AB

Appendix AB – NOEF Cover System Trial Design Report

NOEF Cover System Trial Design

22 February 2018

McArthur River Mining

A GLENCORE COMPANY

O'Kane Consultants

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

NOEF Cover System Trial Design

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1 INTRODUCTION

McArthur River Mining Pty Ltd (MRM), a Glencore Company, is an open cut zinc-lead-silver mining and concentrate processing operation located approximately 70 kilometres (km) south-west of the township of Borroloola, 120 km south of the Bing Bong concentrate storage and ship loading facility (Bing Bong) on the Gulf of Carpentaria, Northern Territory. MRM is currently in the process of preparing supplementary information for the draft Environmental Impact Statement (EIS) for the Overburden Management Project. A cover system and landform design report was prepared for the Northern Overburden Emplacement Facility (NOEF) in support of the EIS. It has been proposed that the NOEF waste management placement strategy as well as the cover systems proposed as part of the Draft EIS and Supplementary EIS be constructed and their performance monitored with a field trial.

O'Kane Consultants Pty Ltd. (OKC) was retained by MRM to assist with developing a field trial program, to assess the overall effectiveness of the proposed waste rock placement strategies and cover system of the NOEF in managing spontaneous combustion, Acid Metalliferous Drainage (AMD) and Neutral Metalliferous Drainage (NMD). This proposal for a field trial has been prepared in support of the Supplementary EIS currently being prepared by MRM.

The overall concept for the field trial is to construct a macroscale multi-lift PAF(RE) cell as described in the Draft EIS submission, install monitoring systems, and measure its performance. Following construction of the PAF(RE) cell in 2018, to simulate what will happen when the NOEF is being developed, a wet season cap will be installed, and the material allowed to sit through the 2018/2019 wet season. In the following dry season, a halo zone and cover system will be constructed to encapsulate the PAF(RE) cell, again with comprehensive monitoring systems installed. The entire trial will then be monitored for a period of approximately 7 years, before it is encapsulated in the final stage of the NOEF's development. This report will describe the project in further detail.

1.1 Project Objectives and Scope

The aim of this field study is to investigate the effectiveness of the proposed NOEF construction methodology including waste rock placement strategy and GSL cover system in meeting the design criteria developed as part of the Draft EIS. The overall objective of the waste rock placement strategy and cover system is to limit the generation of stored oxidation products within the overburden emplacement facility during and following placement. To achieve this, the cover system must limit the ingress of meteoric waters and oxygen, particularly into the PAF(HC) and PAF(RE) materials encapsulated within.

A multi-phase, multi-discipline monitoring system is proposed for evaluating the ingress of meteoric water and oxygen to the field trial cell. The following specific objectives have been identified to support the overall objective of this study:

1) Characterise pore-gas concentration (oxygen and carbon dioxide) in the PAF(RE) cells during placement, throughout construction and following cover system installation;

2) Determine pore-water and pore-gas water (humidity) in the PAF(RE) cell during placement, throughout construction and following cover system installation;
3) Determine oxygen and water ingress through the wet season cap and final cover system;
4) Determine the wetting-up period for the waste rock profile (PAF(RE) cell and Halo) to provide estimates on the lag time to toe/basal seepage;
5) Track the evolution of the cover system performance in response to site-specific physical and chemical processes;
6) Monitor erosion rates on the plateau and embankment areas of the field trials; and
7) Develop confidence in the closure performance of the NOEF.

1.1.1 Developing Criteria

The hydrological and gas flow conceptual models of the NOEF developed for the EIS have been used to develop criteria that satisfy the objectives of evaluating the performance of the overall NOEF concept. Table 1.1 summarises the project objectives and criteria for the project.

Table 1.1: MRM EIS NOEF field trial monitoring objectives and criteria.

Objective	Criteria	Monitoring Criteria/method	Numeric Target
Demonstrate GSL cover system performance	Reduce oxygen ingress	Quantitatively assess oxygen ingress • Gas concentration • Temperature gradient	O_2<5 mol/m^2/yr; Consistent temperature gradients;
	Limit net percolation	Quantitatively assess net percolation • Lysimeter • Water balance • Pressure head	<5% of rainfall “very low net percolation rate”
	Scale-up measured performance to NOEF	Measured components of water balance	NA
	Provide for vegetative layer	Vegetation surveys • Plant available water • Population studies	Pastoral grassland excluding deep rooted woody vegetation
	Subgrade and overliner reduce leakage through GSL	Monitor matric suction and Volumetric Water Content (VWC)	Consistent hydrological parameters
	Cover system is stable Erosion and shallow slope failures	Monitor erosion and pore-water pressure • Remote surveys • Manual surveys and monitoring • Pore-water pressure (+)	Erosion 1-10 t/ha/yr Pressure head < thickness of drainage layer

Table 1.1: MRM EIS NOEF field trial monitoring objectives and criteria **(Cont'd)**.

Objective	Criteria	Monitoring Criteria/method	Numeric Target
Validating PAF(RE) design concept	PAF(RE) waste placement technique is reducing convective oxygen flux	Quantitatively assess oxygen ingress • Gas concentration • Temperature • Air pressure	O_2<150 mol/m^2/yr After placement of wet season cap, prior to final cover system
	PAF(RE) waste placement technique and wet season cap in reducing water ingress	Quantitatively assess water ingress and concentration • Water level • VWC sensor • Pore-gas humidity	~10% of rainfall
	Wet season cap retains water shedding capacity	Direct measure of as-constructed condition • Matric suction and VWC sensors • In situ permeability	Consistent hydrological parameters
	Landform basal seepage collection and drainage system	Quantitatively assess gas flow and integrity • Gas concentration, temperature, differential pressure • Observed chemical clogging	O_2<5 mol/m^2/yr to PAF (RE) cell post final cover system construction Maintain adequate drainage capacity
Construction QA/QC	GSL	Finalised during constructability test pads	TBD
	Waste placement	QA/QC as determined acceptable by construction team	As per design specification
Spatial coverage	Multiple monitoring locations across the field trials	Establish Data Acquisition System (DAS) in centre and near edge of trials. Monitor plateau and slope surfaces.	Spatial performance satisfies numerical targets for various parameters
Temporal coverage	Establish monitoring system design early in construction, and continue for several years to capture climatic variability	Installation of instrumentation and DAS that satisfy performance monitoring objectives	High data capture rates and QA/QC of data.

1.2 Cover System Field Trial Conceptual Model

1.2.1 Conceptual Model for NOEF Waste Rock Placement

MRM's waste placement strategy focuses on managing oxidation of sulphide minerals during waste placement by using several methods, including optimised mine scheduling, low lift construction, compaction, and placement of regular internal low air permeability barriers. The aim is to limit advective gas transport within the NOEF core during construction by controlling air flow capacity (air permeability). Exposed surface of the PAF(RE) will be encapsulated in a wet season cap of alluvium and MS-NAF prior to each wet season. The wet season cap serves to limit oxygen ingress to diffusion to the PAF(RE) core in the short-term following construction of the last lift, and also promote runoff to limit infiltration prior to the completion of the overlying Halo and GSL cover system.

The NOEF management strategy will limit the quantity of stored oxidation products within the facility and delay and/or attenuate basal seepage, resulting in a reduced long-term reliance on a cover system as the “sole” means of managing seepage from the NOEF. This control of the physical environment during the construction phase to limit oxidation represents a fundamental shift in the typical approach to managing reactive mine waste in the mining industry and can be described as leading practice.

1.2.2 Conceptual Model for NOEF Cover System Design

A cover system that utilises both the ‘moisture store-and-release’ and ‘barrier’ concepts was identified as the most suitable cover system for the NOEF. This is based on the site receiving a distinct wet and dry season and being situated in a tropical environment. The profile of the cover system is shown in Drawing 750-47-003.

The conceptual model for cover system performance for MRM is that reduction of the ingress of oxygen and water are required to manage seepage from the NOEF. Reduction of water and reduction of gas flux (due to both diffusive and advective fluxes of oxygen into the NOEF) are the key performance attributes of the cover system and waste placement strategies.

The conceptual model for the cover systems is illustrated in Figure 1.1. The growth medium layer aids in reducing net percolation to the underlying NOEF material by providing storage capacity. Rainfall is stored within the cover system (topsoil, growth medium and drainage layer), and gradually released back to the atmosphere through evaporation and transpiration. During periods of high (and more intense) rainfall, the water store-and-release capacity can be overwhelmed and the cover system (and landform) are designed to be ‘water shedding’, and therefore sheds excess water from the facility. When the overlying storage capacity is exceeded, and deep percolation occurs, the GSL hydraulic barrier limits net percolation.

The rate of water movement through intact GSL is extremely low; hence, the primary source of net percolation is attributed to leakage through holes or defects in the GSL during the trial. This leakage can only be triggered when positive pressures (i.e. ponding) develop on top of the GSL near the hole. Lateral drainage capacity of the coarse textured breccia, drainage layer above the GSL, limits the head of water and period of prolonged ponding.

Oxygen will move across the cover system through molecular diffusion and advection. Diffusion is the movement of molecules or ions from a region of higher concentration to one of lower concentration as a result of random Brownian movement. An advective process is one in which oxygen may be carried along with air or water. The diffusion of oxygen will be low for the cover system given the extremely low diffusivity coefficient of oxygen for a GSL. Advective gas transport across the cover system will be limited to locations of holes in the GSL and regulated by the low air permeability of the fine-textured overliner and subgrade.

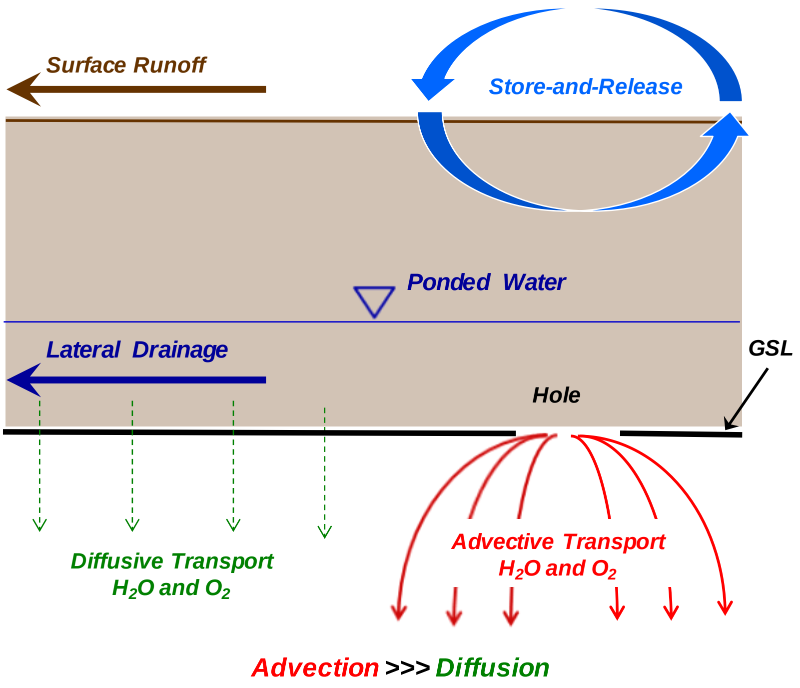

Figure 1.1: Conceptual model of performance for the GSL cover system.

1.3 Report Organisation

For convenient reference, this report has been subdivided into the following sections:

- Section 2 – presents an overview of the field trial design;
- Section 3 – provides an overview of the proposed performance monitoring systems; and
- Section 4 – provides a summary of the proposed final performance monitoring plan.

2 FIELD TRIAL DESIGN SUMMARY

The final landform design proposed for the field trial includes the following features:

- A peak height (on the top of the plateau area of the landform) of approximately 15 m.
- Outer batter slopes that are nominally 40m in slope length from the crest to toe at a linear 1V:3H gradient.
- A plateau that is roughly 40m x 60m in plan area, with an approximate 2-3% slope as illustrated in Dwg 750-47-001.
- MS-NAF will be used to build the halo section of the landform up to the final grade below the cover system.

The following two sections provide details of the GSL cover system and PAF(RE) cell preliminary design.

2.1 GSL Cover System

Final design of the GSL cover system will be supported by outcomes of the constructability test pads (CTPs) expected to be constructed in approximately May of 2018. The CTPs consist of a series of individual GSL test pads constructed using various combinations of materials and/or equipment and/or techniques, under specific QA/QC processes. Key objectives of the CTPs are to establish design criteria, methods of construction, and construction quality assurance and quality control (QA/QC) procedures for the GSL cover system.

The final GSL field trial design will be an outcome of the CTPs; however, the current cover system configuration developed through the cover system design program is:

- Plateau Areas (from the finished surface down):
  - Topsoil – 0.1 m;
  - Alluvium material (growth medium) – 0.6 to 0.9 m;
  - Breccia material (lateral drainage layer) – 0.2 to 0.5 m;
  - Alluvium (overliner) – 0.2 to 0.3 m;
  - GSL; and
  - Subgrade – 0.2 m.
  - Note total depth from surface to barrier layer will be a minimum of 1,500mm
- Embankment Areas (from the finished surface down):
  - Topsoil – 0.1 m;
  - Breccia material (growth medium) – 1.1 to 1.2 m;
  - Alluvium (overliner) – 0.2 to 0.3 m;
  - GSL; and
  - Subgrade – 0.2 m.
  - Note total depth from surface to barrier layer will be a minimum of 1,500mm

2.2 PAF(RE) Cell

The landform waste profile beneath the cover systems will essentially replicate the internal composition of the NOEF, although the PAF (HC) core will be replaced by a reactive PAF(RE) cell in the trial in order to test the effectiveness of the PAF(RE) cell construction. Details of the landform layers can be seen in Dwg 750-47-002.The PAF(RE) core will be constructed in three 1.9 m high lifts, dozed and separated by 0.1 m fine-textured alluvium resulting in a final height of approximately 6 m. The PAF(RE) core will be encapsulated in the wet season cap consisting of a 1.2 m track compacted alluvium layer and 1.5 m Metalliferous Saline Non-Acid Forming (MS-NAF) layer. Following one wet season, the PAF(RE) cell will then be covered by a 'Halo' of MS-NAF and the GSL cover system. The Halo will be 6-8 m in thickness, depending on landform shaping requirements.

3 PROPOSED PERFORMANCE MONITORING SYSTEMS

OKC designed a field monitoring program that specifically addresses the objectives for the project. In general, the monitoring program has been designed to gather information on various components of the water balance such that multiple lines of evidence can be developed to inform on the performance of the field trial. The field trial monitoring will provide validation of the waste placement practice, and an understanding of the internal controls on AMD/NMD production and release.

OKC recommends that performance monitoring occurs for a minimum of five years. This would allow the hydraulic properties of the cover layers to evolve from the as-constructed condition to a post-construction condition, resulting in monitored performance under hydraulic properties more reflective of the long-term. Additional time would be required to evaluate the effects of vegetation development. The period is also required to establish a suitable database of cover system moisture and thermal field responses for calibration of simulation models for prediction of cover system performance under long-term average and extreme climatic conditions.

3.1 Overview of Performance Monitoring Systems

Instrumentation will be installed spatially across the cover system trial to achieve the objectives outlined for the project, as discussed in Section 1. The final location for the monitoring equipment will be determined based on mining operations, construction activities and material placement progress at the time of installations and conditions in the field, such as survey and site inspections. Details of the instrumentation and placement location within the field trial can be seen in Dwg Nos. 750-47-001, 750-47-003, 750-47-004. Sensor numbers and locations are summarised in Table 3.1 and Table 3.2.

It is proposed that the monitoring components are split into multiple installations, scheduled around particular construction 'milestones'. The PAF(RE) monitoring installation will occur along with construction of the PAF(RE) core and wet season cap, and the GSL cover system installation will take place prior to and during cover system construction.

Monitoring / data collection of the PAF(RE) will begin at the onset of construction to validate the placement strategy, (i.e. oxygen ingress is limited to diffusive, and stored acidity generation is managed as practicable for operational conditions). Monitoring will consist of pore-gas concentration, temperature, moisture conditions, and differential pressure.

Table 3.1:Summary of monitoring system layout for the GSL field trial.

Station Name	Location	Monitoring Components / Instrumentation
Plateau Soil Station (SS#1, 2, 3, and 4)	Plateau and Slope	• 10 water content sensors and 10 soil suction / temp. sensors installed throughout the cover system and upper Halo layer • 1 pore-water pressure (+) above GSL • CR1000X datalogger • 12v rechargeable battery / solar panel power source for the data acquisition system (DAS) • Automated field camera • Radio based data collection
Tank Lysimeter (L1, L2, L3, and L4)	Slope and Plateau	• 3 water content sensors and 3 soil suction / temp. sensors installed throughout the lysimeter • 2 pore-water pressure sensors (+) above GSL • 2 differential air pressure sensors, above and below GSL
Automatic gas monitoring system (AG1 and AG2)	Mid Plateau and Mid Slope	• 2 oxygen sensors above GSL • 2 oxygen sensors below subgrade • 2 pore-water pressure sensors (+) above GSL • 2 differential air pressure monitoring points (1 above and 1 below GSL) • 1 air pressure (+) below GSL • 6 manual monitoring ports (humidity, O_2 and CO_2) • CR1000 datalogger • 12v rechargeable battery / solar panel power source for the data acquisition system (DAS) • Radio based data collection
Manual gas monitoring system PG3 and PG4	Plateau and slope	• 6 manual monitoring ports (humidity, O_2 and CO_2)
Runoff Monitoring System	Plateau and slope surface drain collection ditch	• V-notch weir • Pressure transducer • Sonic ranger • CR800 datalogger • 12v rechargeable battery / solar panel power source for the data acquisition system (DAS) • Radio based data collection • Automated field camera
Interflow Monitoring System (IF1 and IF2)	Two Locations Plateau and Slope	• 1L tipping bucket flow gauge and flow gauge housing • Data acquisition part of Plateau runoff monitoring system
Meteorological Station	Central Plateau	• 1 tipping bucket rain gauge • 1 net radiometer • 1 anemometer • 1 air temperature / relative humidity probe • 1 barometric pressure sensor
Basal seepage system	Toe seepage at two locations	• 1 flow gauge • 1 differential air pressure • 1 oxygen sensor • 2 electrical conductivity and temperature sensors

Table 3.2: PAF(RE) cell and Halo monitoring system instrumentation summary.

Sensor	Parameter	Location	No. of sensors
SO-210	O_2	PAF(RE) cell	16
		Halo	16
Nova Gas Analyser and RH probe (manual)	O_2, CO_2 and humidity	PAF(RE) cell	16
EoSense	CO_2	PAF(RE) cell	3
CS109	Temperature	PAF(RE) cell	16
Setra port	Differential air pressure	PAF(RE) cell	6
CS616	Volumetric water content	PAF(RE)	12
		Wet season cap	12
		Halo	16
MPS6	Suction and temperature	Wet season cap	12
229-L	Suction and temperature	Halo	15
OTT-PLS	Positive pore water pressure	Wet season Cap	2
HOBO	Positive air pressure	PAF(RE)	4

3.2 Monitoring System Details

This section outlines the performance monitoring system design for the cover system and constructability field trial including instrumentation, DAS equipment, and sensor placement.

3.2.1 DAS Equipment

Campbell scientific Australia (CSA) CR1000 and CR800 dataloggers (or similar), powered by a solar panel and rechargeable battery source, are recommended to control the various sensors. A local radio network at the site is proposed to allow for remote download of data. The radio network design will be completed in consultation with MRM and can be expanded to include an internet-based modem for internet-based access if desired. Alternatively, data can be obtained by manually downloading through direct connection to the datalogger. The DAS equipment will be enclosed in a fiberglass enclosure which will be mounted on a steel or wooden post.

3.2.2 PAF(RE) Cell water Dynamics

Net percolation through the wet season cap will be estimated utilising analytical techniques, and should it be required, soil-atmosphere numerical models calibrated to thermal and moisture responses. The PAF(RE) cell wetting-up period will be estimated from the initial water content, net percolation rate through the wet season cap and GSL cover system and monitored toe seepage.

Sufficient moisture (humidity) in pore-gas can sustain sulphide oxidation. Humidity will be monitored through the manual gas sampling ports installed through the PAF(RE) cell. Changes in pore-gas humidity will be a function of the *in-situ* pore water content and water ingress rate.

3.2.3 GSL Cover System Net Percolation

Large-scale lysimeters tanks will be installed in the MS-NAF immediately below the GSL to monitor the quantity of water that percolates through GSL. The lysimeters will consist of a large, plastic irrigation tank with the top removed installed within the MS-NAF. The tanks will be bottom drained with flows directed to an automated tipping bucket to allow real-time monitoring of percolation to the base of the tank. Redundancy in the flow monitoring system is included to ensure that there are no breaks in the data capture given the importance of measured water ingress.

The use of lysimeters is often considered to be the most straightforward approach for estimating net percolation. Two tank lysimeters will be installed on the Plateau, and two on the Slope. The dimensions of the tank lysimeters will be approximately 2.0 m in diameter and 1.2 m deep.

Monitoring of net percolation with lysimeters is advantageous in that it provides an immediate measurement of the volume of net percolation at each location. This is important given that basal/toe seepage may not occur over the monitoring period given the water storage capacity of the waste rock, relatively short period of exposure for wetting up, and very low rates of net percolation from the GSL cover system.

A hole will be introduced within the GSL above the lysimeter tanks to simulate a damaged segment/defect of the GSL (i.e. a point of focused net percolation should a pressure head develop above the hole). The measured pressure head above the GSL coupled with measured leakage, will assist in refining empirical leakage equations specific to the cover system configuration. The permeability of the GSL bedding material and the layer above the GSL as well as the quality of the contact between the underlying material and GSL will influence the leakage rate based on the applied pressure head.

Direct measurement of leakage rates as well as water levels on the plateau and slope, coupled with hole detection results from the CTPs and GSL cover system will be used to predict net percolation rates for the landform.

Water level sensors located spatially across the surface will enable characterisation of the “ponded water” above the GSL, which drives leakage or the risk of leakage. Differential pressure between the atmosphere and below the GSL, which has the potential to influence leakage rates due to inward and outward venting, will be monitored. Sensors will be installed within the confinement of the lysimeter to monitor changes in water storage and verify that it is functioning as required. These sensors will allow for changes in *in situ* volumetric water content, matric suction, temperature and differential pressure.

3.2.4 Water Balance Monitoring

The water balance monitoring system consists of instrumentation to measure all the components of the water balance except actual evapotranspiration (AET), which will be estimated from measurements of potential evaporation (PE) and ratios of AET/PE developed through analytical water balance techniques. Components of the water balance monitoring system and a summary of the construction methods are provided in the following sections (3.2.4.1 to 3.2.4.4). Measured water balance parameters will be key parameters to support final design of the NOEF cover system and the surface water management plan.

3.2.4.1 Meteorological Instruments

It is proposed that an automated weather station be installed on the plateau of the GSL field trial as shown in Dwg 750-47-001. Climatic data are key input parameters to the soil-plant-atmosphere numerical models utilised to simulate measured cover system performance and develop predictions of long-term cover system performance.

The meteorological station would include sensors to monitor net radiation, air temperature, relative humidity, and wind speed (the parameters required to calculate potential evaporation using the Penman 1948 method), as well as rainfall, and barometric pressure. Rainfall is a key element of the water balance, and directly affects to net percolation realised through a cover system. Net solar radiation is a dominant factor in the surface energy balance and resulting evaporation and/or transpiration from a soil profile. Potential (or theoretical maximum) rates of evaporation (PE) from a soil surface can be determined through measurements of net solar radiation, air temperature, relative humidity (RH), and wind speed.

3.2.4.2 Soil Monitoring Station

Soil monitoring instrumentation will be installed within the cover system at four locations across the field trial. These sensors will measure *in situ* volumetric water content, matric suction, and temperature.

Two different types of sensors are proposed to automatically record *in situ* water content and temperature conditions of the near-surface cover material. Dwg 750-47-001 shows the location of the soil monitoring stations across the field trial, while Dwg 750-47-003 displays the sensor profiles for each station. CSI Model 229-L thermal conductivity (TC) sensors are being used to monitor *in situ* matric suction (negative pore-water pressure) and temperature. A Model 229-L sensor consists of a probe inserted axially in a porous cylinder, which has a diameter of 15 mm and a length of 32 mm. The probe consists of a stainless steel tube in which a heating element and a thermocouple are embedded. The heating element and thermocouple are connected to extension wires; this connection is embedded in an electrical insulating resin. The TC sensor is heated for 30 seconds to determine the change in temperature, which varies depending on the moisture content of the ceramic block. Each TC sensor will be calibrated at OKC's laboratory over a range of suction values from 0 to 293,000 kPa.

CSI Model CS616 time domain reflectometry (TDR) sensors (or similar) will be used to continuously monitor *in situ* volumetric water content of the cover / upper MS-NAF profile. A CS616-L sensor consists of two stainless steel rods (300 mm long x 3 mm in diameter; referred to as the wave guide) connected to a printed circuit board encapsulated in epoxy. An electromagnetic pulse is propagated along the wave guide and the time between sending the original pulse and receiving the reflected pulse is measured. The time period 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. Material-specific calibration curves for the TDR sensors will be developed in the laboratory, which will enable absolute values of volumetric water content to be determined. OKC would complete this calibration within the field installation scope of work.

Instrumentation will be installed at the appropriate depth in the loose lifts of MS-NAF. Sensors installed below the GSL will be directed to the surface through a conduit welded to the GSL. The conduit will be sealed with silicone, and the weld will be inspected for defects using the proposed QA/QC. Following installation of the GSL, the cover profile will be progressively built up to the final grade to facilitate the installation of sensors at the required depths. The surrounding growth medium layer would be built into the sensor mound to tie it into the cover system.

Water content and matric suction will be monitored within the wet season cap and halo. This will verify that the wet season cap maintains a high degree of saturation in the as-constructed conditions. The halo will be progressively built up to facilitate the installation of sensors at the required depths. The 229-L and CS616 sensors will provide an understanding of any wetting up within the halo.

3.2.4.3 Runoff Monitoring

It is recommended that surface runoff collection and monitoring systems be installed to collect runoff waters from the plateau and slope sections of the field trial. It is important that runoff is monitored from as large of an area as possible and not a subsection of the trial. Monitoring from a larger surface area typically incorporates the processes that will contribute to runoff from the perspective of the reclaimed NOEF. This allows the measured runoff to be scaled-up and used in final design of the NOEF surface water diversion and management plan.

Runoff monitoring will consist of a v-notch weir plate mounted to a concrete culvert situated in a runoff collection ditch. The collection ditch will be positioned at the base of the landform slope to capture surface runoff originating on the side slopes, and at the down-gradient end of the plateau to collect plateau runoff waters. The v-notch will be installed at the down-gradient end of the concrete culvert and fitted with a pressure transducer and sonic ranger to monitor water depth within the weir, which can be translated into a total volume of water. The proposed location of the runoff monitoring system can be seen in Dwg 750-47-001.

3.2.4.4 Interflow

The presence of the GSL will result in the lateral drainage of water above the barrier. Key aspects that the monitoring will inform on include: design of the drainage systems; the barrier and outflow;

as well net percolation for the GSL. Therefore, it is recommended that an interflow monitoring system is installed on the slope and plateau.

An interflow collection system will be constructed for the purpose of collecting subsurface water diverted laterally along the drainage layer (i.e. interflow). The interflow drainage collection system collects interflow waters with a 50 mm perforated PVC pipe buried at the base of a clean gravel-filled collection trench fitted with a flow curtain. The flow curtain is constructed of GSL (or similar) and will be installed to direct interflow waters to flow through the perforated pipe which then transitions to solid PVC pipe where it passes through the flow curtain. The drainage pipe has a downward slope of 2-3% to allow gravity flow of interflow waters from the collection system to the monitoring mechanism. The flow curtain will be welded into place and inspected by a qualified contractor to be free of defects.

The flow measurement device for the interflow monitoring systems is a tipping bucket flow gauge which enables the time and quantity of water discharged from interflow system to be determined. The flow gauge is housed within a monitoring shed positioned on the slope. Proposed positions of the flow curtain and monitoring sheds can be seen in Dwg 750-47-001.

3.2.5 Internal Pore-Gas Monitoring

Pore-gas oxygen and carbon dioxide monitoring will occur across the GSL and within the PAF(RE) core, which will be initiated during construction. Details of the cover system and PAF(RE) pore-gas monitoring is provided in Section 3.2.5.1 and Section 3.2.5.2, respectively.

3.2.5.1 Cover System Pore-Gas Monitoring

Oxygen ingress across the cover system is anticipated to be very low (<5 mol $O_2/m^2/yr$), due to the presence of the GSL. Monitoring of oxygen flux into the waste will be automated with the use of oxygen sensors and manually through pore-gas sampling ports. Carbon dioxide concentrations will be monitored manually. One automated gas monitoring station and one manual gas monitoring station will be installed on both the plateau and slope.

Automated monitoring will consist of the installation of Apogee SO-210 soil oxygen sensors (or similar) above and below the GSL and within the halo to develop concentration flow gradients. The Apogee sensor performs measurements based on a galvanic cell principle, therefore it is a passive sensor and does not require voltage input. A built-in heater dissipates condensation on the measurement diaphragm, and an internal thermistor provides temperature data.

Manual sampling ports will be installed along with the oxygen sensors to validate readings over time. The Nova Gas analyser will be used to collect manual measurements of oxygen and carbon dioxide. During sampling of the manual pore-gas stations, pore-gas humidity will also be measured using a water trap fitted with a humidity sensor.

Differential pressure gradients have the potential to drive air flux into or out of waste landforms. Pressure gradients can develop for multiple reasons, such as passing weather systems, or temperature differentials between the atmosphere and internal waste, and in large part depend on the connectivity between the atmosphere and internal conditions. Differential pressure at the automated gas monitoring stations will be monitored with Setra bi-directional pressure transducers installed at the surface and fitted with tubing to the desired depth. Tubing will extend to depths above and below the GSL to provide an indication of differences in pressure, therefore providing additional context to the observed oxygen concentration provided by the oxygen sensors. A HOBO pressure sensor will also be installed to verify the Setra readings.

3.2.5.2 PAF(RE) and Halo Pore-Gas Monitoring

Pore-gas concentrations, temperature, and pressure will be monitored within the PAF(RE) core and halo during and immediately following material placement. The EoSense carbon dioxide sensor will be installed at three locations in the PAF(RE) core. SO-210 sensors will provide automated O_2 concentration within the PAF(RE) cell and halo. Sensors will be installed concurrent with construction, with cable leads extending to a DAS situated outside the final landform footprint for long-term monitoring. Sensors will be installed within each lift of the PAF(RE) core and wet season cap which will serve to demonstrate the placement strategy is meeting performance criteria (i.e. limiting oxygen ingress to diffusion and subsequent development of stored acidity). Details of the sensor installation depths can be seen in Dwg 750-47-004.

Temperature across the PAF(RE) cell and halo will be monitored to provide an indication of the potential development of temperature driven oxygen advective flux across the wet season cap and final cover system. The temperature of the underlying waste material also provides evidence of oxidation processes and can therefore indicate if oxygen is available for PAF(RE) waste redox should temperature begin to increase.

3.2.6 Landform Stability Monitoring

A key closure objective of the final NOEF landform is to be a stable from a geomorphic perspective, particularly for the embankments. The cover system field trial has been designed with embankments that match the 3:1 segment of the tri-linear slope that is planned for the final NOEF. Monitoring of erosion occurring on the field trial should be conducted regularly to ensure growth medium thickness is not reducing to a point that the cover system performance objectives can’t be met, or sediment discharge to the surrounding environment is not acceptable. Monitoring of lateral drainage and pore water pressure above the GSL, as defined previously, will also inform on landform stability and potential for shallow slope failures.

3.2.6.1 Erosion Monitoring

Erosion should be monitored regularly through the completion of remote surveys (photogrammetry) for generation of digital elevation models (DEM) to quantify soil loss in comparison to the acceptable soil loss levels. The DEM can be used to monitor erosion gullies (meso-scale) while capturing landform geomorphic losses of sediment. A detailed erosion monitoring plan would be developed as part of ongoing site maintenance procedures which would include, site inspections, photographs, and installation of benchmarks to monitor active erosional features.

3.2.6.2 Pore-water Pressure

In general, GSLs are impermeable, limiting water ingress to the underlying waste material. The absence of adequate drainage capacity coupled with a low flux barrier layer can lend to the development of positive pore-water pressures within the cover profile above the GSL. Positive pore-water pressures reduce the effective normal stress and thus reduce the restraining friction along the GSL interface, resulting in conditions with the potential for shallow slope failures.

While slope failures are generally restricted to steep slope angles where the restraining friction may be exceeded, seepage erosion can also occur at the toe of slopes. Seepage erosion occurs when particles are carried out of the soil mass under a hydraulic gradient. Particle movement is initiated as soon as the seepage force is greater than the particle self-weight and inter-particle forces. A seepage face may occur within a cover system at the toe of the slope or when the height of ponded water within the cover profile exceeds the elevation at the base erosional features, which establishes a hydraulic gradient to flow.

OTT PLS pressure transducers (or similar) will be installed at the base of the drainage layer along the slope profile, above the GSL, to monitor the development of positive pore-water pressure.

3.2.7 Basal Seepage

The field trial will be lined with a basal collection system to convey flows to a toe drain monitoring system. This will allow for an understanding of the wetting-up period for the Halo and PAF(RE) profile as well as validation of net percolation rates. The toe drains may also serve as a preferred path for advective flow into the field trial.

Monitoring systems are proposed for the toe drains to provide the duration and magnitude of flows from basal seepage as well as for advective gas flow. The GSL field trial may not wet up in the monitoring period, hence additional engineered holes could be added beyond the reported average in the industry to accelerate the wetting-up period and promote toe drainage.

The flow measurement device for the basal seepage monitoring system is a tipping bucket flow gauge which enables the time and quantity of water discharged. The measurement gauge includes a flow splitter enabling collection of seepage for quality analysis. Samples would be submitted for pH, electrical conductivity and metals. Electrical conductivity and temperature would be measured automatically at the basal seepage outflow and deeper within the field trial using the CS547A sensor.

3.2.8 Vegetation Establishment and Monitoring

The current cover system growth medium varies in dominant material type according to its position on the trial landform. In this section, growth material refers to all material above the GSL as this represents the maximum allowable volume for plant root proliferation. The Plateau Area growth medium is approximately 2m thick, consists of topsoil (0.1 m), alluvium (0.6 to 0.9 m), breccia (0.2 to 0.5 m), and alluvium (0.2 to 0.3 m). While the Embankment Area growth medium is approximately 1.5m thick, comprises topsoil (0.1 m), breccia (1.1 to 1.2 m), and alluvium (0.2 to 0.3 m). This section will focus on vegetation establishment into the alluvium and breccia layers as these are the dominant materials in the plateau and embankment cover system growth mediums.

Re-vegetation efforts should focus on plant communities which possess the physiological and morphological adaptations that allow them to cope with hydraulic and physical characteristics of the material in which they grow. If plant adaptations are matched with the appropriate cover material hydraulic and physical characteristics, plant establishment success should increase over the short and long-term. Because the proposed NOEF cover system material will contain fine and coarse textured materials it is important to consider the plant communities most appropriate to each material type.

3.2.8.1 Fine Material (Alluvium)

Texture analysis of finer materials at MRM separated into three distinct classes: topsoil and alluvium – clay; alluvium – sand; alluvium – cobbles and gravel (Figure 3.1); for this section these will be referred to as fine Alluvium herein. The fine nature of alluvium material may reduce plant root depth as moisture requirements are more likely to be met at shallower depths. The smaller and more abundant pore spaces in Alluvium hold water at more negative pressures (Figure 3.2) even under drying. Contrary to Breccia, alluvium material saturated hydraulic conductivity (k_{sat}) was relatively low ranging between 1.9×10^{-5} – 5×10^{-7} m s^{-1} and had higher overall moisture contents across all suctions, especially at more negative water potentials (Figure 3.1). The higher water holding capacity of alluvium under high suctions (i.e. when water is limiting) will likely benefit plant establishment and survival, as water should be held in pore spaces even under drying conditions thus increasing plant available water during dry periods.

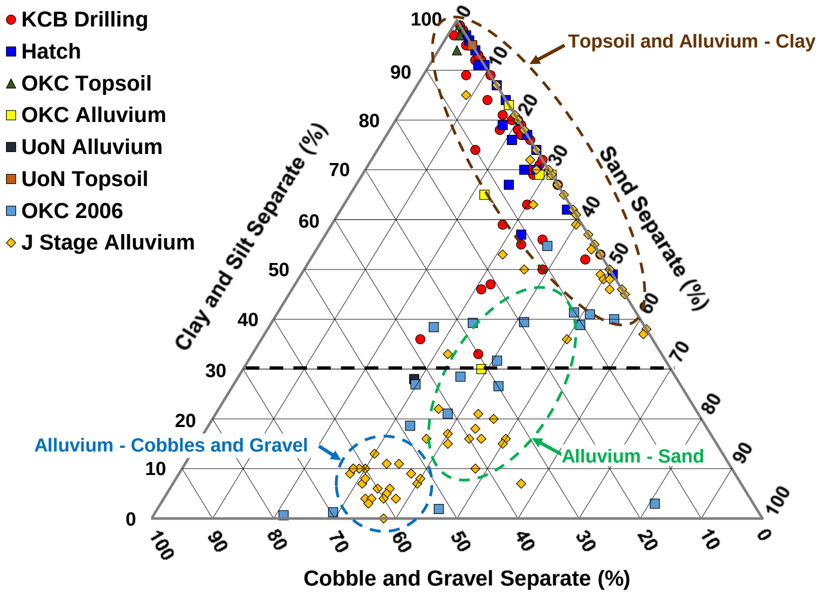

Figure 3.1: Textural triangle of topsoil and alluvium samples. (OKC 2016)

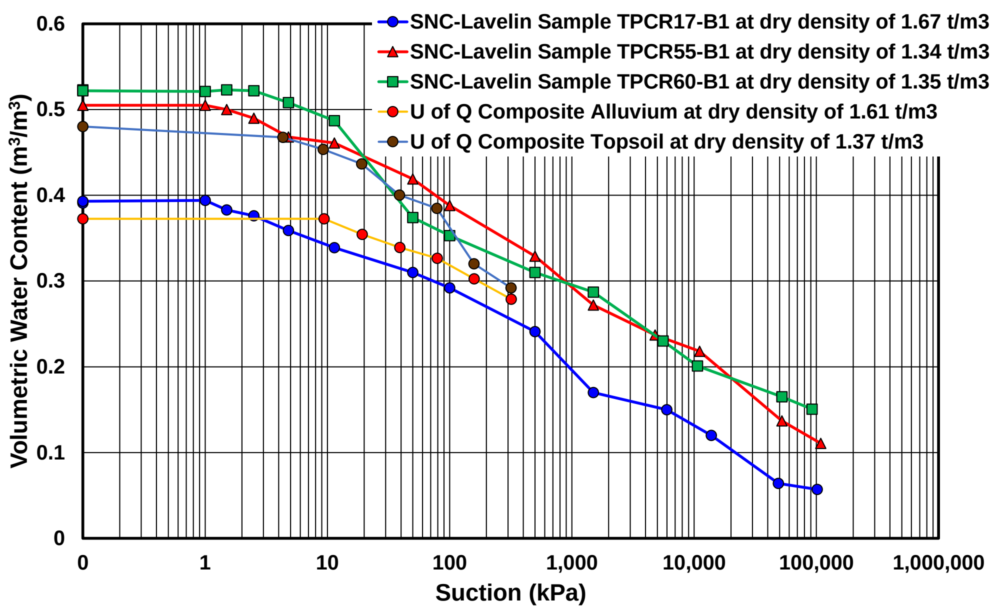

Figure 3.2: Measured WRC data for five MRM alluvium and topsoil samples. (OKC 2016)

Plant species most likely to establish in an alluvium layer (plateau area) are those typically found naturally on fine textured soils in the MRM area, such as those occurring in lowland woodland communities. Using lowland woodland community species for re-vegetation it may be possible to utilise their adaptations for growing on fine soils. The more negative soil water potentials of fine soils reflect the smaller and more abundant pore spaces that hold water at more negative suctions (Sperry and Hacke 2002). Plants growing on fine texture soils are better adapted to removing water from soils at more negative soil water potentials due to the ability to reduce their leaf water potentials when moisture is limiting, also reducing their need for deep roots (Sperry and Hacke 2002). In the Plateau Area growth medium, re-vegetation will likely improve using species that typically grow on fine textured soils.

3.2.8.2 Coarse Material (Breccia)

Breccia in coarse textured (Figure 3.3), has a high $_{sat}$ of 1.74 x 10^{-4} m s^{-1}, and high moisture content only under low suctions (i.e. when water is non-limiting; Figure 3.4) due to larger pore spaces (Sperry and Hacke 2002). The coarse nature breccia may increase the likelihood of roots searching for water in wet zones deeper in the growth medium. The low water holding capacity of breccia under high suction will likely make plant establishment and survival more difficult due to water limitation, especially under drying conditions (Figure 3.4). Plants may overcome the effects of high k_{sat} and low moisture contents under drying conditions by developing higher root to leaf area ratios and placing their roots in wet zones deeper in the growth medium (Hultine et al. 2006).

As water becomes limiting under dry conditions the moisture content of breccia will decrease forming dry zones at the surface, and a gradient of increasing water availability with depth due to large pore spaces (Davis and Mooney 1986, Sperry and Hacke 2002). The formation of surface dry zones will inhibit the migration of deep water to the surface, and Evaporative losses at the surface will be minimised allowing the growth medium to retain more of its stored water (Campbell and Norman 1998). Therefore, wet zones deeper in a Breccia growth medium may remain accessible to plant roots for longer periods under dry conditions. However, the presence of deeper soil moisture in a Breccia growth medium may lead to deeper roots.

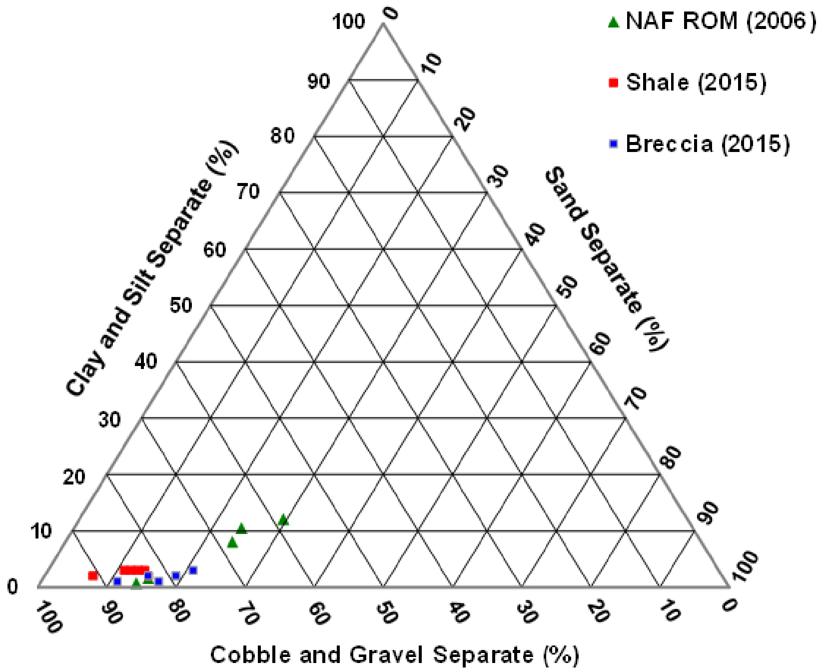

Figure 3.3: Textural triangle of waste rock samples.

OKC 2016

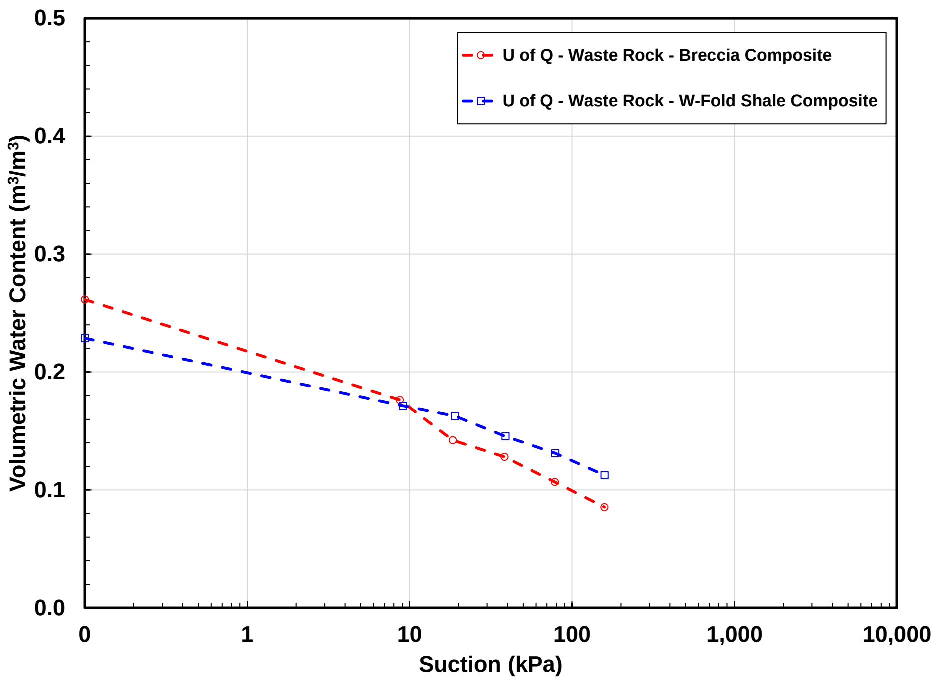

Figure 3.4: Laboratory measurements of water retention for waste rock samples (OKC 2016).

Plant species most likely to establish in a breccia layer on embankment areas are those typically found in upland communities within coarse soils in the MRM area. It may be possible to utilise coarse soil upland community species and their adaptation for re-vegetation in breccia to increase the likelihood of establishment. Plant species on coarse textured soils will typically have less negative water potentials and resistance to stem cavitation compared to species on fine textured soils (Hacke et al. 2000). Less negative plant water potentials with less water availability at relatively low soil suctions force plant roots to extend deeper into the profile in search of wet zones. Higher root to shoot ratios also allow species to persist on coarse textured soils by increasing the surface area of belowground biomass capable of capturing infiltrating soil moisture (Hultine et al. 2006). Using the most appropriate plant species for a breccia growth medium during re-vegetation will improve the survival vegetation.

3.2.8.3 Vegetation Monitoring

The main purpose of re-vegetation as a closure action is to align with closure objectives and hence for the NOEF and trial location pastoral species. This section briefly highlights vegetation monitoring methods for the cover trial that can be expanded in a detailed re-vegetation plan. A clear monitoring strategy and demonstration of re-vegetation effectiveness must be established to achieve the closure objective. To assess the effectiveness of re-vegetation, monitoring results should be evaluated on a two-stage basis; **initial re-vegetation** and **established re-vegetation** monitoring. Initial re-vegetation is an evaluation of performance over the first 12 – 24 months. During this period germination and seedling establishment are extremely susceptible to unfavourable abiotic conditions and processes. If problems arise with establishment during this initial stage, they can be identified and corrected. The second stage of assessment assumes that initial performance is satisfactory, and the cover system can move into established re-vegetation monitoring.

At both stages re-vegetation performance should be quantified through *in situ* monitoring techniques similar to current monitoring of rehabilitation elsewhere on site. Site visits should occur twice annually, once in the wet season and once in the dry season. Dry season die back is common in most semi-arid climates, therefore, it is important to quantify vegetation performance based on wet and dry season conditions. During site visits *in situ* vegetation performance indicators may be gathered by establishing permanent sampling transects, random quadrat sampling, and photographic monitoring over the development of the cover systems. Performance indicators such as species survival and growth, vegetation density, percent cover, species diversity, species richness, and species distribution can all be used in conjunction with the sampling techniques in support of closure objectives. Photographic evidence is also a good means of monitoring the development of vegetation over time and may potentially be utilised.

4 PERFORMANCE MONITORING PLAN

Following the installation of the monitoring equipment, it is important that a performance monitoring plan is initiated to ensure that the Data Acquisition System (DAS) is providing accurate data which satisfies the overall project objectives. Data acquisition has been automated as much as possible to ensure the timely collection of monitoring data, and to limit MRM staff time requirements.

Data will begin to be collected at the initiation of landform construction with the monitoring of the PAF(RE) lifts. It is important that data is collected and reviewed as part of the PAF(RE) monitoring to ensure that the data is being successfully collected, and that the system will be functional for subsequent lifts.

Table 4.1 outlines the performance monitoring plan requirements, including frequency of data collection and reporting for the field trial. In general, it is recommended that monthly MRM memorandums be produced to summarise the data collected that month, and a detailed annual report be completed to identify trends in the data against performance criteria.

The implementation of monthly inspection and data review is utilised to address a common mistake with respect to field performance monitoring systems. That is, if field data is not reduced and quality control checks not performed until an extended period has elapsed, the potential exists that a malfunctioning sensor or data acquisition system will not be discovered. The potential result is that key field data will be lost, even though a significant financial commitment has been made to obtain the field data.

Table 4.1: MRM field trial performance monitoring plan

Performance Monitoring Plan Task	Frequency	Responsible to complete	Task type
Sensor reading	20 min / 2 Hourly	Datalogger / Datalogger program	Automated
Data Download	Daily	Loggernet in MRM Office	Automated
Data QA/QC	Monthly	MRM/OKC	Specialist / technical
Summary of data and comparison against trigger values	Quarterly	MRM/OKC	Specialist / technical
Performance monitoring report	Annual	MRM/OKC	Specialist / technical

5 CONCLUSION

We trust this report for preliminary design of the NOEF field trial and performance monitoring system meets your requirements. We are open to further discussions on all aspects of the design, as our understanding may not have considered all relevant information.

6 REFERENCES

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Appendix A

Drawings

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GLENCORE

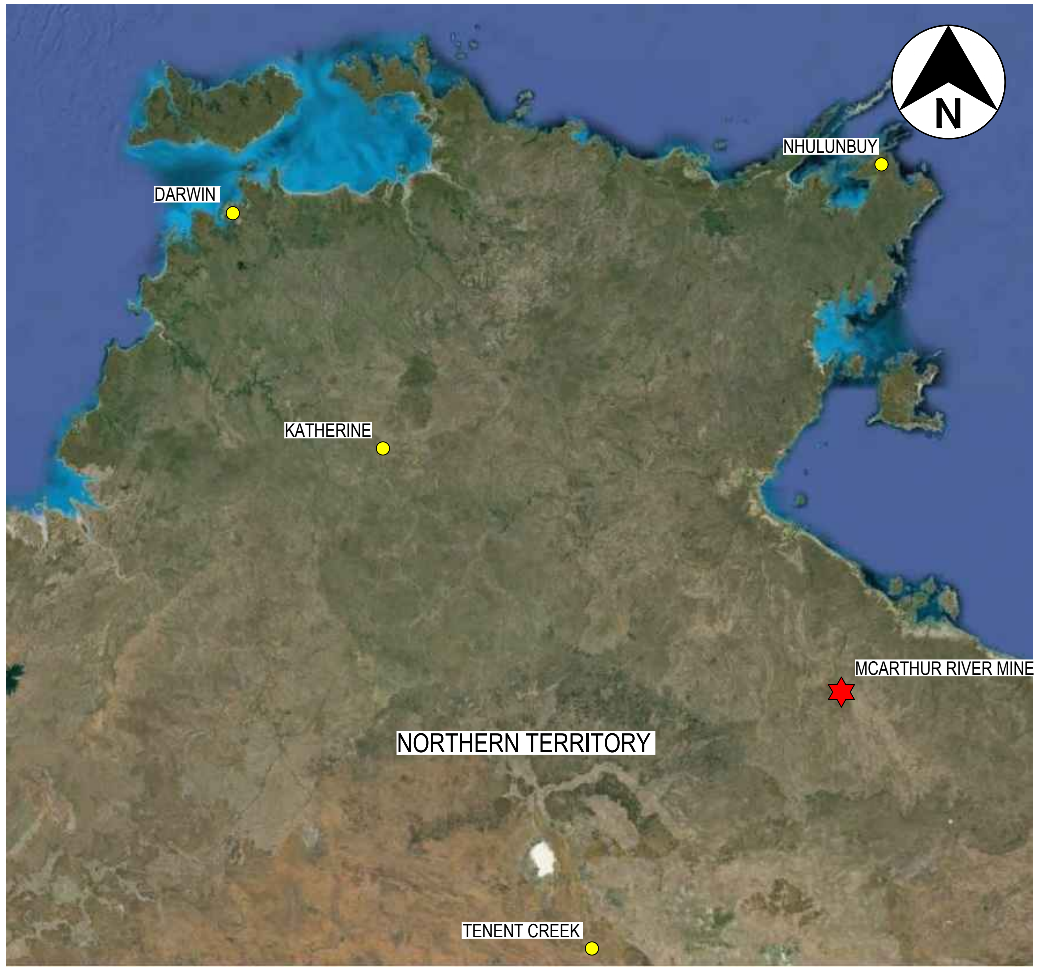
MCARTHUR RIVER MINE
NOEF LARGE SCALE FIELD COVER TRIAL

CONCEPTUAL DESIGN DRAWINGS

DRAWING INDEX

DRAWING #	DESCRIPTION
750-47-000	COVER SHEET, DRAWING INDEX AND LOCALITY MAP
750-47-001	GENERAL ARRANGEMENT
750-47-002	TYPICAL COVER TRIAL SECTIONS
750-47-003	GSL COVER SYSTEM INSTUMENTATION DETAILS
750-47-004	PAF (RE) CELL INSTRUMENTATION DETAILS

LOCALITY PLAN:



AERIAL IMAGERY: GOOGLE EARTH 2016
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PREPARED BY:

O'Kane Consultants Pty Ltd.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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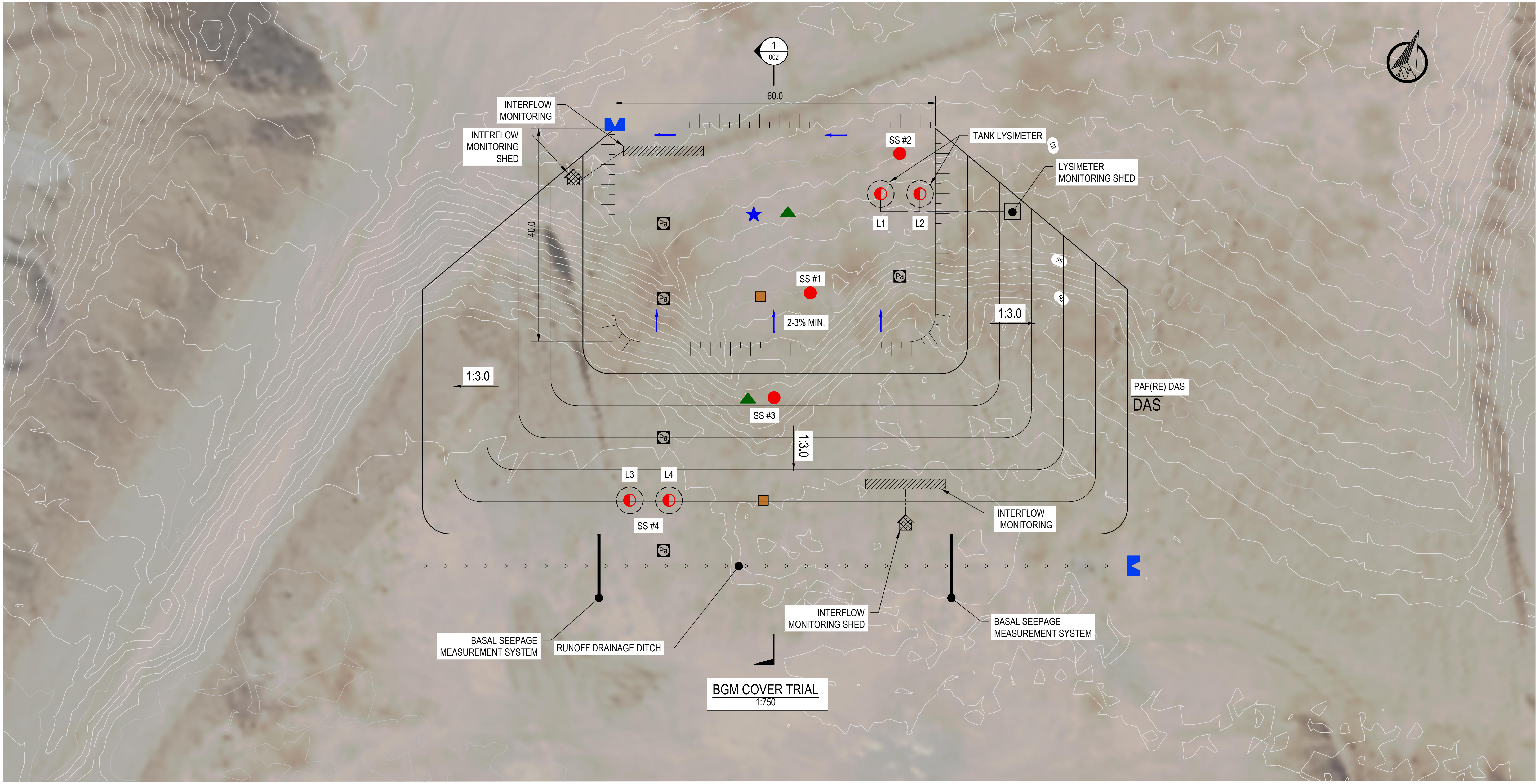

LEGEND

- DESIGN CONTOUR — 160
- EXISTING CONTOUR — 160
- CREST
- SOIL SENSOR NEST / LYSIMETER
- TANK LYSIMETER
- AIR PRESSURE, GAS CONCEN, PORE-WATER PRESSURE (+) SENSOR
- MANUAL GAS MONITORING
- PORE-WATER PRESSURE (+) SENSOR
- RUNOFF MONITORING LOCATION
- WEATHER STATION

NOTES:

1. ALL UNITS IN METERS U.N.O.
2. DO NOT SCALE.

0 7.5 15 22.5 30 37.5 45 52.5 60m
SCALE 1:750

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CLIENT/PROJECT:
LARGE SCALE FIELD COVER TRIALS

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Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology
OKC PROJECT NO.: 750/47

REFERENCE

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REVISIONS

NO.	DESCRIPTION	DRN. BY:	APPD. BY:	DATE
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DRN. BY: H. COOPER		DATE: 15.12.17	
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GENERAL ARRANGEMENT

DWG. NO.: 750-47-001 REV.: A

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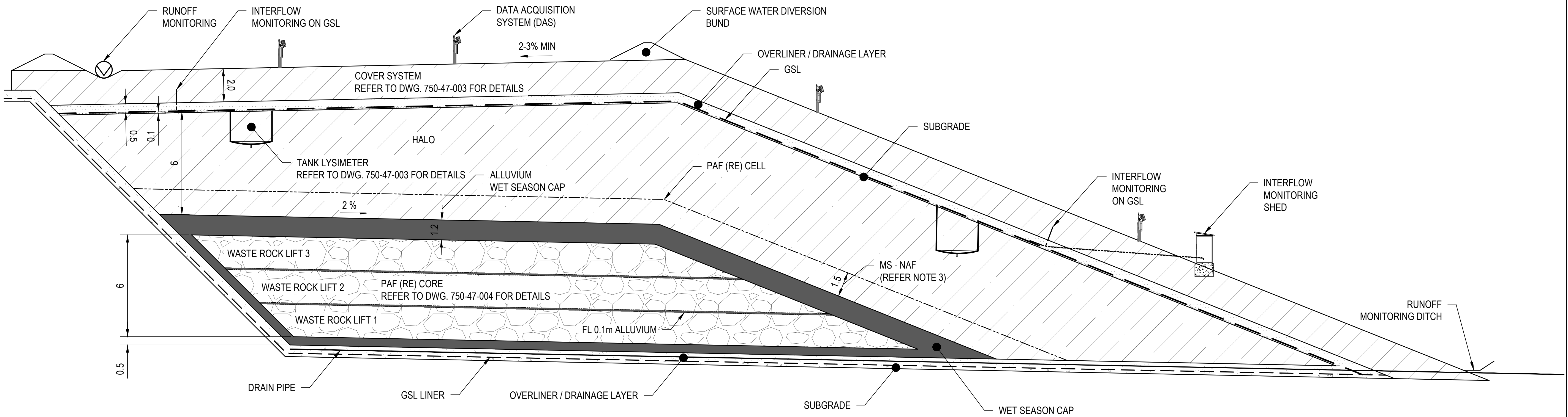

SECTION 1 / 001
1:250

TYPICAL BGM COVER TRIAL SECTION

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NOTES:

1. ALL UNITS IN METERS U.N.O.
2. DO NOT SCALE.
3. MINIMUM THICKNESS REQUIREMENT FOR PAF (RE) PRIOR TO HALO AND COVER SYSTEM CONSTRUCTION

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REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	APPD. BY:	DATE
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TYPICAL COVER TRIAL SECTIONS

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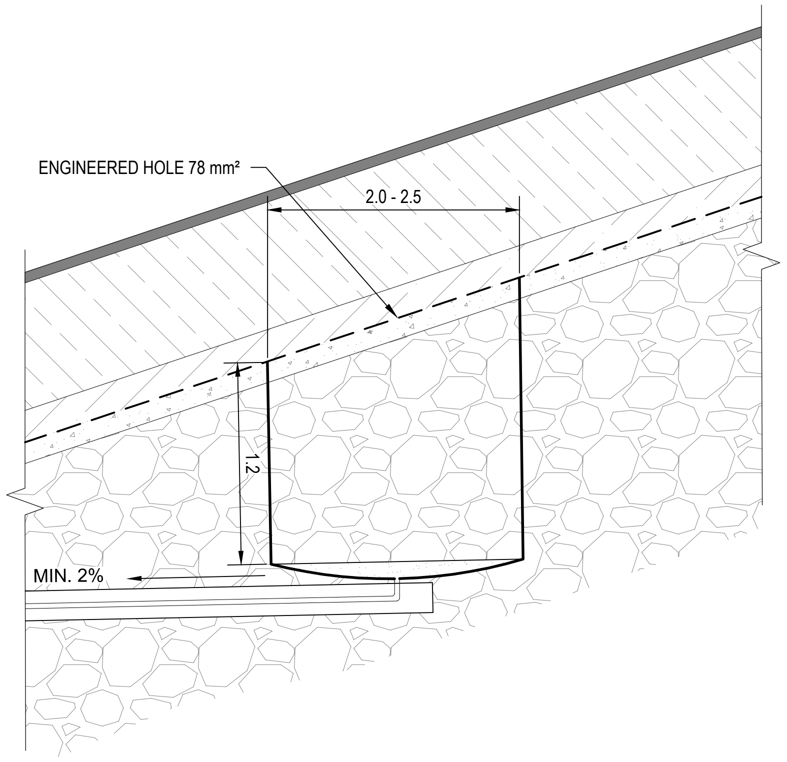
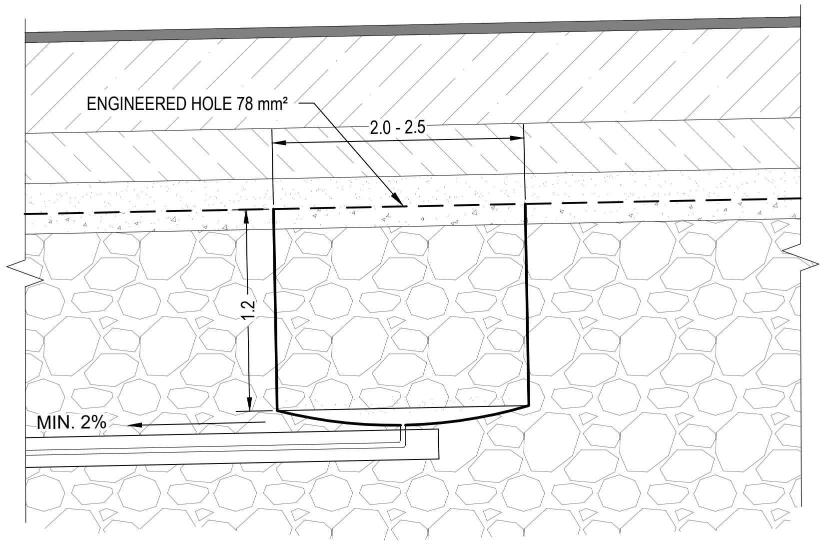
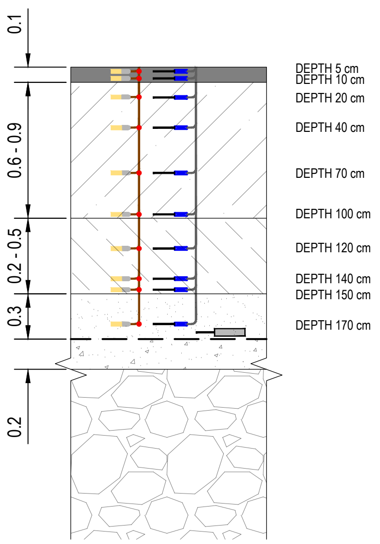


TYPICAL SLOPE TANK LYSIMETER DETAIL
1:75



TYPICALPLATEAU TANK LYSIMETER DETAIL
1:75



TYPICAL PLATEAU SOIL NEST (SS)
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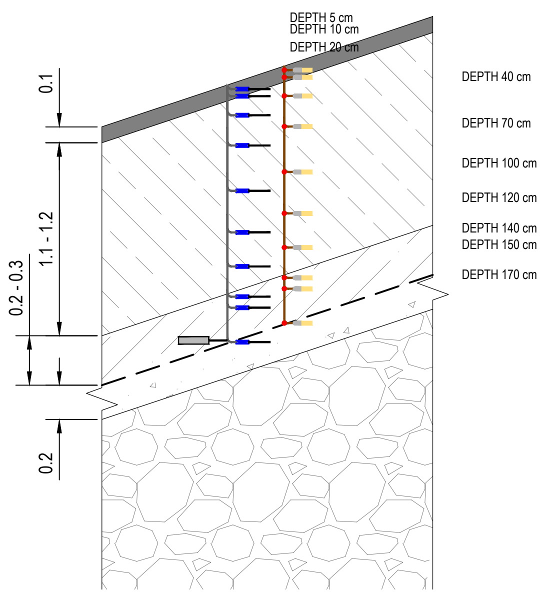

TYPICAL SLOPE SOIL NEST (SS)
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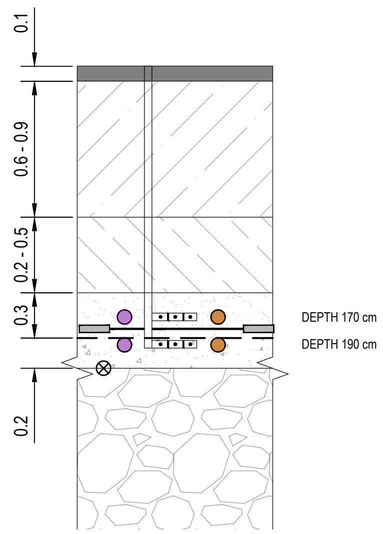

TYPICAL AUTOMATED GAS NEST
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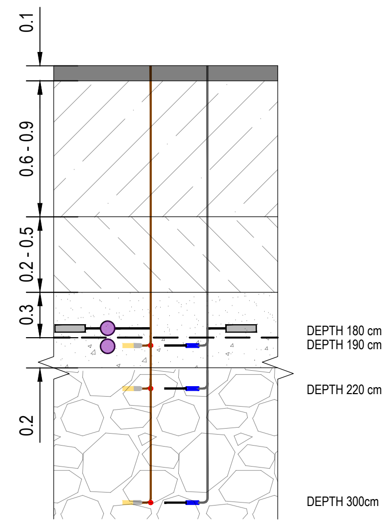

TYPICAL LYSIMETER SENSOR NEST
1:50

LEGEND

- TOPSOIL
- ALLUVIUM
- BRECCIA
- OVERLINER
- GSL LINER
- SUBGRADE
- WASTE ROCK

NOTE

1. ALL UNITS IN METRES U.N.O.

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INSTRUMENTATION LEGEND

- CS229 SOIL MATRIX SUCTION
- CS616 VOLUMETRIC WATER CONTENT
- PORE WATER PRESSURE (+)
- AUTOMATED OXYGEN SENSOR
- MANUAL OXYGEN PORT
- AIR PRESSURE SENSOR SETRA
- AIR PRESSURE

500 0 500 1000 1500 2000 2500mm
SCALE 1:50

CLIENT/PROJECT:

LARGE SCALE FIELD COVER TRIALS

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APPD. BY: M. BARTEAUX		DATE: 15.12.17	
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GSL COVER SYSTEM INSTUMENTATION DETAILS

DWG. NO.: 750-47-003 REV.: A

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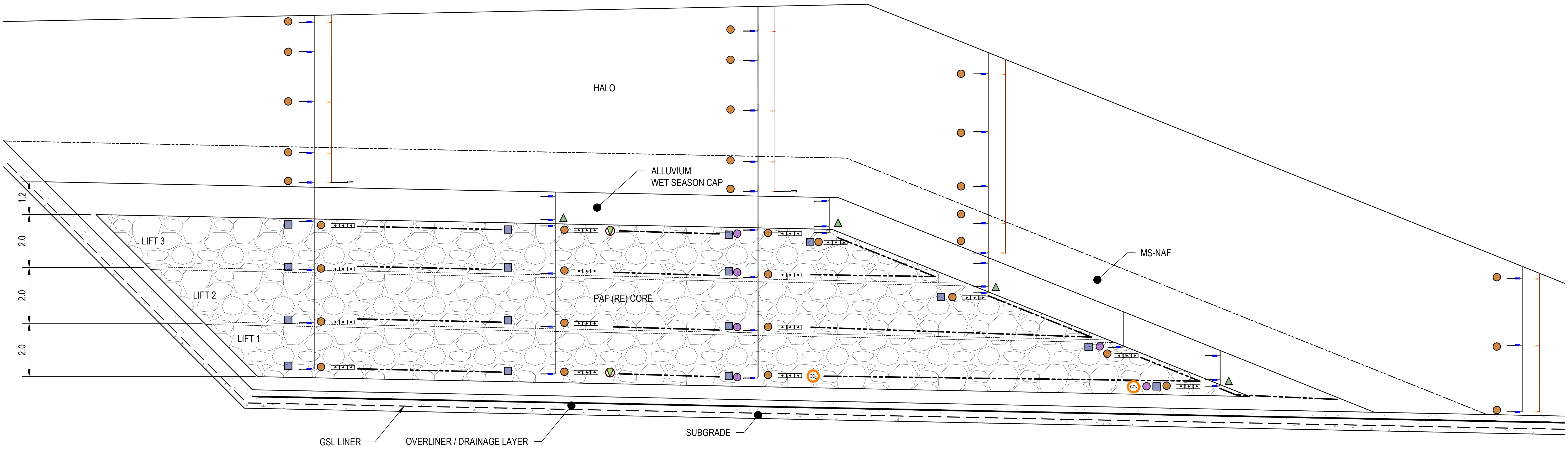

TYPICAL PAF (RE) CELL INSTRUMENT DETAIL
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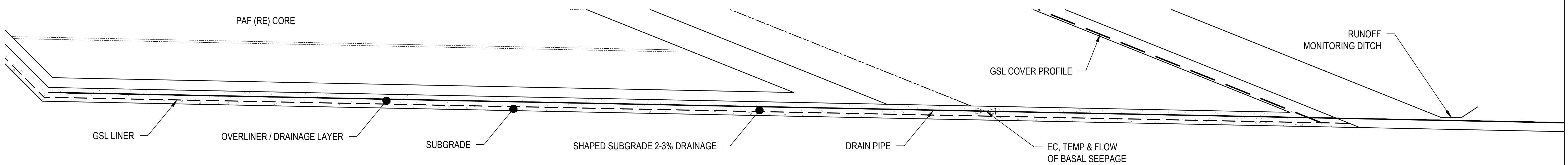


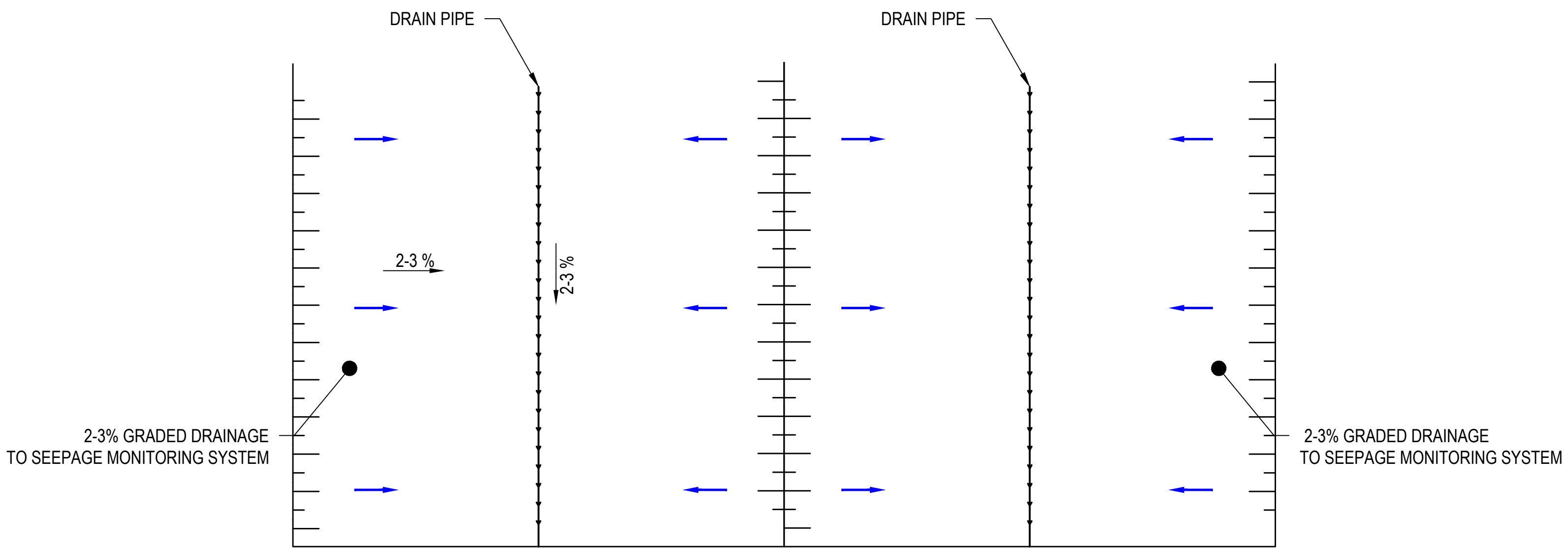
TYPICAL COVER TRIAL SUBGRADE DRAINAGE
1:200

LEGEND

- TOPSOIL
- ALLUVIUM GROWTH MEDIUM
- BRECCIA GROWTH MEDIUM
- OVERLINER
- GSL LINER
- PROTECTIVE CONDUIT
- SUBGRADE
- WASTE ROCK

INSTRUMENTATION LEGEND

- CS229 SOIL MATRIX SUCTION
- CS616 VOLUMETRIC WATER CONTENT
- VIBRATING WIRE PIEZOMETER
- PORE WATER PRESSURE (+)
- AUTOMATED OXYGEN SENSOR, GAS, RH
- MANUAL GAS PORT (O_2, CO_2, RH)
- AIR PRESSURE SENSOR
- TEMPERATURE STRING
- MPS6 MATRIC POTENTIAL SENSOR
- AUTOMATED CO_2



TYPICAL COVER TRIAL SUBGRADE SHAPING
1:1000

NOTE

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OKC PROJECT NO.: 750/47

REFERENCE DWG. NO.	DESCRIPTION

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DRN. BY: H. COOPER		DATE: 15.12.17	
APPD. BY: M. BARTEAUX		DATE: 15.12.17	
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PAF (RE) CELL INSTRUMENTATION DETAILS

DWG. NO.: 750-47-004 REV.: A

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH OKC REPORT 750/47-01