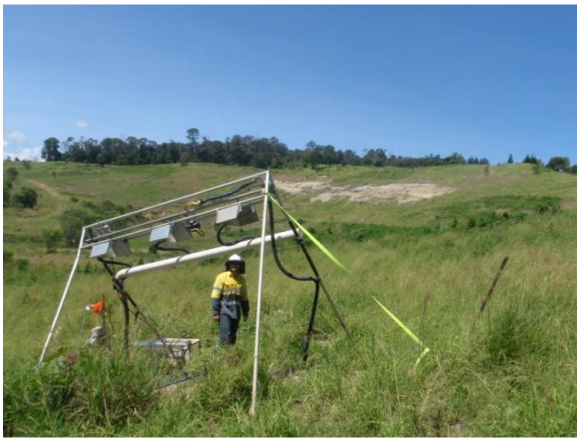

DRAFT REPORT

Material Characterisation and Landform design for New Hope Coal's Oakleigh mine.

June 2013

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Revision	Report Date	Report Author	Reviewer
Draft	June 7, 2013	R. Loch	L. Nicolson

Table of Contents

1. EXECUTIVE SUMMARY

Please note - Executive Summary will be inserted following comments on draft document.

2. INTRODUCTION

New Hope is the last active coal mining operation in the Ipswich area, and it is scheduled to close its New Oakleigh mine in approximately 2 years. New Oakleigh is surrounded by three old mining areas, North Oakleigh, Normanton and West Oakleigh, which have had some rehabilitation but require further work before final signoff.

Many of the existing landforms are unstable, and have been designed to concentrate overland flow rather than dissipate it. As a result, significant erosion gullies have formed and infrastructure such as access roads and culverts have been damaged. Rehabilitation efforts have been successful in generating ground cover; however, weeds are the dominant vegetation in many areas. Landloch Pty Ltd has been engaged to define the key soil characteristics and design rules required to revise the landforms, and develop strategies for effective rehabilitation.

2.1 Scope of work

Landloch was engaged by New Hope Coal to provide guidance on landform design and revegetation, and identify the main points to consider to ensure successful closure strategies for the site. The components of the study include;

- Traverse the North Oakleigh, Normanton and West Oakleigh landforms to assess landform stability and revegetation success.
- Strategically sample materials from each of the areas of interest for laboratory analysis.
- Collect bulk samples of key materials for laboratory rainfall simulation and overland flow studies.
- Use rainfall simulation to measure in-situ infiltration at 2 sites at North Oakleigh.
- Assess the erodibility of materials using the WEPP model.
- Provide landform rules for New Hope's planners to use in the final landform design for North Oakleigh and Normanton.
- Use SIBERIA modelling to validate the landform design proposed by New Hope's planners.
- Provide general recommendations on rehabilitation strategies, topsoil management, fertiliser and soil amendments for North Oakleigh and Normanton.

The Water Erosion Prediction Program (WEPP) model (Flanagan and Livingston 1995) is a complex daily time step model developed by the US Department of Agriculture. For landform design considerations, it provides a powerful and flexible working tool, with the advantages of being able to:

- easily incorporate experimentally-measured parameters;
- use long-term climate files relevant to the site of interest;
- consider a wide range of slope profiles; and
- assess a wide range of soil properties and managements.

Further information on the WEPP model is given in Appendix 1. Information on development of a 100-year climate file to be used in WEPP simulations is given in Appendix 2.

WEPP simulations also provide the time-series data on runoff and erosion necessary to derive SIBERIA parameters.

The SIBERIA model is a 3-dimensional topographic evolution model, which predicts the long-term evolution of channels and hillslopes in a catchment on the basis of runoff and erosion. SIBERIA was originally developed to simulate the evolution of natural landforms over geologic time. It uses as its main data source digital terrain maps, as available from mine planning packages.

Further detail on SIBERIA is given in Appendix 3.

3. ASSESSMENT OF LANDFORM STABILITY AND REVEGETATION

The North and West Oakleigh and Normanton areas were accessed both on foot and via vehicles where suitable roads/tracks were available. General observations of erosion were made while traversing the landforms. Most of the major areas of erosion were identified. However, due to time constraints and thick vegetation obscuring the soil surface, the search was not exhaustive.

3.1 New Oakleigh North landforms and erosion

Areas of significant erosion and existing major gullies are shown in Figure 1. Existing gullies clearly demonstrate the potential for significant erosion at the site. In areas adjacent to the road to the Oakleigh North pit, large gullies have been formed by concentrated flow along the road verge (Figure 2). As well, the southern (north west facing) batter of the Oakleigh North void has gully erosion over large areas (Figure 3). Erosion of that batter has been exacerbated by discharge from the large catchment area upslope.

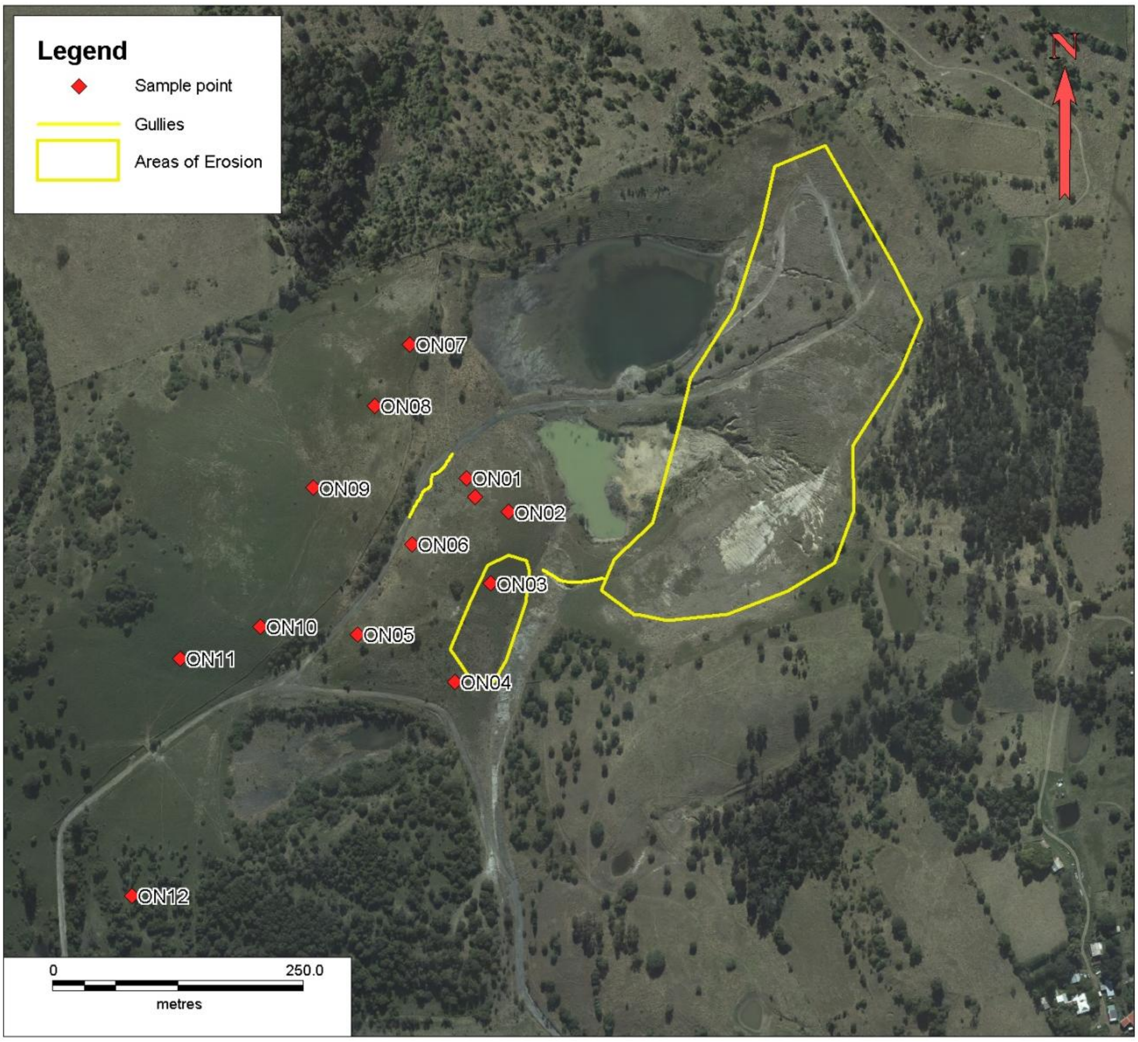

Figure 1 Oakleigh North sampling points and main areas of erosion.

Figure 2 Runoff from the access road, flowing into unconsolidated waste material, has caused a significant gully.

Figure 3 South-west batter of Oakleigh North void. Vegetation has not been able to establish and severe gullies have formed.

The central landform has a relatively natural shape and is well vegetated. There are areas of significant erosion, notably a 1.8m deep gully along the edge of the road to the north west of the landform (Figure 2) and a series of 0.3-0.5m deep gullies on the very steep south eastern side of the landform around ON03. Minor rilling can be felt under foot on many of the other sloping areas of Oakleigh North, but the rills are completely obscured by thick vegetative cover.

3.2 Normanton landforms and erosion

The Normanton area (Figure 4) receives runoff from catchments to the north (above the pit) and to the east, from the eastern side of Blake's Rd. There is a severe gully that has formed parallel to Blake's Rd which discharges into the dam at the southern end of the Normanton landform (Figure 4). The gully appears to have quite a high bed gradient, which may be a major factor in its instability.

On the eastern face of the pit there is a large area of erosion on a very steep slope (Figure 4). This adjoins the northern highwall, and there have been recent landslips in this area.

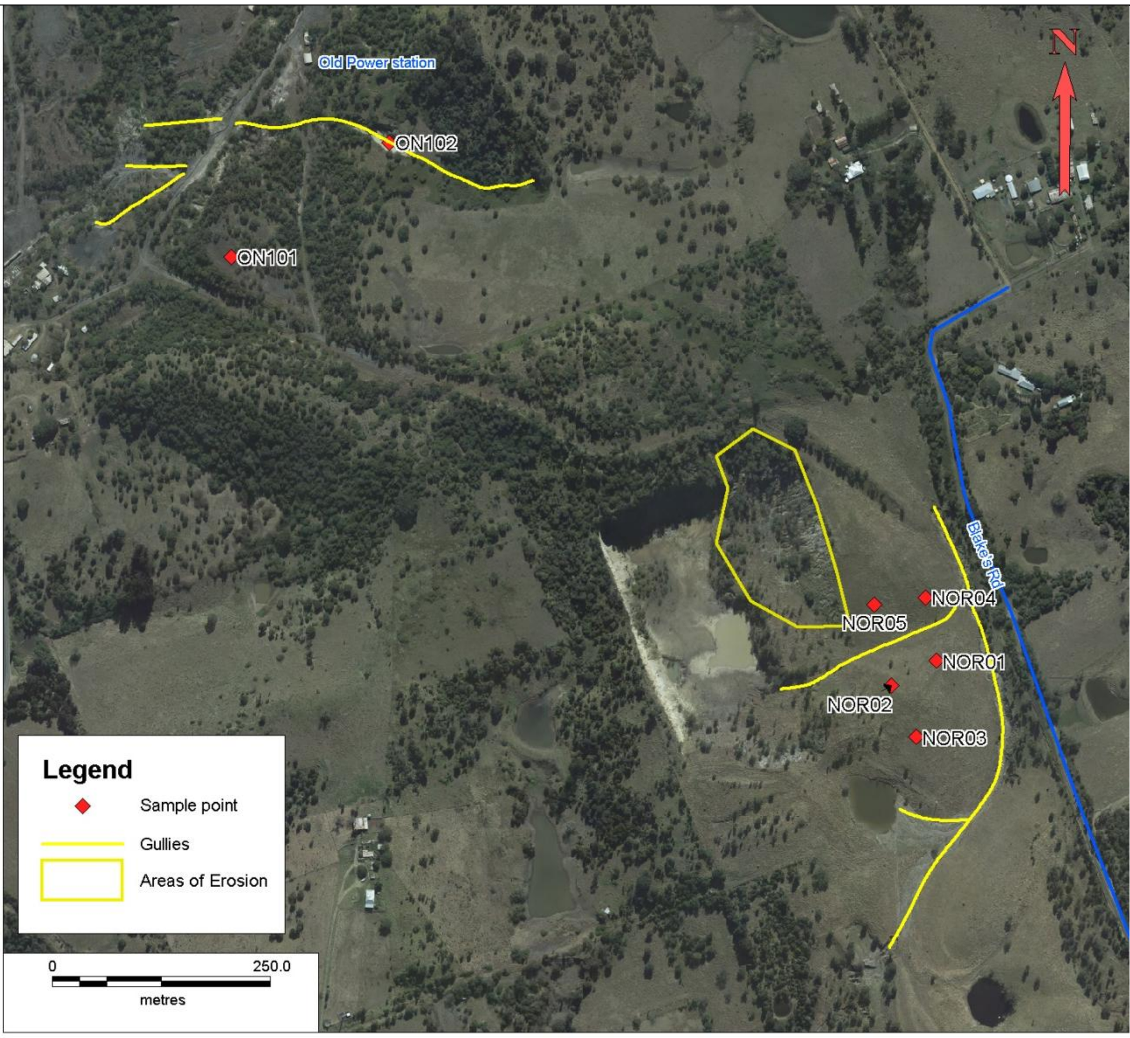

Figure 4 *Southern areas of the Oakleigh North pit (north of picture) and Normanton void and landforms. The old power station can be seen to the northwest of ON102.*

3.3 Oakleigh West landforms and erosion

The Oakleigh West landform is relatively steep at its northern end near sampling point OW01, and flattens out to much gentler slopes towards the southern and western boundaries of the landform (Figure 5).

This landform appears to have been designed to concentrate flow from large areas of very low gradient land into central areas before discharging into pre-existing drainage lines. This flow-concentrating design has resulted in several gullies that are up to 1m deep and highly active (Figure 6 & 7). The erosion gully around the area OW01 has been caused by concentration of flow along a berm (Figure 8). The berm is gently graded out at the end rather than continuing to follow the contour, which has allowed the concentrated flow from the berm to cut a gully directly down the slope. The vegetation around Oakleigh West is well established and in most cases the gullies cannot be seen, which is potentially dangerous for anyone traversing the area on foot or in a vehicle.

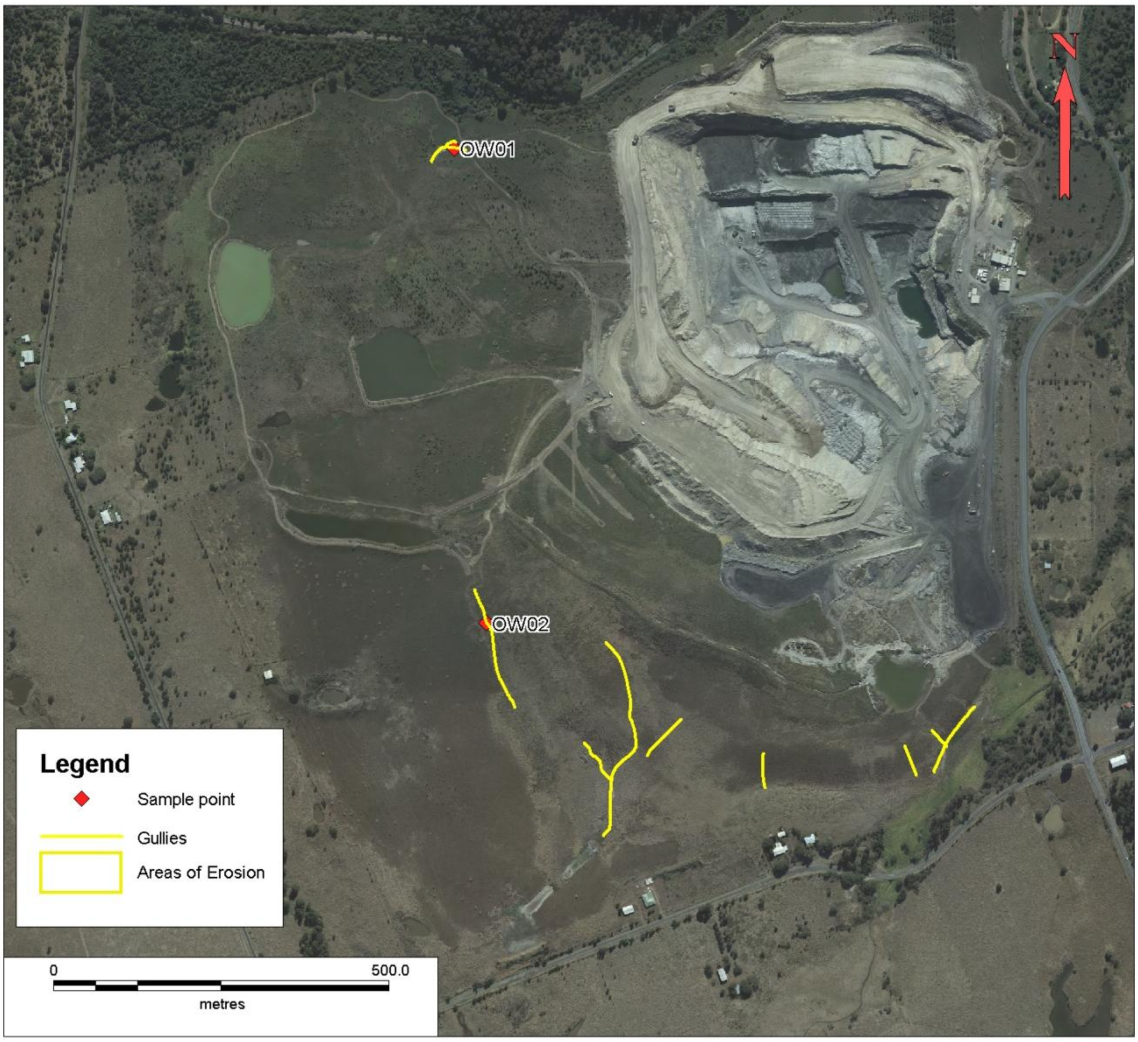

Figure 5 *Oakleigh West sample points and gullies.*

Figure 6 30-40cm deep gully running into a 1m deep head-cut below OW01.

Figure 7 Vegetation obscuring a 1m deep sink hole in the south eastern area of Oakleigh West.

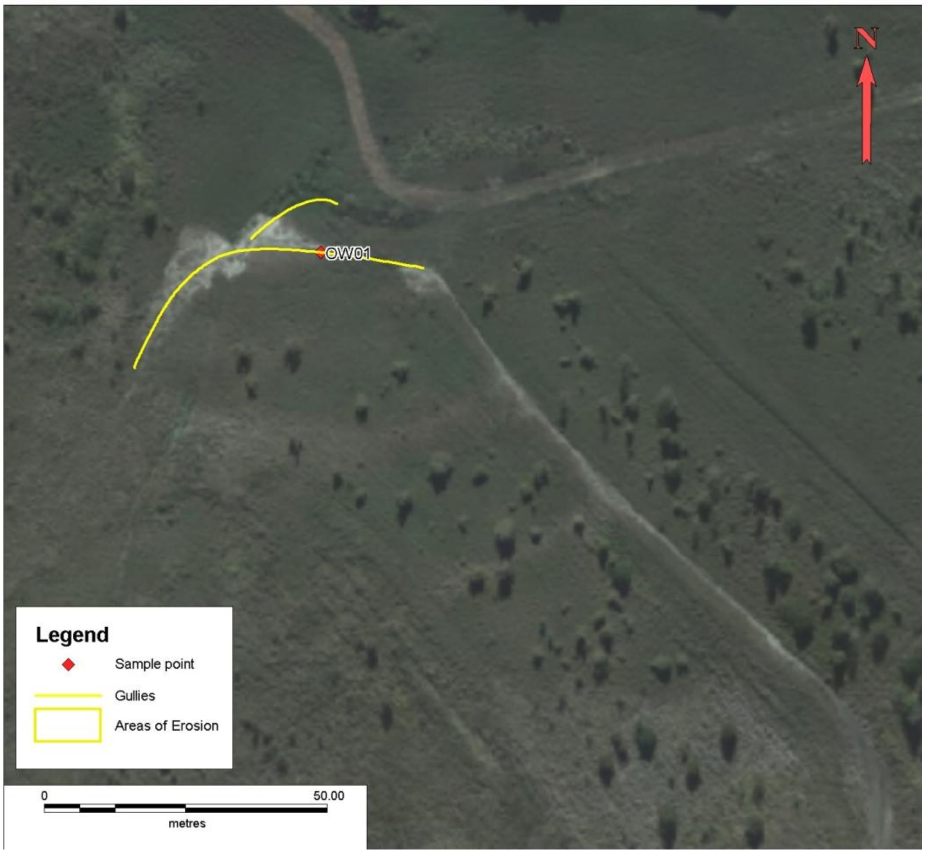

Figure 8 Berm concentrating flow to the northern end of Oakleigh West.

4. SOIL SAMPLING & ASSESSMENT

Topsoil and subsoil samples were initially taken from representative sites at Oakleigh North and Normanton using a motorised hand auger. The subsoil samples were taken at 1m depth where possible, though some areas were too rocky for sampling to reach a 1m depth. Subsoil samples from Oakleigh West were taken from the bottom of existing erosion gullies. On the basis of soil analysis results, sites for bulk sampling and *in-situ* rainfall simulation were selected.

In a number of cases, it is likely that the distinction of "topsoil" and "subsoil" simply distinguishes between a surface layer of greater organic matter content and weathering and deeper layers of the same (waste/soil) material that have undergone less change since placement as part of rehabilitation works.

4.1 Oakleigh North

Initial sampling at Oakleigh North occurred on December 1, 2011, with a further visit on December 16 to take additional samples on the area to the south and south east of the old power station (Figure 4). Bulk samples for laboratory soil erodibility studies were taken from the ON07 site on February 20, 2012.

The Oakleigh North area consists of a number of distinct landforms as well as the remains of the pit void. If significant landform re-shaping is carried out, then the central landform (sites ON01 to ON06) and the north west landform (sites ON07 to ON11) are the features from which material is most likely to be moved to fill the void and reshape the heavily eroded hill slope to the south of the void. The sampling concentrated on areas that are more likely to be reshaped and have material moved, rather than on existing eroded areas which are likely to be largely covered by the reshaping works.

A significant gully (ON102) and a flat topped waste dump (ON101) are located to the south east and south of the old power station area (Figure 4).

4.2 Normanton

The sampling points at Normanton were spread across the two main landforms adjacent to the main void (Figure 3). Auger samples were taken from Normanton on December 1, 2011, and bulk samples of the subsoil were taken from NOR03 site on February 20, 2012 for laboratory soil erodibility assessments.

4.3 Oakleigh West

Oakleigh West was traversed on foot on December 16, 2011, with four samples taken in 2 of the major erosion gullies (Figure 5).

4.4 Material properties

A selection of the materials sampled were analysed by a commercial NATA accredited laboratory for:

- pH and Electrical Conductivity (EC) on 1:5 soil:water suspensions;

- Exchangeable cations and Effective Cation Exchange Capacity (ECEC);
- Macronutrients (N,P,K, S) and Organic Carbon for selected surface samples.
- Particle size analysis for selected samples

Results of analyses are given in Tables 1-3. Sample prefixes refer to the sample location; ON = Oakleigh North, NOR = Normanton, OW = Oakleigh west. Shading of cells in the table indicates values that could be considered “of concern”, being either lower or higher than would be considered suitable for good plant growth. Yellow shading is effectively “probably of concern” and blue shading indicates values that are “definitely of concern”.

4.4.1 Topsoil chemical and physical properties

Topsoil chemical properties shown in Table 1 some similarities between topsoils from all 3 sites. Soil pH was neutral to alkaline for all samples. Electrical conductivity was generally low and at levels unlikely to inhibit plant growth. Exchangeable sodium was generally low, though both samples from Oakleigh West had levels of sodium such that the soils were bordering on sodic.

The Oakleigh North and Normanton samples had a moderately high ECEC, indicating that a proportion of the soil clay was smectite (swelling) clay, which could result in higher fertility and is often associated with higher erodibility (Loch and Donnollan 1983). The Oakleigh West samples were distinctive for quite high ECEC, indicating that they contained a higher proportion of smectite than samples from the other two areas.

Table 1 *Topsoil Chemical Properties*

Sample ID	Depth sampled	Electrical Conductivity dS/m	pH (H2O)	Exchangeable Potassium %	Exchangeable Calcium %	Exchangeable Magnesium %	Exchangeable Sodium %	ECEC meq/100g*
ONO1	**0-10cm**	0.14	7.77	3.55	67.5	27.3	1.60	28.9
ONO3	**0-10cm**	0.14	8.02	3.48	62.1	33.3	1.12	29.4
ONO5	**0-10cm**	0.16	8.00	8.69	56.4	33.4	1.42	28.0
ONO7	**0-10cm**	0.15	8.11	3.05	60.2	35.4	1.30	31.3
ONO9	**0-10cm**	0.17	7.91	3.47	48.0	46.6	1.92	26.3
ON12	**0-10cm**	0.10	7.26	1.24	83.8	14.6	0.38	37.3
ON13	**0-10cm**	0.11	8.01	1.56	66.5	29.8	2.09	34.5
ON101	**0-10cm**	0.13	8.02	1.48	70.4	25.6	2.46	44.4
NOR03	**0-10cm**	0.15	7.11	1.40	48.9	48.1	1.64	43.4
NOR04	**0-10cm**	0.17	8.10	2.38	66.9	27.7	2.97	35.1
OW01	**0-10cm**	0.30	8.53	1.72	54.0	38.6	5.63	68.4
OW02	**0-10cm**	0.19	8.07	1.42	56.6	37.4	4.58	83.9

*ECEC of complete soil

Across all 3 areas, topsoil clay contents (Table 2) were similar (approximately 30%). There was slightly greater variation in proportions of fine and coarse sand. The Oakleigh West samples showed significantly higher levels of fine sand than samples from the other two areas; again indicative of higher erodibility than for topsoils from the other two areas.

From this, it appears that the Oakleigh West topsoils are likely to be of higher fertility and erodibility than soils from the other two areas. Topsoils from Oakleigh North and Normanton areas appear to be reasonably similar.

***Table 2**: Topsoil particle size analysis*

Sample ID	Depth	% Clay <0.002mm	% Silt 0.002-0.02mm	% Fine Sand 0.02-0.2mm	% Coarse Sand 0.2-2.0mm	% Gravel >2.0mm
ONO1	**0-10cm**	27.8	4.7	30.0	21.1	16.3
ONO3	**0-10cm**	34.4	4.2	29.9	22.8	8.6
ONO5	**0-10cm**	26.7	5.8	33.8	22.6	11.1
ONO7	**0-10cm**	30.1	4.9	38.5	20.2	6.3
ONO9	**0-10cm**	27.2	5.2	36.1	16.3	15.2
ON12	**0-10cm**	31.9	5.0	34.6	26.7	1.7
ON13	**0-10cm**	24.3	3.2	17.9	12.1	42.5
ON101	**0-10cm**	29.6	1.4	29.1	39.9	0.0
NOR03	**0-10cm**	30.2	2.0	23.8	18.3	25.6
NOR04	**0-10cm**	27.4	4.9	34.9	23.5	9.4
OW01	**0-10cm**	31.9	5.4	52.4	10.3	0.0
OW02	**0-10cm**	29.5	8.8	56.7	5.0	0.0

4.4.2 Subsoil chemical and physical properties

Subsoil pH (Table 3) tended to be higher than that of the corresponding topsoil, and ON03 and ON07 subsoils were in the >9.5 range that could inhibit growth of some plants. However, given the depth from which those samples were taken (100 and 120 cm), it is unlikely that impacts on plant growth would be significant.

Six of the 13 subsoils analysed were sodic, and another two had exchangeable sodium levels that were of concern.

Two samples (ON09 and OW02) had relatively high soluble salt levels. As both subsoils were sodic, this may reflect some accumulation of salt due to restricted drainage. However, the other profiles with sodic subsoils did not show significant accumulation of salt.

The Oakleigh West subsoils also had considerably higher ECEC than subsoils at the other two areas, showing the same difference in mineralogy as noted for topsoils.

Table 3: *Subsoil Basic Properties*

Sample ID	Depth Sampled	Electrical Conductivity dS/m	pH (H2O)	Exchangeable Potassium %	Exchangeable Calcium %	Exchangeable Magnesium %	Exchangeable Sodium %	ECEC meq/100g*
ONO1	**60cm**	0.13	8.29	1.45	58.1	37.5	2.93	26.1
ONO3	**120cm**	0.26	9.50	1.59	28.2	60.8	9.49	35.1
ONO5	**70cm**	0.19	8.60	1.19	40.3	53.7	4.78	32.0
ONO7	**100cm**	0.21	9.57	1.30	35.1	52.0	11.6	40.6
ONO9	**90cm**	0.85	8.76	1.66	33.2	48.8	16.35	25.4
ON12	**100cm**	0.20	8.60	0.59	77.9	16.2	5.34	49.5
ON101	**50cm**	0.19	8.51	0.90	73.4	21.9	3.85	47.7
ON102	**gully wall**	0.18	8.75	0.77	71.7	24.1	3.47	66.9
ON102	**gully floor**	0.12	8.48	1.33	66.6	28.1	3.91	27.5
NOR03	**100cm**	0.20	9.31	0.50	58.5	33.9	7.11	36.0
NOR04	**100cm**	0.22	9.19	1.19	55.5	32.2	11.1	29.6
OW01	**50-60cm**	0.35	7.96	0.64	58.2	37.2	3.96	74.5
OW02	**100cm**	0.73	8.84	1.45	44.6	46.7	7.22	81.8

*ECEC of complete soil

Particle size distributions (Table 4) showed reasonably similar clay contents (approximately 30%) for all subsoils. Silt was generally low, and proportions of fine and coarse sand were somewhat more variable. Again, the Oakleigh West samples were distinctive for having relatively high fine sand.

It appears that, overall, most "soils" have been formed from relatively deep layers of reasonably uniform material placed during initial site rehabilitation. With time and with development of (largely) vigorous plant growth, there has been some leaching of soluble salts and sodium to depth.

Table 4: *Subsoil Particle size analysis*

Sample ID	Depth	% Clay <0.002mm	% Silt 0.002-0.02mm	% Fine Sand 0.02-0.2mm	% Coarse Sand 0.2-2.0mm	% Gravel >2.0mm
ONO1	**60cm**	28.6	4.7	26.6	21.6	18.5
ONO3	**120cm**	32.2	4.3	40.5	22.7	0.3
ONO5	**70cm**	31.0	3.3	29.2	21.5	14.9
ONO7	**100cm**	33.1	6.6	41.4	9.2	9.7
ONO9	**90cm**	26.9	10.9	43.8	12.9	5.5
ON12	**100cm**	29.5	8.3	50.0	12.1	0.1
ON101	**50cm**	28.8	2.3	28.8	39.6	0.6
ON102	**gully wall**	31.7	3.8	39.5	24.9	0.0
ON102	**gully floor**	25.6	2.9	34.3	37.1	0.0
NOR03	**100cm**	26.7	2.2	31.6	39.5	0.0
NOR04	**100cm**	28.4	7.9	47.5	13.7	2.5
OW01	**50-60cm**	30.7	8.5	53.7	7.1	0.0
OW02	**100cm**	33.5	4.8	52.4	9.2	0.0

4.4.3 Chemical fertility

Chemical fertility of the rehabilitated areas is quite variable, with a number of sites showing low levels of Nitrogen, Phosphorus, Sulphur and Manganese (0).

Of particular note are the two samples from Oakleigh West, for which both total N and organic carbon are quite low. The data indicate a clear lack of fertility that would reduce grass growth, reduce surface coverage, and increase erosion risk. Any re-shaping and revegetation of Oakleigh West will definitely need to address this nutrient deficiency, and application of a sulphur-based N fertiliser would also provide a useful increase in soil S levels.

Marginal to low soil S levels are relatively common across all three sites, and is likely to restrict growth of legumes, fixation of N, and long-term sustainability. In any re-working of the sites, some application of a low level of gypsum would not only address this issue, but possibly also improve soil structure. A gypsum application rate of 1 t/ha would be quite useful.

Although organic carbon levels are generally high, these results are, in many cases, affected by presence of reject coal in the sample. Sample ON101 in particular, is a black sandy clay material with high levels of coal reject. Analysis of historical photographs of the site shows that this area was rehabilitated to pasture in 1983, and then disturbed again somewhere between 1993 and 1997. The final surface is very flat and has bunding around its southern and western edges. This causes seasonal inundation and reduces plant growth and soil development. The material appears to be some form of mixed coal reject or slurry material that has very low phosphorus status and possible manganese deficiency.

Figure 9 *Soil Surface cover at ON101*

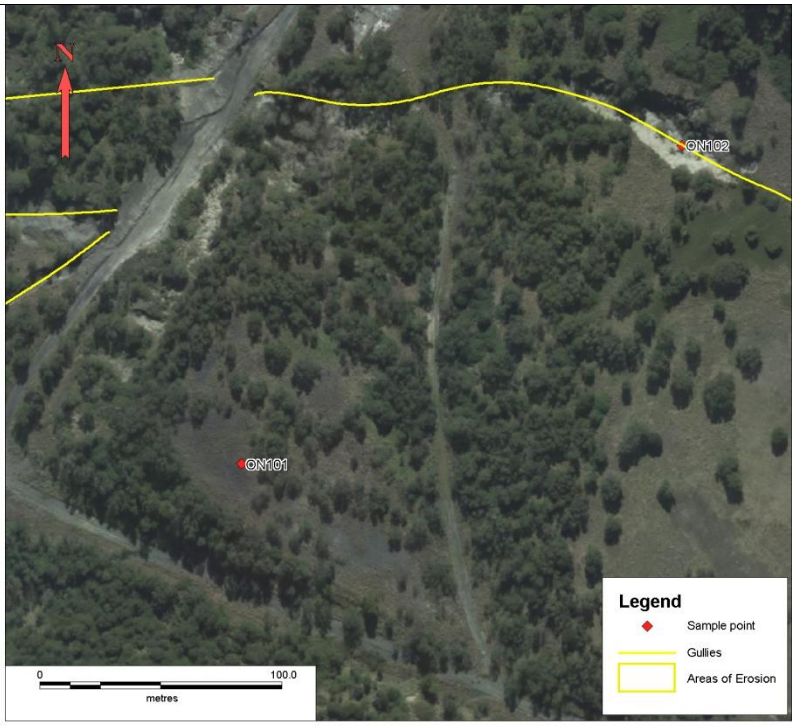

Figure 10 *Overview of vegetation at ON101*

Table 5: Topsoil chemical fertility (0-10 cm samples)

Sample ID	Organic Carbon	Total Nitrogen	Total Phosphorus	Available (Colwell) Phosphorus	Labile Sulphur	Available Copper	Available Zinc	Available Manganese	Available Potassium
	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
ONO1	4.13	3333	591	276	9.66	5.40	13.0	0.17	723
ONO3	3.81	2687	384	21.9	13.9	2.97	5.36	4.26	582
ONO5	5.60	3498	291	136	4.88	1.93	8.00	3.49	1570
ONO7	5.70	1574	185	21.3	4.6	1.60	2.50	5.78	490
ONO9	3.72	2637	472	78.4	21.3	1.89	5.4	6.30	596
ON12	1.79	1736	386	24.1	6.75	0.76	1.87	16.5	307
ON101	16.6	4261	111	8.71	26.5	1.48	3.66	0.61	355
NOR03	6.15	6682	451	88.4	9.60	2.33	13.2	1.83	400
NOR04	2.95	2087	388	143	8.38	6.30	18.1	18.0	486
OW01	1.82	1395	343	23.5	13.8	4.95	8.13	11.4	365
OW02	1.36	1162	354	15.8	4.05	3.29	2.95	11.3	366

5. WEPP SIMULATIONS

5.1 Modelling approach

The Water Erosion Prediction Project (WEPP) model (Flanagan and Livingston 1995) was used in this study to assess erosion potential of individual batter slopes. In the WEPP model, runoff and erosion simulations use a wide range of inputs, with important site-specific information including a site specific climate file and detailed erodibility and infiltration parameters:

- Interrill erodibility (K_i);
- Rill erodibility (K_R);
- Critical shear for rill initiation (τ_c); and
- Effective hydraulic conductivity (K_e).

The necessary parameters are commonly measured through studies on bulk samples delivered to Landloch's Toowoomba laboratory. However, in this case, simulations needed to specifically consider the impacts of vegetation growth on effective hydraulic conductivity, as vegetation growth on the site is not only vigorous in some places, but has considerable potential to affect erosion and landform stability.

For example, Kato *et al.* (2009) summarised data from a number of field infiltration studies (Figure 11), which generally show an increase in steady infiltration rate by 7-10 mm/h for each 10% increase in surface cover.

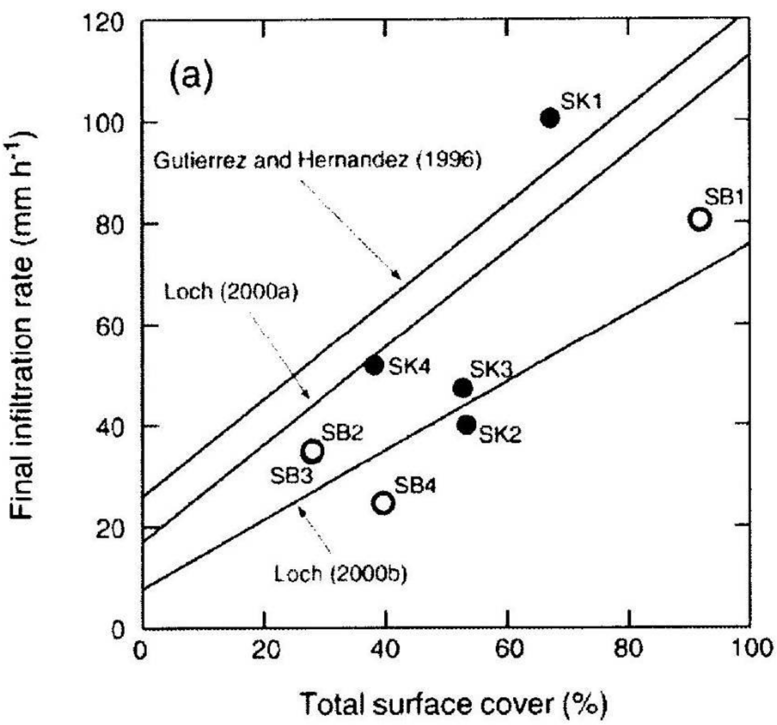

Figure 11: *Impacts of cover on steady infiltration rate across a range of experimental data (figure taken from Kato et al. 2009).*

Therefore, in this study, bulk samples were taken of topsoil and subsoil from site ON7, and subsoil from NOR3. The samples were transported to Toowoomba's erosion laboratory for measurements to determine the erodibility necessary parameters for the WEPP model.

Field studies of infiltration of simulated rain were carried out on sites ON7 and ON1, to determine effective hydraulic conductivity of the undisturbed, vegetated soils. Vegetation on Site ON7 was dominantly legume, whereas site ON1 carried dominantly grass.

5.2 Field rainfall simulation studies

5.2.1 Methods

Field rainfall simulation was carried out using a single module of the rainfall simulator described by Loch *et al.* (2001). Flat fan nozzles mounted on an oscillating manifold produce the simulated rain at a kinetic energy consistent with the energy of natural rainfall at intensities >40 mm/h. The nozzles uniformly sweep back and forth across the plot, achieving good spatial distribution of the generated rainfall.

The single module used in this study applied rain to plots 1.5 m wide and 2 m long (Figure 12), with rainfall rate being measured via a number of rain gauges, and runoff being sampled at the downslope ends of the plots. A total of 10 plots were studied: 6 on site ON7, and 4 on site ON1. At each site, half of the plots were vegetated, and the remainder were undisturbed, but with all vegetation clipped and removed to leave a surface that, although not bare, had drastically reduced cover. (Total removal of all vegetative material would have required disturbance of the surface.)

Figure 12: *Rainfall simulator on Oakleigh North, showing vegetated plot (left) under heavy legume cover and clipped plot (right) in grassed area.*

5.2.2 Results

Measured infiltration rates and calculated K_e values are shown in Table 6. The measured infiltration rates show high variability, indicating large spatial variation in soil structure and infiltration capacity, probably due variations in to vegetation vigour, vegetation type, and soil properties.

The grass-dominated site ON1 showed considerably higher infiltration rates than the legume-dominated ON7, possibly due to a higher root density in the surface layer when the dominant vegetation is grass, and possibly also due to its higher content of gravel-sized particles.

Neither site showed a large impact of presence/absence of surface cover. This may have been partly due to the low level of remnant cover on the clipped plots, but also probably reflects the presence and impact of stable soil macropores.

For modelling re-shaped and revegetated slopes, the K_e value determined for site ON7 was adopted. It represents the more conservative option, although still a relatively high infiltration capacity.

Table 6*: Infiltration data from field rainfall simulation study*

Plot	Site	Cover	Rainfall Intensity (mm/h)	Steady Infiltration rate (mm/h)	Ke (mm/h)
1	ON7	Vegetated	122.1	17.0	
2		Vegetated	119.9	7.4	
3		Vegetated	123.2	62.0	
4		Clipped	101.6	16.1	
5		Clipped	98.3	38.7	
6		Clipped	99.2	51.4	
MEANS			**110.7**	**32.1**	**25**
7	ON1	Clipped	93.5	64.0	
8		Clipped	95.6	45.9	
9		Vegetated	112.7	78.6	
10		Vegetated	114.4	93.7	
MEANS			**104.0**	**70.6**	**60**

5.3 Laboratory measurement of erodibility parameters

The WEPP model's required erodibility and infiltration parameters were derived from data collected using the following laboratory-based experimental methods:

1) Interrill erodibility and effective hydraulic conductivity were measured by applying a simulated "storm" with known rainfall intensity to plots 0.75m wide and 0.75m long (Figure 13). Three plots of each material were tested. The rainfall intensity applied was maintained until steady runoff rates were reached. Runoff rates were measured and sediment samples were taken.

2) Rill erodibility and critical shear for rill initiation were measured by applying various rates of overland flow to flumes 0.4m wide and 2.0m long (Figure 14). Three plots of each material were run, with the rate of water applied determined using a calibrated flowmeter. Samples of sediment in runoff were taken for each applied flow rate. No rainfall was used during the overland flow study.

Rain water was used in all measurements to avoid any potential impacts of water quality on infiltration and on the disaggregation of sediment to finer sizes.

The methods used here were similar to those reported by Sheridan *et al.* (2000) and which were found to give good agreement with field rainfall simulator data.

Figure 13: *Rainfall simulator plots of ON7 topsoil (L) and NOR subsoil (R) following application of simulated rain.*

Figure 14: *Flumes of ON7 topsoil (L) and NOR subsoil (R) following application of overland flows.*

Erodibility parameters are shown in Table 7. They show the rill detachment parameter for the ON7 topsoil to be significantly higher than for the other two materials. Its critical shear is also slightly higher.

Table 7: *Erodibility parameters for the WEPP model*

Parameter	Unit	Material		
		ON 7 topsoil	ON 7 subsoil	NOR 3 subsoil
Interrill erodibility (K_i)	$kg.s/m^4$	1,354,825	2,242,212	1,783,292
Rill erodibility (K_R)	s/m	0.0060	0.0020	0.0024
Critical shear (τ_C)	Pa	14.1	12	9.6

5.4 WEPP simulations

Runoff/erosion simulations using the WEPP model were carried out to consider the heights and gradients of landform slopes that could be stable following re-shaping and revegetation. In carrying out those simulations, a number of assumptions and decisions were made, including:

- Erodibility data for the ON7 topsoil were used to derive slope recommendations as it is likely that the surface layers will be stripped and replaced on the surface of re-shaped landforms, and it presents greater erosion risk than ON1, for example. Therefore, use of ON7 "topsoil" data are likely to lead to the most conservative design.
- Simulations for bare soil used the K_e value measured for bare soil in the laboratory, whereas simulations for vegetated soil used the K_e value derived from field rainfall simulation studies.
- It is anticipated that the target vegetation for the site will be pasture species (grass and legumes). There may be subsequent establishment of varying levels of trees, but the grass/legume pasture will be the vegetation of primary concern for consideration of surface stabilisation.
- Erosion simulations with the WEPP runoff/erosion model used a synthetic 112-year climate file developed using daily rainfall data from Rosewood and rainfall intensity data from Amberley.
- All simulations considered rills spaced at 5 m intervals across batter slopes, and did not allow for any run-on onto batter slopes from upslope areas. As well, all simulations considered a batter height of 20 m.

5.4.1 Bare soil

Initial simulations – used to gain an indication of erosion risk and pattern – considered runoff and erosion for a range of gradients of linear batters (Figure 15). All gradients showed quite high (and unacceptable) rates of predicted annual erosion.

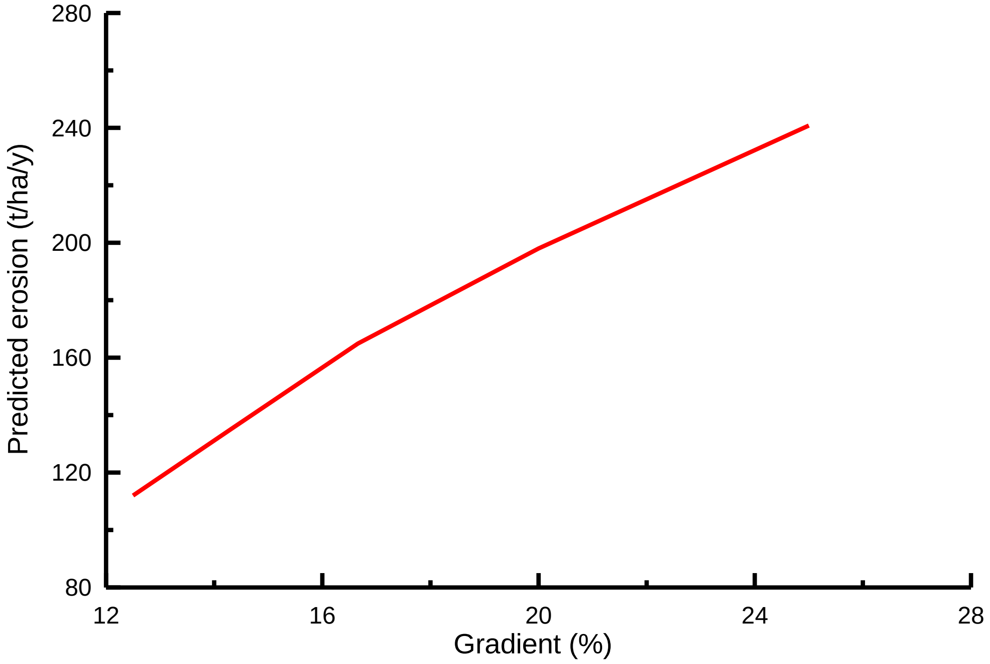

***Figure 15:** Effect of linear batter gradient on predicted annual average erosion from 20 m high batters, bare of vegetation.*

The pattern of erosion (Figure 16) shows erosion rate increasing downslope as overland flow increases and rilling initiates, with erosion reaching a maximum as the overland flow is predicted to reach its transport limit.

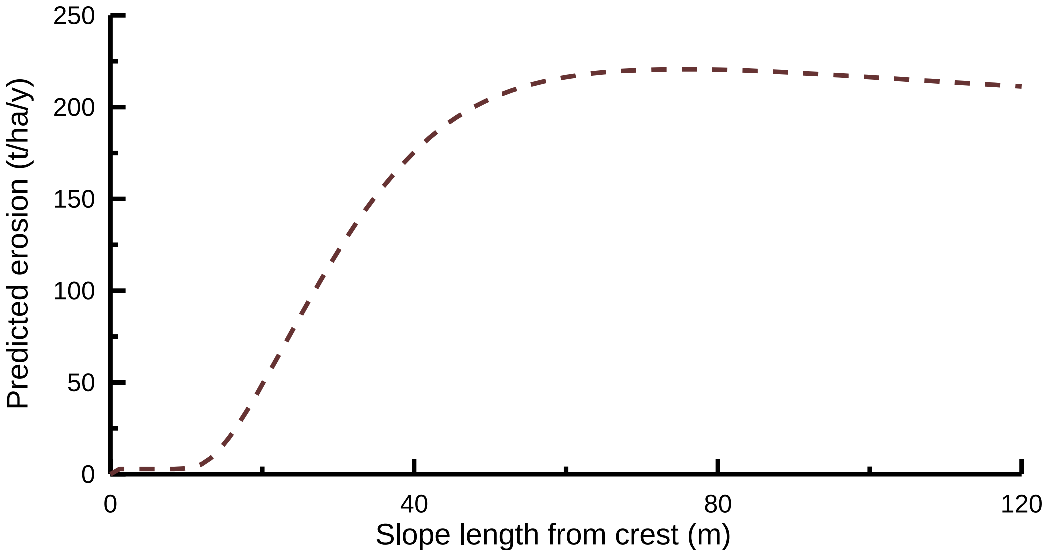

***Figure 16:** Predicted pattern of erosion along a bare 20 m high batter, 16.66% gradient.*

5.4.2 Concave slope profiles

Simulations considered concave slope profiles, but were only able to achieve a maximum reduction in predicted erosion of approximately 30%. Given the large reductions in erosion potential that could be achieved from establishment of vegetation, it was concluded that concave profiles were unlikely to be cost-effective in controlling erosion risk.

5.4.3 Vegetation impacts

When the infiltration capacity of the vegetated topsoil at ON7 is considered, and a Cover (C) factor (derived and applied using Universal Soil Loss Equation (USLE) concepts[1]) is used to consider erosion potential of a vegetated slope, predicted erosion drops to quite low levels (Figure 16).

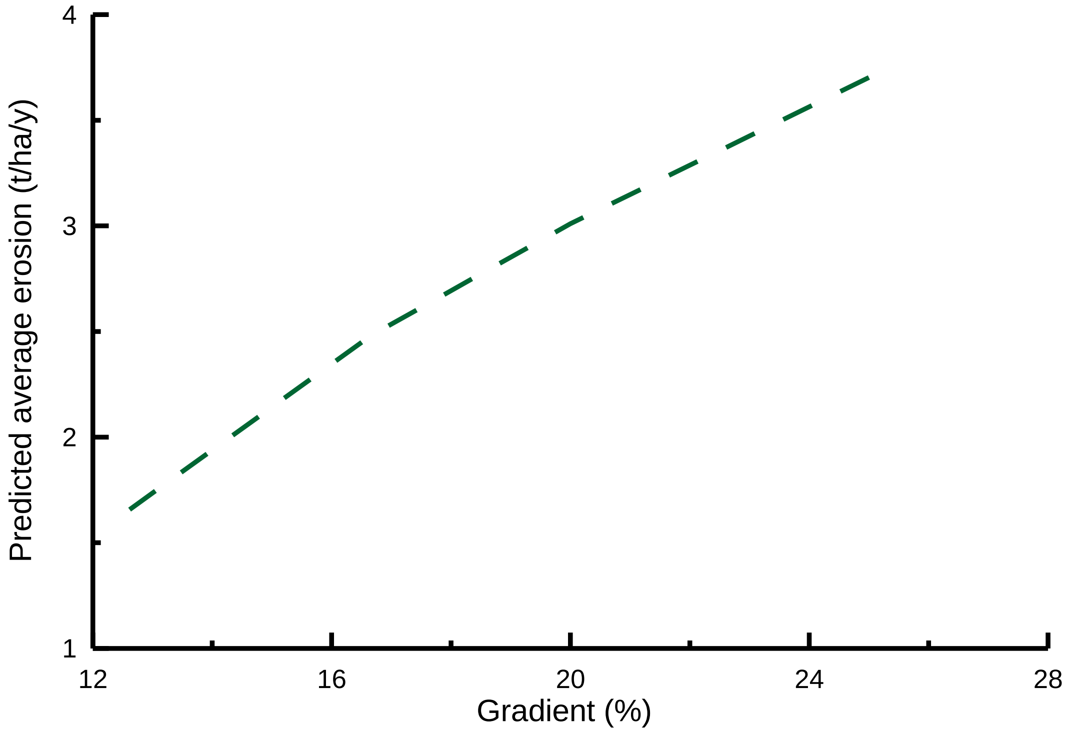

Figure 16: *Predicted erosion potential of 20 m high batter slopes, vegetated to achieve 80% cover of weed/legumes rather than grass. (C-factor of 0.043 from Rosewell 1993).*

5.4.4 Monthly distribution of erosion potential

Monthly variations in erosion potential are shown in Figure 17. Erosion risk is largely concentrated in the months December-March. Figure 17 also indicates the spring period in which vegetation could be expected to establish. Generally, vegetation should be seeded in spring when temperatures increase and monthly rainfall begins to increase. Vegetation established in September could be expected to achieve cover levels of 80% greater by the end of November. Importantly, this crucial growth period occurs ***prior*** to the period of greatest erosion risk.

[1] Cover factors in the USLE are effectively the ratio of soil loss from a covered area to soil loss from a equivalent area bare of cover.

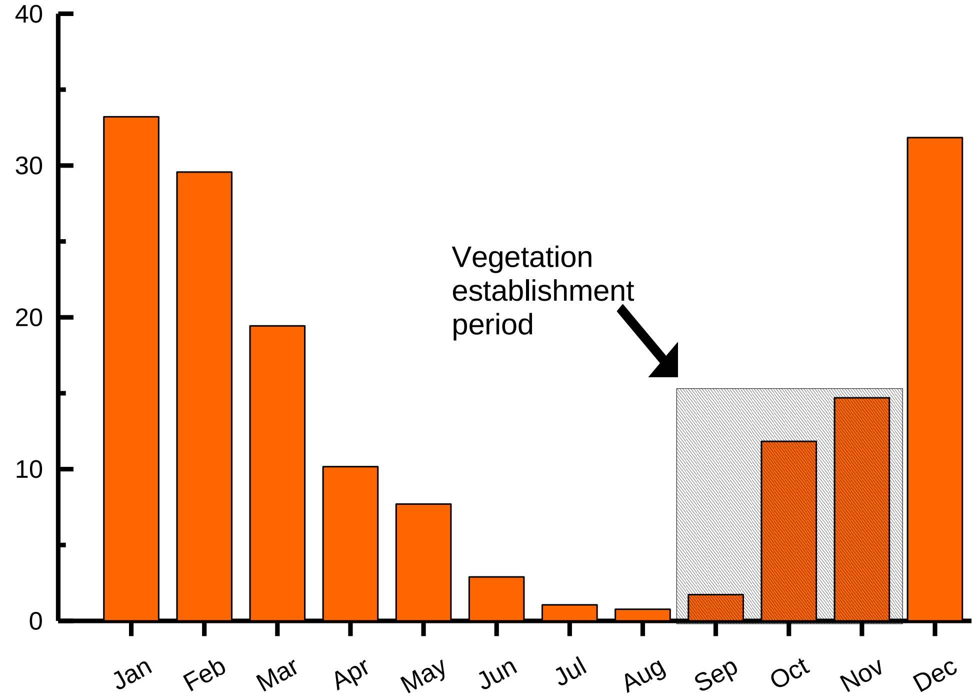

Figure 17: *Monthly distribution of erosion potential; data for a 20 m high slope, bare of vegetation, 16.66% gradient*

5.4.5 Identification of acceptable erosion risk

The data show several points quite clearly:

- initially-formed bare soil slopes are extremely vulnerable to erosion, particularly if erosion is considered on an annual basis;
- vegetation – once established – can reduce erosion to acceptable levels on all slope gradients considered; and
- the initial vegetation establishment period has considerably lower erosion potential than that applying over a 12-month period.

A key conclusion from that is that reliable and effective establishment of vegetation in the September-November period is clearly critical for vegetation success.

However, the monthly data also provide a means of assessing acceptable erosion risk. If it is accepted that:

a) vegetation will be established during the September-November period; and
b) erosion during that period will be, effectively, a once-off loss of soil;

then it is possible to consider: "***what magnitude of once-off soil loss would be acceptable***?"

Of particular concern would be the formation of deep rills, incised well below the growth medium layer, that – even after vegetation established – might continue to carry flow and to incise. (Examples of active gullies associated (probably) with initial scour during rehabilitation can be found at Oakleigh West.)

Therefore, potential depth of rill erosion can be used to estimate an acceptable level of initial soil loss. It is assumed that – for the eroding slopes considered - rills occur every 5 m width of slope, with rill width equal to approximately twice the depth. This is consistent with a rill in moderately gravelly material, with a significant component of bed load sediment. From that it is possible to calculate likely rill depths for various levels of erosion.

For erosion of 30 t/ha and soil bulk density of 1.3 g/cc, rill depth (based on the above assumptions) would be 76 mm. For erosion of 40 t/ha and the same assumptions, rill depth would be 87 mm. If a growth medium layer is placed 200 mm deep, then preservation of a significant portion of that layer would be desirable to enable vegetation to establish in the rill line (for which, inclusion of stoloniferous grasses in the seed mix will be essential).

Consequently, judgment indicates that a once-off erosion of 30 t/ha is probably the maximum that would be advisable if vegetation is to be established across the complete area, and initially-formed lines of concentrated flow are to be gradually eliminated by vigorous vegetation growth. Figure 18 shows very conservative estimates of once-off soil loss during the establishment period, as it does not consider any development of cover during that period. It indicates that a maximum gradient of approximately 18% could be adopted.

Clearly, erosion risk increases as gradient increases, with small increases in gradient causing similarly small increases in risk. But it is recommended that a maximum gradient of 20% be considered, and that a gradient of 17-18% is to be preferred.

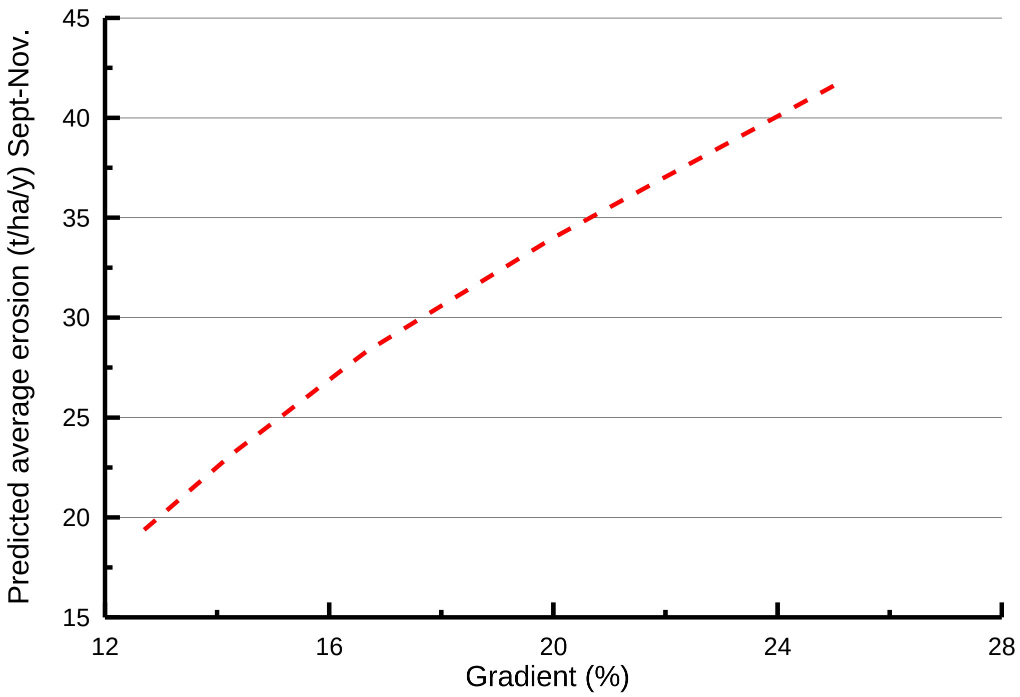

Figure 18: *Predicted average erosion in the September-November period, assuming no vegetation impact on erosion during that period.*

5.5 Landform design recommendations based on WEPP modelling

These recommendations are based largely on the modelling discussed in preceding sections. However, some general recommendations based on Landloch's experience with landform construction are also included.

With respect to batter gradient, it is recommended that the maximum gradient applied should be 20% (11.3 degrees), with 17-18% (9.6 degrees) being preferred.

With respect to slope height, it is concluded that there should be no restriction, as erosion is not greatly responsive to slope length once rills establish.

With respect to the tops of batter slopes, it is essential that areas discharging runoff onto batter slopes be avoided, either by avoiding construction of flat-topped landforms, or by installation of perimeter bunding.

In plan, considerable care should be taken to avoid forming flow-concentrating slopes. As erosion is strongly transport-limited, concentration of flow will drastically increase both transport capacity and erosion rates. As well, all corners formed on landforms should have a radius of curvature no smaller than 100m

6. SIBERIA SIMULATIONS

Landform evolution simulations using the SIBERIA model were carried out to assess the long-term stability of proposed “final” landforms based on the slope recommendations developed using WEPP simulations.

6.1 Input data

SIBERIA simulations used:

- erodibility parameters derived from WEPP time series data for vegetated batter slopes of ON7 topsoil; and
- DTM files for Oakleigh West and North provided by New Hope Coal’s mine planners.

The input elevations and gradients are shown in Figures 19 and 20. The gradients (Figure 20) show significant areas on both leases, though on Oakleigh North in particular, that have gradients of 20º of greater, considerably steeper than the maximum of 11.3º recommended from WEPP simulations.

The steep areas on Oakleigh North are generally associated with:

- Short steep batters adjoining flow lines, or associated with road cuttings or other infrastructure; or
- Batter slopes associated with areas of dumping or significant landform change (such as the north pit area).

An example of this is shown in Figure 21.

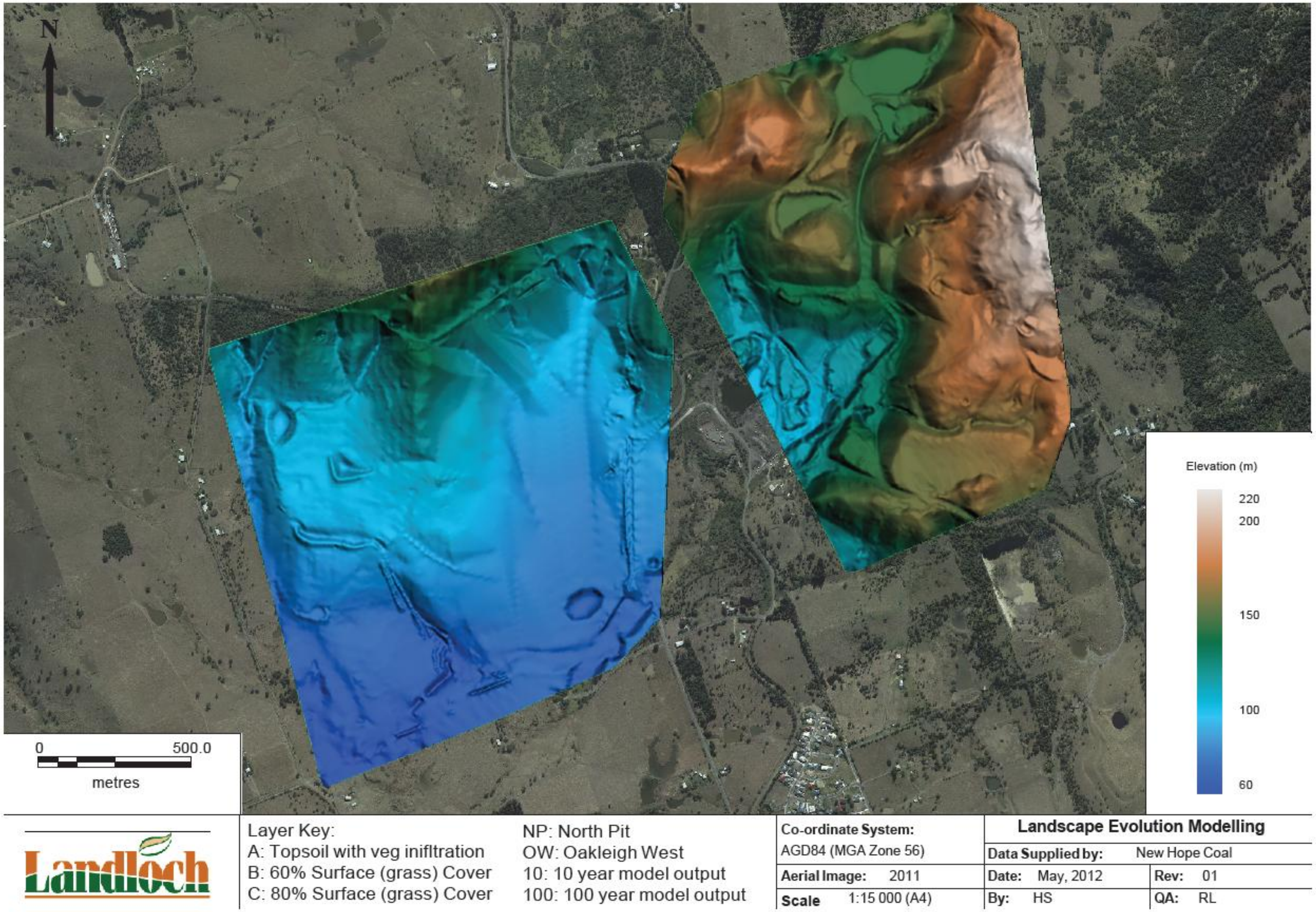

***Figure 19:** Proposed final landforms for Oakleigh West and North*

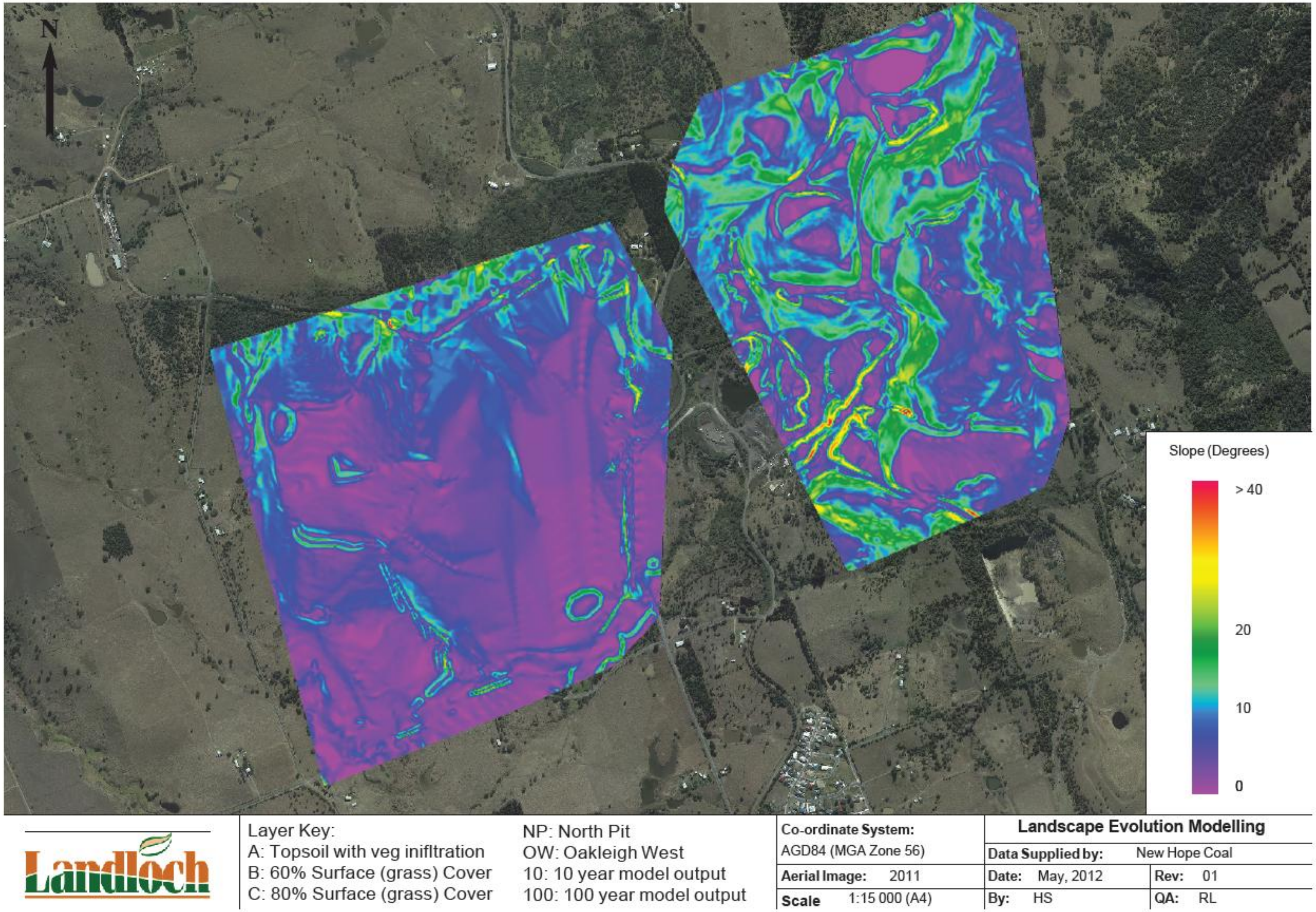

Figure 20: *Gradients of proposed final landforms for Oakleigh West and North*

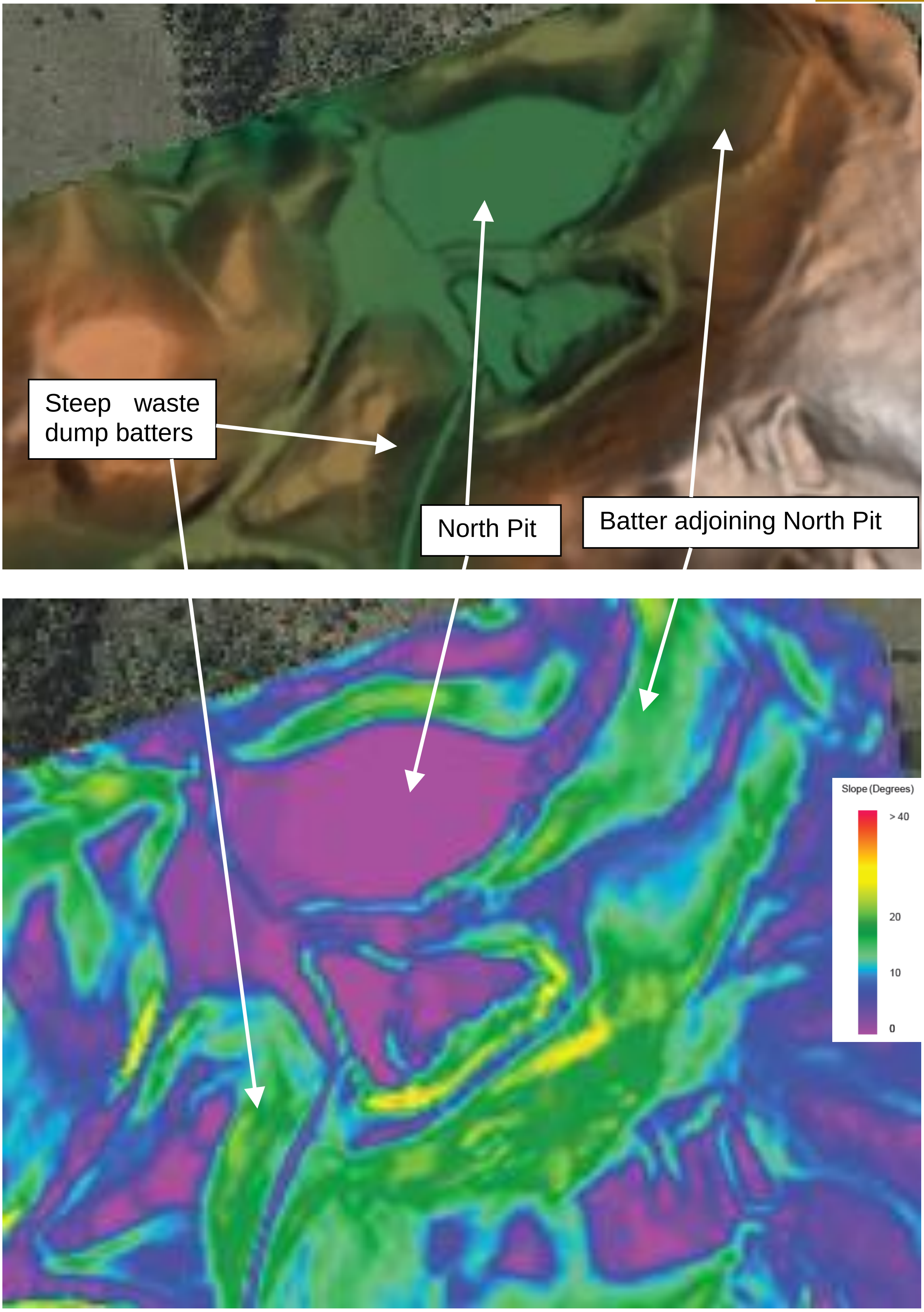

Figure 21: *Closer view of areas with gradients considerably higher than 11.3 degrees.*

6.2 SIBERIA output

6.2.1 Interpreting output

Simulations of landform evolution are shown in Figures 22-27 for a range of surface conditions and for simulation durations of 10 and 100 years.

It should be noted that that the SIBERIA model considers elevation change at all points in the area considered. It does not directly output erosion in – for example – tonne/ha/year. Conversion is possible. For example, an elevation change of -0.5 m in 10 years would be equivalent to an erosion rate of approximately 650 t/ha/y. Over 100 years, that height change would be equivalent to 65 t/ha/y.

Equally, the model also shows areas of deposition as a positive height change.

6.2.2 Base case: bare soil

Figures 22 and 23 show predicted outcomes for bare soil with infiltration set at the higher rate measured in the field when the model was run for periods of 10 and 100 years respectively.

Areas of predicted erosion are associated with:

(a) batter slopes of steeper gradient; and
(b) flow lines, associated with both flow concentration and with steeply-sloping areas adjoining the flow paths.

Any surface irregularities are shown to result in erosion – almost certainly due to flow concentration and diversion.

Both figures indicate that – for bare soil – erosion potential is high. The 100-year simulation shows areas at risk more plainly, though – obviously – the site would never persist or be left in bare condition for that period of time.

These data are – effectively – an indication of erosion risk, rather than a prediction of the erosion likely to occur if the site is remediated.

Layer Key:	NP: North Pit	Co-ordinate System: AGD84 (MGA Zone 56)	Landscape Evolution Modelling
A: Topsoil with veg inifltration	OW: Oakleigh West		Data Supplied by: New Hope Coal
B: 60% Surface (grass) Cover	10: 10 year model output	Aerial Image: 2011	Date: May, 2012 Rev: 01
C: 80% Surface (grass) Cover	100: 100 year model output	Scale 1:15 000 (A4)	By: HS QA: RL

Figure 22: *Predicted elevation change across Oakleigh West and North, 10-year simulation, bare soil.*

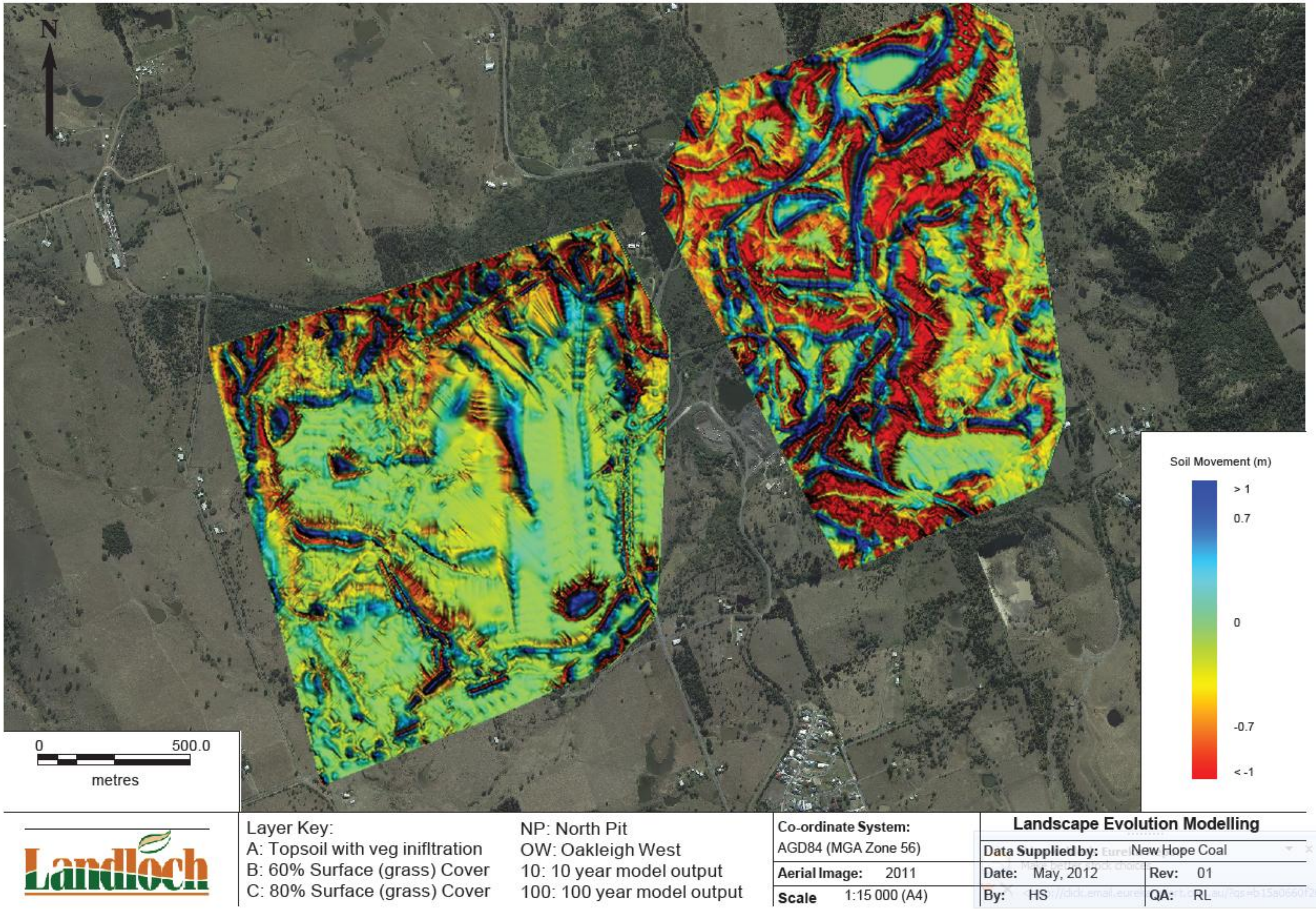

***Figure 23:** Predicted elevation change across Oakleigh West and North, 100-year simulation, bare soil.*

6.2.3 Revegetated soil, poor quality vegetation cover

Simulations for the situation where the level of vegetative cover achieved was relatively low (in the order of 60%) are shown in Figures 24 and 25, for simulation periods of 10 and 100 years respectively.

These simulations show greatly reduced levels or rates of surface elevation change. Nonetheless, they do indicate significant areas of steep batter slope where erosion rates in the order of 65 t/ha/y are likely to occur. This is particularly evident in Figure 25, and most widespread for Oakleigh North.

6.2.4 Revegetated soil, good quality vegetation cover

Simulations for the situation where the level of vegetative cover achieved was high (in the order of 80%) are shown in Figures 26 and 27, for simulation periods of 10 and 100 years respectively.

For much of the area – currently – vegetation cover levels are well in excess of 80%, so this simulation does represent a slightly conservative assessment of what could be achieved with rehabilitation of the site.

The figures show a considerable reduction in predicted elevation change relative to the case of 60% cover, but the 100-year simulation(Figure 27) does indicate potential gullying (largely to approximately 0.5 m depth) on a number of the steeper slopes, and largely on Oakleigh North.

6.3 Overview of SIBERIA output

Broadly, the DTMs provided, and the SIBERIA simulations carried out show:

- Significant areas of landforms at gradients considerably in excess of those recommended on the basis of WEPP simulations;
- A significant number of slope irregularities and landform areas of relatively short, steep slopes;
- High potential for erosion of bare soil;
- A large reduction in erosion potential in response to vegetation establishment;
- Remaining potential for significant rates of erosion on some steep batters even at vegetation cover levels of 80%.

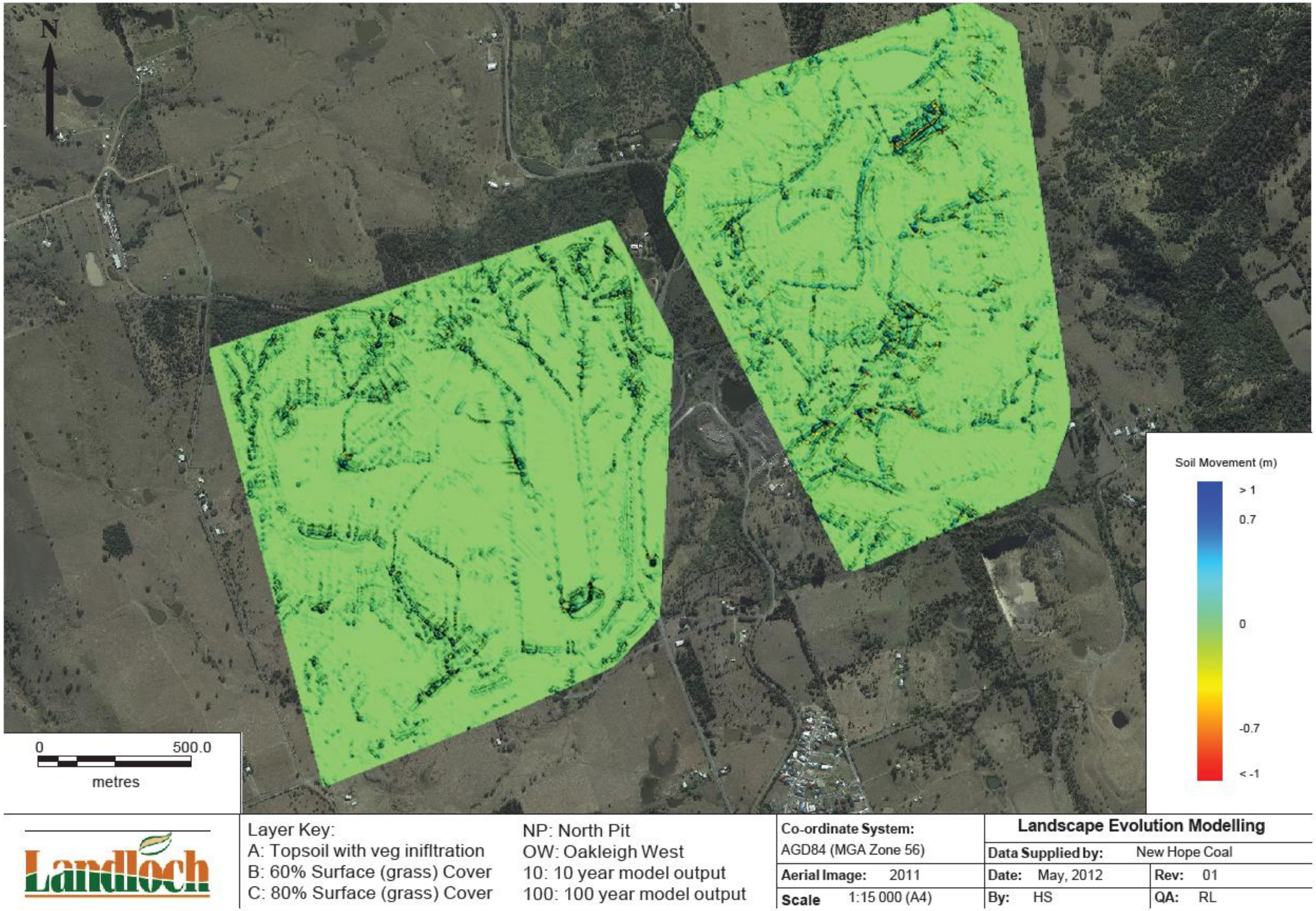

Figure 24: *Predicted elevation change across Oakleigh West and North, 10-year simulation, 60% surface cover.*

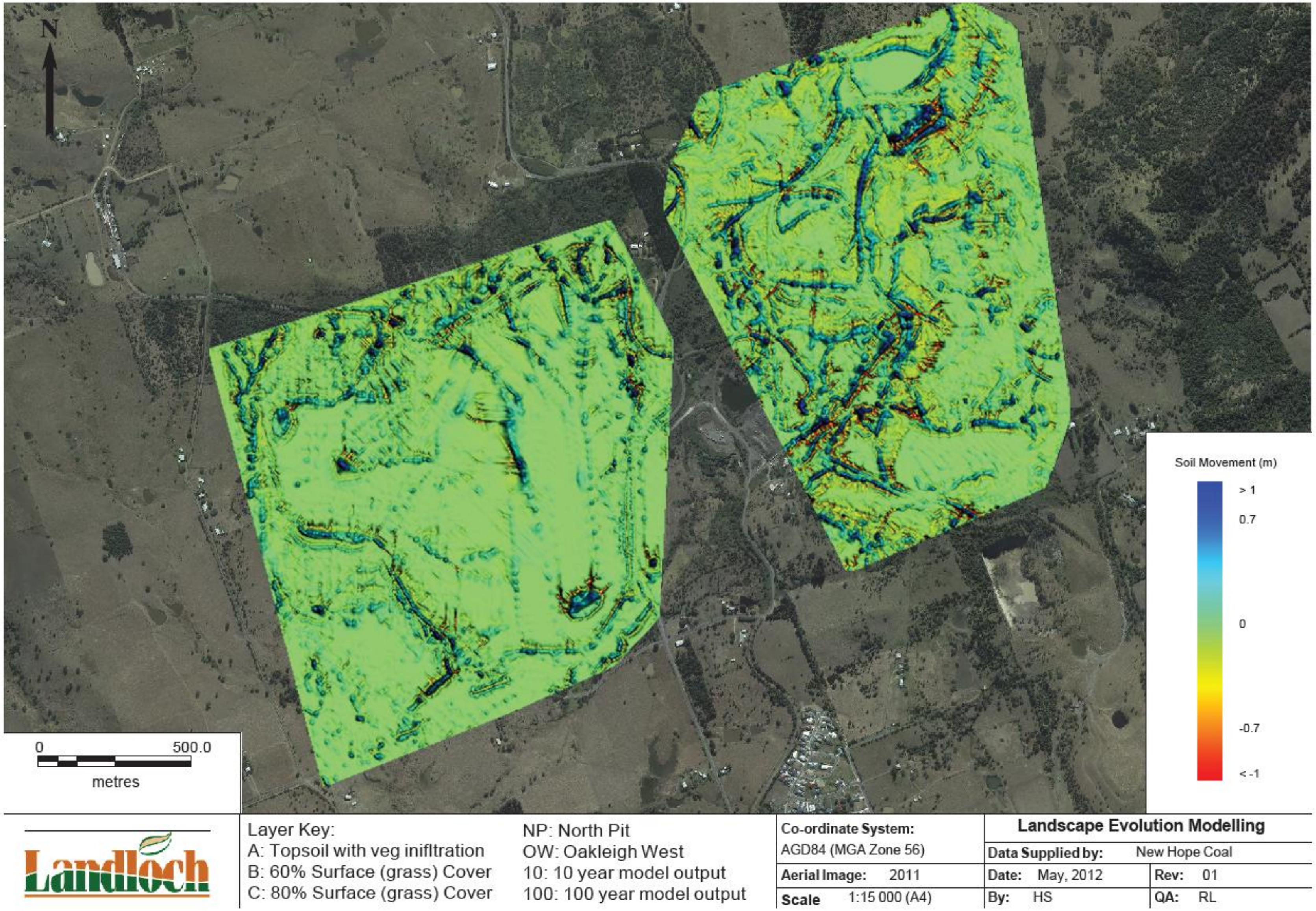

Figure 25: *Predicted elevation change across Oakleigh West and North, 100-year simulation, 60% surface cover.*

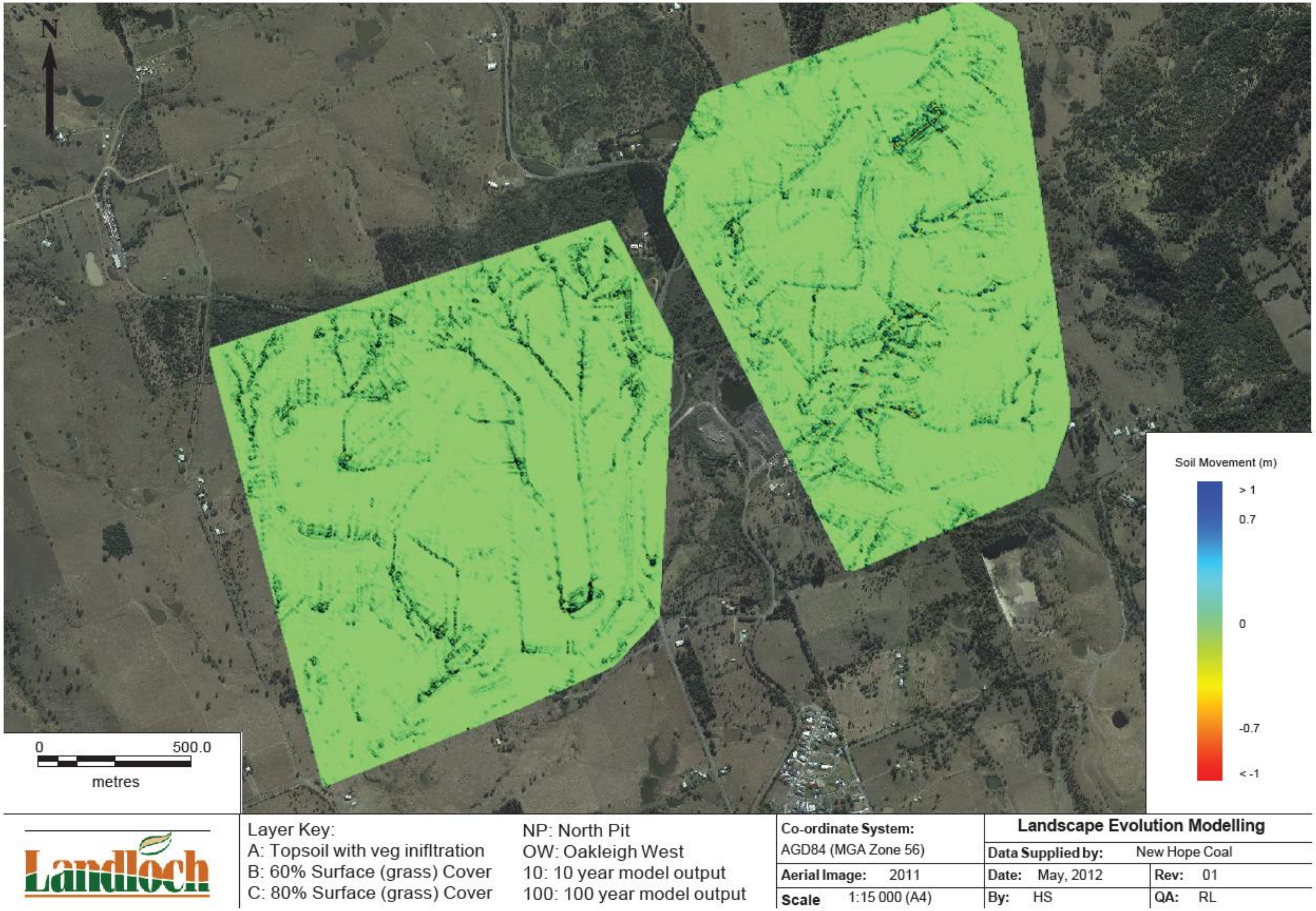

Figure 26: *Predicted elevation change across Oakleigh West and North, 10-year simulation, 80% surface cover.*

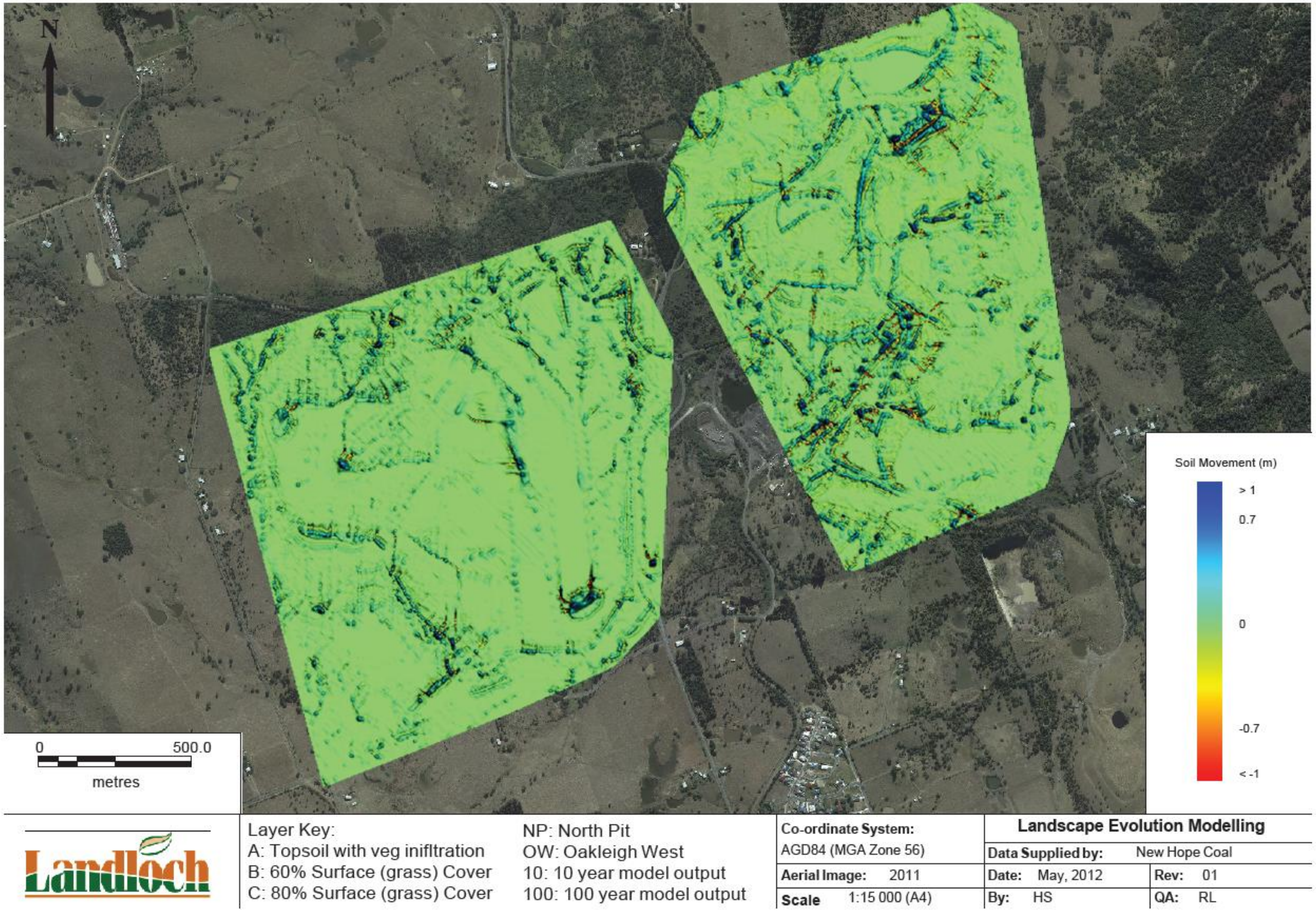

Figure 27: *Predicted elevation change across Oakleigh West and North, 100-year simulation, 80% surface cover.*

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Overview

The measurements and computer simulations in this report show clearly the interaction between soil properties, landform, and vegetation.

The role of vegetation in altering the properties and erosion potential of revegetated soils has been commonly observed (e.g., Loch and Orange 1997, Loch 2000). As well, the physical presence of vegetation contact cover can greatly reduce erosion potential, as demonstrated by cover factors (soil loss ratios) presented in Rosewell (1993). Soil and vegetation also interact with landform; increasing slope lengths and gradients resulting in increased erosion potential. As well, slope gradient can impact on vegetation establishment and vigour, with steep slopes tending to carry much lower levels of vegetation.

For the Oakleigh West and North leases, erosion simulations indicate that re-shaped and rehabilitated areas should have batter gradients no steeper than 20% (11.3 degrees). At those gradients, there could be considerable confidence that sufficient vegetation cover could be established to achieve long-term stability.

Such gradients are obviously lower than occur on many natural slopes and landforms. However, natural landforms are typically underlain by rock, giving them a stable foundation. Waste landforms constructed on minesites lack that foundation, and therefore, have potential for considerably more prolonged and extensive erosion.

For Oakleigh North in particular, final landform shaping will need to consider the natural components of the landscape as well as the constructed elements. Blending the two, whilst achieving stability of the latter, may well represent a significant challenge.

7.2 Proposed final landforms

The DTMs provided by New Hope Coal contain significant areas with gradients in excess of those recommended.

In some instances, these represent areas where a relatively small quantity of surface “smoothing” could eliminate areas of high gradient or flow diversion, and achieve considerable improvement in landscape stability. This appears to be particularly so for the southern and western areas of Oakleigh West.

For Oakleigh North, there are areas of high gradient that are currently unstable, and some re-grading or remediation of those areas is clearly required to achieve acceptable long-term rehabilitation of that lease.

However, the DTM provided for the Oakleigh North lease also contains significant areas of relatively steep batter slopes, which erosion and landform evolution simulations show as being inherently unstable. These areas will require either:

(a) re-shaping and reduction of their gradient; or
(b) extremely high quality revegetation works to achieve continuing cover levels significantly in excess of 80%.

Reliance on vegetation alone to address the potential for erosion would carry significantly increased risk of initial failure, and also place considerably greater emphasis on the need to ensure establishment of a sustainable vegetation cover.

7.3 Flow lines

Within both west and north leases, flow lines are clearly shown to have potential to be unstable. That is quite consistent with observations of the sites during this study.

The erosion simulations presented in this report have not attempted to address issues with respect to flow line stability, nor to present recommendations for their future management and remediation.

For the southern half of the Oakleigh West lease, there would be considerable value in attempting to reduce flow concentration and avoid the formation of gullies at all.

For the Oakleigh North area, there could be value in considering:

- Long sections of major flow lines and the gradients currently applying;
- Channel dimensions relative to the likely flows from the site; and
- Stability of bed and bank materials.

For Oakleigh North to some degree, and particularly for the Normanton lease, steep flow line gradients appear to be a significant factor in their instability.

Changed landforms and land use may well have altered flow regimes, and this may have resulted in channel instability. Some re-sizing of channels may be needed.

Particularly for Oakleigh North, it appears that the material in the banks of the major flow line may be relatively unstable, further adding to the instability of that channel.

7.4 Vegetation

The erosion simulations clearly demonstrate the importance of achieving a high level of vegetation cover as quickly as possible following site shaping and preparation.

The timing of revegetation works is critical, with it being essential for sites to be prepared so that vegetation establishment can commence in September and achieve good surface protection prior to the period of high erosion hazard in December – March.

The available data indicate that the initial target vegetation should be grassland, to maximise improvements in soil infiltration capacity. To be sustainable, the grassland will need a component of legumes, to provide a continuing source of N. In the longer term, stakeholder requirements may require inclusion of some level of tree vegetation, which should not reduce slope stability unless tree density becomes such that surface cover by grass is drastically reduced over significant areas.

8. REFERENCES

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APPENDIX 1: THE WEPP MODEL

The Water Erosion Prediction Program (WEPP) (Flanagan and Livingston 1995) was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for hillslopes and watersheds. It is the product of continued USDA research and development of soil erosion models since the 1940's. As such, it is based on an enormous body of research data and modelling experience, and is widely regarded as the state of the art in erosion modelling at this time.

WEPP is a simulation model with a daily input time step, but internal calculations can use shorter time steps. For example, the climate file (for each day) includes information on:

- Amount of rain
- Duration of the rain
- Time to peak intensity
- Ratio between peak intensity and average intensity.

This information is used in infiltration calculations, so that the model takes intensity and duration of rainfall into account. For every day, plant and soil characteristics important to erosion processes are updated. When rainfall occurs, those plant and soil characteristics are considered in determining whether runoff occurs. If runoff is predicted to occur, the model computes sediment detachment, transport, and deposition at points along the slope profile, and, depending on the version used, in channels and reservoirs.

Conceptually, the WEPP model can be divided into six components: climate generation, hydrology, plant growth, soils, management, and erosion.

Hydrology

The hydrology component of WEPP computes infiltration, runoff, soil evaporation, plant transpiration, soil water percolation, plant and residue interception of rainfall, depressional storage, and soil profile drainage by subsurface tiles. Infiltration is calculated using a modified Green and Ampt infiltration equation. Runoff is computed using the kinematic wave equations or an approximation to the kinematic wave solutions obtained for a range of rainfall intensity distributions, hydraulic roughness, and infiltration parameter values.

Two methods are used to compute the peak discharge rate depending if the model is run in a continuous or single storm mode and if there are multiple overland flow elements (OFE). A semi-analytical solution of the kinematic wave model is used to compute the runoff hydrograph when the model is run in the single storm mode for a single OFE or when multiple OFEs can be treated as a single OFE. A peak discharge approximation based on the kinematic wave model is used for most events when the model is run in the continuous simulation mode. Infiltration and rainfall excess on multiple OFEs are approximated by either averaging the infiltration parameters and treating the multiple OFEs as a single OFE or by computing a simple water balance to determine if runoff occurs. For multiple OFEs, an equivalent depth-discharge coefficient for the kinematic wave model is computed based on the equilibrium storage of water on a cascade of OFEs.

The erosion component uses a steady-state sediment continuity equation as the basis for the erosion computations. Soil detachment in interrill areas is calculated as a function of the effective rainfall intensity and runoff rate. Soil detachment in rills is predicted to occur if the flow hydraulic shear stress is greater than critical shear and the flow sediment load is below transport capacity. Deposition in rills is computed when the sediment load is greater than the capacity of the flow to transport it.

Validation of the WEPP model

The WEPP model has been widely tested against measured data (Nearing and Nicks 1998, Ghidey and Alberts 1996, Liu *et al.* 1997, Zhang *et al*. 1996, Tiwari *et al*. 2000, Yu and Rosewell 2001). In general, the tests indicate that the model performs well – given that no erosion model is expected to be extremely precise, and that experimental erosion data are somewhat variable (Nearing *et al*. 1999). Interestingly, the model is more accurate in its prediction of long-term averages than of erosion associated with individual years (Figure A1-1) – again, a consequence of the extreme variability of erosion from individual events.

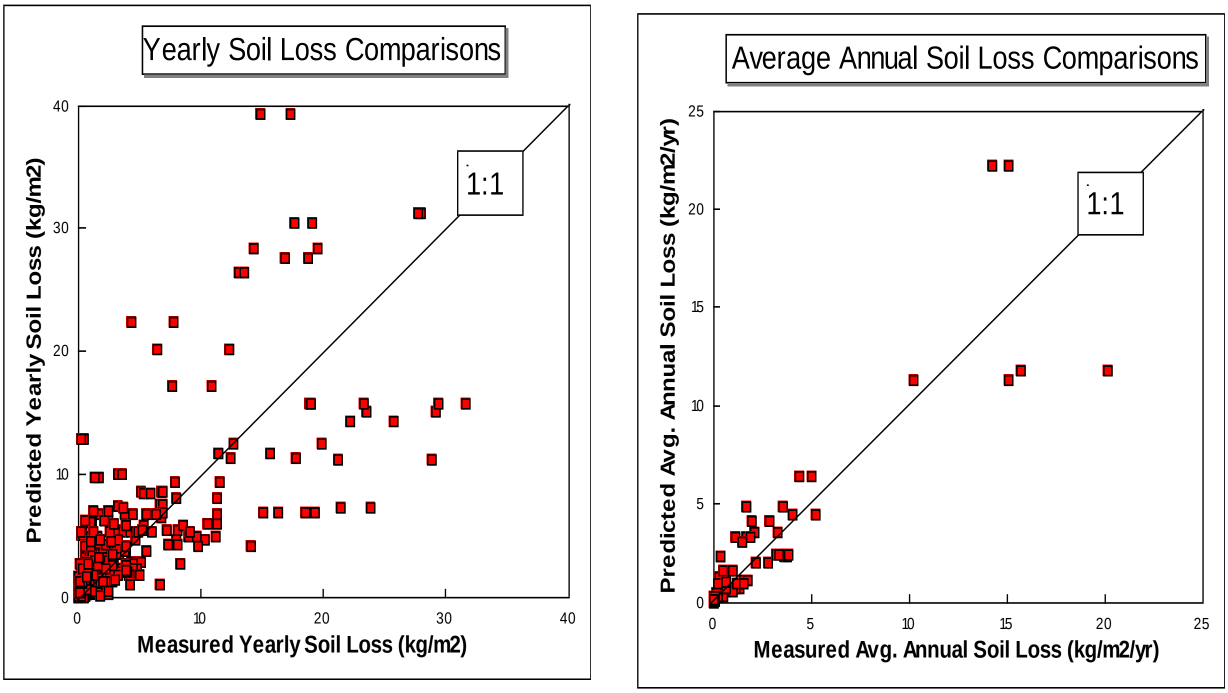

Figure A1-1: *Figures from Nearing and Nicks (1998) showing WEPP model performance against measured data.*

Experience with, and assessment of, the WEPP model for Australian minesite landforms has found that the accuracy of its predictions is high when directly-measured erodibility and infiltration data are available (Figure A1-2 from Howard and Roddy, 2012).

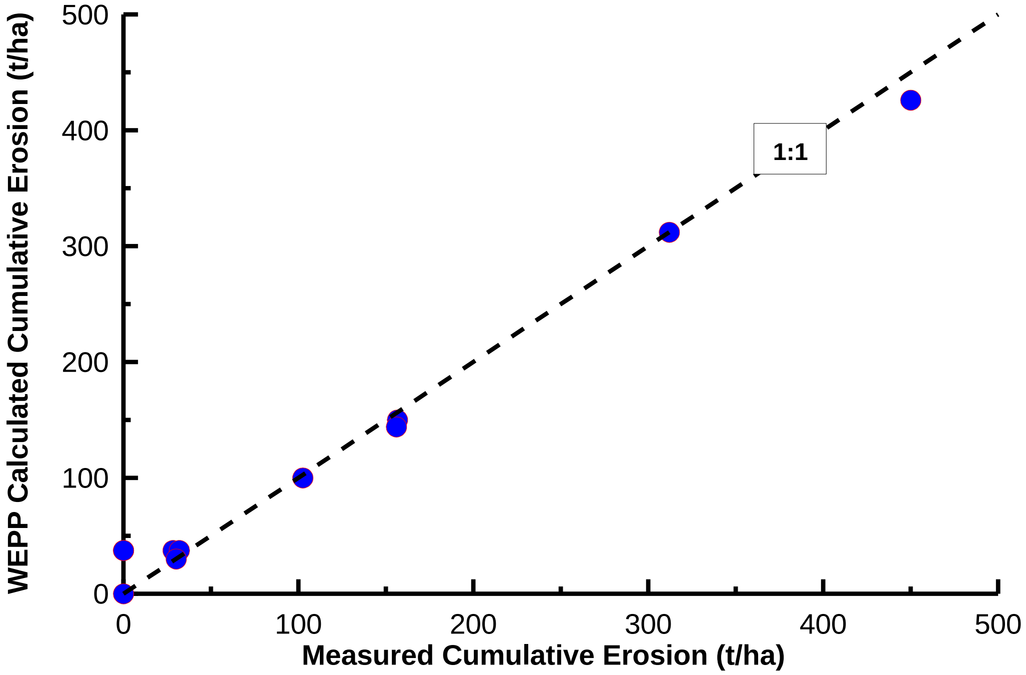

Figure A1-2: *Predicted and observed cumulative erosion rates for 11 batter slope locations in Western Australian mine sites (Howard and Roddy 2012).*

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APPENDIX 2: DEVELOPMENT OF WEPP CLIMATE FILE FOR ROSEWOOD

Introduction

Climate input files for Rosewood were needed to simulate runoff and soil loss using the Water Erosion Prediction Project (WEPP) model. For each day of simulation, WEPP requires ten daily weather variables:

- Precipitation (mm),
- Precipitation duration (hrs),
- Peak storm intensity,
- Time to storm peak,
- Average minimum temperature,
- Average maximum temperature,
- Dew point temperature,
- Solar radiation,
- Wind speed, and
- Wind direction.

Of these, the four precipitation-related variables (underlined in list above) are of particular importance because previous studies have shown that predicted runoff and soil loss are most sensitive to these precipitation variables[2,3].

For most sites around the world, complete historical weather data on these variables are not available. To use WEPP for runoff and erosion prediction, synthetic weather sequences that statistically preserve the mean and variations in the historical observations are required. CLIGEN is a stochastic weather generator that can be used to provide WEPP climate input files. CLIGEN has been extensively assessed for a wide range of climates in Australia, and it was found that CLIGEN was most suitable to provide the required climate input for WEPP to predict runoff and soil loss in Australia[4].

This report briefly summarises how climate parameter values were prepared for CLIGEN to generate 111 years of daily climate data for Rosewood.

Data and method

Rosewood (152.59ºE, 27.64ºS) is located in the Bremer Valley, Queensland, approximately 60km west of Brisbane. Daily climate data – rainfall, maximum and minimum temperatures, and solar radiation – were sourced from the Australian Bureau of Meteorology (BoM) through the Patched Point Data facility. Patched Point Data provides observed data that has been patched (where data is missing) with data from nearby stations. The observed data set that was patched was sourced the Rosewood climate station (40184). Data were used from January 1900 to February 2012. Rainfall intensity

[2] Nearing, M. A., Dear-Ascough, L, Laflen, J. M., 1990. Sensitivity analysis of the WEPP Hillslope Erosion Model. *Transactions of the ASAE*, 33: 839-849.
[3] Chaves, H. M. L., Nearing, M. A., 1991. Uncertainty analysis of the WEPP soil erosion model. *Transactions of the ASAE*, 34: 2437-2444.
[4] Yu, B. 2003. An assessment of uncalibrated CLIGEN in Australia. *Agricultural and Forest Meteorology*, 119: 131-148.

data were also sourced from Amberley (40004) through the Bureau of Meteorology. This site contains pluviograph data from February 1961 to March 2011, with an effective record length of approximately 49 years.

Using the two data sets above, the following parameter values were computed and used to develop the climate sequence for Rosewood:

- Mean daily precipitation on wet days for each month,
- Standard deviation and skewness coefficient of daily precipitation for each month,
- Probability of a wet day following a dry day for each month,
- Probability of a wet day following a wet day for each month,
- Mean daily max. temperature for each month,
- Standard deviation of daily max. temperature for each month,
- Mean daily min. temperature for each month,
- Standard deviation of daily min. temperature for each month,
- Mean maximum 30-min rainfall intensity for each month, and
- Probability distribution of the dimensionless time to peak storm intensity.

These parameter values for rainfall, temperature, and solar radiation were assembled to create a CLIGEN parameter file for the site. A 111-year climate sequence was generated using CLIGEN version 5.1[5]. Use of generated wind data has been switched off because Priestley-Taylor's method for estimating the potential evaporation will automatically be used by WEPP. The generated file is called 40184.cli, and was generated for arbitrary period of 1 Jan 2100 to 31 December 2211. A random seed of 201203 was used for CLIGEN. This particular climate sequence can be reproduced with this specific random seed.

Data assessment

The quality of the simulated climate sequence was compared with the patched and unpatched data for Rosewood. The mean annual rainfall for Rosewood from the CLIGEN data set is 863mm. This compares well with the average annual rainfall for the patched Rosewood data (864mm) and unpatched observed data for Rosewood (867mm). Figure A2-1 shows that mean monthly rainfall values are also well preserved.

[5] Yu, B., 2002. Using CLIGEN to generate RUSLE climate inputs. *Transactions of the ASAE*, 48: 993-1001

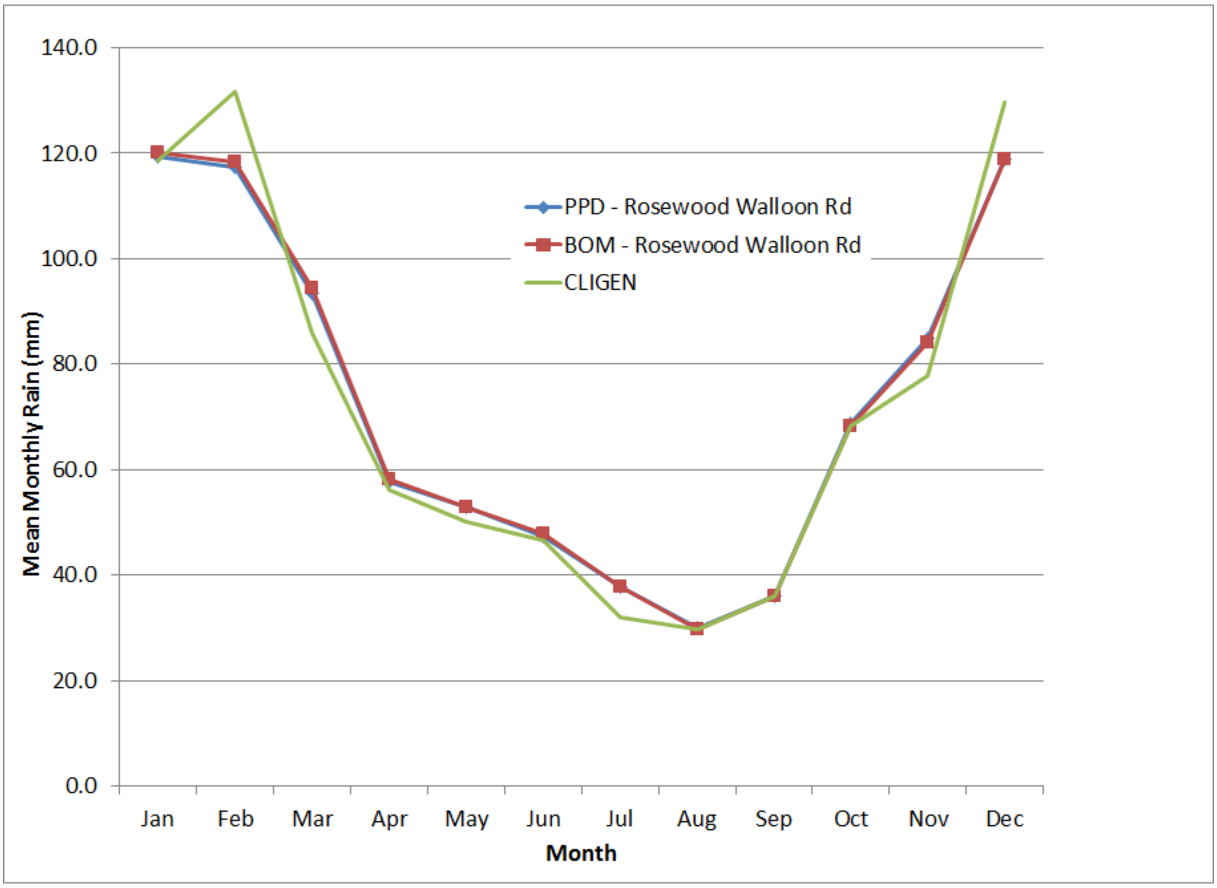

Figure A2-1: *Mean monthly rainfall: Rosewood Patched Point Data (PPD – Rosewood Walloon Rd), unpatched data from Rosewood (BOM - Rosewood Walloon Rd), and CLIGEN data sets.*

The frequency of occurrence of daily rainfall events (ARI) was also compared for the three data sets (Figure A2-2). It can be seen that for this particular CLIGEN simulation run, the maximum daily rainfall totals for both data sets match quite well, especially given the fact that rainfall at the site is highly variable.

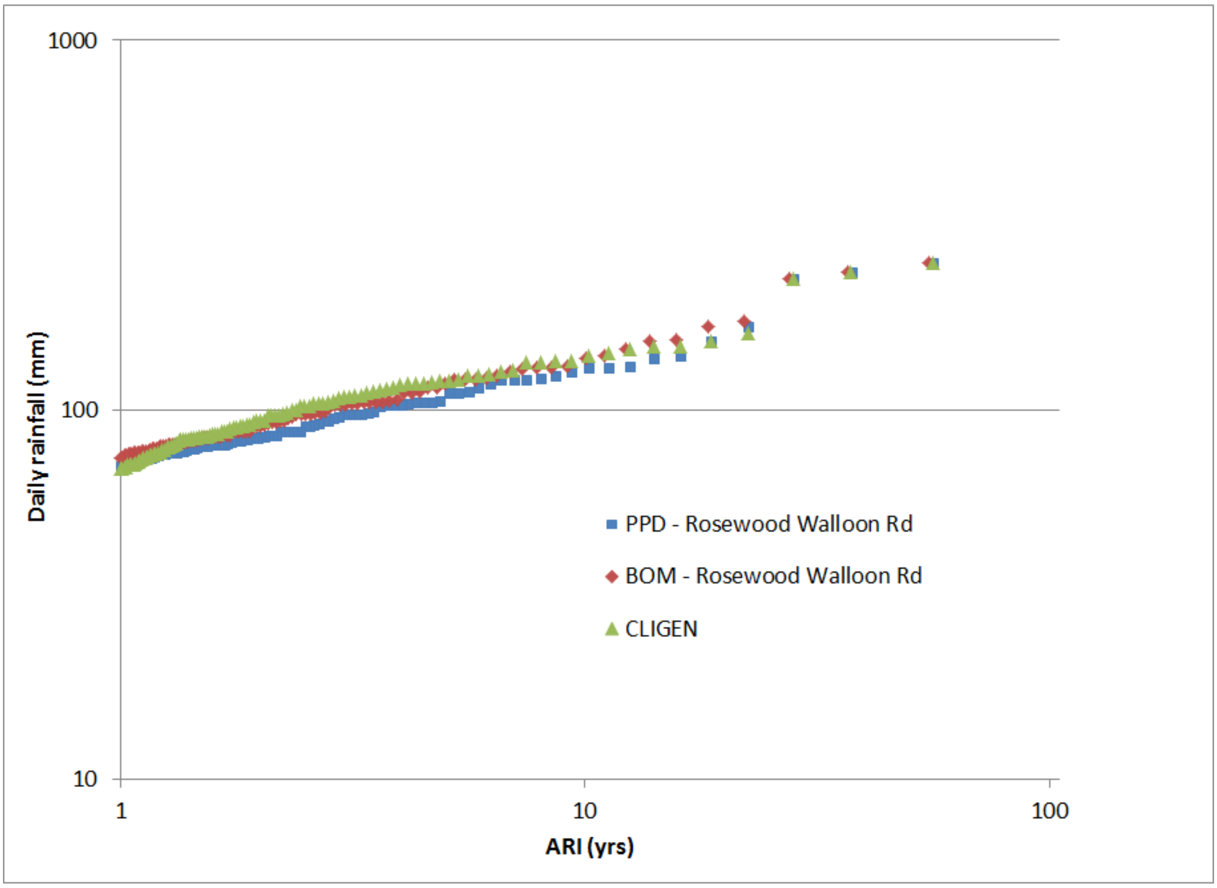

Figure A2-2: *Daily rainfall as a function of average recurrence interval (ARI): Rosewood Patched Point Data (PPD – Rosewood Walloon Rd), unpatched data from Rosewood (BOM - Rosewood Walloon Rd), and CLIGEN data sets.*

Conclusion

A 111-year CLIGEN-generated climate file for Rosewood was developed based on patched daily rainfall, temperature, and solar radiation data derived from long records of observed historical data from Rosewood. The CLIGEN data set correlates closely with the observed data for the area, and can be used with confidence within the WEPP program to simulate runoff and erosion from landform slopes.

APPENDIX 3: THE SIBERIA MODEL

Model overview

The SIBERIA model has been successfully applied to explain aspects of geomorphology of natural landforms (Willgoose 1994). The location and speed with which rills and gullies develop are controlled by a channelisation function. SIBERIA does not input actual rainfall or material erodibility parameters. Rather, the input parameters define this channelisation function that are related to both runoff and soil erodibility (Willgoose *et al.* 1989) and must be derived for each particular material at each particular site[6].

The SIBERIA model solves for two variables:

1. Elevation, from which slope geometries are determined, and
2. An indicator function that determines where channels exist.

Channel growth is governed by an activation threshold that is dependent on discharge and slope gradient. When the activation threshold is exceeded, a channel is predicted to develop. It is possible for a modelled surface to initially have no gullies, and for channels to develop when the activation threshold is exceeded.

SIBERIA has been extensively used by the Supervising Scientist Division of the Commonwealth Department of Sustainability, Environment, Water, Population and Communities, and subjected to extensive validation. In general, the tests indicate that – provided the model is adequately calibrated – SIBERIA predictions appear to be reasonable (Hancock *et al.* 2000, Hancock *et al.* 2002, Hancock *et al*. 2003, Willgoose *et al.* 2003). In addition, Hancock (2004a) notes that rates of erosion predicted by SIBERIA for a catchment in the Northern Territory compared very favorably with estimates of erosion derived using the caesium-137 method for soil erosion assessment. As the two methods used completely independent input information, the agreement is particularly significant.

The SIBERIA model has been widely used for assessment of the development of constructed landforms on a range of mine sites across Australia and overseas (Willgoose 1993, Willgoose and Riley 1995, Boggs *et al*. 2000, Hancock *et al*. 2003, Hancock and Willgoose 2004, Hancock 2004b, Mengler *et al.* 2004, Hancock and Turley 2006). The model is equally applicable to any climatic regime as its input parameters are derived by calibration to runoff and erosion data.

SIBERIA simulations used input parameters derived from WEPP output using methods developed by Landloch in consultation with the developers of SIBERIA. Therefore, the laboratory based assessment of materials are used to derive both the required WEPP and SIBERIA input parameters.

[6] Use of parameters generated for similar materials but for a different rainfall regime is not acceptable. The opposite is also true, with different materials for the same rainfall regime likely to have different input parameters.

Derivation of SIBERIA input parameters from laboratory data

SIBERIA predicts the long-term average change in elevation of a point by predicting the volume of sediment lost from a node. The rate of sediment transport through a node (q_s, in units of m^3/y) is determined by the equation:

$$q_s = \beta_1 q^{m_1} S^{n_1} \quad (1)$$

where β_1 = sediment transport rate coefficient, q = discharge (m^3/y), m_1 = the discharge exponent, S = slope (m/m), and n_1 = the slope exponent.

SIBERIA does not directly model runoff, but uses sub-grid effective parameterisation which relates discharge to area draining through a point as:

$$q = \beta_3 A^{m_3} \quad (2)$$

where β_3= coefficient between discharge and area, A = area (m^2), and m_3 = exponent of the area in discharge.

To run SIBERIA, the parameters β_1, m_1, n_1, β_3, and m_3 are usually needed. However, if the batter area to be modelled is identical to the batter for which erosion data are available for calibration, m_3 and β_3 can be taken as 1.0 (Willgoose, pers. comm.), and a value of n_1 = 1.5 can be adopted for situations where slope gradient does not affect slope erodibility (Willgoose, pers. comm.). Where steeper slopes are subject to greater armoring, the exponent n_1 may be as low as 0.7 (Evans *et al.* 1998). Therefore, the two key parameters that require derivation are β_1 and m_1.

Effectively, the β_1 parameter could be described as a “rate parameter”, as it primarily controls the rate of sediment movement. The m_1 parameter could be considered as primarily controlling slope length responses. However, in practice, there is interaction between all of the parameters with the result that an almost infinite number of parameter sets will all show the same rate of erosion though some aspects of the pattern of erosion that is predicted will vary. It is for this reason that, where possible, fixed values of n_1 and m_3 are adopted – thereby reducing the difficulty of deriving parameter values.

Input parameters for SIBERIA are typically derived by fitting the various model equations to time series data of rainfall and erosion. However, in most instances, sufficiently long series of these data are not available for landforms of interest[7]. Therefore, in conjunction with University of Newcastle researchers (G. Hancock and G. Willgoose) who have been heavily involved in SIBERIA development and validation, Landloch has developed an alternative approach to the estimation of SIBERIA model parameters. The general approach applied is to:

(a) Make measurements on materials to derive WEPP model parameters.
(b) Run the WEPP model to generate data sets of runoff and erosion for slopes and materials of interest using site specific climate data.
(c) Analyse the WEPP output to derive the required SIBERIA input parameters.

[7] Data is essentially never available where waste landforms are concerned.

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