SOILWATER CONSULTANTS

soilwater GROUP
t: +61 08 9228 3060
f: +61 08 9228 3210
a: 45 Gladstone St,
East Perth, WA 6004
e: admin@soilwatergroup.com
w: www.soilwatergroup.com

# MEMO

| | | | | |
|---|---|---|---|---|
| TO: | John Ganser | COMPANY: | LYNAS RARE EARTHS PTY LTD | |
| FROM: | Adam Pratt | PROJECT TITLE: | SEEPAGE ASSESSMENT | |
| DATE: | 11 March 2021 | PROJECT & DOCUMENT NO: | KAS-004-1-24 | 004 |
| SUBJECT: | Seepage Assessment for Lynas Rare Earths – Yarri Road and Lot 500 | | | |

## 1 INTRODUCTION

Soilwater Consultants (SWC) were engaged by Lynas Kalgoorlie Pty Ltd (Lynas) to complete a seepage assessment for the proposed Yarri Road By-Products Storage Facility (BSF) and the Lot 500 Rare Earth Processing Facility (REPF) to be developed and operated by Lynas. At the REPF the following two by-products will be produced, and temporarily stored, whilst at the BSF will be permanently stored the by-products in a purpose-built Waste Material Landform (WML):

- Gypsum by-product
- Iron Phosphate (IP) by-product

Whilst the gypsum by-product is relatively inert, the IP material is considered slightly radioactive, with an Activity level of between 5 – 7 Bq/g. Concerns have therefore been raised as to the potential for seepage from the IP material, possibly containing some radioactivity, interacting with the underlying groundwater at each site.

The objective of this study was to therefore assess the potential risk of seepage from the REPF storage cells and the BSF WML reaching the underlying groundwater and potentially impacting the water quality.

## 2 MATERIAL CHARACTERISTICS

### 2.1 BY-PRODUCTS

The material characteristics of the gypsum and IP are provided in Table 2.1 whilst the derived hydraulic parameters are provided in Table 2.2.

### 2.2 REGOLITH PROFILE

The material characteristics of the kaolinitic-rich weathering profile, underlying both the REPF and BSF, are provided in Table 2.3 whilst the derived hydraulic parameters are provided in Table 2.4.

Table 2.1: Physical properties of the by-product materials

| Property | Unit | Gypsum | IP |
|---|---|---|---|
| Particle Size Distribution | | | |
| Sand (2 – 0.02µm) | % | 0 | 0 |
| Silt (0.02 – 0.002 µm) | % | 60 | 65 |
| Clay (<0.002 µm) | % | 40 | 35 |
| Bulk Density | | | |
| Wet | t/m3 | 1.55 | 1.45 |
| Dry | t/m3 | 0.74 | 0.65 |
| Particle Density | t/m3 | 2.3 | 2.2 |
| Ksat | m/day | 0.005 | 0.005 |
| Total Porosity | % v/v | 55 | 52 |
| Field Capacity | % v/v | 50 | 48 |
| Air-Filled Porosity | % v/v | 5 | 4 |
| Air-Entry Potential | cm | 71.4 | 62.5 |

Table 2.2: Derived hydraulic parameters of the by-product materials

| Property | Unit | Gypsum | IP |
|---|---|---|---|
| Water retention data | | | |
| - 0 kPa | % (v/v) | 55 | 52 |
| - 10 kPa | % (v/v) | 50 | 48 |
| - 33 kPa | % (v/v) | 45 | 42 |
| - 100 kPa | % (v/v) | 40 | 39 |
| - 1,500 kPa | % (v/v) | 30 | 29 |
| van Genuchten parameters | | | |
| - alpha ($\alpha$) | 1/cm | 0.014 | 0.016 |
| - n | - | 1.15 | 1.11 |
| - $\theta s$ | $cm^3/cm^3$ | 0.55 | 0.52 |
| - $\theta r$ | $cm^3/cm^3$ | 0.10 | 0.02 |

Table 2.3: Physical properties of the kaolinitic-rich weathering profile

| Property | Unit | Kaolinite-rich material |
|---|---|---|
| Particle Size Distribution | | |
| Sand (2 – 0.02µm) | % | 40 |
| Silt (0.02 – 0.002 µm) | % | 35 |
| Clay (<0.002 µm) | % | 25 |
| Bulk Density | | |
| Wet | t/m3 | 1.55 |
| Dry | t/m3 | 1.50 |
| Particle Density | t/m3 | 2.36 |
| Ksat | m/day | 0.01 |

| | | |
|---|---|---|
| Total Porosity | % v/v | 36 |
| Field Capacity | % v/v | 30 |
| Air-Filled Porosity | % v/v | 6 |
| Air-Entry Potential | cm | 76.9 |

Table 2.4: Derived hydraulic parameters of the kaolinitic-rich weathering profile

| Property | Unit | Kaolinite-rich material |
|---|---|---|
| Water retention data | | |
| - 0 kPa | % (v/v) | 36 |
| - 10 kPa | % (v/v) | 30 |
| - 33 kPa | % (v/v) | 25 |
| - 100 kPa | % (v/v) | 20 |
| - 1,500 kPa | % (v/v) | 10 |
| van Genuchten parameters | | |
| - alpha ($\alpha$) | 1/cm | 0.013 |
| - n | - | 1.24 |
| - $\theta$s | $cm^3/cm^3$ | 0.36 |
| - $\theta$r | $cm^3/cm^3$ | 0 |

# 3 SITE CHARACTERISTICS

## 3.1 LOT 500 REPF

The local geology and regolith profile underlying the REPF is reported in Ramboll (2020)[1].

The pertinent site characteristics are outlined below:

- Deep regolith (or weathering) profile - > 40 m deep
- Regolith profile composed predominately of metamorphosed felsic volcanics that have produced a kaolinite-rich, fine-grained weathering profile
- Depth to permanent groundwater – approximately 35 m bgl[2] (~ 339 m AHD[3])
- Groundwater is saline, with TDS[4] values varying from 30,200 to 52,400 mg/L

## 3.2 YARRI RD BY-PRODUCTS STORAGE FACILITY (BSF)

The local geology and regolith profile underlying the BSF is currently being investigated. Information on the local geology and regolith profile was therefore taken from work previously undertaken for Ambrose Mining for the proposed Kalgoorlie Clay Project in the adjacent Mining Lease (M26/835), located approximately 1 km north of the proposed BSF.

[1] Ramboll (2020). *Baseline Soil and Groundwater Investigation for Lot 500*. Unpublished report for Lynas Kalgoorlie Pty Ltd by Ramboll Australia Pty Ltd.

[2] bgl = below ground level

[3] AHD = Australian Height Datum

[4] TDS = Total Dissolved Solids

The pertinent site characteristics are outlined below:

- Very deep to deep regolith (or weathering) profile – 70 – 90 m deep
- Regolith profile composed predominately of metasediments of the Black Flag Beds that have produced a kaolinite-rich, fine-grained weathering profile
- Depth to permanent groundwater – > 70 m bgl
- Groundwater is saline to hypersaline

# 4 MODELLING APPROACH

## 4.1 MODEL

All seepage modelling was undertaken using HYDRUS 2D/3D[5]. HYDRUS 2D/3D is considered industry best practice because it explicitly solves the Richards' Equation, whereby the permeability of the soil / material is dependent on its moisture content or matric suction. In contrast, seepage models that rely on Darcy's Equation do not vary permeability based on soil matric suction.

## 4.2 MODEL SETUP

The unsaturated zone model setup is shown in Figure 4.1.

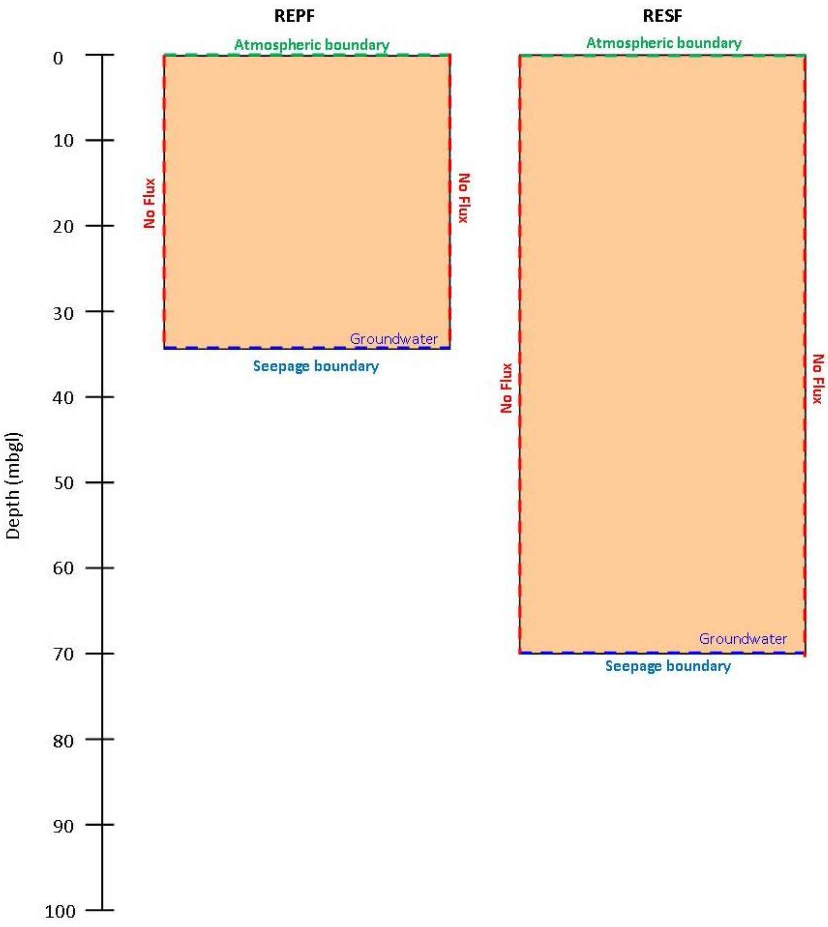


Figure 4.1: Unsaturated zone model setup

[5] PC Progress (Prague, Czech Republic)

## 4.3 CLIMATE DATA

Daily rainfall and pan evaporation data for Kalgoorlie[6] was used for the atmospheric boundary. A summary of the yearly rainfall and pan evaporation data, for the period 01/01/2009 – 31/12/2020, is presented in Table 4.1, whilst Table 4.2 shows the statistics for the daily rainfall and pan evaporation.

Table 4.1: Yearly summary of rainfall and pan evaporation used for the seepage assessment

| Year | Rainfall (mm) | Pan Evaporation (mm) |
|---|---|---|
| 2009 | 254 | 2,700 |
| 2010 | 168 | 2,462 |
| 2011 | 416 | 2,204 |
| 2012 | 247 | 2,655 |
| 2013 | 393 | 2,490 |
| 2014 | 370 | 2,539 |
| 2015 | 237 | 2,774 |
| 2016 | 298 | 2,440 |
| 2017 | 257 | 2,447 |
| 2018 | 328 | 2,456 |
| 2019 | 139 | 2,556 |
| 2020 | 170 | 2,599 |
| ***Statistic*** | | |
| ***Min*** | ***139*** | ***2,204*** |
| ***Max*** | ***416*** | ***2,774*** |
| ***Average*** | ***273*** | ***2,527*** |
| ***Median*** | ***256*** | ***2,515*** |
| ***Std Dev*** | ***90*** | ***148*** |

Table 4.2: Daily rainfall and pan evaporation statistics

| Statistic | Daily Rainfall (mm) | Daily Pan Evaporation (mm) |
|---|---|---|
| Min | 0 | 0 |
| Max | 103 | 66 |
| Average | 0.77 | 8.5 |
| Median | 0 | 7.2 |
| Std Dev | 4.1 | 7.4 |

# 5

[6] Kalgoorlie-Boulder Airport – Station Number 12038

# 6 MODEL RESULTS

## 6.1 HYDRAULIC BEHAVIOUR OF SOILS

When attempting to assess seepage potential from Waste Rock Landforms (WRLs) or in this case Waste Material Landforms (WMLs) it is critical to understand the hydraulic behaviour of soils. All soils and materials can only drain to their field capacity (FC; 10 kPa matric suction) and they will equilibrate to this level over time. As shown in Table 2.2, the field capacity of the two by-product materials is around 50 % or 0.5 $m^3/m^3$. It is only when the moisture content of the soil / material is exceeded that drainage or seepage will occur through a process of piston-flow (i.e. inflowing water effectively 'pushes' water out the bottom of the soil).

The moisture content of a soil that is not at the surface can only drop below field capacity by the action of plant roots, which can effectively 'dry' the soil to permanent wilting point (PWP; 1,500 kPa matric suction). Given the adverse chemical properties of the by-products, no plant roots are expected to access the WML, below the cover system, and therefore the by-products stored in the WML will eventually equilibrate to field capacity (0.5 $m^3/m^{3)}$, which is a considerable volume of water.

All soil moisture held in pores <0.1 µm (cryptopores) is effectively locked away and does not move or redistribute. The effective moisture holding capacity of soils is therefore taken as moisture content (or porosity) between FC and PWP; often referred to as the plant available water content (PAWC).

At the surface, solar drying can result in moisture contents below FC and during summer moisture contents below PWP can occur at the surface. Solar drying can only influence the top 100 cm of the soil, and most of the drying will only occur in the top 30 cm. Using the water retention data provided in Table 2.2, the readily available storage capacity of the by-product materials is around 20 % or 0.2 $m^3/m^3$. This moisture content effectively equates to 200 mm of water storage capacity in the top 1 m of the material, which is around 78 % of the total annual rainfall; hence little actual rainfall is expected to leach past the top 1 m of the stockpiled by-product material.

In addition to the considerable storage capacity of the by-products, it's very low unsaturated permeability will further restrict water movement and associated seepage from the WML. As shown in

Figure 6.1, the permeability of the two by-product materials at field capacity is around 1.0 x $10^{-3}$ cm/day, which is equivalent to 1.2 x 10-$^{10}$ m/s, which is an order of magnitude lower than the DoW (2013) Clay Liner Guideline[7].

[7] DoW (2013). *Liners for containing pollutants, using engineered soils*. Water Quality Protection Note (WQPN) 27. Department of Water, Perth Western Australia.

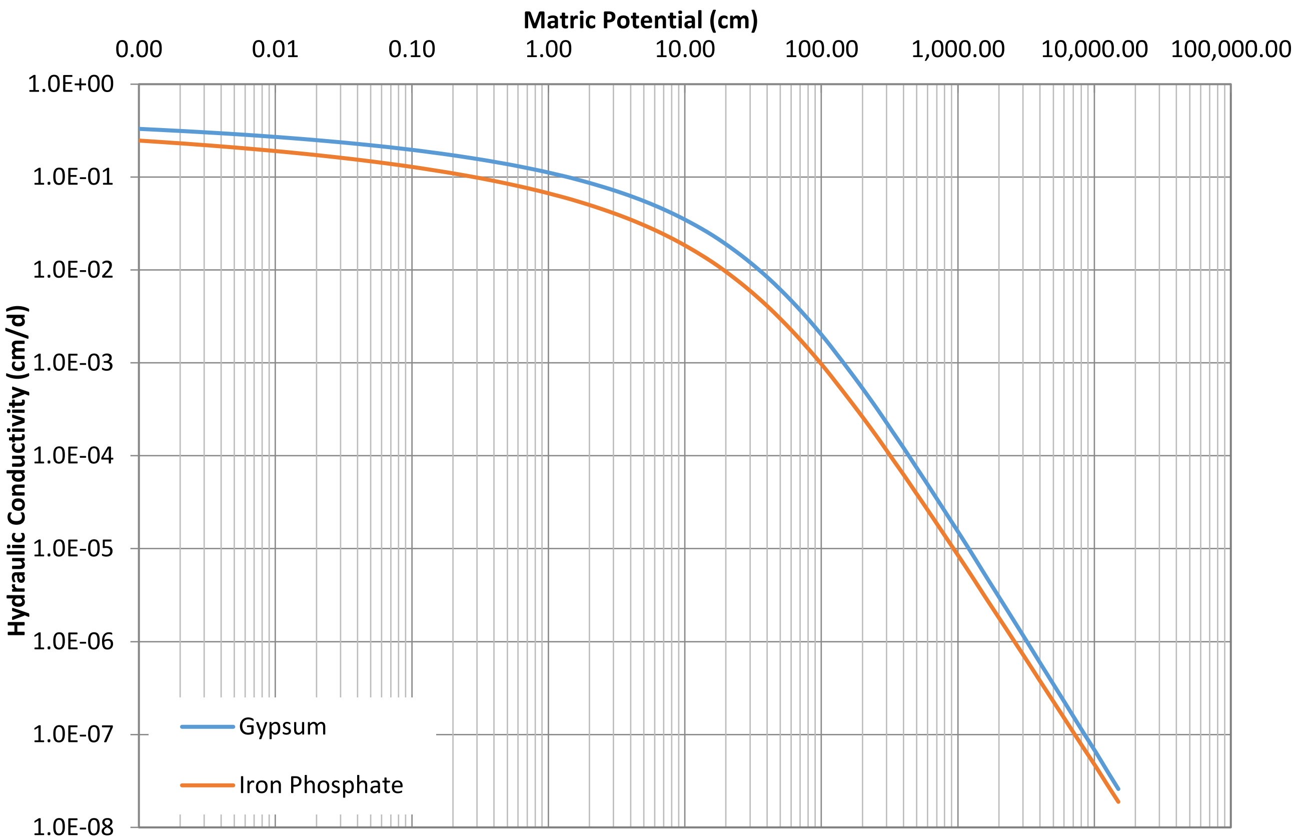


Figure 6.1: Hydraulic conductivity function (HCF) for the gypsum and IP

## 6.2 SEEPAGE

### 6.2.1 LOT 500 (REPF)

The predicted seepage likely to occur through the 35 m deep unsaturated zone profile beneath Lot 500, assuming typical rainfall and pan evaporation conditions, is provided in Table 6.1. These results show that the predicted seepage reaching the underlying groundwater aquifer is expected to be somewhere between 94 mm/yr (2.0 x $10^{-9}$ m/s) and 0.17 mm/yr (5.4 x $10^{-12}$ m/s), which equates to between 2.8 % to <0.01 % of the total annual rainfall. It is important to note that most hydrogeological studies conducted in the Goldfields assume a groundwater recharge of around 1 % of the total annual rainfall, so the results presented in Table 6.1 are considered accurate.

Table 6.1: Model results for Lot 500 REPF

| Parameter | Initial matric suction of *in situ* regolith profile | |
|---|---|---|
| | Field Capacity (10 kPa) | 100 kPa |
| Total seepage over model period (12 years) | 1.12 m | 0.002 m |
| Seepage rate | 93.75 mm/yr (2.0 x $10^{-9}$ m/s) | 0.17 mm/yr (5.39 x $10^{-12}$ m/s) |
| % of rainfall over model period (12 years) | 2.78 % | 0.005 % |

Given the majority of rainfall landing on any stockpiles of by-product materials is expected to be stored in the stockpiles the estimates predicted in Table 6.1 are likely to represent worst-case.

It is also important to acknowledge that by-product material within Lot 500 is expected to be stockpiled in lined cells, meeting the relevant DoW Liner Specifications; hence the risk of any seepage generated from the stockpiled material interacting with the underlying *in situ* regolith profile is very low.

### 6.2.2 YARRI ROAD (BSF)

The predicted seepage likely to occur through the 70 m deep unsaturated zone profile beneath Yarri Road, assuming typical rainfall and pan evaporation conditions, is provided Table 6.2. Even if the regolith profile is at field capacity, the seepage rate at the base of the profile (or into the underlying groundwater aquifer) is between 33.54 mm/yr (1.0 x 10-9 m/s) and 0.06 mm/yr (1.9 x $10^{-12}$ m/s).

As mentioned previously, the quantity of seepage expected to be generated below the BSF is expected to be significantly lower than the predicted seepage under typical rainfall and pan evaporation conditions. These results therefore represent worst case.

Table 6.2: Model results for Yarri Road BSF

| Parameter | Initial matric suction of *in situ* regolith profile | |
|---|---|---|
| | Field Capacity (10 kPa) | 100 kPa |
| Total seepage over model period (12 years) | 0.41 m | 0.001 |
| Seepage rate | 33.54 mm/yr (1.0 x $10^{-9}$ m/s) | 0.06 mm/yr (1.92 x $10^{-12}$ m/s) |
| % of rainfall over model period (12 years) | 1.0 % | 0.002 % |

## 7 CONCLUSIONS

The predicted seepage rates obtained for Lot 500 REPF and Yarri Road BSF show that any seepage generated from these two facilities is unlikely to impact on the underlying groundwater aquifer due to the negligible volume of seepage reaching the water table. Even under worst case conditions (i.e. field capacity), the seepage rate interacting with the underlying aquifer is equivalent to the accepted DoW (2013) Clay Liner seepage rate ($10^{-9}$ m/s).

As shown in Figure 7.1 the primary safeguard for the underlying groundwater aquifer, against any interaction or impact from seepage generated from the REPF or BSF, is the very low permeability of the unsaturated (vadose) zone materials. The HCF (Figure 7.1) predicts that the hydraulic conductivity of the unsaturated sediments at field capacity (worst case) is around 1.0 x $10^{-4}$ m/d, which is equivalent to 1.0 x $10^{-9}$ m/s. The deep regolith profile underlying the REPF and the BSF therefore acts as a clay liner minimising the volume of seepage that can leach through the profile and interact with the underlying groundwater.

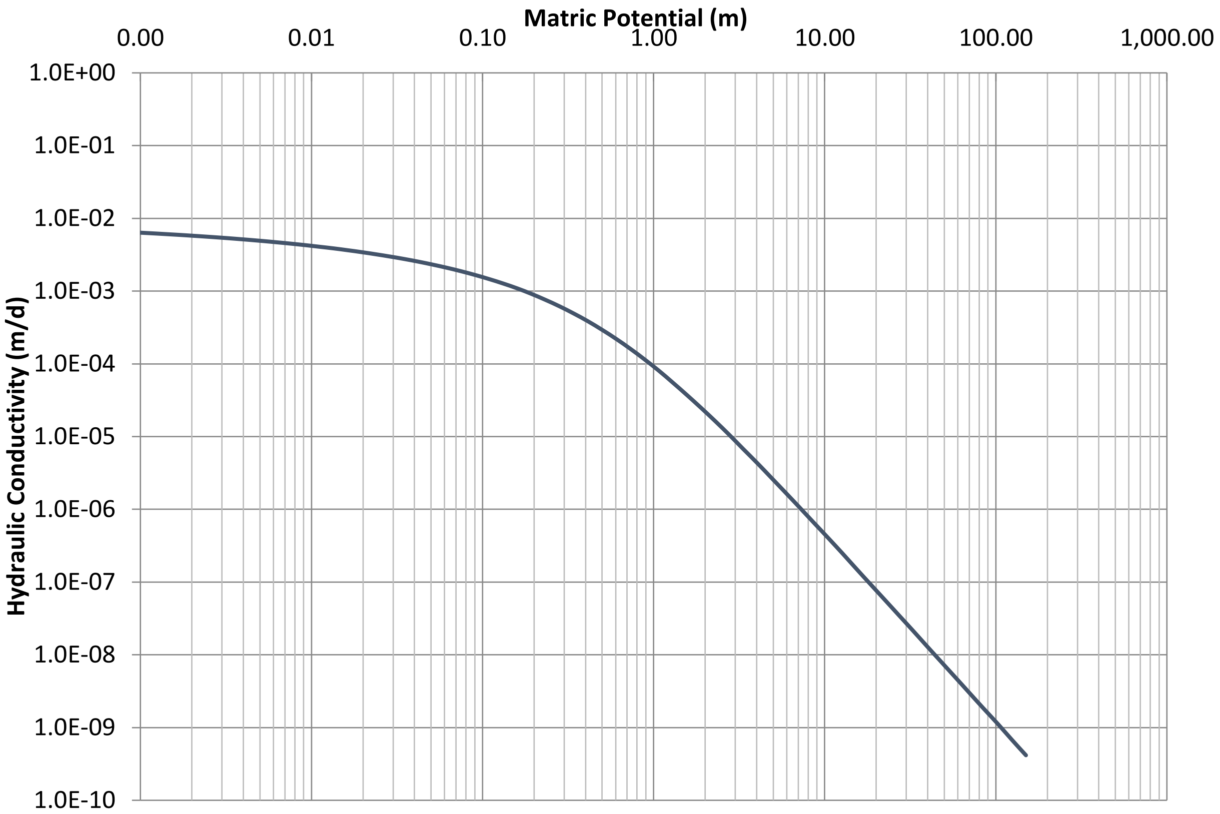


Figure 7.1: HCF for the unsaturated regolith materials underlying the REPF and the BSF

Should you have any queries regarding this report, please do not hesitate to contact us.

Yours sincerely,

Adam Pratt

Director

Principal Soil Scientist

m: +61 (0)427 105 200

t: +61 8 9228 3060

e: Adam.Pratt@soilwatergroup.com