SOILWATER CONSULTANTS

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

MEMO

TO:	Justin Robins	COMPANY:	ABM Resources	
FROM:	Joe Powers	PROJECT TITLE:	Twin Bonanza Soil Assessment	
DATE:	12 December 2013	PROJECT & DOCUMENT NO:	ABM-002-01-01	001
SUBJECT:	Twin Bonanza Soil Assessment and Erosion Study			

Justin,

Soilwater Consultants (SWC) were engaged to undertake a pre-mine soils assessment for the proposed Twin Bonanza Gold Project (TBGP). This study was intended to identify the surficial soil materials present with the Project Area, and to characterise their physical, chemical, and hydraulic properties so that their behaviour during mining, waste dump construction, and rehabilitation is known and predictable.

1 STUDY OVERVIEW

This study focused primarily on the properties of the *in situ* soils, and was confined to the main project disturbance areas (Figure 1). In order to further refine the distribution and properties of the orebody, ABM undertook a surficial (< 2 m depth) trenching program across the proposed deposit/s; this trenching exposed the *in situ* surficial soil profile and provided an ideal scenario in which to examine and sample the surface soils from the proposed pit areas to determine their nature and distribution. Sampling of the exposed *in situ* soils was conducted by ABM personnel, with11 samples being collected from four locations within the proposed pit disturbance areas (Table 1; Figure 1). A depth profile was sampled at 10 cm depth increments at one of the locations to examine any pedogenic organisation and development, while surface spot samples were collected at the other 3 locations.

Table 1: Samples collected for the soil assessment study

Coordinates (GDA94 Zone 52)		Sampling Depth (m)
Easting	Northing	
516690	7767839	0.1 - 1.35
516751	7767879	0.0 - 0.1
516654	7767728	0.0 - 0.1
516824	7766875	0.0 - 0.1

Samples collected in the field were analysed for a range of physical, chemical, and hydraulic properties (see Table 2). Analysis of the physical and hydraulic properties was undertaken at Soil Water Analysis (SWA) Laboratories, whilst all chemical analysis was completed at Chemistry Centre of Western Australia Laboratories (ChemCentre). Erosion and landscape evolution modelling (using SIBERIA; Willgoose (2005)) was conducted by SWC using the results of the physical and chemical analysis, to assess the long-term stability of the proposed waste rock landform (WRL) design.

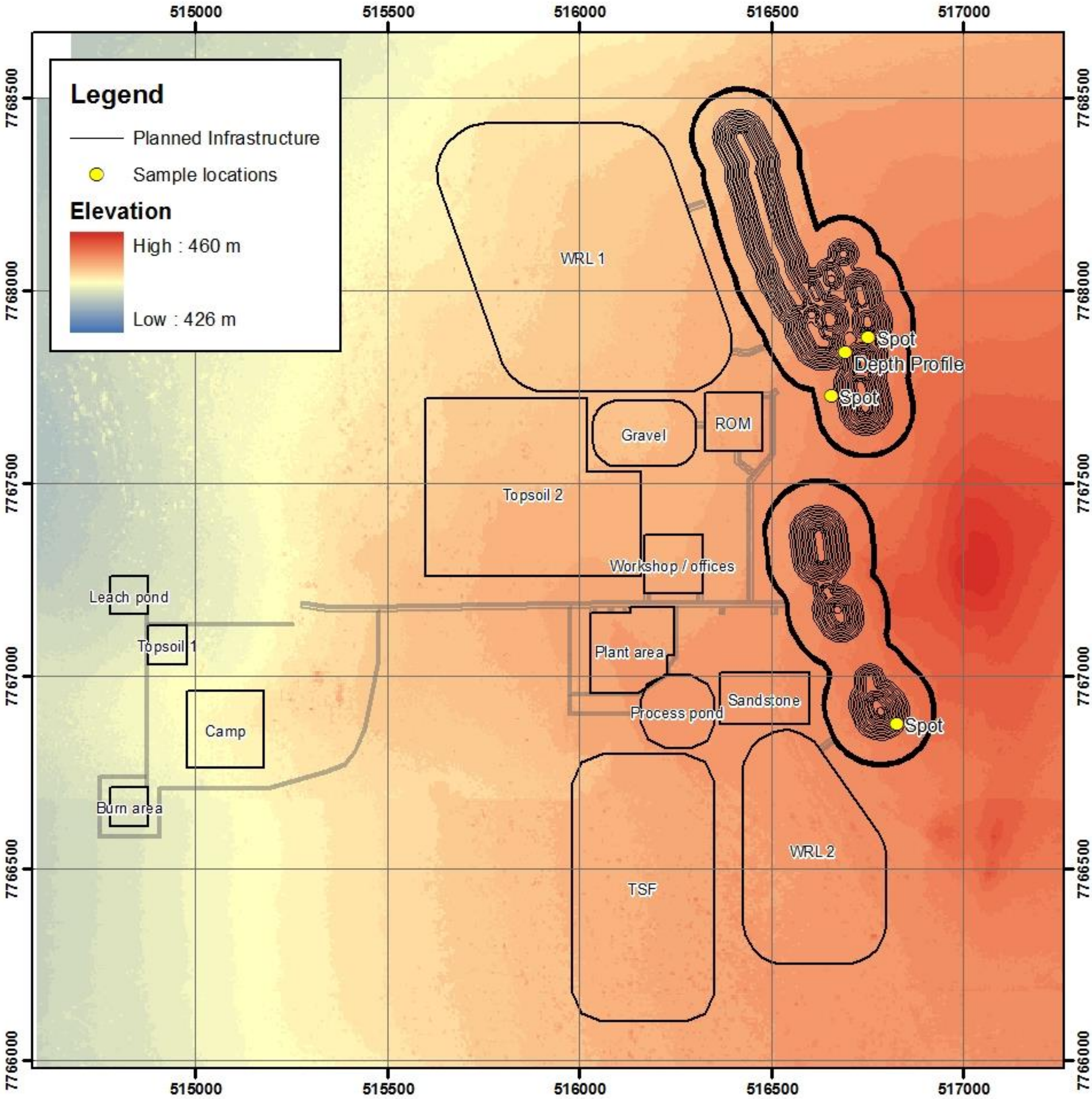


Figure 1: Site layout and soil sampling locations

Table 2: Laboratory analysis conducted on the soil samples

Physical properties	Chemical properties
Particle size distribution (PSD)	pH
Gravel content	Electrical conductivity (EC)
Erosion characteristics	Nitrate and Ammonium
	Organic Carbon (OC)
	‘Mehlich 3’ nutrient suite (B, Ca, Co, Cu, Fe, K, Mg, Mn, Mo, P, Na, S, Zn)
	Exchangeable cations

2 MORPHOLOGICAL AND PHYSICAL PROPERTIES

A characteristic soil profile from the site is shown in Figure 2, and typical physical properties exhibited by the soils are summarised in Table 3. The soil profile is characterised as a shallow sandy loam, consisting of surficial red sandy loam cover (i.e. upper 30 – 50 cm), overlying a partially to completely weathered sandstone (i.e. reflects a saprock or transition material). Plant roots were present throughout the sampled profile.

The surficial cover material contains a significant residual gravel fraction (15 – 40 % gravel), with generally fewer gravels present in the underlying weathered transition zone (5 – 25 %). The underlying *in situ* sandstone is considered to be well cemented, but a high proportion of gravel (55 – 65 %) was measured in the laboratory sample, which is thought to be representative of the properties of this material once broken up during excavation.

Table 3: Particle size distribution profile

Depth (cm)	Texture	% Sand	% Silt	% Clay	%Gravel
0 – 10	Loamy sand	87.2	5.0	7.9	17.5
10 – 20	Sandy loam	81.8	6.7	11.5	43.9
20 – 30	Sandy loam	76.4	11.7	11.9	16.9
30 – 40	Loam	73.9	13.9	12.1	5.7
40 – 50	Loamy Sand	69.2	20.6	10.1	2.3
50 – 60	Loam	62.2	21.4	16.4	25.4
60 – 70	Loam	58.4	19.5	22.1	56.9
70 – 80	Loam	60.3	18.7	21.0	54.4
100 – 130	Loam	75.2	12.9	11.9	66.8

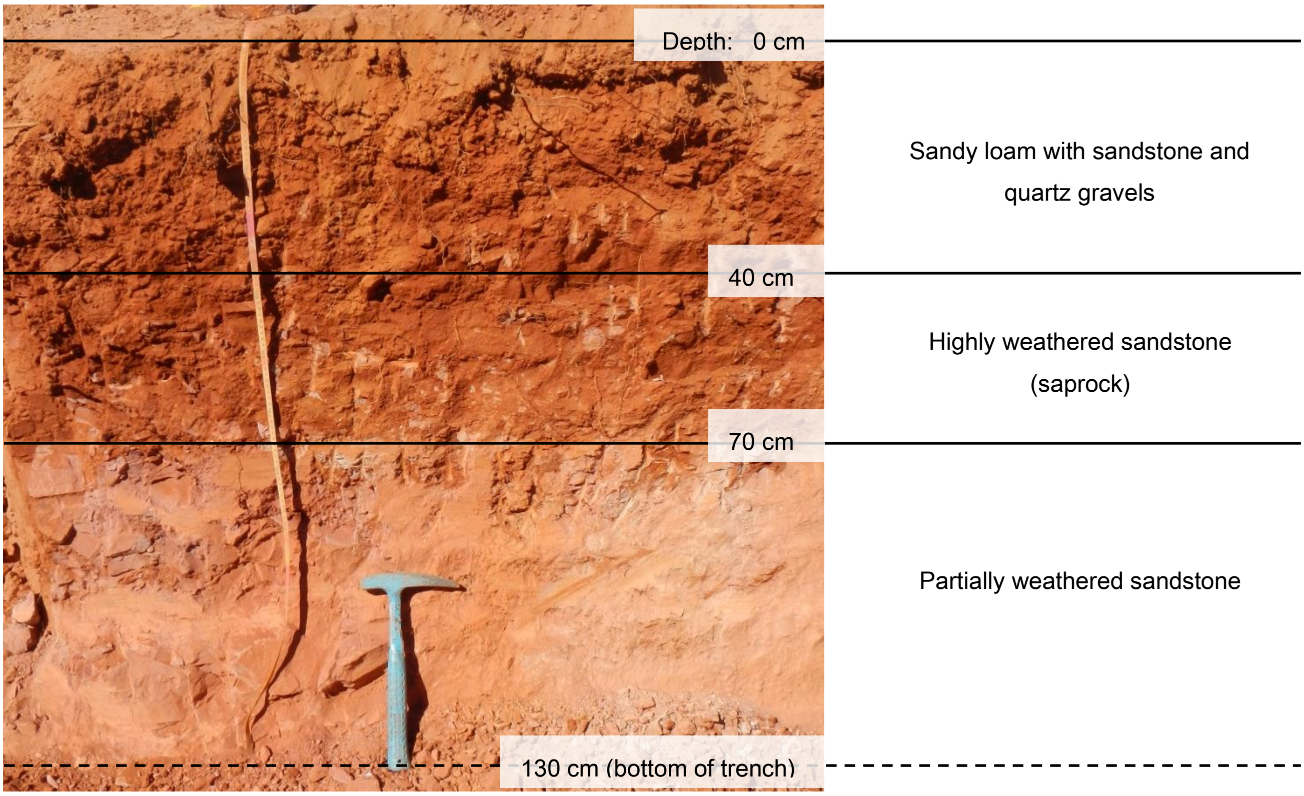


Figure 2: The sampled soil profile

3 CHEMICAL PROPERTIES

The characteristic soil chemical properties of the soils are summarised in Table 4 and Table 5, and a pH and EC depth profile is presented in Figure 3.

In general, the surficial cover material is strongly acidic (pH = 4.0 – 4.9), while the underlying sandstone is moderately alkaline (pH = 8.2 at 135 cm depth). The majority of salts appear to have been leached from the measured profile, and the surface soils are subsequently considered non-saline (EC < 40 mS/m), and non-sodic (ESP < 6 %). The soils are generally low in nutrients and organic carbon highlighting their low chemical fertility and lack of pedogenic development.

Cation exchange capacity (CEC) of the surface soils was low (< 5 meq/100g), with the exchange complex dominated by calcium and magnesium cations (50 – 70 % Ca and 20 – 30 % Mg). This low CEC implies that kaolinite is the dominant clay mineral, and thus these materials are likely to be macro-structurally unstable, with the individual clay plates wanting to separate and mobilise (Note: this is different from micro-structural dispersion caused by elevated Na levels).

Table 4: Nutrients analysis summary

Depth (cm)	NH4-N (mg/kg)	NO3-N (mg/kg)	P (mg/kg)	K (mg/kg)	S (mg/kg)	OC (%)
0 – 10	2.0	20.3	1.7	72	4	0.3
30 – 40	2.0	1.0	< 1.0	55	8	0.2
60 – 70	1.0	< 1.0	< 1.0	77	13	0.2
100 – 130	< 1.0	2.0	< 1.0	70	20	0.1

Table 5: Exchangeable cations

Depth (cm)	Ca (meq/100g)	K (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC (meq/100g)	ESP (%)
0 – 10	1.21	0.18	0.50	0.05	1.90	0.0 %
30 – 40	0.63	0.12	0.30	< 0.02	1.05	0.0 %
60 – 70	1.60	0.17	0.91	0.03	2.71	1.1 %
100 – 130	2.60	0.19	1.20	0.17	4.16	4.1 %

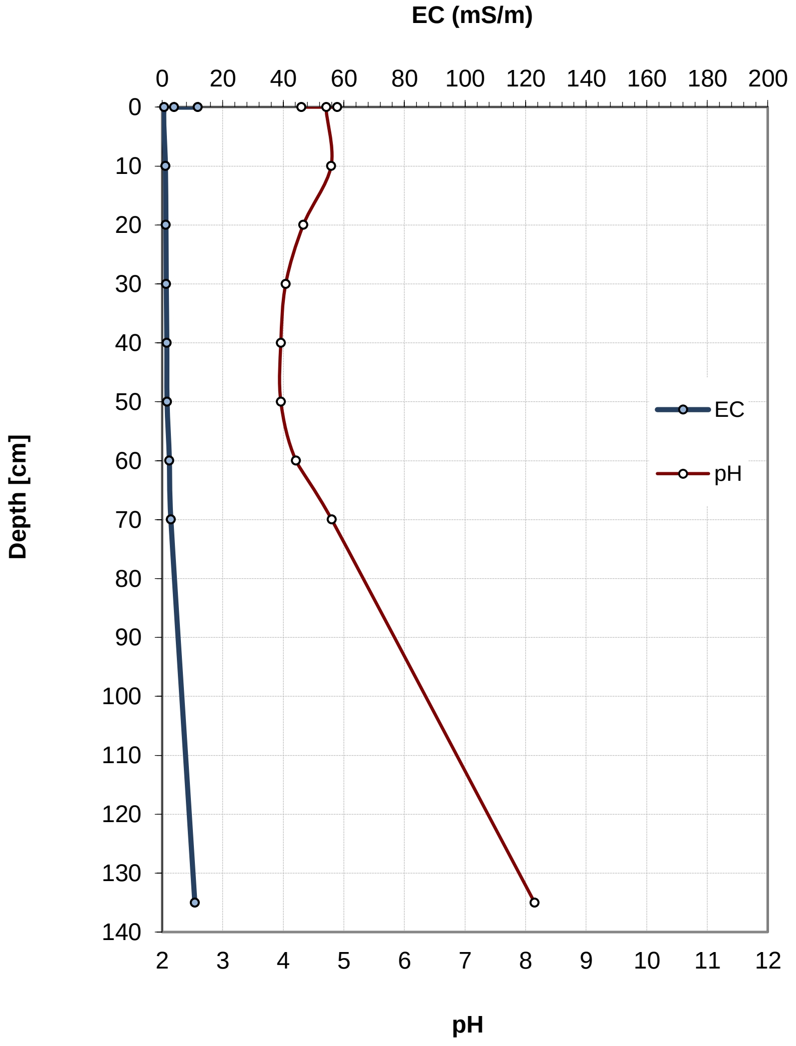


Figure 3: pH and EC depth profile

4 SOIL EROSION POTENTIAL

An analysis of dispersion potential was made using a method based on the work of Rengasamy and Greene *et al.* (1984) (Figure 4). This analysis showed that all of the sampled soils were considered to fall within Dispersion Class 2a. This means that most of the topsoils are potentially dispersive after mechanical disturbance of the soil structure (i.e. after excavation and stockpiling). This classification is mainly attributed to the lack of salts within the soil solution to facilitate aggregation and flocculation of clays. Thus, soils containing the largest fractions of clay (i.e. the weathered "transition" layer) are at the greatest risk of dispersion. Conversely, soils containing larger fractions of gravel will be at the least risk of the effects of dispersion. The topsoils (0 – 30 cm depth) and sandstone (> 100 cm depth) are therefore expected to be the least affected by dispersion because of the moderate clay content and significant gravel content in these soil horizons.

A visual assessment of slaking and dispersion was also conducted by SWA. This assessment indicated that the soils were prone to slaking, but did not readily disperse; supporting the CEC results that the clay mineral fraction is dominated by kaolinite. This indicates a level of susceptibility to structural degradation in the presence of water, although very little true dispersion of the clay fraction was observed.

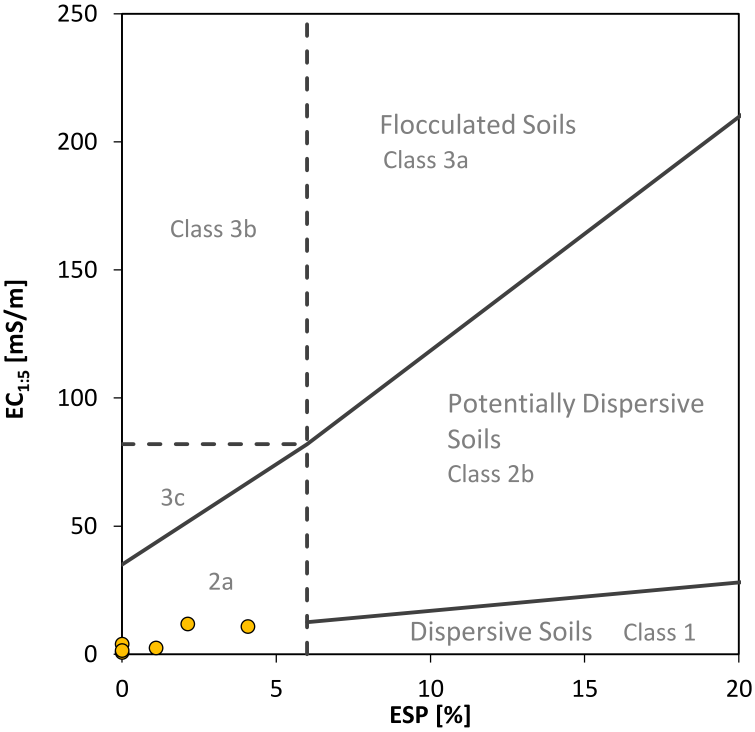


Figure 4: Clay dispersion potential

Table 6: Slaking and dispersion test results

Depth (cm)	Slaking (15 min)	Slaking (24 hr)	Dispersion (15 min)	Dispersion (24 hr)
0 – 10	Complete	Complete	Slight	Slight
30 – 40	Moderate	Complete	None	None
60 – 70	Moderate	Complete	None	None

Laboratory-scale erosion testing was conducted on a sandstone material, as this was considered the most suitable and widely available material for reconstructing the outer surfaces of the post-mine landforms. A laboratory-scale rainfall simulator was used to measure the interrill (raindrop impact) erodibility (K_i) and effective hydraulic conductivity (K_{eff}) of each material, and a rill erosion test was conducted to measure the rill erodibility (K_r) and critical shear stress (τ_C) of the materials under overland flow conditions (Table 7). These parameters were then used within the Watershed Erosion Prediction Project (WEPP) model to determine expected average sediment yields on a range of land surface configurations.

The results of the erosion modelling are summarised in Table 8. In general predicted erosion rates were low, primarily due to the armouring effects of the large gravel fraction (Plate 1) and high infiltration rate of the sandstone material. Predicted erosion rates on WRL batter slopes increased with increasing slope angle and with increasing lift height. The predicted average erosion rate for near-flat surfaces (i.e. pads, roads, etc.) was negligible, at < 0.2 t/ha/yr, with approximately 90 % of the predicted erosion expected in the months of December, January, and February (Figure 5). Expected extreme erosion event frequencies are presented in Table 8 for a WRL design consisting of 15° batter slope angles, and a 10 m lift height.

Table 7: WEPP model input parameters determined through laboratory testing

Material ID	Sand (%)	Clay (%)	OM (%)	CEC (meq/100g)	K_{eff} (mm/hr)	$K_i \times 10^5$ (Kg s / m^4)	K_r (s / m)	τ_C (Pa)
Sandstone	75	12	0.11	4.1	31.2	1.0	0.0007	8.9

Plate 1: Surface armouring after 4 hours of simulated rainfall

Table 8: Predicted annual average erosion rates

Modelled landform	Erosion rate (t/ha/yr)	Erosion rate (mm/yr)
Near-flat disturbance areas (1% grade)	< 0.2	< 0.1
15° batter slopes, with10 m lifts	5.1	0.3
18° batter slopes, with10 m lifts	5.3	0.3
21° batter slopes, with10 m lifts	5.4	0.3
15° batters lopes, with 20 m lifts	9.7	0.6

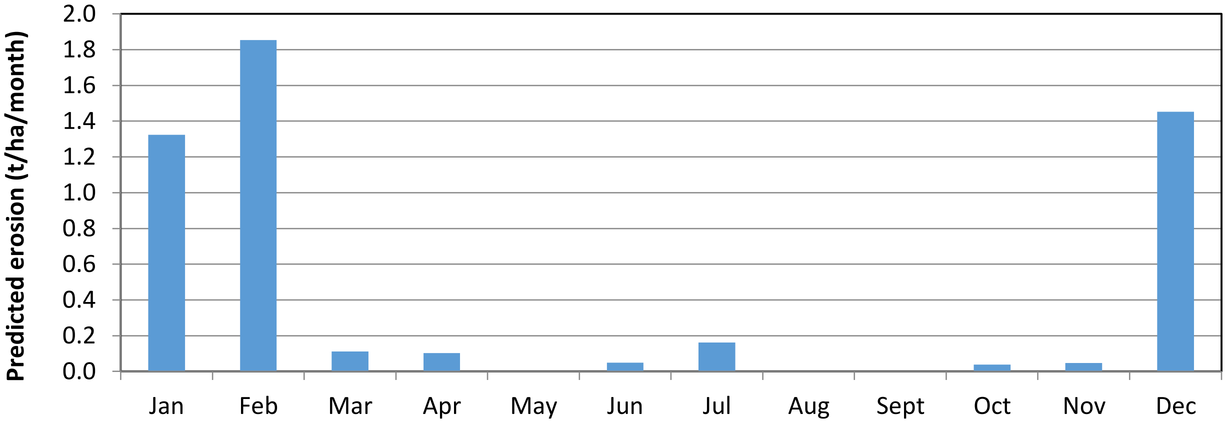


Figure 5: Predicted average monthly erosion rates for a landform with 15° batter slopes, and 10 m lifts

Table 9: Predicted extreme erosion events for a landform with 15° batter slopes, and 10 m lifts

Event frequency	24-hour erosion rate (t/ha)	24-hour erosion rate (mm)
1:1 yr	2	0.1
1:10 yr	13	0.8
1:20 yr	17	1.1
1:50 yr	25	1.6
1:100 yr	30	1.9

5 LANDSCAPE EVOLUTION

A SIBERIA landscape evolution model was developed to test and visualise long-term landform stability. The WEPP model output was used to parameterise the SIBERIA model, and this was applied to the proposed WRL landform design over a 1,000 year period. This model is expected to represent a worst-case scenario, where predicted erosion rates do not decrease with time. In practice, surface armouring is expected to develop over time, and vegetation re-establishment during rehabilitation will further contribute to stabilising the landform. Thus, the predicted erosion rates are expected to decrease to a steady-state rate, resembling “background” erosion rates in the region. Further modelling may be considered beneficial when more information becomes available regarding the expected revegetation schedule, and as more soil and waste materials are tested for stability.

Visual output from the SIBERIA model is presented in Figure 6. The results of this model clearly show:

- The WRL designs do not contain any concave areas that can concentrate flow into large channels.
- The design of the berms is adequate to contain > 100 years' worth of eroded sediment from the upper portion of the landform. This is evidenced in Figure 6, which shows some accumulation of sediment on the berm after 100 years, but very little gullying is predicted on the lower embankment. This means that the majority of eroded sediment is contained on the landform.
- The berms are predicted to fill only after >100 years, at which point some overtopping and more severe gully formation is possible. This is demonstrated in Figure 6, which shows severe gullying of both WRLs at the end of the 1,000-year model run.

Overall, the current WRL design is expected to perform well in terms of erosion resistance, with a safe, stable and sustainable WRL likely to be produced. Given the available materials for construction of the outer landform surface, the majority of sediment is expected to be contained within the landform footprint for at least 100 years post-construction. Thus, as long as adequate vegetation cover is re-established within a 100-year period, minimal sedimentation of the surrounding environment will occur, and a safe and stable landform will remain in the long-term.

6 RECOMMENDATIONS

The following recommendations are made based on the results of this soil assessment, and with the aim of maintaining optimal soil properties during the mining and rehabilitation process, and minimising environmental impacts through appropriate handling and placement of soil materials that exhibit adverse properties:

- All surficial cover materials (i.e. upper 30 – 50 cm of red sandy loam) should be considered as a topsoil and stripped as a single Soil Management Unit (SMU) for use in rehabilitation. These materials exhibit optimal soil physical and chemical properties for rehabilitation and thus should be excavated separately from the underlying sandstone.
- The underlying partially weathered sandstone (i.e. saprock or transition) should be considered as a subsoil, as its high gravel content when broken-down will be beneficial in stabilising the outer surface of the post-mine landforms. An adequate volume of this sandstone material should therefore be stockpiled for later use in the construction of the outer surface of the WRL and TSF. It is important to note that this study was restricted to the surface 1.35 m and the properties or the sandstone below this depth are unknown. It is therefore recommended that the sandstone materials removed or classified as a subsoil should only extend to 1.35 m and further work would be required if deeper materials were to be captured as a subsoil.
- Saline water should not be used for dust suppression on any of the stockpiled materials as this will degrade these materials and make them less suitable for revegetation efforts.
- Batter slopes of ≤ 18° are recommended based on the properties of the assessed materials (sandstone), and assuming a significant proportion of gravels (or sandstone) is present at the surface.
- While sandstone was the only material tested for erosion resistance, the results of additional physical and chemical analysis conducted on the topsoil materials, and experience with similar materials, indicates that topsoil materials containing ≥ 50% gravel will also be suitable for placement on sloping surfaces of up to 18°.
- Appropriate revegetation species should be selected that are compatible with the reconstructed soil profile. Particular attention should be paid to the salinity, pH, and water holding capacity of the profile, and ensuring that the revegetation species used can be adequately supported by the capability of the reconstructed soil profile.

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

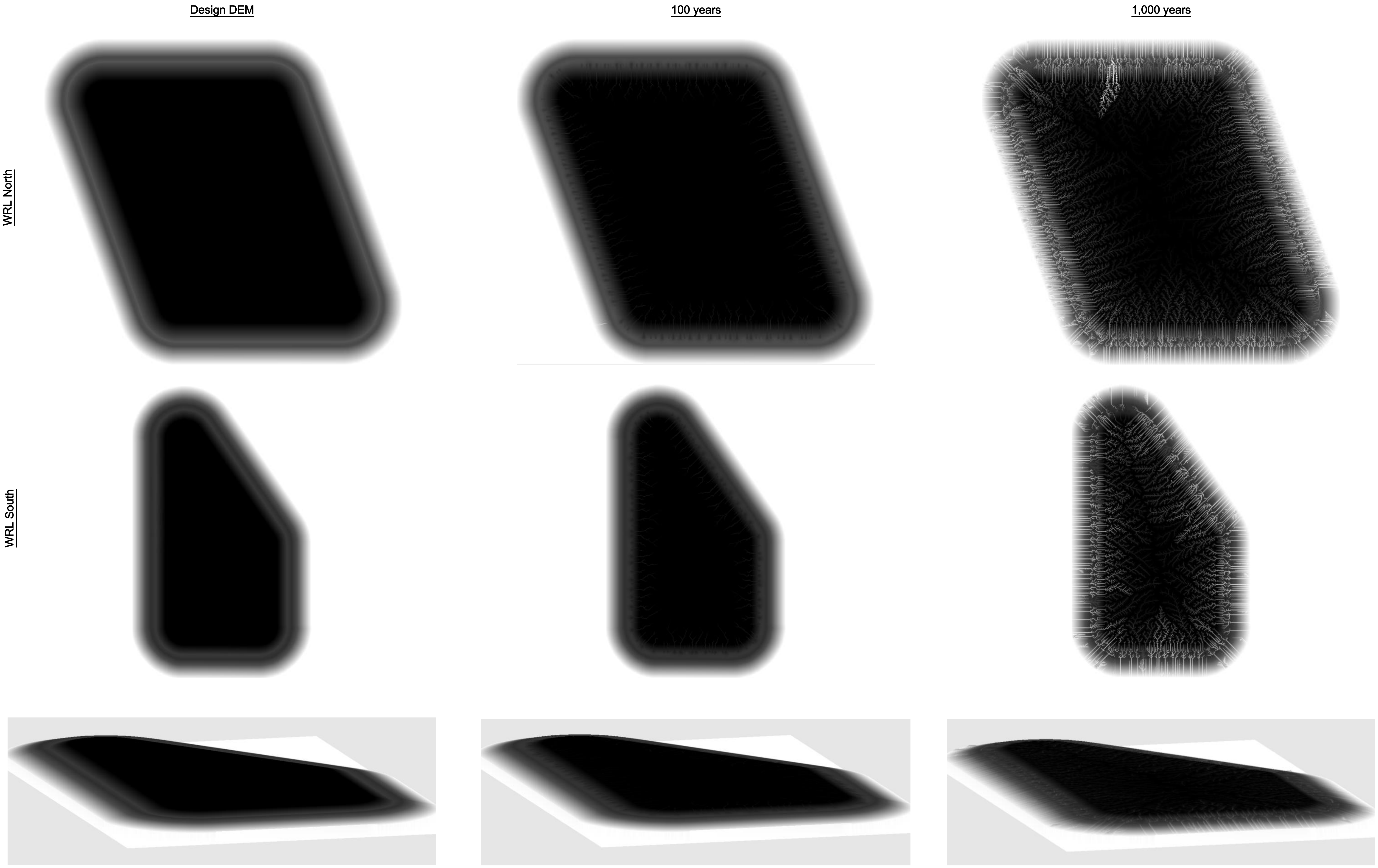
Yours sincerely,

Joe Powers

Water Resource Engineer

t: +61 8 9228 3060

e: Joe.Powers@soilwatergroup.com



ABM Resources

Twin Bonanza Soil Assessment

Figure 6: SIBERIA model output, showing predicted worst-case erosion of the proposed wast rock landforms.

soilwater GROUP

PN: ABM-002-01-01 Prepared by: JP Date: 22/10/13 Reviewed by: ASP Date: 28/10/13 Revision: 1

7 REFERENCES

Rengasamy, P., Greene, R., Ford, G. and Mehanni, A. (1984) Identification of dispersive behaviour and the management of red-brown earths. *Soil Research*, **22**, 413-431.

Willgoose, G. (2005) *User Manual for SIBERIA, Version 8.3*. Telluric Research. Scone, NSW.