northwest of the Mount Morgan mine open cut. Test Plot 1 (TP 1) consists of a nominal 0.5 m thick layer of compacted “grey” clay overlain by a nominal 0.5 m thick layer of non-compacted weathered granodiorite (growth medium). Test Plot 2 (TP 2) consists of a nominal 2.0 m thick layer of non-compacted weathered granodiorite. The two cover materials were obtained from borrow pits located approximately 0.5 km north of the cover trial area. Each cover trial is approximately 30 m wide and 100 m long and comprises three separate sections; an Upper Tier, a 4H:1V Slope, and a Lower Tier. The Upper and Lower Tiers are sloped approximately 2% away from the crest and toe of the 4H:1V slope, respectively. The entire surface of both cover trials was revegetated immediately following construction.

The design of the cover trial profiles was based on the material characterisation and soil-atmosphere numerical modelling. TP 1 is referred to as a “water-shedding” cover system, while TP 2 is referred to as a “moisture store-and-release” cover system. Both cover systems are designed to limit the infiltration of rainfall to the underlying waste rock as a means of controlling acidic drainage from the waste rock dumps. The water-shedding cover is designed to promote overland flow (runoff) and lateral flow within the growth medium layer due to the presence of the compacted clay (barrier) layer. The moisture store-and-release cover is designed to accept as much rainfall as possible, while minimising runoff, with all infiltration remaining within the cover material until it can be released to the atmosphere as evapotranspiration.

A control test plot was also established as part of the waste rock cover field trial programme. Test Plot 3 (TP 3) is located in a natural vegetated area to the north of the cover trial area. The purpose of TP 3 is to develop information for evaluating the influence on the surface water balance due to the presence of native vegetation species, which will be a key design parameter for performance of the full-scale waste rock dump cover systems.

Figure 1 Photograph of the Mount Morgan mine cover system field trials (TP 1 to the right and TP 2 to the left)

3 COVER SYSTEM FIELD TRIAL PERFORMANCE MONITORING SYSTEMS

State-of-the-art monitoring systems were installed at each test plot to allow field performance to be evaluated throughout all seasons of the year. In situ moisture and temperature conditions at each field trial are automatically measured by EnviroSCAN® water content sensors (indirect measurement of volumetric water content) and thermal conductivity (TC) sensors (indirect measurement of matric suction). Each TC sensor (CSI Model 229-L) was calibrated prior to installation, while material-specific calibration curves for the water content sensors were developed to the in situ material properties following the sensor installation. TP 1 and TP 2 also feature lysimeters to measure net percolation through the lower tier of the cover system and a runoff collection system to monitor overland flow across the lower tier and 4:1 sloping surface. The 4:1 slope of TP 1 and TP 2 also contains an interflow system to measure water moving laterally through the cover system above the compacted clay barrier layer-growth medium and waste-cover material interface, respectively. Automated tipping bucket gauges to measure flow are included in the lysimeter, runoff, and interflow collection systems. A weather station was installed on TP 2 to continuously monitor site-specific rainfall, air temperature, relative humidity, wind speed, and net solar radiation. Additional monitoring of in situ moisture conditions is being conducted at each field trial using the Diviner 2000® (D2K) portable moisture content probe.

In situ moisture monitoring systems were also installed at the control test plot. In addition, a tipping bucket rain gauge was installed at the control test plot to evaluate differences in rainfall as compared to the waste rock cover system field trial area.

4 FIELD PERFORMANCE MONITORING

4.1 Climate Conditions

The TP 2 weather station monitors air temperature, relative humidity, wind speed, and net radiation, in addition to rainfall, allowing estimation of potential evaporation (PE) with the measured parameters using the Penman (1948) method. Figure 2 presents the daily rainfall and PE recorded at the site, from the onset of monitoring to December 2005, and provides a summary of five six-month monitoring periods.

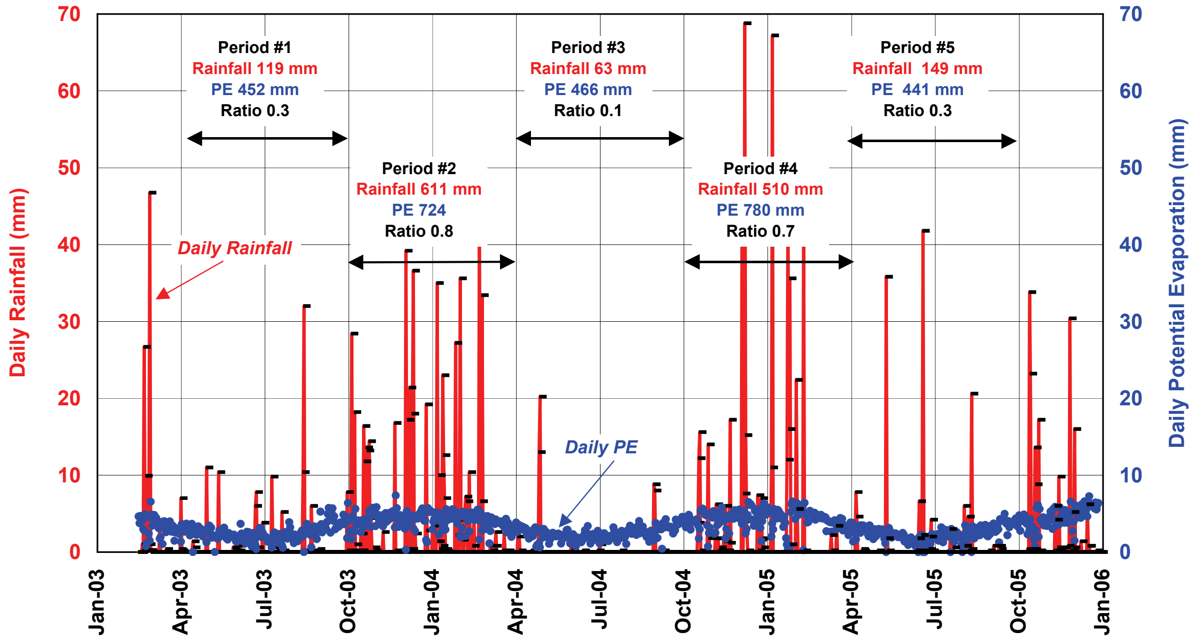

Figure 2 Daily rainfall and potential evaporation recorded at the test plot area

The mean annual rainfall at Mount Morgan is approximately 740 mm, of which approximately 547 mm and 193 mm occur during the climatic summer (October to March) and winter (April to September), respectively. Periods 1, 3 and 5 in Figure 2 mark the climatic winter period, characteristic of lower PE values, while Period 2 and Period 4 mark the climatic summer period, characteristic of higher PE values.

During monitoring Period 1, 119 mm of rainfall was recorded while 452 mm of PE was calculated; therefore, the rainfall / PE ratio (i.e. 119 mm / 452 mm) is 0.26. The rainfall / PE ratio calculated for Period 2, 3, 4, and 5 is 0.84, 0.13, 0.65 and 0.34 respectively. A significant difference in the rainfall / PE ratio is evident when comparing the summer to winter periods.

A review of the meteorological parameters emphasises the high PE demand through all seasons of the calendar year and in particular the summer period. The cover system field trials at Mount Morgan were designed to limit the infiltration of meteoric waters to the underlying waste rock through the process of evapotranspiration, taking advantage of the PE demand.

The maximum and minimum rainfall for any two consecutive six month monitoring periods are 730 mm and 573 mm. These totals fall within a standard deviation of annual rainfall, indicating that rainfall levels for the entire monitoring period should be considered normal.

4.2 In Situ Moisture Conditions

In situ moisture conditions at each test plot are measured using EnviroSCAN® water content sensors and TC sensors. Three sensor nests were installed at TP 1 and TP 2 throughout the depth of the cover material and into the underlying waste rock: one on the lower tier, lower 4:1 slope, and upper 4:1 slope. The lower tier and lower 4:1 slope sensor nest location each consists of fifteen EnviroSCAN® sensors and sixteen TC sensors, while the upper 4:1 slope location consists of fifteen EnviroSCAN® sensors. TP 1 EnviroSCAN® sensors and TC sensors were installed to a depth of 195 cm while the TP 2 EnviroSCAN® sensors and TC sensors were installed to a depth of 275 cm and 270 cm, respectively. One sensor nest was installed at TP 3 (natural site) consisting of ten EnviroSCAN® sensors and eight TC sensors ranging from a depth of 10 cm to 100 cm and 5 cm to 100 cm, respectively.

The volume of water in the cover is an estimation of the "depth" of water if the soil, air, and water components of the test plot profile were separated. The change in volume of water within the cover system profiles can also be referred to as the change in water storage. Figure 3 summarises the cumulative change in volume of water within the lower tier of TP 1 and TP 2, and TP 3 from the onset of monitoring to the end of December 2005.

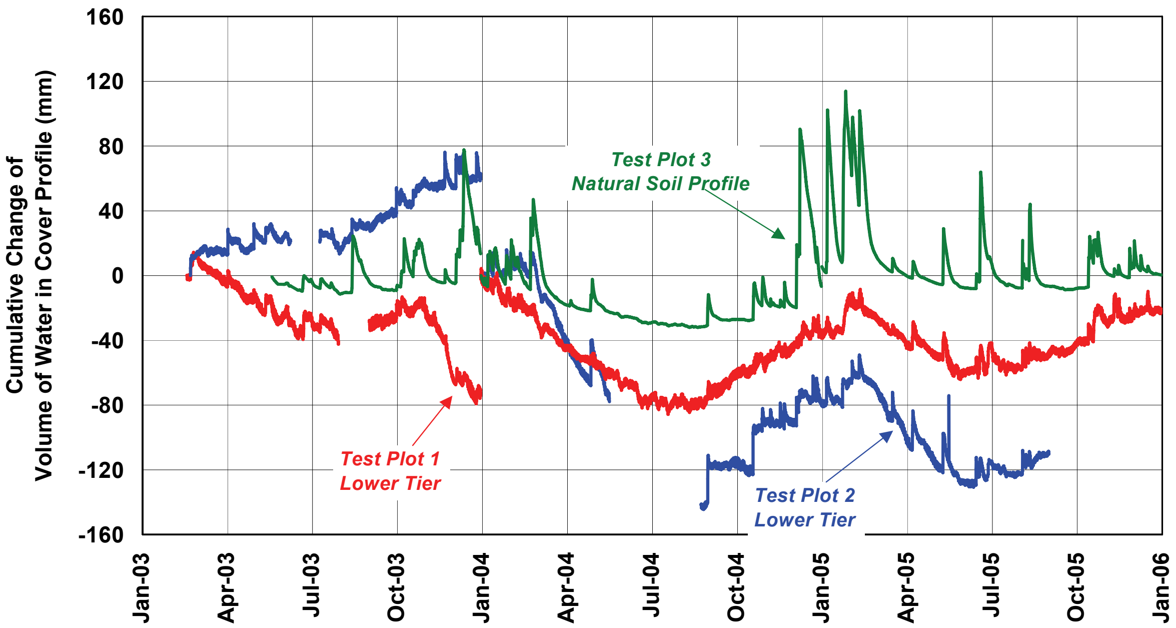

Figure 3 Cumulative change in volume of water (change in storage) within the EnviroSCAN® test plot profiles for TP 1, TP 2, and TP 3

The change in the volume of water measured as a function of time within the TP 1 and TP 2 EnviroSCAN® sensor profiles vary significantly from the onset of monitoring to December 2005. This is largely attributed to: (1) variations in the in situ moisture content of the cover material at the time of placement; (2) relative cover profile thickness, (3) material variability; and (4) runoff volumes. However, following an extended period of time (one annual wet-dry cycle) the effect of differences in the initial moisture content becomes negligible due to atmospheric forcing (rainfall and evaporation). Subsequently, the cumulative change in moisture content shown in Figure 3 was "reset" starting the 2004 monitoring period to negate the effect of variations within the in situ moisture conditions at the onset of monitoring.

The change in the volume of water measured within the natural site soil profile increases instantaneously in response to rainfall and then returns to a "base-line" moisture content in response to evapotranspiration, which is typical of a natural "moisture store-and-release" system. The change in the volume of water measured within the cover system field trial profiles are "seasonal" in that the moisture content gradually increases during the summer and then gradually decreases during the winter. The seasonal fluctuation is due in part to changes in moisture conditions but also changes within the in situ cover profile temperature, the latter of which is explained in more detail below.

Figure 4 shows the volumetric water content and temperature measured at a depth of 35 cm within the TP 1 lower tier profile and daily rainfall. When comparing the change in moisture conditions to rainfall a correlation is marginally evident. However, a good correlation does exist between in situ temperature and moisture content.

The volumetric water content measured with EnviroSCAN® sensors is calculated using material-specific calibration curves. Material-specific calibration curves are developed to address the influence of mineralogy, chemistry, and in situ density conditions on sensor output. The influence of temperature on measurements collected by capacitance-type sensors was demonstrated to be negligible, and therefore OKC does not account for this in developing material-specific calibration curves. The error in moisture content due to changes in the in situ temperature are not evident at TP 3, thus it is anticipated that the error could potentially be incorporated into the material-specific calibration curve itself or due to variation within the mineralogical and chemical properties of the various materials. A reassessment of the material-specific calibration curves is currently underway and monitoring of this relationship will continue to determine if temperature dependent calibration curves are required to interpret cover performance.

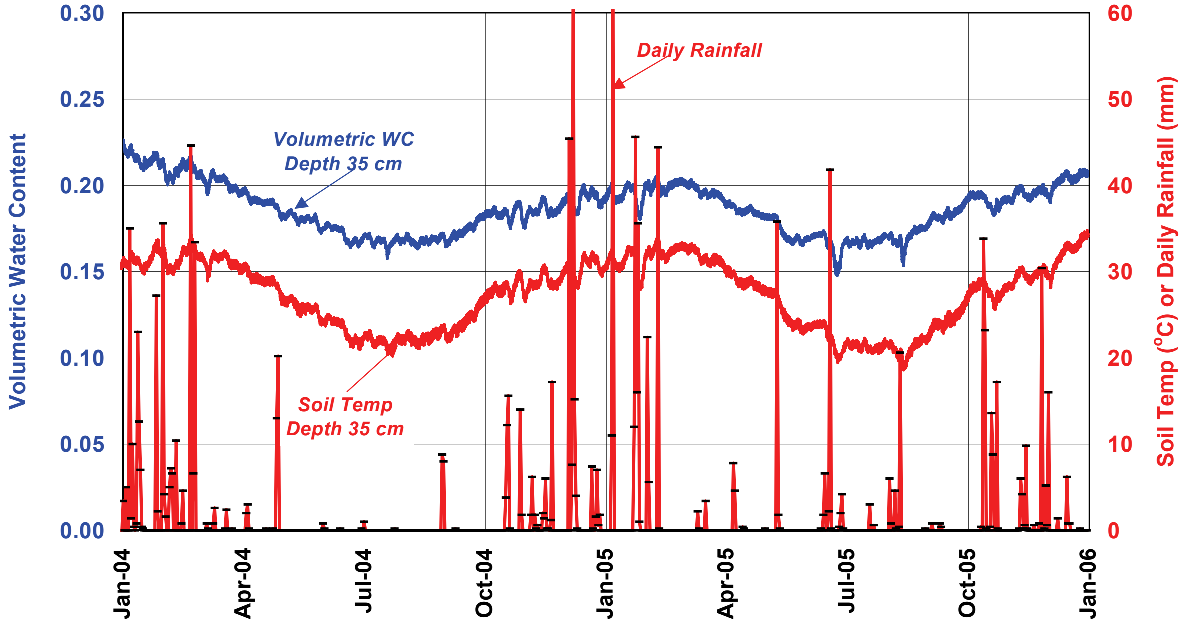

Figure 4 **Change in volumetric water content and in situ temperature at a depth of 35 cm within the TP 1 cover profile (daily rainfall is also included)**

4.3 Plant Available Moisture

Figure 5 shows the matric suction measured at a depth of 35 cm and 40 cm within the TP 1 and TP 2 lower tier cover profiles, respectively, and that measured at a depth of 50 cm within the natural soil profile of TP 3. A consistent increase in matric suction occurs within the TP 1 and TP 2 cover profile from the onset of monitoring to July 2004.

The increase in matric suctions is due to the evapotranspiration or removal of moisture from the cover system profile. The matric suction measured at a depth of 35 cm within the TP 1 cover profile increases beyond 1500 kPa in February 2004, which is commonly associated with the permanent plant wilting point. In comparison an additional four months elapsed until the matric suction exceeded 1500 kPa within the TP 2 cover profile at the 40 cm measurement depth.

The matric suction at the TP 1 cover profile measurement depth remained above 1500 kPa following the initial increase beyond this value, while that within the TP 2 cover profile maintained a value somewhat lower throughout the monitoring period until 2005. The lower values of matric suction maintained within the TP 2 cover profile in relation to TP 1 is due to variations within the cover profile thickness, in that the 2 m cover profile would have had twice the volume of moisture within the profile compared to the 1 m cover system, assuming that the antecedent moisture conditions of the cover material were similar at the time of placement. Changes in matric suction measured throughout the cover profile depth of each field trial indicates that meteoric waters are not percolating into the cover profile at any significant volume. As a result the relative cover profile thickness has significantly influenced vegetation establishment on the respective covers during the monitoring period. Vegetation development on TP 1 has experienced an annual die off during the dry winter period. In contrast the vegetation established on TP 2 has not displayed the same plant stress of that located on TP 1. This is due to the movement of moisture up through the cover profile from depth at TP 2, providing plant available moisture for an extended period of time. However, trends in cover system performance monitoring data and field observations suggest that the additional “store” of moisture within the thicker cover profile have become depleted and vegetation die off will soon occur at TP 2.

Trends in matric suction conditions within the natural soil profile of TP 3 show that the in situ moisture state is in excess of 1500 kPa throughout the majority of the monitoring period. However, in contrast to the cover system field trials there is a significant decrease at depth (50 cm, Figure 5) within the natural soil profile in response to significant rainfall events. The percolation of meteoric waters to depth within the natural soil profile and subsequent uptake by vegetation characterises a sustainable moisture store-and-release system.

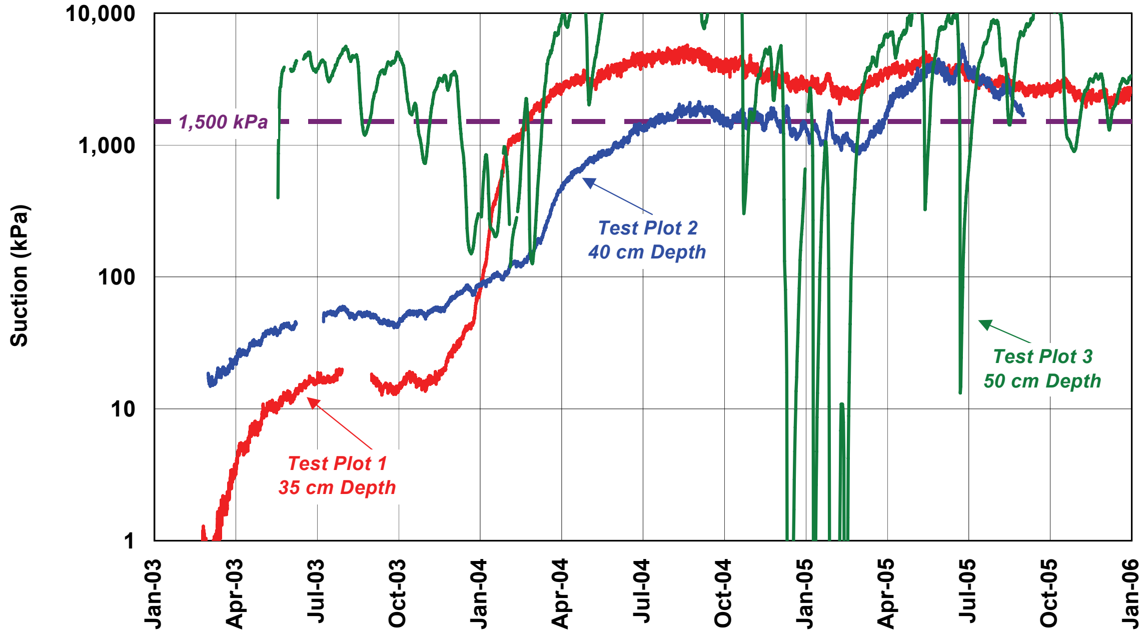

Figure 5 Matric suction measured within the cover profile of TP 1, TP 2 and TP 3

The variations in moisture cycling between the cover system trails and natural soil profile are predominantly due to variations within the material properties, in particular, the lack of structural development within the cover material at TP 1 and TP 2, due to its sodic nature.

4.4 Net Percolation

Net percolation through the cover system trials is being measured with large lysimeter tanks installed at the lower tier of TP 1 and TP 2. Water percolating through the lysimeter tanks is collected in an underdrain system and channelled to a tipping bucket gauge (TBG) for continuous monitoring of net percolation rates. No tips have been recorded by the TP 1 and TP 2 lysimeter tipping bucket from the onset of monitoring to December 2005.

An understanding of moisture cycling characteristics developed at TP 1 and TP 2 indicates that the percolation of meteoric waters to the underlying waste rock is not limited through the process of moisture store-and-release, as was originally intended. A combination of material properties and field performance monitoring data indicates that the occurrence of net percolation is highly unlikely at this time due to high runoff volumes.

4.5 Surface Runoff and Erosion

A collection and monitoring system was installed at the down-gradient end of the 4:1 slope and lower tier sections of each cover trial (TP 1 and TP 2) to assess the runoff and associated erosion from these surfaces due to rainfall events. Table 1 summarises the runoff as a percentage of rainfall for the test plots from December 2003 to December 2005, inclusive. Runoff values for the TP 2 are not presented for the latter part of 2005 due to problems associated with the automated data acquisition system.

When comparing the performance of the two cover system field trials over the monitoring period, in terms of runoff, there are slight variations between the two due to variability within the cover material and variations within the in situ moisture conditions (i.e. hydraulic gradients). However, when comparing the “long-term” performance, near the end of the monitoring period, runoff volumes are almost identical. In particular, during May and June of 2005 runoff volumes for the 4:1 slopes and lower tiers are approximately 73% and 37% of rainfall, respectively.

Table 1 TP 1 and TP 2 runoff measured from December 2003 to December 2005

Date	Rainfall (mm)	TP 1, 4:1 Slope Runoff in mm (% of rainfall)	TP 1 Lower Tier Runoff in mm (% of rainfall)	TP 2, 4:1 Slope Runoff in mm (% of rainfall)	TP 2 Lower Tier Runoff in mm (% of rainfall)
December	**162**	**119 (73%)**	**107 (66%)**	**112 (69%)**	**103 (64%)**
2003 summary:	*162*	*119 (73%)*	*107 (66%)*	*112 (69%)*	*103 (64%)*
January	**129**	**90 (70%)**	**84 (65%)**	**98 (76%)**	**70 (54%)**
February	**161**	**124 (77%)**	**106 (66%)**	**117 (72%)**	**57 (35%)**
March	**7**	**-**	**-**	**-**	**-**
April	**39**	**17 (43%)**	**12 (31%)**	**16 (41%)**	**11 (28%)**
May	**0**	**-**	**-**	**-**	**-**
June	**1**	**-**	**-**	**-**	**-**
July	**1**	**-**	**-**	**-**	**-**
August	**9**	**-**	**-**	**-**	**-**
September	**8**	**4 (50%)**	**-**	**3 (37%)**	**1 (12%)**
October	**48**	**28 (58%)**	**17 (36%)**	**28 (58%)**	**11 (23%)**
November	**39**	**16 (41%)**	**8 (21%)**	**14 (36%)**	**6 (15%)**
December	**160**	**120 (75%)**	**100 (62%)**	**116 (73%)**	**71 (44%)**
2004 Summary:	*602*	*399 (56%)*	*327 (54%)*	*392 (54%)*	*227 (37%)*
January	**188**	**163 (86%)**	**138 (73%)**	**170 (90%)**	**144 (77%)**
February	**73**	**53 (72%)**	**48 (66%)**	**61 (83%)**	**47 (64%)**
March	**6**	**-**	**-**	**-**	**-**
April	**13**	**-**	**-**	**-**	**-**
May	**38**	**29(76%)**	**13 (34%)**	**29 (76%)**	**12 (31%)**
June	**60**	**43 (72%)**	**24 (40%)**	**42 (70%)**	**26 (43%)**
July	**4**	**-**			
August	**33**	**19 (57%)**	**8 (24%)**		
September	**2**	**-**	**-**		
October	**98**	**40 (41%)**	**18 (18%)**		
November	**58**	**17 (29%)**	**-**		
December	**26**	**13 (50%)**	**1 (3%)**		
2005 Summary:	*599*	*377 (62%)*	*252 (42%)*		

Note: Runoff is not reported for TP 2 during the second half of 2005 due to problems with the datalogger

Runoff predicted by soil-atmosphere modelling during the numerical modelling program calculated values of runoff on a continuous cover profile extending from the crest of the 4:1 slope to the end of the lower tier. However, runoff generated at the 4:1 slope of the field trials enters a runoff collection channel at the base of the slope and is subsequently removed from the system. Runoff measured at the lower tier of the trials would be considerably larger in a continuous system.

The cover system design numerical modelling program predicted that runoff would be higher for TP 1 than TP 2, predominately due to the difference in moisture storage capacity. However, due to high runoff volumes the relative storage capacity or cover system design has not influenced the hydraulic performance. During an average rainfall year (776 mm), soil-atmosphere modelling predicted 26.7 mm (3.4%) and 158 mm (20.4%) of runoff for TP 1 and TP 2, respectively.

Measured runoff at the trail area is considerably higher than that which was predicted during the modelling program. The measured in situ hydraulic conductivity (K) of the cover system field trials is similar to what was used for the lower cover profile during the numerical modelling program. When conducting the numerical modelling program the option of inputting rainfall intensity was not available, subsequently rainfall events were applied over a 24 hr period. It is anticipated that the difference between the predicted and measured runoff is in part due to the somewhat limited ability of numerical models to replicate in situ field conditions but more importantly the use of a "toned down" rainfall intensity for the modelling program in comparison with actual rainfall characteristics.

The erosion collection and monitoring system is designed to monitor bedload and suspended sediment generated by runoff events. Bedload sediment is monitored by calculating the volume of sediment deposited within the runoff collection trough. The suspended sediment sampler consists of a flow splitter attached to the tipping bucket frame, which is connected to a plastic sample container via a flexible hose.

During the 2005 monitoring period, 6.8 kg/m^2 and 5.6 kg/m^2 of cover material reported to the 4:1 slope collection system of TP 1 and TP 2, respectively, in the form of bedload sediment. During the same time period, negligible volumes of cover material reported to the lower tier bedload collection system of the cover system field trials. In relation to rainfall, bedload sediment has decreased during the 2005 monitoring period, in comparison to 2003 and 2004. It is anticipated that the reduction in bedload sediment is the result of rill / gillie self armament. However, due to the relative clast stability, rill / gully growth will continue with time.

The suspended sediment load measured at the TP 1 and TP 2 lower tier and 4:1 slope has decreased from the onset of monitoring, from 12 mg/L to 4 mg/L on the 4:1 slopes and from 0.5 mg/L to 0.2 mg/L at the lower tiers.

4.6 In Situ Hydraulic Conductivity

Pressure infiltrometer (PI) and Guelph Permeameter (GP) measurements were obtained for the granodiorite (growth medium) and compacted clay during test plot construction and the subsequent monitoring period.

Figure 6 shows the mean K as a function of time for the granodiorite and compacted clay. The hydraulic conductivity of the granodiorite decreased by approximately one order of magnitude (2.0 x 10^{-4} cm/s to 3.0 x 10^{-5} cm/s) from the "as-built" conditions to that measured during the December 2003 site visit and then remained unchanged until January 2006. It is anticipated that the decreases in hydraulic conductivity is due to the consolidation of the cover profile in response to wet-dry cycling.

Measurements of hydraulic conductivity were also taken at the surface where significant grass has developed. The value of mean K measured at "vegetated" locations is 2 x 10^{-4} cm/s, which is approximately one order of magnitude greater than that measured at non-vegetated surface locations, as shown in Figure 6. The changes in hydraulic conductivity due to biological process, such as vegetation development, are more pronounced near surface and decrease significantly with depth. The mean value of K measured at a depth of 35 cm and 75 cm within the TP 2 granodiorite material, underlying a vegetated location, is 3.0 x 10^{-7} cm/s, which suggests that the changes in hydraulic conductivity due to biological process, at this time, are restricted to the near surface.

The increase in hydraulic conductivity measured due to vegetation development during the monitoring period has not lead to changes beyond the near surface. In combination with vegetation die off and subsequent decrease in surface coverage it is anticipated that vegetation will not lead to any significant changes in the hydraulic properties.

It has been demonstrated through the literature that the development of a secondary structure (cracks and fissures) within fine grained cover materials can lead to a significant increase in the saturated hydraulic conductivity. However, the development of a structure within the granodiorite growth medium will more than likely not occur due to the sodic nature of this material. An amelioration program was implemented in June of 2006 in an effort to increase moisture cycling thus reduce erosion and subsequently stabilise the land form. The cover material was treated with gypsum in an effort to leach sodium from the exchange sites of clay particles. In addition, a significant amount of the woody vegetation was removed from the system and then seeded with a combination of relatively fast establishing grasses local to the area.

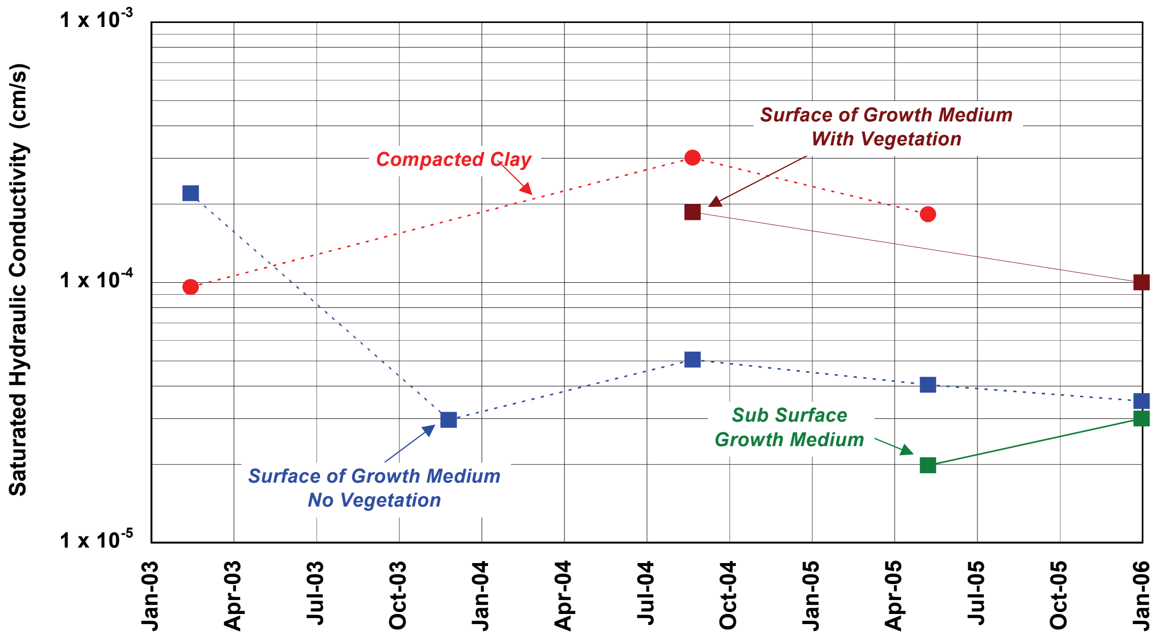

Figure 6 Measurements of field saturated hydraulic conductivity taken at the surface of the non-compacted cover material and compacted clay

The hydraulic conductivity of the compacted clay remained relatively unchanged at approximately 2×10^{-4} cm/s during the monitoring program.

4.7 Water Balance

Performance of the cover system field trials was also evaluated by developing a water balance for each plot. A simple water balance can be completed using performance data collected at the test plots. The change in moisture storage (ΔS) in each cover profile is determined from in situ moisture content measurements. Lateral percolation is measured on the sloping surface and assumed to be zero on the horizontal surface due to one-dimensional flow, thus eliminating lateral flow. Net percolation (NP) is directly measured on the horizontal surface and assumed to be zero on the sloping surface. Rainfall (R) and surface runoff (SR) are directly measured with tipping bucket gauges. Actual evapotranspiration (AET) is not measured on the test plots, but can be back-calculated from the water balance (i.e. AET = R – SR – NP –ΔS).

Figure 7 summarises the cumulative rates for rainfall, net percolation, change in moisture storage, surface runoff, and the AET calculated at the TP 1 lower tier from May 1 to May 31, 2005. Cumulative rainfall was approximately 38 mm for the monitoring period. Total moisture within the EnviroSCAN® sensor profile decreased by 11 mm due to the evaporative demand. Surface runoff and net percolation were measured to be approximately 13 mm and 0 mm, respectively.

The AET calculated from the water balance was approximately 36 mm. Figure 7 shows that the potential evaporation (PE) for the monitoring period, measured for the site based on collected climate data, is approximately 67 mm, which is 31 mm and 29 mm greater than the AET and cumulative rainfall, respectively. The fact that PE significantly exceeds AET indicates that if a reduction in runoff occurs due to an increase in surface permeability, a significant proportion of the moisture would be available for AET. In response to the high runoff volumes a decrease in the volume of water within the cover profile occurred to supply the evaporative demand.

There is a lag in the increase in moisture content of approximately one and one half days in response to 38 mm of rainfall that occurred on May 10, 2005. The lag in time is a reflection of the hydraulic properties of sodic cover materials. This illustrates the time required for infiltrating meteoric waters to penetrate a depth of 10 cm, associated with the near surface EnviroSCAN® moisture content sensor. TC sensors were used to validate or confirm the changes in moisture storage due to the errors associated with respect to temperature fluctuations.

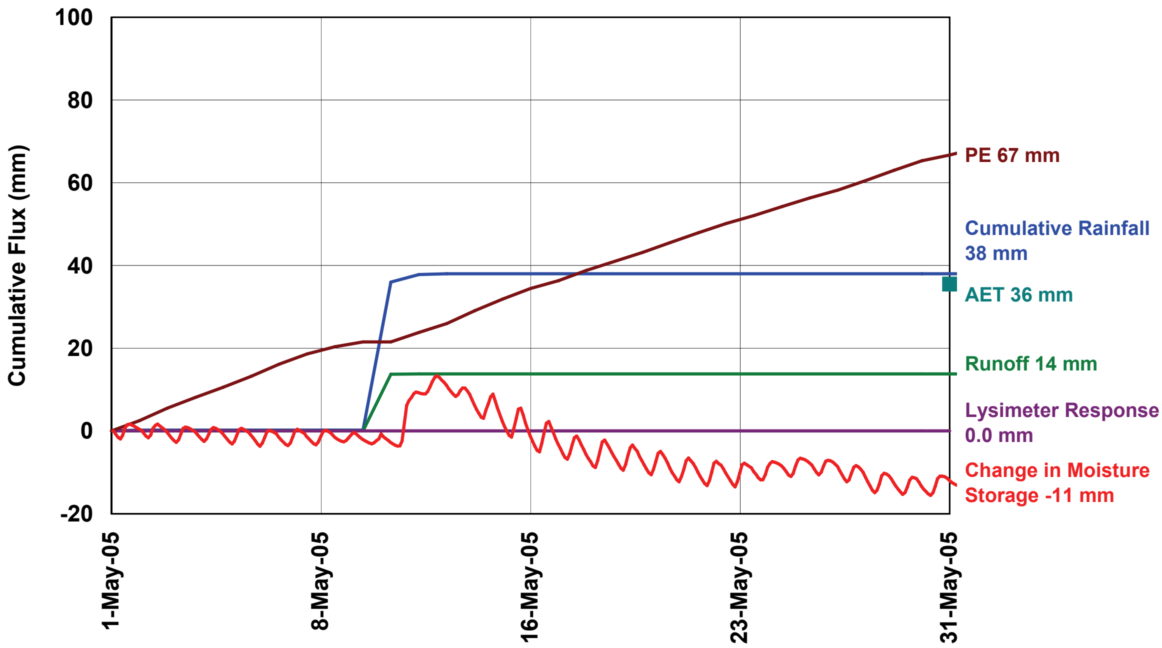

Figure 7 Water balance for the May 2005 monitoring period at TP 1 lower tier

Water balances for the May 2005 monitoring period were completed in a similar fashion for the 4:1 slope of TP 1, and the lower tier and 4:1 slope of TP 2. The AET calculated for the TP 1 lower tier and 4:1 slope is 36 mm and 22 mm, respectively. The AET calculated for the TP 2 lower tier and the 4:1 slope is 37 mm and 17 mm, respectively. The AET measured for the 4:1 slope of TP 1 and TP 2 was lower than that measured at the lower tiers. The lower values of AET calculated for the 4:1 sloping surface of the test plots is due to differences in runoff volumes. Similar volumes of AET measured between the test plot lower tiers and 4:1 slopes is a function of runoff volumes and not cover system design.

5 SUMMARY

Two waste rock cover system field trials were constructed to evaluate the performance of moisture store-and-release and water-shedding cover system at the Mount Morgan mine site. A third monitoring area was established in a naturally vegetated area. The following summarises key field performance aspects from the three monitoring areas.

- For the water-shedding cover system (TP 1):
  - The intended performance was to develop a system that enhanced the potential for saturated overland flow as a result of the underlying low permeability barrier.
  - Currently, runoff is occurring, but it is a result of Hortonian overland flow (rainfall exceeding surface permeability), most likely a result of measured rainfall intensity being greater than that modelled and lower than anticipated surface permeability conditions.
- For the moisture store-and-release cover system (TP 2):
  - The intended performance was to develop a system that minimised surface runoff, stored infiltration within the cover profile, and then released the moisture back to the atmosphere as evapotranspiration, resulting in a low net percolation rate to the underlying waste rock.
  - Following construction, net percolation was initially controlled by runoff (i.e. runoff was the dominant component of the water balance as a result of Hortonian overland flow).

- Subsequently, there was a slight increase in surface infiltration (as a result of grass development increasing surface permeability); however, surface runoff still remains as a dominant water balance component.

- The relatively high runoff volumes measured for the cover trials has produced an "artificial drought" condition. As a result, vegetation die off has occurred and will subsequently limit the influence of vegetation on surface permeability.
- At the current time, the high runoff volumes have "negated" the differences in the two cover system designs in that the available moisture storage capacity of the respective covers are not being utilised and subsequently not influencing performance.
- This issue has been addressed as part of a June 2005 melioration program, which was implemented to treat the sodic cover material and increase surface infiltration and control net percolation through moisture cycling and subsequently create a stable land form.

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