PYRITIC SHALE INTEGRATION INTO WASTE ROCK MANAGEMENT, MT. WHALEBACK[1]

by:

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Abstract. BHP Iron Ore operates the Mt. Whaleback mine in a semi-arid climate adjacent to Newman, Western Australia, approximately 1200 km north-northeast of Perth, Western Australia. More than 2 billion tonnes of waste rock were excavated and deposited on the surface during the past 30 years. Ultimately, approximately 4 billion tonnes will be deposited in waste rock dumps constructed near the open pit. Management of the potentially acid forming pyritic shale is based on the application of state-of-the-art conceptual and numerically modeling tools, and operational considerations. The potentially acid forming material is encapsulated within barren run-of-mine material. A moisture storage and release cover system is employed to control water infiltration on the sloping and horizontal waste rock surfaces. This paper will first summarize the overall environmental management plan at Mt. Whaleback. The rationale for differentiating waste rock types is presented. A summary of the design of the moisture storage and release cover system is offered. Finally, performance of field trials are summarized.

Additional Key Words: acid rock drainage, cover systems, field test plots, waste rock management

Introduction

The Mt. Whaleback iron ore mine is located in the Hamersley Iron Province in the northwestern corner of Australia and situated adjacent to Newman, WA approximately 1200 km north-northeast of Perth, WA. Development of the mine started in 1968. The mine currently produces approximately 23 million tonnes of iron ore and moves 90 million tonnes of waste material annually. BHP Iron Ore initiated research programs in January of 1995 to develop long term plans for decommissioning of the waste rock material at their Mt. Whaleback operation. More than 2 billion tonnes of waste rock were deposited during the past 30 years. Ultimately, the operators will deposit a total of approximately 5 billion tonnes in waste rock dumps constructed near the open pit. The Mt. Whaleback operation is located in a semi-arid climate.

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Background

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

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

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units have the potential to produce in the range of 50 to 100 kg of H_2SO_4 per tonne of waste rock (Graeme Campbell & Associates, 1996). The disseminated and nodular Mt. McRae Shale units may oxidize rapidly once exposed to the atmosphere. The non-acid forming (NAF) materials typically have low concentrations of pyrite and a low to moderate capacity to consume acid.

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

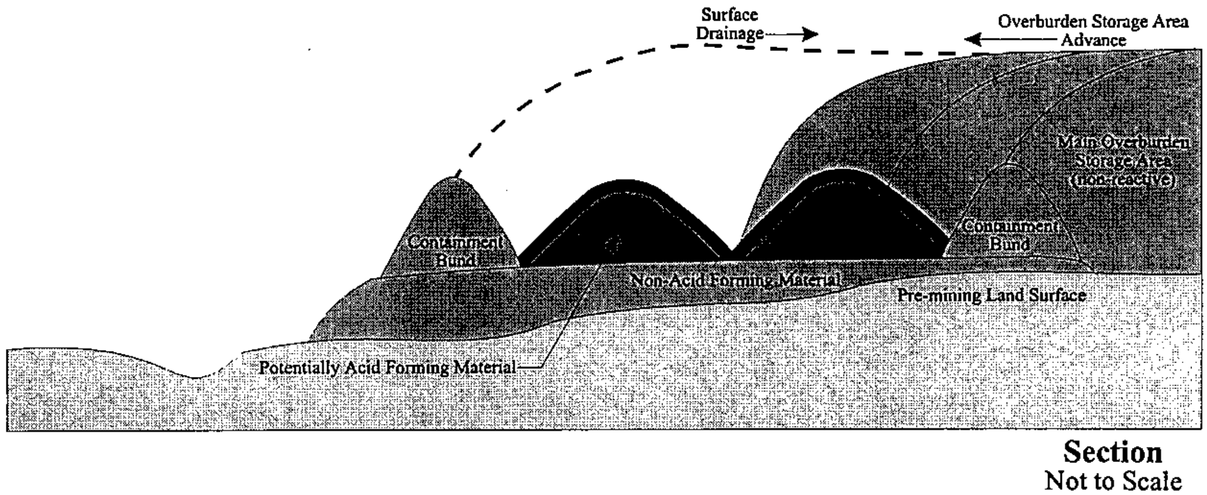

Figure 1 Schematic representation of encapsulation method for potentially acid forming waste rock.

Encapsulation of Pyritic Waste Rock

Management of potentially acid forming (PAF) waste rock focuses on selective handling and burial using an encapsulation approach, as shown schematically in Figure 1. The objective is to control entry of atmospheric moisture to the encapsulated PAF waste rock material thus controlling acid rock drainage (ARD). Ingress of atmospheric oxygen to the PAF material will be reduced as compared to uncovered PAF material. However, the objective of the encapsulation method is not to specifically limit ingress of atmospheric oxygen.

Currently the PAF waste rock is placed on existing non-acid forming (NAF) waste rock piles. The typical height of the NAF waste rock piles is approximately 25 m.

Rationale for differentiating waste rock types

The Mt. Whaleback mine is one of the worlds largest and most complex hematitic iron ore deposits. The overburden and interbedded materials are primarily composed of Banded Iron Formation (BIF), dolerites, and shales. These are folded and faulted into various formations and present significant operational challenges.

The overburden materials were studied for their chemical and physical properties to ascertain their relative reactivity and suitability for use in the encapsulation process. These studies have shown that approximately 90% of the overburden is NAF, has the desired water holding capabilities, and therefore suitable for use in the encapsulation process. It is important that the NAF materials are selectively placed, below, around, and on the top of the PAF material to ensure that the encapsulation is successful

The NAF material is typically blocky and well graded, but deficient in nutrients. This provides challenges in rehabilitation efforts however it provides superior erosion resistance as these materials are very effective in armoring the surface. Coupled with effective water management techniques, this should help to maintain the stability and integrity of the encapsulated areas.

Cover system design philosophy

ARD is a major environmental problem facing the mining industry today. ARD is the result of the combined chemical and biological oxidation of sulphide minerals and the release of associated metals, such as iron, aluminum, manganese, and other heavy metals. Mine waste rock and tailings that contain sulphide minerals will react with atmospheric oxygen and water to produce sulphuric acid. Waste rock and tailings materials often have some potential to neutralize the acid generated. The net acid released to the collection system and/or environment is defined as acid rock drainage.

It is common practice to construct single or multi-layered engineered cover systems to control ARD from mine waste rock and tailings. The three principal objectives of cover systems are: 1) to function as an oxygen ingress barrier for the underlying PAF waste material; 2) to function as a water infiltration barrier for the underlying PAF waste material; and 3) to provide a medium for establishing a sustainable vegetation cover that is consistent with the current and final land use of the area.

It is difficult and usually not economically feasible in arid and semi-arid climates to construct a cover system which 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 evapotranspiration will be significant. However, subjecting the cover system to evaporative demands can be beneficial in arid climates and result in a reduction of infiltration to the underlying sulphidic waste material. An upper cover surface layer possessing sufficient storage capacity can be used to retain water during a precipitation event or freshet. Subsequent to the increase in moisture storage in the upper layer, it would release a significant portion of pore water to the atmosphere by evapotranspiration during extended dry periods, thereby reducing the net infiltration across the soil cover system. The objective is to control acid rock drainage as a result of preventing moisture movement into and through the waste rock material. A cover system with the above objectives is often referred to as a "moisture store and release" type cover system.

Durham (1999) reported on the performance of two cover system trials constructed at the Kidston Gold Mines in the state of Queensland, Australia. Average annual potential evaporation for the site was approximately 1900 mm and exceeded average annual precipitation by almost 1200 mm. Three years of monitoring demonstrated the promise of a moisture store and release type cover system design for the site as well as the importance of maintaining good vegetation. The field trial cover systems were constructed using well graded non-acid forming run-of-mine waste. No moisture has reported to the lysimeters (see Bews *et al.*, 1997 for design details) installed to measure percolation to the underlying potentially acid forming waste during the three year monitoring period (Durham, 1999). However, a progressively longer period of time was required to reduce moisture conditions in the run-of-mine cover material to pre-wet season conditions following the wet season precipitation. Vegetation is not as well established as compared to earlier in the monitoring period and appears to be a key factor for successful performance of the store and release cover system trials. Transpiration is a key component of the water balance and appears to significantly reduce moisture conditions in the run-of-mine cover material profiles. It is postulated that nutrient deficiency is the likely contributor to the vegetation problems and is being addressed (Durham, 1999).

Swanson (1995) modelled field measurements and conducted predictive soil-atmosphere saturated-unsaturated numerical modelling of a moisture store and release cover system constructed on the waste rock material at the Golden Sunlight Mine in the state of Montana, USA. The site is located in a semi-arid climate where average annual potential evaporation exceeds average annual precipitation. The site experiences freezing conditions and snow fall. A well graded oxidized cap rock material was placed over steeply sloping waste rock piles at the site. Swanson (1995) predicted no net infiltration would percolate to the underlying waste material for the historic annual dry and mean annual precipitation records. Percolation to the underlying waste rock was predicted to be approximately 7% of the historic annual wet precipitation record. A reduction in oxygen ingress of 30% from uncovered conditions was predicted for the mean historic climate record. The key benefit of the cover system comes in the ability to provide a sufficient depth of homogenized non-acid forming material at the surface of the waste rock pile (Swanson, 1995). A waste rock pile characterization field and laboratory research program completed by Herasymuik (1995) illustrated the performance of the Golden Sunlight Mine waste rock piles and verified Swanson's (1995) predictions.

<u>Mt. Whaleback cover system design philosophy</u>. It is not feasible to limit the ingress of oxygen to the PAF material at the Mt. Whaleback operation. In addition, it is not practical to attempt to control the bacteriological activity within the waste material. The most promising closure option to control ARD at the Mt. Whaleback operation is the utilization of a moisture "store and release" cover system which takes advantage of the high evaporative conditions at the site. The Mt. Whaleback

cover system is designed to accept as much rainfall as possible, while minimizing runoff and associated erosion, with all infiltration remaining within the cover material. The cover system is constructed using suitable NAF run-of-mine waste material to minimize closure costs. The moisture is subsequently released to the atmosphere as evapotranspiration with the design objective being a near "net zero moisture transfer" from the run-of-mine cover material to the underlying PAF waste rock. The objective is to control ARD as a result of preventing moisture movement into and through the waste rock material.

The principles applied to the design of the Mt. Whaleback cover system are well developed and established by researchers and practitioners around the world. The key design principle is the utilization of unsaturated soil mechanics (Fredlund and Rahardjo, 1993) to describe the flow and storage of heat and moisture. Additional design principles as described by Wilson *et al.* (1994), Bews *et al.* (1997), and Wilson *et al.* (1997) were employed to couple the performance of the cover system to site climate conditions.

Field Test Plots to Demonstrate Moisture Store and Release Cover System

Two 1 ha field test plots were constructed in February, 1997 to verify the results predicted by soil-atmosphere modelling as described by O'Kane *et al.* (1998). The test plots were constructed with common operational considerations. Test Plot No.1 had a cover thickness of 2 m since this consisted of a single lift of material placed on the original waste rock surface by 240 tonne capacity haul trucks. Two lifts of material were placed during construction of Test Plot No.2 to achieve a 4 m cover layer thickness. A field performance monitoring program was designed and instruments were installed in each test plot in August, 1997.

The Test Plot No.3 area is on the sloped surface of a historic waste rock dump originally at angle of repose. The slope of the test plot area was reduced to approximately 20° and the surface landscaped to "moonscape" features as part of historic reclamation research activities at the site. The undulating moonscape features were removed and an area approximately 165m long (top to bottom of slope) x 45 m wide was leveled in January, 1998 to serve as Test Plot No.3. A sediment collection area was also prepared and extends 40 m from the toe of the sloped test plot area. A berm was constructed around the sediment collection area to prevent migration of sediment associated with runoff events outside the test plot area.

Field performance monitoring

Field performance of the horizontal surface field test plots (i.e. Test Plot No.1 and No.2) is monitored by a system designed to measure infiltration to the underlying waste rock, changes in moisture conditions within the cover material profile, and climate conditions. Large-scale lysimeters to measure infiltration into the underlying waste rock were installed in Test Plots No. 1 and No. 2 in January, 1997 prior to construction of the test plots. The remaining components of the monitoring system were installed in August, 1997. The performance of the sloped surface field test plot is monitored by a tipping bucket rain gauge as well as moisture and temperature sensors installed laterally from six access culverts. Two sets of access culverts were installed at the top, mid-slope, and base of the slope. The Test Plot No.3 monitoring system was installed during a January, 1998 site visit. All field monitoring instruments are controlled by remote data acquisition systems.

Summary of Performance

Performance of the ARD control cover system trials can be summarized by evaluating: 1) the change in moisture storage within the cover material; and 2) determining the extent of infiltration, following a rainfall event. The response of the field lysimeters (tanks to measure percolation from the base of the run-of-mine cover material) is also a good indication of cover performance. The change in moisture storage within the cover material is calculated based on the combined response of the various water content sensors installed in the profile of the cover material. The extent of infiltration is determined by noting the response to a rainfall event by individual sensors installed at increasing depths below the surface of the cover material.

Change in Moisture Storage

It was assumed the volume of solids remained relatively constant since construction of the Mt. Whaleback ARD cover system trials. Using a similar assumption for the total volume and a unit area perspective, the total volume is equal to the depth of the run-of-mine material placed on the test plot in question. Accordingly, the volume of voids also remained constant since construction.

A porosity equal to 0.34 was used for the run-of-mine cover material during moisture storage calculations and was based on field and laboratory measurements. Run-of-mine cover material thickness at Test Plot No.1 is approximately 2 m. Therefore, the volume of voids, V_v, or the maximum volume of water storage available for infiltrating water is equal to the porosity multiplied by the depth, or approximately 0.68 m. This is also representative of the "assumed cover thickness" for the sloped test plot (Test Plot No. 3). The maximum volume of water storage available for Test Plot No. 2 is approximately 1.36 m (i.e. 0.34 × 4 m).

The ratio between the volume of air, V_a, and volume of water, V_w, within the test plot run-of-mine cover material profiles is based on the response of the moisture content sensors prior to, during, and subsequent to rainfall events. The sensors measure an increase in the volume of water within the run-of-mine cover material profiles as the water content increases in response to rainfall. A subsequent decrease in the volume of water within the run-of-mine cover material profiles can be calculated as the water content decreases in response to evaporation.

Figure 2 shows the change in the volume of water within the Test Plot No.1 run-of-mine cover material profile since construction. Approximately 770 mm of rain was recorded at the horizontal surface test plot area during this period. A net increase of approximately 118 mm in the volume of water within the Test Plot No.1 run-of-mine cover material profile was measured for the same period. Rainfall during the months of December, 1998, January, 1999, and February, 1999 (≈ 420 mm) accounted for the 118 mm net increase in volume of water within the cover material profile. It is anticipated that forthcoming extended dry climate conditions will result in evaporation from the Test Plot No.1 run-of-mine cover material profile and a return to antecedent moisture conditions. In other words, at the current time the Test Plot No.1 run-of mine cover material profile has not had the opportunity to respond to atmospheric demand for moisture, decrease in moisture content following rainfall during the months of December, 1998 to February, 1999 inclusive, and return to moisture conditions prior to December, 1998.

Rationale for the anticipated return to antecedent moisture conditions was based on the response of the Test Plot No.1 run-of-mine cover material profile to the significant single rainfall event in February, 1998 (≈ 80 mm). Rainfall during the February, 1998 event caused an approximate 40 mm net increase in the volume of water within the Test Plot No.1 run-of-mine cover material profile. The net increase was eventually reduced to a negligible volume following moderate unseasonable June, 1998 rainfall and subsequent seasonable dry climate conditions, as shown in Figure 2. The high potential evaporative climate conditions following wet climate conditions is a key factor controlling hydraulic performance of the Mt. Whaleback ARD control cover system trials. Evaporation of the cover material profile during the dry climate conditions allowed the profile to return to antecedent conditions and begin the "wet season" at a low degree of saturation in preparation for infiltration resulting from rain.

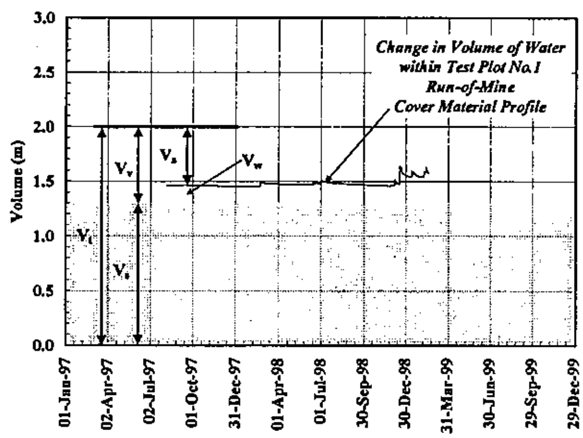

Figure 2 Cumulative change in moisture storage (i.e. V_w) in Test Plot No.1 run-of-mine cover material profile.

The 118 mm net increase in the volume of water within the Test Plot No.1 run-of-mine cover material profile since construction represents approximately 17.5% of the volume of voids available in the profile (i.e. 118 mm ÷ 680 mm). The antecedent volume of water in the cover material profile is approximately 20% of the volume of voids available (i.e. 137 mm ÷ 680 mm). Hence, approximately 37.5% of the volume of voids available for water within the Test Plot No.1 cover material profile were filled with water (i.e. [118 mm + 137 mm] ÷ 680 mm) following rainfall during the months of December, 1998 to February, 1999 inclusive. It is fundamental to understand that an additional 62.5%, or 425 mm, of the volume of voids is currently filled with air and theoretically available for infiltration of water.

Figure 3 shows the change in the volume of water within the Test Plot No.2 run-of-mine cover material profile since construction. A 247 mm, or

18.2%, net increase in the volume of water within the Test Plot No.2 run-of-mine cover material profile was measured since construction.

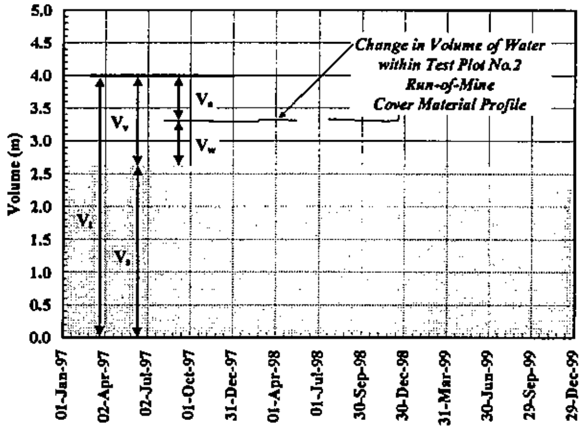

Figure 3 Cumulative change in moisture storage (i.e. V_w) in Test Plot No.2 run-of-mine cover material profile.

The volume of water within the Test Plot No.2 run-of-mine cover material profile subsequent to construction was approximately 665 mm, or 49% of the volume of voids. Rainfall during placement of the Test Plot No.2 run-of-mine cover material appears to have led to higher "antecedent" moisture conditions within the Test Plot No.2 cover material as compared to Test Plot No.1. The 247 mm net increase in the volume of water within the Test Plot No.2 run-of-mine cover material profile was a result of rainfall during the months of December, 1998 to February, 1999 inclusive. The current volume of water within the Test Plot No.2 profile represents approximately 67% of the volume of voids (i.e. [247 mm + 665 mm] ÷ 1360 mm) available for air and/or water. Hence, approximately 33%, or nearly 450 mm, of the volume of voids is currently filled with air and theoretically available for further storage of water infiltration resulting from rain.

The Test Plot No.2 run-of-mine cover material profile responded to the February, 1998 rainfall event in a similar manner to that described for Test Plot No.1. That is, moisture conditions prior to the February, 1998 rainfall event were achieved following an opportunity for the cover material profile to respond to atmospheric demand for moisture. Therefore, it is reasonable to anticipate the increase in the volume of water within the Test Plot No.2 run-of-mine cover material profile will dissipate during the forthcoming dry climate conditions.

Depth of Infiltration

Suction is a fundamental measure of moisture conditions in an unsaturated porous medium. It is a measure of the negative pressure head present in the material and a suction sensor can be thought of as a piezometer of the unsaturated zone. In simple terms, low suctions imply a high degree of saturation and high suctions imply a low degree of saturation. The response of the suction sensors installed at the test plot run-of-mine cover material profiles can be used to estimate the depth of infiltration, or increase in moisture conditions with depth, as a result of rainfall. A decrease in suction recorded by a particular sensor implies an increase in water content (i.e. degree of saturation) and is an indication of the depth of advancement of a wetting front resulting from rainfall.

The response of the suction sensor installed at 2 m below the surface of the Test Plot No.1 run-of-mine cover material profile (i.e. at the base of the run-of-mine cover material placed during construction) is shown in Figure 4 for the measurement period covering August, 1997 to February, 1999. Rainfall during the 1997-1998 wet season infiltrated to the a depth of 2 m in the Test Plot No.1 run-of-mine cover material because suction decreased by one order of magnitude from approximately 2,000 kPa to about 200 kPa.

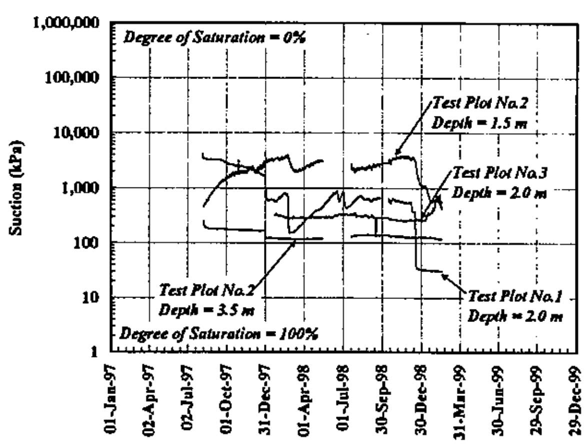

Figure 4 Depth of infiltration measured by soil suction sensor response in Test Plot No.1 (2.0 m), Test Plot No.2 (1.5 m and 3.5 m), and Test Plot No.3 (2.0 m).

Suction measured at a depth of 2 m increased to approximately 1,000 kPa following the 1997-1998 wet season as a result of evaporation. This was followed by a marginal decrease in suction, as moisture infiltrated to the base of the run-of-mine cover material profile in response to June, 1998 rainfall. Rainfall during the months of December, 1998 to February, 1999 led to a decrease in suction from approximately 800 kPa to approximately 30 kPa at a depth of 2 m in response to infiltration, as shown in Figure 4.

The suction sensor installed at a depth of 2 m below the surface of the Test Plot No.2 run-of-mine cover material profile did not function properly throughout the monitoring period shown in Figure 4. However, the response of the suction sensors installed at depths of 1.5 m and 3.5 m bound the depth of water infiltration following rainfall during the monitoring period. The suction sensor installed at 1.5 m responded to an advancing wetting front following rainfall while the suction sensor installed at 3.5 m measured a relatively constant suction. Response by the latter sensor indicates no change in moisture conditions at a depth of 3.5 m in the Test Plot No.2 run-of-mine cover material profile throughout the monitoring period.

The response shown on Figure 4 of the Test Plot No.3 suction sensor installed at a depth of 2 m illustrates the impact of a sloped waste rock surface on infiltration resulting from rainfall at the Mt. Whaleback site. Measured suction at a depth of 2 m below a sloped run-of-mine cover material surface did not decrease during the monitoring period. This is in sharp contrast to the response of the suction sensor at 2 m below the horizontal surface of the Test Plot No.1 run-of-mine cover material surface where suction responded dramatically to infiltration following rainfall. It appears that the sloped surface at Test Plot No.3 enhanced surface runoff during rainfall and decreased infiltration as well as the depth of infiltration.

Percolation from the base of the run-of-mine cover material

O'Kane et al. (1998) presented the design of the two lysimeters installed into the existing waste rock dump surface at each of the Test Plot No.1 and Test Plot No.2 ARD control cover system trials prior to placement of run-of-mine cover material. No water has reported to the base of the lysimeters installed to monitor percolation from the base of the Test Plot No.1 and Test Plot No.2 run-of-mine cover material during the monitoring period.

Integration with operational issues

Material identified as net acid generating (NAG) is flagged within each mining block for separate excavation and transport to designated overburden storage areas following classification of material from the blast hole cones. Quality control personnel on each shift establish and locate identification tapes showing the boundaries of the NAG material and monitor the excavation process (a similar procedure is used for ore grade control).

Each haul truck at the Mt. Whaleback operation have Global Positioning Systems (GPS) on board and their location is continuously monitored using GPS interfaced Truck Dispatch software. Accuracy of location of the GPS on board the trucks is approximately 5 m. Dumping areas are defined by a polygon in the truck dispatch system. Trucks are given a destination (e.g. crusher, stockpile, overburden storage area) using the Truck Dispatch system. Similarly, the trucks carrying NAG material are sent to a designated NAG storage area. The entrance to each dumping location is controlled by a beacon in the truck dispatch system. A warning alarm is triggered in the truck and on the truck dispatchers computer if a truck loaded with NAG material passes a "non-NAG" beacon (i.e. enters the wrong dump area). These beacons are located considerable distances from the tipping point and there is time for both the truck driver and the dispatcher to react and avoid dumping in undesignated areas. Truck Dispatch also records the location of every load of material that is placed in these locations. This allows for audits to be conducted to ensure that NAG materials are properly placed in areas to be encapsulated.

The workforce and supervision have been made aware of the issues with NAG placement and management. This process is ongoing to ensure that all personnel understand the importance of this issue and their roles in effectuating the desired outcome.

The management of NAG materials in the manner described has been followed with success and minimal operational difficulties have been encountered in implementing the cover system design philosophy.

Summary and Discussion

Evidence that infiltration advanced to a depth of approximately 2 m below the horizontal surface of the Test Plot No.1 and Test Plot No.2 run-of-mine cover material was obtained during the August, 1997 to February, 1999 monitoring period. The infiltration did not advance to a depth of 2 m during the monitoring period at the sloped surface field test plot. It would appear surface runoff at the sloped surface test plot led to the change in cover performance.

Infiltration resulting from rainfall during a February, 1998 event led to an increase in the volume of water within the run-of-mine cover material profiles. However, the increase in the volume of water did not reach the capacity of the cover material profile. Moisture conditions within the profiles returned to antecedent conditions during the subsequent dry climate conditions. Rainfall during the months of December, 1998, January, 1999, and February, 1999 also led to an increase in the volume of water within the run-of-mine cover material profiles. The increase was approximately three times more as compared to the February, 1998 rainfall event due to the greater amount of rainfall during the latter three month period. Approximately 420 mm of rain was measured at the test plot area during the latter three month period as compared to nearly 80 mm during the single February, 1998 event. The increase in the volume of water within the run-of-mine cover material profiles during the three month period did not reach the capacity of the profiles. It is anticipated that forthcoming dry climate conditions at the Mt. Whaleback site will provide the required atmospheric demand for moisture from the run-of-mine cover material profiles to return the profile to antecedent conditions prior to the next wet season.

The data presented for an eighteen month monitoring period has demonstrated the potential for success of the "moisture store and release" type cover system at the BHP Iron Ore Mt. Whaleback site. It is fundamental to understand though that the eighteen months of monitoring are simply a brief "snapshot" in time and should not be taken as being indicative of long term performance. The improved understanding in performance of the moisture store and release ARD control cover system trials is the direct benefit of the current field performance monitoring program. Key factors controlling performance will continue to be developed and understood. The data base required for field calibration of a coupled heat and mass transfer soil-atmosphere saturated-unsaturated numerical model is being developed. Accurate, and more importantly defensible, predictions for long term performance of the Mt. Whaleback ARD control waste rock cover system can only be obtained using a predictive tool properly calibrated to field conditions.

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