


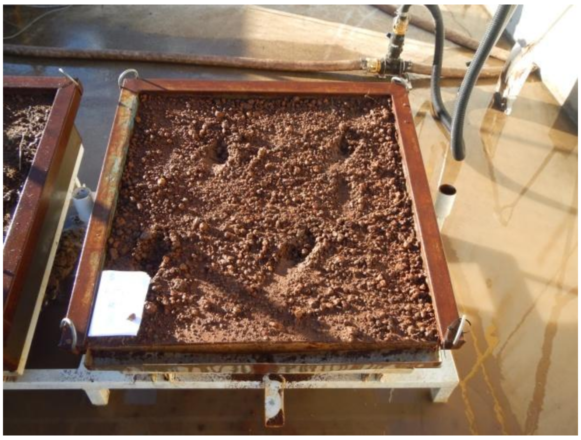

Landform design study, Carmichael Coal Project.

August 2013

Landloch Pty Ltd
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Draft	9 August 2013	R. Loch	E. Howard
Final	22 August 2013	R. Loch	A. Clark

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The landscape is not uniform. Because of this non-uniformity, no monitoring, testing or sampling technique can produce completely precise results for any site. Any conclusions based on the monitoring and/or testing presented in this report can therefore only serve as a 'best' indication of the environmental condition of the site at the time of preparing this document. It should be noted that site conditions can change with time.

The information that comprises this report should only be used within the limitations stipulated in this report. Landloch does not accept any risks and responsibilities for losses, damages, costs and other consequences resulting from using any information, material and recommendations in this report.

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EXECUTIVE SUMMARY

Adani Mining Pty Ltd commenced an Environmental Impact Statement (EIS) process for the Carmichael Coal Mine and Rail Project (the Project) in 2010. To support preparation of a Supplementary EIS (SEIS), Landloch was engaged by GHD to carry out erosion modelling to provide assessment of the potential stability of proposed waste landforms.

There were no spoil or overburden materials available for assessment of runoff and erosion potential for this study. Therefore, Landloch has assumed for modelling purposes that the eventual stability of rehabilitated waste landforms would depend largely on the erosion characteristics of the topsoils used in rehabilitation. To assess the potential stability of those topsoils, samples were taken of two *in situ* topsoils most likely to be used in rehabilitation. These two samples were subsequently transported to Landloch's laboratory in Toowoomba, where erosion studies using simulated rainfall equipment and overland flow flumes were used to derive infiltration and erodibility parameters.

These infiltration and erodibility parameters were then used as inputs into the Water Erosion Prediction Program (WEPP) runoff/erosion model (Flanagan and Livingston 1996), to derive final landform stability parameters based on simulations for a 100-year period using a synthetic climate file developed for the Project site. For the two topsoils tested, the simulations showed:

(a) A major impact of soil type and soil erodibility on potential batter slope stability, and therefore, on the potential landform design parameters; and
(b) The critical impact of vegetation cover.

Simulations indicate that <u>the light clay Sample 1 topsoil is unsuitable for placement on the outer batter slopes</u>, and should only be placed on the top of the dump, where it may be highly productive in terms of vegetation growth.

Achieving sufficient vegetation contact cover will be <u>critical</u> for rehabilitation success, and for the long-term stability of the batter slopes to be formed.

<u>For the sandy Sample 2 topsoil, t</u>he simulations (Figure 9) indicate that, provided the surface material acts similarly to the topsoil tested, erosion rates would increase with slope length to a maximum rate that would be acceptable at gradients of 6.3 - 10 degrees, provided:

a) vegetation cover in excess of 60% was achieved sustainably and reliably.
b) there is no discharge of runoff from the top of the landform onto the outer batter slopes; and
c) appropriate progressive rehabilitation practices are applied.

However, for rehabilitated inner batter slopes, for which gradients of 12-14 degrees have been proposed, other landform stabilisation measures such as mixing competent rock into the batter surface would be need to be implemented to achieve suitable stability, even when using the sandy Sample 2 topsoil and achieving 60% vegetative cover.

A number of risks to landform stability were identified, including:

i. Supply of a sufficient quantity of suitable topsoil (with properties equivalent to the sandy Sample 2;
ii. Interactions with underlying waste (placement of highly impermeable waste could render the permeable topsoil highly unstable due to saturation of the surface layer); and
iii. Climate change, with one study indicating that a temperature increase of 4 degrees Celsius at Charters Towers in north-eastern Australia would increase runoff by 20% and soil erosion by 39% under conservative stocking. Current publically available projections suggest similar levels of climate change could be expected for the Carmichael Project, and by association, these increased levels of erosion potential are reasonable estimates for the Project site.

1. BACKGROUND

Adani Mining Pty Ltd commenced an Environmental Impact Statement (EIS) process for the Carmichael Coal Mine and Rail Project (the Project) in 2010.

The proposed mine is a 60 million tonne (product) per annum (Mtpa) thermal coal mine in the northern Galilee Basin, approximately 160 kilometres (km) north-west of Clermont, Central Queensland, Australia.

To support preparation of a Supplementary EIS (SEIS), Landloch was engaged by GHD to carry out erosion modelling to provide assessment of the potential stability of proposed waste landforms. Landloch was advised that during the life of the Project (Mine), there will be approximately 1.64 billion m³ of out-of-pit waste. The maximum height above the natural surface of the out-of-pit dumps is estimated to be up to 140 m. The outer face of the dumps will be profiled to a final rehabilitation gradient of 10 percent (6.3 degrees). The inner face will be dumped to angle of repose, and later re-profiled to between 12 to 14 degrees to assist in rehabilitation of the final landform and mining voids.

2. APPROACH APPLIED

At this stage (prior to any mining being carried out), there are no spoil or overburden materials available for Landloch to assess their runoff and erosion potential. However, it can be expected that waste landforms, when rehabilitated, will be re-shaped, sheeted with topsoil, and then revegetated. Assuming that spoils do not act as an impeding layer for infiltration and that they are not prone to tunnelling, the eventual stability of the rehabilitated waste landform will depend largely on the erosion characteristics of the topsoils used in rehabilitation. There may be quite significant potential for interactions with the underlying waste, depending on its physical and chemical properties, however those issues were not addressed in this study.

To assess the potential stability of topsoils, samples were taken of two *in situ* topsoils most likely to be used in rehabilitation. These two samples were subsequently transported to Landloch's laboratory in Toowoomba, where erosion studies using simulated rainfall equipment and overland flow flumes were used to derive infiltration and erodibility parameters. These infiltration and erodibility parameters were then used as inputs into the Water Erosion Prediction Program (WEPP) runoff/erosion model (Flanagan and Livingston 1996) to derive final landform stability parameters based on simulations for a 100-year period using a synthetic climate file developed for the Project site. Greater information on the model is given in Appendix A.

A 100-year synthetic climate file was developed for the site, and 100-year simulations of runoff and erosion for a range of batter slope options were tested to inform landform design guidelines.

3. SOILS SAMPLED

The Carmichael project site was visited by Dr Anthony Clark of Landloch Pty Ltd on 27-28 June 2013. Anthony supervised the selection of soils for sampling by site staff (Figure 1).

Observations were made of the level of vegetative cover (Figure 2), which was composed of areas of buffel grass and tree belts in lower-lying areas Surface cover was in the order of 60% (Figure 3), though spatially variable. For the purposes of rehabilitation, it could be assumed that protection from grazing and some additional fertilisation would achieve significant increases in standing biomass and surface cover.

Figure 1: *Excavation of surface layer assumed to be consistent with "topsoil" that would be stripped for rehabilitation.*

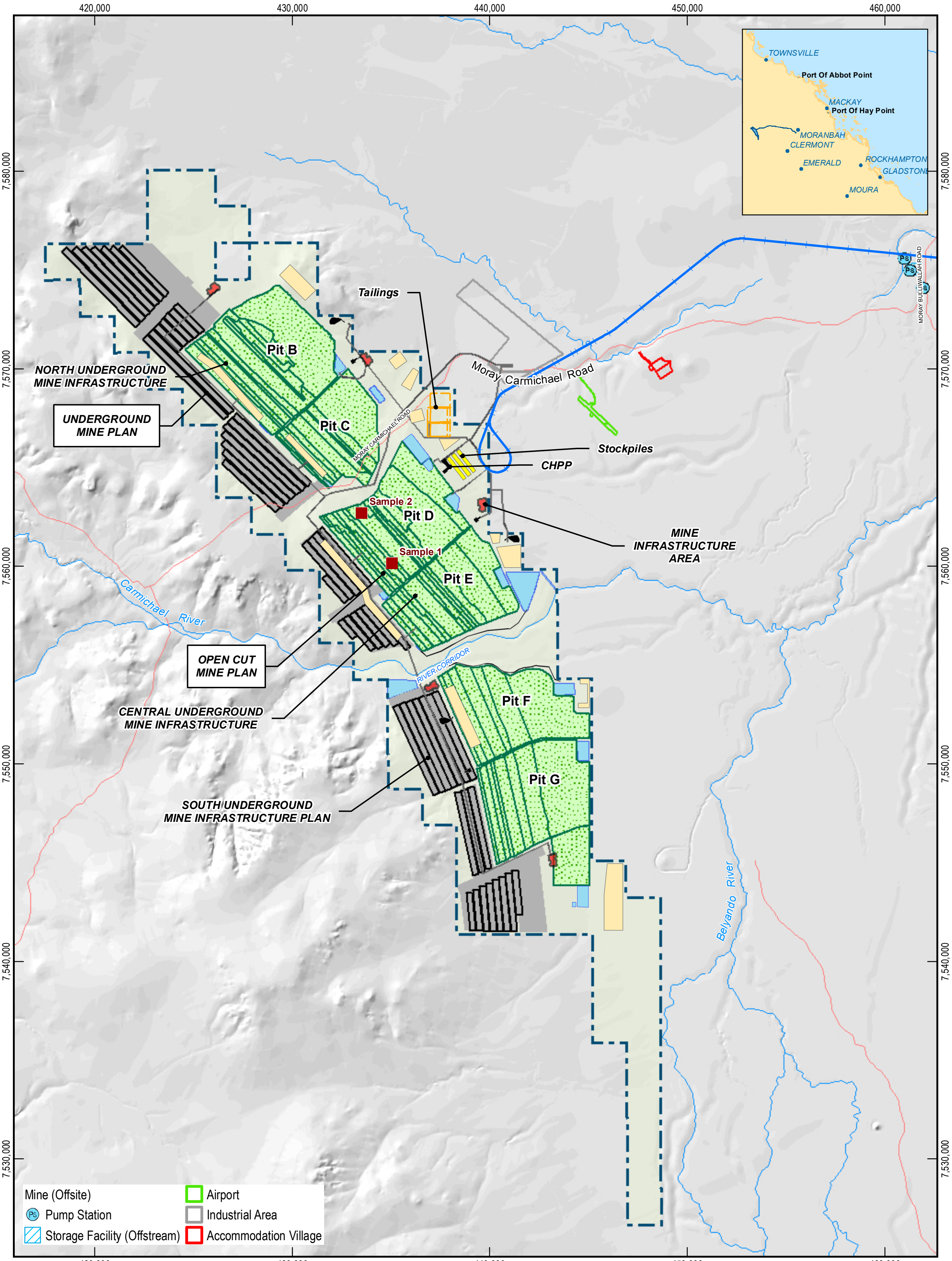
Figure 2*: Vegetation present: buffel grass and areas of trees.*

***Figure 3**: Sparser cover grading into an area of more dense cover.*

The landscape on the Carmichael site is dominated by low relief, but with observable terraces formed by the Carmichael River (McClurg 2011). Two topsoil samples representative of the observed soil variation were taken in an area proposed for the mine waste landforms (Figure 4):

- Sample 1 is a light clay material taken from an area of cracking clay soils (Vertisol). This part of the landscape is characterised by large gilgai, occurring on the second terrace of the Carmichael River.
- Sample 2 is a soil with a strong texture contrast between the light sandy topsoil and heavier clay subsoil (Chromosol). These soils occur on the third terrace of the Carmichael River.

The sandier alluvial soils on the first terrace of the river were inspected but not sampled. These occur in a narrow band, within the 500m buffer zone of the Carmichael River, and are therefore not likely to be disturbed or used as a material in rehabilitation of the waste landform.



LEGEND

- Soil Sampling Location
- Local Road
- River / Watercourse
- Overland Conveyors
- Rail (West)
- Mine (Onsite)
- Open Cut Blocks
- Water Management Dams
- Mine Infrastructure Area
- Mine Infrastructure
- Stockpiles
- Tailings Cell
- Top Soil Storage

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1:275,000 (at A4)

0 2 4 6 8 10

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

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Adani Mining Pty Ltd
Carmichael Coal Mine and Rail Project SEIS

Job Number	41-26422
Revision	B
Date	31-10-2013

Soil Sampling Locations

Figure 4

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Data Source: GA: Road, River / Watercourse (2007); DME:EPC1690 (2010), EPC1080 (2011); DNRM: DEM (2010); Adani: Alignment, Offsite(2013), Mine Layout / Infrastructure (2013); Landloch: Sample Location (2013). Created by: MS

One bulk sample (approximately 0.8 m^3) was collected of each of the two selected "topsoils" which were transported to Landloch's Toowoomba laboratory by truck. Subsamples were taken from each of the two bulk samples and sent to a commercial soils laboratory for detailed physical and chemical analysis. Summary results of that analysis are shown in Table 1, with laboratory certificates provided in Appendix B. The results in Table 1 indicate that both soils have:

- near-neutral pH;
- low soluble salts;
- low total N;
- low total P;
- low available P;
- very low S; and
- low organic carbon.

These results are consistent with what would be expected for pastoral soils in relatively poor condition, and largely, the vegetation cover levels observed (Figures 2 and 3) are consistent with the low fertility indicated. In general, there are no "ideal" ranges for most soil parameters, as the vegetation present (and its specific adaptations and productivity) can vary greatly.

Exchangeable cations and Cation Exchange Capacity (CEC) show that neither soil is sodic, but the sandier soil (Table 1, sample S2) has considerably lower CEC as expected.

Particle size distributions show large differences between the soils, with Sample 2 having a significant proportion of gravel, considerably more coarse sand, and considerably less clay.

4. CLIMATE FILE

Daily climate observations were obtained from the Queensland Government's Patched Point Data Set for the Twin Hills meteorological station, located 71 km SE/NW from site. Sub-daily storm characteristics were obtained from the Bureau of Meteorology's pluviograph station from Moranbah, located 173 km east/SE from site. Climate simulations were run with the CLIGEN weather generator using this data. The 100 year climate record produced by CLIGEN is suitable for planned erosion modelling, as it is representative of observed variability at the Twin Hills station, including general storm characteristics.

Climate change projections were obtained through CSIRO's OzClim scenario generator. For a high climate change scenario in 2040, the region in which the project is located is projected to experience:

- Mean annual temperature change of + 2-3 degrees Celsius by 2040; and
- Increases in mean annual rainfall of 25-50mm.

The project site is in the same climatic zone and has similar climate change projections to Charters Towers, where a detailed assessment of changes to rainfall intensity and erosion potential has been carried out (Fraser *et al.* 2011). This study is discussed further in section 7.2.3.

Table 1: Analytical data for the two topsoils sampled.

Analyses	Unit	Sample	
		S1	S2
Basic properties and fertility parameters			
pH - Water	pH units	7.11	6.29
Electrical Conductivity	dS/m	0.03	0.03
Total Nitrogen - Kjeldahl	mg/kg	541	660
Total Phosphorus - Nitric/Perchloric	mg/kg	185	195
Phosphorus - Colwell extract	mg/kg	21.1	11.0
Potassium - Colwell extract	mg/kg	193	157
Sulphur - KCl	mg/kg	2.4	4.1
Organic Carbon	%	0.74	1.29
Exchangeable cations			
Cation Exchange Capacity	meq/100g	15.2	6.8
Exchangeable Calcium Percent	%	70.2	69.8
Exchangeable Magnesium Percent	%	25.0	22.9
Exchangeable Potassium Percent	%	2.36	4.40
Exchangeable Sodium Percent	%	2.38	2.78
Particle size			
Gravel >2.0mm	%	2.2	27.7
Coarse Sand 0.2-2.0mm	%	13.4	22.2
Fine Sand 0.02-0.2mm	%	37.8	32.1
Silt 0.002-0.02mm	%	9.2	1.3
Clay <0.002mm	%	37.4	16.7

5. ERODIBILITY ASSESSMENT

5.1 Laboratory methods

Erodibility was assessed using:

- flumes (Figure 5) exposed to a range of overland flows to measure critical shear (τ_c) and rill erodibility (K_R); and
- small plots exposed to simulated rainfall (Figure 6) to measure interrill erodibility (K_i) and hydraulic conductivity (K_e).

These four parameters are used within the WEPP model to describe the erodibility of a soil (refer Section 5.2). Rain water was used in all measurements to avoid any potential impacts of water quality on infiltration and on breakdown of sediment to finer sizes. The methods used are broadly similar to those reported by Sheridan *et al.* (2000). The rainfall simulator was of the same design as that described by Loch *et al.* (2001).

Figure 5: *Flumes of (from left) cloddy Sample 1 on initial application of flow and after application of overland flows, and the gravelly Sample 2 prior to and after application of flows.*

Simulated rain at an intensity high enough to generate moderate runoff rates (50-70 mm/h) was applied to duplicate plots 0.75 m square and 0.2 m deep set at a 20% gradient for a period sufficient for the samples to reach steady infiltration/runoff rates[1]. The plot housing is designed to ensure that neither the wetting front reaching the base of the plots nor air entrapment can alter infiltration. Plots were lightly compacted during packing so that the re-packed samples were consistent with soil that had consolidated naturally under rainfall. Runoff generated by simulated rain was sampled at regular intervals (2-3 minutes), and sediment concentrations were measured gravimetrically.

[1] Because the method of data analysis derives soil parameters, the precise rainfall and runoff rates are not important. Equally, provided the rainfall rate is >50 mm/h, considerations of rainfall energy are also not important, as the simulator delivers a drop kinetic energy consistent with rainfall in that intensity range.

Figure 6: *Rainfall simulator plots of Sample 1 (left) and Sample 2 (right) following application of simulated rain, showing indents where samples were taken post-rain for water content measurement.*

5.2 Laboratory data and derivation of model parameters

Erodibility parameters required for the WEPP model are K_i (interrill erodibility), K_R (rill erodibility), and τ_c (critical shear for rill initiation). These parameters are used to predict changes in erosion processes and rates in response to changes in rates of runoff, slope length, and land management. Also important is a Green-Ampt Hydraulic Conductivity parameter (K_e) used in the model to predict runoff. Parameters derived for Sample 1 and Sample 2 using the results of the simulated rainfall and flume tests are shown in Table 2.

Table 2: *Erodibility parameters for the WEPP model. Note that parameter units are complex as a consequence of the need to maintain parameter consistency across the wide range of internal model calculations.*

Material	Interrill erodibility (kg.s/m^4), K_i	Critical shear (Pa), τ_c	Rill erodibility (s/m), K_R	Hydraulic conductivity (mm/h), K_e	Measured steady infiltration rate (mm/h)
Sample 1	1,667,084	12.1	0.00096	15	39.4
Sample 2	394,489	15.4	0.00165	40	74.6

5.2.1 Interrill erodibility (K_i)

Interrill erosion refers to shallow overland flows in which sediment detachment and transport are due to the combined action of flow and drop impacts.

Interrill erodibility values (Table 2) were derived on the basis of plot gradient and delivery rate of sediment per unit area (calculated on the basis of runoff rate and sediment concentration).

The data show the K_i value for Sample 1 to be considerably higher than the value for the gravelly Sample 2, which is to be expected, as the gravel would have reduced interrill erosion potential by intercepting drop impacts and by impeding the shallow surface flow (refer soil physical properties in Table 1).

5.2.2 Rill erodibility (K_R) and critical shear

Rill erosion refers to lines of concentrated flow in which detachment and transport are solely due to the action of flow. The WEPP model applies tractive force concepts, with a critical tractive force to be exceeded before rill flow can initiate detachment.

Rill erodibility (a detachment rate parameter) and critical shear (Table 2) were calculated from the overland flow data. Values of critical shear were similar for both materials, but rill erodibility was approximately 50% higher for Sample 2. Nonetheless, values for both materials were relatively low.

5.2.3 Infiltration parameters

Steady state infiltration rates for both materials were quite high (Table 2). For Sample 1, which was higher in clay, the cloddy nature of the sample may have increased its relative infiltration capacity. For Sample 2, the high infiltration rate measured is consistent with its coarse particle size (Table 1).

Estimated effective hydraulic conductivity (K_e) values are, however, a function not only of steady infiltration rates, but also of antecedent soil water contents and soil particle size distributions. Consequently, there is not a direct linear relationship between steady infiltration rates and K_e.

6. WEPP SIMULATIONS

6.1 Model inputs

WEPP simulations were carried out for both samples 1 and 2 for the following basic landform properties:

- Linear batter slopes;
- No berms or rock drains on the batter slopes;
- Rill spacings across slope of 3 metres (rationale explained below); and
- No runoff from the top of the dump being allowed to discharge onto the batter slopes.

Rill spacing across slopes has been widely observed - and is predicted within the WEPP model - to have major impacts on erosion rates. Effectively, the greater the degree of flow concentration, the more widely spaced rills become, and the more strongly they erode. Differences in spacing across slope are illustrated in Figure 7.

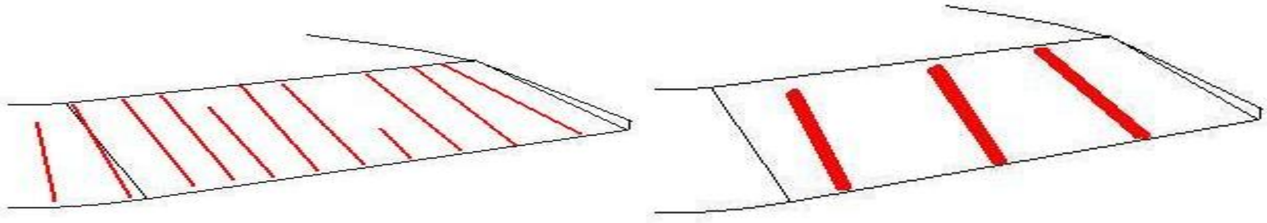

***Figure 7:** Schematic of variations in rill spacing across a batter slope, with narrow spacing (left) and wide spacing (right).*

The reason that a 3 m rill spacing was adopted in this case (5 metres would normally be used for bare soil) was to allow for some reduction in flow concentration by surface vegetation. As the main grass present is buffel, only a small impact of grass on flow paths was considered to be likely. (Buffel grass is tussocky and relatively ineffective in causing flow to remain spread rather than concentrated.)

It was planned that the simulations for bare soil would provide the initial data from which erosion of vegetated surfaces would be considered. Grass cover observed on the site was in the order of 60% surface cover, which gives a soil loss ratio (based on data in the SOILOSS Manual (Rosewell 1993)) of 0.042.

The simulations considered a situation with no berms on the batter slopes, which could (and should) be achieved if the slopes are constructed and rehabilitated progressively. Berms could be used to provide temporary protection during the first years of rehabilitation, but should then be removed or they would eventually trigger gully erosion as they inevitably fail.

6.2 Target erosion rate

For a slope to be stable, it is assumed that rilling must be minimal, and therefore, a target maximum erosion rate of 5 tonnes per hectare per year (t/ha/y) at any point on the batter was adopted as the maximum acceptable rate of erosion from vegetated, rehabilitated, slopes. Assuming that grass cover of 60% can be achieved, and that a cover factor (soil loss ratio) of 0.042 could be applied, then the maximum "bare soil erosion rate" that could be acceptable on batter slopes is 120 t/ha/y.

6.3 WEPP model version and options

6.3.1 Importance of sediment size and model version

Initial simulations indicated that predicted erosion rates were strongly limited by sediment transport capacity on the very long slopes considered. Consequently, the WEPP model's estimates of maximum erosion rate are, in this case, highly sensitive to the sediment size and density distributions considered in simulations.

At this stage, the version of WEPP used in initial simulations is the only version released for general use, and it has been coded to estimate sediment properties solely on the basis of input soil particle size data. As the algorithm used for that estimate is based on research on silty loessial soils in Minnesota (US), its applicability to estimation of sediment from Australian soils is highly doubtful. However, that version of the model offers no alternative.

However, Landloch does have access to a version of WEPP not publically available that specifically allows input of detailed sediment size and density data. Consequently, this modified version of the model has been applied in this study.

6.3.2 Measurement of likely sediment properties

Landloch has access to settling columns (described in Loch (2001)), which enable direct measurement of sediment settling velocity. This is a particularly useful measurement as it integrates both particle size and density.

Consequently, samples of the rain-impacted surface of both Samples 1 and 2 were taken using sampling and handling methods described by Loch (1994) and Loch *et al.* (1988), and settling velocity distributions measured. (The rain-impacted surface provides a more accurate estimate of sediment detached and transported when erosion rates are high than does sediment eroded from small plots in transport-limiting situations).

6.3.3 Comparison of WEPP version output

When measured sediment size and density data were input, WEPP simulations predicted considerably higher rates of erosion relative to simulations when the model's internal algorithms predicted sediment properties. For example, for the clay Sample 1, predicted peak erosion rates on a 140 m high batter on 17.6% gradient were 507 and 200 t/ha/y respectively for simulations with or without sediment input data. For Sample 2, peak erosion rates for the same scenario were 109 and 36 t/ha/y.

This comparison strongly justified the decision to apply the version of WEPP with enhanced sediment particle size capacity.

6.4 Simulations for sample 1: Light clay

This light clay showed (experimentally) a reasonably high steady infiltration rate of 39.4 mm/h under simulated rain. WEPP simulations based on that data indicated an average annual runoff of 93.6 mm/y, which is not high for a bare soil.

Initial simulations (Figure 8) considered batter slope gradients of 10% (6.3 degrees) and 17.6% (10 degrees). Because the two batter gradients would result in very different batter slope horizontal lengths, the erosion predictions are plotted against fall in metres from the crest of a 140 m high batter slope, allowing easier comparison of batter performance.

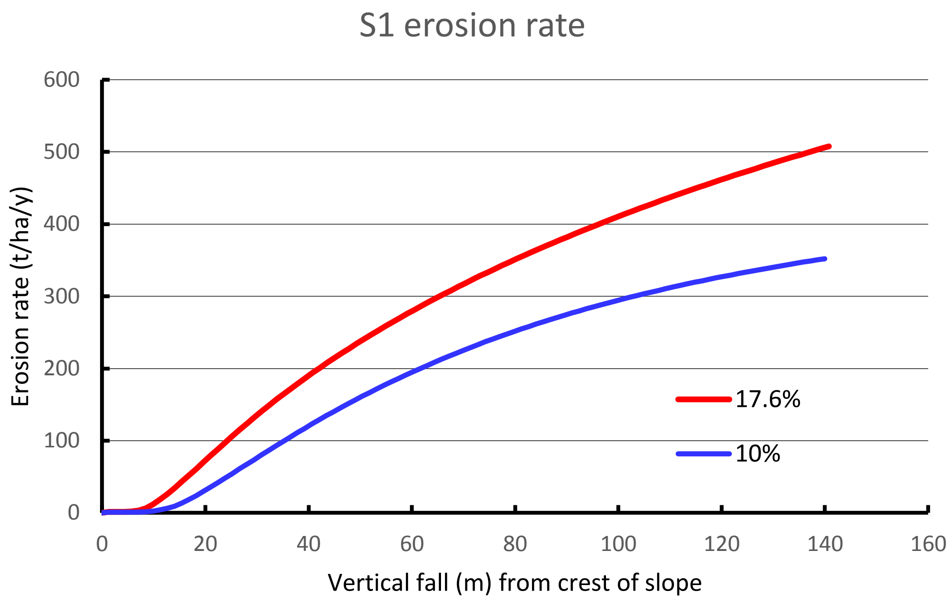

***Figure 8**: Predicted erosion rate on linear batter slopes 140 m high, for gradients of 10 and 17.6% (6.3 and 10 degrees): bare sample 1 (light clay) topsoil.*

The simulations for bare soil showed that at both gradients, the maximum acceptable bare soil erosion rate was exceeded at less than 40 metres fall from the crest, with the bulk of the batter slope being predicted to generate unacceptable rates of erosion even when vegetated.

Noticeably, with the finer sediment generated by this light clay soil, predicted erosion rates did not reach a transport limit with increasing slope length.

6.5 Simulations for sample 2: sandy loam soil

<u>6.4.1 Base data</u>

The sandy loam soil showed (experimentally) a high steady infiltration rate of 74.6 mm/h under simulated rain. WEPP simulations using that data indicated an average annual runoff of 35 mm/y, which is low for a bare soil in central Queensland.

Initial simulations (Figure 9) considered batter slope gradients of 10% (6.3 degrees) and 17.6% (10 degrees). Again, because the two batter gradients would result in very different batter slope horizontal lengths, the erosion predictions are plotted against fall in metres from the crest of a 140 m high batter slope, allowing easier comparison of batter performance.

Predicted erosion rates (Figure 9) showed erosion rates increasing rapidly to a maximum, and then remaining at a similar rate for the remainder of the slope. This is due to the combination of:

- relatively high detachment rates (higher K_R);

- low sediment transport capacity due to the sandy nature of the sediment; and
- reduced runoff volumes to transport sediment, with many smaller events not fully concentrating on the long slope considered.

Importantly, both gradients showed predicted erosion rates less than the maximum acceptable "bare soil erosion rate", though the risk of erosion is greatly increased at the higher gradient.

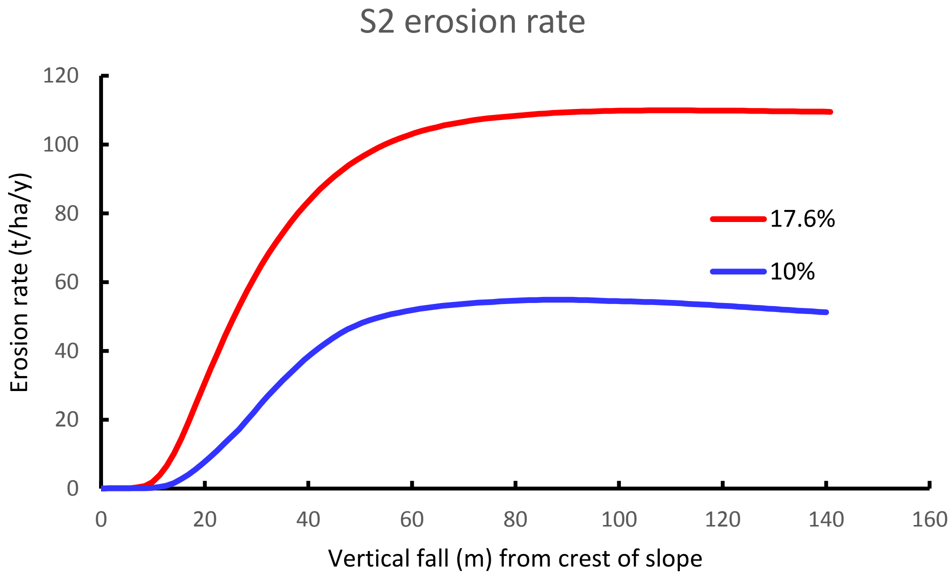

Figure 9: *Predicted erosion rate on linear batter slopes 140 m high, for gradients of 10 and 17.6% (6.3 and 10 degrees): bare sample 2 (sandy loam) topsoil.*

Subsequently, a batter slope with 25% (14 degrees) linear gradient was tested, consistent with a maximum proposed rehabilitated inner slope angle for the waste rock dumps. This showed a maximum erosion rate of approximately 160 t/ha/y, which is outside the range of acceptable values. Stabilisation of such steep gradients on inner batters is unlikely to achieve higher vegetative cover levels than the 60 % considered for the outer batters, leading to the conclusion that 25% gradient slopes are only likely to be successfully stabilised if there is sufficient competent rock to provide a rock armour layer on those batters.

6.4.2 Impacts of hydraulic conductivity

Simulations (Figure 10) show that - across a broad range - variation in the hydraulic conductivity input to the model has little impact on the maximum erosion rate predicted for the sandy topsoil (sample 2). However, if hydraulic conductivity was reduced to a very low level, then predicted annual erosion rates increased considerably. This means that if this topsoil is to be used to achieve batter slopes producing acceptable rates of erosion, care must be taken to ensure that soil hydraulic conductivity and resultant infiltration capacity is kept high. Of particular risk is the presence of underlying materials that may act to reduce the effective infiltration rate of the topsoil.

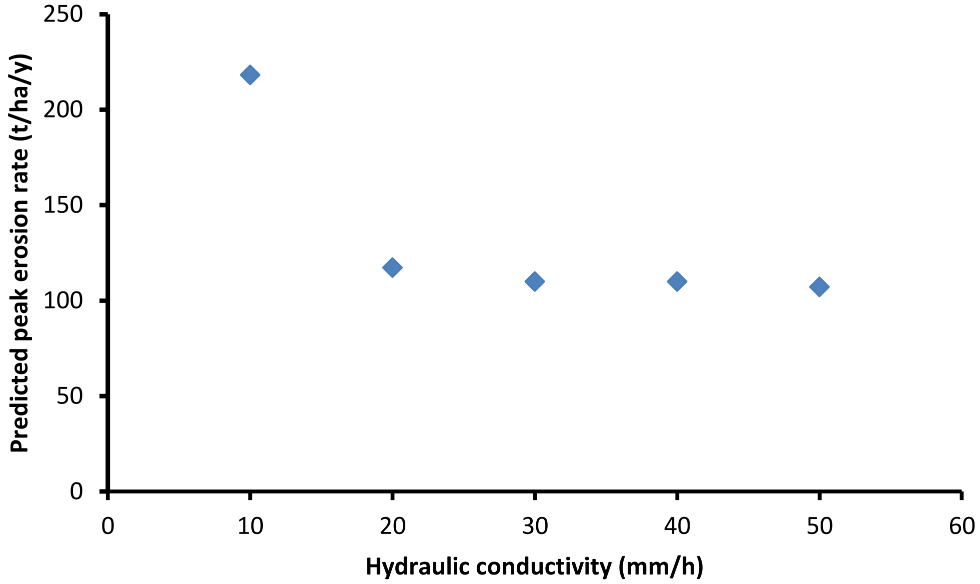

Figure 10: *Effect of hydraulic conductivity on predicted peak erosion rates for a 800 m long batter slope of Sample 2 topsoil, 17.6% (10 degree) gradient.*

7. PRELIMINARY LANDFORM DESIGN GUIDANCE

7.1 Conclusions based on topsoil properties only

For the two topsoils tested, the simulations showed:

(c) A major impact of soil type and soil erodibility on potential batter slope stability, and therefore, on potential landform design parameters; and
(d) The critical impact of vegetation cover.

7.1.1 Vegetation considerations

Achieving sufficient vegetation contact cover will be critical for rehabilitation success and for the long-term stability of the batter slopes to be formed. Issues to be addressed will include:

- fertiliser strategies to maximise initial biomass production;
- establishment of a sustainable vegetation cover meeting the target requirement of >60% cover;
- exclusion of grazing animals; and
- establishment of grass species giving higher levels of surface contact cover than can be achieved with buffel grass.

7.1.2 Sample 1 and batter slope stability

Simulations (Figure 8) indicate that the light clay Sample 1 topsoil is quite unsuitable for placement on the outer batter slopes, and should only be placed on the top of the dump, where it may be highly productive in terms of vegetation growth.

7.1.3 Sample 2 and batter slope stability

The simulations (Figure 9) indicate that, provided the surface material acts similarly to the topsoil tested, erosion rates would increase with slope length to a maximum rate that would be acceptable at gradients of 6.3 - 10 degrees, provided:

d) vegetation cover in excess of 60% is achieved sustainably and reliably.
e) there is no discharge of runoff from the top of the landform onto the outer batter slopes (i.e. a store/release cover not a water shedding cover); and
f) appropriate progressive rehabilitation practices are applied.

For this material, a consequence of the pattern of predicted erosion in response to batter length is that slope length (or landform height) will have little impact on average batter slope erosion rates for materials showing that form of erosion response. Consequently, a wide range of landform heights up to 140 m would be acceptable.

Batter gradient strongly affects predicted erosion rates, and for outer batters, the lower gradient considered was shown to have considerably lower erosion potential (and risk). Similarly, the simulations indicate that - if using the sandy topsoil (sample 2) – steeper batter gradients such as 25% (14 degrees) (1V:4H) which have been proposed for internal batter slopes would deliver unacceptable erosion rates even if 60% vegetative cover was established. Therefore, other landform stabilisation measures such as mixing competent rock into the batter surface would be need to be implemented if the proposed rehabilitated inner slope angle of 12-14 degrees is constructed.

7.2 Potential risks

7.2.1 Topsoil availability

Supply of a sufficient quantity of suitable topsoil (with properties equivalent to sandy loam Sample 2) will be critical for rehabilitation success.

Therefore, a more detailed study of topsoil in the pit/waste dump areas is strongly recommended to provide a more accurate assessment of topsoil resources and their suitability for batter slope rehabilitation.

7.2.2 Interactions with properties of underlying waste

The high infiltration capacity of the sandy loam (Sample 2) topsoil is both a benefit and a hazard.

If topsoil with characteristics of sandy loam Sample 2 is placed over relatively or highly impermeable mine waste material, the resulting layered profile will likely have water pond on top of the waste layer in large rainfall events. Water movement downslope through the overlying permeable topsoil layer will result in the lower slope sections of the topsoil layer becoming saturated. The saturated layer with positive pore water pressures is potentially extremely unstable, and erosion rates on saturated lower slope areas have been observed to be quite high.

A slope constructed in a way that created this situation would be highly erodible and quite unsustainable.

Important actions or outcomes to reduce that risk are:

- placement of an underlying mine waste material with relatively high infiltration capacity;
- ensuring that the mine waste is suitable for plant root growth, so that there is strong root penetration into the underlying waste to anchor the topsoil layer; and
- applying a relatively deep topsoil layer, with a depth of 300mm being desirable if possible.

7.2.3 Climate change

The likely effect of climate change on erosion of mine waste landforms at the Carmichael project is to cause increases in erosion rates in the order of 40% for a temperature rise of 4 degrees Celsius.

The following is taken from a paper by Fraser *et al.* (2011), who reported on their development of an empirical model for the daily maximum 15 minute rainfall intensity (I_{15}), which is strongly correlated with erosion rates. They used data from 12 selected pluviograph stations around Australia. The model accounted for 46% ($P < 0.01$) of the variation in observed daily I_{15} for a validation data set derived from 67 Australia-wide pluviograph stations. The model also accounted for 70% ($P < 0.01$) of the variation in the observed historical trend in I_{15} for the full record period (average record period was 37 years) of 73 Australia-wide pluviograph stations.

At the daily timescale, daily rainfall (daily rainfall ≥10mm) has increased over the period 1910 – 2009, though not evenly across the continent. The warmer climatic zones of Australia increased the most, with an average change of 5% over the 99 year period.

Application of the empirical models for sub-daily and daily rainfall intensities indicated that for a 1 degree Celsius increase in daily average temperature on rainfall days, rainfall intensity (I_{15}) increased by ~ 9%. This is result is consistent with the Clausius-Clapeyron relationship, which quantifies the non-linear (exponential) relationship between temperature and humidity and subsequently rainfall intensity (O'Gorman & Schneider 2009). These impacts translate to a heightened risk for runoff and erosion risk in Australian rangelands. For example, a temperature increase of 4 degrees Celsius at Charters Towers in north-eastern Australia would increase runoff by 20% and soil erosion by 39% under conservative stocking.

As the Carmichael project is not, geographically, overly distant from Charters Towers, a somewhat similar level of increase in erosion potential could be expected as a consequence of climate change. On the basis of that potential increase in erosion rates, it would be prudent for landform gradients to be kept at a level such that predicted erosion rates are 30-50% below those considered the maximum acceptable.

7.3 Construction and rehabilitation requirements

It is strongly recommended that the waste landform outer face should be constructed and rehabilitated progressively. Recommended actions include:

- construction of the outer batter in 15 m lifts separated by berms (based on bare soil erosion predictions shown in Figure 8);
- progressive rehabilitation of each lift once constructed;
- removal of berms once vegetative cover on the areas up and downslope from the berms reaches a minimum of 60% (note that this requires berms to be constructed such that they can be subsequently removed and the area they covered can be rehabilitated); and
- the pattern of berm removal to ensure that only every second berm is removed in any one year.

7.4 Overview

The data broadly show that construction of a mine waste landform to a maximum height up to 140 m, with outer batter gradients of 6.3-10 degrees is possible. Not surprisingly, the lower (6.3 degree) batter gradient would present a lower risk of erosive failure.

The specific landform adopted will be governed by the erodibility of the topsoil available, and possibly also by properties of the underlying wastes. As only one of the topsoils tested appears likely to be suitable for stabilisation of batter slopes, selective stripping and placement of the appropriate topsoil will be critical for rehabilitation success.

For internal batters likely to be profiled to gradients of 12-14 degrees, even the more stable sandy loam topsoil is likely to require addition of competent rock to achieve adequate levels of stability.

It should be noted that the simulations also clearly identified a range of conditions that will need to be met for a landform of those dimensions to be sustainable. Those conditions are detailed in the preceding sections.

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APPENDIX A: THE WEPP MODEL

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 the:

- Amount of rain;
- Duration of the rain;
- Time to peak intensity; and
- 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.

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.

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.

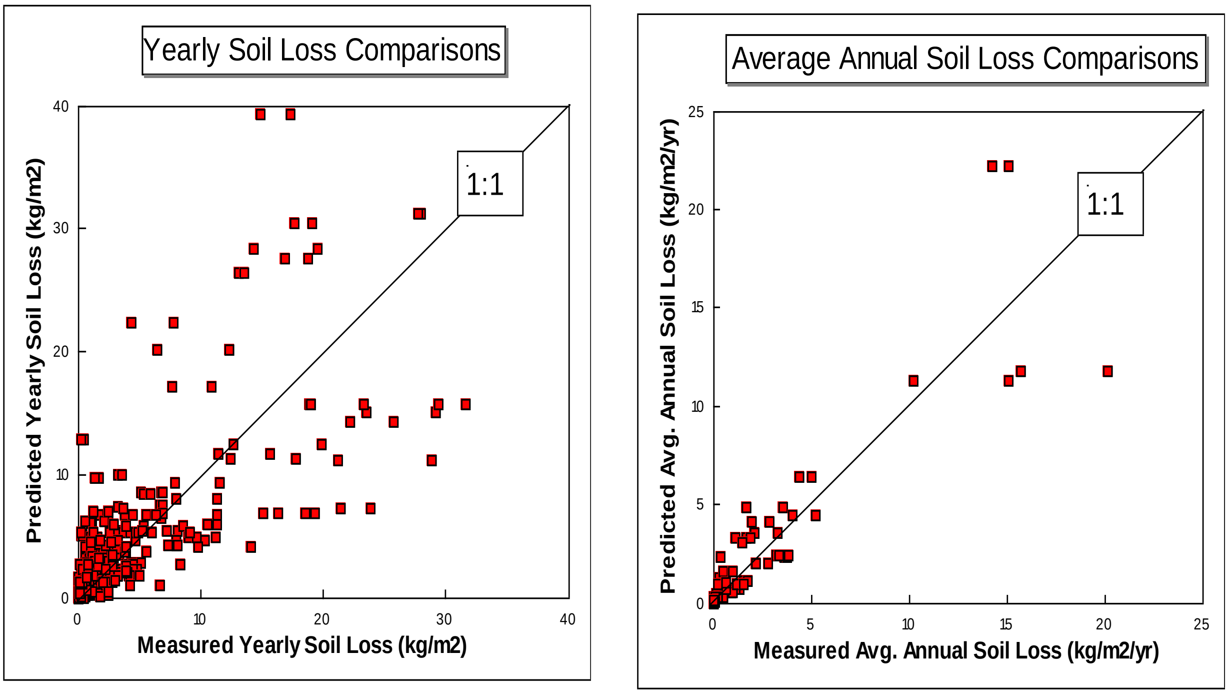

Figure A1-1: *Figures from Nearing and Nicks (1998) showing WEPP model performance against measured data.*

As the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) is calibrated to existing erosion data, its performance is effectively the benchmark for soil erosion model performance. Tiwari *et al*. (2000) found that WEPP performed as well or better than the USLE at 85% of sites. As the USLE parameters had undergone considerable refinement whereas the WEPP model was not calibrated at all, they considered that the WEPP model had performed quite successfully.

Various relationships within the WEPP model are based on considerable data and testing, with interpretations also being mindful of appropriate fundamental relationships and concepts. For example, recent unpublished experiments on steep slopes in China have shown that the model deals accurately with slope gradient in the range 9-58%, and with variations in slope length (Laflen, pers. comm.).

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APPENDIX B: LABORATORY ANALYTICAL DATA

ANALYSIS REPORT

Project Number:	EW130546
Location:	HARLAXTON
Sample Collection Date:	31/07/2013
Sample Receival Date:	2/08/2013
Sample Analysis Date:	8/08/2013
Project Contact Person:	Lyndon McGrath

East West Enviroag
82 Plain St Tamworth NSW 2340
ph:02 67621733

	Lab No	130546-1	130546-2
	Order	HARLAXTON	HARLAXTON
	Sample ID	S1	S2
	Sample Depth	*	*
Analyses	**Unit**	-	-
pH - Water	pH units	7.11	6.29
Electrical Conductivity	dS/m	0.03	0.03
Total Nitrogen - Kjeldahl	mg/kg	541	660
Nitrate Nitrogen	mg/kg	*	*
Total Phosphorus - Nitric/Perchloric	mg/kg	185	195
Phosphorus - Colwell extr	mg/kg	21.1	11.0
Phosphorus - Bray extr	mg/kg	*	*
Potassium - Colwell ext	mg/kg	193	157
Sulphur - KCl	mg/kg	2.4	4.1
Organic Carbon	%	0.74	1.29
Copper	mg/kg	*	*
Iron	mg/kg	*	*
Manganese	mg/kg	*	*
Zinc	mg/kg	*	*
Cation Exchange Capacity	meq/100g	15.2	6.8
Ex Calcium Percent	%	70.2	69.8
Ex Magnesium Percent	%	25.0	22.9
Ex Potassium Percent	%	2.36	4.40
Ex Sodium Percent	%	2.38	2.78
Ex Aluminium Percent	%	0.04	0.13
Exchangeable Calcium	mg/kg	2135	944
Exchangeable Magnesium	mg/kg	456	186
Exchangeable Potassium	mg/kg	140	116
Exchangeable Sodium	mg/kg	83.1	43.3
Exchangeable Aluminium	mg/kg	0.6	0.8
Exchangeable Calcium	meq/100g	10.7	4.7
Exchangeable Magnesium	meq/100g	3.8	1.6
Exchangeable Potassium	meq/100g	0.36	0.30
Exchangeable Sodium	meq/100g	0.36	0.19
Exchangeable Aluminium	meq/100g	0.01	0.01
Calcium/Magnesium Ratio	-	2.8	3.0
Gravel >2.0mm	%	2.2	27.7
Coarse Sand 0.2-2.0mm	%	13.4	22.2
Fine Sand 0.02-0.2mm	%	37.8	32.1
Silt 0.002-0.02mm	%	9.2	1.3
Clay <0.002mm	%	37.4	16.7
ADMC	%	6.6	3.5