Appendix D

Soil Characterisation Assessment (Soilwater Consultants 2019)

SOILWATER CONSULTANTS

NORTH KIAKA SOIL CHARACTERISATION	
Prepared for:	SIMCOA OPERATIONS PTY LTD
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Revision Code*

A - Report issued for internal review

B - Draft report issued for client review

0 - Final report issued to client

LIMITATIONS

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to undertake a Soil Characterisation for the proposed North Kiaka Quartzite Mine to be developed by Simcoa Operations Pty Ltd. This work was conducted in accordance with the Scope of Work presented to GHD ('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 Soil Characterisation was confined to North Kiaka Disturbance Area. No extrapolation of the results and recommendations reported in this study should be made to areas external to this project area. In preparing this study, SWC has relied on relevant published reports and guidelines, and information provided by the Client. All information is presumed accurate and SWC has not attempted to verify the accuracy or completeness of such information. While normal assessments of data reliability have been made, SWC assumes no responsibility or liability for errors in this information. All conclusions and recommendations are the professional opinions of SWC personnel. SWC is not engaged in reporting for the purpose of advertising, sales, promoting or endorsement of any client interests. No warranties, expressed or implied, are made with respect to the data reported or to the findings, observations and conclusions expressed in this report. All data, findings, observations and conclusions are based solely upon site conditions at the time of the investigation and information provided by the Client. This report has been prepared on behalf of and for the exclusive use of the Client, its representatives and advisors. SWC accepts no liability or responsibility for the use of this report by any third party.

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1 INTRODUCTION

Simcoa Operations Pty Ltd (Simcoa) are proposing to expand the existing Moora Quartzite Operations to the north of the Kiaka Road (North Kiaka Operations) on tenement M70/1292. The existing Moora Operations occur on the eastern side of The Midlands Road, approximately 15 km north of Moora, and 170 km north of Perth (Figure 1.1 and Figure 1.2).

The North Kiaka Operations will involve the excavation of the quartzite orebody from four large open pits and three smaller mine pits, with waste materials permanently stored in two above-ground Waste Rock Landforms (WRLs) (Figure 1.3). A Process Area and Workshops will be centrally located and a large Administration Area, including Product Stockpiles and Weighbridge, will be located in the southwest corner of the Project Area. The North Kiaka Operations will be linked to the existing Operations via an Access Corridor (Figure 1.3).

The proposed Disturbance Footprint (DF) associated with the North Kiaka Operations is provided in Table 1.1.

Table 1.1: North Kiaka Disturbance Footprint

Feature	Area (ha)
Administration, Product Stockpiles & Weighbridge	20.68
Process Area and Workshops	2.84
Pit 4	6.64
East Waste Rock Landform	13.39
Small Open Pit (SOP)	1.09
Small Open Pit (SOP)	2.4
Small Open Pit (SOP)	1.38
Pit 1	11.94
Pit 2	26.44
Pit 3	21.43
North Waste Rock Landform	18.59
Access Road Corridor	12.12
TOTAL DISTURBANCE (ha)	138.94

The primary purpose of this Soil Characterisation was to identify and characterise all surficial soil materials within the proposed disturbance area and suggest management strategies for their handling and utilisation. This information provides baseline data that can be used to assist in the mining of these materials, and in the construction and rehabilitation of any post-mine landforms. Implementation of the soil management recommendations suggested in this report will ensure that only optimal materials are used in the construction of the outer surface of the waste rock landform (WRL), thus facilitating stability and revegetation, and ultimately closure and bonds return.

1.1 OBJECTIVES OF WORK

The objectives of the soil characterisation were to:

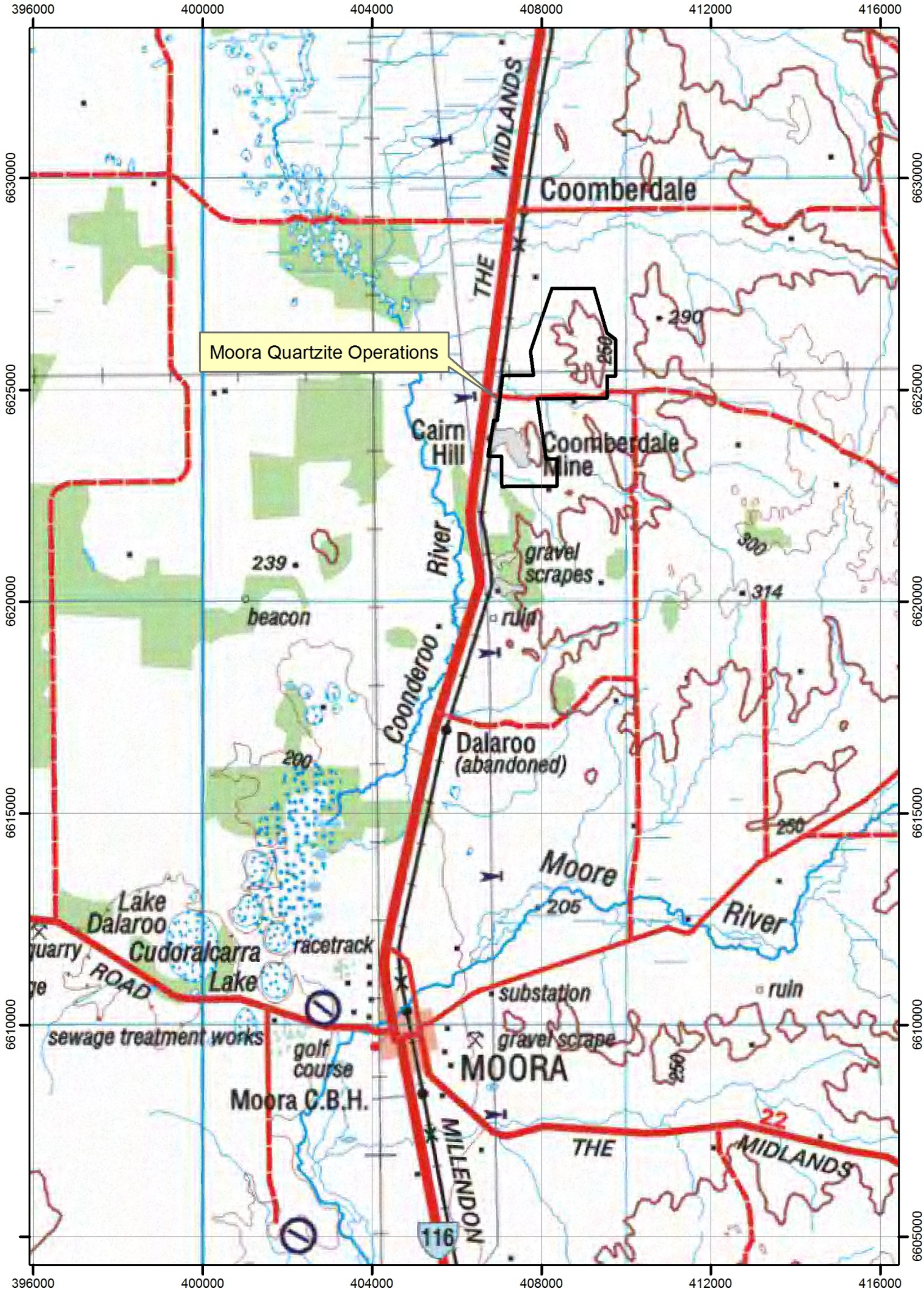
- Define the distribution of soil materials in the North Kiaka Operations;
- Characterise the physical and chemical properties of these materials;
- Identify materials that may be beneficial to the rehabilitation and materials that may have an adverse impact on rehabilitation;

- Suggest management strategies for the handling and utilisation of these materials during mining and rehabilitation.

1.2 SCOPE OF WORK

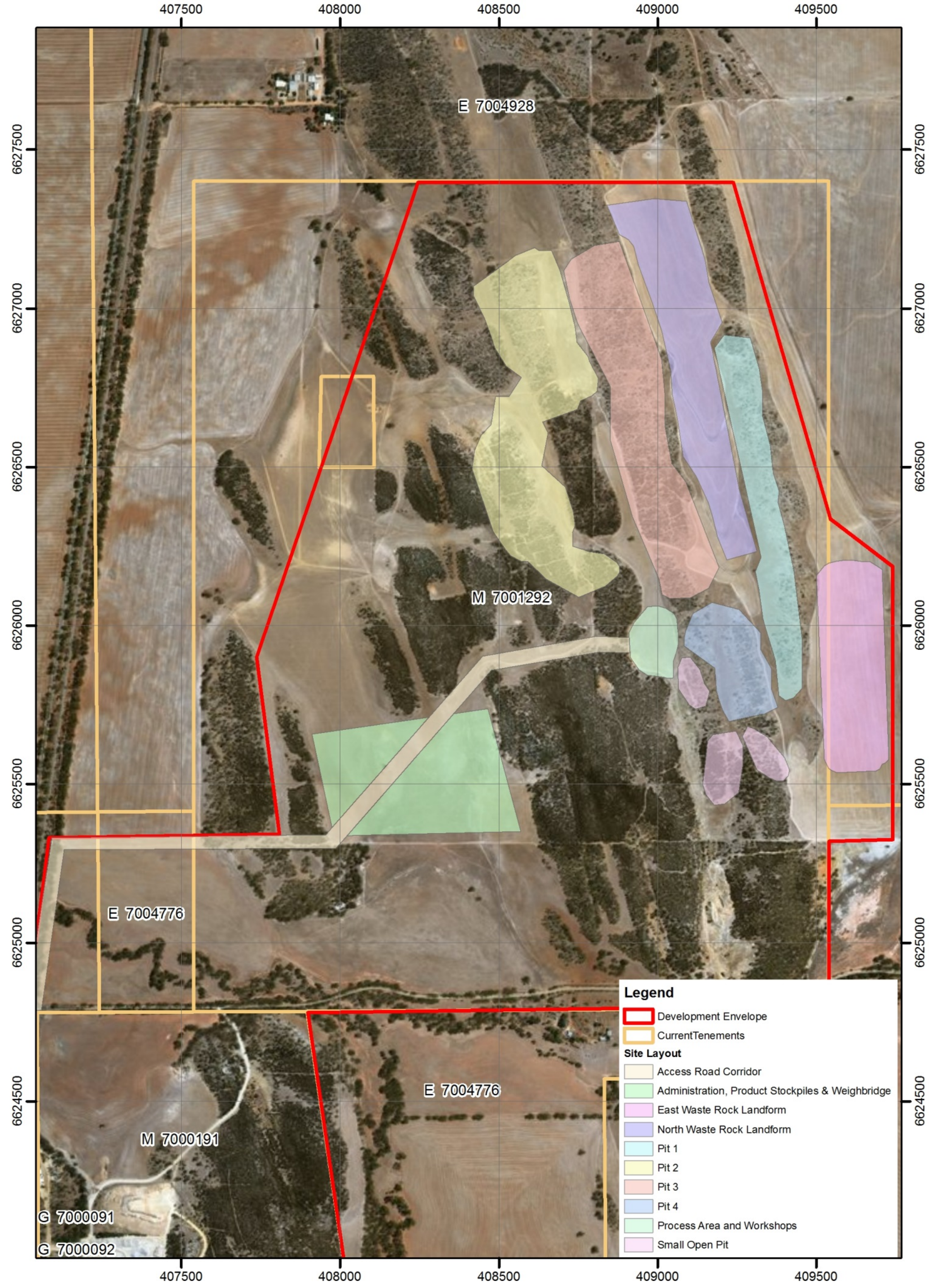
The Scope of work completed by SWC included:

- Collection of soil material samples from the proposed disturbance areas.
- Describe the surface soil materials and their distribution throughout the disturbance areas.
- Conduct laboratory tests to quantify soil material properties, stability and erodibility.
- Preparation of this report



GHD	Figure 1.1: Regional location	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		

GHD	Figure 1.2: Local location	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		



GHD	Figure 1.3: Site Layout	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		

2 STUDY METHODOLOGY

2.1 SOIL SAMPLING

The soils throughout the North Kiaka Operations were investigated by trench excavation, utilising a 20 t excavator (Plate 2.1). A total of 17 soil sites were investigated across the Project Area, with the location and details provided in Figure 2.1 and Table 2.1. At each site soil trenches were excavator to a maximum depth of 3 m or until refusal.

Plate 2.1: Trench excavation for the North Kiaka Soil Characterisation

Table 2.1: Details of the soil sampling sites

Site ID	Easting	Northing	Depth (m)
T2	408574	6626664	2.5
T3	409666	6626947	1.5
T4	408977	6626921	2.4
T5	409037	6626227	2
T7	408510	6626325	2
T8	409297	6626259	2
T9	409065	6626514	1.5
T10	409254	6626597	1.5
T11	409333	6626051	2.3
T12	409090	6626952	2.5

Site ID	Easting	Northing	Depth (m)
T13	409151	6626684	2.2
T14	409568	6626019	1
T15	409560	6625706	0.9
T16	408136	6625660	1.3
T17	408348	6625486	1.1
T18	409332	6625933	2.5

The sampling protocol at each location involved:

- Recording the location in a hand-held GPS.
- Recording surface features such as topography, vegetation and soil surface condition using field recording sheets and a digital camera.
- Describing the soil profile morphology in terms of colour, texture, structure and horizonation / layering. All field information was recorded using recording sheets and by digital camera. Field texture analysis was performed to estimate soil type (McDonald and Isbell, 2009) and subsequent identification of soil management units (SMUs).
- Discrete samples were collected down the exposed soil profile for subsequent laboratory analyses.
- Estimated root density was recorded using the semi-quantitative method of McDonald and Isbell (2009) (Table 2.2).

Table 2.2: Semi-quantitative assessment of plant roots used in this investigation.

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

2.2 LABORATORY ANALYSIS

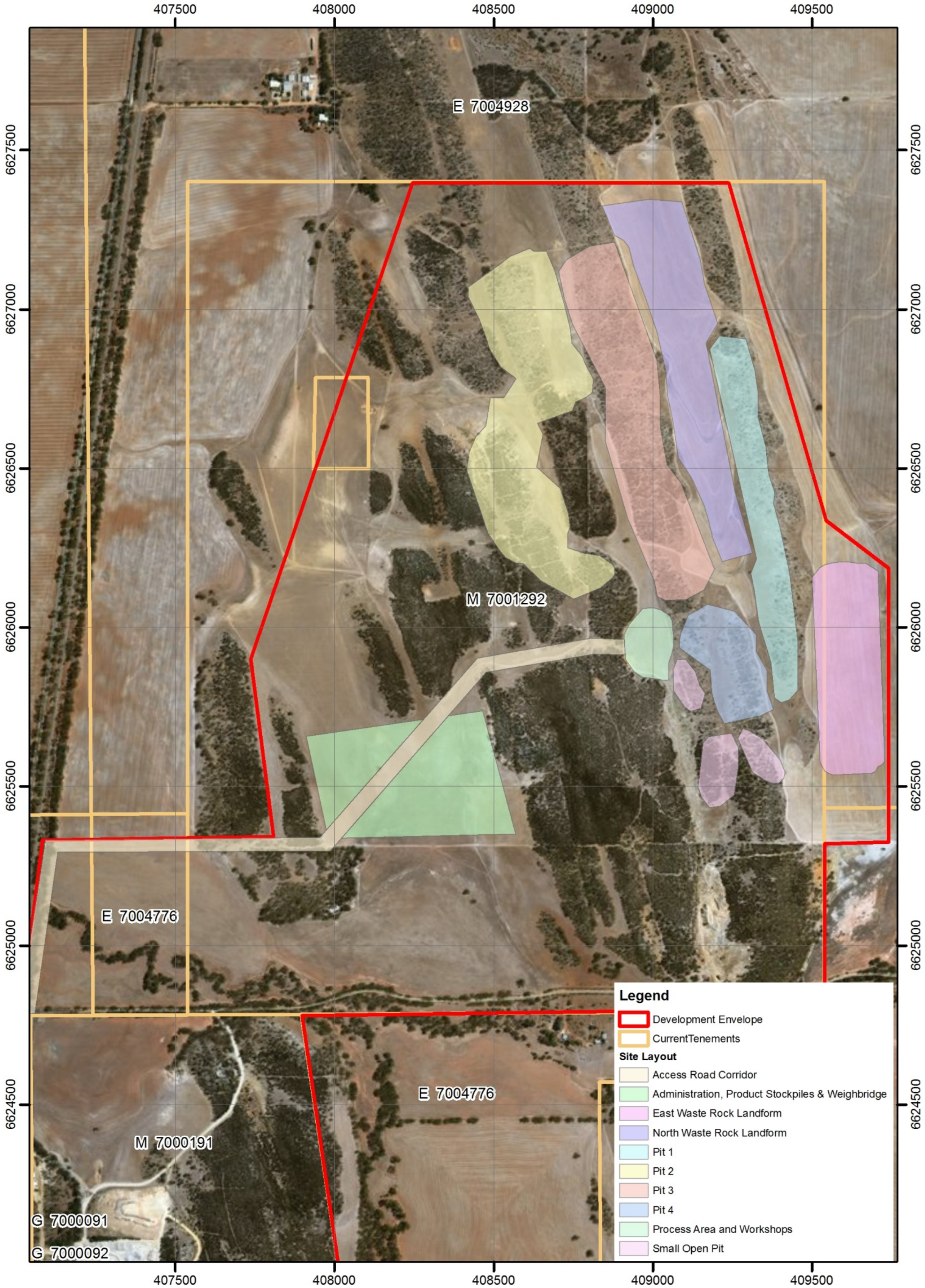
The physical and chemical properties of the soil materials were assessed at Soilwater Analysis (SWA) and CSBP Laboratories in Perth. All samples collected in the field were analysed for pH, EC, field (gravimetric) moisture content and gravel content, to initially screen samples for more detailed analyses and to establish key properties that may distinguish important soil characteristics (e.g. salinity limitations, texture, surface charge chemistry etc.). The remaining properties (Table 2.3) were assessed on a select number of samples that reflect the physical and chemical properties of soil materials within each of the major soil mapping units. The analytical methods for measuring the soil physical and chemical properties are detailed in McKenzie *et al.* (2002) and Rayment and Lyons (2010). The specific method used for each analysis is:

- pH and electrical conductivity (EC) measured on a 1:5 soil to water suspension (Method 4A1);
- Gravel content (>2.36 mm sieve);

- Field gravimetric water content;
- Inorganic nitrogen (ammonium and nitrate, (2M KCl Method 7C2);
- Exchangeable Al (Method 15G1),
- Exchangeable cations (no pre-wash, Method 15A2),
- Colwell P and K (Method 9B),
- Organic carbon (Walkley Black, Method 6A1),
- Available sulfur (KCl 40, Method 10D1);
- Particle size analysis (pipette method),
- Aggregate dispersion index;
- Soil water retention (Pressure Plate Method 504.02); and
- Saturated hydraulic conductivity (Intact Core – Constant Head Method).

Table 2.3: Physical and chemical properties of the soils measured in the laboratory.

Parameter	Method	Standard Reference
Soil Physical Properties		
Particle size distribution	Pipette sedimentation	McKenzie *et al.* (2002)
Gravel content	Sieve analysis (> 2 mm soil fraction)	
Bulk density	Constant volume	
Aggregate stability	Emerson dispersion	
Hardsetting Potential		Harper and Gilkes (1994)
Soil Hydraulic Properties		
Saturated hydraulic conductivity	Constant head permeameter	McKenzie *et al.* (2002)
Water retention characteristics	Pressure plate equipment	
Soil Chemical Properties		
pH	1:5 soil/water extraction	Rayment and Lyons (2010)
Electrical conductivity (EC; salinity))	1:5 soil/water extraction	
Macro-nutrients		
- Total Nitrogen (N)	Leco	
- Colwell Phosphorus (P)	$NaHCO_3$ extraction	
- Colwell Potassium (K)	$NaHCO_3$ extraction	
- Available Sulfur (S)	KCl extractable S/ICP	
Organic Carbon	Walkley Black Method	Rayment and Lyons (2010)
Exchangeable cations – Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K)	NH_4Cl extraction	Rayment and Lyons (2010)
Effective Cation Exchange Capacity (ECEC)	Sum of exchangeable cations	-
Exchangeable Sodium Percentage (ESP; sodicity)	ESP = (Ex. Na/CEC)×100	-



GHD	Figure 2.1: Soil sampling locations	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		

3 EXISTING ENVIRONMENT

3.1 GEOMORPHOLOGY

The geomorphology across the North Kiaka Project Area is shown in Figure 3.1 and Figure 3.2, and Plate 3.1. The relief across the site varies from 210 mAHD to 285 mAHD, and the relationship between the quartz orebody and the ridge lines can clearly be seen (Plate 3.2), with the proposed mine pits occurring on, and following, the positive topographic features whilst the North and East WRLs and the Administration Area occur on the lower topographic areas.

The slope within the Project Area varies < 5° to a maximum of 25 ° (Figure 3.1; Plate 3.3). Whilst the majority of the area is generally flat (< 5°), the slopes associated with the quartz ridges are typically between 15 – 18 ° (Figure 3.1).

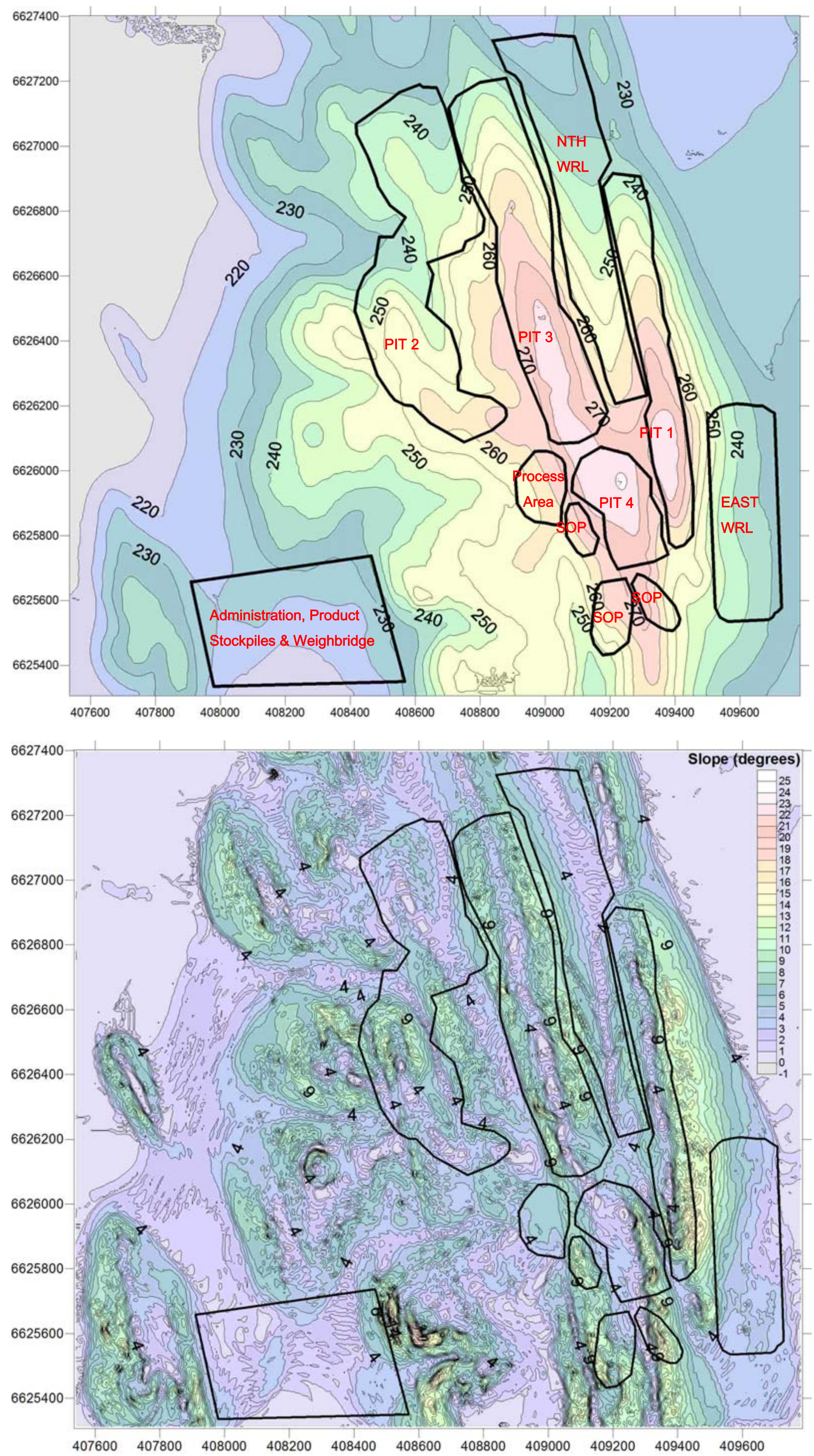
Plate 3.1: General geomorphology within the Project Area

Plate 3.2: Elevated quartz ridge representing the orebody within the Project Area

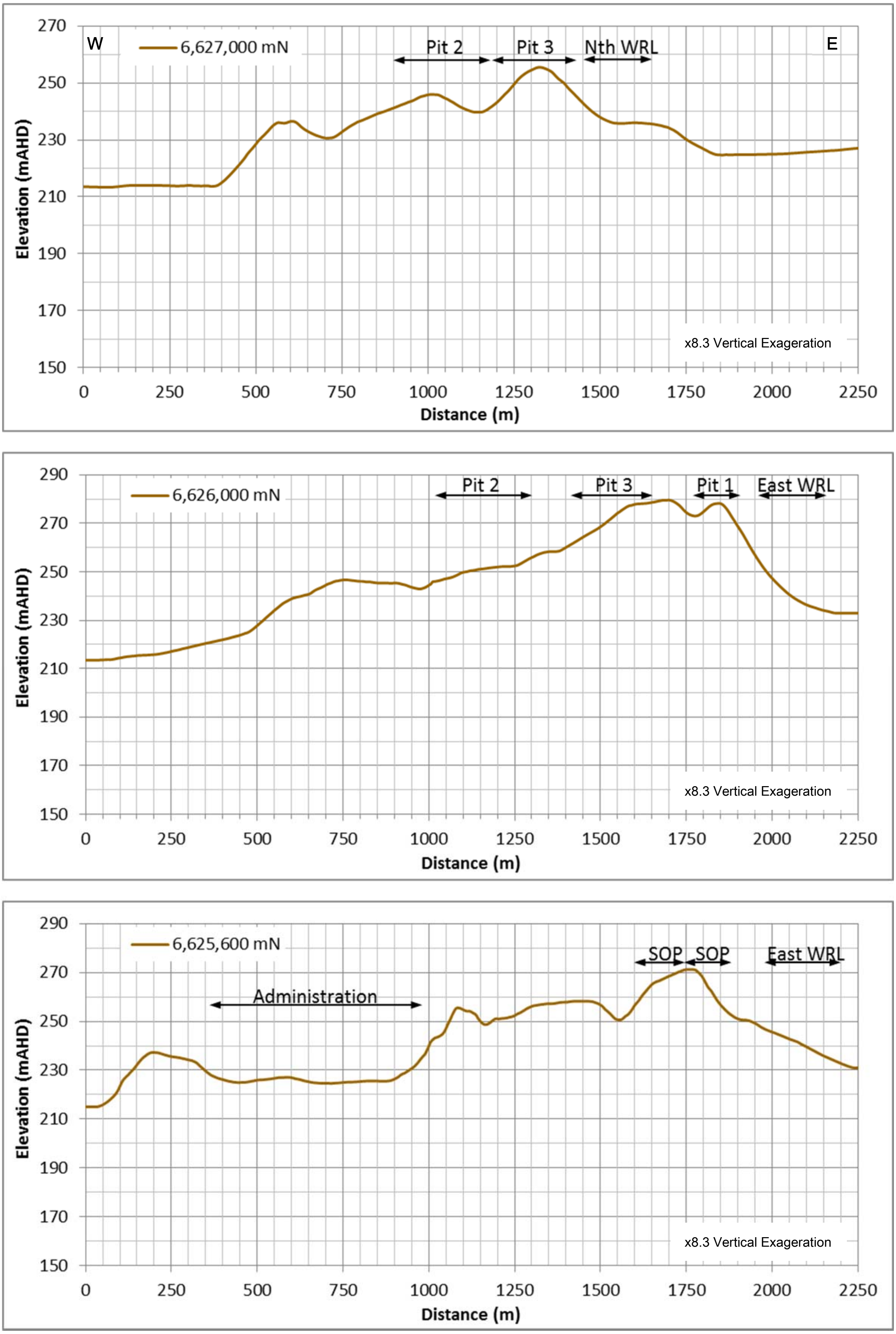
Plate 3.3: Relief and slope within the Project Area

A)

B)



GHD	Figure 3.1: A) Surface elevation and B) slope within the Project Area	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		



GHD	Figure 3.2: Topographic cross section within the Project Area (SOP = Small Open Pit)	soilwater GROUP
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3.2 REGIONAL SOILS

The regional soils across the Project Area are shown in Figure 3.3. The soils associated with the remnant quartz ridges belong to the Zone of Ancient Drainage, which represent residual soils that have experienced prolonged weathering and lateritisation. The soils in the lower topographic areas belong to the Northern Zone of Rejuvenated Drainage, which is characterised by erosional surfaces producing a gently undulating landscape. Colluvial processes are highly active in this region and the soils represent either colluvium or *in-situ* weathered rock, mainly from Jimperding Metamorphic Rocks.

A description of the regional soils covering the Project Area is provided in Table 4.6.

Map Unit	Soil Name	Description
256Bg	Burabidge Hill System	Undulating rises to low hills with rock outcrop. granite, migmatite, gneiss. Brown and red loamy and sandy earths, yellow/brown shallow loamy duplex and some stony soil. York gum-jam woodland
256Ra	Ranfurly System	Level to gently undulating plain being a relict flood plain, partially rejuvenated; loamy earths and clay, some duplex; from alluvium
258Cw	Coorow System	Undulating to gently undulating rises and intervening level to gently undulating flats; Yellow deep sand, pale deep sand and grey sandy duplexes (some alkaline), some yellow sandy earths, and minor loamy earths and duplexes and rock

3.3 GEOLOGY

The North Kiaka Deposit occurs on the western margin of the Yilgarn Craton, approximately 8 km east of the Darling Fault. Given its proximity to the Darling Fault, which has been active since the Proterozoic, the geology is dominated by intrusives (e.g. quartz, dolerite) which have been injected into the existing granitic country rock.

The quartz orebody to be mined at the North Kiaka belongs to the Proterozoic Noondine Chert (P_{Occ}), comprising chert and orthoquartzite, with minor siltstone, sandstone, claystone and dolomite (Figure 3.4).

The massive nature of the intruded quartzite has resulted in less weathering and thus the intruded quartzite represents the ridges seen in Section 3.1. A schematic diagram showing the intruded quartzite and the surrounding granitic bedrock is provided in Figure 3.5. The pertinent point with this figure is that in vertical profile, the quartzite remains unweathered and massive, whilst the adjacent granitic rocks have weathered to form a typical saprolitic regolith, resulting in an abrupt contact between the quartzite and the weathered granite.

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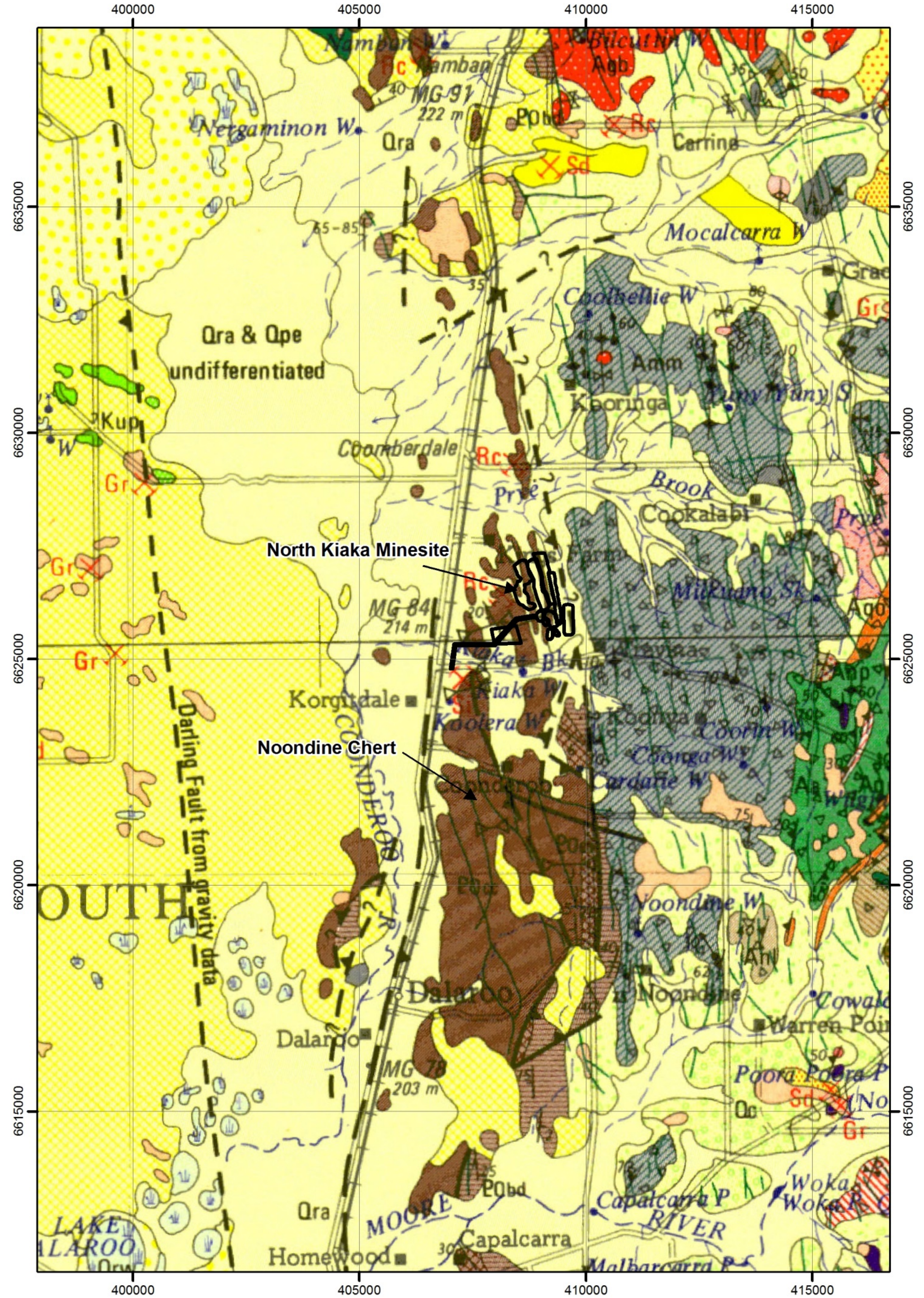
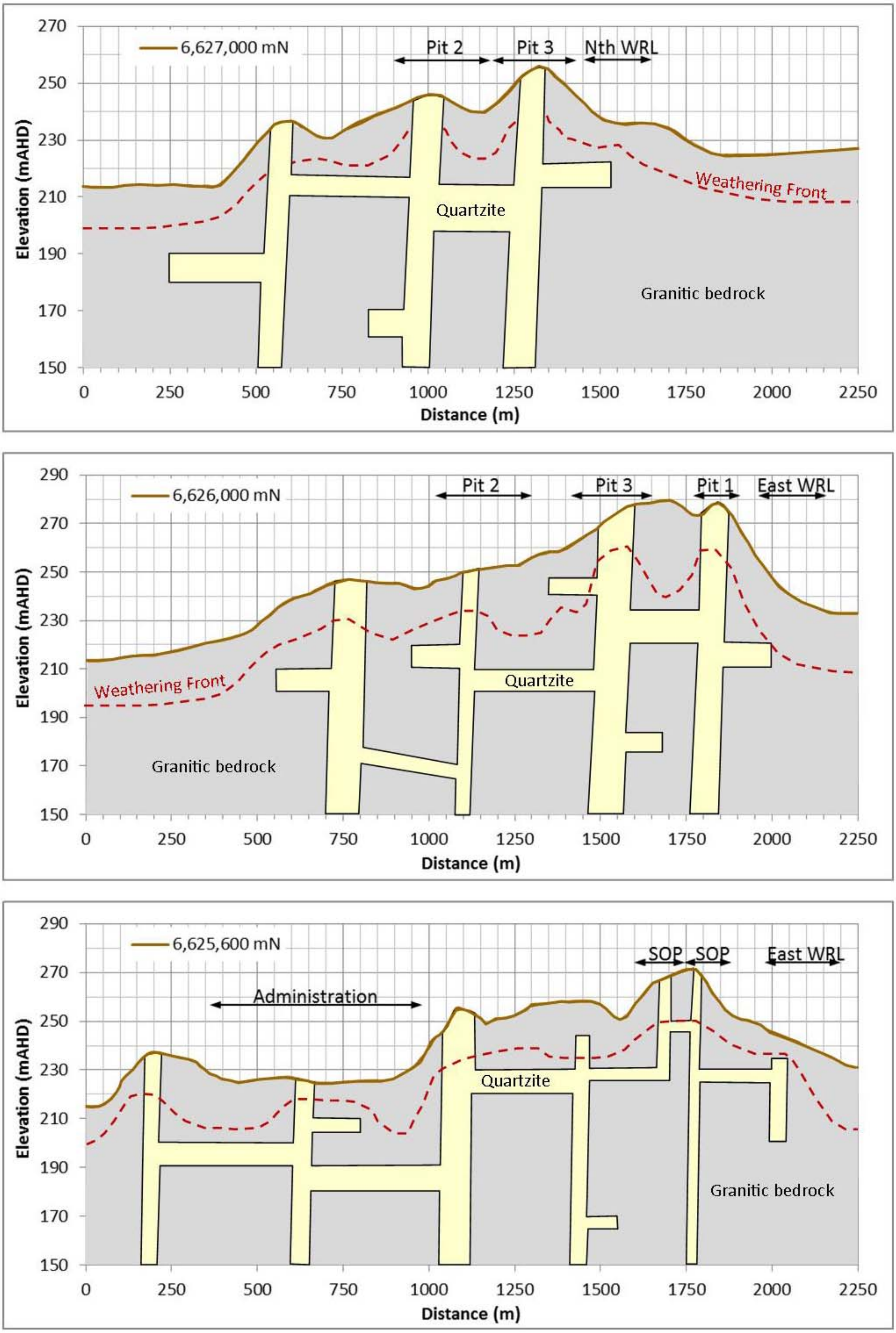
NORTH KIAKA SOIL CHARACTERISATION

Figure 3.3: Regional soils across the Project Area

soilwater GROUP



GHD	Figure 3.4: Regional geology across the Project Area	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		



x8.3 vertical exaggeration

GHD	Figure 3.5: Local geology across the Project Area
NORTH KIAKA SOIL CHARACTERISATION	

4 STUDY RESULTS

4.1 SOIL DISTRIBUTION

Based on the field survey and the laboratory results there are three distinct Soil Mapping Units (SMUs) across the Project Area:

- SMU 1: Skeletal Stony Soil
- SMU 2: Shallow Gravelly Duplex
- SMU 3: Deep Gravelly Duplex

The distribution of the three SMUs is shown spatially in and schematically in Figure 4.1 and Figure 4.2, whilst the area of each SMU in the proposed Disturbance Footprint is provided in Table 4.1.

Table 4.1: SMU distribution within the Disturbance Footprint

Mine Feature	SMU 1	SMU 2	SMU 3	TOTAL (ha)
Pit 1	6.63	5.08	0.23	11.94
Pit 2	8.74	8.45	9.25	26.44
Pit 3	9.24	9.38	2.81	21.43
Pit 4	4.91	1.39	0.34	6.64
Small Open Pits (3 in total)	1.39	3.10	0.38	4.87
North WRL	0	0.47	18.12	18.59
East WRL	0	0	13.39	13.39
Process Area & Workshops	0	0.33	2.51	2.84
Administration Area	0	0.04	20.64	20.68
TOTAL (ha)	30.91	28.24	67.67	126.82

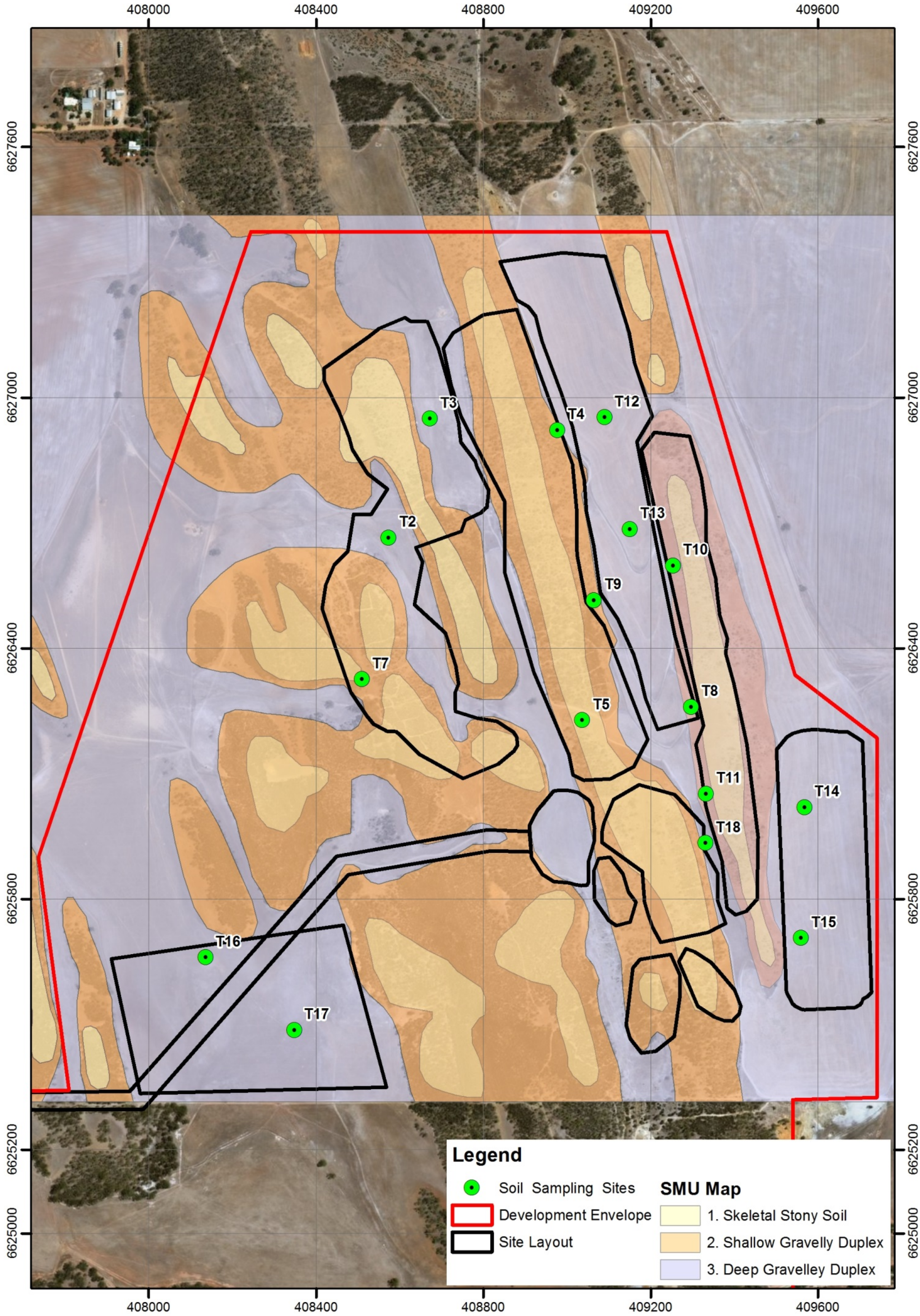
As discussed in Section 3, the geology within the Project Area is relatively simple, comprising only of massive, unweathered quartzite, which form the observed ridges (SMU 1), and adjacent weathered granite, which forms the intervening lower topographic areas. All of the granitic regolith is covered by a surficial gravel layer which shows a defined topographic sequence, such that the gravel layer is thinner and coarser along the ridge crest and upper slope (SMU 2), and is thicker and finer on the mid to lower slope positions (SMU 3).

The relationship of the identified to the SMUs to the WA Soil Groups (Schoknecht and Pathan, 2013) and the Australian Soil Classification (ASC; Isbell, 2002) is provided in Table 4.2.

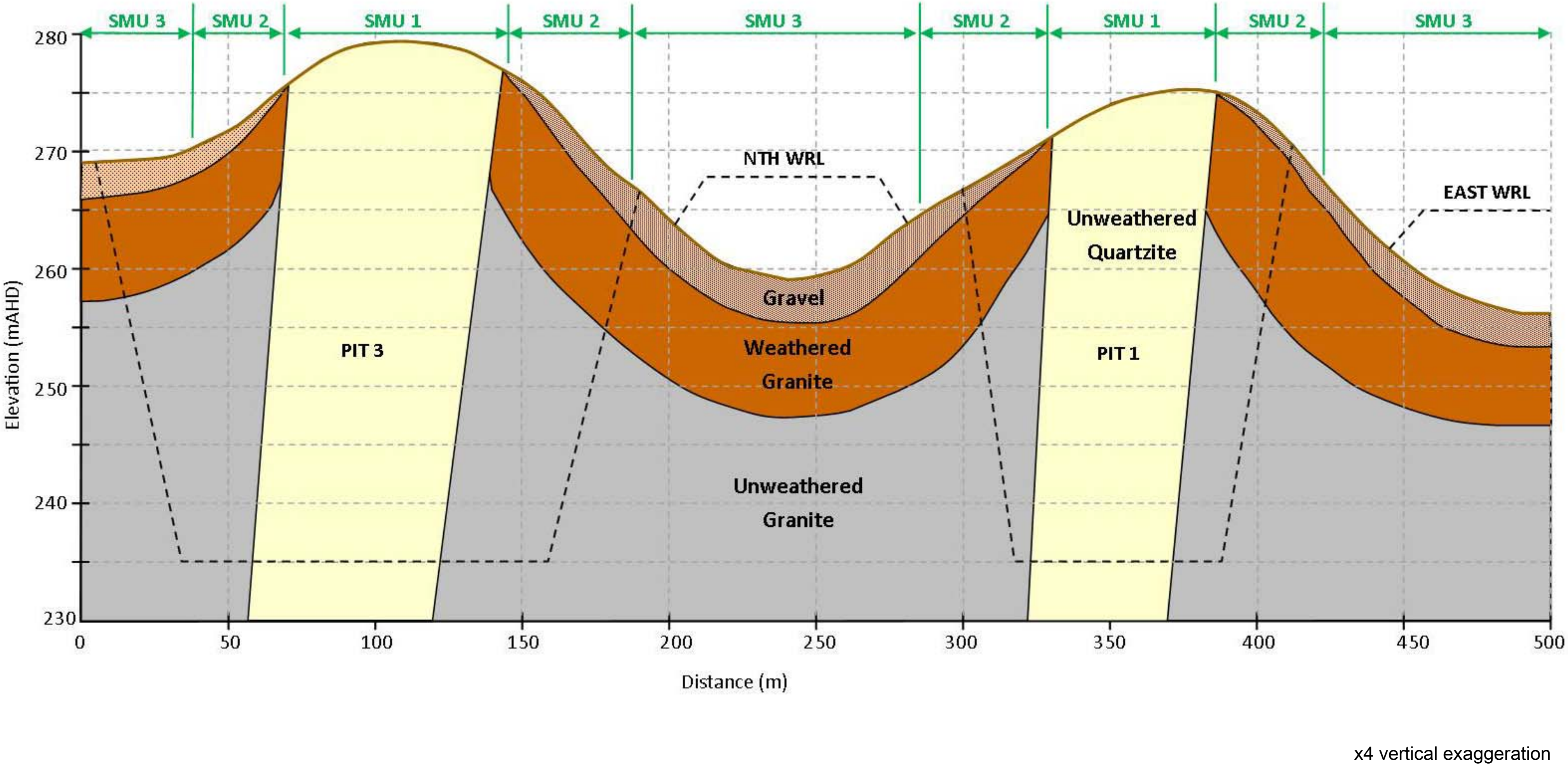
Table 4.2: Relationship between the SMU's, WA Soil Groups and ASC

<table>
<tr><th>SMU</th><th>Parent Geology</th><th>WA Soil Group</th><th>ASC</th></tr>
<tr><td>1. Skeletal Stony Soil</td><td>Quartzite</td><td>Stony Soil</td><td>Lithosolic Clastic Rudosol</td></tr>
<tr><td>2. Shallow Gravelly Duplex</td><td rowspan="2">Granite</td><td>Shallow Gravel</td><td>Ferric Petroferric Tenosol</td></tr>
<tr><td>3. Deep Gravelly Duplex</td><td>Duplex Sandy Gravel</td><td>Ferric Chromosol</td></tr>
</table>

A detailed description of the three SMUs identified within the Project Area are provided in Section 4.1.1 and Section4.1.2.



GHD	Figure 4.1: SMU distribution across the Project Area	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		



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NORTH KIAKA SOIL CHARACTERISATION

Figure 4.2: Soil distribution cross section

soilwater GROUP

4.1.1 SMU 1 – Skeletal Stony Soil

The Skeletal Stony Soils are associated with the outcropping quartzite intrusion, which represents the orebody (Plate 4.1). The surface soils are < 10 cm in depth and are composed of weathered quartzite and organic debris. Given the irregular surface of the outcropping quartzite it would be impractical to try and strip this surface soil (or topsoil) from SMU 1.

Plate 4.1: Skeletal Stony Soils in SMU 1

4.1.2 SMU 2 (Shallow Gravelly Duplex) and SMU 3 (Deep Gravelly Duplex)

SMU 2 and SMU 3 are morphologically and functionally similar, with the only difference being the depth of the surficial gravels. The soil profile in SMU 2 and SMU 3 consists of the following three Soil Material Management Units (SMMUs):

- SMMU 1: Topsoil – Friable sandy gravels, with minor organic accumulation (transported)
- SMMU 2: Subsoil – Friable sandy gravels, with negligible organic accumulation (transported)
- SMMU 3: Overburden – Granitic (mottled) saprolite (*in-situ*)

Characteristic soil profiles for SMU 2 and SMU 3 are shown in Figure 4.3.

The physical, chemical and hydraulic properties of each of these SMMUs are provided in Table 4.3 to Table 4.5. These results highlight the sandy gravelly nature of the Topsoil and Subsoil materials, having been derived from the weathering of the upslope quartzite and deposited onto the lateritised upper portion of the granitic saprolite. The sandy gravels are friable and structurally stable, with Emerson Classes typically between 5 and 6, and have high saturated permeabilities. However, the organic-enriched topsoil exhibits high to severe water repellence which will restrict the infiltration of rainfall, and result in infiltration-excess overland runoff.

Given the high gravel content of the Topsoil and Subsoil materials they contain negligible water holding and plant available water contents, with values of only 6.5 – 8.5 % (or 65 – 85 mm/m) and 5.4 – 6.7 % (or 54 – 67 mm/m), respectively.

In contrast to the surficial gravels, the underlying granitic saprolite contains only minor gravels (10 %; although this may be as high as 25% depending on the extent of lateritisation) and is typically classified as a Sandy Loam. The fine fraction is structurally unstable and will slake and dispersive readily, but this is likely due to lack of salinity in this material, and thus there is insufficient electrolyte concentration to flocculate the clays.

Chemically the gravelly Topsoil and Subsoil materials contain elevated plant available nutrients, with mineralised N (NH4-N and NO3-N) levels up to 20 mg/kg and 10 mg/kg, respectively. Similarly the Colwell P, K and Ext. S are elevated and the Topsoil and Subsoil materials have Organic C contents of 2.6 % and 0.6 %, respectively. The underlying granitic saprolite is considered chemically infertile, with very low levels if plant available nutrients.

All soil materials are slightly to moderately acidic and are non-saline. The CEC values vary from 6.5 meq/100g for the Topsoil to 1.5 meq/100g for Subsoil and 2.9 meq/100g for granitic saprolite. These low CEC values reflect the dominance of kaolinite in the clay mineral structure and the general lack of sodium (Na) in the exchange complex, as shown by the low sodicities (ESP typically below 6).

Table 4.3: Physical properties of the SMMUs within SMU 2 and SMU 3

Parameter	Statistic	Topsoil	Subsoil	Overburden
Gravel content (%)	Min	15	45	< 5
	Max	65	90	25
	Average	**45**	**75**	**10**
% Sand*	Min	81.40	84.61	80.65
	Max	85.43	91.58	83.32
	Average	**83.34**	**88.56**	**81.99**

Parameter	Statistic	Topsoil	Subsoil	Overburden
% Silt*	Min	7.99	5.62	7.18
	Max	10.00	12.14	7.74
	Average	**9.33**	**6.47**	**7.46**
% Clay*	Min	6.80	2.68	8.94
	Max	8.60	9.95	12.17
	Average	**7.33**	**4.97**	**10.55**
Texture*	**Average**	**Loamy Sand**	**Loamy Sand**	**Sandy Loam**
Water Repellence	-	**High**	**Moderate**	**Low**
Emerson Class	-	5 - 6	5 - 6	2 - 3

*<2.36 mm soil fraction

Table 4.4: Chemical properties of the SMMUs within SMU 2 and SMU 3

Parameter	Statistic	Topsoil	Subsoil	Overburden
pH_{Ca}	Min	4.2	4.4	5.4
	Max	6	5.6	5.8
	Average	**5.05**	**4.83**	**5.63**
pH_{W}	Min	5.2	5.1	6.1
	Max	6.6	6.2	6.4
	Average	**5.83**	**5.61**	**6.23**
EC (mS/m)	Min	4.3	1.7	2.4
	Max	13.9	7.1	3.8
	Average	**7.82**	**3.56**	**3**
Nutrients				
NH_4-N (mg/kg)	Min	5	0.5	0.5
	Max	12	20	0.5
	Average	**8.33**	**4.21**	**0.50**
NO_3-N (mg/kg)	Min	14	0.5	1
	Max	31	14	2
	Average	**20.50**	**5.79**	**1.67**
Colwell P (mg/kg)	Min	26	6	1
	Max	54	45	4
	Average	**34.17**	**25.43**	**2.00**
Colwell K (mg/kg)	Min	70	34	23
	Max	178	168	37
	Average	**114.83**	**75.00**	**29.00**
Ext. S (mg/kg)	Min	6.8	2.1	9.5
	Max	15.1	9.4	22.9
	Average	**9.58**	**3.73**	**14.23**
Organic C (%)	Min	1.54	0.1	0.06
	Max	4.96	1.86	0.19

Parameter	Statistic	Topsoil	Subsoil	Overburden
	Average	**2.94**	**0.62**	**0.13**
Exchangeable Cations				
Ca (meq/100g)	Min	2.82	0.3	1.33
	Max	10	2.86	1.58
	Average	**5.39**	**1.06**	**1.47**
Mg (meq/100g)	Min	0.33	0.09	0.69
	Max	1.7	0.34	1.88
	Average	**0.79**	**0.19**	**1.19**
K (meq/100g)	Min	0.14	0.05	0.03
	Max	0.37	0.36	0.06
	Average	**0.24**	**0.15**	**0.04**
Na (meq/100g)	Min	0.09	0.03	0.11
	Max	0.17	0.11	0.22
	Average	**0.12**	**0.06**	**0.15**
CEC (meq/100g)	Min	3.58	0.56	2.19
	Max	12.23	3.67	3.64
	Average	**6.54**	**1.46**	**2.86**
Sodicity (%)	Min	1.31	2.27	3.99
	Max	3.91	8.93	6.04
	Average	**2.15**	**4.81**	**5.32**

Table 4.5: Hydraulic properties of the SMMUs within SMU 2 and SMU 3

Parameter	Statistic	Topsoil	Subsoil	Overburden
Ksat (m/day)	Min	1.1	3.2	0.01
	Max	8.6	11.6	0.1
	Average	**4.2**	**7.8**	**0.05**
Water Retention Properties (adjusted for gravel content)				
0 kPa (%; v/v)	Min	8.2	4.6	35.6
	Max	14.8	12.5	48.5
	Average	**11.0**	**9.2**	**43.6**
10 kPa (%; v/v)	Min	6.4	3.9	21.4
	Max	11.3	10.7	32.6
	Average	**8.5**	**6.5**	**28.2**
33 kPa (%; v/v)	Min	6.1	2.8	19.0
	Max	9.4	8.7	26.5
	Average	**7.6**	**5.8**	**23.9**
100 kPa (%; v/v)	Min	3.2	1.5	15.6
	Max	5.2	4.3	19.5
	Average	**3.7**	**3.2**	**17.8**
1,500 kPa (%; v/v)	Min	1.6	0.9	12.9

Parameter	Statistic	Topsoil	Subsoil	Overburden
	Max	2.2	2.5	13.8
	Average	**1.8**	**1.1**	**13.5**
PAWC (%; v/v)	Min	4.8	3.0	8.5
	Max	9.1	8.25	18.8
	Average	**6.7**	**5.4**	**14.7**

4.2 EROSION TESTING

Laboratory-scale erosion tests were undertaken on bulk composites taken of the following material types:

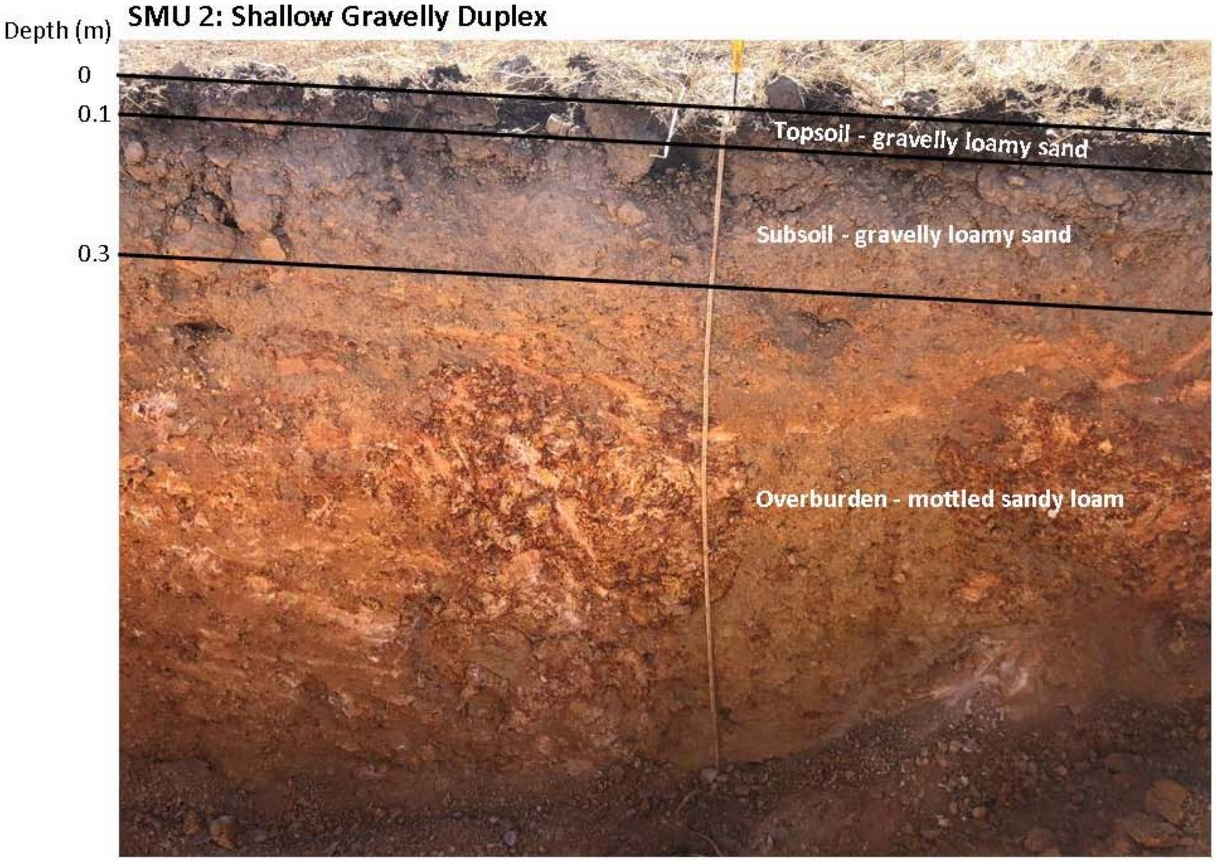
- Topsoil,
- Subsoil, and
- Weathered Granite.

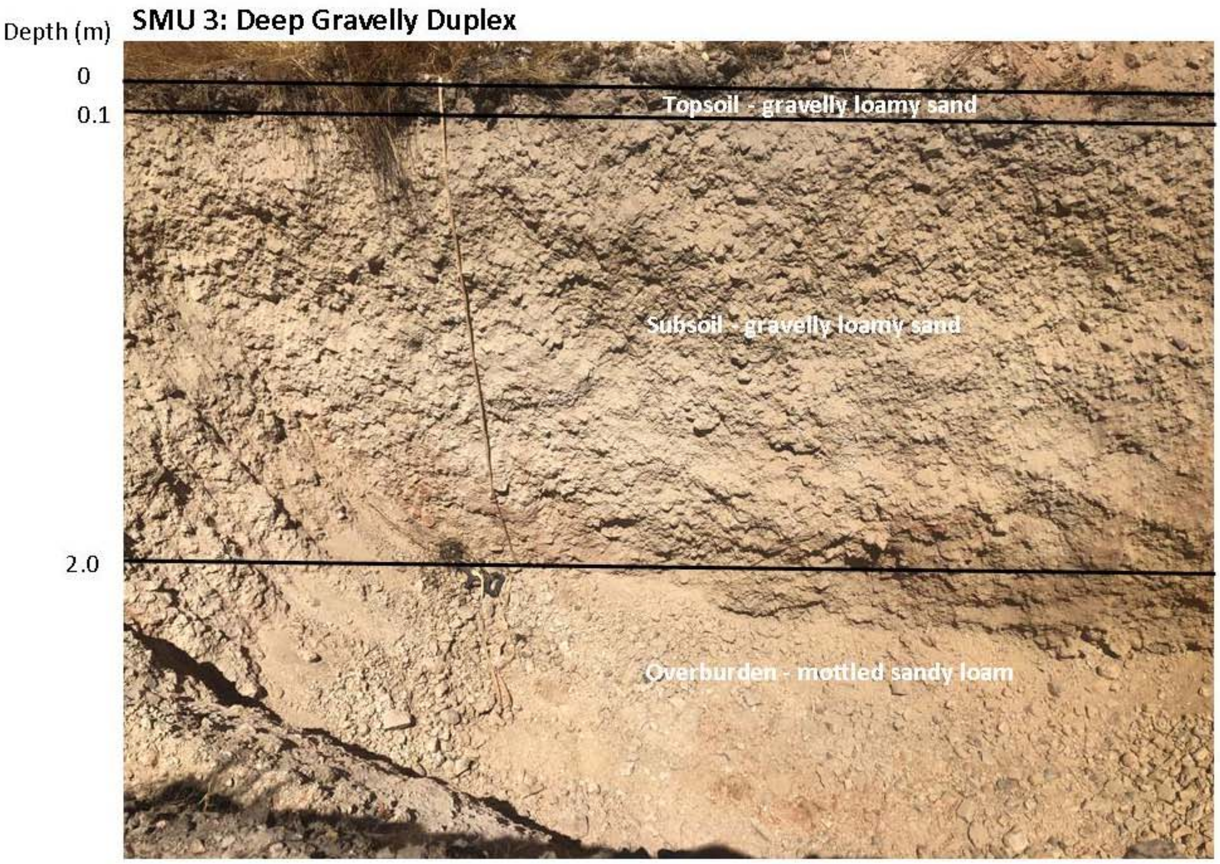
The objective of the testing was to establish the erosion potential for the range of soil materials most likely to be used as surface cover for the Waste Dump(s).

4.2.1 Rainfall Simulator

A laboratory-scale rainfall simulator (Plate 4.2) was used to measure the interrill (raindrop impact) erodibility of each material. The rainfall simulator was designed to apply water at an intensity of approximately 85-100 mm/hr, with a raindrop size and spatial distribution closely resembling natural rainfall. An intensity of 85 mm/hr corresponds to a 1:10, 1:20 and 1:100 year ARI storm event of approximately 6, 10, and 20 min duration, respectively, for this region.

Plate 4.2: Laboratory rainfall simulator.





GHD	Figure 4.3: Characteristic soil profiles for SMU 2 and 3	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		

Prior to testing, each material was placed into a 0.75 x 0.75 x 0.20 m container and lightly compacted to approximate the expected field conditions. The base of the container was free draining to avoid saturated conditions and air entrapment within the samples. Each material was pre-treated by sequentially wetting and drying the surface to allow natural organisation and settling of the soil particles, with a final bulk density of approximately 1.8 g/cm3 being achieved.

The container was set at a slope angle of 15°, and the materials were subjected to a simulated rainfall of approximately 85 mm/hr, and 10 samples of the resulting surface runoff were collected over a 4 hour period. Runoff volume and sediment loss in each sample were determined gravimetrically. Measurements from the rainfall simulator were used to calculate soil erodibility parameters required for the WEPP erosion model. The methods used for calculating these parameters are discussed further in Section 4.3.

4.2.2 Rill erosion measurements

Laboratory scale testing was completed to measure the rill erodibility (Kr) and critical shear stress (τC) of the materials under overland flow conditions. The laboratory testing was designed to expose the materials to a range of overland flows to simulate storm events of different sizes, and to measure the resulting sediment content in the surface runoff, generated by rill erosion.

An erosion flume was used to subject each material to 5 different overland flow rates (Plate 4.3), and the following measurements were made in triplicates for each:

- A timed sample of the resulting surface runoff was collected. Surface flow rate and sediment loss were then determined gravimetrically.
- A measurement of average flow velocity was made visually, using a blue dye and stopwatch according to the method described by Zhang *et al* (2010).
- Measurements of rill width were made at three standardised locations along the rill.

Measurements from the erosion flume were used to calculate rill erodibility parameters required for the WEPP erosion model. The methods used for calculating these parameters are discussed further in Section 4.3.

4.3 EROSION MODELLING

The Watershed Erosion Prediction Project (WEPP) (Flanagan and Livingston, 1995) model was used to predict the long-term (100 year duration) erosion rates from the surface of the proposed waste rock landforms. The WEPP model used a series of input files describing the soils, climate, slope geometry, and land management regime for the site. Model input values and assumptions are discussed in the following sections.

4.3.1 Climate Data

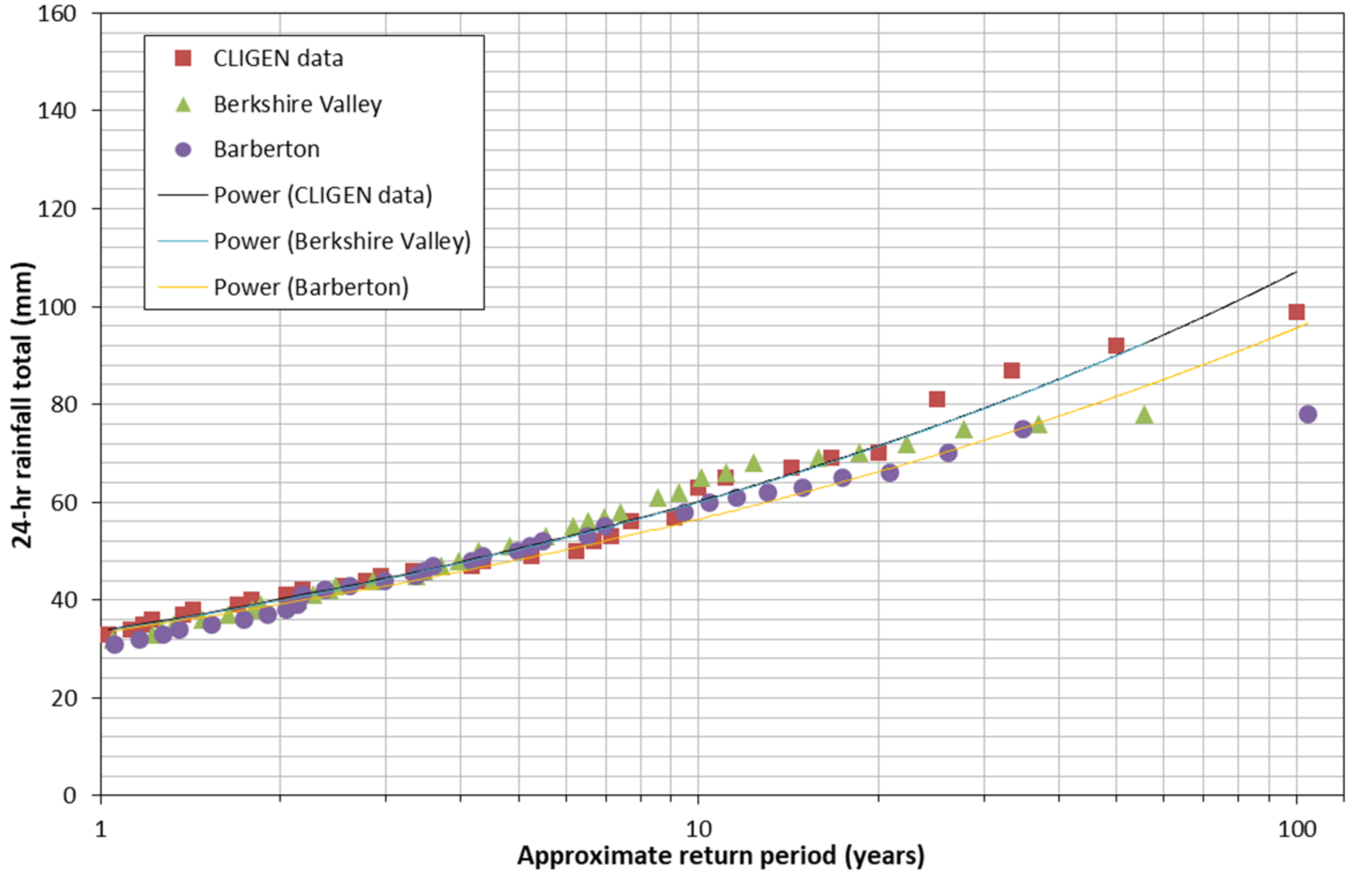
A synthetic climate file was generated using the CLIGEN stochastic weather generator (Yu, 2003), and was used in the WEPP model to simulate 100 years of rainfall, runoff, and erosion. The following climate data was input to CLIGEN to generate this file from BOM station 8297 (Dalwallinu):

- 0.5 hourly rainfall data from Jan 1997 to Mar 2019.
- Daily rainfall, maximum and minimum temperatures and solar radiation.
- As the Dalwallinu climate station is located only approximately 30 km from the Project, the climate data is considered sufficiently representative to form the baseline data when creating a reliable CLIGEN climate file

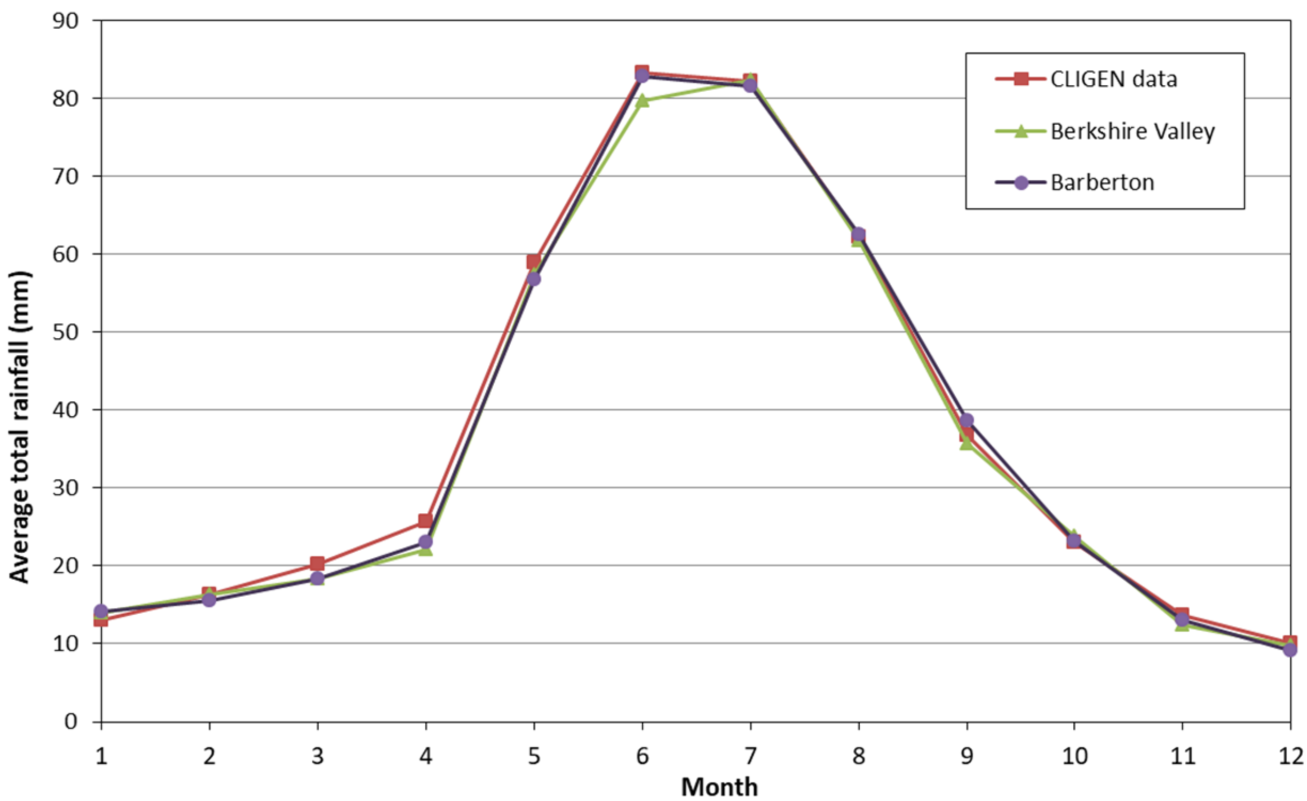
- An analysis of the available data from Berkshire Valley (BOM station #8008); 15 km west of the Project Area and Barberton (BOM station #8005); 15 km south suggests that the CLIGEN file generated from the Dalwallinu data is consistent with local weather patterns. Figure 3.2 compares the frequency of 24-hour rainfall totals, indicating that larger 24-hour storms occur at a similar frequency in the measured local data as in the CLIGEN file. Figure 3.3 compares the monthly and annual rainfall depths, and shows that the CLIGEN file captures a similar degree of variability in rainfall depths within and between years as was observed over the previous 100 years at Berkshire Valley and Barberton.

Plate 4.3: Laboratory-scale, rill erosion flume

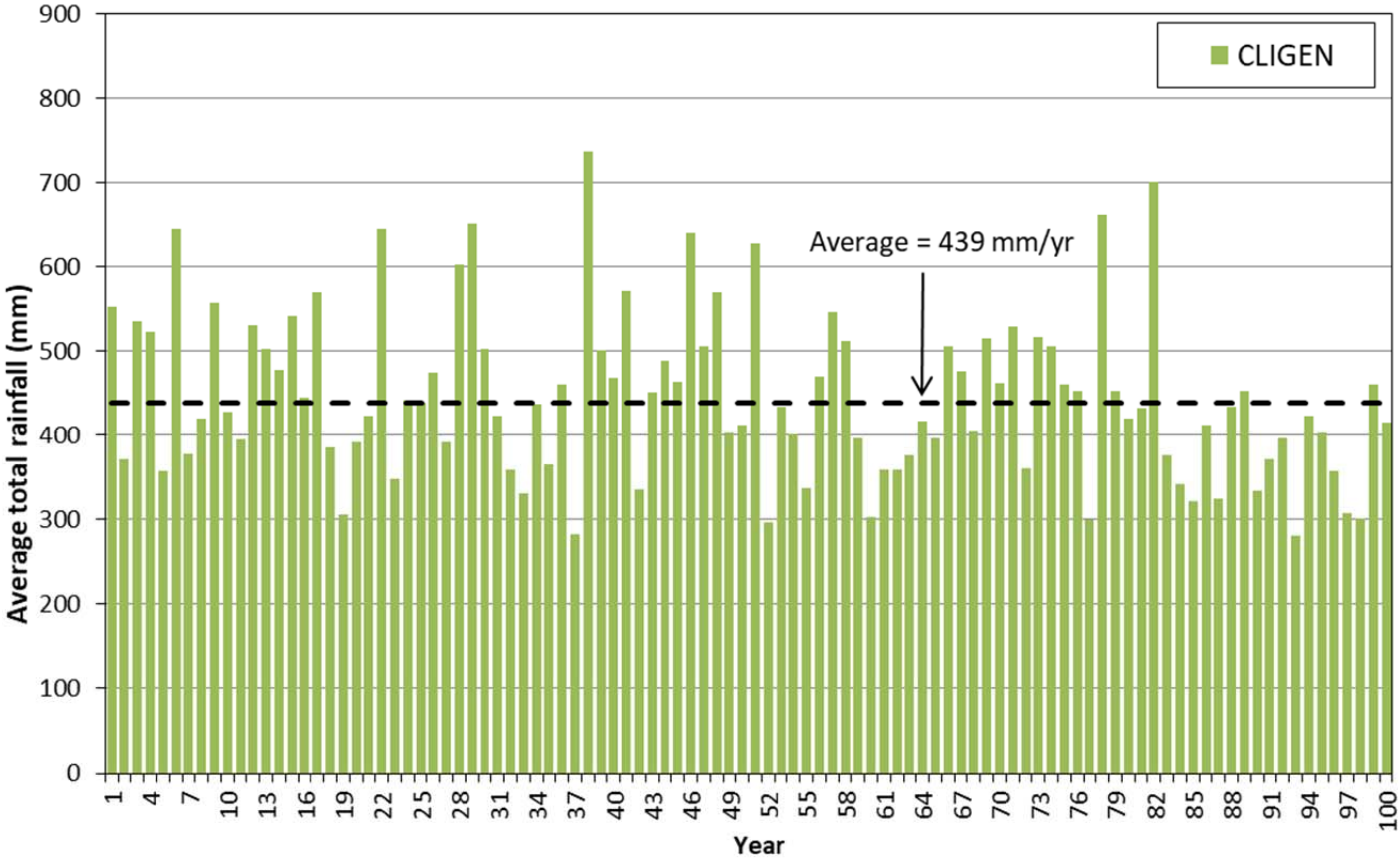
A)

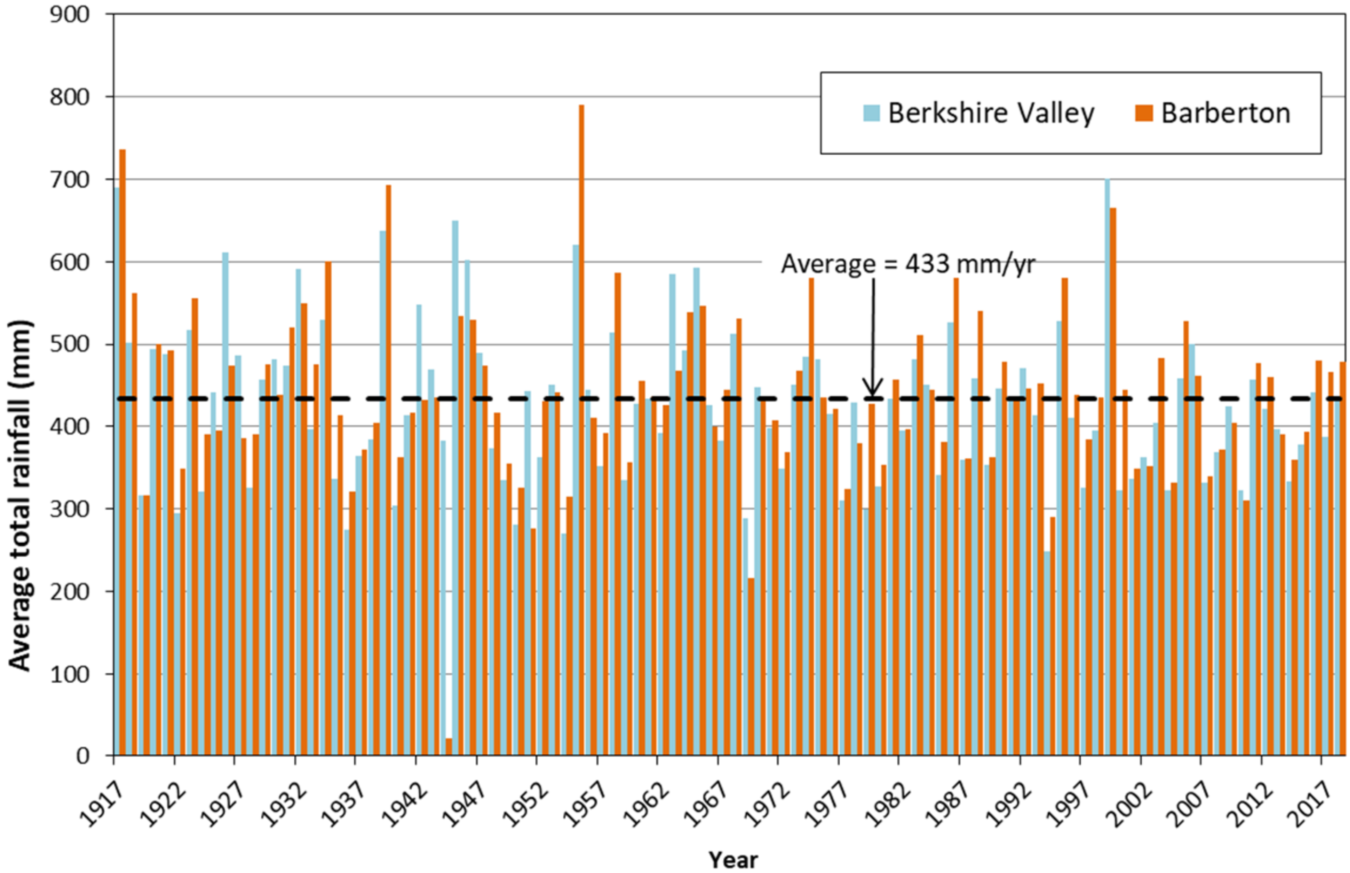


B)



GHD	Figure 4.4: a) 24-hour and b) mean monthly rainfall data	soilwater GROUP
NORTH KIAKA SOIL CHARACTERISATION		





GHD	Figure 4.5: Annual rainfall data	
NORTH KIAKA SOIL CHARACTERISATION		

4.3.2 Soil Parameters

The soil parameters required by WEPP were derived from the laboratory testing undertaken at SWA Laboratories. These parameters include the particle size distribution, effective hydraulic conductivity (Keff), interrill erodibility (Ki), rill erodibility (Kr), and soil critical shear stress (τC), and are summarised in Table 4.6.

Keff was estimated by fitting the Green-Ampt equation (Green and Ampt, 1911) to the measured infiltration rates using Equation 1:

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

where:
- f = infiltration rate (mm/h)
- Keff = effective saturated hydraulic conductivity (mm/h)
- Ns = effective matric potential at the wetting front (m), and
- F = cumulative infiltration (m).

K_i was calculated from the inter-rill erosion rate measured in the rainfall simulator, according to Elliott *et al.* (1989) using Equation 2:

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

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

K_r and τ_C were determined from the shear stress (τ) and rill erosion rate (D_c) measurements collected in the laboratory. This was done by a linear regression analysis according to the method described by Foster (1982) and Elliott *et al.* (1989). The rill erodibility parameters are related to the measured parameters τ and Dc by Equation 3:

$$D_c = K_r \left(\tau - \tau_C\right) \qquad \text{Equation 3}$$

where:
- D_c = measured erosion rate (kg/m2 s)
- K_r = rill erodibility (s/m)
- τ = measured shear stress (Pa), and
- τ_C = critical shear stress (Pa).

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

Table 4.6: Key soil parameters used in the WEPP model.

Material ID	Sand (%)	Clay (%)	OM (%)	CEC [meq/100g]	K_{eff} (mm/hr)	K_i (Kg s / m^4)	K_r (s / m)	τ_C (Pa)
Topsoil	83	7	2.94	6.54	21.7	5.2	0.0016	3.3
Subsoil	84	8	0.62	1.46	20.2	12	0.0341	1.1
Weathered Granite	82	10	0.13	2.86	68.1	17	0.0394	6.0

4.3.3 Slope Properties

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

4.3.4 Management Assumptions

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

- A pre-consolidated soil surface. This means that no further settling is simulated within the model, and that the measured infiltration rates and runoff characteristics apply for the duration of the model (i.e., no further changes in these properties with time). This is reasonable because the laboratory measurements (from which the input parameters were derived) were conducted on pre-consolidated soil samples.
- No vegetation. This assumption will result in conservative (i.e. "worst-case") erosion results, and will apply to the landform during the period prior to re-vegetation establishment. Subsequent vegetation growth is likely to act to enhance the stability of the landform by dissipating rainfall impact energy, producing leaf litter as a ground cover, and stabilising the sub-surface and improving infiltration with root growth. The degree of stabilisation will depend on the types of vegetation used, and their rates of establishment.
- Zero initial surface cover (i.e. no woody debris or plant litter). This means that no additional surface cover was expected to be added to the soil surface to reduce erosion rates. This assumption does not have any impact on the armouring effect of the rock and gravel fraction in the soil, which is already accounted for within the measured soil parameters discussed in Section 4.3.2.
- Expected rill geometry is adjusted internally in the model based on the input soil parameters and on the size of the erosion events encountered.

4.3.5 Erosion Modelling Results

Table 4.7 summarises the average runoff and sediment yield values predicted by the WEPP erosion model, given the input parameters previously summarised in Section 4.3.

The WEPP model indicated that the lowest average sediment yields of <3 t/ha/yr were reported for the Gravelly Subsoil under both slope configurations tested, indicating that this material can be considered highly erosion resistant, and is expected to perform well on the slopes of waste landforms. The Gravelly Subsoil was seen to readily self-armour (Plate 4.4), and subsequently showed a high degree of resistance to erosion, producing a maximum of 3.0 t/ha/yr from the range of potential slope configurations tested. This is considered a very low erosion rate for material under these conditions.

As expected the granitic saprolite performed the worst, in response to its structural instability and elevated silt and clay contents. Interestingly, the Gravelly Topsoil performed worse that the equivalent Gravelly Subsoil, and this is due to the high water repellence of the Topsoil materials.

Table 4.7: Summary of WEPP erosion modelling results

Material Type	Lift height (m)	Slope angle	Average annual runoff (mm/yr)	Average erosion rate (mm/yr)	Average erosion rate (t/ha/yr)
Topsoil	10	15°	7	0.2	2.0
		18°	9	0.3	5.1
	20	15°	5	0.4	6.4
		18°	12	0.6	10.1
Subsoil	10	15°	2	0.1	1.9
		18°	2	0.1	1.9
	20	15°	2	0.2	2.9
		18°	3	0.2	3.0
Weathered Granite	10	15°	8	0.3	4.9
		18°	10	0.5	8.1
	20	15°	7	0.8	12.1
		18°	14	1.2	18.5

Plate 4.4: Self-armouring of gravelly material during erosion testing

5 SOIL MANAGEMENT

5.1 REHABILITATION RESOURCES

As shown in Table 4.1, the majority of the areas within the proposed mine pits belong to SMU 1 (Skeletal Stony Soils) and SMU 2 (Shallow Gravelly Duplex). As specified in Section 4.1.1, there is limited ability to strip soils from SMU 1 due to the outcropping quartzite. The total area of SMU 1 within the proposed mine pits is approximately 31 ha, which is around 43 % of the total mine pit area. SMU 2 covers a further 24.3 ha of the proposed mine pits (34 % of the total mine pit area). Based on the dominance of SMU 1 and 2 within the mine pits, close to 80 % of the mine pit areas will only yield minimal soil resources for use in rehabilitation. It is therefore likely that there will be a shortage of rehabilitation resources, and highlights the need to strip the gravelly subsoils below the proposed WRLs to obtain sufficient resources to effectively rehabilitate the WRLs.

The estimated soil resources that are likely to be captured for rehabilitation purposes are provided in Table 5.1. The estimated volumes are based on the following stripping depths:

- Topsoil (SMU 2 and 3): 10 cm (0-10 cm depth)
- Subsoil: SMU 2 = 20 cm (10-30 cm depth); SMU 3: 30 cm (10-40 cm depth)

It is important to note that surface soils stripped from the Administration Area, Process Area and Workshops, and the Access Corridor will simply be stockpiled around the perimeter of these areas for later return during rehabilitation works; hence they are not factored into any rehabilitation resource material balance.

Table 5.1: Proposed rehabilitation resources to be captured

Mine Feature	Total Area to be Stripped (ha)	SMU 1 (m^3)	SMU 2		SMU 3		TOTAL (m^3)
			Topsoil (m^3)	Subsoil (m^3)	Topsoil (m^3)	Subsoil (m^3)	
Pit 1	5.3	0	5,080	10,160	230	690	16,160
Pit 2	17.7	0	8,450	16,900	9,250	27,750	62,350
Pit 3	12.2	0	9,380	18,760	2,810	8,430	39,380
Pit 4	1.7	0	1,390	2,780	340	1,020	5,530
Small Open Pits	3.5	0	3,100	6,200	380	1,140	10,820
North WRL	18.6	0	470	940	18,120	54,360	73,890
East WRL	13.4	0	0	0	13,390	40,170	53,560
TOTAL	72.4	0	27,870	55,740	44,520	133,560	261,690

5.2 REHABILITATION REQUIREMENTS

Assuming that no backfilling of mine pits will occur, all of the excavated soil and waste material will be permanently stored in either the North or East WRL. Given the disturbance footprint of these features, and allowing for a 30 % increase in surface area when the WRL is constructed, the total surface area to be rehabilitated for the two WRLs is:

- North WRL: 24.2 ha
- East WRL: 17.4 ha

If the rehabilitation profile is to consist of 0.1 m of Topsoil and 0.4 m of Subsoil, then the required rehabilitation resources are provided in Table 5.2. As can be seen, a total of 208,000 m^3 of soil will be required to effectively rehabilitate both the North and East WRLs, comprising 41,600 m^3 of Topsoil and 166,400 m^3 of subsoil.

When the rehabilitation requirements specified in Table 5.2 (208,000 m^3) are compared with the available rehabilitation resources from the open pits (147,250 m^3), it is clear there is a deficit of soil resources. It is therefore imperative that the topsoil and some of the subsoil is stripped from the WRL areas to ensure sufficient soil resources are available for rehabilitation.

Table 5.2: Rehabilitation resource requirements

Feature	Rehabilitation Area (ha)	Topsoil (m^3)	Subsoil (m^3)	TOTAL (m^3)
North WRL	24.2	24,200	96,800	121,000
East WRL	17.4	17,400	69,600	87,000
TOTAL (m^3)	41.6	41,600	166,400	208,000

5.3 HANDLING AND UTILISATION

Based on the results of this study the following materials management strategies are recommended:

- All gravelly soils (Topsoil and Subsoil) are structurally stable and friable and represent optimal soil materials for use in rehabilitation of the outer surface of the WRLs.
- All granitic saprolite is structurally unstable, dispersive and highly erodible, and therefore should not be used in the reconstruction of the outer surfaces of the WRLs.
- Given the limited water holding and plant available water content of the gravelly soils, it is recommended that only small (i.e. < 30 cm) shallow-rooted revegetation species are used on the batter slopes to ensure the sustainability of the rehabilitation. Taller (i.e. > 50 cm high), higher water holding capacity revegetation species should be restricted to the flat berms and WRL top as the vertical infiltration into the deeper soil profile will support the transpiration requirements of these species.
- Based on the erosion testing and modelling, a batter slope of 18° is acceptable to produce a stable and sustainable WRL at closure.

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