SOILWATER CONSULTANTS

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Prepared for:	DORAY MINERALS LTD
Date of Issue:	2 June 2017
Project No.:	DRM-001-1-8

Distribution:

Electronic Copy – XXXX

A Member of the SOILWATER GROUP
SOILWATER CONSULTANTS | SOILWATER ANALYSIS | SOILWATER TECHNOLOGIES
www.soilwatergroup.com
45 Gladstone Street, East Perth, WA 6004 | Tel: +61 8 9228 3060 | Email: swc@soilwatergroup.com

DOCUMENT STATUS RECORD

Project Title:	GNAWEEDA DEPOSIT SOIL CHARACTERISATION
Project No.:	DRM-001-1-8
Client:	DORAY MINERALS LTD

Revision History

Revision Code*	Date Revised	Revision Comments	Signatures		
			Originator	Reviewer	Approved
A	30/05/17	Internal review	SC	ASP	ASP
B	02/06/17	Client review	SC		

Revision Code*

A - Report issued for internal review

B - Draft report issued for client review

C - Final report issued to client

LIMITATIONS

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to undertake a soil characterisation of the proposed Gnaweeda Deposit. This work was conducted in accordance with the Scope of Work presented to Doray Minerals (‘the Client’). SWC performed the services in a manner consistent with the normal level of care and expertise exercised by members of the earth sciences profession. Subject to the Scope of Work, the geochemical investigation was confined to the Gnaweeda deposit area. No extrapolation of the results and recommendations reported in this study should be made to areas external to this project area. In preparing this study, SWC has relied on relevant published reports and guidelines, and information provided by the Client. All information is presumed accurate and SWC has not attempted to verify the accuracy or completeness of such information. While normal assessments of data reliability have been made, SWC assumes no responsibility or liability for errors in this information. All conclusions and recommendations are the professional opinions of SWC personnel. SWC is not engaged in reporting for the purpose of advertising, sales, promoting or endorsement of any client interests. No warranties, expressed or implied, are made with respect to the data reported or to the findings, observations and conclusions expressed in this report. All data, findings, observations and conclusions are based solely upon site conditions at the time of the investigation and information provided by the Client. This report has been prepared on behalf of and for the exclusive use of the Client, its representatives and advisors. SWC accepts no liability or responsibility for the use of this report by any third party.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Soil Water Consultants (SWC) were commissioned by Doray Minerals Ltd (Doray) to undertake a pre-mine soil characterisation for the proposed Gnaweeda Deposit, including the mine pit, and infrastructure footprints (Study Area). The purpose of this assessment was to identify and characterise all surficial soil materials within these proposed disturbance areas and suggest management strategies for their handling and utilisation. This information provides baseline data that can be used to assist in the mining of these materials, and in the construction and rehabilitation of the WRL. Implementation of the soil management recommendations suggested in this report will ensure that only optimal materials are used in the construction of the outer surface of the waste rock stockpile, thus facilitating stability and revegetation, and ultimately closure and bonds return

1.1 OBJECTIVES OF WORK

The objectives of this soil characterisation were to:

- Define the distribution of soil materials in the Study Area;
- Characterise the physical and chemical properties of these materials;
- Identify materials that may be beneficial to the rehabilitation of the waste rock stockpile, and materials that may have an adverse impact on rehabilitation;
- Suggest management strategies for the handling and utilisation of these materials during mining and rehabilitation.

1.2 SCOPE OF WORK

The Scope of Work completed by SWC included:

- Collection of soil material samples from the proposed disturbance areas using shallow trench excavations;
- Description of the surface soil profiles throughout the disturbance areas and preparation of a soils map for the area;
- Undertake and coordinate the laboratory analysis;
- Review of laboratory results and preparation of this report.

.

2 SITE DESCRIPTION

2.1 STUDY LOCATION

The Gnaweeda deposit is located approximately 40 km northeast of Meekatharra and approximately 15 km southeast of the existing Andy Well operations in the Northern Murchison region of Western Australia. The Study Area characterised in this investigation is centred on the proposed project infrastructure and covered an approximate area of 900 ha. The proposed project infrastructure will comprise the mine site (mine pit, waste rock landform, laydown area and support infrastructure) with a haul road corridor connecting the project to the mill at Andy Well.

2.2 CLIMATE

The Study Area is located within the arid desert region of the northern Murchison region of Western Australia. Data measured by the Bureau of Meteorology (station number 007045 – Meekatharra Airport) from 1950 to 2017, show that the area experiences an average mean maximum temperature of 29.0° C that varies between 38.3°C and 19.1°C, and average mean minimum temperature of 15.9° C varying between 24.4°C and 7.4°C in January and July, respectively.

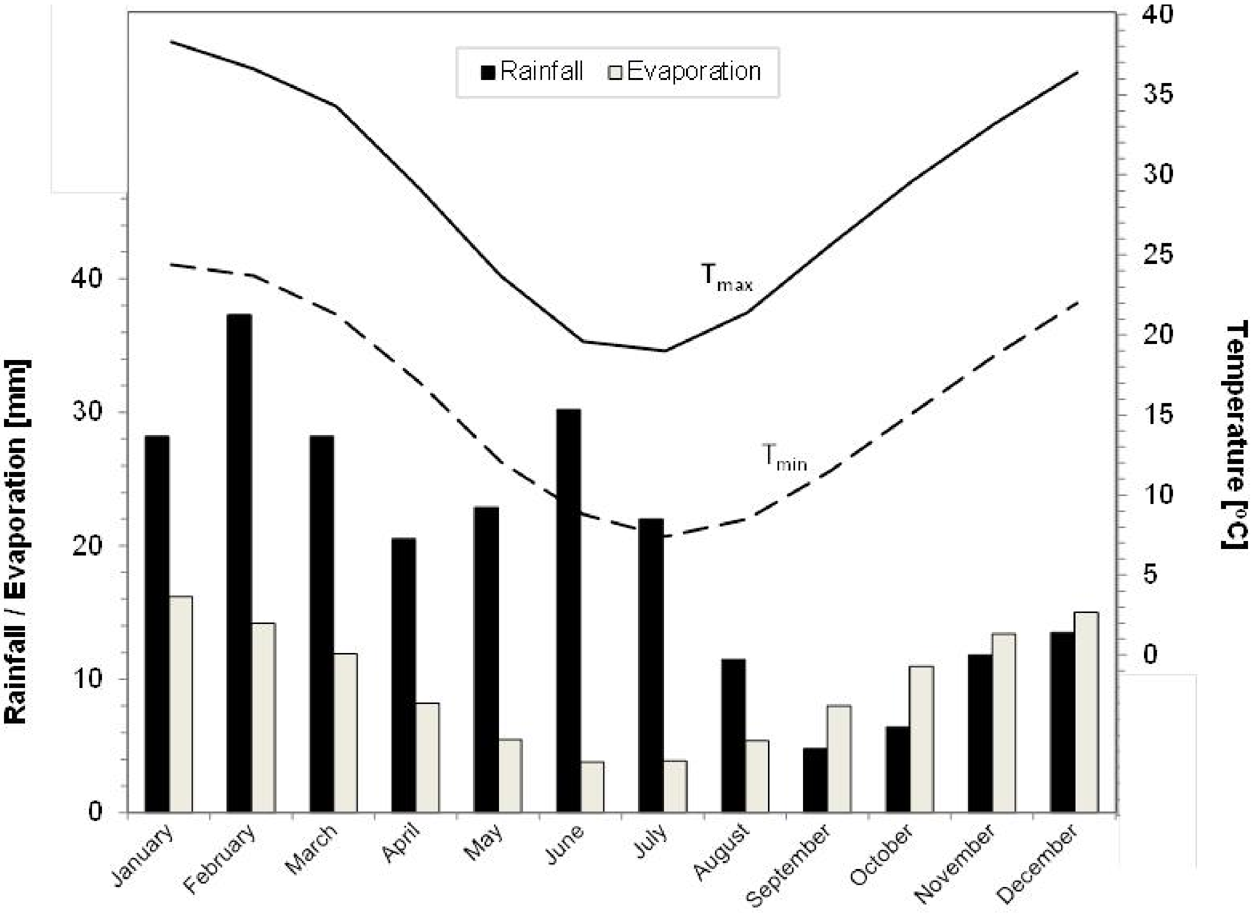


Figure 2.1: Summary climate statistics

Precipitation data for this period shows a mean rainfall of 239.1 mm annually. Monthly rainfall averages are not in sync with the sinoidal pattern shown by temperature and evaporation with maxima in average monthly rainfall of 36.3 mm in February and 30.1 mm in June, and minima September of 4.5 mm. Rainfall in the summer period is highly variable associated with tropical cyclonic depressions originating in Northern Australia. These rainfall events are responsible for localised flooding on the subdued plains of the region. Typically, the region experiences arid conditions, with potential evapotranspiration exceeding precipitation in most months.

2.3 GEOMORPHOLOGY

The Study Area is characterised by low rises and generally subdued topography, with the central, western and southern areas dominated by a surface water focal area expressed as flat hardpan wash plains with extensive fine sediment and minor quartz gravels (Plate 2.1). Further to the north and east are kaolinised footslopes and breakaways on extensive gently sloping plains over granite (Plate 2.2). These gently positive areas within the landscape control the surface run-off in the area, resulting in diffused surface flow to the south and west.

Plate 2.1: Wanderrie grass and Mulga on flat hardpan wash plains

Plate 2.2: Surface lag from breakaway slopes

2.4 VEGETATION

The vegetation of the Andy Wells Deposit can be broadly described as “Mulga” (*Acacia aneura*) or *Acacia* semi-desert scrub consisting of *Acacia* groves roughly aligned to contours within an otherwise treeless broad, flat hardpan wash plain supporting low open scrub of *Eremophila* spp. MWH (2017) mapped 18 vegetation communities across the broader study area and recorded a total of 151 vascular flora taxa representing 28 families and 55 genera, including *Acacia* (22 taxa), *Eremophila* (15 taxa) and *Senna* (10 taxa). No introduced flora taxa (weeds) were recorded during the survey. Vegetation over the landforms can be generally grouped into the following six primary groupings[1]

- Isolated *Acacia* over *Eremophila* on heavy clay pans
- *Acacia* shrubland on sandy clay quartz plains
- *Mulga* woodland on medium to sandy clay
- Chenopod shrublands on sandy clay plains
- *Eremophila* on quartz or sandy plains
- Outcrops and ridges

---

[1] MWH (2017) communities listed in parenthesis

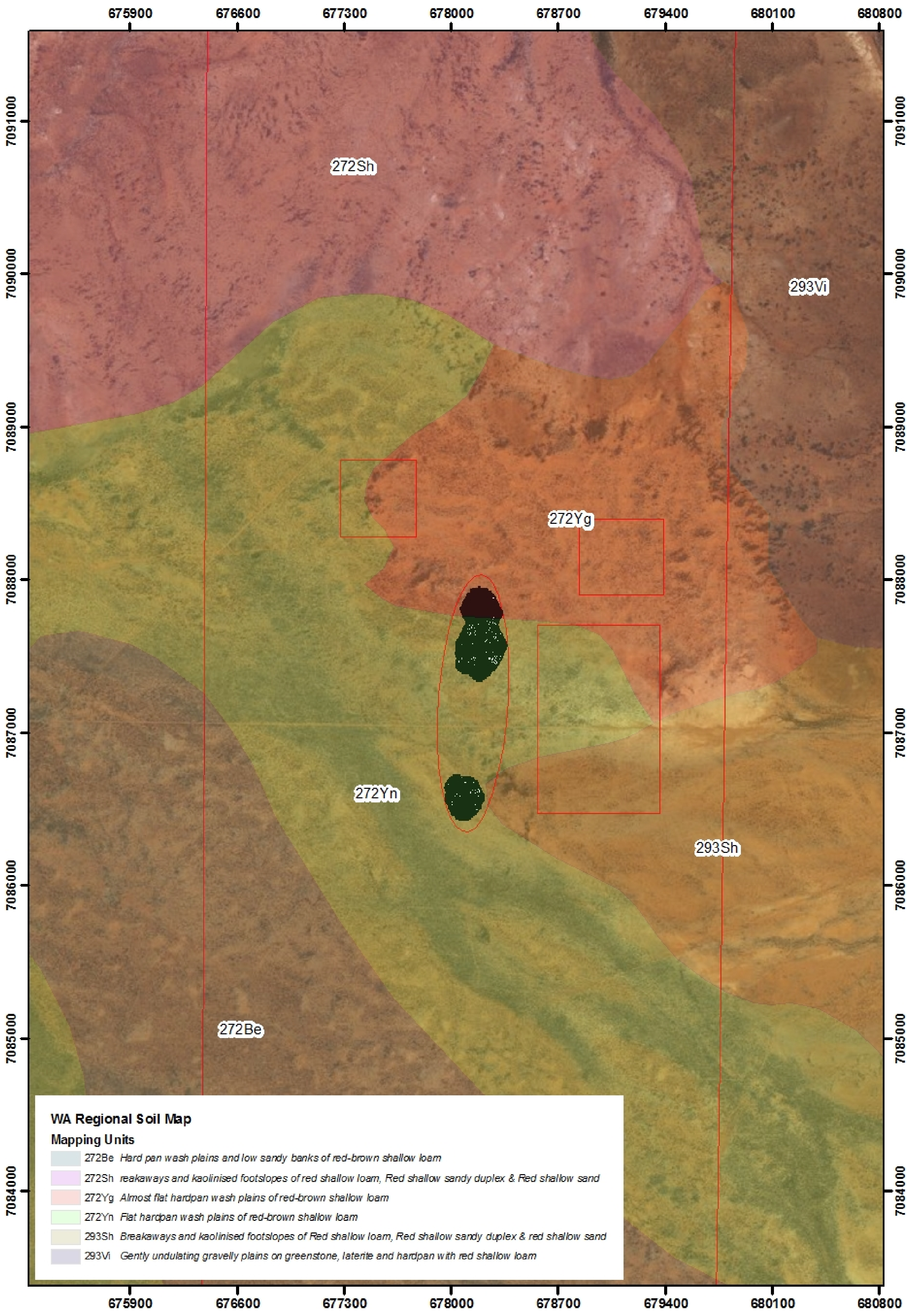
2.5 REGIONAL SOILS

The soils across the Study Area have been mapped at a regional scale (1:250,000) by the Western Australian Department of Agriculture as part of the Murchison River catchment and surrounds survey. The regional soils distribution is shown in Figure 2.2.

At this scale there are 4 major soil land systems across the study area:

- (272Be) - Reddish brown hardpan with shallow loams associated with hardpan wash plains and low sandy banks on flat alluvial plains of the Belele land system - this soil is typically shallow (< 1m) underlain by a red brown hardpan of cemented alluvium (Curry et al., 1994).
- (272/293Sh) – Red shallow loam, shallow sandy duplex & shallow sands all occurring in areas of breakaways, kaolinised footslopes and extensive gently sloping plains on granite of the Sherwood land system.
- (272Yg) – - Reddish brown hardpan with shallow loams associated with almost flat wash plains of the Yanganoo land system - this soil is typically shallow (< 1m) underlain by a red brown hardpan of cemented alluvium (Curry et al., 1994).
- (272Yn) – Reddish brown shallow loam over hardpan on flat colluvial plains of the Yandil land system – these soil types are commonly referred to as “flat hardpan wash plains” (Curry et al., 1994) consisting of a shallow loamy surface mantle of quartz or ironstone pebbles and gravels.

Underlying all of the soil groups is a regionally extensive Quaternary hardpan feature colloquially known as the Wiluna Hardpan (Bettenay and Churchward, 1974) which occurs from north of Mundiwindi to south of Paynes Find. The material varies in lithology with region, consisting primarily of a colluvial / alluvial conglomerate (clays, sands, gravels, rock fragments) that have been progressively altered through clay illuviation and cementation by amorphous silica. These conditions are thought to result from bioclimatic pedogenesis, in particular, sequential wet-dry cycles associated with the episodic (cyclonic) flooding and prolonged, intense dehydration highlighted in Section 2.2 (Teakle, 1936; Bettenay and Churchward, 1979).



DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 2.2: Regional Soils

soilwater GROUP

3 STUDY METHODOLOGY

3.1 SOIL SAMPLE COLLECTION

Soil materials within the Study Area were investigated by shallow trench excavation across the different disturbance areas. Sampling was undertaken in April 2017, and the locations of the sampling sites are shown in Figure 3.1.

Shallow trenches were mechanically excavated to a maximum depth of 2 m, or until a consolidated layer (e.g. hardpan) was reached. A total of 12 trenches were excavated across the proposed disturbance area. Samples were collected at 10 cm intervals down the surficial profile to ensure that any pedologic organisation or horizonation was identified and that each of the major soil materials present were sampled. Approximately 3 kg of soil was collected for each material for detailed laboratory analysis (Section 3.3).

The details of the trenches excavated are summarised in Table 3.1.

Table 3.1: Details of representative drillholes chosen for screen analysis

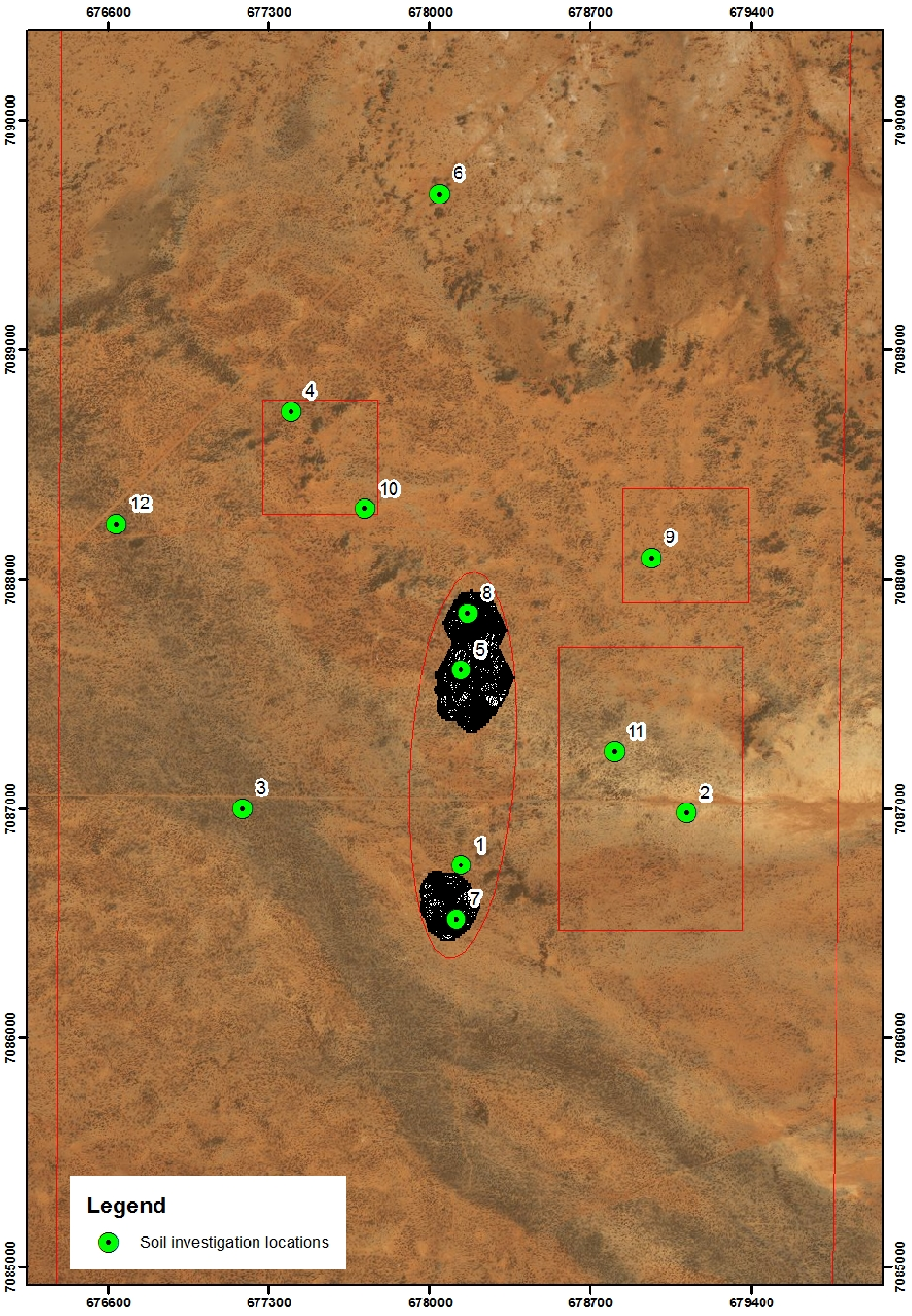
ID	Coordinates (GDA 94, Zone 50)		Trench depth (cm)	ID	Coordinates (GDA 94, Zone 50)		Trench depth (cm)
	Easting	Northing			Easting	Northing	
1	678,140	7,086,753		7	678,118	7,086,519	
2	679,121	7,086,983		8	678,170	7,087,851	
3	677,189	7,087,002		9	678,969	7,088,094	
4	677,399	7,088,731		10	677,722	7,088,306	
5	678,142	7,087,603		11	678,808	7,087,249	
6	678,048	7,089,680		12	676,639	7,088,241	

3.2 SOIL PROFILE DESCRIPTION

All soil profiles assessed in the field were described in accordance with McDonald and Isbell (2009), whilst the land surface was assessed using the classification scheme outlined in McDonald et al. (2009). Soil profiles were assessed for degree of horizonation, nature of contacts between horizons, presence and abundance of coarse fragments (i.e. gravels) and mottling, and structure, fabric and field texture of soil materials. A semi-quantitative assessment of plant roots (Table 3.2) was also undertaken to assist in identifying any potential adverse soil materials.

Table 3.2: Semi- quantitative assessment of plant roots used in this investigation (McDonald and Isbell, 2009).

Rating	Number of roots per 0.01 m2 (10 cm × 10 cm)	
	Very fine - fine roots (< 2 mm diameter)	Medium - coarse roots (> 2 mm diameter)
0 No roots	0	0
1 Few roots	1 - 10	1 - 2
2 Common roots	10 - 25	2 - 5
3 Many roots	25 - 200	> 5
4 Abundant roots	> 200	> 5



DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 3.1: Soil investigation locations

PN: DRM-001-1-8 Prepared by: SC Date: 06/01/17 Reviewed by: ASP Date: 06/02/17 Revision: 1

3.3 LABORATORY ANALYSIS

The physical and chemical properties of the soil materials were assessed in Perth based laboratories. The properties listed in Table 3.3 were assessed for a representative number of samples from all waste materials.

Analysis of the key physical and hydraulic properties was undertaken at Soil Water Analysis (SWA) Laboratories, whilst the chemical properties were assessed at CSBP Laboratories.

Table 3.3: Physical, hydraulic and chemical properties examined in the laboratory

Physical properties	Chemical properties
Bulk density	Nutrients (Mineralised Nitrogen, Colwell Phosphorus and Potassium, and extractable Sulfur)
Particle size distribution	
Saturated hydraulic conductivity	Organic carbon
Unsaturated hydraulic conductivity	pH
Hardsetting potential	Electrical conductivity (salinity, EC)
Structural stability	Exchangeable cations (Ca, Mg, Na and K)
Water retention properties	Cation exchange capacity (CEC)
	Sodicity (Exchangeable sodium percentage – ESP)

3.4 STABILITY & EROSION POTENTIAL

The stability and erosion potential of the major surface soils encountered during the investigation were tested using a laboratory-scale (0.75 × 0.75 m) rainfall simulator (Plate 3.1). Bulk samples (~300 kg total) of the dominant surface soil material (i.e. reddish brown loam) were taken from different sampling locations across the Study Area. These samples were combined and packed into the rainfall simulator at a bulk density to approximate the friable nature of disturbed surface soils that would be applied in post-mine operations (i.e., 0.5 g cm3 < field measured; see Sect. 4). Prior to testing each material and slope angle, the soil surface was pre-treated by sequentially wetting and drying the surface to facilitate organisation and settling of the soil particles expected under field conditions. A rainfall intensity of approximately 100 mm/hr was then applied over 4 hours, which corresponds to actual rainfall events of 5 – 20 minute duration with return periods of 10 – 100 years, respectively (Figure 2.1).To estimate surface runoff and sediment loss, the generated runoff was sampled at regular intervals for set time periods, with the sediment concentration determined gravimetrically, by weighing prior to and following drying at 105˚ until constant weight was achieved.

An angle of 18° was tested to simulate the batter slope angles likely to be used for the rehabilitated slopes of a WRL. The key parameters influencing the erodibility of soils include:

- Particle size distribution (Gravel fractionation and sand/silt/clay %).
- Organic Carbon (C) content.
- Exchangeable cation content (sum Ca, Mg, Na and K).
- Interrill erodibility (K_i)
- Rill erodibility (K_r)
- Critical shear for rill initiation (t_c)
- Effective hydraulic conductivity (K_{eff}).

Data on the particle size distribution, organic C content and exchange cations was obtained from the results from the Soil Characterisation, whilst the erodibility parameters (i.e. interrill and rill), critical shear for rill initiation and effective hydraulic conductivity were derived from the actual surface runoff and sediment yields. The effective hydraulic conductivity was estimated by fitting the Green Ampt equation to the infiltration rates measured on the rainfall simulator plot (Equation 1):

$$f = K_{eff}\left(1 + \frac{N_s}{F}\right) \qquad \text{Equation 1}$$

with f = infiltration rate [mm/h], K_{eff} = effective saturated hydraulic conductivity [mm/h], Ns is the effective matric potential at the wetting front [m], and F is the cumulative infiltration [m].

The interrill erodibility was calculated by applying Equation 2 to the measured sediment yields:

$$D_i = K_i \, I^2 \, S_f, \qquad \text{Equation 2}$$

where D_i = interrill erosion rate [kg/(m^2*s)], K_i= interrill erodibility [(kg*s)/m^4], I = rainfall intensity [m/s] and S_f = dimensionless slope factor (1.05 - 0.85 EXP $^{(-0.85 \sin(alpha))}$).

Plate 3.1: Laboratory-scale rainfall simulator used in this investigation

3.5 EROSION MODELLING

Long-term (100 year period) runoff and erosion from both the gravelly and loamy surface materials was modelled using the WEPP (Water Erosion Prediction Program; Flanagan and Livingston, 1995). A 100 year climate file was generated using CLIGEN (stochastic weather generator; Yu, 2003) from actual climatic data from Meekatharra (Table 3.4). Values which correspond to the rainfall intensity used in laboratory trials are highlighted. The climatic data used included:

- 30 minute rainfall intensity data
- 30 year daily rainfall, temperature and solar radiation data.

The model simulations utilised both a 10 and 20 m high slope with no vegetation to assess the erosion response on newly formed slopes to erosion factors.

Table 3.4: Intensity frequency duration data for Meekatharra (mm rainfall sourced from BOM)

Duration	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins	42.8	56.9	80.2	**94.9**	114	139	159
6Mins	39.9	53	74.8	88.6	**106**	130	149
10Mins	32.3	42.9	60.7	71.9	86.1	**105**	121
20Mins	23.3	31.1	43.7	51.7	61.9	75.7	86.6
30Mins	18.8	25	35.2	41.6	49.8	60.9	69.7
1Hr	12.4	16.5	23.4	27.8	33.3	40.9	46.9
2Hrs	7.76	10.4	15.1	18	21.8	27	31.1
3Hrs	5.83	7.88	11.5	13.9	16.9	21.1	24.5
6Hrs	3.55	4.84	7.28	8.92	11	13.9	16.2
12Hrs	2.17	2.98	4.58	5.68	7.06	9.01	10.6
24Hrs	1.33	1.84	2.86	3.56	4.45	5.7	6.74
48Hrs	0.8	1.1	1.72	2.15	2.69	3.45	4.08
72Hrs	0.57	0.79	1.24	1.55	1.95	2.51	2.97

4 STUDY RESULTS

Based on the evolutionary history of the Study Area and the morphological characteristics of the soil profiles exposed by trench excavation, just one distinct Soil Mapping Unit (SMU) was defined. The relationship between this SMU and the major soil groups of Western Australia (Schoknecht, 2001) and the Australia Soil Classification (Isbell, 1996) is presented in Table 4.1.

Table 4.1: Relationship between identified SMU and major soil group definitions

SMU (Present study)	Major soil group, WA (Schoknecht, 2001)	Australian Soil Classification (Isbell, 1996)
1. Reddish brown loam over hardpan	Red brown hardpan shallow loam	Duric Red Kandosol

4.1 SOIL DISTRIBUTION

The soils encountered were generally uniform across the larger potential disturbance area, consisting predominately of a reddish-brown loam between 40 and 100 cm over a consolidated hardpan layer. The mapping unit can be partially differentiated according to the depth of the surficial soils overlying the red-brown hardpan, with shallower profiles typically found occupying slightly elevated positions in the landscape and / or areas of reduced vegetation cover. The deeper soils encountered however showed little correlation with position in the landscape and are likely reflective of changes in the previous quaternary aged surfaces formed by repeated wetting and drying cycles. The key aspect of the soils throughout the Study Area is their shallow nature, with an underlying hardpan being prevalent over the entirety of the area.

This hardpan (Plate 4.1) has developed as a consequence of episodic (cyclonic) flooding and prolonged, intense dehydration on the upper surface of transported sediments which cover the underlying bedrock to depths of between 10 and 30 m across the deposit area.

4.2 REDDISH BROWN LOAM CHARACTERISTICS

The reddish brown loam with underlying hardpan occurs over the entire Study Area. The surface of the soils is typically either covered by low grass (generally Wanderrie grass) or quartz cobbles to gravel (Plate 4.2). The soil cover thickness overlying the hardpan varied between 40 and 110 cm, with an average of approximately 70 cm. Therefore although the soils are shallow there is considerable variation in the depth of cover available for use by flora as a growth medium. The underlying hardpan itself generally consists of a conglomerate of sand and gravels with an amorphous clayey matrix with fracturing uncommonly occurring along horizontally laminated strata. This strata layer is also quite variable, likely a reflection of the different geomorphic and biogenic factors which are responsible for its formation. A characteristic soil profile through the red brown loams is presented in Figure 4.1, along with summary statistics on key physical, chemical and hydraulic properties.

The basic chemical properties (pH and salinity) within the soil profile at each soil investigation location trench are shown in Figure 4.2to Figure 4.4. The profiles show variation in salinity with depth, often increasing from non-saline values (0-40 mS/m) to moderately saline closer to the hardpan depth, reflecting decreased hydraulic conductivity and higher evaporation rates. The pH varies only slightly within the profile, maintaining a slightly acidic pH between 5 and 7.

Plate 4.1: Hardpan underlying the reddish brown loam within the Study Area

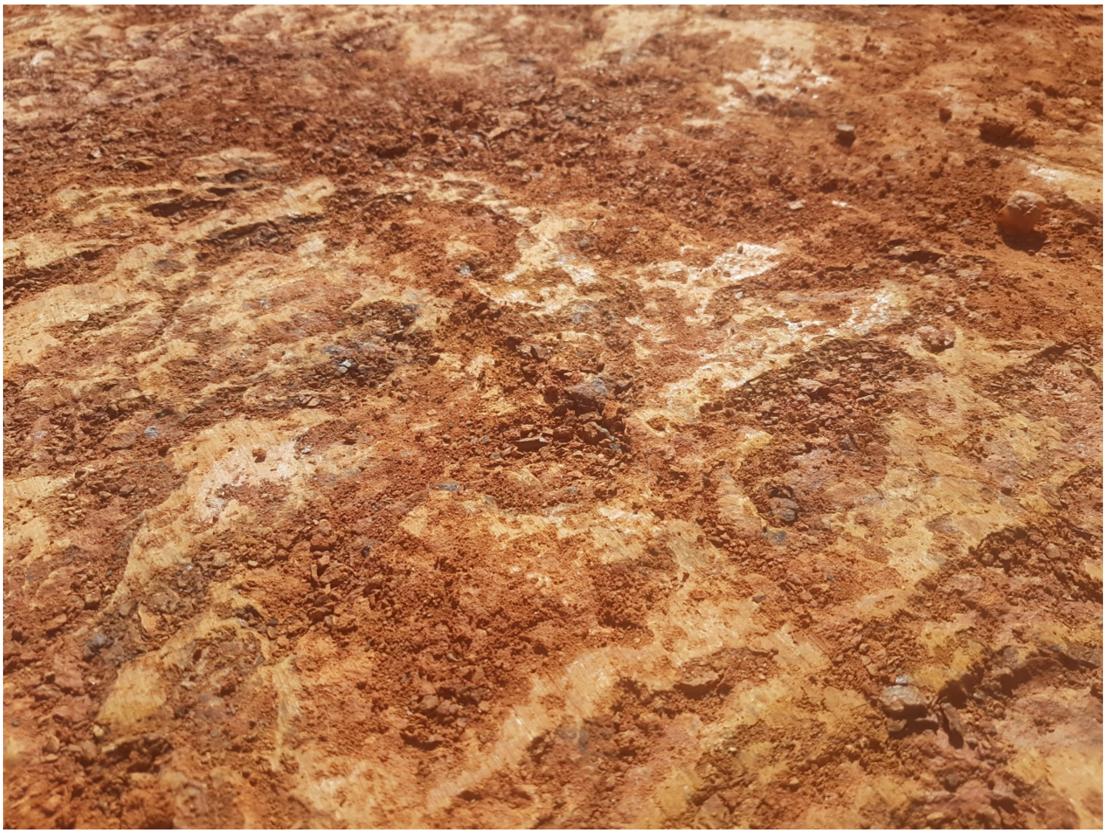


Plate 4.2: Quartz cobble surface cover over reddish brown loam within the Study Area

Depth (cm)	Horizon	Description
0		
5	A	Reddish brown sandy loam with minor sub-rounded to rounded pisolithic gravels (<10 %); horizon has a friable earthy fabric and is weakly coherent with abundant fine roots and common large lateral roots (1-2 cm diameter)
	B	Reddish brown sandy loam to clay loam with minor sub-angular to sub-rounded quartz and ironstone gravels; weakly structured with an earthy fabric and common fine roots throughout. Abrupt boundary to underlying hard pan
70	C	Massive reddish brown hardpan / conglomerate of gravels and sand with minor clay present as cementing matrix. Fractures are common along horizontally laminated strata and fine roots penetrate along these structural discontinuities and areas of higher gravel content

Physical properties

Depth (cm)	Structure	Particle size distribution (< 2mm)				Gravel % (> 2mm)	Field Moisture (%)	Ksat (m/day)	Structural stability	
		Sand (%)	Silt (%)	Clay (%)	Texture				Macro (slaking)	Micro (dispersive)
0-5	Granular	83.1	7.2	9.6	Sandy loam	3.7	3.4	0.55	moderate	poor
5-(70+)	Granular	79.7	6.8	13.6	Sandy loam	4.4	7.6	0.36	moderate	poor
Hardpan	Massive	99.4	0.4	0.2	Consolidated	7.0	-	-		

Chemical Properties

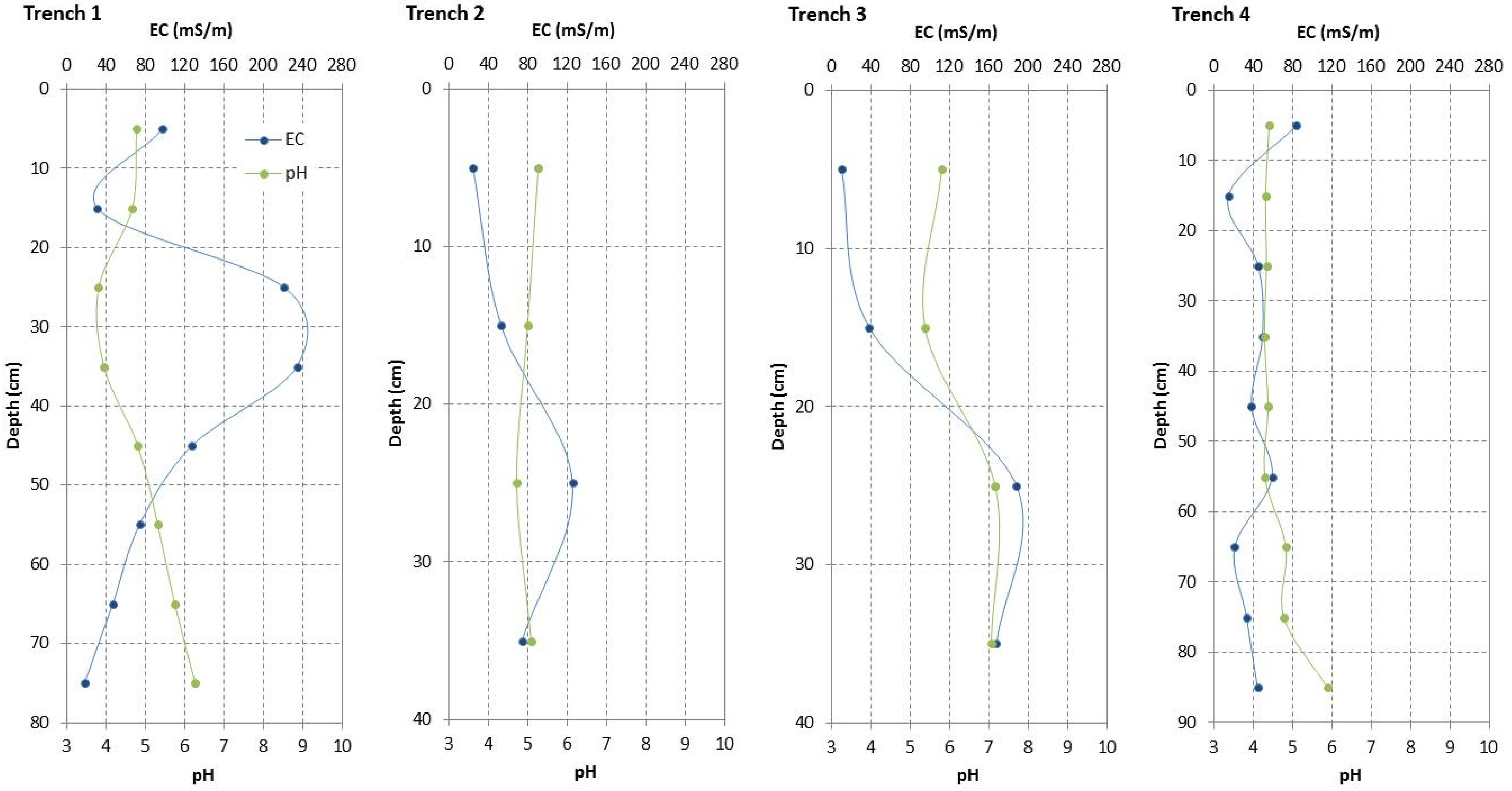
Depth (cm)	Nutrients (mg/kg)					Organic C (%)	Exchangeable Cation (meq/100g)					ESP (%)
	NO_3 - N	NH_4 - N	Colwell P	Colwell K	Ext. S		Ca	Mg	Na	K	CEC	
0-5	6	3	12	384	14	0.52	1.24	0.45	<0.10	0.35	2.04	2.63
5-(70+)	28	<1	3	215	9	0.24	1.09	0.61	<0.10	0.26	1.96	2.74

DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 4.1: Characteristic soil profile within the Study Area

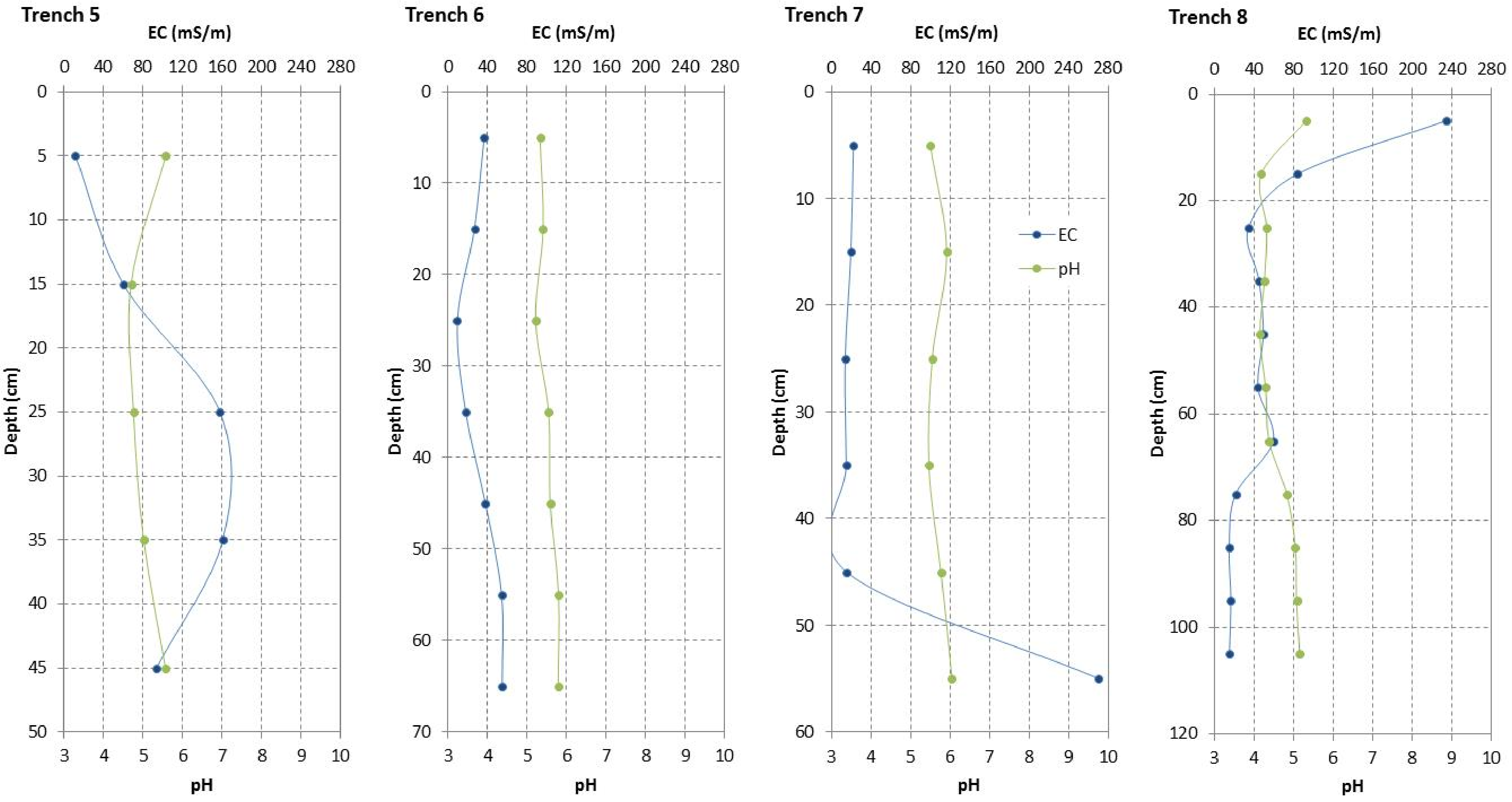
soilwater GROUP



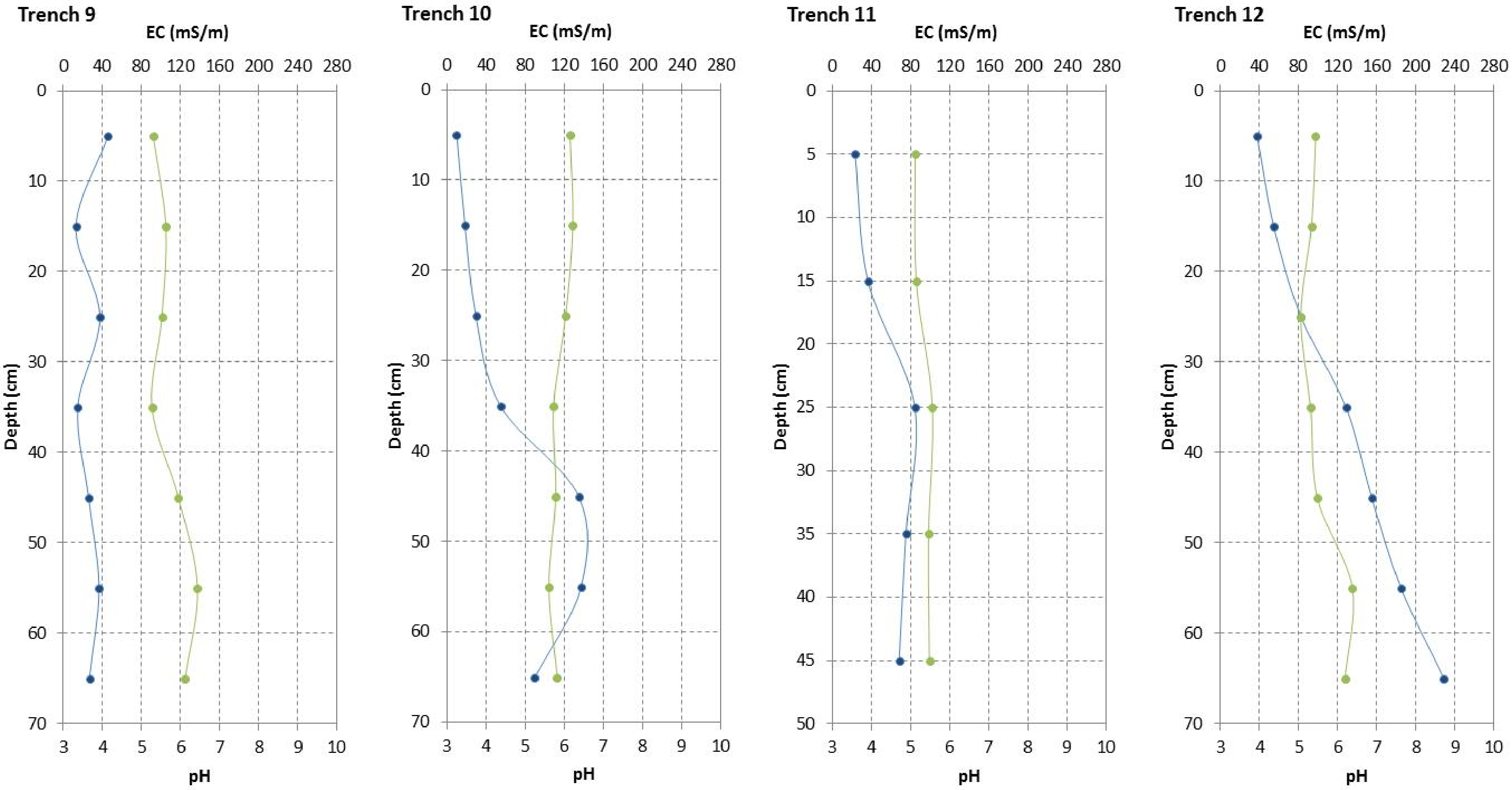
DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 4.2: pH and salinity depth profiles



DORAY MINERALS LTD	Figure 4.3: pH and salinity depth profiles continued..
GNAWEEDA DEPOSIT SOIL CHARACTERISATION	



DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 4.4: pH and salinity depth profiles continued..

The materials are predominately sandy in nature, with sand contents typically in the range of 70 to 90% (Table 4.2), which results in a relatively low plant available water (PAW) content. The PAW content is typically taken as the moisture which is retained between 10 kPa and 1500 kPa matric suctions then the red brown loam can supply approximately 14 % moisture, which equates to 0.14 m^3/m^3 or 140 mm/m soil depth (Table 4.2). Given the limited PAW content of these soils, the native vegetation is required to extend their roots to a considerable depth in order to access a large enough volume of soils to extract sufficient moisture to meet their transpiration requirements; this was clearly observed in the field with consistent evidence of roots extending below the base of the soil trenches into the hardpan layer (Plate 4.3). From the moisture contents presented in Figure 4.5 it can be seen that all surface soils are for the most part considered ‘dry’ with only a small portion of Trench 8 having plant available moisture (i.e. water contents are at or just below the laboratory determined permanent wilting point – 1,500 kPa matric suction); hence the vegetation must access the deeper soil profile.

Table 4.2: Particles size distribution and water retention data

Trench ID	Depth (cm)	PSD < 2 mm fraction (%)			Water retention data (v/v %)					PAW (%)
		Sand	Silt	Clay	0 kPa	10 kPa	33 kPa	100 kPa	1500 kPa	
9	5	83.1	7.2	9.6	29.2	20.4	16.8	8.0	5.0	15.5
3	15	73.0	6.0	21.0	37.8	25.4	24.1	15.9	11.5	13.9
8	15	67.5	6.0	26.4	35.8	23.5	22.3	13.8	8.2	15.2
7	15	84.0	5.4	10.6	-	-	-	-	-	-
2	25	74.2	11.3	14.5	35.5	27.0	24.6	17.6	11.9	15.1
9	25	75.9	8.0	16.0	37.7	26.5	23.5	17.6	13.2	13.3
1	25	88.5	2.4	9.1	32.5	20.7	18.0	11.1	6.7	14.0
3	35	90.1	6.9	3.0	36.0	23.0	21.5	11.5	8.7	14.3
9	55	85.7	6.8	7.4	-	-	-	-	-	-
8	65	70.8	9.4	19.7	32.3	21.8	19.1	10.9	6.9	14.9
1	65	86.7	5.5	7.9	34.2	21.3	18.8	10.4	7.2	14.1
8	105	78.7	6.5	14.8	31.9	20.9	18.0	10.0	6.1	14.9
7	hardpan	99.2	0.6	0.2	-	-	-	-	-	-
1	hardpan	99.6	0.2	0.2	-	-	-	-	-	-

The low PAW content of the surface soils and the resulting requirement of the vegetation to access a considerable volume (and depth) of the soil profile will have important implications with regards to the construction of the growth medium zone of the waste dump and the selection of species to be used in revegetation seed mixes on post-mine landforms. If the vegetation (or vegetation community) requires a transpiration rate of 300 mm/yr and assuming a PAW content of only 14 % (140 mm/m) then the vegetation must access at least 2 m of the soil profile to obtain sufficient water to satisfy their transpiration requirements. This means that there can be no physical or chemical limitations to root growth in the surface 2 m of the reconstructed waste dump profile. However, given the likely lower PAW content within the upper regolith or waste material which will underlie the outer soil cover there is likely to be insufficient ‘good’ or favourable soils to reconstruct such a deep root system; hence the selection of smaller, shallower-rooting and lower transpiring species should be considered for the revegetation of the waste dumps to be constructed on site.

Plate 4.3: Roots penetrating into the underlying hardpan

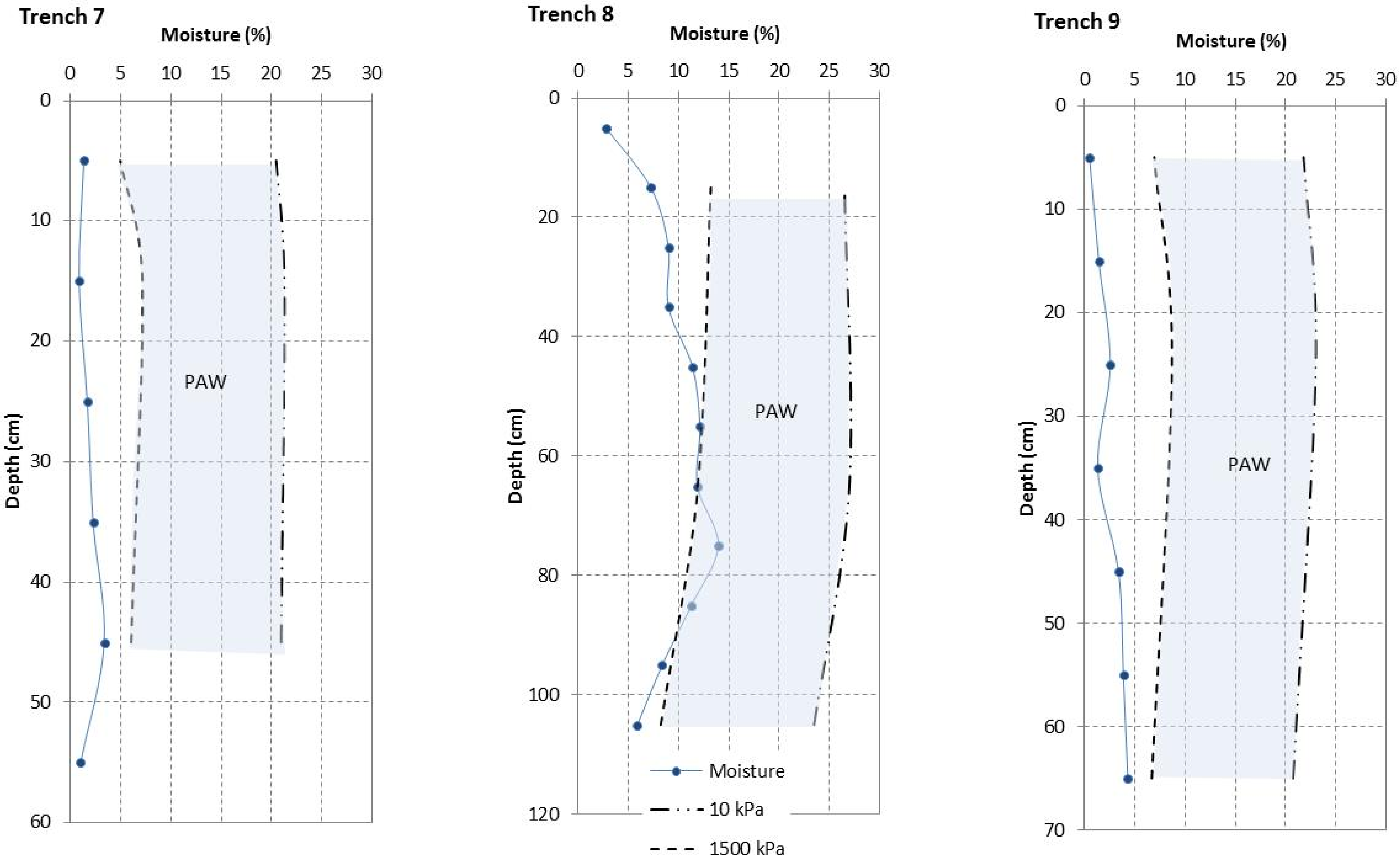
The characteristic chemical properties of the soils encountered across the Study Area are provided in Table 4.3. The soils are nutrient deficient with generally very low to low levels of mineralised N (NO_3^- - N + NH_4^+ - N < 10 mg/kg) and plant available P (Colwell P < 30 mg/kg), with only moderate levels of plant available K (Colwell K ~200 mg/kg). The exchange sites of all soils are dominated by sodium (Ca), with exchangeable sodium contents (ESP) < 5 %. The low CEC of these soils suggests that kaolinite is the dominate clay mineral, with more unstable mineral types such as smectite and illite absent. The organic C content is also low, indicating little pedogenic formation within the upper profiles has occurred and reflecting the generally low rainfall and hence organic matter production in the area.

Table 4.3: Nutrient and exchangeable cation contents

Depth	Nutrient (mg/kg)					Organic	Ex. Cations (meq/100g)				CEC	ESP
(cm)	NH_4-N	NO_3-N	Colwell P	Colwell K	Exct. S	C (%)	Ca	K	Mg	NA		(%)
5	< 1	6	18	304	2.2	0.46	0.82	0.38	0.46	< 0.10	1.66	3.0
5	< 1	< 1	8	277	2.1	0.26	0.92	0.38	0.51	< 0.10	1.81	2.8
5	130	1230	11	758	49.5	0.79	2.02	0.45	0.58	< 0.10	3.05	1.6
5	1	5	9	196	2	0.55	1.18	0.2	0.24	< 0.10	1.62	3.1
15	< 1	< 1	4	228	11.6	0.28	0.95	0.3	0.68	< 0.10	1.93	2.6
15	< 1	1	2	249	5	0.23	1.06	0.31	0.44	< 0.10	1.81	2.8
15	1	9	3	279	18.3	0.4	1.67	0.34	0.44	< 0.10	2.45	2.0
15	4	8	6	239	5.1	0.44	0.66	0.25	0.16	< 0.10	1.07	4.7
25	< 1	15	3	185	2.9	0.18	0.93	0.24	0.5	< 0.10	1.67	3.0

Depth	Nutrient (mg/kg)					Organic	Ex. Cations (meq/100g)				CEC	ESP
(cm)	NH_4-N	NO_3-N	Colwell P	Colwell K	Exct. S	C (%)	Ca	K	Mg	NA		(%)
35	< 1	28	3	150	8.5	0.33	0.98	0.2	0.27	< 0.10	1.45	3.4
35	< 1	7	3	288	10.8	0.18	1.16	0.37	0.46	< 0.10	1.99	2.5
45	< 1	44	2	188	6.4	0.12	1.26	0.22	0.73	< 0.10	2.21	2.3
45	< 1	150	< 2	299	27.2	0.14	1.81	0.32	0.97	< 0.10	3.1	1.6
45	< 1	1	3	204	3.5	0.21	1.34	0.29	0.88	< 0.10	2.51	2.0
45	< 1	49	3	158	3.5	0.21	0.84	0.17	0.48	< 0.10	1.49	3.4
85	< 1	5	6	115	6	0.18	0.42	0.15	1.32	< 0.10	1.89	2.6

The exchangeable cation results show that all soil sampled within the soil profile are non-sodic, with ESP levels < 6 %. Even though these surface soils are non-sodic they still are potentially dispersive due to their generally low salinity, as shown in Figure 4.6. The deeper soils are only generally not dispersive as their higher EC acts to flocculate soil particles which are in solution, lowering dispersion rates and increasing the expected stability of these soils. Therefore there are no expected stability issues when utilising these soils.

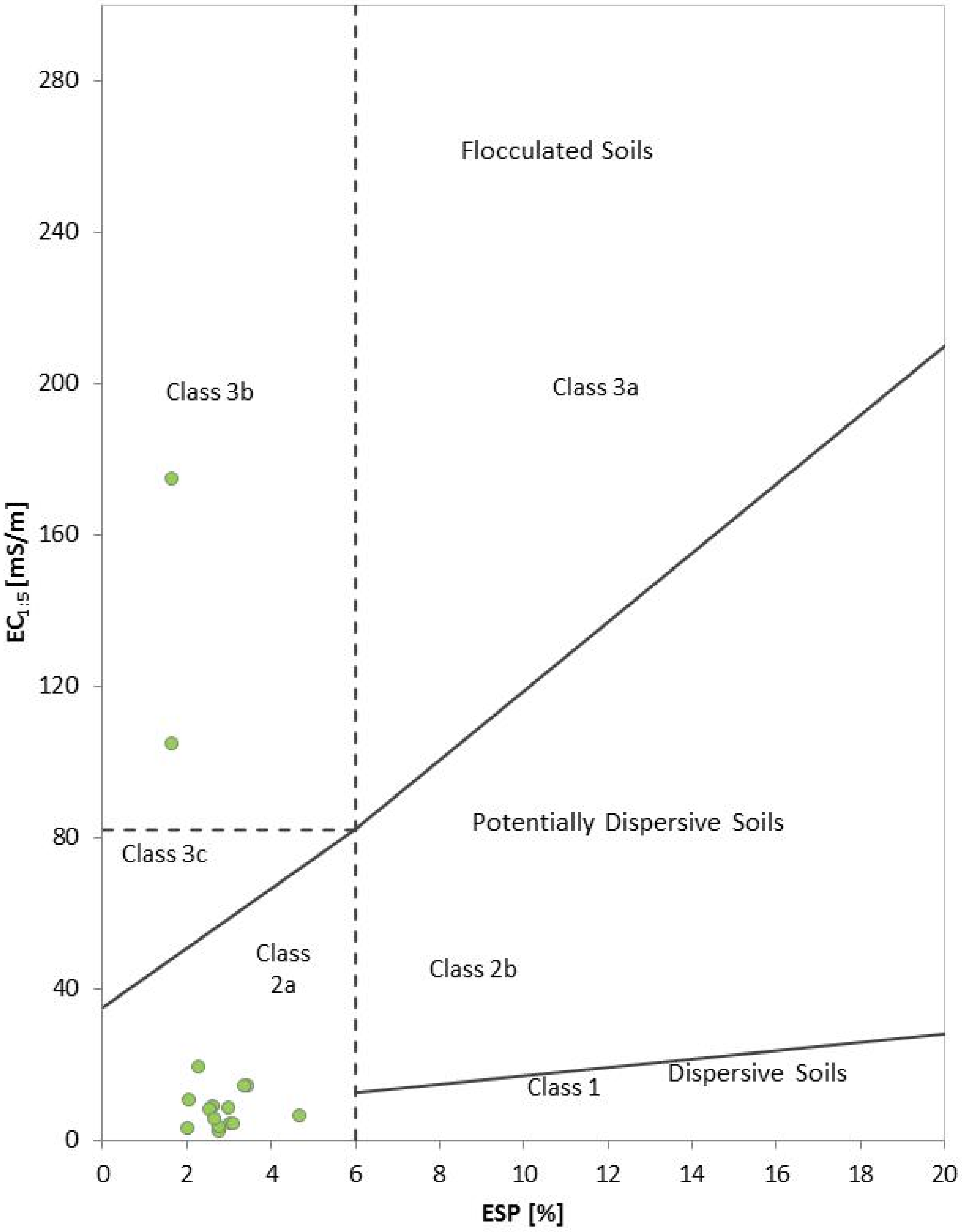


DORAY MINERALS LTD

GNAWEEDA DEPOSIT SOIL CHARACTERISATION

Figure 4.5: Field moisture content and PAW content of soil profiles (April)

soilwater GROUP



DORAY MINERALS LTD	Figure 4.6: Sodicity – salinity relationship for the surficial soils in the Study Area
GNAWEEDA DEPOSIT SOIL CHARACTERISATION	

soilwater GROUP

4.3 EROSION MODELLING RESULTS

The stability and erodibility of the surface soils within the Study Area were quantified using a laboratory-scale rainfall simulator. Their stability was tested for large storm events with an applied rainfall intensities of 100 mm/hr for three waste dump slope angles (12 15 & 18°). Using the results from this erosion testing, and the laboratory derived physical and chemical properties of the surface soils, the long-term stability and erosion potential was modelled using the Watershed Erosion Prediction Project (WEPP) software.

The soil parameters required by WEPP were derived from the laboratory testing undertaken at SWA Laboratories. These parameters include the particle size distribution, effective hydraulic conductivity (K_{eff}), interrill erodibility (K_i), rill erodibility (K_r), and soil critical shear stress (τ_C), and are summarised in Table 4.4.

Keff was estimated by fitting the Green-Ampt equation (Green and Ampt, 1911) to the measured infiltration rates using Equation 3:

$$F = K_{eff} (1 + Ns / F) \qquad \text{Equation 3}$$

where:

f = infiltration rate (mm/h)

Keff = effective saturated hydraulic conductivity (mm/h)

Ns = effective matric potential at the wetting front (m), and

F = cumulative infiltration (m).

K_i was calculated from the inter-rill erosion rate measured in the rainfall simulator, according to Elliott *et al.* (1989) using Equation 4:

$$D_i = K_i \ I^2 \ S_f \qquad \text{Equation 4}$$

Where:

D_i = interrill erosion rate (kg/(m^2 s)

K_i = interrill erodibility (kg s)/m^4

I = rainfall intensity (m/s), and

S_f = dimensionless slope factor ($1.05 - 0.85^{-0.85 \sin(\alpha)}$)

K_r and τ_C were determined from the shear stress (τ) and rill erosion rate (D_c) measurements collected in the laboratory. This was done by a linear regression analysis according to the method described by Foster (1982) and Elliott *et al.* (1989). The rill erodibility parameters are related to the measured parameters τ and D_c by Equation 5:

$$D_c = K_r \, (\tau - \tau_C) \qquad \text{Equation 5}$$

where:

D_c = measured erosion rate (kg/m2 s)

K_r = rill erodibility (s/m)

τ = measured shear stress (Pa), and

τ_C = critical shear stress (Pa).

D_c was plotted against τ for each of the flume measurements. The slope of the linear regression line was K_r, and the intercept with the horizontal axis was τ_C.

Table 4.4: Key soil parameters used in the WEPP model

Material ID	Sand (%)	Clay (%)	OM (%)	CEC [meq/100g]	K_{eff} (mm/hr)	K_i (Kg s / m^4)	K_r (s / m)	τ_C (Pa)
Reddish brown loam	79.7	13.6	0.5	2	18.4	1.11	0.10	10.3

4.3.1 SLOPE PROPERTIES

Batter slopes were modelled assuming slope angles of 12, 15 and 18°, and lift heights of 10 and 20 m, to simulate the range of batter-berm scenarios considered likely for a Waste Dump design.

4.3.2 MANAGEMENT ASSUMPTIONS

The land management input file used in the WEPP model was designed to describe the expected conditions on the remediated waste rock landform. The key features of the input management file include:

- A pre-consolidated soil surface. This means that no further settling is simulated within the model, and that the measured infiltration rates and runoff characteristics apply for the duration of the model (i.e., no further changes in these properties with time). This is reasonable because the laboratory measurements (from which the input parameters were derived) were conducted on pre-consolidated soil samples.
- No vegetation. This assumption will result in conservative (i.e. “worst-case”) erosion results, and will apply to the landform during the period prior to re-vegetation establishment. Subsequent vegetation growth is likely to act to enhance the stability of the landform by dissipating rainfall impact energy, producing leaf litter as a ground cover, and stabilising the sub-surface and improving infiltration with root growth. The degree of stabilisation will depend on the types of vegetation used, and their rates of establishment.
- Zero initial surface cover (i.e. no woody debris or plant litter). This means that no additional surface cover was expected to be added to the soil surface to reduce erosion rates. This assumption does not have any impact on the armouring effect of the rock and gravel fraction in the soil, which is already accounted for within the measured soil parameters discussed above.
- Expected rill geometry is adjusted internally in the model based on the input soil parameters and on the size of the erosion events encountered.

4.3.3 EROSION MODELLING RESULTS

Table 4.5 summarises the average runoff and sediment yield values predicted by the WEPP erosion model, given the input parameters summarised above.

The WEPP model indicated average sediment yields ranging between 10 and 16 t/ha/yr for the range of slope configurations tested, indicating that the loamy materials are relatively erosion resistant, and are expected to perform adequately on the outer surface of constructed landforms.

While the soil material tested is considered to be well suited to each of the slope configurations tested, those scenarios which restricted the overall length of the slope (i.e. lower lift height and higher batter angle) displayed the best outcome, with the lift height having the greatest effect on erosion runoff.

Considering that the surficial soil material only exhibited moderate erosion resistance it is recommended that this material be blended if possible with competent waste rock (rock mulch) to increase resistance to surface erosion (inter-rill) and slow down surface runoff to minimise the possibility of the formation of rilling during the initial stages of rehabilitation.

Table 4.5: Summary of WEPP erosion modelling results

Material	Lift height (m)	Slope angle	Average annual runoff (mm/yr)	Average erosion rate (mm/yr)	Average erosion rate (t/ha/yr)
Reddish brown loam	10	12°	19	1.7	9.9
		15°	19	1.9	11.1
		18°	20	1.9	10.9
	20	12°	21	2.7	15.4
		15°	22	2.7	15.6
		18°	22	2.5	14.7

5 SOIL MANAGEMENT & RECOMMENDATIONS

This section outlines management recommendations for the handling and utilisation of the surficial soil materials characterised in Section 4. These recommendations are suggested with the aim of:

- Maintaining optimal soil properties during the mining and rehabilitation process.
- Ensuring the appropriate management of soils exhibiting 'good' or favourable properties for use in rehabilitation.
- Minimising environmental impacts through inappropriate handling and placement of soil materials that exhibit adverse properties.
- Implementing management strategies that will facilitate revegetation growth and establishment, and overall rehabilitation success.

5.1 TOPSOIL

- The topsoil in the Study Area is typically poorly developed with only minor accumulation of organic matter and negligible nutrient content in comparison to underlying soil. The only benefit of treating the topsoil (top 10 cm) differently than underlying soil is for the contained seed store, which will need to be utilised within 18 - 24 months.
- If stripping topsoil the stockpiles should be limited to a maximum height of 2 m to maintain the soils biological component and retention of any nutrient sources. These stockpiles should ideally be used as soon as possible (i.e. by direct placement) or utilised within 24 months.

5.2 SUBSOIL

- Subsoil in the Study Area consists of reddish-brown loam above the hardpan and averages a thickness of 0.7m.
- The subsoil does not exhibit and adverse physical or chemical properties to revegetation growth and establishment.
- The subsoil is only moderately resistant to erosion and is potentially dispersive due to very low salinity, therefore consideration should be given to the use of a 'rock mulch' as a stabilising agent to reduce erosion during the crucial establishment period of rehabilitation vegetation on post mine landforms.
- Where possible, subsoil should be completely stripped down to the hardpan and utilised as the outer surface of post mine landforms to supply a maximum depth of PAW to aid in the establishment of revegetation species. As investigation has indicated that the majority of plant species rely on soil moisture below the surficial layer (i.e. within the hardpan) use of shallow rooting, low transpiring species in revegetation seed mixes should be considered to reduce the required PAW contents.

6 REFERENCES

Green, H. W. and Ampt, G. A. (1911) Studies on Soil Phyics. The Journal of Agricultural Science, 4, 1-24.

Hardie M, Deurer M, Doyle R, Lisson S, Cotching WE, (2012) 'Development of unstable flow and reduced hydraulic conductivity due to water repellence and restricted drainage', Vadose Zone Journal, 11, (4) pp. 1-11.

Elliot, W.J., A.A. Liebenow, J.M. Laflen, K.D. Kohl, 1989. A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments 1987 and 88. NSERL report, vol. 3 Agricultural Research Service, U.S. Department of Agriculture, National Soil Erosion Research Lab., West Lafayette, Indiana.

Isbell, R.F. (1998). The Australian Soil Classification, CSIRO Publishing, Collingwood, Victoria.
McDonald, R.C., Isbell, R.F. and Speight, J.G. (2009). ‘Land Surface’. In: McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (2009). Australian Soil and Land Survey – Field Handbook. Australian Collaborative Land Evaluation Program, CSIRO Land and Water, Canberra, pp. 127 - 146.

McDonald, R.C. and Isbell, R.F. (2009). ‘Soil Profile’. In: McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (2009). Australian Soil and Land Survey – Field Handbook. Australian Collaborative Land Evaluation Program, CSIRO Land and Water, Canberra, pp. 147 - 204.

Schoknecht, N R, and Pathan, S. (2013), *Soil groups of Western Australia : a simple guide to the main soils of Western Australia (4th ed)*. Department of Agriculture and Food, Western Australia. Report 380, 175p.

Tille P (2006) Soil-landscapes of Western Australia’s Rangelands and Arid Interior. Resource Management Technical Report 313, Department of Agriculture and Food, Government of Western Australia

Yu, B. (2003) An assessment of uncalibrated CLIGEN in Australia. Agricultural and Forest Meteorology, 119, 131-148.

Zhang, G.-h., Luo, R.-t., Cao, Y., Shen, R.-c. and Zhang, X. C. (2010) Correction factor to dye-measured flow velocity under varying water and sediment discharges. Journal of Hydrology, 389, 205-213.