Dry Cover Trials at Mt Whaleback — A Summary of Overburden Storage Area Cover System Performance
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ABSTRACT
BHP Billiton Iron Ore initiated a program in January 1995 at the Mt Whaleback operation in Newman, Western Australia to develop a closure plan for the overburden storage areas (OSA), which have the potential to generate acid rock drainage. The primary research program includes the development of technology for the long-term performance of OSAs with respect to slope stability, surface run-off, erosion, water infiltration and vegetation.

The objective is to control acid rock drainage by preventing moisture movement into and through the OSA material. Infiltration to the underlying OSA material and closure costs are minimised due to the presence of the run-of-mine (ROM) cover material. A summary of the field data is presented to illustrate low percolation rates to the underlying OSA and key performance characteristics of the moisture store and release cover system design. Field data collected to date demonstrates that a moisture store and release cover system constructed with suitable ROM material has good potential as a final cover system at the Mt Whaleback site. The performance of the cover system on a sloped surface was significantly different as compared to placing the cover system on a horizontal surface.

INTRODUCTION
The Mt Whaleback iron ore mine is located in the Hamersley Iron Province in the northwestern corner (Pilbara Region) of Australia and situated adjacent to Newman, Western Australia (WA), approximately 1200 km north-northeast of Perth as shown in Figure 1. Development of the Mt Whaleback mine commenced in 1968. The mine currently produces approximately 18 million wet tonnes of saleable product and 53 million tonnes of waste material annually. To date, some two billion tonnes of waste rock have been mined. Ultimately, some 3.3 billion tonnes of waste rock will be mined and located into overburden storage areas (OSA) in and around the final pit.

The OSAs contain unoxidised waste rocks, which possess varying amounts of carbonaceous matter and sulfide minerals. Approximately 15 per cent of the waste rocks contain elevated levels of carbon and sulfides, with negligible carbonates and are referred to as ‘reactive shales’ (Waters and O’Kane, 2003, these proceedings). The nodular zone of the Mt McRae Shale has sulfide values greater than 20 per cent by weight. The oxidised waste rocks at Mt Whaleback are geochemically similar and deficient in pyrite as well as carbonates (Campbell, 1996), and are classified as ‘inert’. The reactive material is potentially acid forming (Porterfield et al, 2003, these proceedings), with certain components also being prone to spontaneous combustion (Waters and O’Kane, 2003, these proceedings).

The climate of the Pilbara region is semi-arid, tropical with a mean annual rainfall of approximately 320 mm. There are two distinct seasons, a hot, wet summer (December to April), and the rest of the year, which is more temperate and generally experiences low rainfall conditions. Rainfall generally occurs in high intensity, short duration events, usually associated with cyclonic events in the summer months. The annual potential evaporation typically exceeds 3000 mm. (O’Kane et al, 1998, 1999, 2000).

BACKGROUND
Porterfield et al (2003, these proceedings) summarise the acid rock drainage (ARD) management strategy for the Mt Whaleback operation. A key component of the ARD management strategy is research into the application of dry cover systems. The dry cover systems research program was initiated in 1996, and is currently in progress. The objective of the research program is to evaluate the effectiveness of dry cover systems at the Mt Whaleback site (as well as at satellite orebodies) to buffer rainfall incident to the OSA surface, such that seepage into and through OSAs is minimal; thus providing an at source control of ARD.

The two principal objectives of a cover system are to control the ingress of oxygen to the underlying reactive mine waste and/or to control infiltration of meteoric waters to the underlying waste. Additional objectives include: control of consolidation and differential settlement; oxygen consumption (ie organic cover materials); reaction inhibition (ie incorporate limestone at the surface which does not prevent oxidation but can control the rate of acid generation); control of upward capillary movement of process water constituents/oxidation products; and to provide a growth medium for revegetation.

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 thereby reducing oxygen
transport. The cover system will be subjected to extended dry periods and therefore the effect of evaporative processes 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 sulfidic 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. Subsequent to the increase in moisture storage in the well-graded layer, it would release a significant portion of pore water to the atmosphere by evaporative processes during extended dry periods, thereby reducing the net infiltration across the cover system. The principal objective is to control acidic drainage by preventing the increase in moisture storage in the well-graded layer, thereby reducing the net infiltration across the cover system.

MT WHALEBACK COVER SYSTEM DESIGN

O’Kane et al (1998, 1999, 2000) summarise the cover system design, construction of field trials, and installation of the field performance monitoring systems. However, the information is repeated here for clarity.

Physical characterisation of run-of-mine oxidised material

The run-of-mine (ROM) oxidised material represents the most promising cover material at the site. A field-sampling program completed in October 1996 included collection of 27 bulk samples (material >300 mm) in 200 litre drums. The samples and locations were chosen to represent ROM material that had been placed in OSAs, as well as material from within the open pit, that had been drilled and blasted, but not yet hauled to an OSA.

Particle size distribution (PSD) analysis for the bulk samples was completed. Typical PSD curves for the ROM cover material as well as the Mt McRae Shale waste rock (see Waters and O’Kane, 2003, these proceedings, for description of the Mt McRae Shale) are shown in Figure 2. The materials are generally coarse in texture and relatively well-graded, and while being physically similar are geochemically dissimilar (Porterfield et al., 2003, these proceedings).

Soil water characteristic curve (SWCC) and saturated hydraulic testing using large-scale (30 cm diameter) laboratory testing apparatus was completed on representative samples that were chosen based on a review of the PSD data. The large-scale apparatus ensured that as much of the material as possible was included as part of the test (larger sized particles up to material <75 mm), such that a minimal amount of correction for over-size material was required to the soil water characteristic curves measured in the laboratory. The samples chosen for testing represented the coarse, fine, and intermediate textured ROM material. The drying portion (ie increasing matric suction) of the SWCC is shown in Figure 3. The ROM cover material has a distinctive low air entry value with a gradual decrease in the slope of the SWCC near the residual suction, as shown in Figure 3. The saturated hydraulic conductivity measured in the laboratory was in the range of $5 \times 10^{-4}$ cm/s, although this value was lower (approximately 1.5 orders of magnitude) for higher density conditions typical of compacted haul truck traffic surfaces.

Figure 3 - Soil water characteristic curve (drying portion) of intermediate textured ROM waste rock material.

Soil-atmosphere cover system design modelling

Soil-atmosphere cover system design modelling was completed to evaluate alternate designs on the basis of predicted net percolation to the underlying waste (O’Kane et al., 1998). A 2 m ROM cover thickness was modelled because it was estimated that the thickness of a single lift of material placed by 240 tonne haul trucks on a level surface was approximately 2 m. Numerous simulations were completed based on conditions observed in the field and the variability of the laboratory measured material properties. The soil-atmosphere numerical modelling predicted the net percolation of water to the underlying waste rock was less than one per cent of the 30-year maximum annual rainfall ($= 500$ mm) for bare surface conditions (ie no vegetation). The model predicted that the ability of the ROM cover material to store moisture and subsequently release the moisture through evaporation was a key factor in controlling performance.

CONSTRUCTION AND FIELD PERFORMANCE MONITORING OF TP#1 AND TP#2

Two 1 ha field test plots were constructed in February 1997 on a relatively horizontal surface to verify the results predicted by the soil-atmosphere model. The test plots were constructed with common operational considerations. Test Plot No 1 (TP#1) had a cover thickness of 2 m. Two lifts of material were placed during construction of Test Plot No 2 (TP #2) to achieve a 4 m cover layer thickness. The undulating surface created by 'paddock' dumping was not levelled in order to maintain short surface run-off paths during the life of the test plots.
A field performance monitoring system was installed to measure actual evaporation, potential evaporation, rainfall, net percolation (large-scale lysimeters), and in situ temperature and moisture (suction and volumetric water content) conditions at TP#1 and TP#2. The in situ monitoring profiles included sensors installed into the overlying ROM cover material as well as underlying reactive shale.

Figure 4 shows the volume of water stored in 2 m of ROM cover material at TP#1 over a five-year period for bare surface conditions. The volume of water is an estimation of the ‘depth’ of water if the solid, air, and water components of the cover profile were separated. For example, if a volumetric water content of 0.20 or 20 per cent was measured in a 1.0 m thick cover material profile with a porosity of 0.30, the ‘depths’ of soil, air and water would be 70 cm, 10 cm and 20 cm, respectively.

The data shown in Figure 4 are based on in situ volumetric water content and matric suction sensors installed throughout the 2 m cover material profile. The well-graded oxidised ROM cover material significantly buffered incident rainfall. The antecedent volume of water in the cover system was approximately 200 mm at the start of monitoring. The first year of monitoring saw an increase in moisture storage from 200 mm up to a high of 250 mm during the wet season. Prior to the start of the next wet season the volume of water had decreased to the antecedent levels as a result of evaporation.

The ability of the ROM cover material to significantly buffer rainfall to the underlying potentially acid forming waste is further demonstrated by the increase and decrease in the volume of water in the cover material profile during subsequent wet seasons. Note that nearly three times (870 mm) and nearly four times (1160 mm) the average annual rainfall was recorded during the second year and third year of monitoring, respectively. The third year of monitoring represented twice as much rainfall as had been recorded in the previous 35 years of rainfall monitoring at the site. Rainfall during the second and third years of monitoring led to greater net percolation than predicted by the cover design modelling conducted prior to construction of the test plots because the maximum annual rainfall recorded (and modelled) had been 500 mm. However, significant buffering of rainfall still occurred, as shown in Figure 4 for the second, third, fourth and fifth years of monitoring. For example, the total rainfall recorded during the five-year monitoring period was more than 3190 mm, whereas the large-scale lysimeters installed to measure net percolation reported an average of approximately five per cent net percolation over the five-year monitoring period.

The net percolation measured at TP#1 for each of the five years of monitoring is also shown in Figure 4. Note that the net percolation recorded for Year Five is greater than that recorded for Year Two, even though rainfall during Year Two was more than twice as high, compared to Year Five. The response of the lysimeters is a function of the lag-time required before rainfall reports to the base of the lysimeter, which is approximately 2.5 m below the base of the ROM cover material profile. Therefore, net percolation reporting to the lysimeters during Year Five, is likely a result of rainfall recorded during Years Three and Four. The response of the lysimeters for this project illustrates the caution that is required when interpreting the response of field lysimeters. The ability of the lysimeter to properly represent net percolation increases as the time frame over which the measurements are obtained increases. In general, it is difficult to properly assess the response of a field lysimeter after only one or two years of monitoring data, although clearly the required time frame is site-specific.

No water has reported to the TP#2 lysimeters during the five-year monitoring period. As discussed for TP#1, the lysimeter measurement is a function of the time frame over which measurements occur. Since the TP#2 cover material is twice the thickness of TP#1, the time frame for any moisture to report to the lysimeter may be substantially longer. There is also the potential for any percolating moisture to be ‘lost’ in the material above the lysimeter. The lysimeter results from TP#1 and TP#2 have been implemented as part of the mine site closure plan in that the site has assumed that a minimum of 4 m of ROM cover material is required for capping the reactive OSAs.
COMPARISON OF SLOPING SURFACE AND HORIZONTAL SURFACE COVER SYSTEM PERFORMANCE

Similar to all mine sites, significant portions of the OSAs at the Mt Whaleback operation have sloping surfaces. The performance of a cover system can be much different on a sloping surface as compared to a horizontal surface, with the difference being a function of the site-specific climate conditions, in situ cover and waste material properties, and the slope angle and length. To address this issue, a third test plot (TP#3) was established in January 1998 on a sloping surface of an OSA at the Mt Whaleback site.

In situ moisture monitoring profiles were installed at near-crest, mid-slope, and near-toe locations of an OSA with a nominal cover thickness of 2 m, a slope length of approximately 165 m, and a slope angle of approximately 3.3H:1V.

Figure 5 compares the response of a matric suction sensor installed at a depth of 1 m at TP#1, to a sensor installed at the same depth in TP#3. A decrease in suction results from surface infiltration in response to rainfall. The response of the sensor installed at a depth of 1 m at the mid-slope location of TP#3 is much less, and significantly dampened. The sloping surface conditions have a significant influence on performance of the cover system in terms of the depth of infiltrating water, as well as the net percolation. Rainfall incident to the sloping cover surface is partitioned into run-off and infiltration, whereas run-off at TP#1 is essentially zero. Although not presented in this paper, an analysis of the TP#3 data clearly illustrates that the percentage of run-off in comparison to rainfall is strongly dependent on antecedent moisture conditions, as well as the duration and intensity of rainfall events. For example, there were numerous times during the monitoring period when no run-off was generated from the sloping surface after a relatively high intensity rainfall event. However, if a second rainfall event occurred immediately following the first one, then run-off was typically more than 50 per cent of rainfall, even though the duration and intensity of the second rainfall event may have been less than the first one.

Monitoring at TP#3 has illustrated that while vertical gradients are still dominant within the cover profile on the sloping surface, the orientation of the cover system and the location along the slope (top, mid, toe) significantly influence net percolation. In addition, the sloped surface monitoring at the Mt Whaleback site has demonstrated that physical and landform stability of the outer slopes of an OSA is the most significant long-term performance concern. Work is in progress to determine the optimal configuration of the outer slopes of the OSAs at Mt Whaleback.

IMPLICATIONS OF TP#1 AND TP#2 FIELD PERFORMANCE

The field data generated from TP#1 and TP#2 was reviewed during the third year of monitoring. Results from the significant Year Two wet season, and initial monitoring during Year Three, indicated that the predicted performance of the 2 m ROM cover system did not agree with measured performance.

Calibration of the soil-atmosphere numerical model

The soil-atmosphere modelling completed prior to construction of the test plots was re-visited by developing a model calibrated to the Year One and Year Two field data. SWCC and hydraulic conductivity data input to the model was altered to develop a model that predicted the same response, in terms of the change in the volume of water on the TP#1 cover profile, as that measured in the field.
Figure 6 shows the model calibration results that were obtained. The model responded to increases and decreases in moisture conditions to the same extent and at the same time as measured in the field. This provided confidence that significant improvement had been achieved in predicting cover system performance, in comparison to the soil-atmosphere modelling completed prior to construction.

The amount of water data shown in Figure 6 for the field measurements is lower than that presented in Figure 3 for Year One and Year Two. At the time model calibration work was completed during Year Three, the raw data from the volumetric water content data was reduced using a ‘default’ calibration curve. Calibration work on the sensors has been completed since that time, which resulted in the development of material specific calibration curves for the cover material. The data shown in Figure 4 are based on the material specific calibration curves.

Improving moisture release from the cover system

The significant rainfall events during the Year Two and Year Three monitoring periods resulted in infiltration reaching to a greater depth than predicted by the modelling completed to design the test plots. As each subsequent rainfall event occurred, moisture was ‘driven’ deeper into the profile. The combination of continued wet climate conditions and gravity overcoming the effects of evaporation led to deeper infiltration than predicted.

The calibrated model was used to simulate different vegetation conditions (transpiration rates and rooting depth) to determine whether the addition of transpiration could improve the measured performance. Figure 7 shows the change in the volume of water in the cover material profile predicted by the calibrated soil-atmosphere model for the Year One and Year Two data, as well as three successive years of Year Two climate data. Bare surface conditions are shown in Figure 7, as well as the predicted performance for the TP#1 cover profile with poorly transpiring vegetation (leaf area index less than 1.0) and a root depth of 1 m. The modelling results indicate that the cover profile could return to antecedent moisture conditions, and reduce net percolation to near zero for the actual Year Two conditions, as well as for each successive Year Two climate year modelled.

It would appear that, in general, a bare moisture store and release cover system at the Mt Whaleback site can control net percolation for average annual rainfall conditions, or even above average rainfall conditions provided the higher than average wet seasons do not occur in succession. However, the addition of vegetation has the potential to significantly improve the long-term performance of a store and release cover system for all climate conditions by removing deeper infiltration. Two key questions arise however, when reviewing the results presented in Figure 7. First, is the vegetation sustainable, and second are the transpiration rates and rooting depths representative of vegetation native to the Pilbara region? In terms of the latter issue, a literature search indicates that minimal knowledge is available on transpiration rates and rooting characteristics for native grasses, shrubs, and woody species in Australia. The majority of research is focused on the response of woody species to changes in water table depths near surface water courses due to de-watering of groundwater systems.

Construction and field performance monitoring of TP#4 and TP#5

It was decided that, in order to address the need for more information on native species transpiration rates and develop a more defensible basis for predicting long-term performance of the Mt Whaleback store and release cover systems, additional field trials were required. Field trials were created on an OSA encapsulating reactive shale (see Waters and O’Kane 2003, these proceedings), within a landform created on the top of the OSA, which had nine different catchment areas ranging in size from 0.17 ha to 0.68 ha. The catchment areas were created by placing approximately 3 m high bund walls of ROM material. Topsoil was placed within the catchment areas to a nominal thickness of 20 mm, and the catchment areas were seeded with various mixes of cover crop and native species.
Moisture monitoring profiles (matric suction and volumetric water content) were installed in June 2001 to a depth of 4.5 m at two of the catchments (i.e., TP#4 and TP#5). The seed mix applied to TP#4 and TP#5 catchments includes *Senna leuresserti*, *Senna notabilis*, *Acacia bivenosa*, *Maireana canosa* and *Triodia wiseana*. Figure 7 shows the cumulative change in moisture content for the TP#1, TP#2, TP#4, and TP#5 test plot profiles. The data shown in Figure 8 'starts' in March 2002 because no rainfall occurred at the site from March 2002 to October 2002, inclusive. The seed applied to the catchment areas has not germinated to any significant extent, although there is evidence of *Acacia bivenosa* and *Triodia wiseana*. However, it would appear that germination of seed within the topsoil itself has resulted in an impact on the surface water balance in that actual evapotranspiration from the TP#4 and TP#5 test plots is greater than actual evaporation at TP#1 and TP#2.

BHP Billiton plans to continue monitoring the test plots for at least three more years to allow for determination of the bulk transpiration rates of the species seeded in the catchment areas. Vegetation monitoring coupled with *in situ* monitoring of the moisture profile will provide defensible data when the soil-atmosphere cover design model is re-visited after the three years of monitoring. In addition, the instrument to measure actual evapotranspiration (Bowen Ratio System) has been re-located from TP#1 to TP#4, and re-commissioned so that actual evapotranspiration rates can be measured directly.

![Figure 7 - Comparison of predicted change in volume of stored water for bare and poorly vegetated surface conditions.](image1)

![Figure 8 - Cumulative change in stored water volume in the cover layer of each test plot.](image2)
Linking cover system performance to impacts on groundwater and surface water receptors

Measured and predicted performance of the cover system for OSAs at Mt Whaleback must also be put into context with seepage characteristics (flow and storage) and geochemistry within the OSA, spontaneous combustion of reactive shale encapsulated within the OSA (see Waters and O’Kane, 2003, these proceedings), and ultimately to impacts on groundwater and surface water receptors. For example, the presence of angle of repose segregated fine and coarse-textured layers and haul truck traffic compacted layers within the OSA will significantly influence moisture and gas transport and storage. The predicted and measured rates of net percolation will be a function of the preferential flow path. The coarse-textured layers will not be the preferential flow path for liquid moisture transport because rainfall events are significantly buffered by the presence of the cover system, and as such the preferred flow path will be the fine-textured material due to its ability to retain moisture. In addition, material within the OSA was placed in a relatively dry condition. Therefore, the OSA material will ‘wet up’ to a field capacity condition (as defined by the net percolation rate, and the unsaturated material properties of the OSA material), before moisture resulting from rainfall events will exit the OSA. Linking cover system performance to surface water and groundwater impacts at the site will include these, as well as other key performance aspects.

SUMMARY DISCUSSION

The data presented for the five-year monitoring period demonstrates the potential for success of the ‘moisture store and release’ type cover system at the Mt Whaleback site. Improved understanding in performance of the moisture store and release ARD control cover system trials is a direct benefit from the current field performance-monitoring program. Key factors controlling performance will continue to be developed and understood through continued monitoring of the bare surface and vegetated cover system field trials.

The following are key lessons learned from the Mt Whaleback ARD control cover system field trials.

1. The importance of field performance monitoring over an extended time frame is clearly illustrated by the Mt Whaleback cover system monitoring database. The cover system has responded differently for each year of the five-year monitoring period with respect to changes in moisture storage and net percolation.

2. Re-visiting the soil-atmosphere cover design model is fundamental because it allows for development of a calibrated model, which can be used for developing defensible predictions of long-term performance. The calibrated model also provides the opportunity to highlight aspects of cover system performance that require further investigation and research.

3. Net percolation measured over the five-year period did not agree with the net percolation predicted by soil-atmosphere cover design modelling completed prior to construction of the field trials. The difference between the climate years modelled beforehand, and the climate conditions during the monitoring period are clearly a significant reason for the difference between the predicted and measured performance.

4. Transpiration is a key aspect of long-term performance of a store and release cover system. In general, bare surface conditions (ie no vegetation) can control net percolation for average climate conditions. However, for extreme wet conditions, or successive years of wetter than average conditions, transpiration is required to control net percolation.

5. Research on transpiration rates and rooting characteristics of native grasses and shrubs is required to ensure that defensible predictions of long-term performance can be developed for store and release cover systems.

6. There is no unique set of input conditions to a field calibrated model. However, the moisture retention and saturated hydraulic conductivity properties developed from field data and during model calibration for this project were different than those developed in the laboratory beforehand. The difference between the laboratory material properties and those developed based on field conditions highlights the need to validate laboratory results in the field, because it is difficult if not impossible to properly replicate field conditions in the laboratory. There are physical, biological, and chemical processes that impact on as-built performance, and generally cannot be simulated in the laboratory.

REFERENCES


