Title: Demonstration of the Application of a Soil Moisture Monitoring System at the Mt. Leyshon Tailings Dam and Waste Rock Cover System

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Conference: ICARD6

ABSTRACT

Newmont Australia is the operator of the Mt. Leyshon mine near Charters Towers, Queensland. Mt. Leyshon is an open cut gold mine, which processed on average 5.0 Mt of ore and produced up to 250,000 ounces of gold per year. Mining was completed in early 2001, followed by treatment of low-grade ore stockpiles for a further 12 months. Approximately 250 ha of waste rock dumps have been rehabilitated. Rehabilitation of two of the three tailings storage facilities (TSF) has been completed and the third is in progress.

A field performance monitoring system that includes an automated meteorological station, large-scale lysimeters (measurement of net percolation), and *in situ* moisture content sensors (measurement of moisture storage changes in the cover material) were installed to monitoring performance of the cover systems placed on the waste storage facilities. This paper focuses on the installation and calibration of the *in situ* moisture monitoring system. The moisture monitoring system provides automated detailed *in situ* volumetric water content data above and within the large-scale lysimeters. A portable unit that provides spatial *in situ* moisture content measurements at additional locations on the cover system is also utilised. The paper will focus on installation and calibration of the *in situ* water content monitoring instrument in the waste rock, coarse cover material, and fine textured cover material.

INTRODUCTION

Acid rock drainage is (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, copper, 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 neutralise the acid generated. The net acid released to the collection system and/or environment is defined as acid rock drainage.

Dry cover systems as a closure option for management and decommissioning of waste rock and tailings is a common ARD prevention and control technique used at numerous sites around the world. The primary purpose of placing dry cover systems over reactive waste material is to minimise further degradation of the receiving environment following closure of the waste impoundment. This requires long-term control of the quality of surface runoff and seepage waters from the waste facility to protect the local surface and groundwater systems.

Another important purpose of dry cover systems is to provide a medium for establishing a sustainable vegetation cover that is consistent with the final land use of the area. Achieving this goal will minimise the effects of water and wind erosion on the surface of the cover system, thereby providing stability of the engineered structure in the long term. The establishment of a vegetation cover using native species will also potentially restore wildlife habitat lost from the development of the waste facility. Vegetation is also vital to the long-term performance of dry cover systems in terms of controlling net percolation to the underlying waste material.

The net percolation across a mine waste cover system is an important consideration in the design of a closure system for a mine waste disposal facility. The objective is to control/limit the quantity of water that flows downward through the cover to the underlying waste material, because the infiltrating water ultimately contributes to subsequent production of ARD. The net percolation is a function of, in general, the total precipitation, actual evapotranspiration, change in soil moisture storage, and runoff.

Verification of the full-scale implementation of a cover system or of a research test plot is a key component of a mine closure plan. In general, the objectives of a cover system field performance monitoring system are:

1) to develop an understanding for key processes and characteristics that control cover system performance;
2) to identify practical construction and implementation issues;
3) to develop a database to calibrate a numerical model; and
4) to develop credibility with respect to mine closure performance.

Field performance monitoring involves measuring site atmospheric conditions, vegetation development and sustainability, surface runoff, *in situ* moisture and heat storage/transfer within the cover layers and underlying waste (vertical and lateral), oxygen ingress, and percolation of moisture to the underlying waste from the base of the cover layers. *In situ* moisture conditions are a key component of the field performance monitoring system because a cover system installed to control ARD relies on moisture retention (i.e. control of oxygen ingress), and/or moisture storage and release (i.e. control of water infiltration).

A need exists to develop a practical, robust, accurate *in situ* moisture monitoring system, capable of being installed in relatively coarse but well-graded waste rock, as well as mine tailings. The issue is that the vast majority, if not all, commercial moisture monitoring sensors have been developed for the agriculture industry, where *in situ* materials do not possess the extreme textures and conditions encountered in the mining industry. This paper describes a project undertaken by four companies to evaluate the applicability of the Sentek Sensor Technologies moisture monitoring system to materials and conditions typically encountered at mine sites.

BACKGROUND

Newmont and its Mt. Leyshon Operations, Sentek Sensor Technologies Pty Ltd., (Sentek), Integrated Environmental Services Australia Pty Ltd. (IESA), and O'Kane Consultants Inc. (OKC) have agreed to work cooperatively in conducting a field evaluation of Sentek's field moisture measurement system at Newmont's Mt. Leyshon site in Queensland, Australia. This paper discusses the objectives of the field evaluation trials, presents the laboratory calibration work completed for the sensors using the Mt. Leyshon materials, and provides discussion on the results and interpretation of the laboratory calibration programme.

Newmont Australia – Mt. Leyshon Operation

Newmont is the world's largest gold producer with assets and operations on five continents. Newmont is also engaged in the exploration for and acquisition of gold properties. Newmont operates core assets in Peru, the United States, Australia and Indonesia.

The Mt. Leyshon mine site, owned and operated by Newmont, is located 24 km south of Charters Towers in Queensland. The mine has operated since 1987 producing gold ore from an open cut operation. Mining ceased near the end of 2001, and was followed by treatment of low-grade ore for an additional ten months. The climate at the mine site is considered semi-arid with 660 mm of annual precipitation falling in high intensity storms between November and March. The average annual pan evaporation is approximately 2000 mm.

Sentek Sensor Technologies

Sentek is an Australian based company with products now used to monitor and manage water in a variety of markets segments, such as agriculture, mining, turf, wastewater, and environmental applications. Sentek contributed to the project by supplying the moisture monitoring system installed at the site.

Integrated Environmental Services Australia

IESA is an Australian based firm that provides a complete range of professional services including investigations, specialist fieldwork, sample collection/analysis, and reporting services within the environmental science, instrumentation and hydrogeologic disciplines. IESA contributed to this project by assisting with the installation of the Sentek monitoring systems and developing material-specific calibration curves for the monitoring systems in their Mackay, Qld. laboratory.

O’Kane Consultants Inc.

OKC is a geotechnical engineering consulting firm based in Saskatchewan, Canada. OKC provides material characterisation and numerical modelling services associated with the design, construction, and field performance monitoring of mine waste cover systems. OKC contributing to this project by assisting with the installation of the

Sentek monitoring systems and reducing, interpreting and reporting the data gathered from the monitoring systems.

Installation of Field Performance Monitoring System

Newmont has installed large-scale lysimeters and automated meteorological stations to monitor performance of cover systems installed on tailings storage facilities (TSFs) and overburden storage areas (OSAs). Sentek's EnviroSCAN and Diviner 2000 monitoring systems were installed in the TSF and OSA cover systems in December 2000 to compliment the lysimeters and meteorological stations, and provide a more complete picture of cover performance at the site.

Three tailings storage facilities are located on the mine site. One tailings pond, the Old North tailings storage facility (ONTSF), was selected for the project. The ONTSF been capped with two to three metres of waste rock to allow machinery access. A dry cover system consisting of 0.6 m of compacted heap leach material and 0.3 m of topsoil was then placed over the waste rock surface. Sentek EnviroSCAN and Diviner 2000 access tubes were installed in the cover system at the ONTSF.

The OSAs at the site are capped with a minimum of 0.8 m of compacted porphyry waste rock, overlain with 0.3 m of topsoil to promote vegetation growth. Sentek EnviroSCAN and Diviner 2000 access tubes were installed in a portion of the OSA cover system, which at the time was under construction. The cover system for the Mt. Leyshon OSAs has since been completed.

For the purposes of this paper, the details of the sensor depths, access tube locations, and other details of the field performance monitoring system are not required. In addition, correlation of the moisture storage values with the response of the lysimeters (i.e. development of a cover system water balance) is not within the scope of this paper. The focus of this paper is on the laboratory calibration methodology undertaken, as well as the results of the calibration programme itself. Discussion is also provided on the implications of the results as related to mine waste cover performance monitoring.

LABORATORY CALIBRATION OF SENTEK SENSORS IN MT. LEYSHON COVER MATERIALS

EnviroSCAN is an integrated monitoring system consisting of multiple sensors positioned in access tubes, which are inserted into the ground without disturbing the soil texture to be measured. This allows measurement of the soil moisture at different levels. Sensors are connected to probes (up to 16 sensors per probe), which are then inserted into the access tubes. The probes and associated sensors can be accessed and controlled using a variety of interface boards, such that it is possible to utilise virtually any data acquisition system.

The Diviner 2000, which utilises the same core technology as the EnviroSCAN, is a stand-alone portable, less expensive unit, comprising one sensor on a shaft with an automatic depth sensor. The patented ‘Swipe and Go^{TM}’ technology means that the Diviner 2000 does not need to be held at each depth in the soil profile. The encapsulated capacitance sensor is swiped in and out of the access tube to take a reading, measuring up to 16 depths in just a few seconds. The probe is connected to a hand-held display unit which gives the operator graphical displays of the data, as well as storage of multiple sets of readings. The display unit can be connected to a personal computer to download the data.

The EnviroSCAN and Diviner 2000 systems use electrical capacitance to measure the *in situ* volumetric water content of the material surrounding the access tube. A high frequency electrical field, created around each sensor, extends through the access tube into the soil. The magnitude of the frequency is a function of the apparent dielectric constant of the soil (K_a), which is strongly dependent on the volumetric water content of the soil. This is due to the large difference in the dielectric constant values for each of the soil matrix components ($K_{water} \approx 81$; $K_{solids} \approx 4\text{-}8$; $K_{air} \approx 1$) (Hillel, 1998). The more water in the soil, the higher the K_a value and the lower the frequency measured by the sensor. A calibration curve is then used to convert the field-measured frequency to a volumetric water content value for each sensor.

Sentek has developed standard "default" calibration equations using sands, loams, and clay loams for the EnviroSCAN and Diviner 2000 systems. This is suitable for assessing "relative" changes in the *in situ* moisture conditions; however, material-specific calibration curves are required to quantitatively assess the *in situ* volumetric water content with the measurement systems. Material-specific calibration testing was completed for four different materials used in the Mt. Leyshon TSF and OSA cover system designs.

The main objective of the laboratory calibration process was to compile material-specific calibration curves for the EnviroSCAN and Diviner 2000 sensors for each of the four cover materials. In addition, the effect of material texture and material density on the laboratory calibration curves was investigated.

Calibration Methodology

Representative samples were collected for each cover material present in the OSA and TSF dry cover systems. The OSA cover system includes a porphyry rock layer and a topsoil layer overlying waste rock material. The ONTSF cover system includes a base waste rock layer with overlying heap leach material and topsoil layers. Note that the moisture monitoring systems were not installed into tailings material. Large bulk samples were collected in 20 litre pails and 200 litre drums for use in the laboratory calibration programme.

Table 1 summarises the full set of tests completed during the laboratory calibration programme. The densities used in the calibration of the materials were representative of densities measured at the Mt. Leyshon site with a nuclear density meter during installation of the monitoring systems. The calibration work was completed on bulk samples representative of the entire particle size distribution for the porphyry rock and waste rock materials. Both the porphyry and waste rock materials possess a significant amount of coarse materials with approximately 30% and 50% of the samples greater than 19 mm in size for the porphyry and waste rock materials, respectively. Additional calibration measurements were completed on screened samples (material less than 4.75 mm) for comparison to the calibration curves developed for the bulk samples to determine whether a smaller sized fraction can be tested to accurately reflect the characteristics of the porphyry and waste rock materials.

Table 1. Summary of the laboratory calibration testing programme.

Calibration Run	**Material type**	**Density (kg/m^3)**	**Material Size Tested**
1	Topsoil	1600	Entire bulk sample
2	Topsoil	1900	Entire bulk sample
3	Porphyry rock	1900	< 4.75 mm
4	Porphyry rock	1900	Entire bulk sample
5	Porphyry rock	2200	< 4.75 mm
6	Porphyry rock	2200	Entire bulk sample
7	Waste rock	1900	< 4.75 mm
8	Waste rock	1900	Entire bulk sample
9	Waste rock	2200	< 4.75 mm
10	Waste rock	2200	Entire bulk sample
11	Heap leach rock	1900	Entire bulk sample
12	Heap leach rock	2200	Entire bulk sample

The materials were mixed to target gravimetric water contents, then placed and compacted into the measurement mold shown in Figure 1. The calibration mold is a cylindrical galvanised steel vessel, with and inside diameter of 550 mm and a height of 500 mm. The material was placed and compacted in 5 cm lifts to a depth of approximately 45 cm. For saturated and field-drained moisture contents the materials where mixed to a known moisture condition, compacted and then saturated by low-pressure injection of potable water through ports located in the base of the calibration mold. The field-drained condition was achieved by allowing a compacted and saturated sample to gravity drain via the basal ports until free water was evacuated.

Measurements of the volumetric water content were taken with both the EnviroSCAN and Diviner 2000 sensors at three different depths.

The reading captured by the moisture monitoring sensors is called the scaled frequency. Scaled frequency is a comparison of the water content of the surrounding material to a water content of zero (a constant measurement of the sensor in air) and a 100% water content (a constant measurement of the sensor in water). A material sample was collected for measurement of the gravimetric water content after the sensor measurements were obtained. The volumetric water content was calculated from the product of the gravimetric water content and the material density, with the latter being measured using sand replacement techniques as the material within the calibration vessel was removed.

A more accurate calibration curve defining the relationship between scaled frequency and volumetric water content can be created using a wide range of moisture contents. The calibration curve generated is much more accurate if the scaled frequency is measured across the potential range of volumetric water content for a given material. The following five different moisture conditions were targeted in the calibration process:

- One point on oven-dried material;
- Three points at varying moisture contents; and
- One point at 100% saturation.

Presentation and Discussion of Sensor Calibration Results

Figure 2 shows a sample of the calibration results for the four material types obtained with the EnviroSCAN sensor, and also includes the Sentek “default” calibration curve. Table 2 summarises the results of the entire laboratory calibration programme. The data points collected in the calibration procedure were curve fit with the equation:

$$SF = A \cdot VWC^{B} + C$$

where: SF = scaled frequency,

A = best fit coefficient A,

VWC = volumetric water content,

B = best fit coefficient B, and

C = best fit coefficient C.

Table 2. Calibration equation coefficients developed for the Mt. Leyshon materials.

Material	Material Size Tested	Density (kg/m^3)	EnviroSCAN			Diviner 2000		
			A	B	C	A	B	C
Topsoil	Bulk	1,600	1.65	0.55	0.12	1.44	0.327	0
Topsoil	Bulk	1,900	1.32	0.279	0	1.27	0.215	0
Porphyry rock	Bulk	1,900	1.29	0.31	0.02	1.26	0.32	0.10
Porphyry rock	Bulk	2,200	1.06	0.22	0.11	1.06	0.22	0.15
Porphyry rock	< 4.75 mm	1,900	1.29	0.31	0.02	1.26	0.32	0.10
Porphyry rock	< 4.75 mm	2,200	1.06	0.22	0.11	1.06	0.22	0.15
Waste rock	Bulk	1,900	1.58	0.38	0.05	1.42	0.37	0.14
Waste rock	Bulk	2,200	1.58	0.38	0.05	1.42	0.37	0.14
Waste rock	< 4.75 mm	1,900	1.16	0.25	0.04	1.10	0.24	0.12
Waste rock	< 4.75 mm	2,200	1.16	0.25	0.04	1.10	0.24	0.12
Heap leach rock	Bulk	1,900	1.41	0.355	0.05	1.17	0.275	0.15
Heap leach rock	Bulk	2,200	0.90	0.55	0.45	0.78	0.53	0.50
sensor default calibration coefficients			*1.27*	*0.43*	*0.045*	*1.25*	*0.35*	*0.03*

The laboratory calibration programme completed for the Mt. Leyshon cover system materials produced well-defined calibration curves from low moisture content to saturated conditions. However, the programme was time-consuming and may not be economically feasible for some projects. The results were evaluated to identify areas within the calibration procedure where the testing programme could be reduced.

Five data points defining the relationship between scaled frequency and volumetric water content were collected for each calibration test. A review of the laboratory calibration data, and development of "best-fit" curves for the materials suggests it is likely that four data points would be sufficient. It is imperative that the oven-dry and saturated data points be collected as well as two additional data points at low and moderate moisture contents to define the shape of calibration curves.

The effect of material density should be considered within the calibration programme. Each of the tested materials, except for waste rock, show a significant difference in sensor response between the low-density and high-density condition. The similarity between the low-density and high-density calibration equations for the waste rock material is attributed to the high percentage of coarse particles.

Calibration tests on the porphyry and waste rock materials were completed on bulk samples and samples screened to less than 4.75 mm. The waste rock showed a significant difference between the two conditions while the porphyry rock did not. Examination of the particle size distributions of the materials found that only 25% of the waste rock bulk sample passed the 4.75 mm sieve as compared to 50% for the porphyry rock. It is likely that bulk sample calibration curves are required for materials with higher percentages of material greater than 4.75 mm, while finer materials such as the porphyry rock can be calibrated with screened material.

The Diviner 2000 sensor consistently measured a higher scaled frequency than the EnviroSCAN sensor at identical volumetric water contents. The Diviner 2000 sensor produced scaled frequencies 0.05 – 0.08 higher than the EnviroSCAN at low volumetric water contents. The difference was 0.02 – 0.05 between the Diviner 2000 and EnviroSCAN sensors at the highest volumetric water contents. This suggests that a separate calibration is desirable for the both sensors; however, if material-specific calibration curves are developed for only one the sensor models, these curves could be altered slightly to make them applicable for the other type of sensor.

MOISTURE CONTENT MONITORING AT MT. LEYSHON

Automated measurement of the moisture conditions within the TSF and OSA dry cover systems began in October 2001. The volumetric water content is measured at two-hour intervals to provide information on the response of the cover system to high infiltration events. Figures 3 and 4 depict the change in moisture storage (ΔS) of the TSF cover system measured with the EnviroSCAN and Diviner 2000 sensors, respectively. Moisture storage is a measurement of the equivalent “depth” of water located within the cover profile if the soil, air, and water components of the test plot profile were separated. For example, if a volumetric water content of 0.20 or 20% was measured in a 1.0 m thick cover material profile with a porosity of 0.3, the “depths” of soil, air, and water would be 70 cm, 10 cm, and 20 cm, respectively. Use of the moisture storage parameter collectively describes the performance of all the sensors located within the cover system.

Figure 3 compares the change in moisture storage for the TSF cover system calculated with the material-specific calibration equations and the Sentek default equation. The material-specific calibration is less sensitive to the climatic conditions at the

Mt. Leyshon site. For example, the first significant rainfall recorded by the monitoring instrumentation occurred on November 10, 2001. A tipping bucket rain gauge installed at the Mt. Leyshon site recorded a total of 38 mm of rainfall. The response of the cover system, calculated from the material-specific calibration equations, was an increase in moisture storage of approximately 39 mm, which is close to the measured total rainfall. The change in moisture storage calculated with the Sentek default calibration curve was approximately 61 mm, which clearly does not represent actual field conditions because rainfall was only 38 mm. During the dry season of 2002, the decrease in moisture storage calculated with the Sentek default calibration curve was greater than the material-specific calibration curves.

Figure 4 is similar to Figure 3 as it shows the change in storage calculated from Diviner 2000 moisture content measurements recorded adjacent to the EnviroSCAN sensors. The change in moisture storage calculated from the material-specific calibration curves does not respond to climatic conditions to the same extent as compared to that calculated using the Sentek default calibration. Comparing Figures 3 and 4, the Diviner 2000 water content measurements did not respond to the November 10, 2001 rainfall event. It is likely that the manual measurements "missed" the increase in water content, which the automated system measured because the moisture content had decreased to antecedent conditions before the next Diviner 2000 reading was obtained. However, the Diviner 2000 system showed a similar response to remaining rainfall events during the wet season, as well as the predominantly dry conditions experienced between March 2002 and November 2002.

THE NEED FOR QUANTITATIVELY MEASURING THE CHANGE IN MOISTURE STORAGE PARAMETER

The change in moisture storage within the cover system is required to complete a water balance of the cover system, as shown in Figure 5. Net percolation of water to the underlying waste material at the Mt. Leyshon site is measured using large-scale lysimeters. Discounting the two-dimensional components of runoff and lateral percolation within the cover system, the net percolation can then be back-calculated from measurement of rainfall and change in moisture storage and an estimation of the actual evapotranspiration at the site.

SUMMARY

In situ moisture content monitoring is being completed at the Mt. Leyshon site using automated EnviroSCAN sensors and a portable, manual Diviner 2000 sensor probe. The moisture content measurements are important in characterising the subsurface percolation of water within the tailings storage facility and overburden storage area dry cover systems. Currently, there is one EnviroSCAN sensor tube and nine Diviner 2000 access tubes installed in the tailings storage facility and one EnviroSCAN and five Diviner 2000 access tubes established in the overburden storage area cover system.

The cooperative project described in this paper has demonstrated that the technology can be applied to a mining situation once calibrated to the particular site materials. The technology utilised in the project enables widespread monitoring of the entire cover system rather than being limited to one area. The technology provides the opportunity for implementing a cost effective method to monitor performance of a full-scale cover system using an automated system coupled with a portable moisture measurement device. A key aspect of the portable device is the quick and simple manner in which data can be obtained. Accurate, repeatable, and defensible data to a depth of 1.6 m can be obtained from a particular monitoring site in minutes, such that the time required for obtaining readings is greatly reduced as compared to other portable devices (e.g. neutron moisture probe).

The following are the key results of the laboratory calibration programme on the Mt. Leyshon cover materials.

1) A material-specific calibration curve is required to develop quantitative *in situ* moisture content measurements for the materials tested. Note that these materials are, in general, representative of typical reactive mine waste materials and associated cover materials.

2) Determination of calibration points at oven-dry conditions, 100% saturated conditions, and a minimum of two moisture conditions between the two extreme conditions are required to properly develop a material-specific calibration curve.

3) The density of the material has a strong influence on the shape of the sensor calibration curves.

4) The calibration curves developed for the porphyry rock cover material using a bulk sample and a sample of material less than 4.75 mm were similar. The porphyry rock is a geochemically inert material with approximately 50% of material passing 4.75 mm. The calibration data suggests that for materials with similar characteristics, a material-specific calibration curve can be developed using only material less than 4.75 mm (note that the required density condition must be corrected from the full-scale density to that representative of material less than 4.75 mm).

5) The calibration curves developed for the waste rock material using a bulk sample, and a sample of material less than 4.75 mm were not the same. The waste rock material is reactive (i.e. contains sulphides), possesses stored oxidation products, and has approximately 25% of material passing 4.75 mm. The dissimilar

calibration curves (bulk versus material less than 4.75 mm) is likely a result of the coarse-textured nature of the waste rock material, the increase of “inherent” conductivity due to the stored oxidation products, or a combination of these two factors. This suggests that development of a calibration curve for a waste rock material should include the entire representative particle size distribution.

REFERENCES

Hillel, D., 1998. Environmental soil physics. Academic Press, San Diego, CA.