Final Report

Soil Assessment

Yoongarillup Mineral Sands Mine

Doral Mineral Sands Pty Ltd

January 2014

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To reference this report: Landloch Pty Ltd (2014), *Soil assessment. Yoongarillup Mineral Sand Mine.* Report prepared for Doral Mineral Sands Pty Ltd.

Job Number:			
Revision Number	**Date**	**Author**	**Reviewer**
Draft	18/12/2013	Brendan Roddy	Evan Howard
Final	10/1/2014	Brendan Roddy	Evan Howard

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Yoongarillup Mineral Sand Mine (The Project) is located approximately 17km south east of Busselton in the south-western region of Western Australia, and aims to extract a ~4.5MT heavy mineral sand deposit using dry mining techniques. Landloch was engaged by Doral Mineral Sands Pty Ltd to undertake an assessment of the soils of The Project.

The Project is geologically situated between the Swan Coastal Plain sedimentary basin (sand dune sequence) and the Whicher Scarp (laterite). The combination of the geology, climate, and vegetation has resulted in the development of primarily one soil type across the disturbance footprint of the Yoongarillup Project: Deep Pale Sand soil. Two other soils types have been identified; a variable Disturbed soil that is the result of previous extractive activities (sand quarrying) by the landowner, and smaller areas of a Shallow Gravel that is outside the disturbance footprint.

The Deep Pale Sands is ~10-15cm of A_1 over >1.5m B_2. The surface horizon is hydrophobic, as indicated by water beading on the surface in the field and laboratory assessment. The Deep Pale Sands are grey loamy sands over yellow to pale sands and sandy loams with an acid pH. Soil pH does decrease with depth, but is not identified as an acid sulphate soils. The soil is poorly structured (massive). The soil has very low salinity levels throughout the profile ($EC_{1:5}$<0.05dS/m). Surface coarse fragments were largely absent and some charcoal fragments were observed in the subsurface, most likely from the agricultural clearing practices.

The Disturbed soil is a mapping unit that contains a rehabilitated area from previous sand mining, a gravel pit, areas of standing water, and more organic rich low lying soils. The Shallow Gravel soils are associated with the exposed laterite geology to the south of proposed pit and are slightly acid pale gravel materials of colluvial origin.

Details on soil management for available quantities, stripping, and handling techniques are contained within this report.

1. INTRODUCTION

1.1 Overview

Landloch has been engaged by Doral Mineral Sands Pty Ltd to undertake a baseline soil assessment of the proposed Yoongarillup Mineral Sands Mine (The Project). The Project includes a mining area, waste dump, workshop, ROM pad, and connecting haul roads.

The Yoongarillup Mineral Sands project is in the pre-approval stage and is therefore required to undertake baseline environmental and other studies. The baseline soil assessment will be used as part of the approvals process, as well as in preparation of the Project's mine closure plan in accordance with the Environmental Protection Agency (EPA) and Department of Mines and Petroleum (DMP) *Guidelines for Preparing Mine Closure Plans (EPA/DMP 2011).*

The purpose and scope of the baseline soil assessment is to provide information on the properties of the undisturbed soil resource of The Project area, including an indication of any adverse properties that pose a risk to successful rehabilitation. The tasks completed for the baseline soil assessment included:

- A desktop review of publically available information relating to the soils and landforms of the Yoongarillup Mineral Sands project area;
- An two-day survey of the soils of the Yoongarillup Mineral Sands project area, including sampling of soils and description of soil profiles;
- Interpretation of the physical and chemical soil test results;
- Mapping of the approximate functional soil boundaries and estimation of available soil volumes;
- Production of a report that outlines the assessment methods, analysis results and their interpretation, provides the mapping, and broadly details the implication of these in terms of landform rehabilitation and mine closure planning.

1.2 Project overview/background

The Project is located approximately 17km south east of Busselton in the south-western region of Western Australia. The Project is located on Mining Leases M70/459 and M70/458, constituting a project area of 277ha, of which the pit disturbance area is approximately 90ha (Figure 1). The Project aims to extract a ~4.5MT heavy mineral sand deposit using dry mining techniques. It is expected that the pit will reach a maximum depth of 10m below the natural land surface elevation, and dewatering will be required during the life of the mine (DEWA 2013).

The mineral sands will be mined from several pits expected to comprise a disturbance footprint of approximately 90ha. The heavy mineral concentrate (HMC) will be extracted from the waste material (sand, clay, and oversized material) by a series of screens, cyclones, and spirals. The HMC will be trucked to the existing Picton processing plant, while the waste products will be backfilled into the void for later rehabilitation.

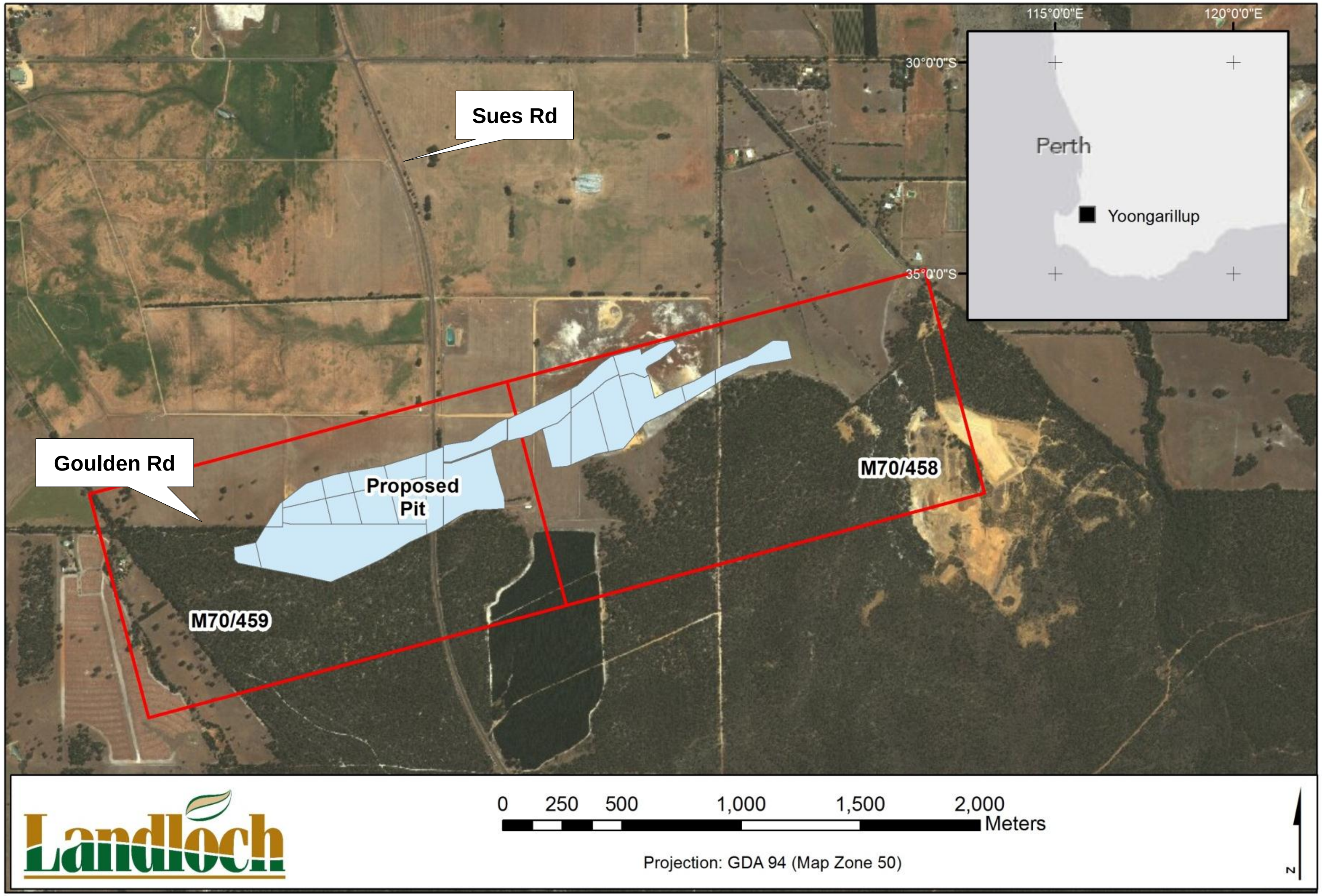


Figure 1: *Location of the proposed Yoongarillup Mineral Sand Mine.*

1.3 Existing environment

1.3.1 Climate

The climate at The Project is Mediterranean with a distinct summer and winter season. The summer months of November to March typically have very warm and dry conditions, while winters are cool and wet (Table 1). Mean annual rainfall is approximately 850mm per year and occurs mainly in the winter months due to cold fronts associated with Sub-Tropical Ridges at that time of year. The largest monthly rainfall on record (364.2mm) occurred in the month of June.

Table 1: *Mean monthly rainfall and daily maximum temperature averages for nearby weather stations to the Yoongarillup Mineral Sand Mine (BOM 2013).*

Month	Mean Rainfall* (mm)	Mean Daily Maximum Temperature^ (°C)
January	10.8	30.1
February	9.9	30.2
March	18.3	28.1
April	47.3	24.0
May	120.2	20.7
June	162.1	17.8
July	167.5	16.7
August	121.7	17.2
September	84.4	18.2
October	48.0	21.2
November	33.1	24.8
December	16.3	28.0
	845.7 (MEAN ANNUAL)	**23.1** (DAILY AVERAGE)

*Yoongarillup (9771) 1957-2013
^Busselton Aero (9603) 1997-2013

1.3.2 Geology

The Project is geologically situated within the Swan Coastal Plain which is bound by the Indian Ocean on the west and the Dunsborough-Collie Scarp on the east (Figure 2). The Yilgarn Craton lies to the east of this sedimentary basin and the surface geology is dominated by materials that are of alluvial or fluvial origin. A series of parallel dune systems runs the length of the Swan Coastal Plain with the youngest (Quindalup) dunes fringing the ocean, with the Spearwood (~40,000BP), and the Bassendean (~800,000BP) dunes located inland of the Quindalup dunes. Further inland still is the Pinjarra Plain which is a low lying area of deposited alluvial sediment originating from eroded scarp material to the east. The Pinjarra Plain abuts the foothills of the Darling and Dunsborough-Collie scarps (McArthur and Bettenay 1974; Salma *et al*. 2001; Moore 2004).

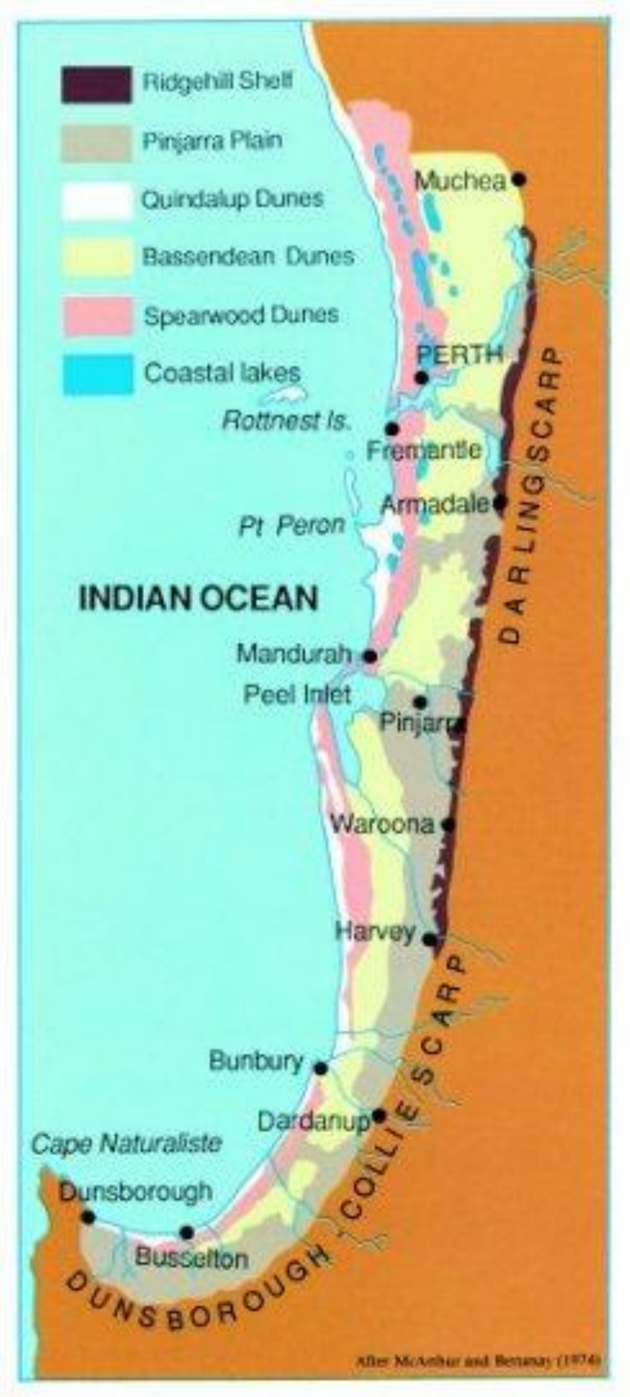


Figure 2: *Map of the regional geology of the Yoongarillup Mineral Sand Mine, southeast of Busselton (Bolland 1998).*

The Project resides on the flank of the Whicher Scarp (Figure 3). The localised geology is aeolian grey sands over deep yellow sands on the low lying areas, with sections of colluvial sands and gravels over the laterite (Figure 4).

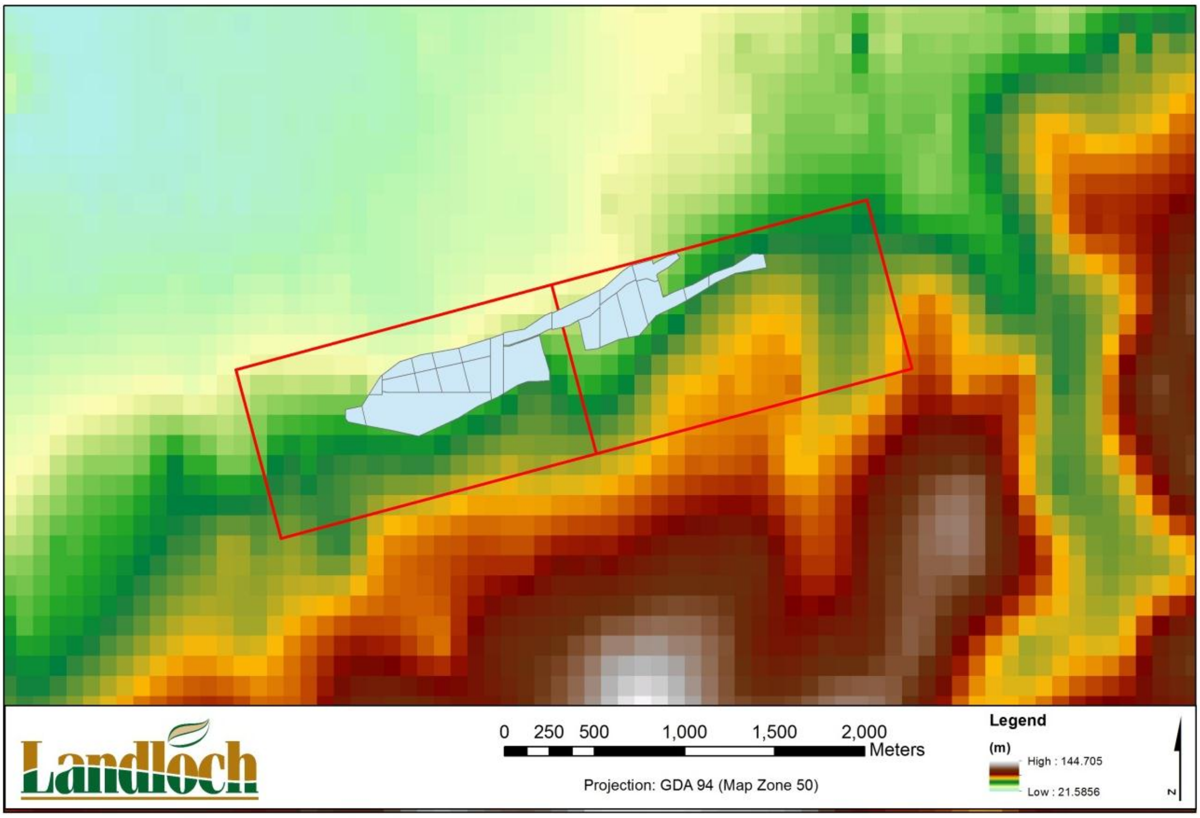
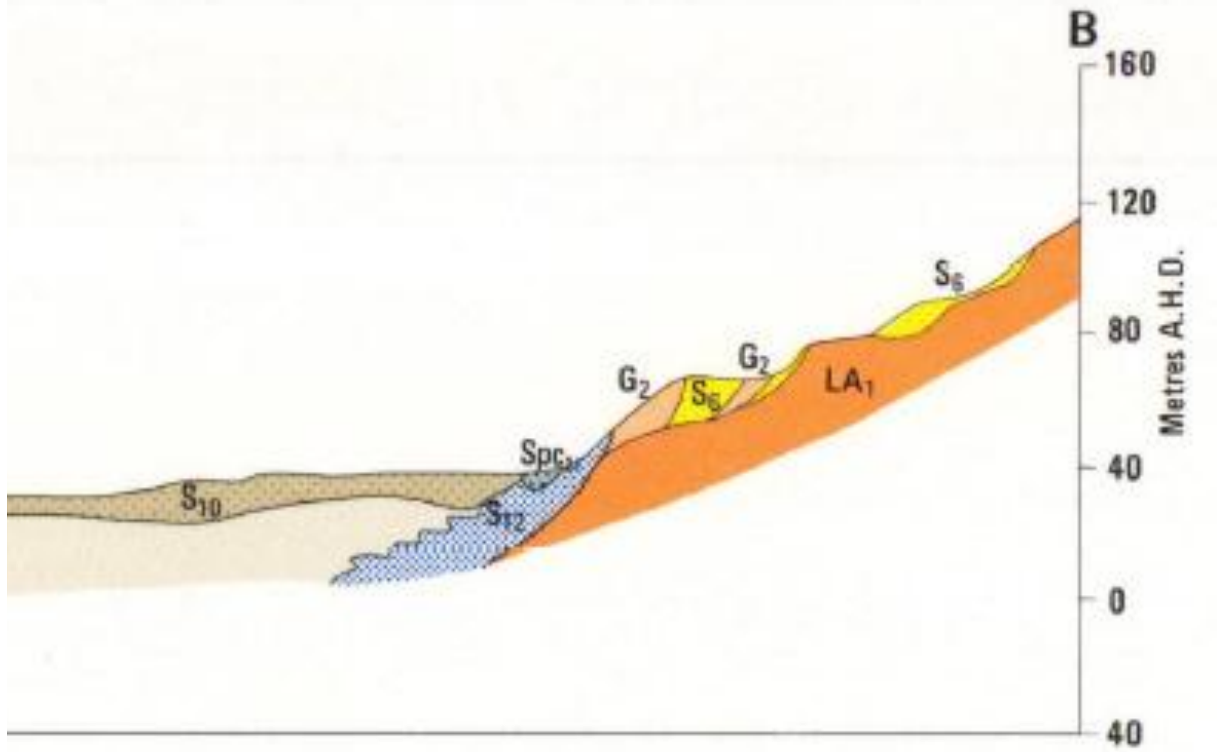


Figure 3: *Digital elevation model of the Yoongarillup Mineral Sand Mine surrounds.*



S10	Sand over silt and sandy silt. Sand is very light grey at surface, yellow at depth, fine to medium grained sub-rounded quartz, local concentrations of heavy minerals, local development of coffee rock, moderately well sorted, of aolian origin
Spc	Clayey peaty sand. Grey to black with variable organic content.
S12	Sand. Yellow, fine to medium grained, sub-angular to rounded quartz with some feldspar, local local concentrations of heavy minerals, well sorted, overlying boulder and cobble conglomerates, of alluvial and marine origin.
G2	Gravel. Brown and reddish brown, ferrunginous, pisolitic, occasionally cemented in a clay silt matrix, moderately sorted, of colluvial origin.
S6	Sand. Light grey, fine to coarse, angular to sub-rounded quartz with some feldspar, moderately sorted, loose, of elluvial origin modified by colluvial processes
LA1	Laterite. Massive and cemented, occasionally vesicular, up to 4m thick. Sometimes overlain by a ferruginous gravel set in a clay-sand matrix.

Figure 4: *Cross section of the dune-scarp local geology of the Busselton area (Bellford 1987).*

1.3.3 <u>Geomorphology, soils, and vegetation</u>

The Project is located on the flanks of the Whicher Scarp which forms a sickle shape around the low lying southern extent of the Swan Coastal Plain. The Whicher Scarp rises to over 100m in elevation with gentle to moderate slopes and is incised by several rivers and streams. The Whicher Scarp is within the Southern Jarrah Forest Biogeopraphic Sub-region. The vegetation consists of forests to open woodlands of Jarrah with an understorey of Bull Banksia and Balga over low herbs and grasses. The lower-relief Swan Coastal Plain has been extensively cleared for cropping and grazing activities. The soils are described as sandy gravels and pale deep sands, with loamy gravels on the scarp, and non-saline wet and semi-wet pale deep sands on the flats (DAWA 2002; Keighery *et al.* 2008; DEWA, 2013).

2. SOIL ASSESSMENT METHODOLOGY

2.1 Regulatory requirements

The DMP requires an assessment of soils that are the subject of Mining Proposals. Analysis of both topsoil and subsoil layers is required and should *"identify possible adverse parameters such as low or high pH, high salinity, nutrient/trace element deficiencies, poorly structured soils, dispersive or sodic soils and potentially hazardous compounds"* (DMP 2011). The impacts of proposed mining activities on soil properties, and any topsoil management plan that is developed should include consideration of:

- Topsoil and subsoil characteristics in relation to plant growth;
- Harvestable topsoil and subsoil volumes;
- Estimated volumes of topsoils and subsoils required for rehabilitation;
- Stockpile dimensions (footprint) and their location on mine site plans;
- Harvest, preservation, and redeployment methodologies; and
- Proposed field trials relating to soil depth requirements, suitability for plant growth, and amendment and fertiliser requirements.

DMP provides guidance on the minimum set of soil parameters that should be measured as part of the development of Mining Proposals (DMP 2011). This set includes:

- Soil pH;
- Soil salinity (Electrical Conductivity [EC]);
- Particle size distribution;
- Emerson test;
- Total Phosphorus (Total P);
- Total Nitrogen (Total N);
- Available P (as phosphate); and
- Nitrate N.

These parameters specified by DMP are broadly consistent with normal assessments of soil quality and address most of the major soil properties affecting plant growth. In addition to these parameters, Landloch includes other tests as standard in soil assessment in order to more fully characterise the soil being disturbed. The tests are detailed below.

2.2 Assessment methodology

2.2.1 Survey scale

Broad area project feasibility and land resource inventory studies are typically conducted at a 1:100,000 scale which as a minimum, requires a soil pit for every 100ha. As The Project has smaller disturbance areas, the survey was conducted at a 'medium' level that equates to a mapping scale of 1:50,000 or an approximate delineation of 10ha (McKenzie *et al*., 2008). At the medium scale, this required the description of six soil pits within the disturbance footprint.

Although a soil map (and assessment of the soils mapped) will be provided for the entire M70/0459 and M70/0459 lease area, the greatest confidence will be associated with the mapped area within the pit disturbance footprint provided by Doral Mineral Sands. The remainder of the soil map covering other areas within the lease area has been inferred from information gathered from within the disturbance area. Therefore should be regarded with a lower confidence level, but is nonetheless useful for planning purposes.

2.2.2 Preliminary desktop review

A preliminary desktop review of available information relevant to this assessment was conducted from publically available sources. The information sources included:

- Technical Bulletins from the Department of Agriculture (WA);
- Geological maps from Geological Survey (WA), and Geoscience Australia; and
- Online journal articles and reports.

The review of soil, geology, land systems, and vegetation attributes (Section 1) in the region was used to develop an understanding of the soils likely to be encountered in the Yoongarillup Project Area and their location within the landscape. Soil description pits were allocated for each landscape location and used to describe the different soils found in each location.

2.2.3 Field assessment

A two day field inspection was conducted by Landloch staff from the 4th of November 2013. The purpose of the field assessment was to collect samples to validate information collated as part of the desktop review. Soil data were collected by examination of soil pits and check holes, and these data were used to determine soil types and their extent across the site. The information collected in the field consisted of general landscape observations and detailed descriptions of the soils and soil profiles. This information was supplemented by laboratory analysis of selected soil samples.

The description of the soil profiles and general landscape observations in the field were conducted in accordance with McDonald *et al*. (1998). Soil profiles were classified according Isbell (1996). Broad colour names are those of Isbell (1996), while more detailed colour descriptions were defined using the Munsell Soil Colour Charts. Field pH was measured using the paste calorimetric method described by Raupach and Tucker (1959).

Field observations were made by examining soil pits excavated within the disturbance footprints. The soil pits were constructed using a 5 tonne excavator to dig to a depth of 1.5m. Location of the soil pits is shown in Figure 5.

The soil pit sampling sites were numbered sequentially as they were collected during the field inspection, and soil material analysed for chemical and physical properties was labelled with the same corresponding sample number. Check hole sites were denoted by their GPS coordinate.

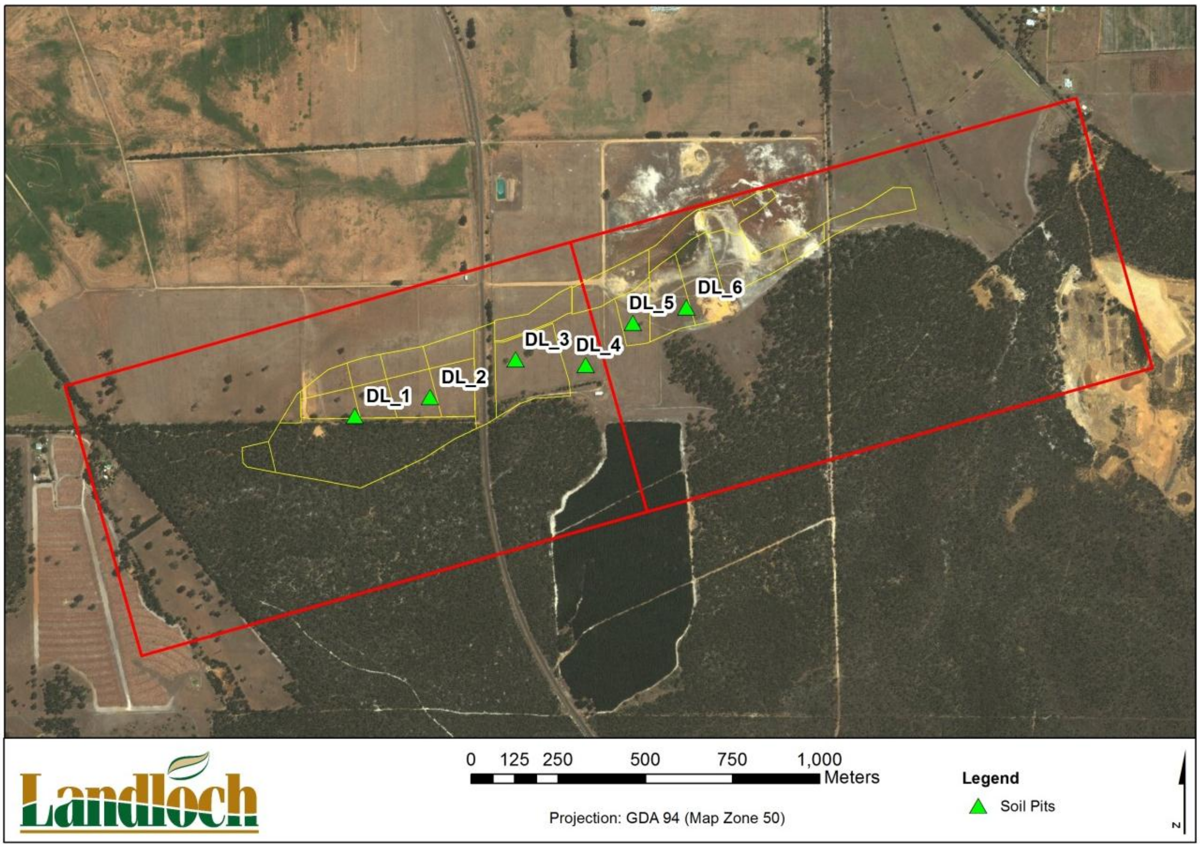


Figure 5: *Soil pit sampling sites.*

At each soil pit location, observations of the topography and surface condition included:

- Location (GPS);
- Aspect and slope;
- Elevation;
- Geomorphology;
- Vegetation;
- Drainage;
- Surface condition; and
- Coarse fragment percentage.

Soils descriptions within each soil pit included:

- Depth;
- Horizonation;
- Colour;
- Field texture;
- Coarse fragment percentage;
- Structure;
- Fabric;
- Consistence; and
- Permeability.

The soil pit descriptions were used to broadly assign boundaries of the different soils on hard copy maps. The boundary locations were then confirmed in the field by digging check holes in the vicinity of the estimated boundary. The boundaries were defined in the field using a hand held GPS.

2.2.4 Soil characterisation

During the field assessment soil samples were collected for more detailed laboratory analysis. Samples were collected from the A horizon (surface) and subsurface (B, C, or R horizon) for every soil pit. The samples were returned to Landloch's Perth laboratory and an initial assessment on all samples was made by in-house tests for field pH, electrical conductivity, colour, and hand texture. From this initial assessment, a representative selection of each soil type (approximately 30% of the samples) was sent to a NATA accredited soils laboratory. This approach is consistent with the Australian soil survey guidelines (McKenzie *et al.* 2008).

Surface and subsurface soils were assessed for the following properties:

- Soil pH;
- Electrical Conductivity (EC);
- Particle size distribution (gravel, sand, silt, clay);
- Total N;
- Total P;
- Organic Carbon;
- Available (Colwell) P and K;
- Available Sulphur (KCl);
- Available trace elements (Cu, Zn, Mn, and Fe);
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and Al^{3+});
- Effective Cation Exchange Capacity;
- Exchangeable Sodium Percentage;
- Particle size distribution (gravel, sand, silt, clay);
- Hydrophobicity (surface soils only); and
- Emerson class number.

Test details are contained in Appendix 1.

3. RESULTS

3.1 Soils of the Yoongarillup Project

Surface geology exerts the dominant control over The Project's soils. The wind blown and reworked sands make up most of the parent material for the soils at The Project, associated with the S10 surface geology shown in Figure 4. The entire proposed pit area consists of this one soil type. There are smaller areas of shallow gravels on the laterite geology to the south of the proposed pit. In the eastern sections of the assessment area are zones of disturbed soil from previous extractive industries (sand quarrying) by the landowner. Consequently, three soil types have been identified and mapped; Deep Pale Sands, Shallow Gravels, and Disturbed soils (Figure 6).

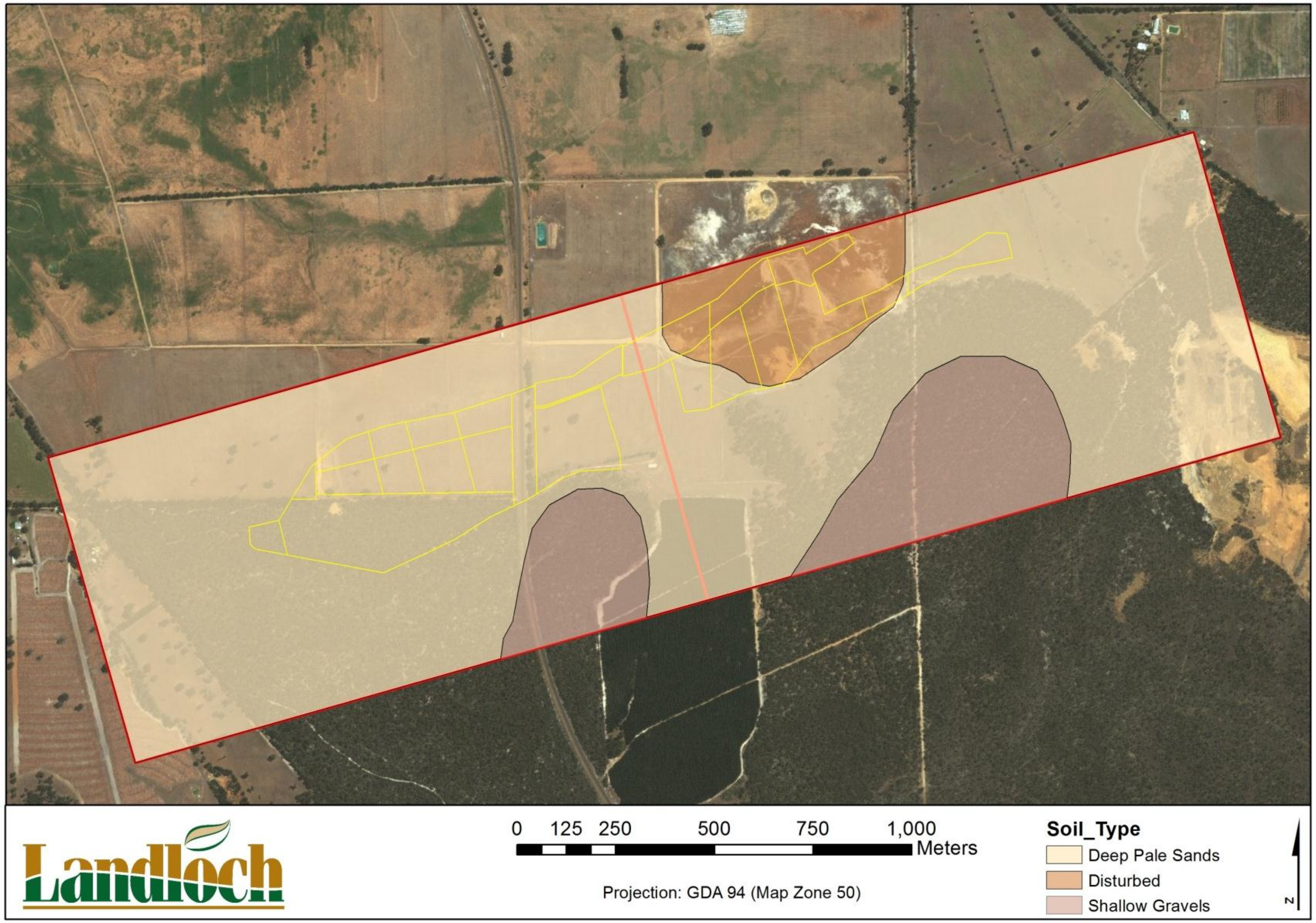


Figure 6: *Soil map of the Yoongarillup Mineral Sand Mine site.*

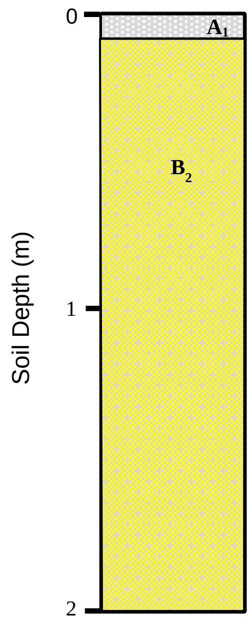
3.1.1 Deep Pale Sands

The Deep Pale Sands are the dominant soil type across the assessment area and occupy all of the proposed pit area. Typical soil profiles consist of a shallow grey organic A horizon over deep yellow sandy B horizons (Figure 7A and 7B). One soil pit assessed had a lighter coloured B horizon and this is most likely attributable to a variation in parent material with differing levels of iron oxide content (Figure 7C).

The horizonation of the Deep Pale Sands is ~10-15cm of A_1 over >1.5m B_2. The surface horizon is hydrophobic, as indicated by water beading on the surface in the field (Figure 7D).

Overall, the Deep Pale Sands are dark brown loamy sands over yellow to grey sands and sandy loams with an acid pH. Soil pH does decrease with depth and the coastal areas are known zones of acid sulphate soils, but does not exceed pH <4 which would indicate potentially acid forming soil material. Previous mapping and reports have stated that The Project has a low risk for the presence of acid sulphate soils (Soilwater 2012). The soil is poorly structured (massive). The soil has very low salinity levels throughout the profile ($EC_{1:5}$<0.05dS/m). Surface coarse fragments were largely absent and some charcoal fragments were observed in the subsurface, most likely from the agricultural clearing practices.

Table 2: *Characteristics of Deep Pale Sand soils.*

Property	**Inspection Site Description**	
Brief description	Deep yellow/grey sand to loamy sands	
Extent	27.9ha	
Soil samples	DL_1 to DL_5	
Gradient	Gently undulating	
Soil Landscape	Swan Coastal Plain – Whicher Scarp	
Soil classification	Bleached Orthic Tenosol	
Surface coarse fragments	<5%	
Surface condition	Soft	
*Permeability**	Moderate	
*Water repellent**	Yes	
*Drainage**	Sheet wash	
Soil depth (cm)	**Soil Profile Description**	
0–15	A_1 Greyish-brown (5YR-4/2), massive, loamy sand, <5% coarse fragments, pH 6 (field)	
>15	A_2 Yellowish (10YR-7/3), massive, sand, <5% coarse fragments, pH 5.5 (field)	

* Glossary of terms contained in Appendix 2.

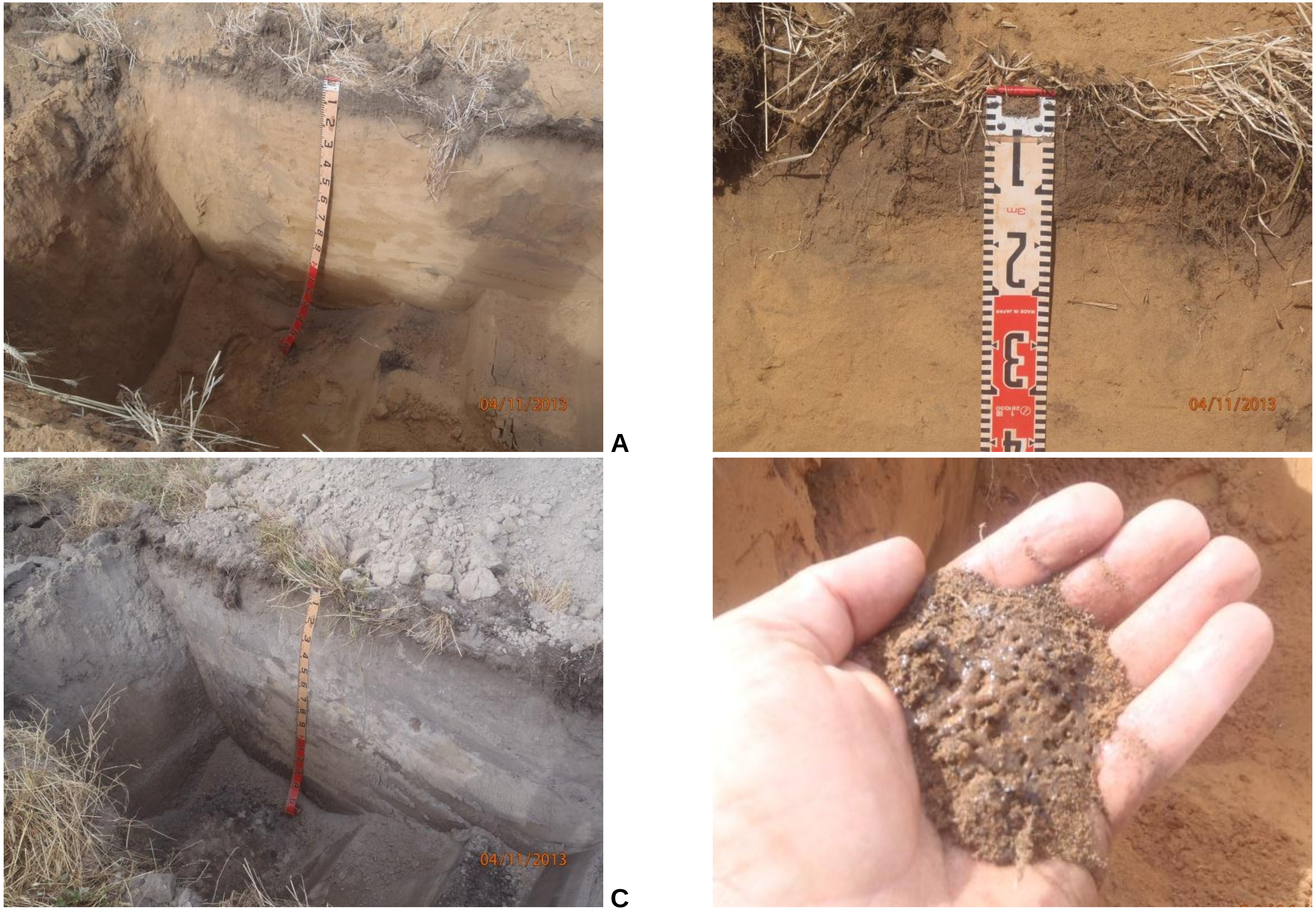


Figure 7: *A) Typical grey sandy topsoil over deep yellow sand, B) detail of grey A_1 horizon; C) pit DL4 showing pale sandy B horizon, and D) evidence of hydrophobicity in surface soils.*

3.1.2 Shallow Gravels

It is noted that there is a change in surface geology in the forested southern sections of the mining lease (Figure 8A). Exposed outcrops appeared to be massive and cemented yellow to red laterite rocks. The associated soil was a shallow gravel that was very pale in colour. Coarse surface fragments were present, and ~20% of the loamy sand soil profile contained gravel (Figure 8B). The field pH was 6 and hand augering the material to depths of greater than 30cm was difficult. This soil type was not examined by soil pits as it was not within the cleared farm area and thus access with machinery was difficult. Boundaries of this soil were inferred from a low intensity reconnaissance of the area, and the typical soil condition and boundary should not be regarded with a high level of confidence.

3.1.3 Disturbed soils

Sections of the proposed pit on M70/0458 have been previously used as a sand quarry (construction base materials), as well as a gravel quarry as undertaken by the landowner (N. Haddon *pers. comm*) (Figure 8C). The sand quarried areas have been rehabilitated and the surface condition is variable. On the elevated areas the vegetation cover consists of crops or weeds and there is evidence that builders rubble has contaminated the reapplied topsoil (Figure 8D). The light grey sandy surface soil is in a loose condition and there are many areas of bare soil. On the low lying areas the surface vegetation is pasture species, or waterlogging-tolerant species. The surface soil of some of the low lying areas is darker in colour due to a higher organic content and there are areas of standing water. Figure 9A shows the undisturbed agricultural paddock that has been recently cropped and the darker green vegetation associated with the low lying areas. Figure 9B shows the same paddock disturbance extent from the sand quarrying activities.

It was not possible to map the variety and spatial diversity of soils within this area, and these soils have been grouped together under the Disturbed soil type.

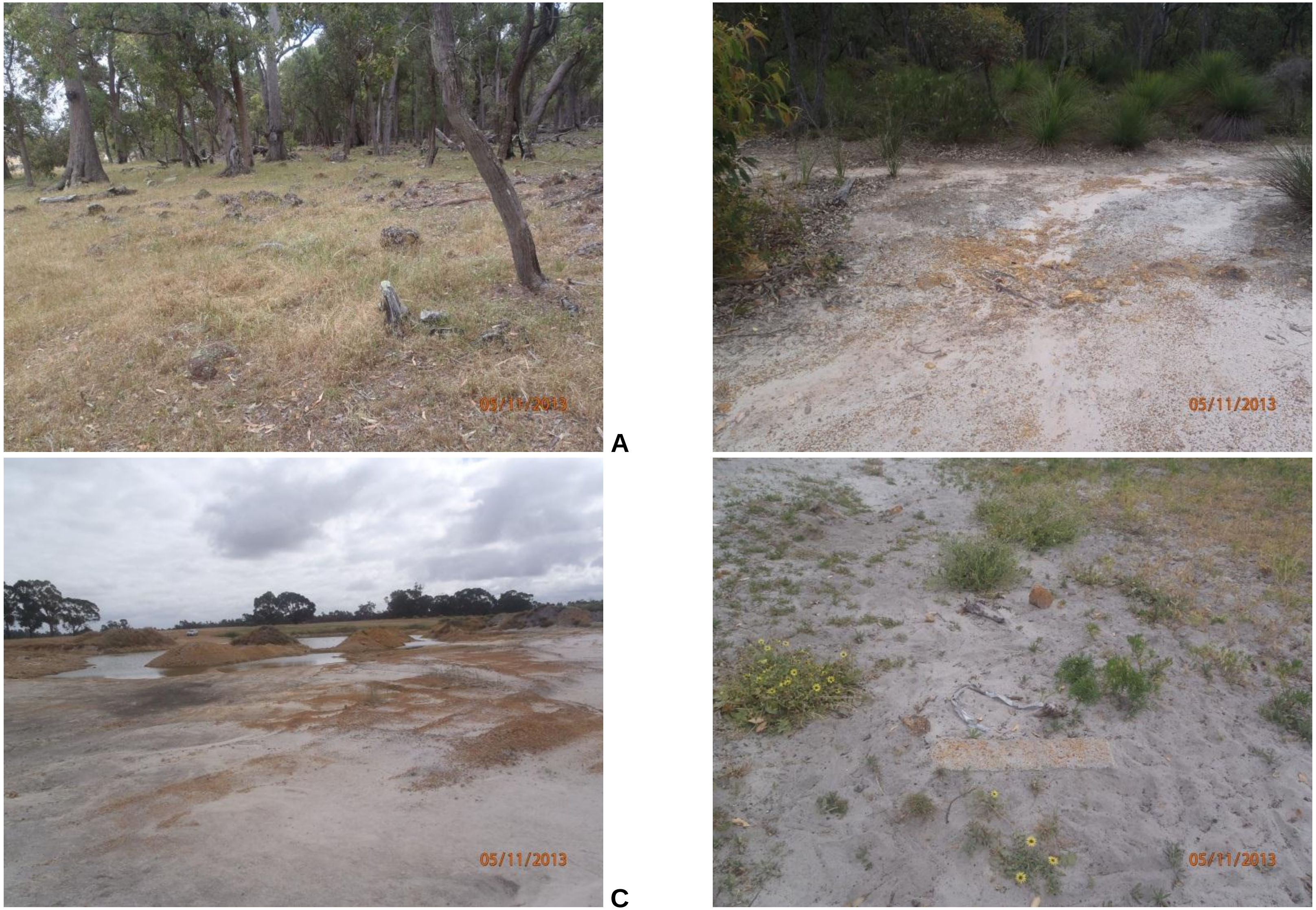


Figure 8: *A) Laterite outcrop, B) shallow gravel material with surface coarse fragments and exposed underlying rock in forested areas; C) abandoned gravel pit and lake, and D) detail of rehabilitated surface soil with building rubble, weeds, and bare surfaces.*

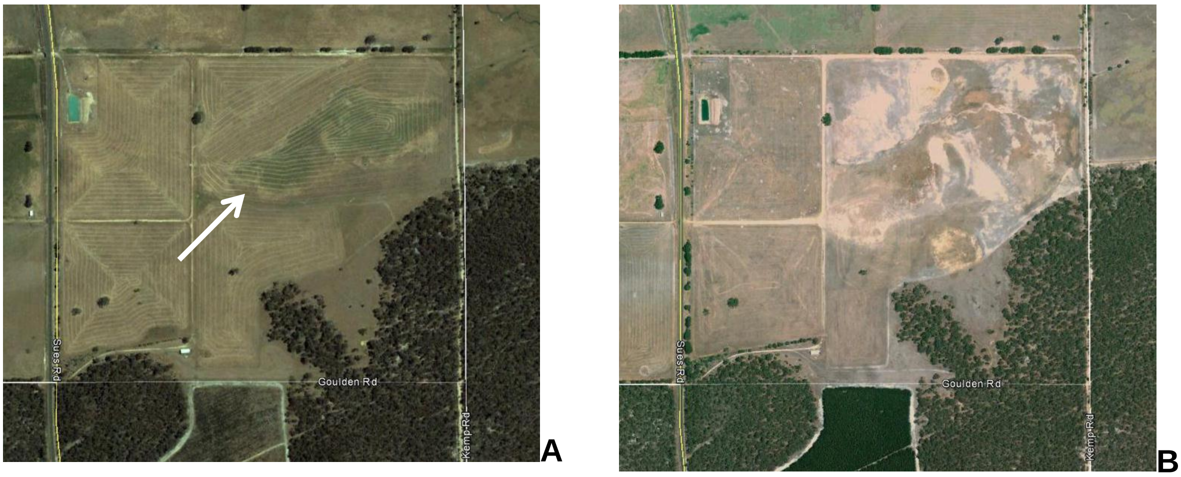


Figure 9: *Comparison of the area of disturbance east of Sues Rd in 2003 (A) and in 2010 (B). A) Undisturbed agricultural paddocks showing low lying areas (arrow); and B) general disturbance area. (Source: Google Earth)*

3.2 Laboratory analysis

3.2.1 Soil analysis results

Laboratory results are shown in Table 3, and are interpreted against industry standards using references such as *Interpreting Soil Test Results* (Hazelton and Murphy 2011) for soil chemistry. For reference, an agricultural guide has been included in Appendix 3.

It should also be noted that since the proposed disturbance footprint for The Project is relatively small, only a few soil pits were required to be analysed. It is therefore prudent to consider the results as an indication of the nature of the undisturbed soils, adequate at the proposal stage. Further testing will be required to gain a more detailed understanding of the soils for long term storage and use to rehabilitate mine infrastructure at closure.

Table 3: *Soil analysis results for the Yoongarillup Mineral Sand Project.*

Analyses		Unit	Sample ID					
			DL1_1	**DL1_2**	**DL1_3**	**DL4_1**	**DL4_2**	**DL4_3**
		Depth	**10cm**	**30cm**	**100cm**	**10cm**	**30cm**	**100cm**
pH		*pH units*	6.24	5.63	5.79	5.46	5.24	4.73
Electrical Conductivity		*dS/m*	0.05	0.02	0.02	0.04	0.02	0.03
Total Nitrogen		*mg/kg*	1894	1433	<10.0	3105	605	145
Total Phosphorus		*mg/kg*	425	330	39.6	287	52.3	28.8
Organic Carbon		*%*	2.77	2.4	0.1	4.33	1.32	0.33
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	81.5	60.6	18.8	67.7	24.6	18.1
	Potassium - Colwell	mg/kg	94.2	76.9	73.5	89.9	77.8	65.9
	Sulphur - KCl	mg/kg	32.3	24	32	3.5	2.9	16.9
	Copper – DTPA	mg/kg	0.68	0.44	<0.25	0.4	<0.25	<0.25
	Iron – DTPA	mg/kg	48.1	56.3	32.7	52.9	44.7	16.4
	Manganese – DTPA	mg/kg	1.8	0.5	<0.25	0.6	<0.25	<0.25
	Zinc – DTPA	mg/kg	2.5	0.5	<0.25	1.2	0.3	0.3
Exchangeable Cations	*Calcium*	meq/100g	4.525	2.82	0.4925	3.66	0.71	0.4215
	Magnesium	meq/100g	0.44	0.21	0.11	0.30	0.11	0.09
	Potassium	meq/100g	0.13	0.05	0.03	0.06	0.02	0.01
	Sodium	meq/100g	0.08	0.11	0.02	0.06	0.03	0.03
	Aluminium	meq/100g	0.02	0.06	0.08	0.15	0.27	0.25
	Effective Cation Exchange Capacity	meq/100g	5.19	3.25	0.73	4.24	1.12	0.80
	Exchangeable Sodium Percentage	%	1.45	3.35	3.29	1.50	2.28	3.20
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	53.8	57.8	49.8	27.0	21.1	30.7
	Fine Sand 0.02-0.2mm	%	40.9	35.8	47.5	62.8	67.7	57.8
	Silt 0.002-0.02mm	%	0.0	1.9	0.0	2.8	1.9	0.0
	Clay <0.002mm	%	5.3	4.5	2.6	7.4	9.3	11.4
Dispersion Index		*Class*	5	5	5	5	5	5

NB: EC1:5: Electrical conductivity as measured in a 1:5 soil water solution
pH1:5: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2–-2.0 mm, Gravel >2.0 mm
* Below detection limit

4. DISCUSSION

4.1 Soil chemistry results

4.1.1 Material $pH_{1:5}$ and salinity ($EC_{1:5}$)

The materials' pH and electrical conductivity (EC) were measured using a 1 part soil to 5 parts deionised water solution.

The pH of the Deep Pale Sands can be summarised as mildly to strongly acid (6.2-4.7). Acid soils can inhibit plant growth due to aluminium toxicity. The threshold at which aluminium is mobilised and becomes increasingly toxic to vegetation is considered to be <5, which was only recorded for a 100cm depth subsoil. The highest exchangeable Al result (DL4_2), when expressed as a percent of the effective cation exchange capacity (ECEC) was 24%. When coupled with $EC_{1:5}$ of <0.07dS/m, this soils would be suitable for 'tolerant' agricultural plants such as wheat, phalaris, and perennial rye only (Hazelton and Murphy 2011). Although the risk of aluminium toxicity is low, it would be prudent to stockpile these subsoils separately and respread them below the surface rooting zone.

The Deep Pale Sands have very low salinity levels $EC_{1:5}$ values of <0.05dS/m, most likely due to the free salt being washed through the sandy profile.

4.1.2 Effective cation exchange capacity and exchangeable cations

The ECEC is a measure of a material's ability to adsorb and hold cations[1], and can also be used to indicate clay mineralogy. The ECEC values measured for the Deep Pale Sands are 0.73-5.19meq/100g which is very low. When considered in conjunction with clay content, the ECEC values also indicate that the dominant clay type will be a 1:1 class (such as kaolin) which is typical of highly weathered soils. Kaolinitic soils tend to have low nutrient status, and are not reactive (shrink and swell when wet). The very low result is also a reflection of the inert nature of the transported silicate sands that make up this soil type.

4.1.3 Exchangeable sodium percentage and structural stability

The exchangeable sodium percentage (ESP) value of a material is an indicator of clay dispersion potential. Materials with an appreciable dispersive clay fraction tend to be prone to tunnel erosion, hardsetting, and are prone to high levels of runoff and surface erosion.

Whether or not a material will actually disperse is a function of complex interactions between exchangeable cation concentrations, salinity, and clay content. The threshold value for soils of concern is an ESP >6%. The Deep Pale Sands have ESP

[1] All samples were washed of dissolved salts prior to testing for exchangeable cations and ECEC.

values below this threshold (<3.35%) and when combined with low ECEC and clay contents (<11.4%), the dispersion for this soil risk is low.

The sandy texture of the soils will likely render them of little use for construction purposes such as dam wall construction, or drainage channel construction.

4.1.4 Emerson test

The Emerson dispersion test is a simple laboratory method to determine the behaviour of soil aggregates when rapidly wet by water. It is an indicator of clay dispersion potential. Class 1 is highly dispersive and Class 8 is highly aggregated in water (Figure 10). A classification of >5 means that the soil is non-dispersive. All soils assessed had an Emerson result of 5. This result supports the findings of the ESP assessment and indicates that there is a low risk of soil dispersion.

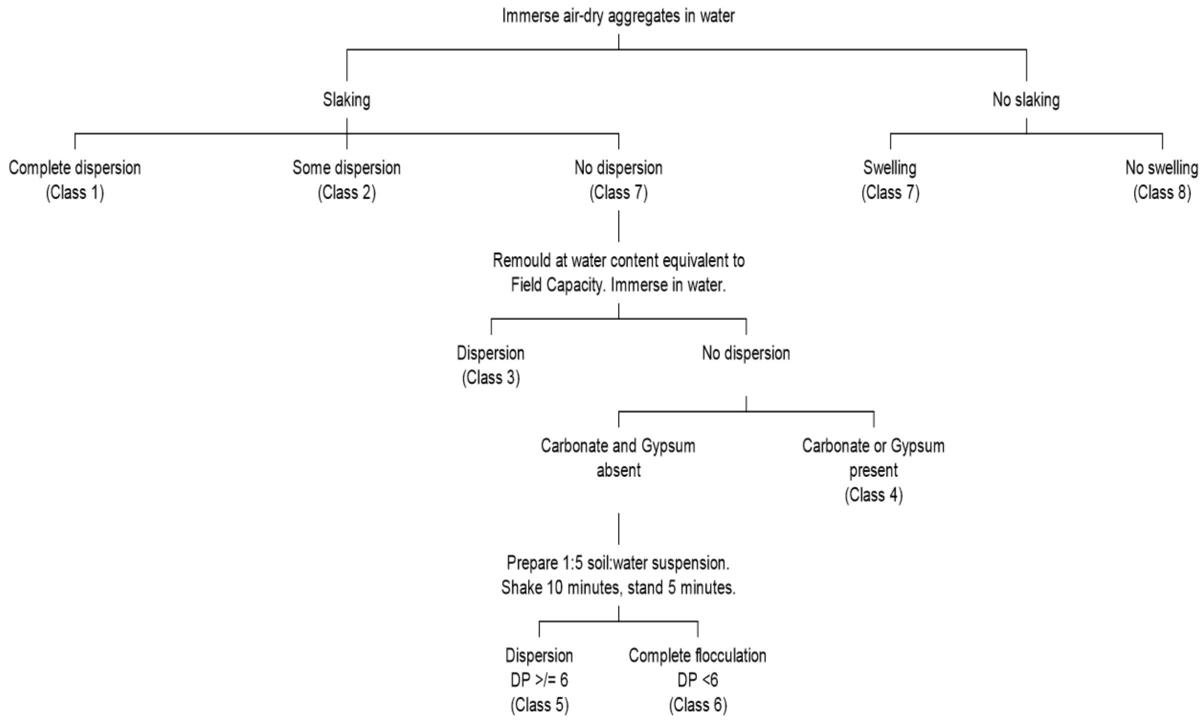


Figure 10: *The Emerson classification system of soil based on its dispersion in water (Australian Standards 1997).*

4.1.5 Fertility

The soils of the Swan Coastal Plain have been formed on geologically recent dune sands of aeolian and alluvial origin. As such, they have low ECEC, clay and silt contents, and have a low base fertility status (Bolland 1998). However, this zone receives average annual rainfall amounts >600mm/yr and has been extensively cleared for agricultural production. The fertility results (table 3) summarised in Table 4, apart from available K, were at medium to high levels which most likely reflects the addition of fertilisers as part of standard agricultural practices.

Table 4: *Summary of fertility results for the topsoils of the Yoongarillup Mineral Sands Project.*

Parameter	Deep Pale Sands
Total N (mg/kg)	1894-3105
Total P (mg/kg)	287-425
Avail P (mg/kg)	67.7-81.5
Avail K (mg/kg)	89.9-94.2
Organic C (%)	2.77-4.33

Rating	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH

Disturbance of these soils by mining is likely to reduce the nutrient status of the soils, and as such, it is likely that application of amendments will be required during rehabilitation activities to increase the success of vegetation establishment.

4.1.6 Hydrophobicity

Indications from the field showed that the Yoongarillup topsoils were hydrophobic. Hydrophobicity is generally caused by the coating of soil particles with plant derived waxy materials. High sand and low clay content soils are particularly susceptible due to the lower surface area of the soil and the smaller amount of waxy material needed to cause water repellence.

Landloch conducted an assessment of the degree of hydrophobicity of Yoongarillup topsoils (Hunt and Gilkes 1992). The method initially required placement of drops of demineralised water onto a sieved topsoil sample and measurement of the time taken for the drop to penetrate the soil; all samples failed with some drops not penetrating the soil after several hours. Subsequently, droplets of ethanol/water solutions of varying molarity (1M (slight repellence), 2M (moderate repellence), 3M (severe repellence), to 4M (very severe repellence)) were placed on the soil surface (Figure 10) and the molarity required to achieve penetration within 5 seconds was recorded. Based on this assessment, the following hydrophobicity ratings were recorded for the 6 topsoil samples:

- DL1 topsoil – severe
- DL2 topsoil – moderate
- DL3 topsoil – very severe
- DL4 topsoil – severe
- DL4 topsoil – moderate
- DL5 topsoil – very severe

Treatment of soils for water repellence includes addition of clay, increasing organic content, application of surfactant, and management strategies such as zero till and permanent pastures.

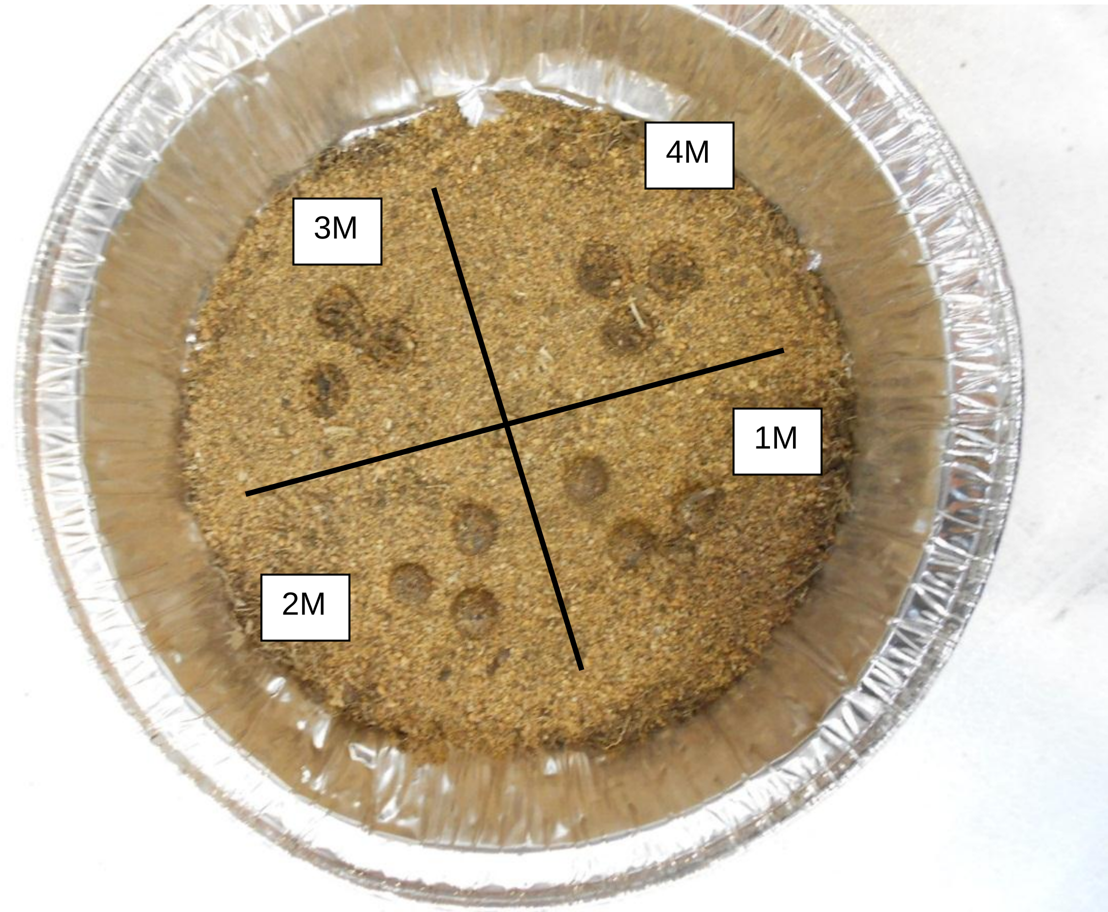


Figure 11: *Testing for hydrophobicity. Groups of different molar solutions and the classification of this material as a Class 3 (severe) material.*

4.1.7 Summary of soil properties

Most of the soil within the disturbance footprint is described as Pale Deep Sands. It is an acidic sandy material that is poorly structured (massive). Surface soils are water repellent which can result in increased potential for erosion from water and wind while it is stockpiled. The surface 10cm contain the highest levels of nutrients, but significant levels are also found down to 30cm. The subsoil, while more acidic and lower in nutrients, will be useful as a plant growth medium to place above the production waste that will be backfilled into the pit.

5. SOIL MANAGEMENT

Soil management strategies are based on the assumptions that:

- Pit areas in the forested area south of Goulden Rd will be returned to native vegetation.
- Pit areas in the existing farmland will be returned to an agricultural land use.
- The topsoil/subsoil stripped from the forest, the agriculture area, and the disturbed area will be stripped and stored separately.

Therefore, the aim in the forested area will be to harvest topsoil to ensure the greatest amount of seed store and fertility, and subsoil for plant growth medium. The aim in the agricultural area will be to harvest topsoil for the greatest fertility level and subsoil for plant growth medium.

5.1 Available soil resource

5.1.1 <u>Soil extent and volumes</u>

Ideally topsoils in the forested area should be stripped to a depth of 10cm so as to selectively harvest the zone containing the highest amounts of seed, biological activity, and fertility. For the agricultural area, the recommended topsoil stripping depth is 15cm as this is the average depth of the A horizon and also corresponds to the soils with the highest levels of plant nutrients and organic material.

For the subsoils in both the forested and agricultural zones, a depth of 100cm is recommended if possible as this will provide a growth medium for both native and agricultural species as well as a barrier for the mining wastes likely deposited under the respread soils. The characteristics of the mined wastes that will likely underlie the soils are currently not fully known, but will likely comprise, among other materials, a clay-rich process waste that will be potentially ill-suited for supporting vegetation.

No subsoil volume is given for the Disturbed soil type. There may be a potentially useful subsoil resource in this area, but this will require further investigation to assess the nature of the material that has been placed in this area by previous mining activities.

The estimation of recoverable soil materials is made with the following assumptions:

- Topsoil and subsoil will be stripped within the disturbance footprint (i.e. pit) only; and
- A planar surface was used to calculate the soil type areal extents.

Therefore the soil extents from the disturbance pit are:

- Deep Pale Sand soil (agriculture) – 19.2ha
- Deep Pale Sand soil (forest) – 8.8ha
- Disturbed soil – 10.4ha

The recoverable topsoil volumes are:

- 28,739m^3 of Deep Pale Sand soil (agriculture)
- 8,773m^3 of Deep Pale Sand soil (forest)
- 15,588m^3 of Disturbed soil

The recoverable subsoil volumes are:

- 279,321m^3 of Deep Pale Sand subsoil

5.1.2 Identification of soil useful for rehabilitation

An important element in successful mine site rehabilitation is the consideration of the soil material's properties that will govern the way they are stripped, stockpiled, and respread. For the Yoongarillup Project, key soils related risks include the presence of hydrophobic soils, soil erosion, and the need to re-establish soil profiles that are able to support cropping activities.

In terms of addressing water repellency, an approach that could be considered by Doral Mineral Sands involved the use of clay to ameliorate the hydrophobic sandy topsoil material. Addition of clay is a traditional method of reducing hydrophobicity as it increases the overall surface area of the soil and reduces the effects of organic waxes within the soil matrix (Blackwell, 1996). Clay addition also has the benefit of increasing soil strength which will allow the soil to more effectively resist erosion (Harper and Gilkes 2004). The addition of clay may also have the potential to improve the water holding capacity of the soil as well as its fertility. Normally agricultural clay is purchased and spread at rates approximately 100t/ha. Given that the Yoongarillup Project will be generating a clay-rich (and non-saline) waste as part of the mineral sand process, it would be appear worthwhile investigating whether this waste could be used as a resource to improve the condition of the topsoil. Such investigations would have to determine the composition of the clay, the salt content, and appropriate application rates, and application methods. Landloch is aware of one mineral sand site in south west WA that trialled the use of clay waste for just this purpose. The trial showed that clay could be applied via a slurry mix sprayed from a water truck. However, the application rates were too high, resulting in the creation of a boggy, wet soil prone to pugging[2] due to the blocking of soil pore spaces with fine clay material.

Other methods of addressing the water repellent nature of the soil that could be investigated include:

- application of surfactants to break down hydrophobicity. This may be useful if stockpiling periods are short
- mixing the topsoil with the upper section of the subsoil. Hydrophobicity is generally restricted to the top 10cm of the soil profile (Carter and Hetherington, 2006) and subsoil mixing will dilute the effects of organic waxes. Mixing may reduce the nutrient status of the agricultural soils; this would need amending via application of fertiliser. Mixing would reduce the nutrient status and seed bank of the forested soils; this would need amending via application of fertiliser and application seed.

[2] Pugging is where the soil pore spaces are blocked, either by clay addition or mechanical action (e.g., trampling by hoofed animals), which leads to poor drainage, poor plant growth, waterlogging, and greater erosion.

The reshaped landform will likely consist of short batter sections constructed from sandy materials. These batters will be prone to erosion, particularly when bare of vegetation. Figure 12 shows that the surface and subsurface soils are quite erodible even at very low gradients. The dominance of sand sized particles in the soil means that they lack cohesion and are readily eroded by flowing water. In addition, it has been show that the soils of The Project are hydrophobic (Section 4.1.6) which will increase the tendency for rainfall to runoff rather than infiltrate the soil profile. Rapid establishment of vegetation will be essential. Assessment of stable batter gradients should also be conducted for the soils. This can be done through laboratory or field based assessment of soil erodibility.

Figure 12: *A) Examples of surface erosion of the topsoils and subsoils at the Yoongarillup Mineral Sand Project.*

In terms, of soil profile reestablishment, it will be important that the water holding capacity of the re-established soil profile is consistent with that of the existing soil profiles. An assessment of the soil's water holding capacity, and the establishment of a soil-vegetation-water balance is recommended.

For the purposes of this report it is assumed that the topsoils and subsoils will be stripped, stored, and respread in a conventional management framework. It is therefore critically important for successful mine site rehabilitation and closure that the recovery of the soil resource be considered in the following context:

- **Topsoils are stripped and stockpiled so that they can be maintained as an ongoing biologically active resource in terms of microbial activity and a seed reserve to be used to develop self-sustaining ecosystems at closure.**
- **Suboils and stripped and stockpiled so that they will provide a suitable plant growth medium for deeper rooted plants and a barrier over the waste material that may potentially be of a different in terms of its chemical and texture nature.**

The following soil management recommendations are made in this context.

5.2 Soil handling

Ideally, stripping and stockpiling of soils should be avoided where possible, and if stripped, soils should be directly respread to areas prepared for rehabilitation rather than stockpiled. This is because stockpiling of soils can lead to compaction, nutrient depletion, and loss of seed stock and soil microfauna. However, direct respreading is not always achievable, and stockpiles are often constructed as part of mining operations. If soil stripping and stockpiling are to be conducted, the following principles should be applied. Each section is divided into 'generic' principles applicable for all areas of the proposed operations, and specifics for the Deep Pale Sand soils currently supporting forest ('forested'), and the Deep Pale Sand and Disturbed soils supporting agricultural activities ('agriculture').

5.2.1 Soil stripping

Forested

Soil stripping to the recommended depth of 10cm should be performed at a time of year when the soil seed bank is highest. This is likely to be just after the wetter months of winter, so springtime would be the ideal. However, soil should not be handled when wet, as this tends to increase compaction.

Agriculture

Preservation of a soil seed bank is not required for the agricultural areas, and soils should be stripped to a depth of 15cm. The time of stripping should coincide when weed infestation is at its lowest. If possible, it may be prudent to also apply a herbicide before stripping to reduce the weed seed stock.

Generic

Inevitably, some degradation of soils will occur during stripping and other soil handling activities, with different types of machinery causing different levels of soil degradation. The use of scrapers for soil stripping is not recommended. The *Mine Rehabilitation* handbook, that forms part of a series produced by the *Leading Practice Sustainable Development Program for the Mining Industry* (DITR 2006) confirms this recommendation by stating that, *"...combined use of a front-end loader, truck and bulldozer for the removal, transport, and spreading of topsoil is the best combination to reduce compaction".*

Landloch is aware that carry graders have also been successfully used to strip thin layers of soil from other mineral sand operations in south west WA. These machines can have large flotation tyres and cause little compaction, and have the precision to strip the 10cm and 15cm recommended depths.

5.2.2 Soil stockpiling

Forested

The management focus of the stockpiled forest topsoil is to maintain a biologically active and fertile soil resource with the greatest amount of seed before respreading. It is commonly recommended that topsoil stockpiles should be no deeper than 1.0m (DME 1996), though information providing a basis for recommendation of best practice for effective stockpiling of topsoils is limited[3]. It is generally considered that stockpiling topsoils deeper than 1.0m tends to kill the topsoil seed bank and, to a lesser extent, degrade the structure of the soil at the bottom of the stockpile (Keipert *et al*. 2002). Deeper soil stockpiles may also potentially decrease the soil nutrients levels and soil microbial populations by creating anaerobic conditions at depth (Abdul-Kareem and McRae 1984). These outcomes would largely negate the properties of topsoil that are advantageous to rehabilitation activities. Therefore, where topsoil is stockpiled to greater depths, additional seed and fertiliser may be required to counter the reduction in soil seed bank and soil microbial propagules caused by stockpiling although this is not recommended.

Tree debris could also be placed onto the forested topsoil stockpiles to increase organic matter, biological activity, and seed stock (see Section 5.3).

Fertiliser application rates for stockpiles should be determined based on the results of field trials. The species seeded should be fast growing, and ideally leguminous to provide some nitrogen input to the soil, though care should be taken to avoid introducing weeds, and to avoid undue distortion of the natural diversity and abundance of species present in the soil seed bank from the forested areas.

For best preservation of the soil seed bank and biota, the topsoil stockpiles should be flat-topped or slightly domed. Slight doming of the topsoil reduces the risk of waterlogging, which will be an issue throughout the winter months. Encouraging water entry will make more water available to plants and minimise the risk of erosion and sediment movement from the stockpile.

Agriculture

The agricultural soil stockpiles are expected to be more hydrophobic than the forested soil stockpiles and will require management for this characteristic. As identified in Section 5.1.2, one potential method is the addition of clay (either from processing waste or agricultural clay). Another alternative is the application of a surfactant to assist the breakdown of organic waxes. The use of green manures to build up soil organic matter may also be an option. Green manures may also help to compete with weeds, as they are anticipated to be an ongoing problem for the agricultural topsoil stockpile.

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[3] Interactions between soil texture, environment (particularly rainfall) and vegetation type have yet to be addressed in a logical framework.

Generic

Stockpiling soils can cause structural degradation (particularly of the soil at the bottom of the stockpile) and loss of soil biota (DITR 2006). Compaction caused by stockpiling may be largely removed by soil respreading during rehabilitation works, but the soil biota cannot be replaced without intervention.

Some studies have suggested that much of the loss of soil organic carbon occurs during stripping and stockpile construction (Visser *et al.* 1984), and this is particularly likely in sandy soils for which rates of organic matter loss can be relatively rapid. For example, Dalal and Mayer (1986) found that the half-life of organic carbon in the surface layer of a tilled sandy loam was only 0.6 year, whereas organic carbon in clay soils was found to have a half-life of up to 12 years.

Subsoils are generally sandy and do not contain seed and respreading is likely to remove any compaction caused by stockpiling. As a result, subsoils can be stockpiled to greater depths; up to 4.0m.

Stockpiling subsoil to greater depth also provides clear delineation between subsoil and topsoil stockpiles, reducing the risk that topsoils and subsoils will be mixed. As for topsoil stockpiles, subsoil stockpiles should be built to maximise water entry.

All soil stockpiles should be monitored for erosion (wind and water) and weed infestations, particularly for the topsoil derived from the agricultural areas. Control of weeds in stockpiled soil is likely to be more cost effective than controlling infestations once the soil is respread. Weeds can be controlled by planting species that will outcompete the weeds, or by spraying herbicides. While acid sulphate soils is not anticipated to be a hazard, it would be prudent to monitor the subsoil stockpiles for changes in pH during storage.

5.2.3 Soil respreading

Forested

The rehabilitation aim for the forested area is that it quickly becomes a self-sustaining ecosystem. Issues that will affect this aim are soil compaction from respreading, dilution of the topsoil by inadvertent mixing with the subsoil, and short term reduction of organic matter input that will create an imbalance in the organic matter cycle until vegetation is well established (Schwenke *et al*. 2000).

The use of large rubber tyred equipment for respreading is recommended to minimise compaction. The respreading of topsoil by placing rather than pushing will minimise the dilution of topsoil with subsoil. The use of mulch or tree debris will help in addressing the organic matter deficit in the early years of rehabilitation.

Agriculture

Like the forested areas, compaction of the soil and mixing of subsoil with topsoil should be avoided. The agricultural soil respread area will be a lot larger and more exposed than the forested area, so wind erosion will be more of a concern. The addition of clay to the soil was discussed in Section 5.1.2 to address hydrophobicity (but it at the correct concentration) will assist to form a temporary crust on the soil surface to protect against wind erosion, that could then be incorporated into the soil when the area is prepared for cropping.

5.2.4 Soil amendments

Forested

From a rehabilitation perspective, it is preferable to replace or supplement the nutrients lost through disturbance to encourage rapid establishment of vegetation. It is assumed that the soil from the undisturbed forested areas will have a lower nutritional status than for the material derived from the agricultural areas.

The precise nature of these nutrient additions will in part be determined by the success of the soil stockpiling strategies outlined above. If done successfully, the topsoil can be spread containing a seed bank of target species and adequate nutritional levels to ensure good germination and growth. Soil stockpile monitoring (soil characterisation) before spreading should be undertaken to determine the nutrient status of the material. Levels should be at least comparable to those found in undisturbed soils.

Application of fertiliser to the topsoil is recommended based on the predicted low nutrient status of the bare soils in the stockpiles and the loss of nutrients caused by the removal of vegetation and disturbance of the soil. Likely fertiliser requirements are not high and as an example, Landloch has seen success in arid zone rehabilitation at application rates in the order of 10–30 kg/ha of both N and P and 3–8 kg/ha of S. These could be supplied through the application of 40–80 kg/ha of mono-ammonium phosphate (MAP) and 15–30 kg/ha of ammonium sulphate. This fertiliser application rate can be applied to all soil types and is calculated assuming it is incorporated into a soil depth of 0.3m.

It should be noted that the application of an immobile element such as P to the surface of soils is not recommended as it will not be accessible to plant roots within the active root zone. Therefore, incorporation of fertiliser into the soil profile (surface 0.3-0.5m) rather than simply applying it to the surface is strongly recommended.

As the soils, particularly the subsoils, are acidic, it would be worth mitigating the risk of acidic subsoils being mixed into the surface layers by applying lime. Ideally, it would be best to apply the lime at the time of stripping to fully incorporate it into the subsoil soil matrix. As it has been recommended to strip as much as 1m of subsoil, this may not be practical. An alternative approach would be to apply lime after the subsoils have been respread so that the top layer of the subsoil has been treated.

The necessary application rates for addressing subsoils acidity are low and indicative rates of approximately 0.5t/ha are suggested.

Agriculture

As the agricultural area will be returned to dairy and crop production, the amendment of the soil should be conducted in consultation with the landowner to meet the levels required for agronomic purposes, and to manage soil hydrophobicity.

5.2.5 Soil monitoring protocols

Generic

If topsoil is to be stockpiled, the stockpiles should be clearly labelled and be reflected in mine operations documents and maps. Soils will require monitoring for changes in its physical and chemical condition. Monitoring should occur at a minimum of every 12 months and should record:

- Surface condition and erosion;
- Nutrient status, pH, and EC;
- Weed type and infestation rates; and
- Seed germination rates.

The monitoring protocols should form part of the site-wide rehabilitation monitoring strategy so that if monitoring shows deterioration of the topsoil resource, this will trigger actions to address the issues.

5.3 Tree debris

Tree debris is often overlooked in soil assessments but can be an important resource for mine site rehabilitation. There are significant amounts of trees, shrubs, brush, and grasses across the forested section of the site that could be recovered (Figure 13). The surface vegetation should be stripped separately from the topsoil and stored separately. The tree debris (trunk diameters greater than ~10cm) can then be used as erosion protection for stockpiled and respread soil material, and the trees, shrubs, brushes, and grasses, will add seed, nutrients, and organic carbon to the soil.

Figure 13: *Example of woody vegetation within the proposed pit disturbance footprint in the forested area. Note deep sand layer beneath the native vegetation.*

5.4 Implications for mine closure design

Successful rehabilitation outcomes require detailed and careful planning that typically not only reduces environmental risk, but also minimises the actual cost of rehabilitation activities. Unlike ore mining activities, there will not be large waste landforms to rehabilitate at the Yoongarillup Project as the processing waste will be backfilled into the pit. Mine planners must still plan for an erosionally stable surface at closure as it is evident that even at low gradients the sandy soil material is quite erodible (refer Figure 12). Surface water control will be key for erosional stability of the final land landform surface. Of particular importance will be the avoidance of landform designs that act to concentrate runoff.

Soil management during operations and rehabilitation activities will also be important. It is possible, through poor management of soil and waste resources to result in rehabilitation failure where success was very achievable. This is particularly the case as most of the disturbance footprint has the rehabilitation end land use of productive agriculture, a use with quite specific soil requirements. The careful planning and management of the soil resource will ensure this goal is met in the most efficient and cost effective manner.

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APPENDIX 1. Analysis methods used on topsoils and subsoils.

Soil Analyses	Abbreviation	Units	Methodology	Reference
pH	pH	na	1:5 soil:water	Rayment & Lyons (2011)
Electrical Conductivity	EC	dS/m	1:5 soil:water	Rayment & Lyons (2011)
Exchangeable Cations	Ex (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+})	meq/100 g	NH_4Cl	Rayment & Lyons (2011)
Dispersion Potential	NA	Value 1–8	Emerson Index	Australian Standard (1980)
Total Nitrogen	Total N	mg/kg	Kjeldahl	Rayment & Lyons (2011)
Total Phosphorous	Total P	mg/kg	Nitric/Perchloric	Rayment & Lyons (2011)
Available Phosphorous	Av P	mg/kg	Colwell	Rayment & Lyons (2011)
Available Potassium	Av K	mg/kg	Colwell	Rayment & Lyons (2011)
Available Sulfur	Av S	mg/kg	KCl-40	Rayment & Lyons (2011)
Organic Carbon	OC	%	Walkley–Black	Rayment & Lyons (2011)
Micro Nutrients	Cu^{2+}, Mn^{2+}, Zn^{2+}, Fe	mg/kg	Diethylamine triamine pentaacetic adic (DTPA)	Rayment & Lyons (2011)
Particle size distribution (% of clay, silt and sand)	PSD	%	Hydrometer	Rayment & Lyons (2011)
Phosphorous Buffer Index	PBI	na	PBI_{+ColP}	Rayment & Lyons (2011)
Effective Cation Exchange Capacity	*ECEC*	meq/100g	NH_4Cl	Rayment & Lyons (2011)
Exchangeable Sodium Percentage	*ESP*	%	NH_4Cl	Rayment & Lyons (2011)

Note: Not all tests were conducted on each sample. Subsoil samples were not subjected to fertility analyses.

APPENDIX 2. Glossary of terms.

Acidic	A soil property expressed by a pH that is less than 7.0 in soil/water suspension.
Active gully	Gully is actively eroding: walls, head and/or bed are unstable.
Aggregate	Unit of soil structure consisting of primary soil particles held together by cohesive forces or by secondary soil materials such as iron oxides, silica or organic matter. Aggregates may be natural, such as peds, or formed by tillage, such as crumbs and clods. See ped. Macro-aggregates are more than 250 μm in diameter and micro-aggregates are less than 250 μm.
Alluvial fan	Fan shaped deposit of alluvium (silt etc) at the mouth of a stream or gully where flows flatten out and sediment is able to fall out the flow.
Alluvium	Sediment (sand, clay, silt etc) deposited by flowing water.
Alkaline	A soil property expressed by a pH that exceeds 7.0 in soil/water suspension.
Ameliorant	A substance used to improve the chemical or physical properties of a soil. For example, gypsum to improve aggregate stability and soil structure, lime to increase pH levels.
Armouring	The accumulation of coarse (rocky) particles at the soil surface due to preferential removal of finer size fractions.
ASWAT test	'Aggregate stability in water' test – developed by Field *et al.* (1997) to assess the stability of a soil.
Biota	Soil biology – eg. earthworms, fungi and algae.
Bulk density (BD)	Ratio of the mass or weight of dry soil to its volume or bulk. Usually shown as grams per cubic centimetre. Is a measure of soil porosity and can be used to measure compaction. A high bulk density has a low porosity and is usually hardest and compacted.
Bund	An impervious embankment of earth that forms part or all of the perimeter or barrier to retain or exclude something such as water.
Cation exchange capacity (CEC)	Measure of the capacity of a soil to hold the major cations (i.e. the amount of exchange sites on negatively charged clay particles and organic matter in a soil). The major cations include calcium, magnesium, sodium, potassium and aluminium. It is also a measure of the potential fertility of the soil.
Compaction	The process whereby soil density is increased as a result of tillage, stock trampling or vehicular traffic. Compaction can lead to lower soil permeability and poorer soil aeration resulting in increased erosion hazard and poorer plant productivity. Deep ripping and conservation tillage can alleviate the condition.

Consolidation	Refers to increases in soil bulk density and cohesive strength that occur as a consequence of repeated wetting and drying under natural conditions.
Crust	See surface crust.
Degradation	Decreasing functionality and sustainability of a landscape.
Dispersive soil	Soils that are structurally unstable and disperse in water into basic particles (such as sand, silt and clay). Dispersive soils tend to be highly erodible and present problems for successfully managing earthworks.
Drainage	Refers to to the rapidity and extent of water removal from the soil profile or site. Drainage is distinct from *permeability* which refers to the rate at which water moves internally through a soil profile.
Electrical conductivity (1:5 soil:water) (EC_w)	A measure of the conduction of electricity through a soil water extract (1:5 soil:water). The value can reflect the amount of salt in a soil extract or the salinity of soil and water. Measured in DeciSeimens per metre (dS/m).
Emerson Aggregate Test	Also referred to as the slaking test – an aggregate or ped of soil is placed into distilled or rain water and assessed for slaking and dispersion characteristics. Describes the inherent stability of a soil.
Erodibility	Refers to the rate of detachment and/or movement of soil in response to some erosive force. The exact definition of erodibility varies from model to model, depending on the types of erosive forces considered. Equally, the units of erodibility may seem somewhat counter-intuitive, but are a function of the units used in calculating erosive forces. Some models, such as the Water Erosion Prediction Project (WEPP), use different erodibility factors for different erosion process.
Exchangeable cations	Cations that can be exchanged in the soil complex for or by other cations.
Exchangeable sodium percentage (ESP)	A measure of exchangeable sodium in relation to other exchangeable cations. Soils with a high ESP are typically unstable and, therefore, have high erodibility.
Gully erosion	Removal of soil in a narrow path by water erosion to considerable depths, typically deeper than 0.5 m.
Gypsum	A naturally occurring soft crystalline material, which is a hydrated form of calcium sulphate ($CaSO_4.H_2O$). Usually, gypsum contains approximately 23% calcium and 18% sulphate. It is used to amend soil structure and reduce crusting in hard setting clay soils. Gypsum also acts to replace exchangeable sodium attached to clay particles with exchangeable calcium, reducing clay dispersion and sodicity.

Hardsetting	Condition of a soil where the surface is dry, hard and compacted with no apparent pedal development. These soils are not disturbed or indented by pressure of the forefinger. These harder setting soils tend to result in high runoff.
Headwall	Vertical wall at the beginning/top of a gully.
Horizons	Horizons refer to the horizontal organisation of the soil profile. An individual horizon will have physical and chemical characteristics that differ from the one above or below it. The A horizon consists of one or more mineral horizons that have organic accumulations but lower clay content then the underlying horizon. The B horizon is a mineral layer that has a concentration of clay/Fe/Al, a structure differnet and stronger colours to the A horizon, and is the horizon of maximum pedological development. The C horizon is dominated by partially weathered rock and little pedological development. The R horizon consists of hard rock.
Hydraulic conductivity	The flow of water through soil per unit of energy gradient. For practical purposes, it may be taken as the steady-state percolation rate of a soil when infiltration and internal drainage are equal, measured as depth per unit.
Infiltration	The movement of water through the soil surface. Soils with a high infiltration capacity allow more rain to enter the soil than those with a low infiltration capacity. Runoff will occur when the rate of rainfall exceeds the soil's infiltration capacity. Surface soil structure and texture are important determinants of the infiltration capacity of a soil.
Interrill erosion	Describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows. When a drop impacts the flow, the resulting turbulence ejects particles up into the flow, and the particles remain in the flow for a period of time, during which the particle travels some distance in the direction of flow. In the absence of raindrop impact, such shallow flows have little or no erosive capacity.
KPI	Key Performance Indicator.
Leaching	Removal in solution of soluble minerals and salts as water moves through the profile.
Macropores	Spaces/voids in soil fabric, generally <2 mm in diameter produced by soil biota, roots, coarse-grained particles, spaces/cracks in the soil structure.
Mass wasting	Mass wasting occurs when a block of soil collapses by soil topple/soil fall/circular slip.
Micro nutrients	An element/nutrient required by plants for growth but only in small/minute quantities.

Nutrient availability	A general expression which refers to the ease with which plants can absorb a particular nutrient from the soil – depending on factors such as solubility.
Ped	An individual, natural soil aggregate. See aggregate.
Permeability	The characteristic of a soil which governs the rate at which water moves through it. It depends on soil texture, soil structure, the presence of compacted or dense soil horizons and the size and distribution of pores in the soil.
pH_w	Measure of soil acidity and alkalinity in 1:5 soil:water on a scale of 0 (extremely acidic) to 14 (extremely alkaline). A pH of 7 is neutral.
Porosity	Degree of pore space in a soil i.e. the percentage of the total space between solid particles.
Remnant vegetation	Native vegetation remaining after widespread clearing has taken place.
Resources	Components that contribute to the functionality and production of a landscape such as water, soil, nutrients and seed.
Rill erodibility	The rate of detachment in a rill per unit of effective shear stress.
Rill erosion	An erosion process on sloping land; small channels of only several centimetres in depth are formed.
Runoff	That portion of precipitation or irrigation on an area that does not infiltrate, but instead is discharged from the area over the surface of the soil.
Salinity	A measure of the total soluble salts in a soil that can hinder plant growth.
Scour	Occurs where the shear (flow sliding/frictional forces) and wrenching forces (flow eddies – turbulent forces) imposed by the flow are greater than the resistant forces of the material of the channel bed.
Seedbed	Soil layer that affects and supports the germination and emergence of seeds.
Sheet erosion	Removal of the upper layers of soil by overland flow, often accelerated by raindrop splash.
Shear strength	The maximum strength of soil at which point significant plastic deformation or yielding occurs due to an applied shear stress. There is no definitive "shear strength" of a soil as it depends on a number of factors affecting the soil at any given time.
Slaking	Partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces within the aggregate. These aggregates may subsequently disperse.

Sodic soil	Soil containing sufficient exchangeable sodium (commonly greater than six per cent) to adversely affect soil structure. Sodic soils tend to have poor drainage and have a tendency to disperse.
Sodium adsorption ratio (SAR)	Proportion of sodium cation (Na^+) held in the soil relative to that of calcium and magnesium.
Soil	Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics.
Soil instability	The tendency of soil to break down into smaller granules or individual particles in contact with water as a result of poor chemical or physical conditions or mechanical disturbance. These soils are prone to formation of surface seals, crusts, and erosion.
Soil organic matter	The organic fraction, plant and animal residues, of the soil. **Soil organic carbon** is the organic fraction of the soil exclusive of undecayed plant and animal residues.
Soil profile	Vertical section of the soil from the soil surface down through the layers of soil (eg. topsoil, subsoil) including the parent material.
Soil texture	Proportion of soil particles of different sizes – silt, clay and sand in a soil. It can also be influenced by the presence of organic matter and the clay type. The particle composition of a soil can dictate the behaviour and inherent characteristics of that soil.
Structure	Describes the way the soil particles are arranged to form soil peds. Peds are units of soil structure that are separated from each other by natural planes of weakness. They differ from clods which are formed as a result of soil disturbance such as ploughing.
Subsoil	Layer of soil underneath the topsoil, usually has higher clay content, denser and stronger in colour. In most cases it is a poor medium for growth without the topsoil layer. If exposed, can be quite erosive.
Subsoiling	Deep ploughing into the subsoil (similar to subsoil shattering).
Surface crusting (surface sealing)	The arrangement of dispersed clay particles in the immediate soil surface layers, making a crust that is comparatively impermeable to water. This typically occurs due to raindrop impact on bare soil. The potential for runoff and erosion are increased.
Swelling clay (shrink-swell)	Process that occurs when interacting clay platelets move apart due to the absorption of water molecules between clay platelets.
Tension crack	A crack that develops on gully wall, sidewalls and above tunnel erosion indicating imminent failure or collapse: often the result of undercutting, caving or tunnelling.

Topsoil	Original surface layer of mineral soil containing material that is usually darker, more fertile and better structured than the underlying layers.
Tunnel erosion	Tunnelling is an insidious form of sub-surface erosion, resulting as the name suggests in a tunnel through sub-surface soil layers. Tunnel erosion is caused by the movement of excess water through dispersive (usually sodic) subsoil.
Undercutting	Undercutting occurs where the flow in the main gully channel undercuts the sidewall, often leading to mass wasting.
Water repellent soils	Soils that are resistant to wetting (from a dry state). It is a condition usually associated with sandy surface horizons caused by an organic coating on sand grains
WEPP	Water Erosion Prediction Project – erosion simulation software.

APPENDIX 3. Soil test paramaters and classification.

Test Parameter		Units	Classification				
			Very low	Low	Medium	High	Very high
$EC_{1:5}$		*dS/m*	0.15	0.15-0.45	0.45-0.9	0.9-2	>2
Total N		*mg/kg*	500	500-1500	1500-2500	2500-5000	>5000
Total P		*mg/kg*	50	50-200	200-500	500-1000	>1000
Available P		*mg/kg*	<10	10-20	20-40	40-100	>100
Available K		*mg/kg*	<391	391-782	782-1955	1955-3910	>3910
Organic C		%	<0.5	0.5-1.5	1.5-2.5	2.5-5	>5
Trace elements	Copper	*mg/kg*	<0.1	0.1-0.3	0.5-5	5.-15	>15
	Manganese	*mg/kg*	<1	1-2	2-50	50-500	>500
	Zinc	*mg/kg*	<0.3	0.3-0.8	0.8-5	5-15	>15

$pH_{1:5}$	***pH Units***
Extremely acid	<4.5
Very strongly acid	4.5-5
Strongly acid	5.1-5.5
Medium acid	5.6-6
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Mildly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9
Very strongly alkaline	>9

Exchangeable sodium percent (ESP)	**%**
Non-sodic	<6
Sodic	6-14
Strongly sodic	>15

(Source: Hazelton and Murphy, 2011, and Bruce and Rayment, 2004.)

SOILWATER CONSULTANTS

YOONGARILLUP DEPOSIT ASS SURVEY

Prepared for:	**DORAL MINERAL SANDS LIMITED**
Date of Issue:	15 August 2012
Project No.:	PN0208-1-5-DM-001

DOCUMENT STATUS RECORD

Project Title:	**YOONGARILLUP DEPOSIT ASS SURVEY**
Project No.:	PN0208-1-5-DM-001
Client:	DORAL MINERAL SANDS LIMITED

Revision History					
Revision Code*	Date Revised	Revision Comments	Signatures		
			Originator	Reviewer	Approved
A	13/08/2012	Internal review of draft report	SC	ASP	SC
B	14/08/2012	Draft report issued for client review	SC		

Revision Code*	
A - Report issued for internal SWC review	1 - First Revision
B - Draft report issued for client for review	2 - Second Revision
C - Final report issued to	3 - Third Revision

LIMITATIONS

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to conduct an acid sulfate soils (ASS) survey for the Yoongarillup Deposit. This work was conducted in accordance with the Scope of Work presented to Doral Mineral Sands Limited ('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 ASS Survey was confined solely to the Yoongarillup Deposit. 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 published soil reports from various soil researchers 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

List of Plates

1. INTRODUCTION

Soil Water Consultants (SWC) were commissioned by Doral Mineral Sands Limited (Doral) to undertake an Acid Sulfate Soil (ASS) Survey for the proposed Yoongarillup Deposit, which is located approximately 15 km south-east of Busselton, W.A. (Figure 1.1). Mining of the heavy mineral deposits at this site will involve the excavation, stockpiling and processing of a large volume of soil; creating several separate mine pit voids (Figure 1.2). With the increasing awareness of Acid Sulfate Soils (ASS) on the Swan Coastal Plain (SCP) (DEC, 2009; 2011), an ASS Survey for the proposed Yoongarillup Deposit was required to confirm the presence or absence of Actual Acid Sulfate Soils and Potential Acid Sulfate Soils (PASS) in this region.

The approach taken in this ASS Survey followed the assessment framework outlined in the revised guidelines for the Identification and Management of Acid Sulfate Soil Hazards for Mineral Sands Operations (DEC, *in prep.*). This assessment framework is shown in Figure 1.1. Whereas the existing ASS Identification and Investigation Guidelines for small urban development projects utilise a prescriptive, laboratory-based approach, the revised guidelines adopt a more iterative risk-based approach for assessing and managing ASS, with the onus on the mining companies to prove to the stakeholders that sufficient investigation has occurred to appropriately manage the risks associated with the disturbance of sulfidic sediments.

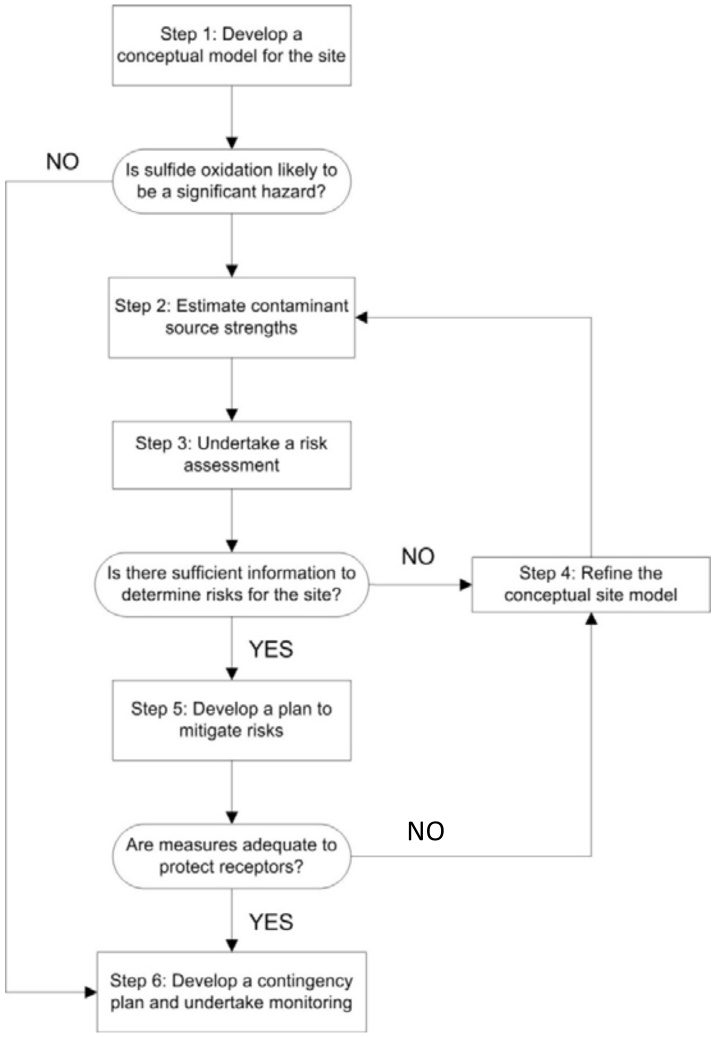


Figure 1.1: Assessment framework utilised in the revised ASS guidelines for mineral sands operations.

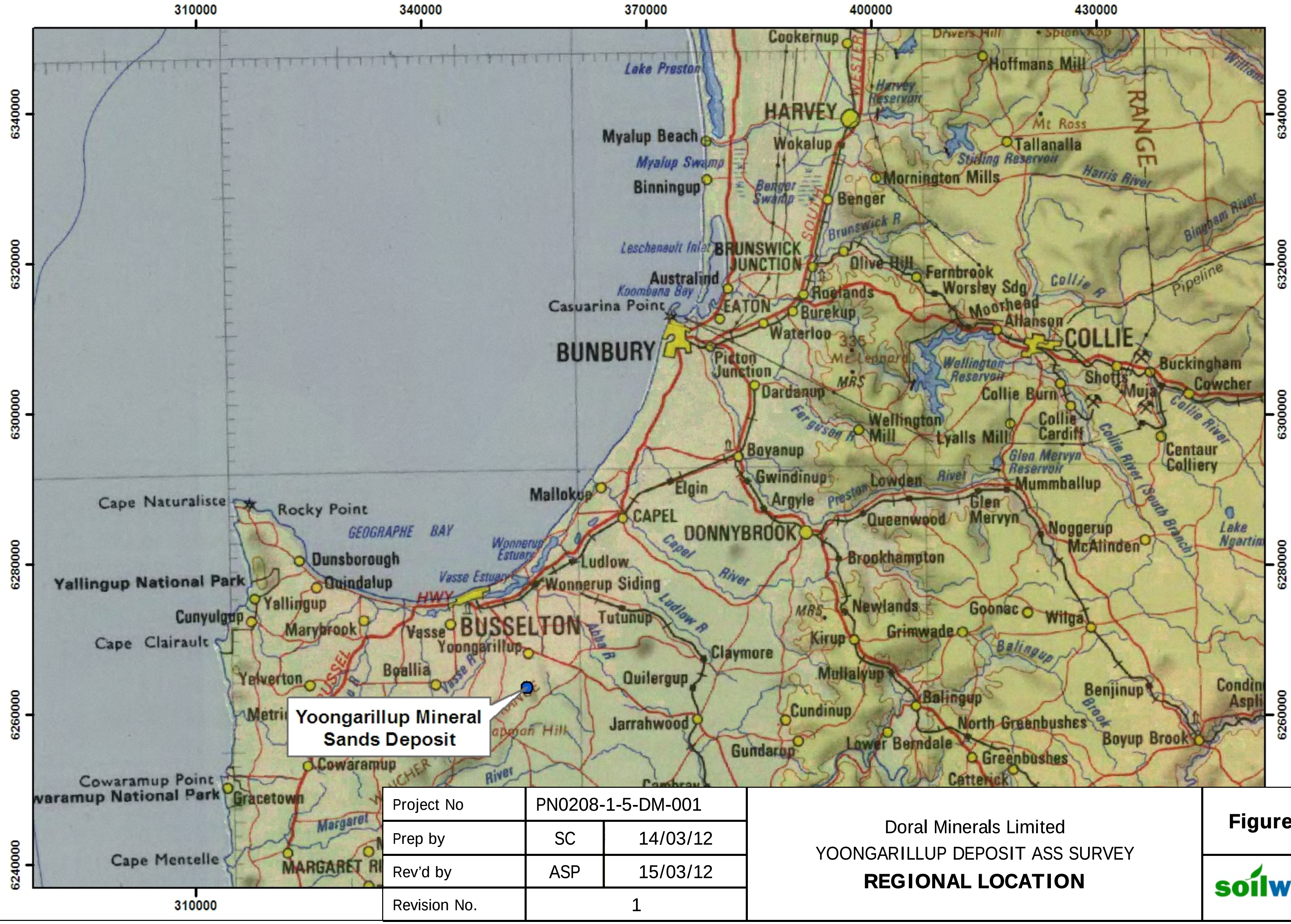
Other sources referred to in the preparation of this ASS Survey were:

- Treatment and Management of Disturbed Acid Sulfate Soils (DoE, 2004).
- Acid Sulfate Soils Manual (Stone *et al*., 1998).
- Analysis of Acid Sulfate Soils – Part 1: Dried sample – pre-treatment of samples (Standards Australia, 2006).
- Preparation of Acid Sulfate Soil Management Plan (ASSMP) (DoE, 2003).

The general objectives of this ASS Survey were to:

- Establish whether ASS are present or absent within the sediments to be disturbed by mining operations at the Cataby Deposit.
- Quantify the pyritic content and spatial distribution of ASS at the site (i.e. determine the source strength).
- Assess the potential for both direct and indirect disturbance of ASS at this site.
- Assess the potential risk of metals release to the environment following sulfide disturbance.

Propose strategies for the management of PASS within the proposed Cataby Mine Site.

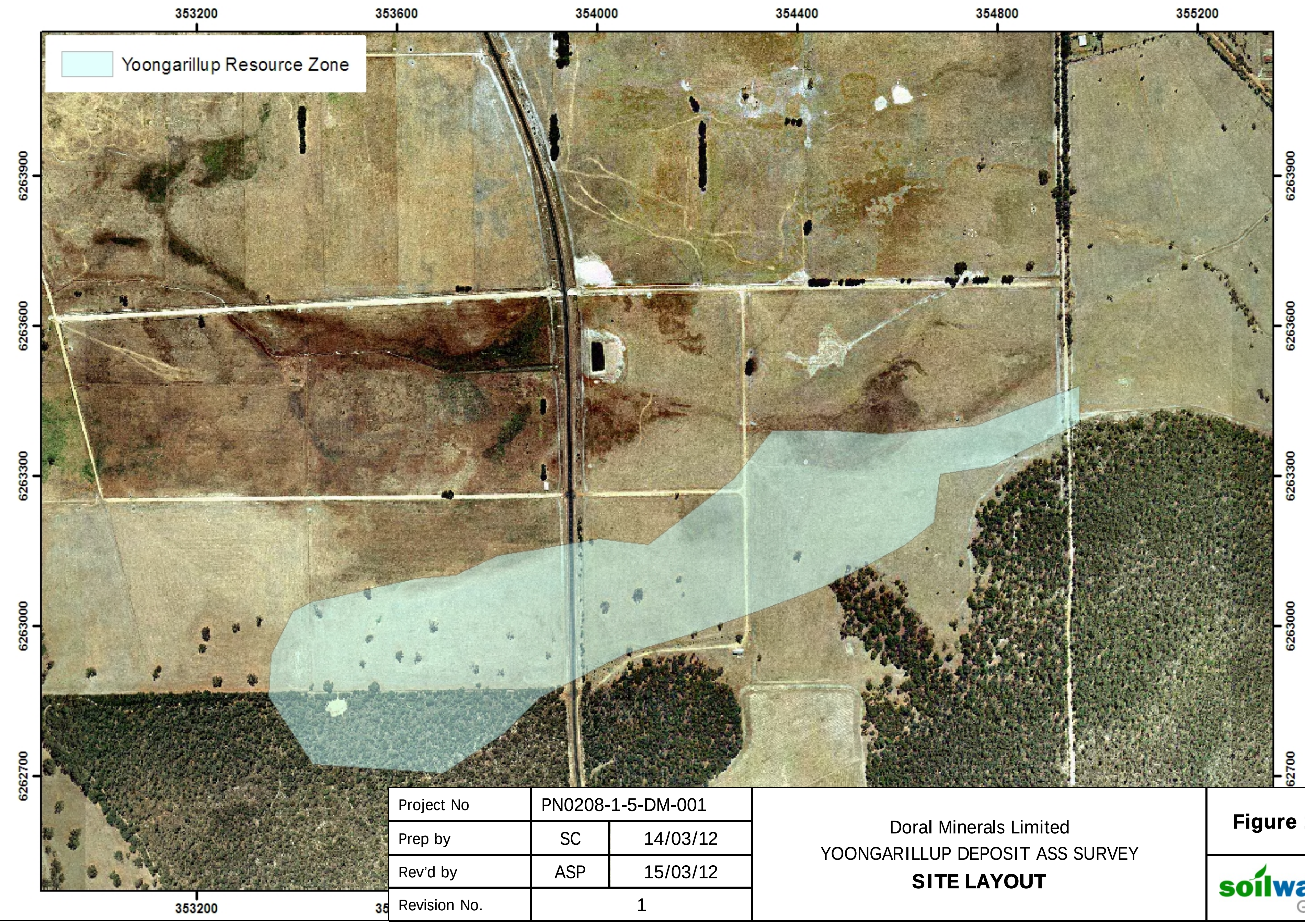


Project No	PN0208-1-5-DM-001	
Prep by	SC	14/03/12
Rev'd by	ASP	15/03/12
Revision No.	1	

Doral Minerals Limited
YOONGARILLUP DEPOSIT ASS SURVEY
REGIONAL LOCATION

Figure 1.1

soilwater GROUP



Project No	PN0208-1-5-DM-001		Doral Minerals Limited YOONGARILLUP DEPOSIT ASS SURVEY **SITE LAYOUT**	**Figure 1.2**
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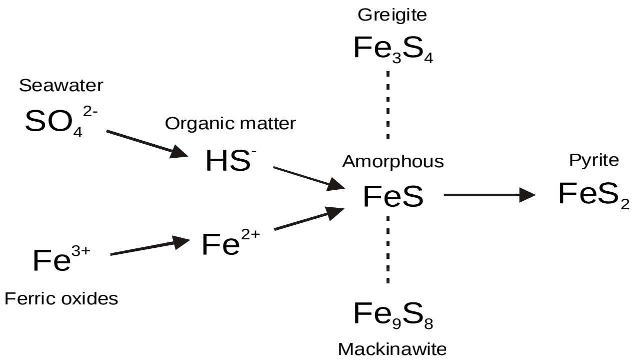
Rev'd by	ASP	15/03/12		
Revision No.	1			

2. ASS SOILS

2.1 FORMATION OF ASS SOILS

ASS are naturally occurring soils and sediments that contain iron sulfide minerals (predominately pyrite) (Stone *et al*., 1998; DEC, 2009). Iron sulfide minerals form under reducing conditions (i.e. under a watertable), in the presence Fe^{3+}, SO_4^{2-} (commonly from seawater), organic matter and sulfur-reducing microorganisms (*Desulforibrio* spp.) (Shamshuddin *et al*., 2004). Amorphous iron 'monosulfides' (FeS), which include greigite (Fe_3S_4) and mackinawite (Fe_9S_8), are typically the first iron sulfide precipitates to form and are characterised by a 'black ooze' (Bush and Sullivan, 1999). FeS is thermodynamically unstable and consequently it rapidly alters to the more stable pyrite (FeS_2) according to Equation 3.1.



Eqn. 2.1

Under reducing conditions pyrite is the most thermodynamically stable iron sulfide mineral, hence it is the most abundant iron sulfide mineral present in low-lying, estuarine environments (Berner, 1967; Bush and Sullivan, 1999). However, pyrite is metastable under oxidising conditions, and subsequently it partially alters to jarosite ($KFe_3(SO_4)_2(OH)_6$) or completely alters to iron hydroxide ($Fe(OH)_3$) and sulfuric acid (H_2SO_4), according to Equations 3.2 and 3.3. Using these equations, it can be determined that for every tonne of pyrite that oxidises, 1.6 tonnes of H_2SO_4 is produced and released into surrounding environment.

$$FeS_2 + 15/4O_2 + 5/2H_2O + 1/3K^+ \rightleftharpoons 1/3KFe_3(SO_4)_2(OH)_6 + 1/3SO_4^{2-} + 3H^+ \quad \text{Eqn. 2.2}$$

$$\downarrow$$

$$1/3KFe_3(SO_4)_2(OH)_6 + H_2O \rightleftharpoons Fe(OH)_3 + H^+ \ 1/3K^+ + 2/3SO_4^{2-}$$

Eqn. 2.3

Once the acid (H^+) is released into the environment (decreasing the soil and water pH) it has the potential to breakdown the structure of the soil matrix causing the release of aluminium, nutrients and heavy metals (particularly chromium and arsenic) into the soil solution, and ultimately into the groundwater.

2.2 REQUIREMENTS FOR AN ASS SURVEY

An ASS investigation is required if any of the following works are proposed (DEC, 2009):

- Soil or sediment disturbance > 100 m^3 in areas that have a high risk of ASS occurrence.
- Lowering of the watertable (either temporary or permanent) in areas shown in the ASS Risk Maps as 'high risk of actual acid sulfate soils (AASS) or potential acid sulfate soils (PASS) occurrence', or dewatering operations

in areas shown in the ASS Risk Maps as 'moderate to low risk of AASS or PASS occurrence' within 500 m from a high risk area.

- Where there is evidence of a significant risk of disturbing acid sulfate soils in areas shown in the ASS Risk Maps as 'moderate to low risk of AASS or PASS occurrence at > 3 m below natural surface'.
- Any dredging operations.
- Extractive industry works (i.e. mineral sands mining).
- Flood mitigation works including construction of levees and flood gates.
- Any works proposed in any of the areas listed in Section 3.3.

If the proposed disturbance satisfies any of the criteria listed above, then a detailed ASS Investigation, involving soil sampling and laboratory analysis of samples, will be required.

3. SCREENING LEVEL ASSESSMENT

3.1 METHODOLOGY

An ASS drilling and soil sampling program was developed to confirm the presence or absence of ASS in the proposed Disturbance Area. The DEC has established guidelines for determining the minimum number of boreholes to be drilled and the vertical sampling interval (Table 3.1). These guidelines were addressed when designing the drilling and soil sampling program.

Table 3.1: DEC sampling and analysis requirements for ASS investigations (DEC, 2009)

Extent of site project	Number of boreholes	Sampling intensity
1. Project Area		
< 1 ha	4	Every 0.25 m vertical interval
1 – 2 ha	6	Every 0.25 m vertical interval
2 – 3 ha	8	Every 0.25 m vertical interval
3 – 4 ha	10	Every 0.25 m vertical interval
> 4 ha	2 for every hectare	Every 0.25 m vertical interval
2. Volume of disturbance		
< 250 m^3	2	Every 0.25 m vertical interval
250 – 1000 m^3	3	Every 0.25 m vertical interval
> 1000 m^3	1 for every 500 m^3	Every 0.25 m vertical interval
3. Linear project		
Minor width and volume and low S (%)	@ 100 m intervals	Every 0.25 m vertical interval
Major width and volume	@ 50 m intervals	Every 0.25 m vertical interval

Drilling and soil sampling for ASS identification at the Yoongarillup Deposit occurred July of 2011. The drilling was undertaken in accordance with the DEC guidelines with a total 72 holes drilled across the proposed Yoongarillup Deposit Disturbance Area. The locations of the ASS drillholes sampled at the Yoongarillup site are shown in Figure 3.1.

The depth of drilling varied from 9– 30 m (average hole depth 21 m), and all drillholes extended at least 2 m below the base of the proposed minepit. Given these depths and the nature of the sediments (i.e. heavy clay), drilling was conducted using a Reverse-circulation (RC) drill rig (Plate 3.1), which is the same as is used during mineral exploration drilling. This type of drill rig uses air to push the sample up the drill rod and out of the cyclone, with water commonly used to aid recovery of sample particularly in heavy, stiff clays. No oxidation of samples, in response to the use of air or water, has been observed to date during sample collection, even in highly reactive ASS samples (SWC, 2006). It is therefore considered that this drilling technique was suitable for ASS identification in at this site.

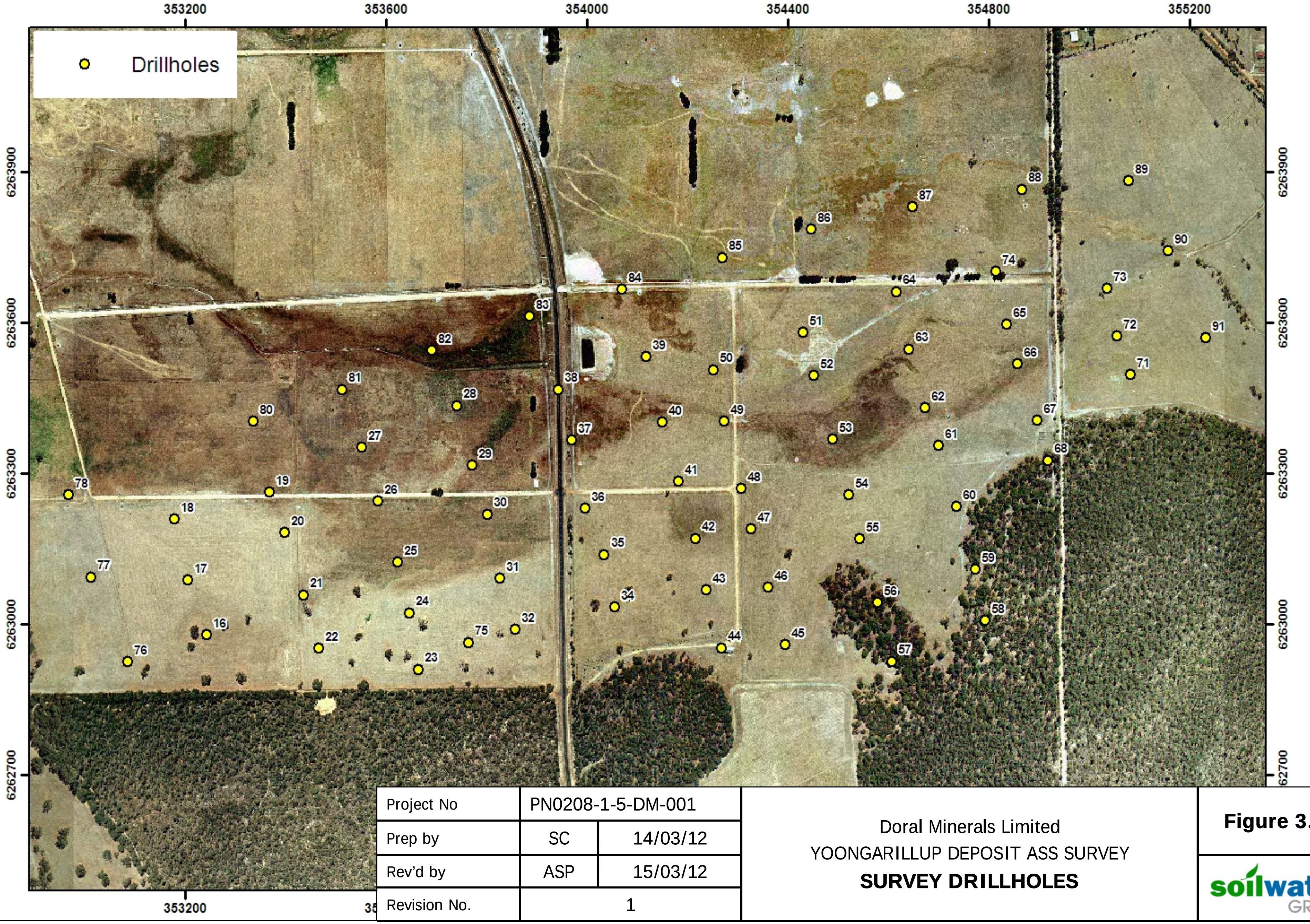
Soil samples were collected at 1 m vertical intervals over the entire drillhole length. In areas where black soils were encountered the sampling frequency was doubled (i.e. 2 per metre). This procedure was put in place as it was expected from previous studies conducted in soils of the Swan Coastal Plain (SWC, 2007; SWC, 2008) that the majority of PASS would be present in specific morphological soil types (i.e. black soils). Although this differs from the 0.25 m vertical intervals specified by the DEC (Table 3.1), it was identified as an appropriate sampling interval to accurately identify and delineate any ASS present in this area given the depths to which sampling occurred (i.e. 30 m) and the geological and soil distribution in the Disturbance Area. Based on this sampling interval and the depths drilled, a total of 1,445 samples were collected across the Disturbance Area. Samples were collected at the cyclone outlet in sealable plastic containers. To minimise potential oxidation of samples during storage air was excluded from the plastic containers where possible before sealing.

If water was used during sample recovery, then this was retained with the sample. Collection of this water was required to ensure that there is no loss of soluble acidity if AASS were present. In AASS there is a risk that any water used in the drilling process may remove the soluble acidity that is present in such soils, and if this water is lost during sample collection then an underestimation of the actual acidity may result. Research has been conducted to examine if there is significant removal of soluble acidity into the water fraction during sample collection and storage (SWC, 2005). To date, negligible transfer of soluble acidity into the water fraction has been observed, however it is still recommended that all water used during sample collection is retained with the sample and routine checks made to examine the pH and electrical conductivity (EC) of the water fraction in addition to the soil. At each sampling interval, the drill rod and cyclone was flushed clean with water to ensure no contamination of the soils between consecutive samples. This is required as trace amounts of sulfidic material remaining in the drilling equipment from previous sampling may contaminate a sample that has no sulfides present, resulting in a false positive test.

The amount of sample collected at each sampling interval varied from 0.5 to 1 kg. Collection of this amount ensured that sufficient sample was obtained for detailed chemical and physical analysis in the laboratory. Collected soil samples for each drillhole were placed into well-labelled nylon bags and placed immediately into a generator-powered field freezer located on the back of the sample vehicle (Plate 3.2). At the end of each day of drilling, the samples were transferred from the field freezer to a mobile cool room, set at –1°C for short-term storage. Stored samples were transported back to the laboratory within 24 – 48 hours of collection for field pH testing (Section 3.2).

Plate: 3.1: Collection of ASS samples using a Reverse Circulation (RC) drill rig.

Plate: 3.2: Storage of samples in field freezer.



Project No	PN0208-1-5-DM-001	
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YOONGARILLUP DEPOSIT ASS SURVEY

SURVEY DRILLHOLES

Figure 3.1

soilwater GROUP

3.2 SCREEN RESULTS

pH_F & pH_{FOX} Results

A total of 1,445 samples from 72 drillholes were analysed for pH_F and pH_{FOX}. The down drillhole profiles are shown in Appendix A whilst the distribution of pH_F and pH_{FOX} for all samples is shown in Figure 3.2.

The pH_F results for all samples tested varied from 8.20 (slightly alkaline) to 4.29 (moderately acidic) with an average of 5.62. The large majority of samples tested (85%) had pH values between 5 and 7 which is typical of surficial soils on the Swan Coastal Plain (McArthur, 1991), and reflects their poor buffering capacity and the natural equilibrium which exists between the soil particle surface and the surrounding soil solution (i.e. adsorption/desorption ratios and surface hydrolysis reactions (Hsu, 1989). Approximately 5% of samples had a pH value between 4 and 5 which indicates that previous oxidation has possibly occurred within these soils (DEC, 2009). No samples tested had a $pH_F < 4$, indicating that AASS (i.e. previously oxidised soils with high actual acidity *in situ*) are unlikely to occur within the Yoongarillup deposit.

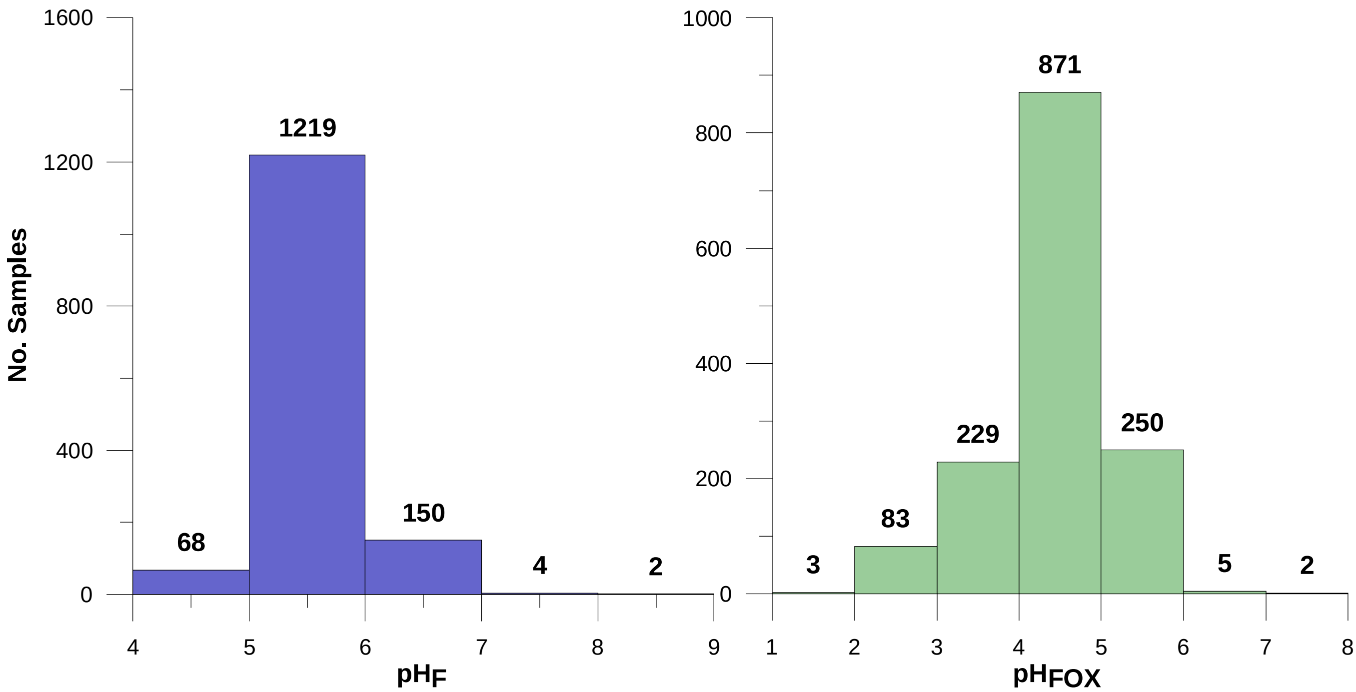
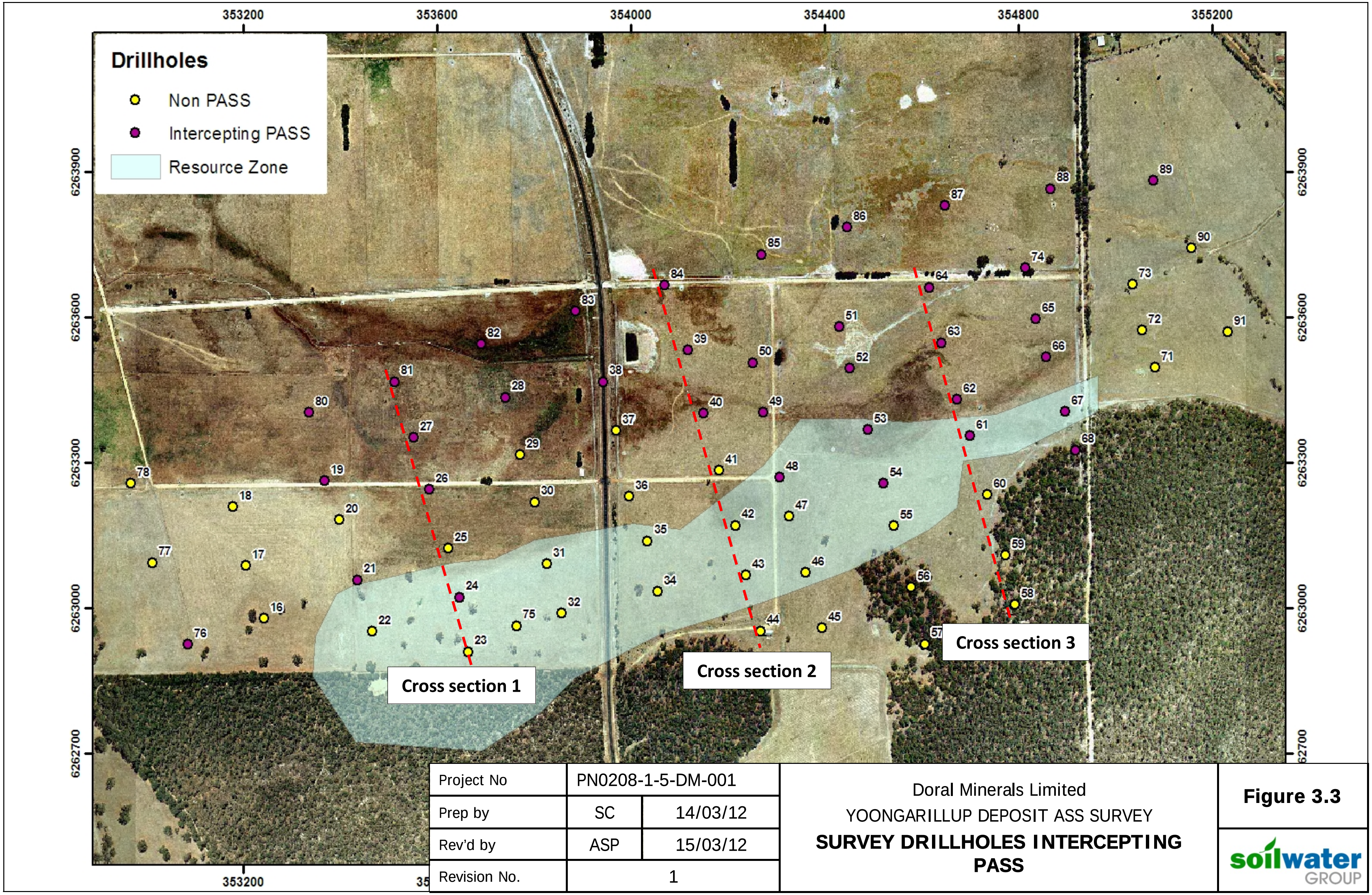


Figure 3.2: Distribution of pH_F and pH_{FOX} results.

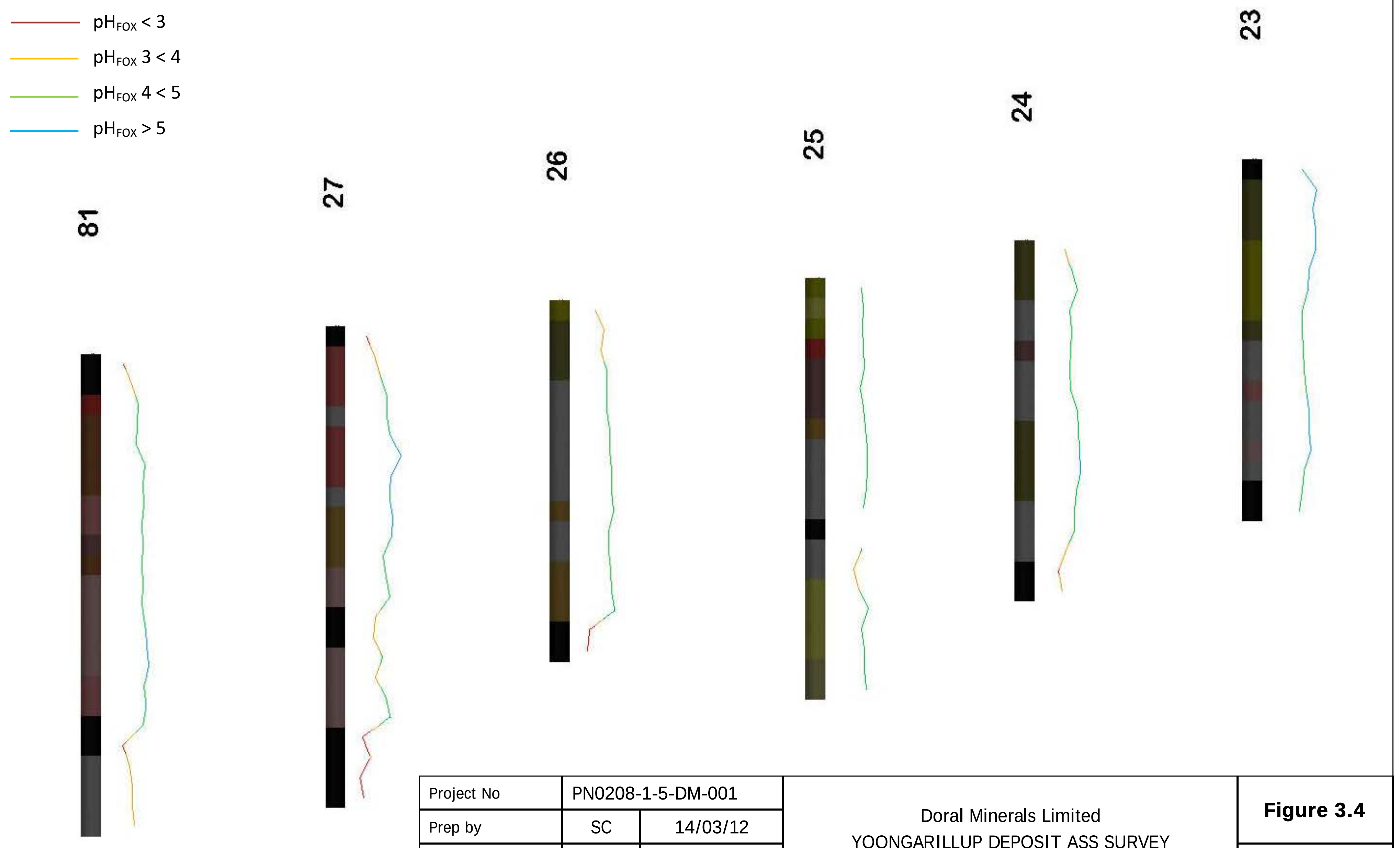
The pH_{FOX} values for all soils analysed varied from 7.79 to 1.99. Approximately 20% of the soils tested had pH_{FOX} values less than 4, indicating that potentially acid sulfate soils (PASS) are likely to be present. Of these low pH_{FOX} samples, 27% (or 6% of total samples tested) had pH_{FOX} values < 3, indicating that a portion of the soils are likely to contain significant PASS.

A review of the drillhole profiles (Appendix A) shows that the majority of these low pH_{FOX} values occur within a defined zone within the soil profile rather than being spread evenly throughout the deposit. Figure 3.3 shows an overview of the drilling program conducted, with drillholes intercepting PASS materials (pH_{FOX} < 4) highlighted purple. It can be seen that the PASS material encountered is concentrated in the northern drillholes surveyed. Cross sections of the drilling data were created using SURPAC and these are presented in Figure 3.4. To illustrate the relationship between the deposit materials and the observed low pH_{FOX} values, the drillhole trace shows the logged colour of the material whilst the line graph shows the pH_{FOX} values recorded for each sample taken. The cross sections show that those areas which experience significant drops in pH upon oxidation (i.e. where the pH_{FOX} drops below 4, orange and 3 red) is uniformly concentrated within the dark coloured (grey to black) sandy clay materials encountered below the well sorted sand layer containing the majority of the heavy minerals concentrations (i.e. the ore). Some areas at the top of the drillhole traces also experience drops, however these drops can be attributed to organic material present in the top portion of the soil profile and not inorganic sulfide.

The cross sections also show that these black clays are encountered predominately on the western side of the surveyed area at the termination of the drillholes whilst matching up with the low pH_{FOX} values obtained from the laboratory screen testing. It is therefore considered that the potential for acid generation within the proposed Yoongarillup deposit will likely be confined to these soil materials (i.e. dark grey to black clays) which are encountered below the defined ore zone. As part of the ongoing ASS investigation the distribution of these greyish - black clay materials should be carefully defined and their spatial variability delineated as a precursor to establishing a management plan.

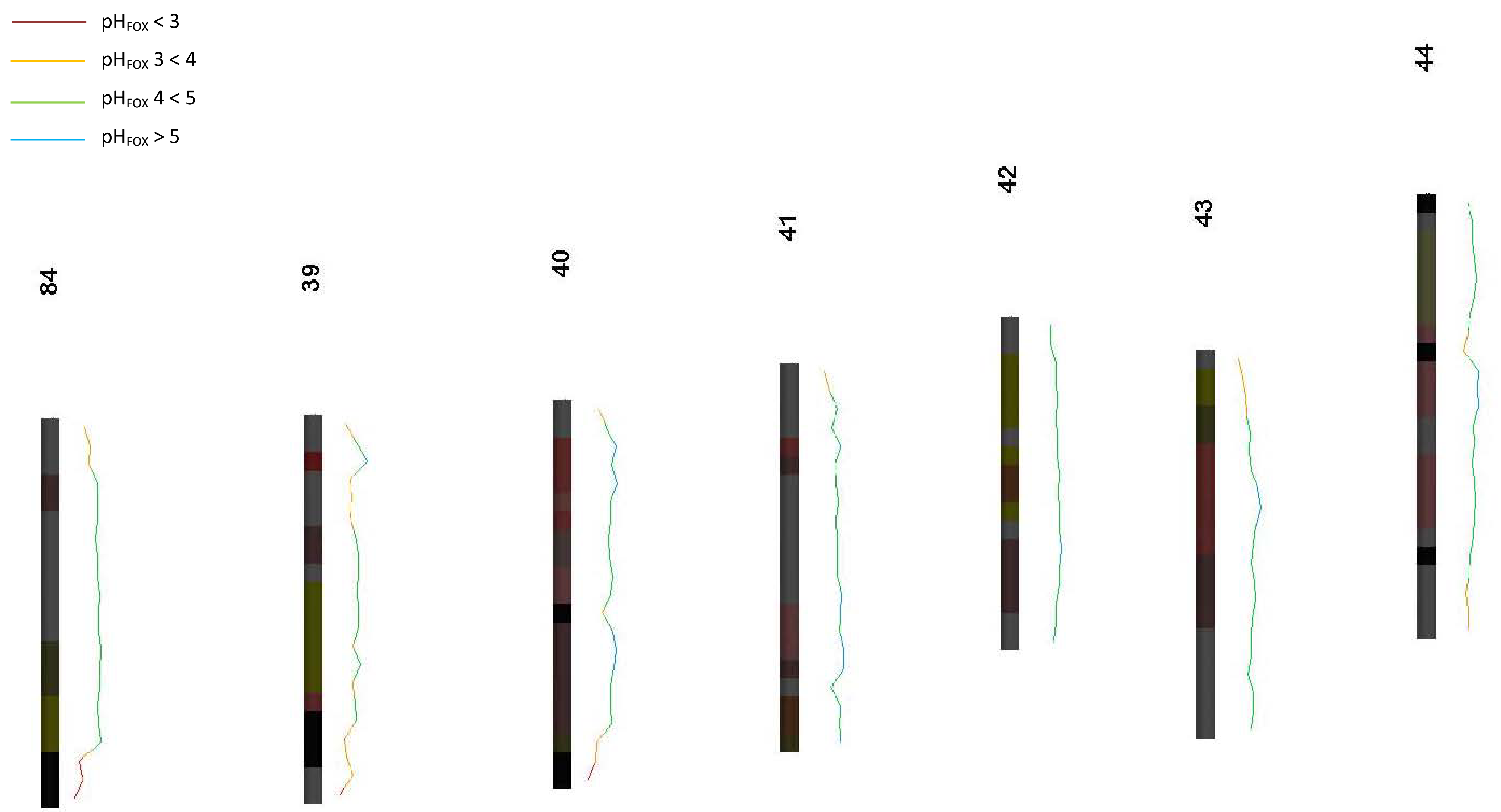


Project No	PN0208-1-5-DM-001		Doral Minerals Limited YOONGARILLUP DEPOSIT ASS SURVEY **SURVEY DRILLHOLES INTERCEPTING PASS**	**Figure 3.3**
Prep by	SC	14/03/12		soilwater GROUP
Rev'd by	ASP	15/03/12		
Revision No.	1			



Project No	PN0208-1-5-DM-001		Doral Minerals Limited YOONGARILLUP DEPOSIT ASS SURVEY **CROSS SECTION ONE**
Prep by	SC	14/03/12	
Rev'd by	ASP	15/03/12	
Revision No.	1		

Figure 3.4

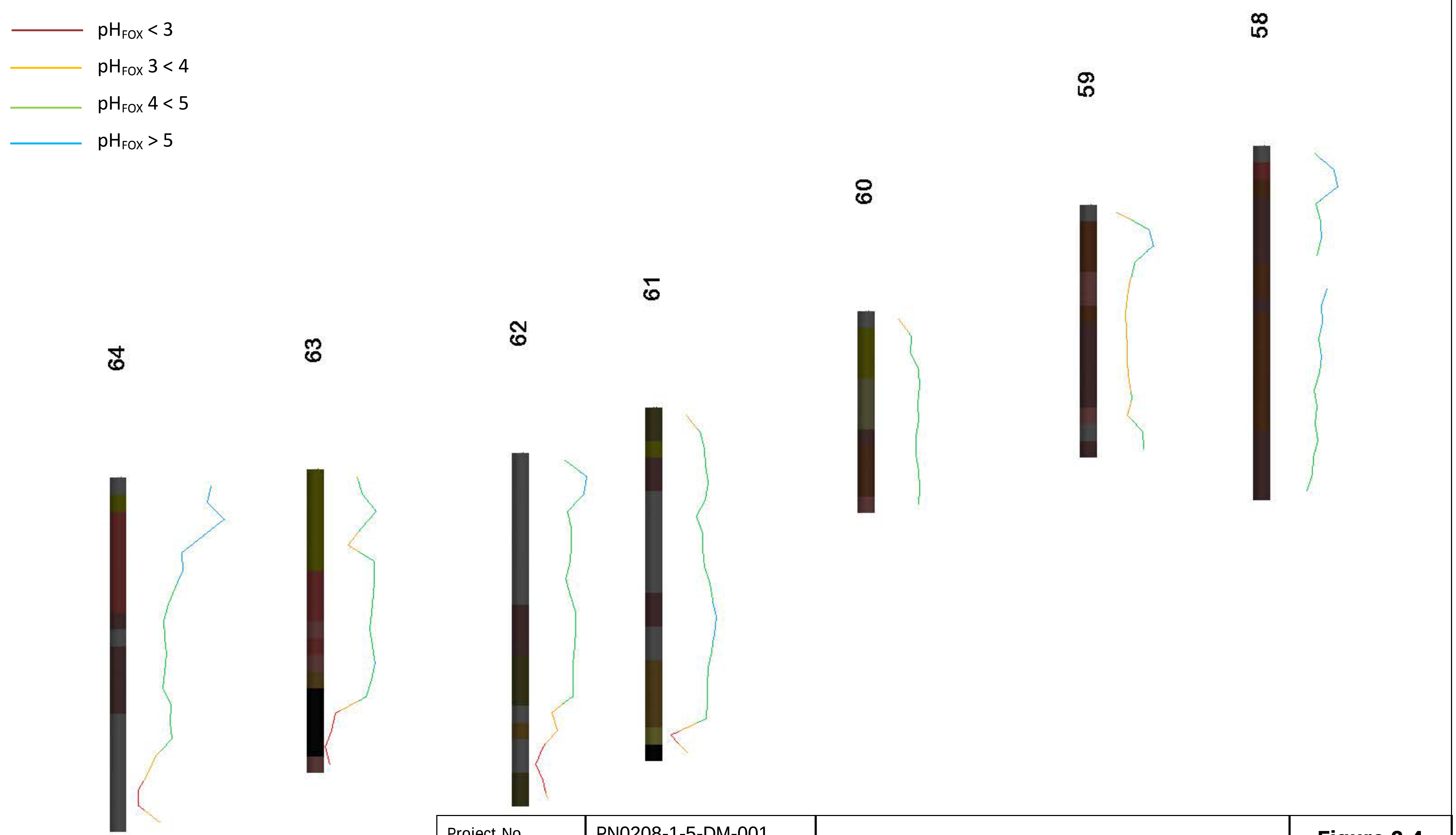


Project No	PN0208-1-5-DM-001	
Prep by	SC	14/03/12
Rev'd by	ASP	15/03/12
Revision No.	1	

Doral Minerals Limited
YOONGARILLUP DEPOSIT ASS SURVEY
CROSS SECTION TWO

Figure 3.4 cont...

soilwater GROUP



Project No	PN0208-1-5-DM-001	
Prep by	SC	14/03/12
Rev'd by	ASP	15/03/12
Revision No.	1	

Doral Minerals Limited

YOONGARILLUP DEPOSIT ASS SURVEY

CROSS SECTION THREE

Figure 3.4 cont…

soilwater GROUP

4. DETAILED TESTWORK ASSESSMENT

The next step in the ASS investigation involves estimating source strengths of potential contaminants. In order to do this a range of samples from different material types were selected for detailed laboratory testing, to both confirm the results from the screen level assessment, and provide accurate estimates of source strength for potential contamination should oxidation and subsequent acid generation occur.

This further investigation included determining the acidity already present with the sediments, determining the pyritic sulfur content within the sediments through chromium reducible sulfur (S_{CR}) testing, and testing sediments to determine the potential for hydrolysis and metals release if acid generation occurs.

Laboratory analysis of selected soil samples included:

- Total Actual Acidity (TAA) on selected samples including any samples with a $pH_F < 4.0$
- Chromium Reducible Sulfur (S_{CR}) analysis on selected samples
- Leaching of non-pyritic soils (S_{CR} < 0.03 %) and pyritic (S_{CR} > 0.03 %) to determine potential hydrolysis and metals release characteristics of selected samples

In this investigation S_{CR} analysis was conducted on selected samples to quantify the amount of potential acidity present (i.e. PASS). The decision to use S_{CR} analysis is based upon the recommendation from the DEC (DEC, 2009). At the time of the field studies and laboratory analysis the DEC considered that S_{CR} analysis provided a better measure of potential acidity (i.e. from iron sulphide sources), than the Suspension Peroxide Oxidation Combined Acidity and Sulfate (SPOCAS) technique, which relies on hydrogen peroxide (H_2O_2) to oxidise all acidity sources. This technique is strongly influenced by non-pyritic sources of acidity (i.e. due to the hydrolysis of Fe and Al oxides and hydroxides) and organic matter; hence it overestimates the amount and distribution of pyrite (Sullivan *et al*., 1999).

4.1 TAA ANALYSIS RESULTS

In order to quantify the amount of actual acidity present, a selection of samples (12) were tested for total actual acidity (TAA). All samples tested had a pH_F value < 6 in order to gain an understanding of the existing acidity within samples that may have had sulfide material previously oxidise. The TAA (and corresponding pH_{KCL}[1]) data for these samples is provided in Table 4.1. The DEC have established that the critical acidity content of a soil (either existing and/or potential), for defining an ASS, is 18 mol H^+/tonne (Table 4.2) with those samples exceeding this criteria highlighted in bold (Table 4.1). Using the derived equation for pH_{KCL} (Figure 4.1) and the DEC critical acidity value (18 mol H^+/tonne), the corresponding pH_{KCL} value can be determined that defines an AASS. As the values obtained for pH_{KCL} for any given sample is expected to correspond closely with the pH_F, the critical soil pH value is 4.8.

[1] Note pH_{KCL} is determined during TAA analysis. If the pH_{KCL} of a sample is > 6.5 then it is considered that the soil has no actual or existing acidity and no TAA analysis is required (Ahern *et al*., 2004).

Table 4.1: TAA and associated pH_{KCL} results.

Sample ID	Depth (m)	Soil colour	Soil texture	pH_{KCL}	TAA mole H^+/tonne
18282	3.5	Yellow Grey	Sandy loam	5.8	4
20290	5.5	Grey	Sandy clay	4.9	11
18818	8.5	Light Grey	Sandy clay	4.9	10
20333	9.5	Grey	Clay	4.8	14
18435	10.5	Red Brown	Sandy clay	5.1	6
19828	15.5	Black	Clay	5.4	8
19364	16.5	Black	Sandy clay	5	12
18845	17.5	Black	Sandy clay	4.9	16
19878	17.5	Grey Brown	Sandy clay	5.1	10
DM128	**19.5**	**Black**	**Clay**	**4.5**	**50**
18444	19.5	Dark Grey	Sandy clay	5.3	5
18469	**20.5**	**Black**	**Clay**	**4.8**	**22**

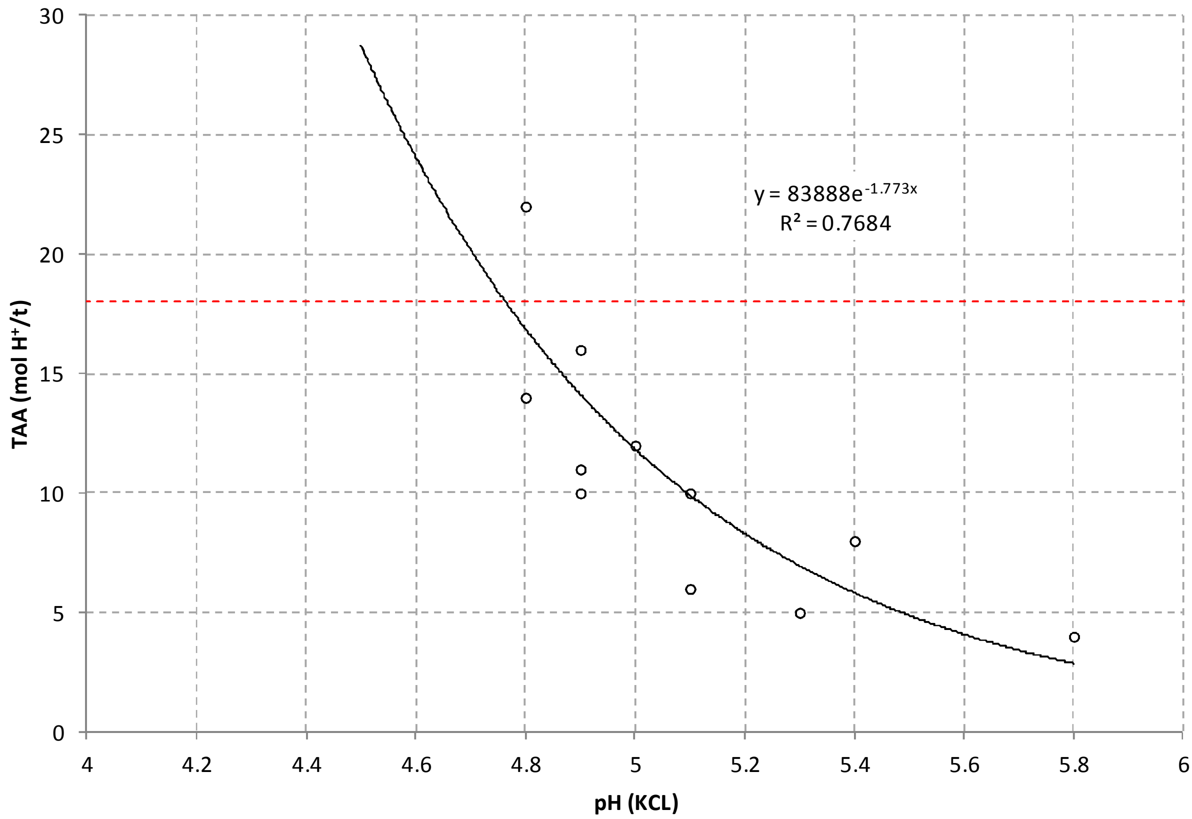


Figure 4.1: Relationship between pH_{KCL} and TAA for samples tested.

It is considered that this soil pH value (pH 4.8) is too high for defining AASS. The majority of soils on the SCP, with the exception of current coastal dunes, have soil pH values between 5 – 7 (McArthur, 1991). Most of the lateritic soils on the Darling and Whicher Scarp have natural soil pH values between 5 – 6, which reflects their old age, dominance of kaolinite clay fraction (i.e. low buffering capacity), and abundance of Fe and Al oxyhydroxides (McArthur and Bettenay, 1974). In addition, most topsoils and subsoils have pH values between 4.5 and 5 due to fertiliser usage, and not previous oxidation of PASS.

A more realistic soil pH for identification of AASS would be 4.5, or for a more definitive assessment of the presence and distribution of AASS, 4 (a pH_F value of < 4 is used as part of the field assessment for AASS, Section 2).

Table 4.2: Action criteria for the identification of ASS (DEC, 2009)

Soil Material		Action criteria < 1000 tonnes ASS disturbed		Action criteria > 1000 tonnes ASS disturbed	
Soil Texture	Approx. clay content (%)	S_{CR} (%S)	TAA (mol H+/tonne)	S_{CR} (%S)	TAA (mol H+/tonne)
Coarse texture (Sands to loamy sands)	< 5	0.03	18	0.03	18
Medium texture (Sandy loams to light clays)	5 – 40	0.06	36	0.03	18
Fine texture (Medium to heavy clays and silty clays)	> 40	0.1	62	0.03	18

4.2 Chromium Reducible Sulfur (S_{CR} %) Content

The S_{CR} content was determined for 12 samples collected in the field. This analysis was undertaken to quantify the actual amount of pyrite (or PASS) present in the soils and to develop a relationship if possible between inorganic sulfides (S_{CR}) and lithology type (i.e. colour and texture). The total S_{CR} results from this investigation are provided in Table 4.3.

Table 4.3: Chromium reducible sulfur results for samples tested.

Sample ID	Depth (m)	Soil colour	Soil texture	S_{CR} (%)
18282	3.5	Yellow Grey	Sandy loam	<0.01
20290	5.5	Grey	Sandy clay	<0.01
18818	8.5	Light Grey	Sandy clay	<0.01
20333	9.5	Grey	Clay	<0.01
18435	10.5	Red Brown	Sandy clay	<0.01
19828	15.5	Black	Clay	0.01
19364	16.5	Black	Sandy clay	<0.01
18845	**17.5**	**Black**	**Sandy clay**	**0.04**
19878	17.5	Grey Brown	Sandy clay	<0.01
DM128	**19.5**	**Black**	**Clay**	**0.04**
18444	19.5	Dark Grey	Sandy clay	0.02
18469	20.5	Black	Clay	<0.01

The S_{CR} results varied from below detection limit (BDL, < 0.01 %) to 0.04 %, with two samples tested being above the 0.03 % cut-off specified by the DEC as an action criteria (DEC, 2009; Table 4.2). Both of the samples which exceeded the 0.03 % cut-off where characterised as black coloured clay and sandy clay materials which were obtained from below the ore layer within the deposit (i.e. below pit boundaries). These results further confirm the initial screen assessment, indicating that the presence of appreciable levels of sulfides (i.e. S_{CR} > 0.03 %) is likely to be confined to the black clay – sandy clay materials which underlie the well sorted sand zone which contains the concentrated mineral sands ore.

4.3 MULTI-ELEMENT COMPOSITION

Element enrichment was determined using the Geochemical Abundance Index (GAI), through Equation 4.1:

$$GAI = \log_2\left(\frac{C}{1.5 * ACA}\right), \qquad \text{Eqn. 4.1}$$

with *C*= element content in sample (mg/kg) and *ACA*= average crustal abundance (Bowen, 1979). A GAI of 0 indicates that the content of the element is less than, or similar to, the average crustal abundance, a GAI of 3 corresponds to a 12-fold enrichment above the average crustal abundance, and a GAI of 6 indicates a 96-fold or greater enrichment above average crustal abundances. In general, a GAI >3 indicates significant enrichment. Elemental compositions were compared against the Department of Environment and Conservation (DEC) Ecological Investigation Levels (EIL; DEC, 2010) to identify metals and metalloids that may, if present, pose a risk to the surrounding environment or to environmental values as a result of non-acid metaliferous drainage. The EIL used by the DEC are based primarily on the Environmental Investigation Levels listed in the Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (ANZECC/NHMRC, 1992). They represent only screening levels, in which to provide a first-pass or a Tier 1 level of assessment for a site. It is important to note that these levels do not specifically apply to mineralised zones whereby elevated metal and metalloid contents often exceed the EIL criteria in a natural functioning ecosystem. Site specific information should therefore be used in conjunction with the EIL to assess the appropriateness of these criteria values. Therefore the values of the EIL are compared to the ACA values to provide a context within which to interpret them.

The multi-element composition of the selected materials tested in this investigation is provided in Table 4.4, whilst their corresponding enrichment, compared to average global crustal abundances, is provided in Table 4.5. Values which exceed the corresponding EIL (Table 4.4) or are above a GAI of 3 (Table 4.5) are shown in bold. The results show that only one sample (DM128) returned a level of vanadium which exceeds the Department of Environment and Conservation (DEC) Ecological Investigation Level (DEC, 2010). When this elevated level of vanadium is compared against the average crustal abundance (160 mg/kg), this sample is not considered geochemically enriched with respect to background levels, returning a GAI of 0 (i.e. less than, or similar to, average crustal abundance; Table 4.5).

The results of the GAI calculation show that elevated element contents occur in only one sample. The elevated content is of mercury which occurs in sample 18435, with significant enrichment (i.e. GAI 4) recorded. However, when compared to the associated EIL, which for mercury is 1 mg/kg it can be seen that the level does not exceed this, and indeed is significantly lower than this (< one third) for all other samples tested.

Table 4.4: Multi-element composition for samples tested.

Element	LOR (mg/kg)	EIL (mg/kg)	DM128	18444	18845	19364	19878	18818	18435	20290	18469	19828	20333	18282
Ag	*0.05*	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05
Al	*10*	-	24500	4830	10000	5390	6300	7130	4820	12900	4230	6590	15600	27300
As	*0.2*	20	1.6	1.7	1	8.5	1.4	2.8	12	<0.2	1.3	0.8	0.3	1.1
B	*5*	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ba	*0.1*	300	110	34	89	12	21	43	16	3.4	190	11	15	7.9
Cd	*0.05*	3	0.08	0.23	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Co	*0.1*	50	20	13	10	2.9	5	5.2	7.1	7	43	4.5	1.9	9.4
Cr	*0.05*	400	88	14	23	26	16	7.4	36	21	23	19	23	48
Cu	*0.1*	100	38	8.6	12	5	7.8	5.6	1.2	1.1	28	9.5	0.8	<0.1
Fe	*5*	-	40000	13000	35000	15000	21000	6600	19000	2400	21000	72000	2200	32000
Hg	*0.02*	1	0.04	0.27	0.06	0.05	0.05	0.22	1	0.15	0.03	0.06	<0.02	0.12
Mn	*0.2*	500	120	14	28	12	11	2.6	1.9	2.4	27	18	6	6
Mo	*0.5*	40	0.5	0.7	0.6	3.1	0.6	<0.5	3.9	<0.5	0.9	0.7	<0.5	1
Ni	*1*	60	30	14	10	1	1	<1	<1	3	53	1	3	7
Pb	*0.5*	600	19	10	8.2	12	15	7.6	5.8	5.9	12	16	16	14
Sb	*0.05*	-	<0.05	<0.05	<0.05	0.32	<0.05	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	<0.05
Se	*0.05*	-	0.29	0.28	0.14	0.25	0.16	0.06	0.32	<0.05	0.17	0.13	<0.05	0.15
Sn	*0.5*	50	1.1	<0.5	1.1	<0.5	0.8	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5
Sr	*0.2*	-	20	4.9	8.7	3.2	4.8	9.4	5.2	1.7	6.2	2.2	8	3.8
Th	*0.05*	-	23	8.7	19	11	16	7.1	5.4	11	17	15	16	17
U	*0.01*	-	1.1	1.3	1.2	2.3	1.2	1.9	2.3	0.33	1.6	1.3	0.43	1.8
V	*0.2*	50	**170**	26	40	36	30	15	36	6.2	37	34	44	50
Zn	*5*	200	76	6.9	51	4.3	8.1	1.4	2.5	1.2	5.8	22	1.9	1.1

Table 4.5: Global abundance index for multi-element content.

Element	ACA (mg/kg)	DM128	18444	18845	19364	19878	18818	18435	20290	18469	19828	20333	18282
Ag	*0.07*	0	0	0	0	0	0	0	0	0	0	0	0
Al	*8.2 %*	0	0	0	0	0	0	0	0	0	0	0	0
As	*1.5*	0	0	0	2	0	0	2	0	0	0	0	0
B	*10*	0	0	0	0	0	0	0	0	0	0	0	0
Ba	*500*	0	0	0	0	0	0	0	0	0	0	0	0
Cd	*0.11*	0	0	0	0	0	0	0	0	0	0	0	0
Co	*20*	0	0	0	0	0	0	0	0	1	0	0	0
Cr	*100*	0	0	0	0	0	0	0	0	0	0	0	0
Cu	*50*	0	0	0	0	0	0	0	0	0	0	0	0
Fe	*4.1 %*	0	0	0	0	0	0	0	0	0	0	0	0
Hg	*0.05*	0	2	0	0	0	2	**4**	1	0	0	0	1
Mn	*950*	0	0	0	0	0	0	0	0	0	0	0	0
Mo	*1.5*	0	0	0	0	0	0	1	0	0	0	0	0
Ni	*80*	0	0	0	0	0	0	0	0	0	0	0	0
Pb	*14*	0	0	0	0	0	0	0	0	0	0	0	0
Sb	*0.2*	0	0	0	0	0	0	0	0	0	0	0	0
Se	*0.05*	2	2	1	2	1	0	2	0	1	1	0	1
Sn	*2.2*	0	0	0	0	0	0	0	0	0	0	0	0
Sr	*370*	0	0	0	0	0	0	0	0	0	0	0	0
Th	*12*	0	0	0	0	0	0	0	0	0	0	0	0
U	*2.4*	0	0	0	0	0	0	0	0	0	0	0	0
V	*160*	0	0	0	0	0	0	0	0	0	0	0	0
Zn	*75*	0	0	0	0	0	0	0	0	0	0	0	0

4.4 METAL BIOAVAILABILITY

Metal bioavailability was carried out on four of the samples which underwent multi-element composition testing to investigate to what extent metals were available to leaching in solution. The Australian Standard Leaching Procedure (ASLP) was used, with the results of the ASLP presented in Table 4.6.

Table 4.6: Bioavailability of metals under neutral leachate conditions.

	18469		19828		20333		18282	
Element	Solid phase (mg/kg)	% leached	Solid phase (mg/kg)	% leached	Solid phase (mg/kg)	% leached	Solid phase (mg/kg)	% leached
Ag	<0.05	-	<0.05	-	<0.05	-	0.05	-
Al	4230	0.3	6590	0.2	15600	0.1	27300	0.1
As	1.3	6.2	0.8	10.0	0.3	6.7	1.1	-
B	<5	-	<5	-	<5	-	<5	-
Ba	190	8.3	11	34.5	15	16.0	7.9	27.8
Cd	<0.05	-	<0.05	-	<0.05	-	<0.05	-
Co	43	60.5	4.5	27.1	1.9	44.2	9.4	40.4
Cr	23	0.3	19	0.1	23	0.1	48	0.1
Cu	28	5.1	9.5	-	0.8	5.0	<0.1	-
Fe	21000	0.0	72000	0.0	2200	0.1	32000	0.0
Hg	0.03	46.7	0.06	23.3	<0.02	-	0.12	10.0
Mn	27	48.9	18	3.1	6	6.3	6	5.3
Mo	0.9	-	0.7	-	<0.5	-	1	-
Ni	53	60.4	1	-	3	-	7	-
Pb	12	0.3	16	0.6	16	1.6	14	1.6
Sb	<0.05	-	<0.05	-	<0.05	-	<0.05	-
Se	0.17	82.4	0.13	-	<0.05	-	0.15	-
Sn	0.7	-	<0.5	-	<0.5	-	<0.5	-
Sr	6.2	26.8	2.2	35.5	8	15.5	3.8	51.1
Th	17	-	15	-	16	-	17	-
U	1.6	3.5	1.3	1.8	0.43	14.4	1.8	6.1
V	37	-	34	-	44	0.1	**50**	-
Zn	5.8	14.8	22	-	1.9	-	1.1	-

For the majority of elements tested the percentage of the solid phase leached under neutral conditions is typically low with values of < 5 % leached (many elements had no detectable leached percentage, i.e. below detection limit). Leach percentages > 5 % were obtained in one or more samples for the elements of As, Ba, Co, Hg, Mn, Ni, Se, Sr, U and Zn. Although these elevated leaching percentages were reported, the initial very low solid phase element content of these samples across all elements tested (Section 4.3) suggests that no leachate of environmentally significant levels of metals or metalloids is likely to occur, notwithstanding the laboratory derived moderate to low leachate percentages.

It is important to note that the standard bottle leach extraction (i.e. AS4439.3 – 1997) used in this study to quantify the mobility of the various metals and metalloids uses a generous soil/extractant ratio of 1:20. This wide ratio ensures that no common ion effects occur which may act to limit the dissolution, desorption or release of elements into the solution in contact with the solid phase, and minimises the risk of precipitation of released elements in the liquid phase. In both saturated (i.e. aquifer) or unsaturated (vadose zone) soil conditions a significantly lower soil/solution ratio occurs (<< 1:1), which minimises the contact between soil and liquid phases and consequently prevents the dissolution of most soluble salts and restricts the desorption of elements from the mineral surfaces. As a consequence of this, the moderate to low metal and metalloid mobility observed in this investigation, using the standard bottle leach extraction, is likely to represent the worst case scenario, with the predominately clay rich materials likely to have significantly lower metal mobility rates than those reported in the above results (Table 4.6).

Based on the above results and observations the potential for environmentally significant levels of metal or metalloid leachate to develop at this deposit is considered low.

5. CONCLUSIONS & RECOMMENDATIONS

An ASS survey was conducted for the Yoongarillup deposit to determine whether AAAS or PASS are likely to be present within the proposed project area and surrounds. This assessment reviewed the results from previous geological drilling within the Project Area, with the key results from this survey and associated laboratory testing program being:

- The majority of soils sampled (85 %) had *in situ* pH values (pH_F) between the ranges of 5 – 7 (slightly acidic to neutral) which is typical of soils on the Swan Coastal Plain. None of the samples tested had an *in situ* pH < 4 indicating that the presence of AASS within the Cataby project area is unlikely.

- Approximately 20 % of soils tested had pH_{FOX} values < 4, with 27 % of these low pH_{FOX} soils (or 6 % of total samples tested) having pH_{FOX} values < 3. This indicates that PASS are likely to be present within the Yoongarillup Deposit project area. A review of the drilling data shows that these low pH_{FOX} values (PASS) are found within materials outside of the resource reserve, with the majority occurring to the north of the resource or in a sedimentary layer beneath the resource, and therefore are unlikely to be directly disturbed (i.e. excavated) during mining.

- An analysis of screen testing results (pH_F and pH_{FOX}) versus soil colour via the use of 3D geological mapping software (SURPAC) shows that the overwhelming majority of soils which experienced large pH drops following oxidation (i.e. pH_{FOX} < 3) were black or dark grey in colour, and occurred at the base of the drilling conducted (i.e. at or below the base of the proposed mine pit). This result shows that the use of soil colour as a management technique for the field identification of PASS is likely to be effective, and it is recommended that the black clay materials below the ore zone within the Yoongarillup deposit be classified as PASS. A block model can then be generated using geological drilling information; this information can then be used to inform dewatering management plans.

- The majority of soils sampled (10 of 12) had an S_{CR} value below that determined by the DEC as an indicator for PASS (0.03 % S_{CR}). The two samples which returned S_{CR} values > 0.03 % were both black clay to sandy clay samples from the base of the drilling conducted, further confirming that this soil material represents the majority of PASS which can potentially occur within the Yoongarillup Deposit.

- The results of multi-element analysis conducted on 12 representative samples showed no elevated levels of metals or metalloids, with only one sample returning a value above the Ecological Investigation Level for Vanadium. When compared to the average crustal abundance (ACA) for vanadium, this sample was equivalent to back ground levels for this element. No other element levels in any of the 12 samples tested exceeded the corresponding EIL.

- As the majority of identified PASS are not within the resource reserve the potential for direct disturbance is considered to be low. However there is a potential for indirect disturbance with dewatering of the mine pit possibly impacting on PASS in the later stages of mining. In order to understand the potential impacts of dewatering on PASS, a site hydrological model should be developed, along with modelled groundwater draw down curves, to enable a detailed risk assessment to be completed.

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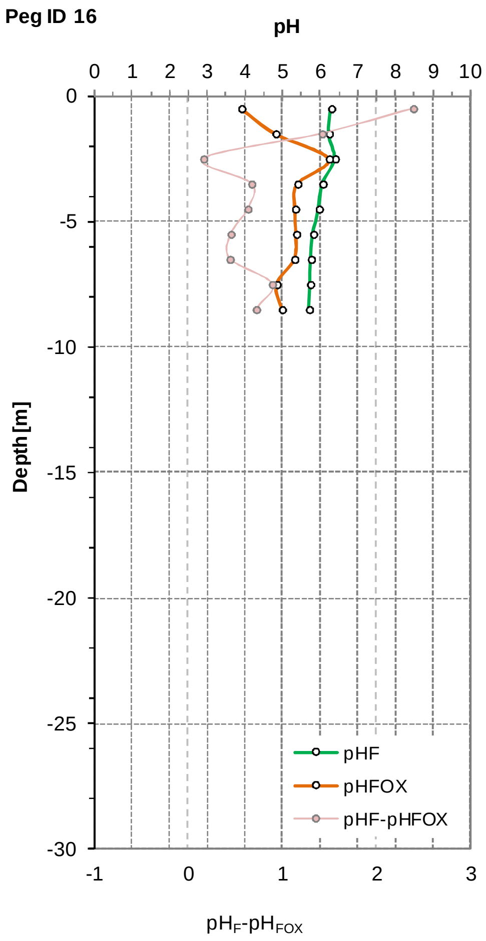

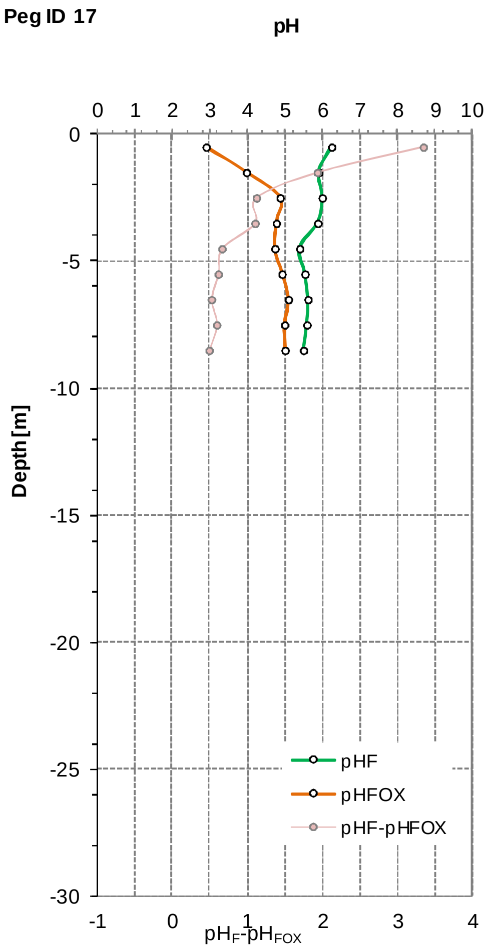

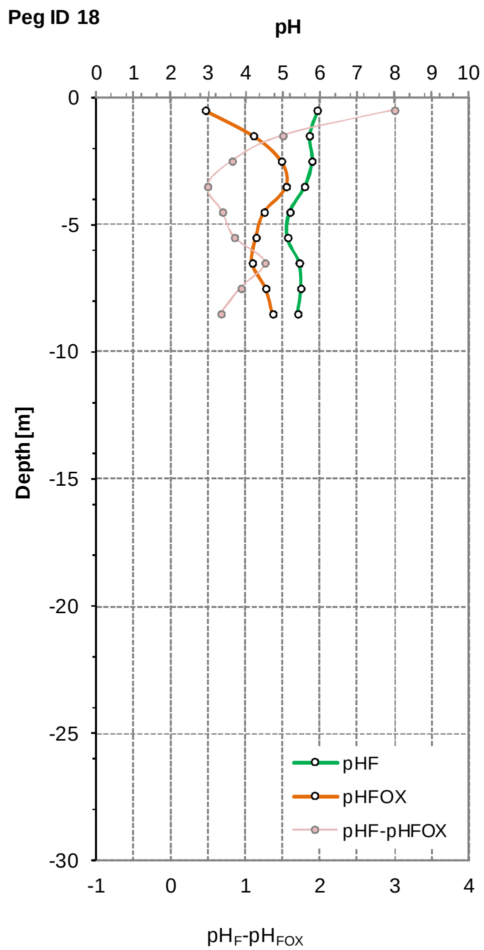

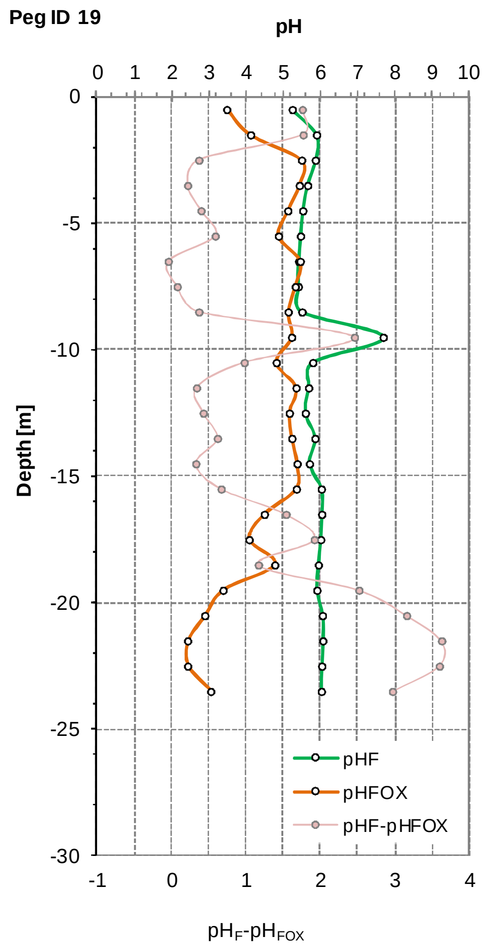

PN	Project No. PN0208		Doral Mineral Sands Pty Ltd YOONGARILLUP DEPOSIT ASS SURVEY **pH + pHfox Graphs**	**Appendix A**
Prep by				soilwater GROUP
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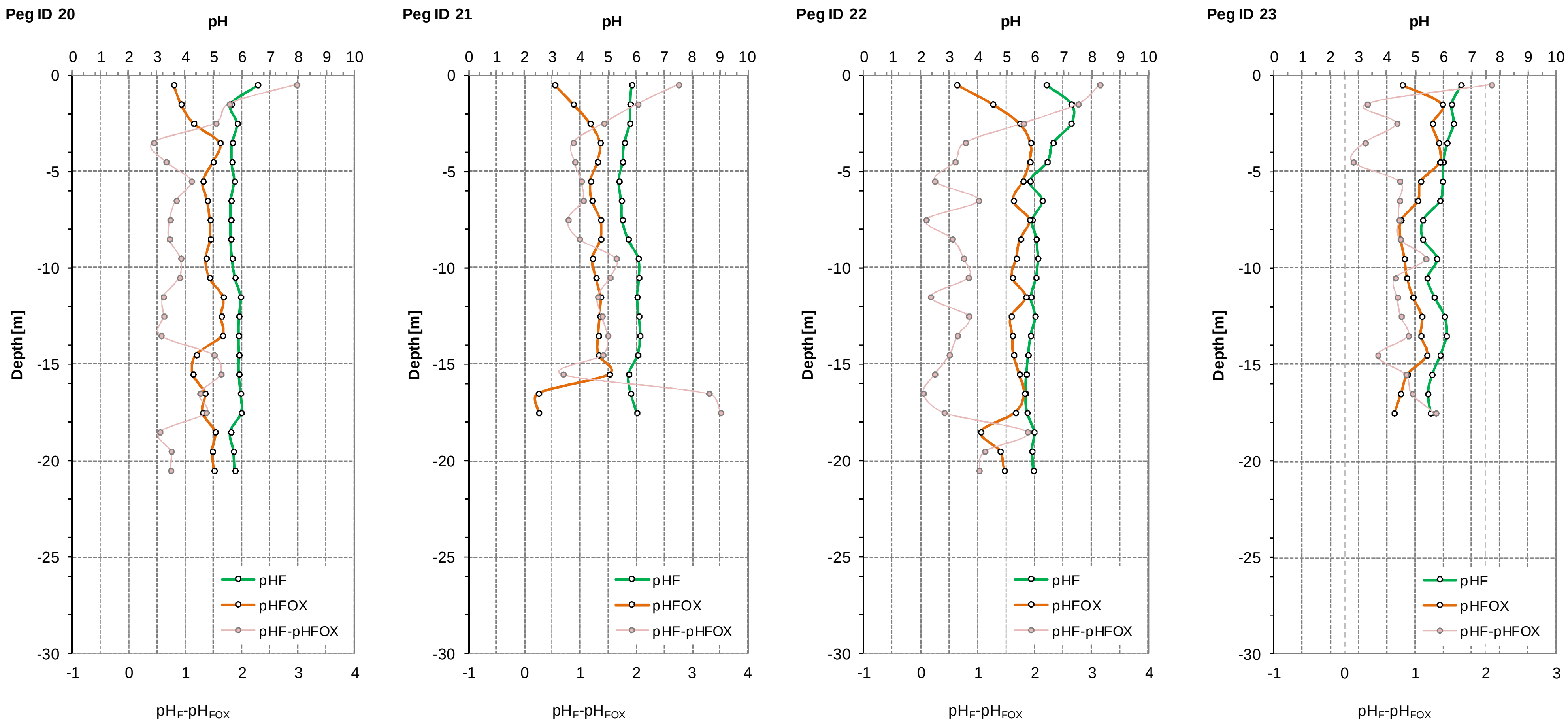
Revision No.	0			



PN	Project No. PN0208		Doral Mineral Sands Pty Ltd YOONGARILLUP DEPOSIT ASS SURVEY **pH + pHfox Graphs**	**Appendix A** *continued…*
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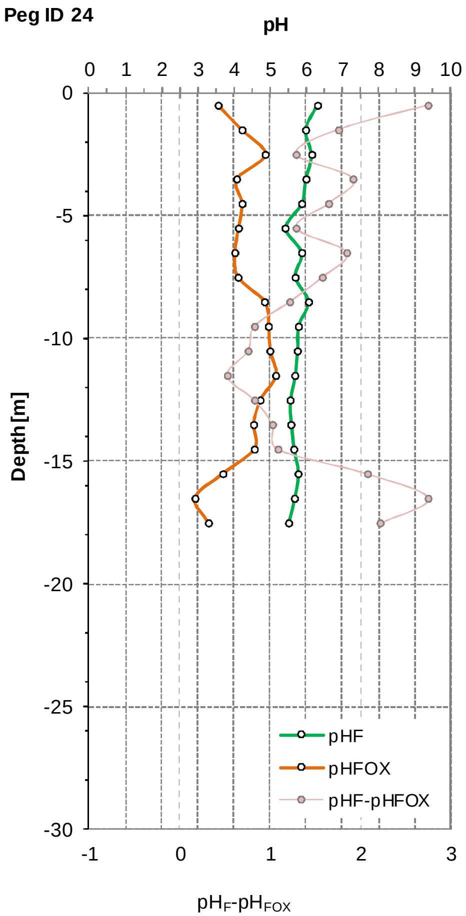

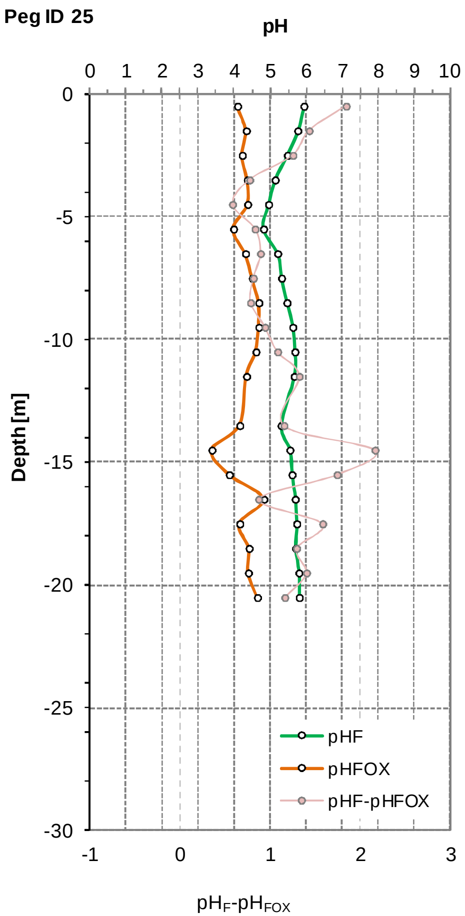

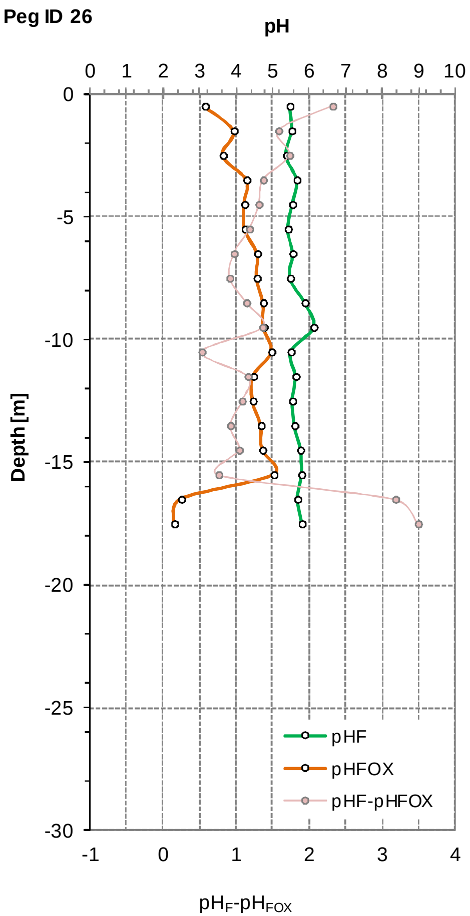

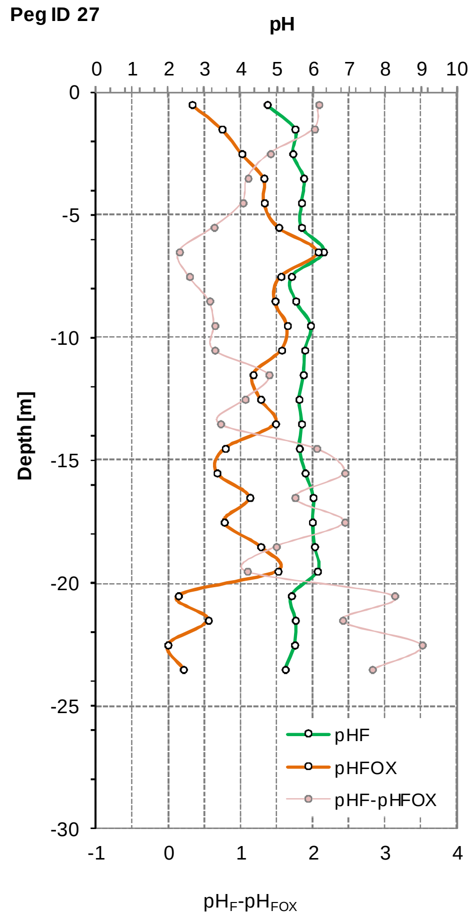

PN	Project No. PN0208		Doral Mineral Sands Pty Ltd YOONGARILLUP DEPOSIT ASS SURVEY **pH + pHfox Graphs**	**Appendix A** *continued…*
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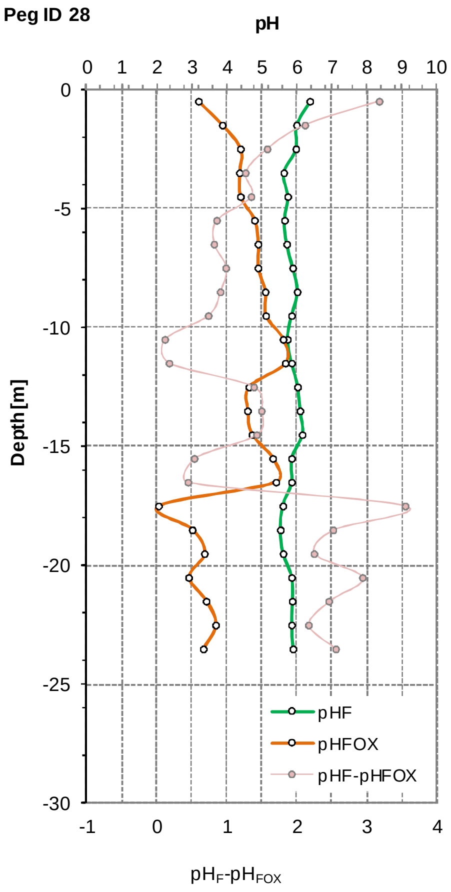

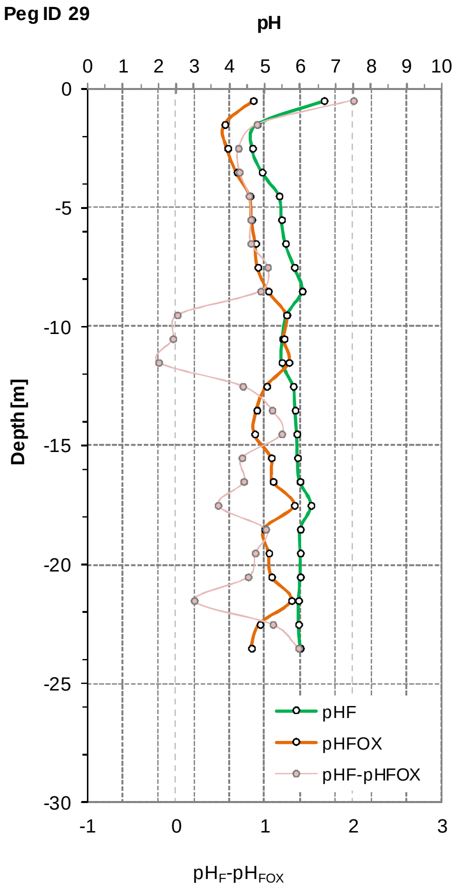

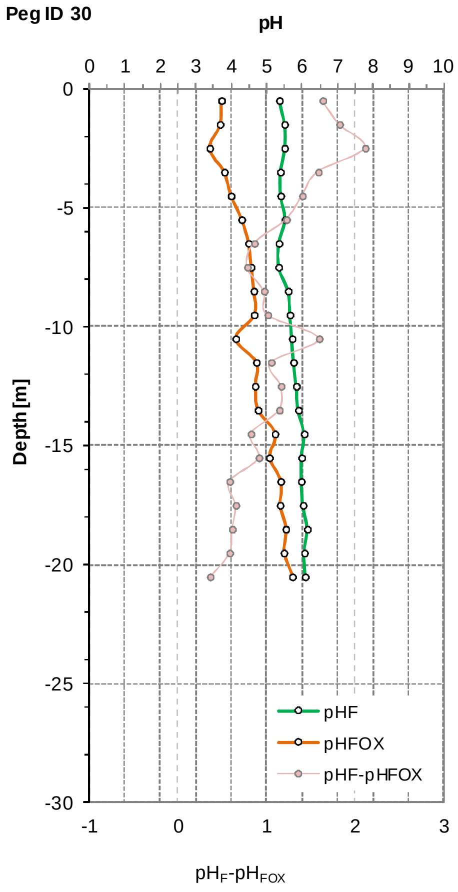

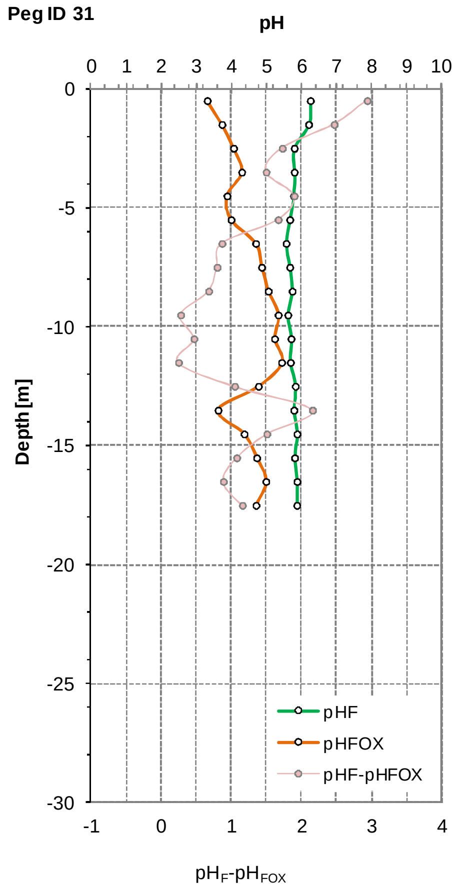

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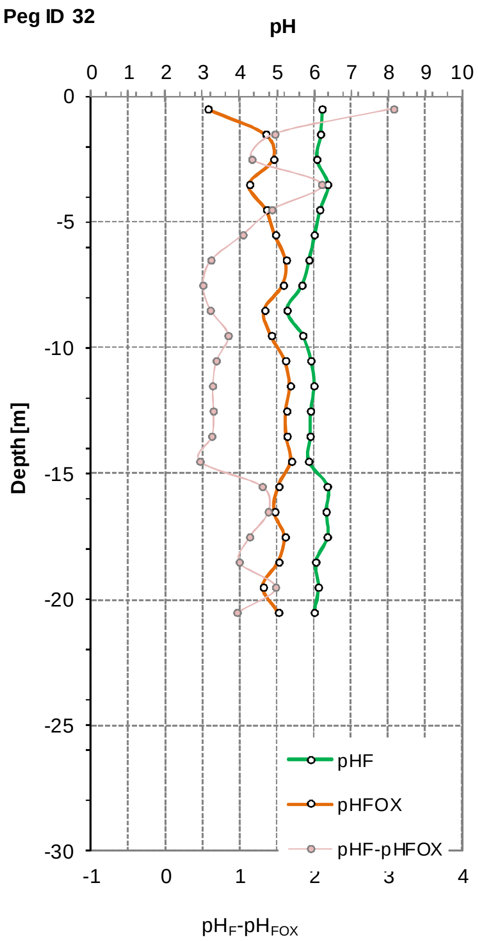

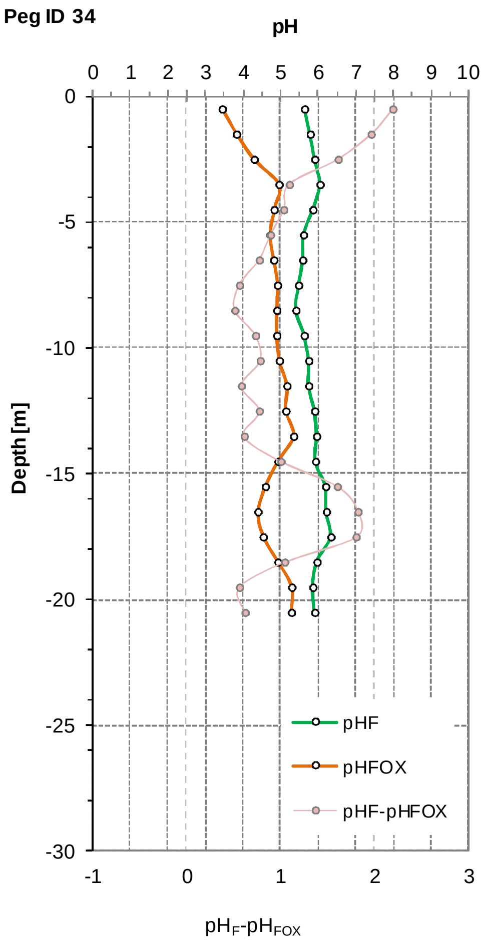

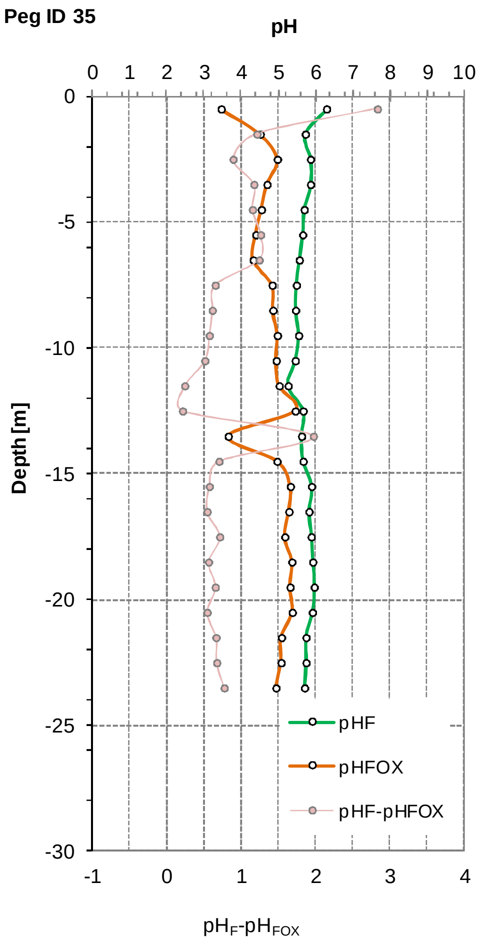

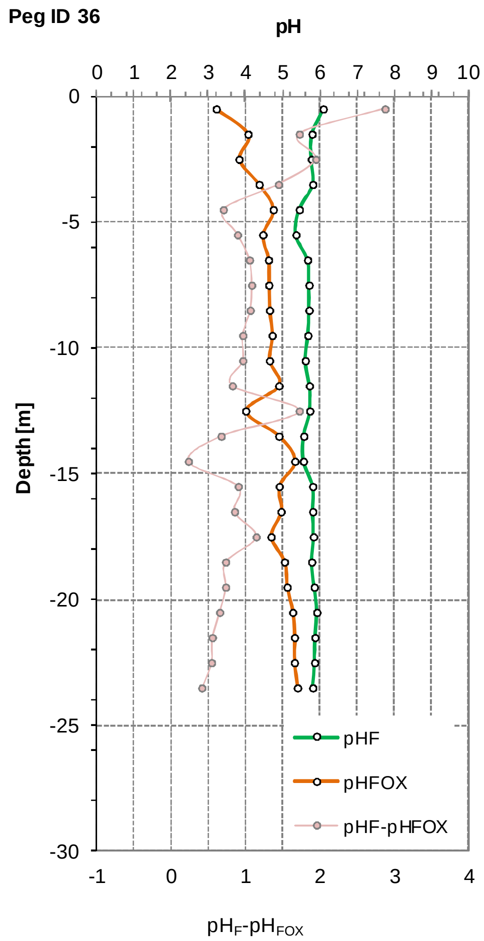

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Prep by				soilwater GROUP
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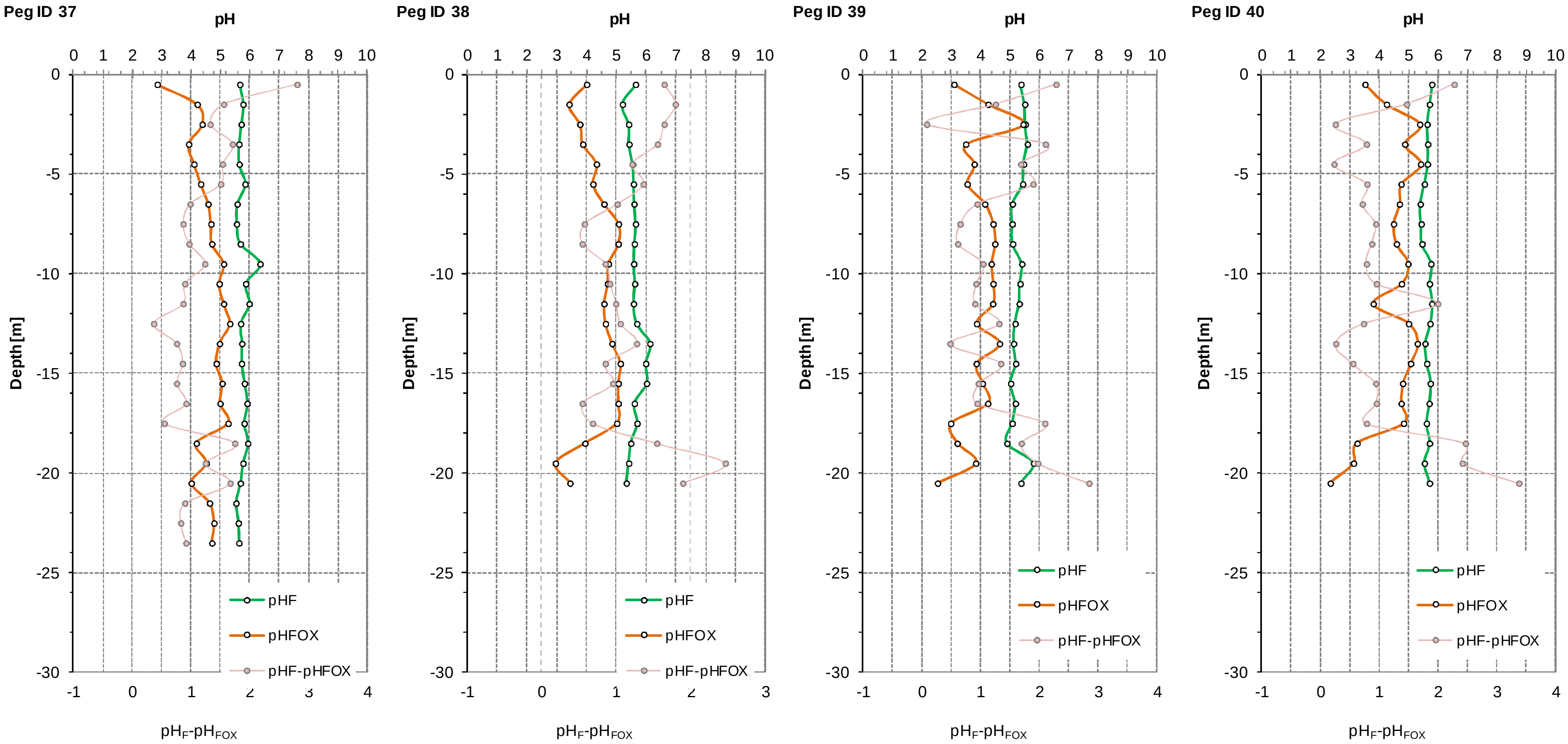

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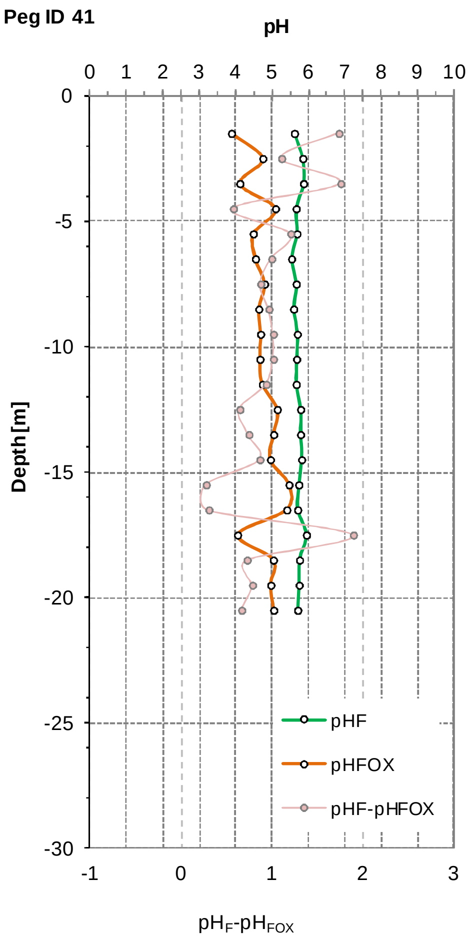

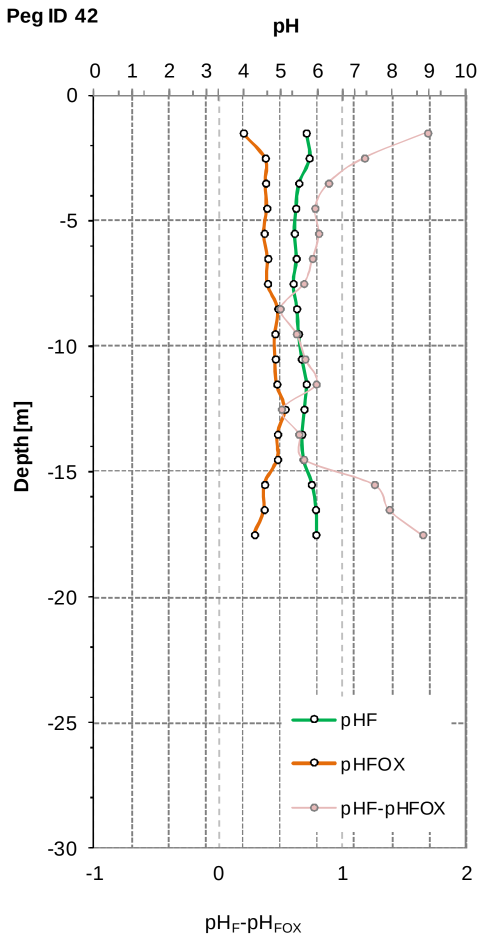

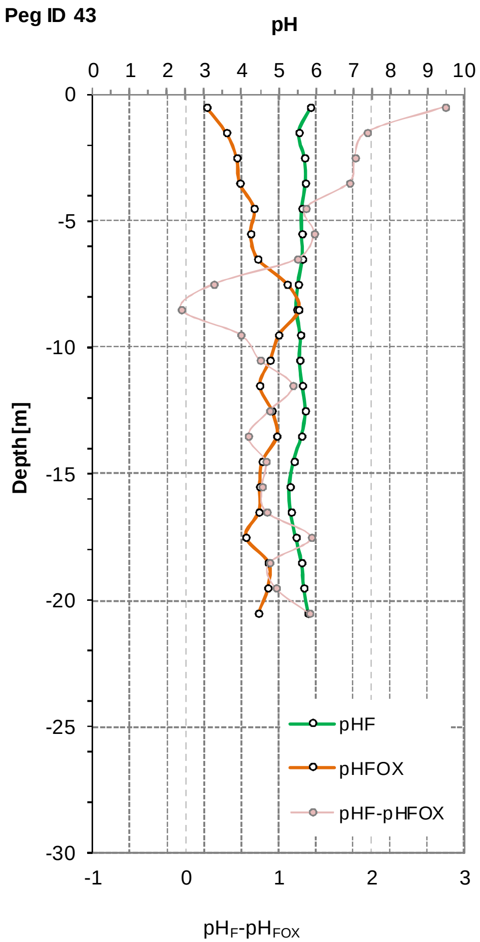

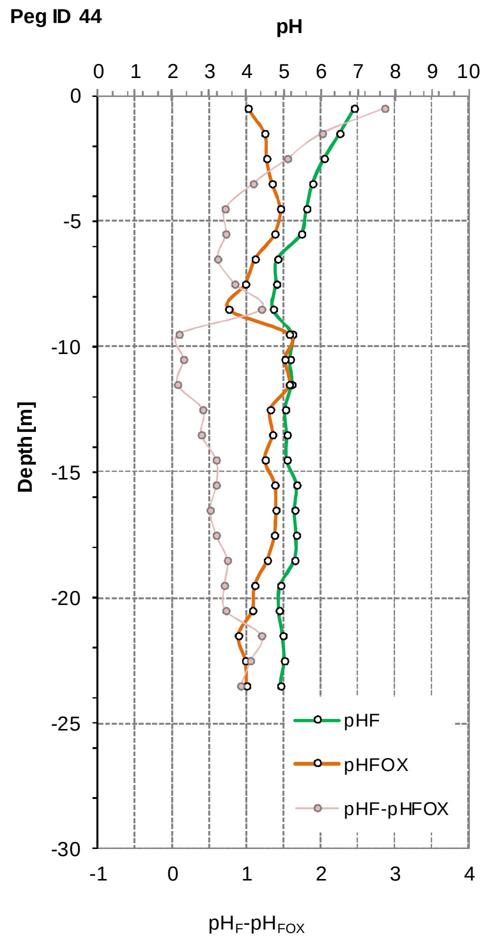

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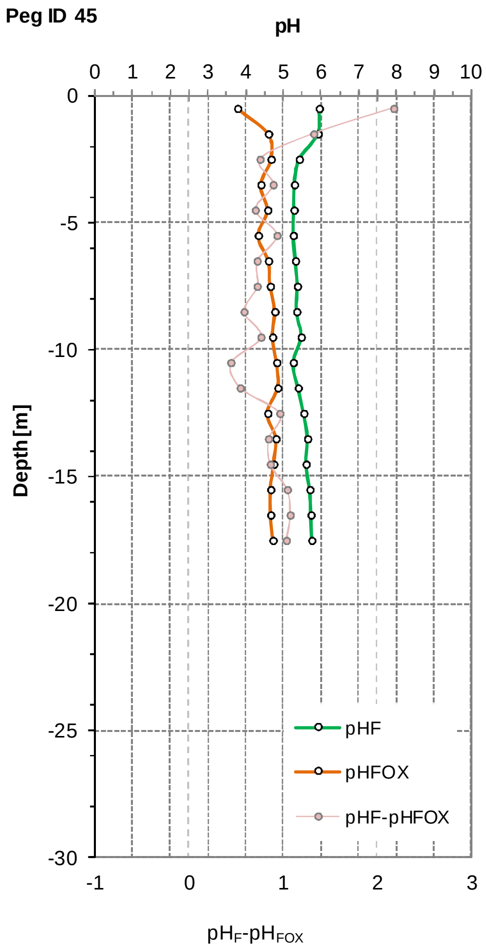

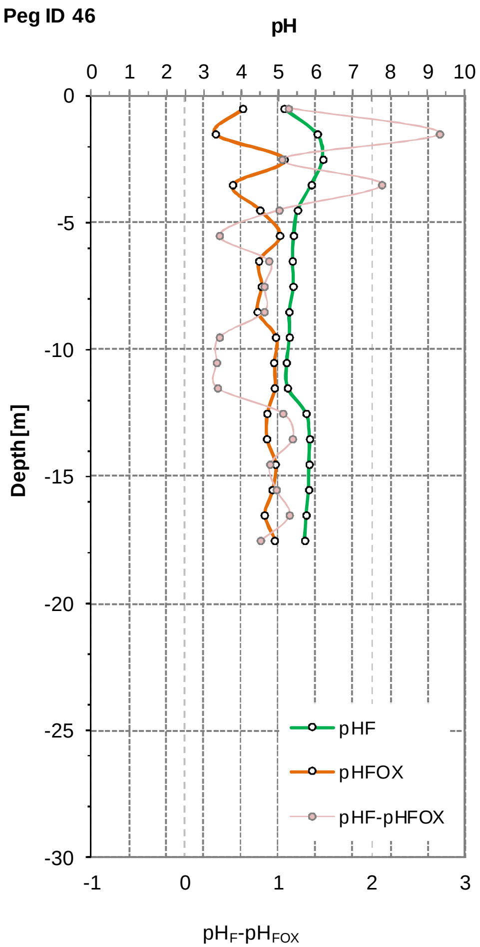

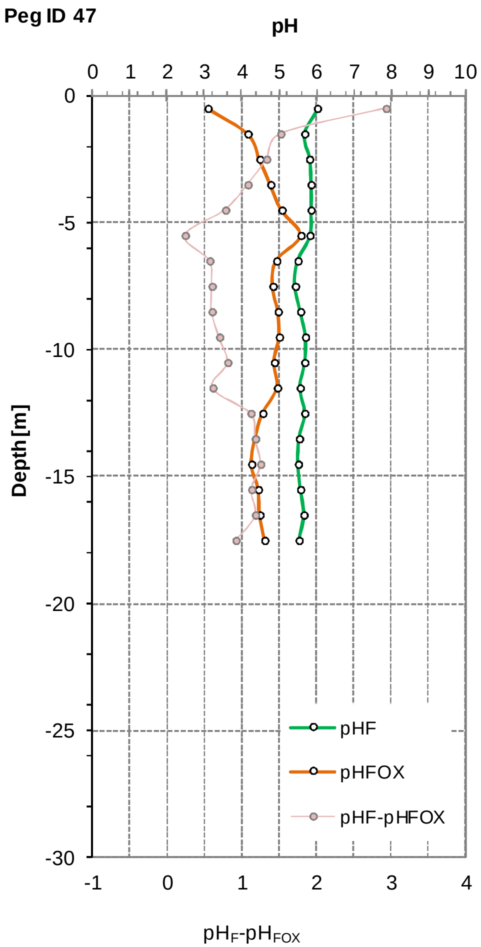

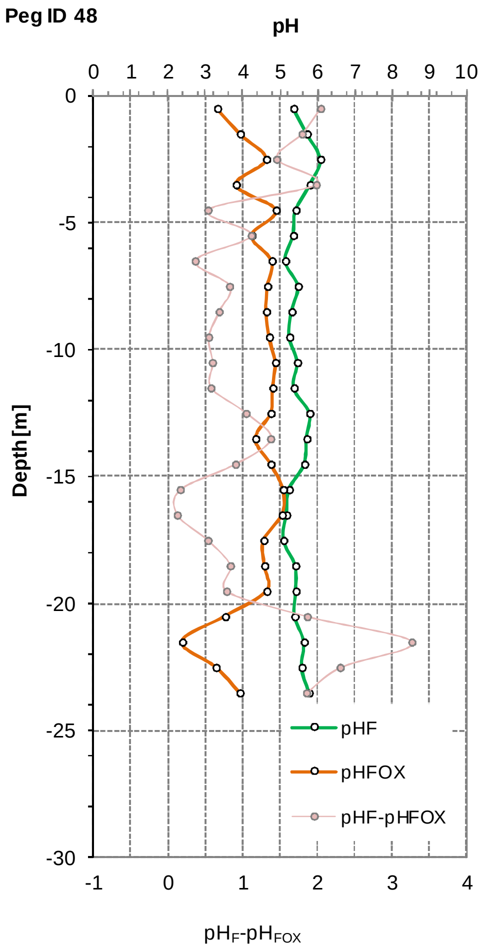

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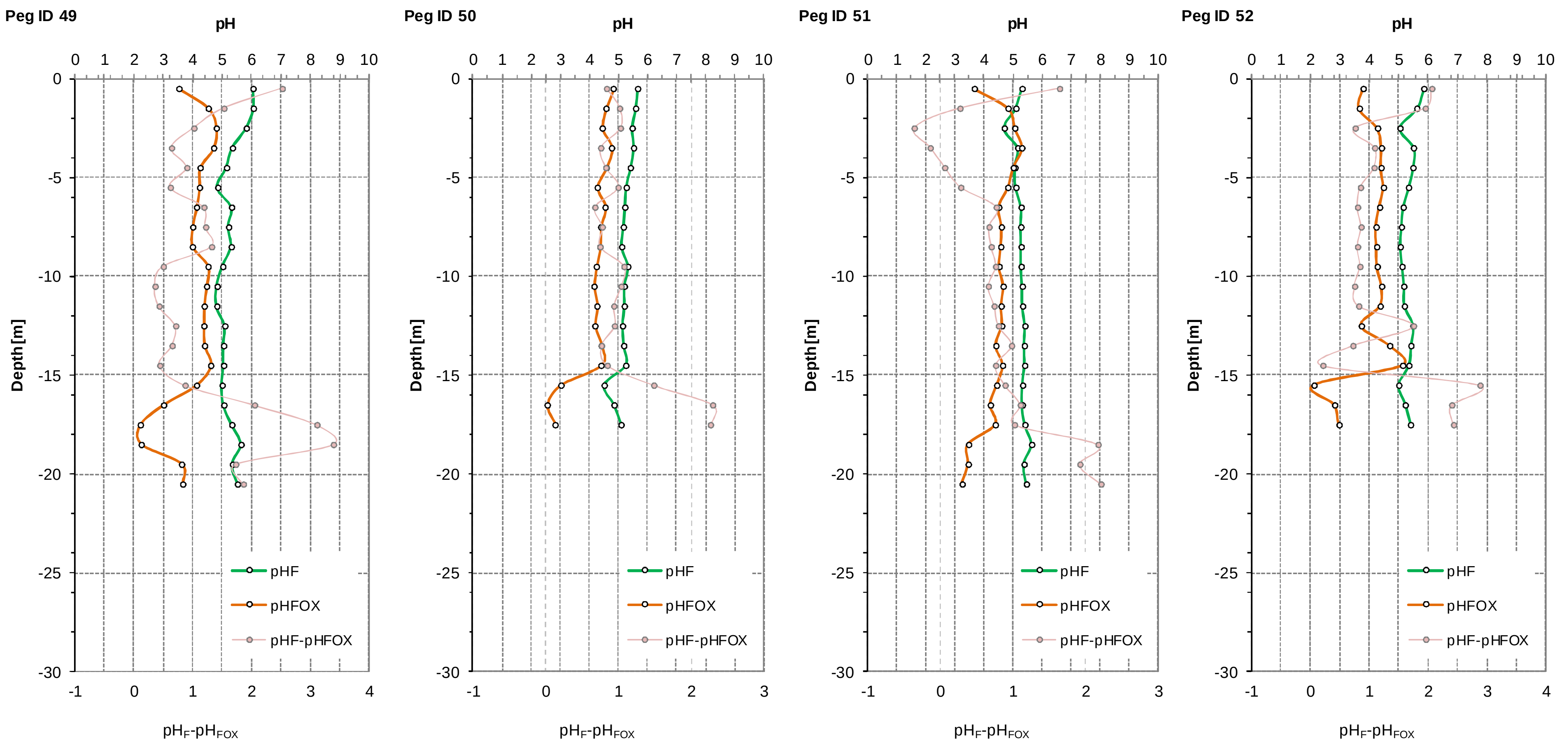

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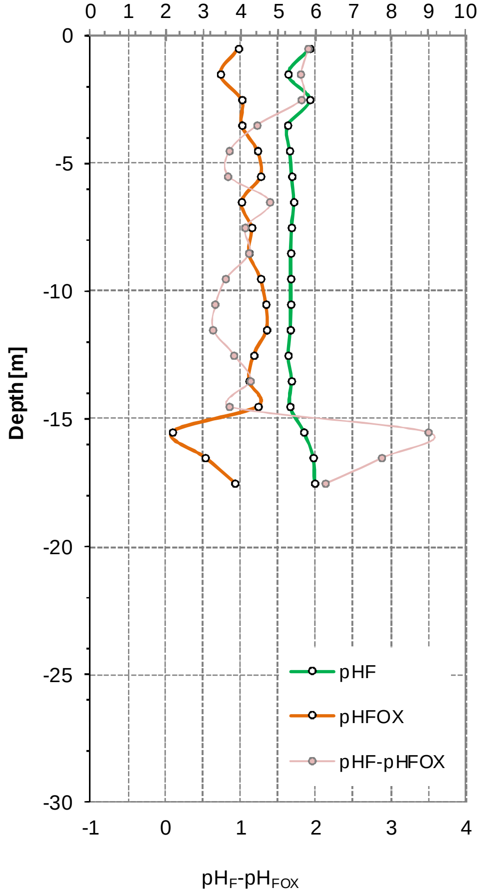

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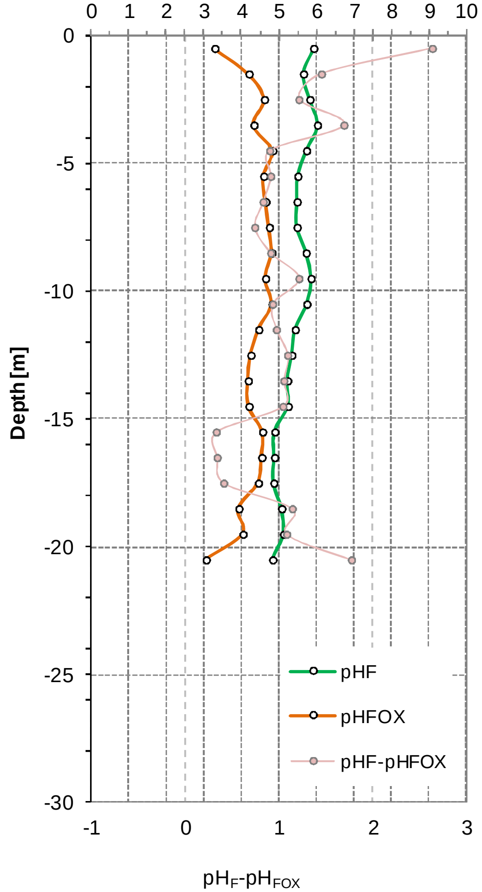

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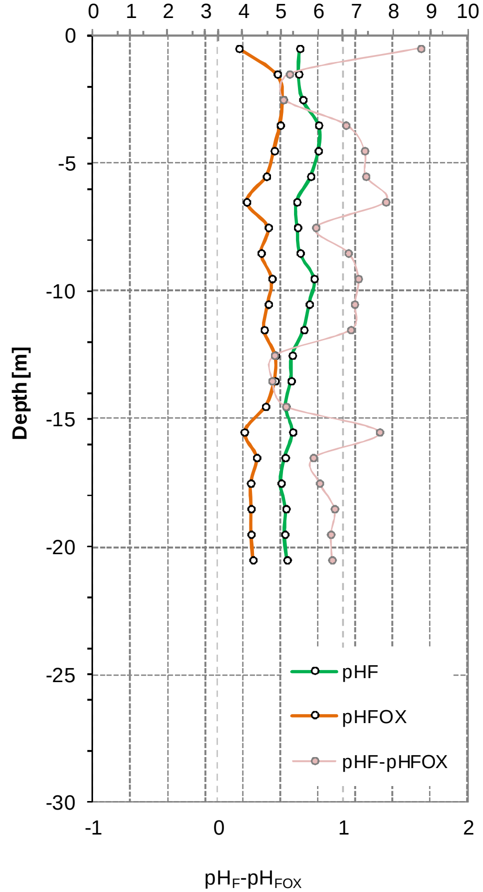

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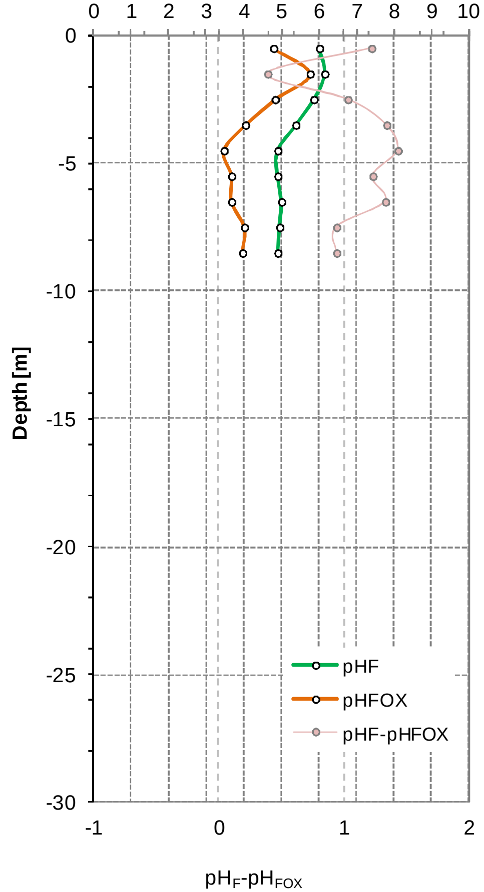

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Prep by				soilwater GROUP
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Revision No.	0			

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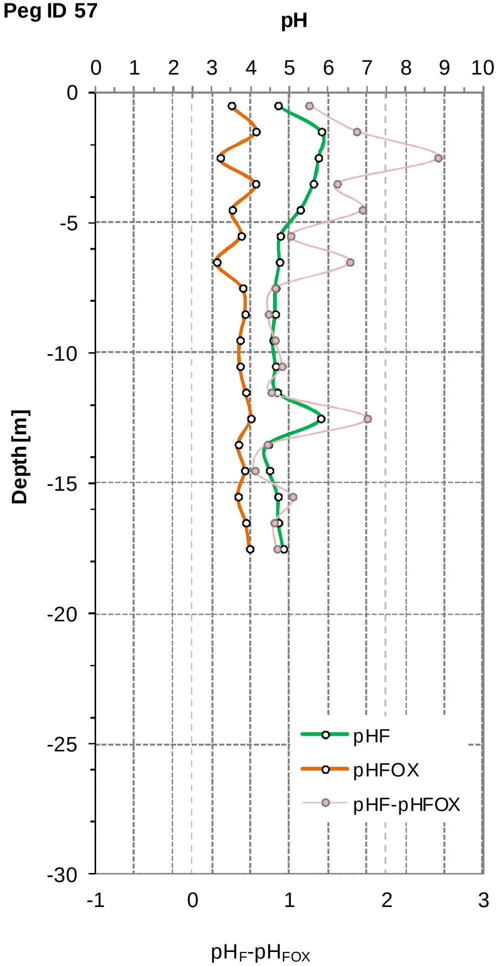

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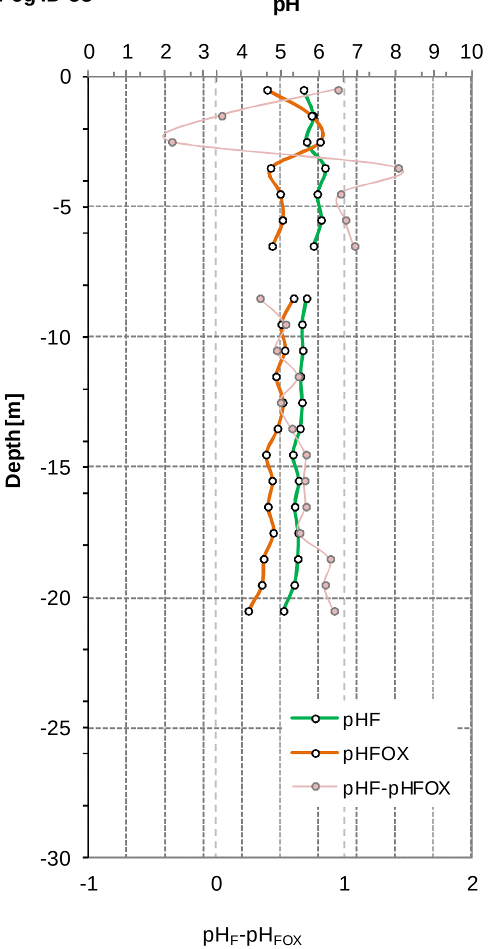

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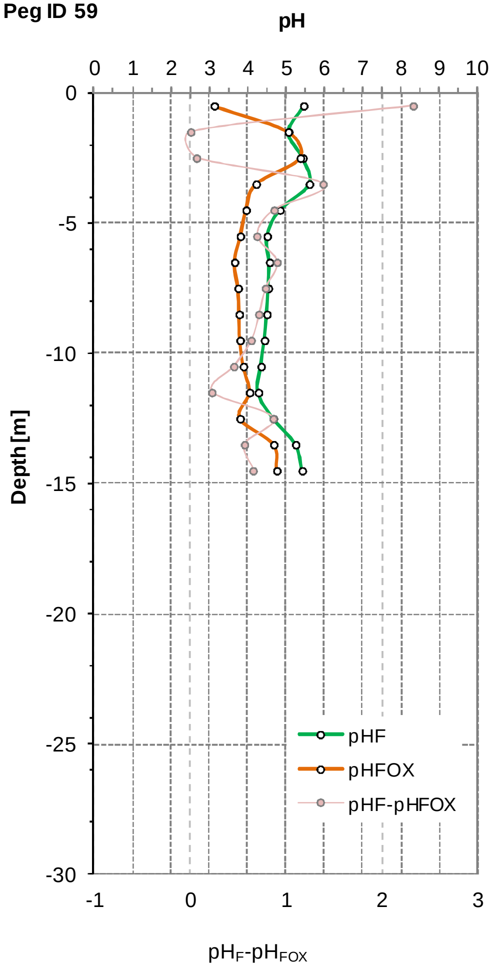

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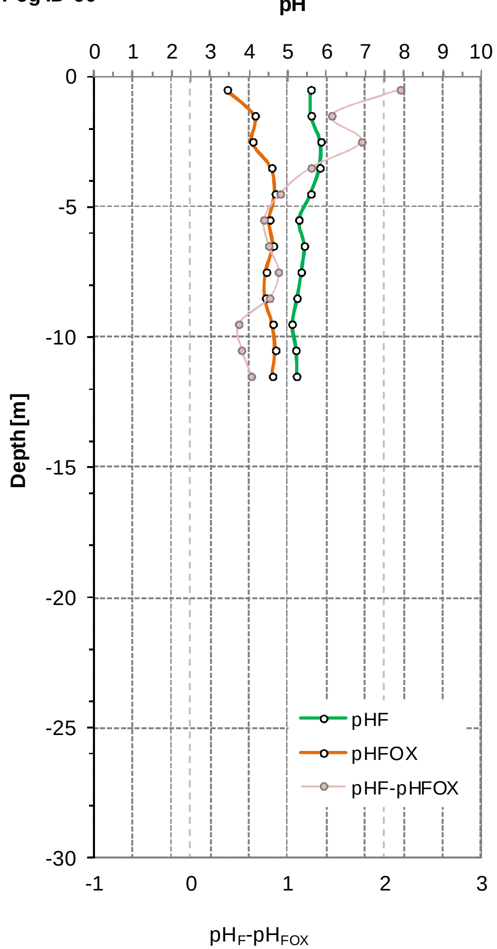

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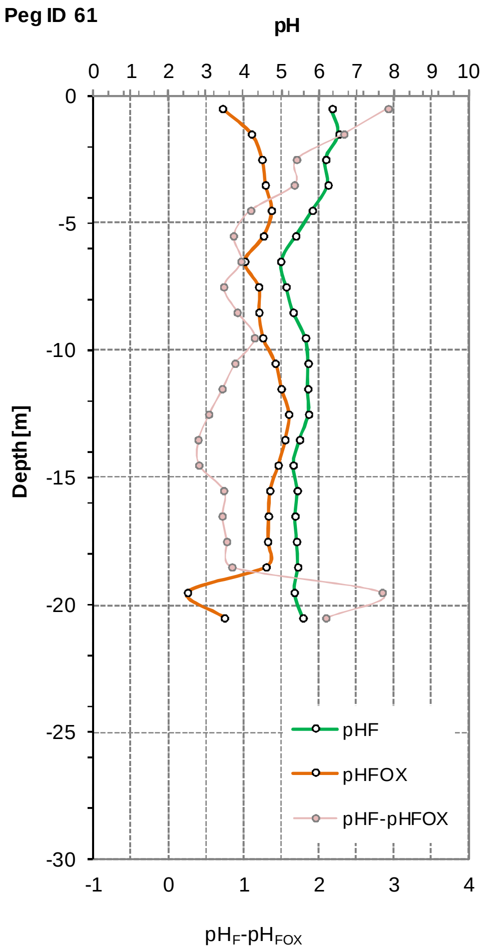

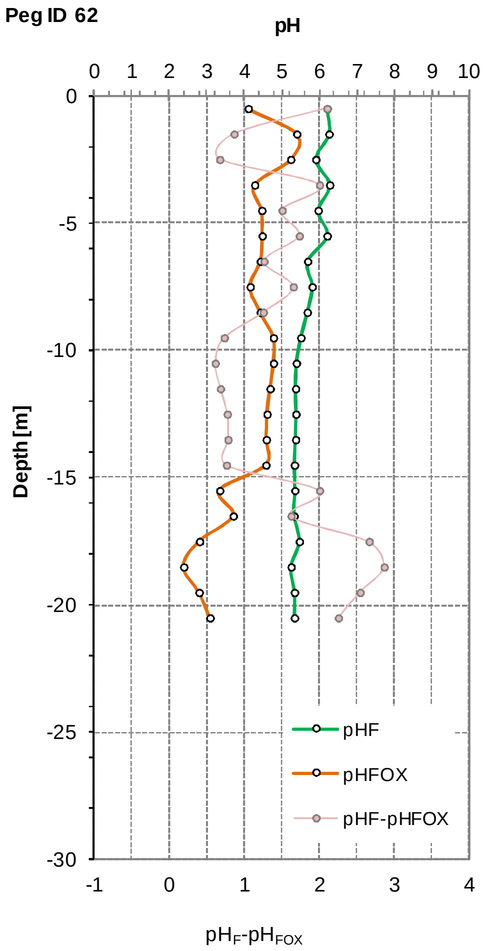

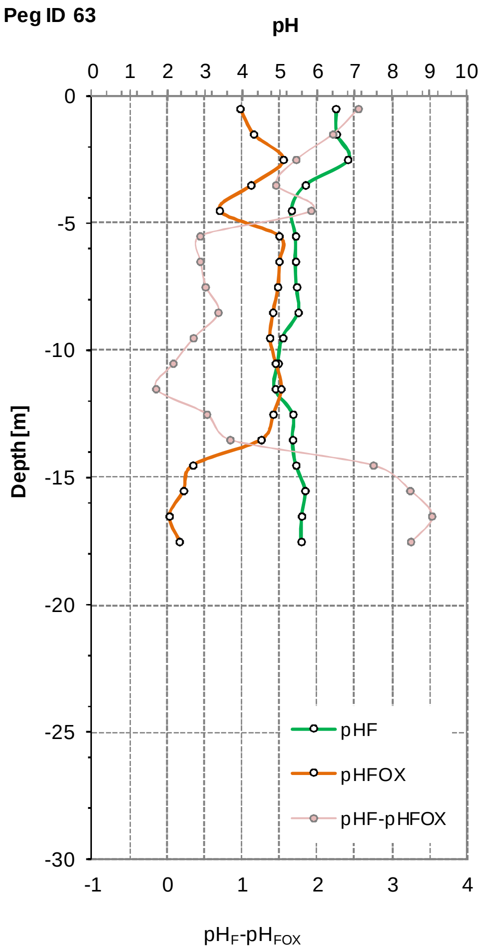

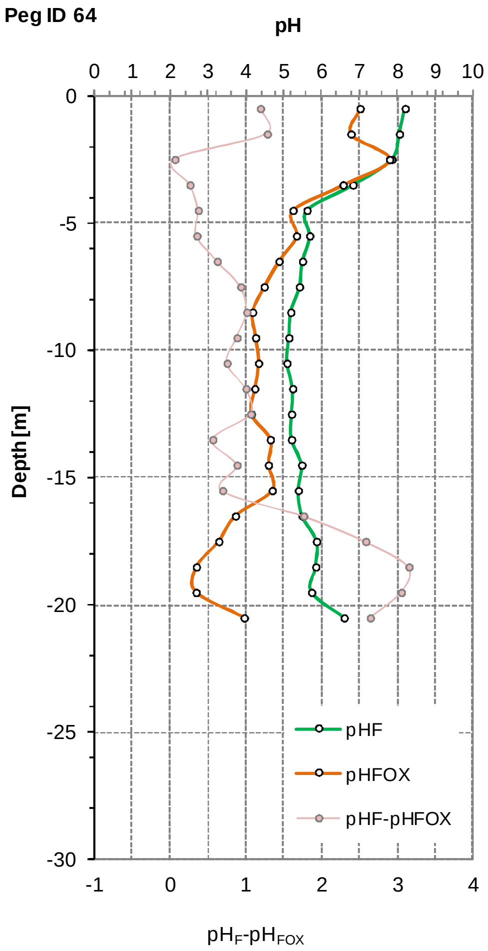

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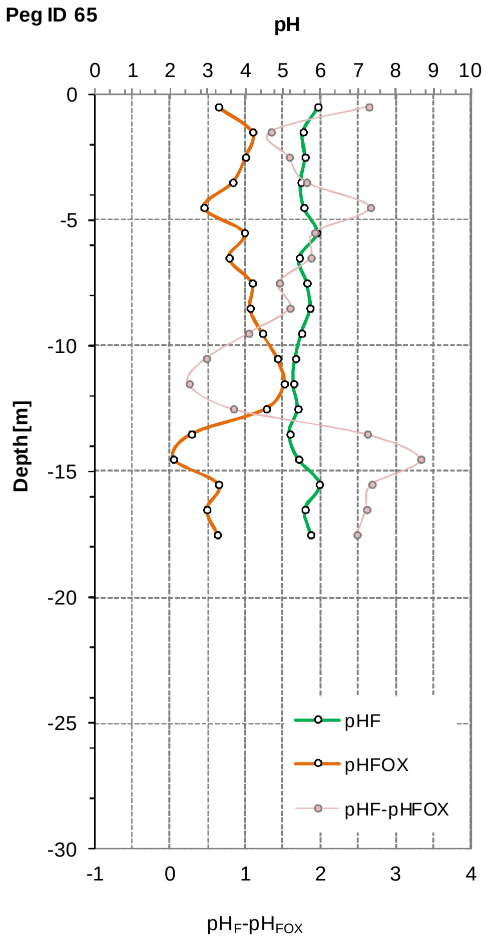

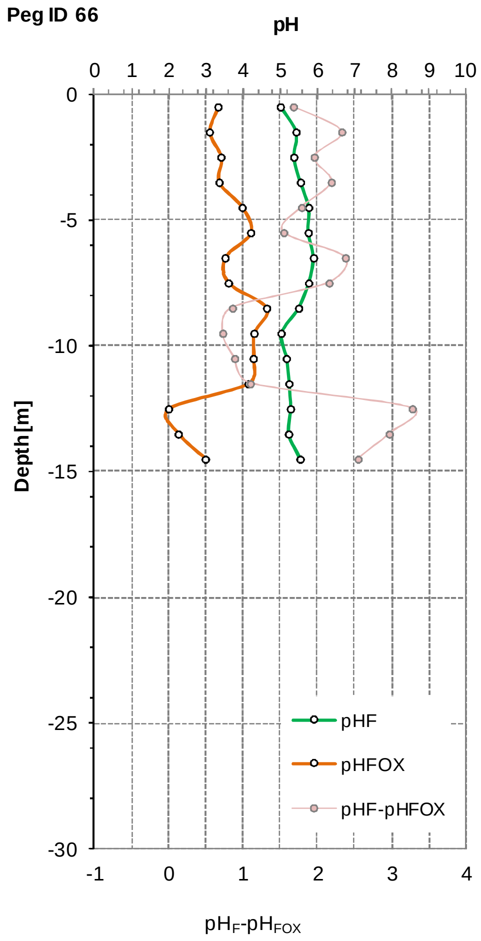

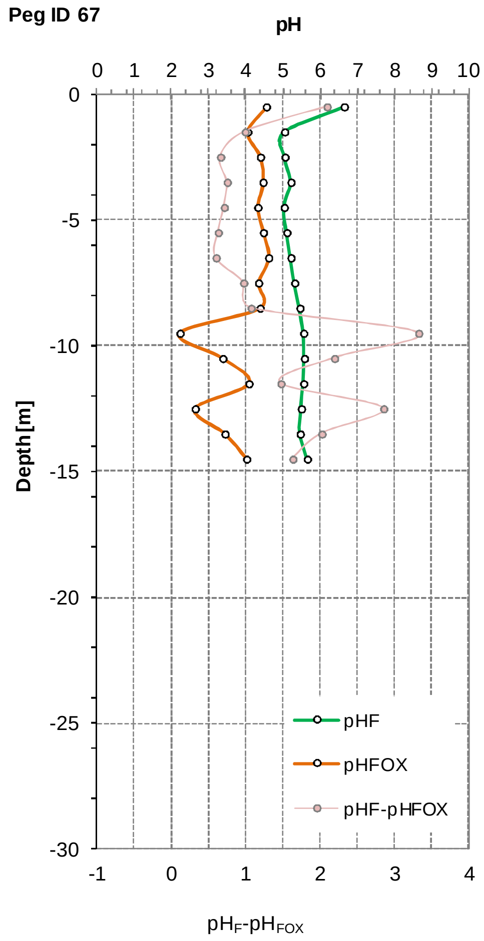

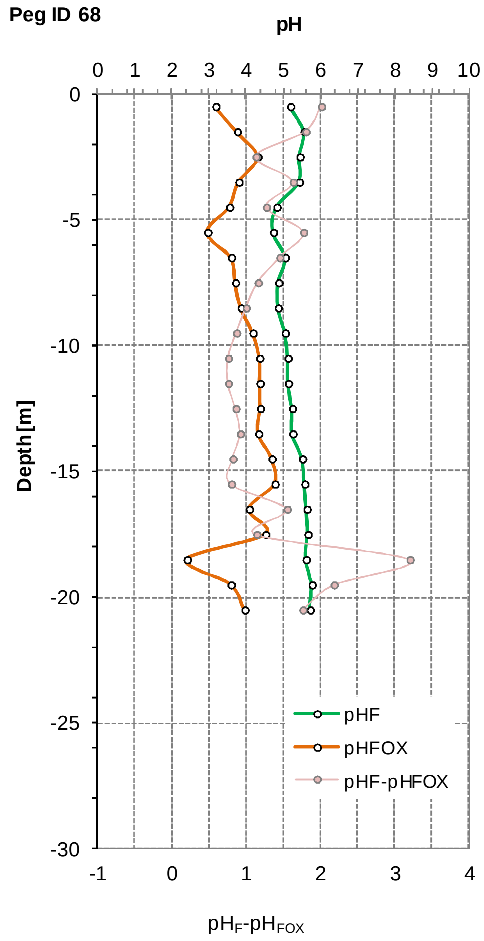

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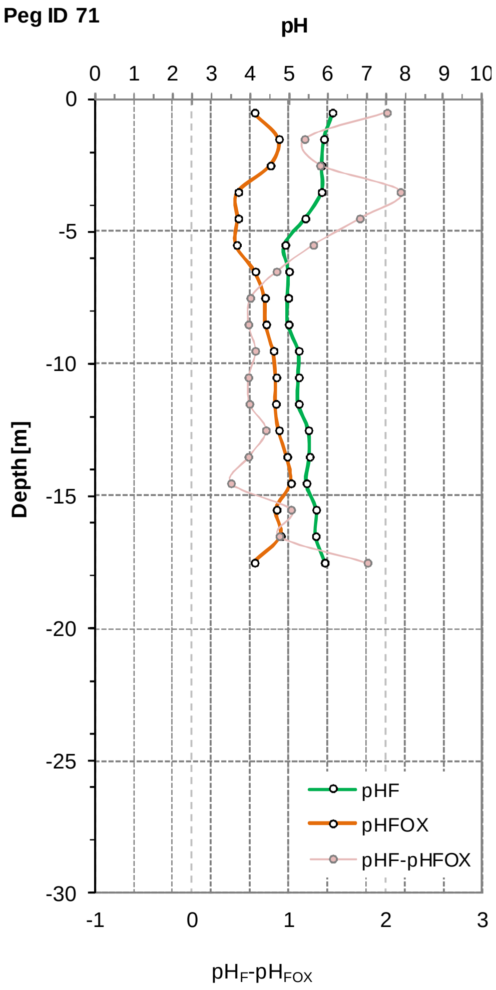

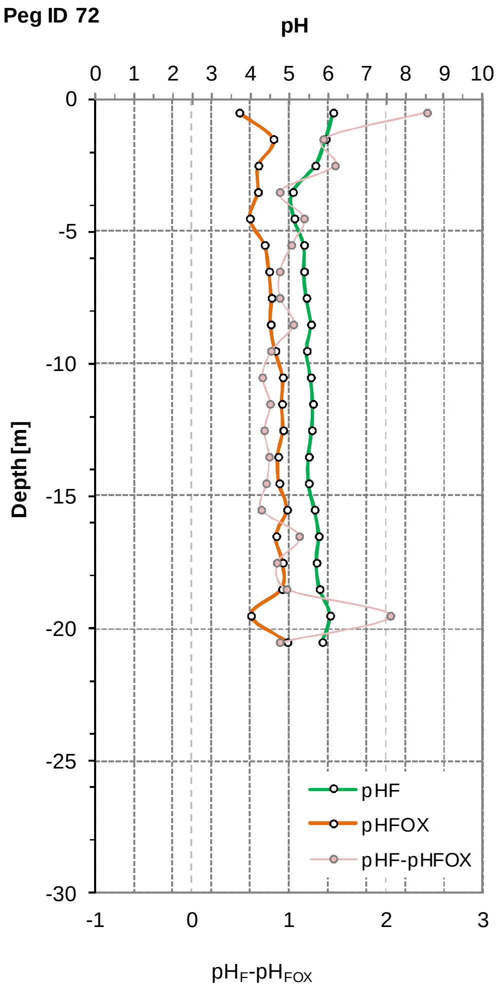

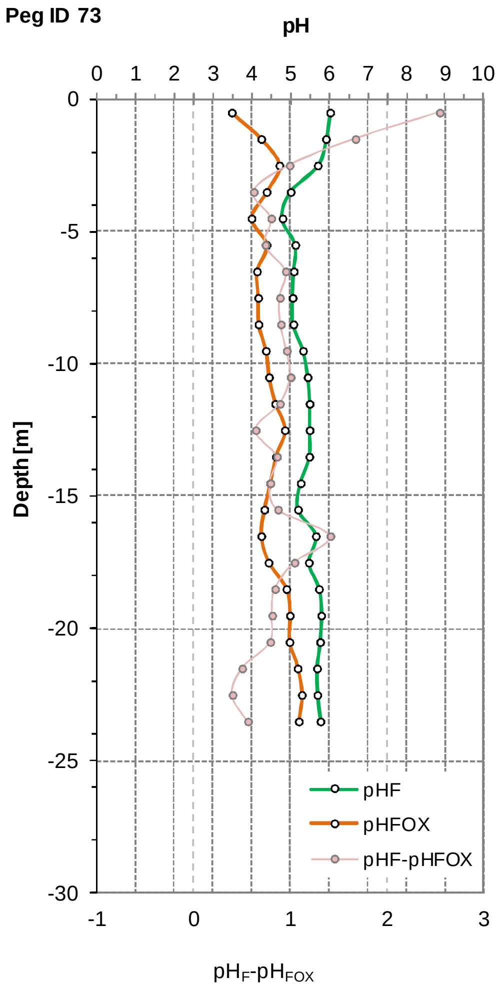

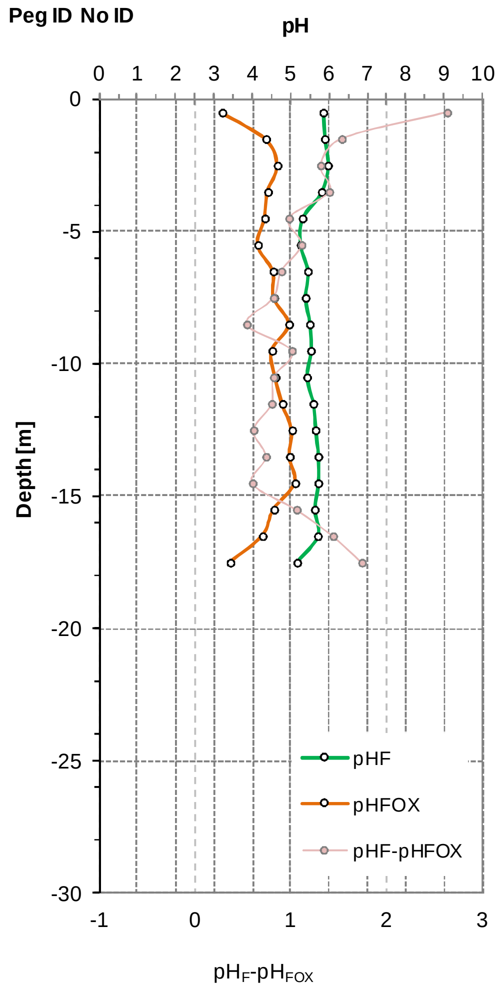

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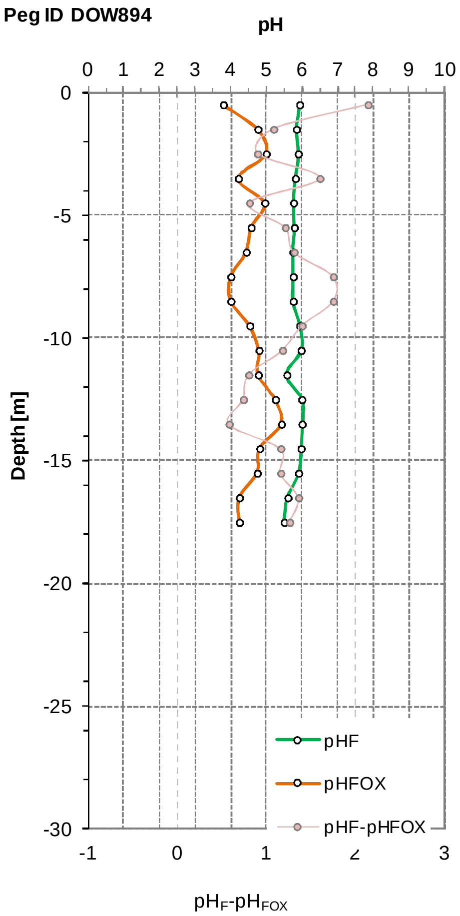

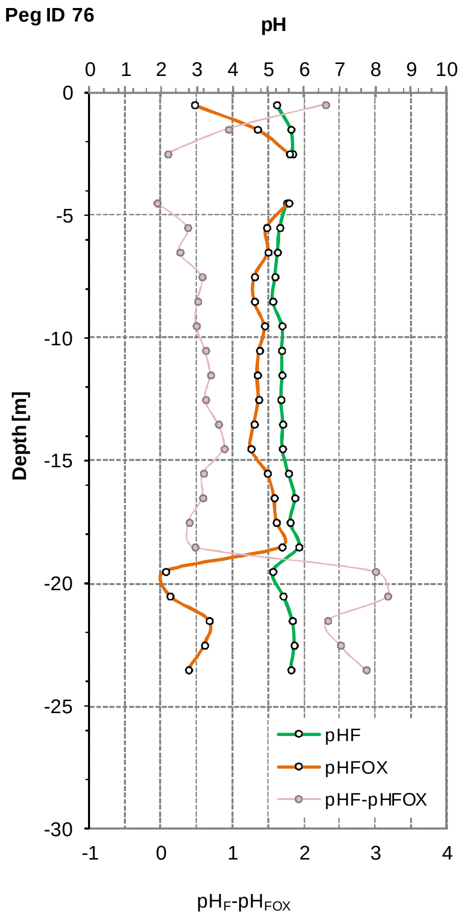

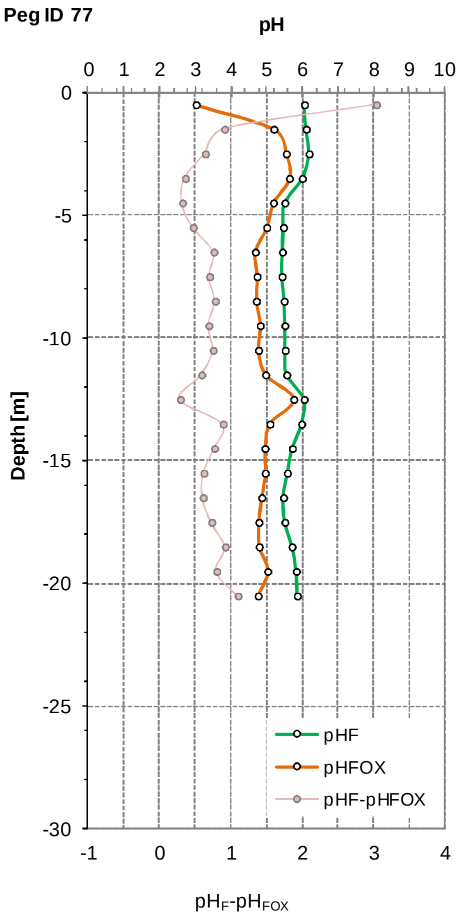

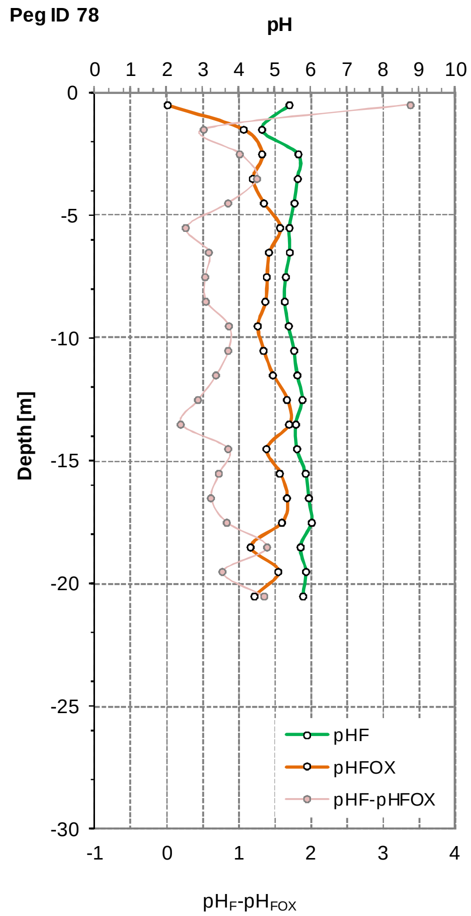

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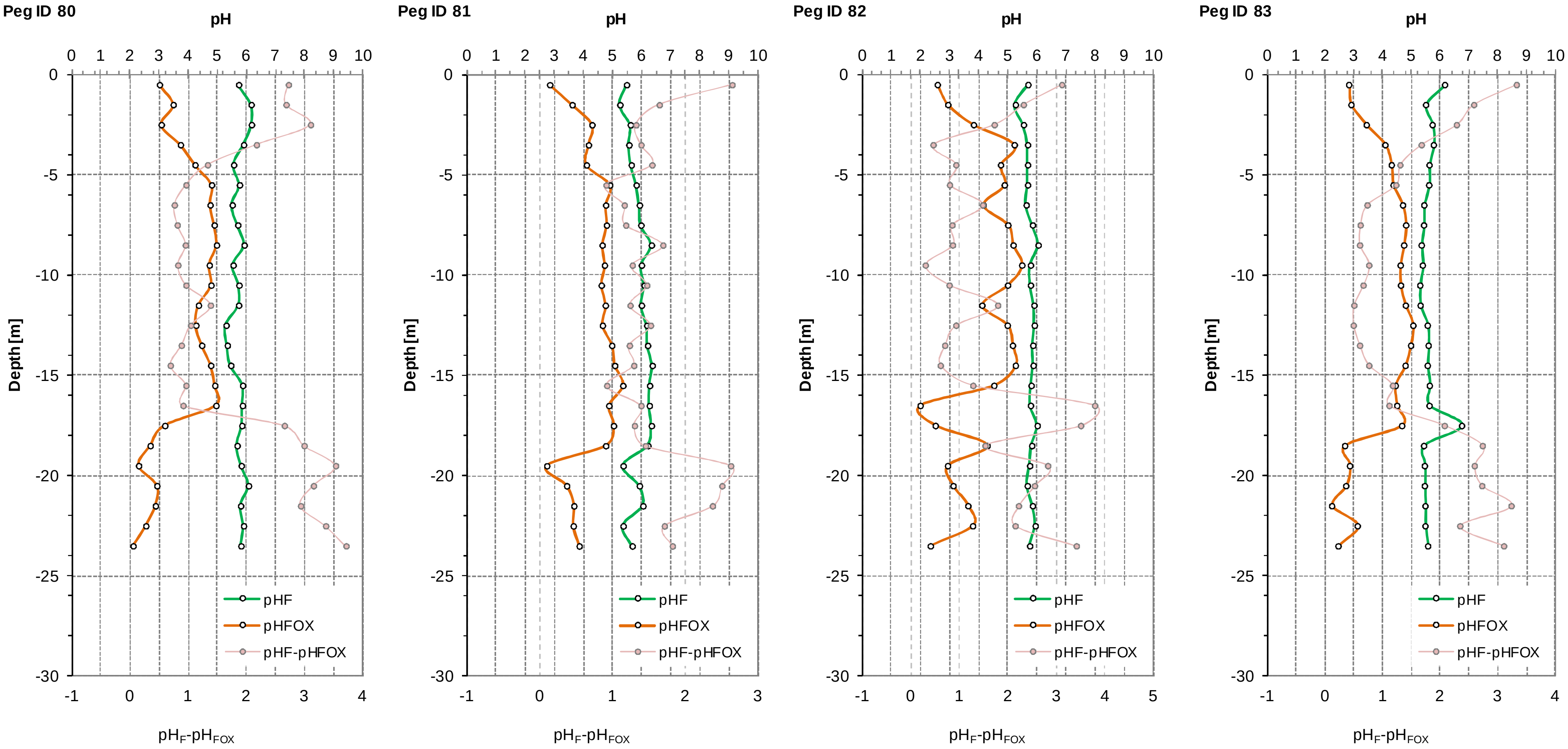

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Prep by				soilwater GROUP
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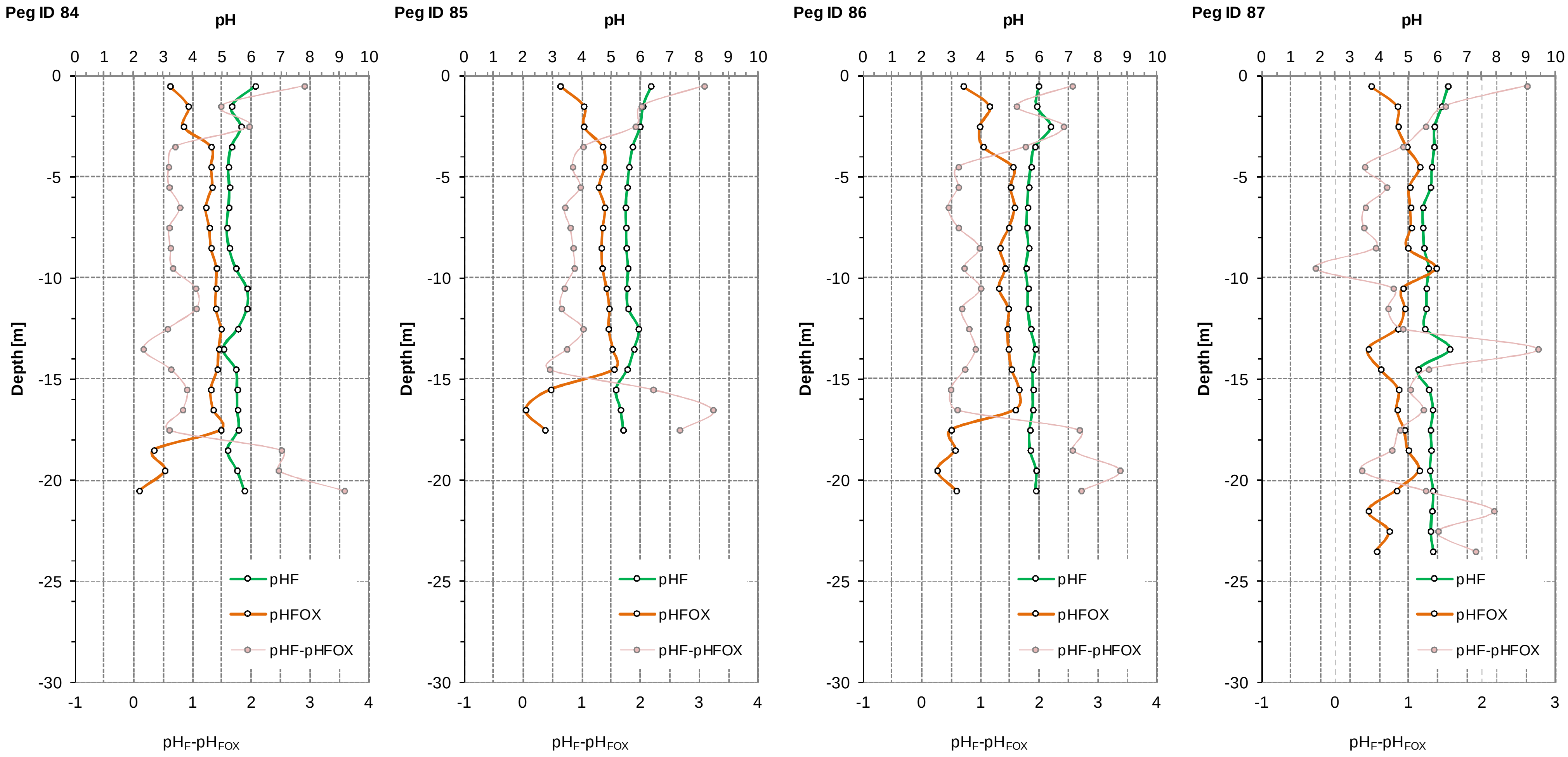
Revision No.	0			



PN	Project No. PN0208		Doral Mineral Sands Pty Ltd YOONGARILLUP DEPOSIT ASS SURVEY **pH + pHfox Graphs**	**Appendix A** *continued…*
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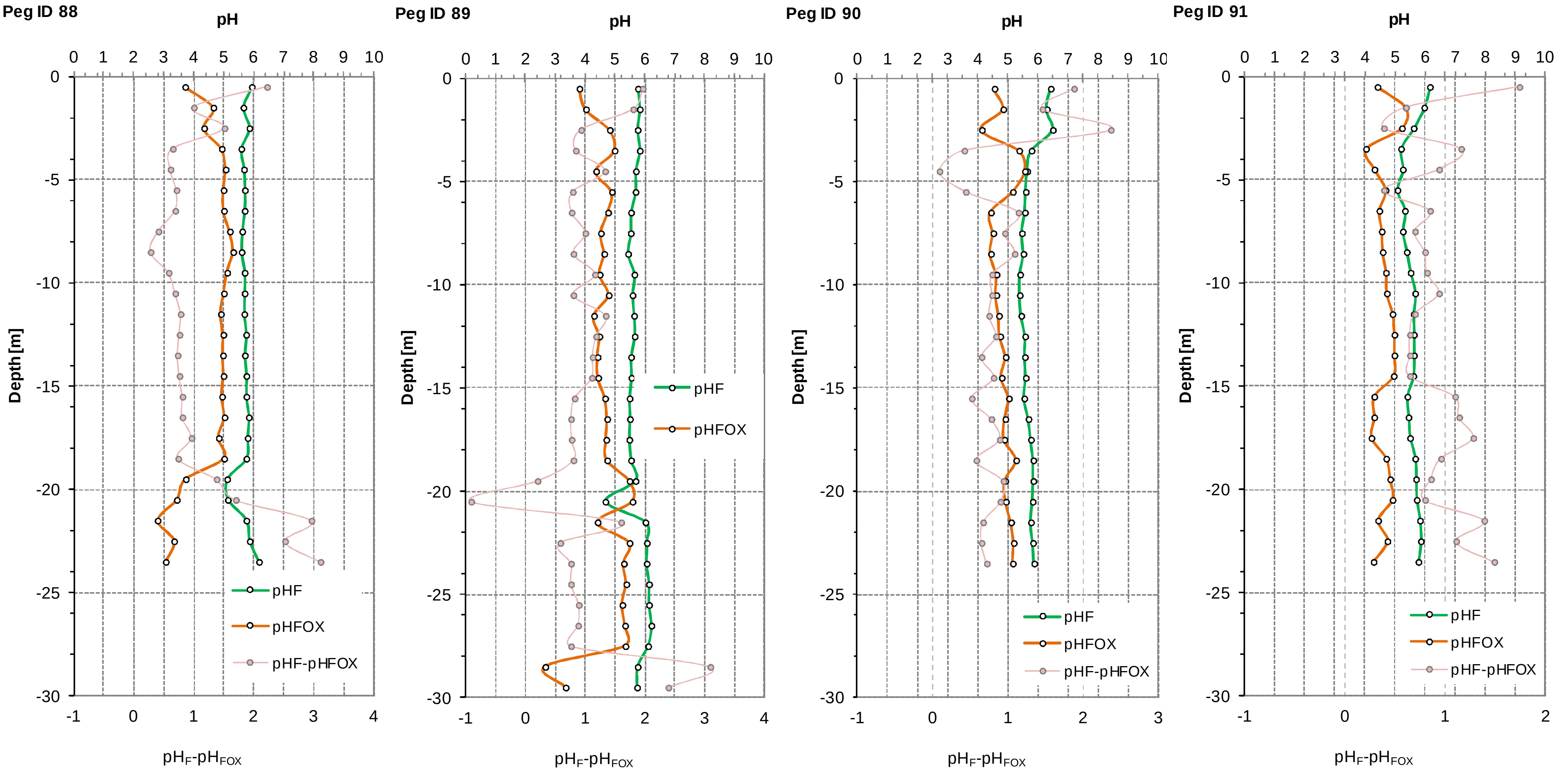
Revision No.	0			



PN	Project No. PN0208		Doral Mineral Sands Pty Ltd YOONGARILLUP DEPOSIT ASS SURVEY **pH + pHfox Graphs**	**Appendix A** *continued…*
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Revision No.	0			