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9 February 2017

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Attention: Brad Williams

Dear Brad

Leigh Creek Erosion Modelling – Letter Report

1. Introduction

This letter report details the initial assessment of potential erosion rates of constructed and rehabilitated slopes of waste landforms containing spontaneously combusting waste ('spon com') at the Leigh Creek open cut coal mine (Leigh Creek) in South Australia. The 2D Water Erosion Prediction Project (WEPP) erosion simulation model was used to assess potential erosion under different slope parameters, using the specific characteristics of cover materials on site where possible, and site specific climate information.

Detailed within this letter are:

- Background information to the erosion modelling;
- Model simulation input parameters and assumptions;
- Sensitivity analysis of critical input parameters and cover material considerations; and
- Model simulation outcomes.

2. Background information

Current planning and implementation of mine closure operations at the Leigh Creek site includes consideration of the management of 'spon com' waste materials in existing in-pit and external waste landforms. To manage the 'spon com' waste, inert mine waste materials are used as a cover to encapsulate the 'spon com' to limit oxygen ingress. Design recommendations have been made for rehabilitation and management of the 'spon com' materials (MWH 2016a), and soil and mine waste cover material characterisation assessments (MWH 2016b, MWH 2016c). This erosion modelling has been undertaken to provide an initial indication of potential cover material stability and associated soil loss from a range of constructed slope angle scenarios. The erosion modelling provides a preliminary indication of the suitability

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of the cover materials to provide a stable, long-term cover for ongoing management and encapsulation of 'spon com'.

The WEPP erosion model is a distributed parameter, continuous simulation, numerical model used for erosion prediction, that allows for both temporal and spatial estimates of erosion and deposition at both the hillslope and watershed (catchment) scale (Flanagan and Livingston 1995). The model runs on input parameters for climate (e.g. rainfall amounts and intensity), soil properties (e.g. soil texture), plant growth, slope (e.g. shape, steepness, length), management practises (e.g. agricultural tillage, forestry practises, disturbance), and soil erodibility parameters.

Preliminary WEPP modelling has been performed for prediction of long term erosion rates using measured and estimated soil characteristics for the Leigh Creek cover materials, and a 100 year continuous climate data set derived from the Bureau of Meteorology (BOM 2016) and simulated SILO climate information for Leigh Creek (SILO 2016).

3. Input parameters and limitations

Input parameters and limitations used to assess long-term erosion rates for the Leigh Creek waste cover materials are detailed as follows;

- Soil parameters;
    - Averaged soil physical and chemical characteristics (particle size distribution, coarse fragment (> 2mm) content, Cation Exchange Capacity (CEC) and organic matter) for the cover materials sourced from Dragline Spoil (DSLP) A, B and C blocks (**Table 1**);
    - 1 m cover depth;
    - Initial saturation level of 10% (for bare, dry soil);
    - Model assumes homogenous soil characteristics;
- Soil erodibility parameters (refer to **Section 4**);
    - Predicted effective hydraulic conductivity for the DSLP A, B, C materials;
    - Model generated values for interill erodibility, rill erodibility and critical shear due to limited material specific data;
- Slope parameters;
    - Three design slope scenarios (as outlined in **Table 2** below);
    - Linear slope shape;
    - Slope height for model simulations of 40 m
    - Slope width for model simulations of 100 m;
    - No run-on from upslope areas (assumption of crest bund placement at top of slope);

- Management parameters;
  - Rill spacing of 100 cm;
  - Permanent rill type;
  - Surface roughness of 2 cm;
  - No vegetation parameters;
  - No surface treatments (e.g. no contour ripping);
- Climate parameters;
  - Generation of a simulated long term continuous climate file for Leigh Creek based on a 100 year range of recorded site data from 1916 to 2015.

Input parameters for soil properties were derived from the Cover and Rehabilitation Material Characterisation report (MWH 2016c), for cover materials collected from the DSLP A, B and C blocks. Soil characteristics were averaged for the DSLP A, B, and C block materials (**Table 1**).

Table 1: Average material properties for DSLP A/B/C blocks used for soil input parameters

Soil parameter			DSLP A, B, C average
Organic matter		%	6.3
Cation Exchange Capacity			50.8
Particle Size Distribution [1]	Clay	%	23.1
	Silt	%	62.2
	Sand	%	14.6
Coarse fragments (>2 mm)		%	26.7
Soil texture		-	Silt loam

1. Particle Size Distribution for the soil sized (<2 mm) fraction, excluding coarse fragments >2 mm. Clay plus silt fractions combined for the CLAY input parameter.

Slope input parameters were based on rehabilitation design recommendations outlined in the Design Considerations to Minimise Spontaneous Combustion at Leigh Creek report (MWH 2016a). Three rehabilitation slope design scenarios were used to assess long-term erosion rates for a range of slope angles, ranging from the existing angle of repose of in-pit and external waste landforms at the Leigh Creek site (Scenario 1, 1:1.3 slope grade), to an upper slope angle (Scenario 2, 1:3 slope grade), to the recommended slope angle for rehabilitation (Scenario 3, 1:4.5 slope grade) (**Table 2**). Slope lengths were calculated based on slope angle for each scenario.

Table 2: Slope scenarios for initial WEPP erosion modelling assessment

Slope parameters	Scenario		
	1	2	3
Description	Angle of Repose	Upper slope angle	Recommended slope angle
Grade	1:1.3	1:3	1:4.5
Slope angle (degrees)	38	18.5	12.5
Slope steepness (%)	77	34	22
Slope length (m)	51.2	119.5	180.4

4. Parameter sensitivity

As specific erodibility characteristics of cover materials were not known, a brief assessment of the sensitivity of critical input parameters was performed to improve confidence in the erosion simulation outcomes for the Leigh Creek cover materials. The following parameters were tested for sensitivity on predicted erosion rates;

- Soil erodibility parameters;
- Predicted vs model calculated effective hydraulic conductivity; and
- A range of fine fraction percentages (based on the 60% clay recommended threshold for cover materials used for rehabilitation and management of 'spon com' waste).

Results of the sensitivity assessment are included in **Attachment A**. Erosion rates were most sensitive to effective hydraulic conductivity. The sensitivity analysis suggests that erosion rates are less likely to vary with combined clay and silt contents of greater than 85% (note that the clay and silt percentages represent percentage of soil sized component (<2 mm) of the cover materials – based on the average coarse size component, 85% of the soil sized fraction equates to approximately 60% of the bulk cover waste material)

5. WEPP model simulation outcomes

Long-term erosion rates were simulated for the Leigh Creek cover materials and slope design scenarios. Comparison of predicted erosion rates for the three slope angle scenarios is presented in **Table 3** and **Figure 1**.

Table 3: WEPP predicted annual average erosion rates for three slope design scenarios

WEPP output	Scenario		
	1	2	3
Average annual runoff (mm/yr)	12.82	9.99	8.04
Average annual soil loss (kg/m^2/yr)	0.50	0.49	0.32
Average annual sediment yield (t/ha/yr)	5.03	4.87	3.20

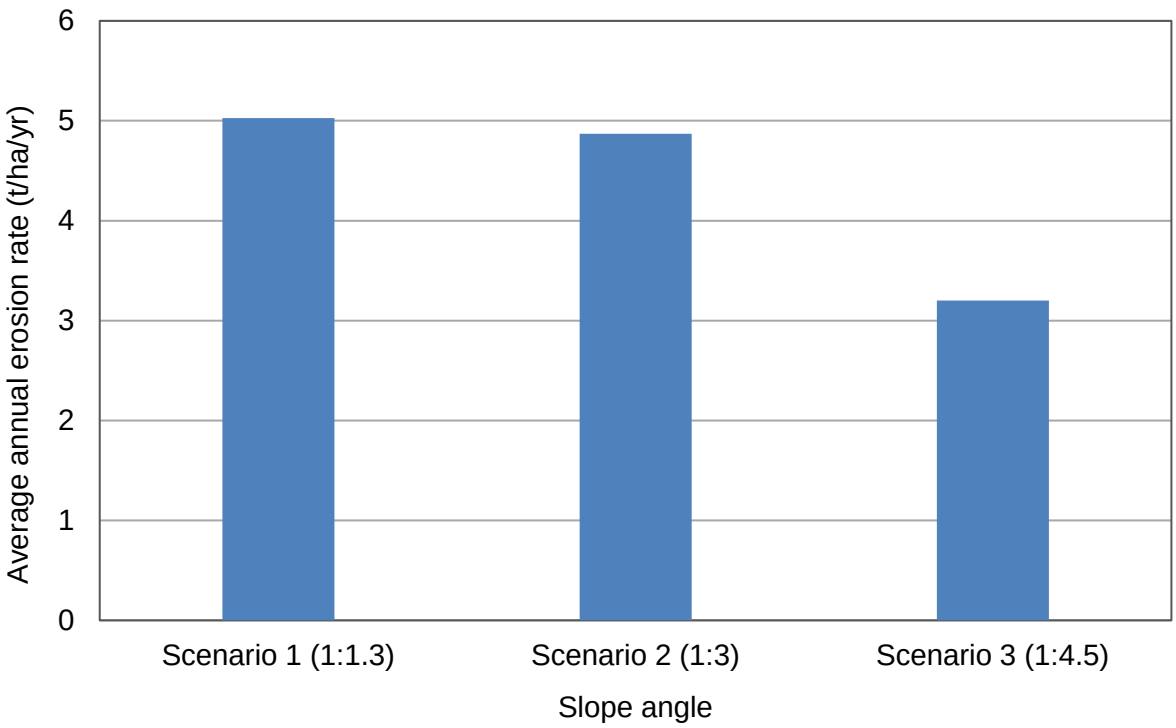

Figure 1: Comparison of predicted annual erosion rates for three slope angle scenarios

Simulation of the angle of repose 1:1.3 slope grade (Scenario 1), representing the current slope angle of the Leigh Creek waste landforms, predicted the highest erosion rate. The slope angle with 1:3 grade (Scenario 2), yielded comparable results to Scenario 1, though slightly lower. Predicted erosion rates were lowest for the recommended slope angle 1:4.5 grade (Scenario 3), at 3.20 t/ha/yr of sediment yield. The simulated hillslope profiles and predicted soil loss for each scenario are presented in **Figures 2 to 4**.

Comparison of the hillslope and soil loss profiles for each slope angle scenario indicates lower soil loss rates at lower positions along the length of the slope for Scenario 3. This suggests that a lower slope grade of 1:4.5 with a longer slope length has a greater resistance to erodibility based on the characteristics of the

DSLP A, B, C cover materials. The soil loss profile also suggests that the cover materials are more susceptible to rill erosion at higher slope angles.

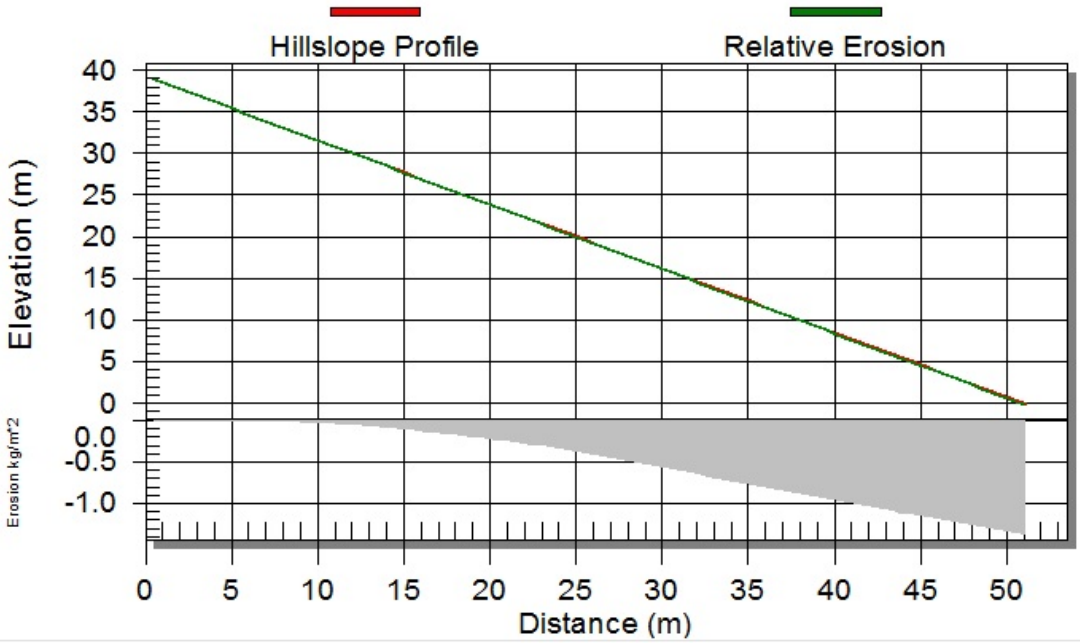

Figure 2: Predicted soil loss for Scenario 1 (Angle of repose, 38 degree slope angle) (soil loss shaded grey)

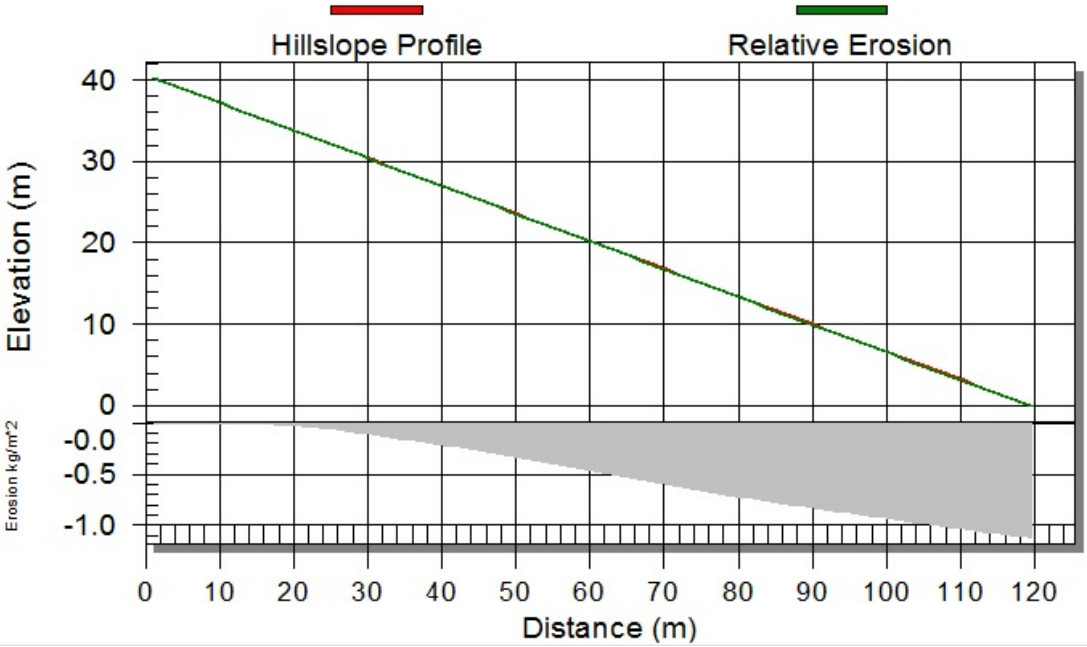

Figure 3: Predicted soil loss for Scenario 2 (Upper slope angle, 18.5 degree slope angle) (soil loss shaded grey)

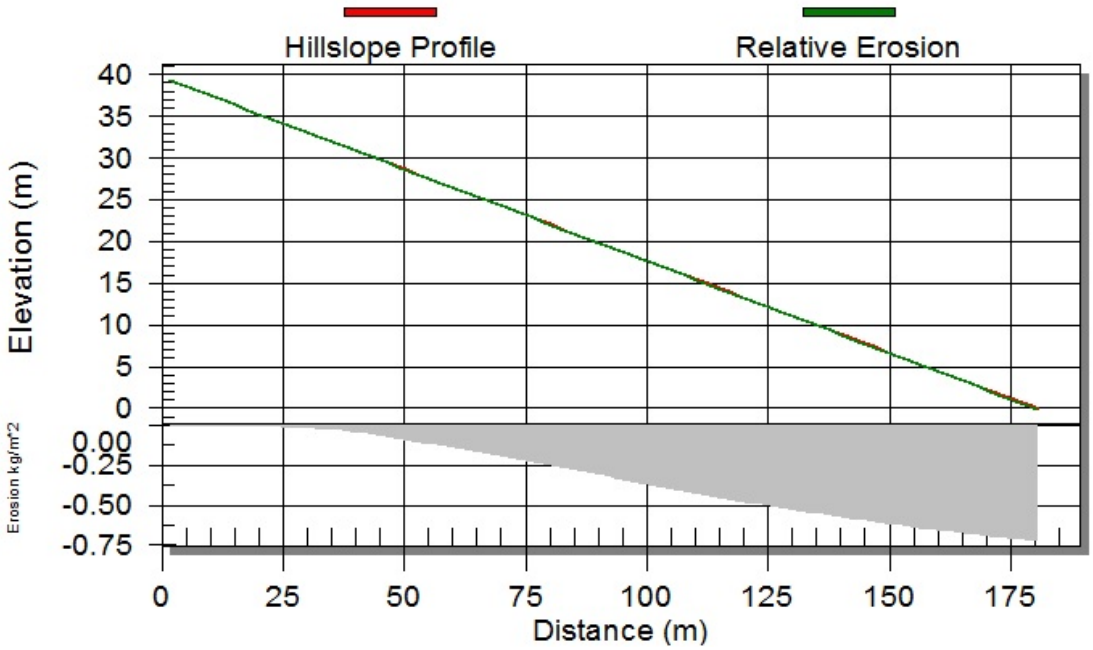

Figure 4: Predicted soil loss for Scenario 3 (recommended slope angle, 12.5 degree slope angle) (soil loss shaded grey)

6. Summary

Potential erosion rates of proposed mine waste cover materials for constructed and rehabilitated slopes of waste landforms at the Leigh Creek site have been assessed for a range of rehabilitation slope designs based on recommendations for 'spon com' management. It is noted that the model outcomes assume simulated parameters that vary in reality and do not take into account natural processes that affect erosion in a constructed landform, such as armouring, changes in soil conditions with settling and mineral weathering, and additional slope stability variations related to rainfall events and soil physical properties.

Of the three slope angle scenarios assessed, WEPP model simulations predicted the lowest long term erosion rates for the recommended slope angle scenario of a 1:4.5 grade slope. The model results support the recommended rehabilitation slope design of 1:4.5 slope grades for longer-term slope stability. This is consistent with the slope angle recommendations for effectively limiting oxygen ingress and encapsulating the 'spon com' waste materials.

It is intended that these model results for potential soil loss over time be viewed in conjunction with the planned on-site assessment of existing and historical erosion to identify the likely erosion of the rehabilitated areas over time.

Yours sincerely

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Reviewed By: Matt Braimbridge

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REFERENCES

Bureau of Meteorology (BOM) (2016). Climate Data Online [online]. Available at http://www.bom.gov.au/climate/data. Accessed December 2016.

Flanagan, D.C. and Livingston, S.J. (1995). WEPP User Summary. USDA Water Erosion Prediction Project. NSERL Report No. 11, July 1995.

MWH (2016a). Design Considerations to Minimise Spontaneous Combustion at Leigh Creek. Jolimont, Australia: MWH Australia Pty Ltd.

MWH (2016b). Leigh Creek Coalfield – Soil and Waste Characterisation. Jolimont, Australia: MWH Australia Pty Ltd.

MWH (2016c). Leigh Creek Coalfield – Cover and Rehabilitation Material Characterisation. Jolimont, Australia: MWH Australia Pty Ltd.

Nearing, M.A., Deer-Ascough, L. and Laflen, J.M. (1990). Sensitivity Analysis of the WEPP Hillslope Profile Erosion Model. Transactions of the ASAE (Vol. 33, No. 3, pp. 839-849, 1990). American Society of Agricultural Engineers, St Joseph, MI, USA.

SILO, Queensland Department of Science, Information Technology and Innovation (DSITIA) [online], (2016). Available at: http://www.longpaddock.qld.gov.au/silo

ATTACHMENT A

Sensitivity assessment

WEPP uses four soil erodibility input parameters to predict soil loss by erosion (Flanagan and Livingstone 1995);

- Effective hydraulic conductivity (K_e);
- Interill erodibility (K_i), the susceptibility of the soil to detachment by raindrop impact and shallow flows;
- Rill erodibility (K_r), the susceptibility of the soil to shear detachment by concentrated water flowing in rills; and
- Critical hydraulic shear (τ_c), a threshold value under which rill detachment does not occur.

Of these, effective hydraulic conductivity is the key parameter affecting infiltration and runoff in WEPP (Flanagan and Livingstone 1995), and is influenced by soil texture (Nearing *et al.* 1990).

The effect of a range of values for each of the four erodibility parameters were tested as detailed in **Table A-1**. For effective hydraulic conductivity, a predicted value was first calculated as a 'baseline' estimation (K_b) based on the following equation (Flanagan and Livingstone 1995);

[1] $Kb = 0.0066\exp(244/CLAY)$

for soils with > 40% clay content, and where CLAY is the percentage of the fine fraction (clay + silt).

For Leigh Creek, the predicted effective hydraulic conductivity was calculated to be 0.105 mm/hr, based on the average particle size distribution of the DSLP A, B, and C block waste cover materials[1]. The predicted effective hydraulic conductivity was taken as the moderate value for the purposes of the sensitivity assessment, with low and high values calculated by orders of magnitude of 10. For all other erodibility parameters, an estimated range of arbitrary low, moderate and high values were tested (**Table A-1**).

Erosion rates were most sensitive to effective hydraulic conductivity. Low values for rill erodibility and critical shear were also found to have a comparative impact on erosion rates, which is likely to be influenced by rill initiation thresholds for these two parameters based on other material characteristic input parameters used for the Leigh Creek waste cover materials.

[1] The average particle size distribution of the <2 mm fraction of the DSLP A, B, C block waste materials, excluding D&B and topsoil materials and coarse fragments >2 mm. Refer to Appendix A of the Leigh Creek Coalfield – Cover and Rehabilitation Material Characterisation report (MWH 2016).

WEPP simulations were then run for the range of predicted effective hydraulic conductivity for the Leigh Creek DSLP A, B, C waste materials for each of the slope angle scenarios for Leigh Creek (**Figure A-1**). Similar erosion rates were predicted for the 1:1.3 (angle of repose) and 1:3 (upper slope angle) slope scenarios, with a comparative difference for the 1:4.5 recommended slope angle scenario.

Table A-1: Sensitivity assessment for WEPP soil erodibility parameters

Value range	Soil erodibility parameter				WEPP output
	Effective hydraulic conductivity (K_e)	Interill erodibility (K_i)	Rill erodibility (K_r)	Critical shear (τ_c)	Average annual erosion rate (t/ha/yr)
	mm/hr	kg.s/m4	s/m	Pa	
Low	1				2.63
Moderate	10				2.04
High	100				1.17
Low		200,000			3.14
Moderate		1,000,000			3.15
High		2,000,000			3.16
Low			0.0001		0.43
Moderate			0.001		3.1
High			0.01		3.15
Low				10	0.15
Moderate				20	0.02
High				100	0.02

1. Predicted value based on average fine fraction (% clay + silt) for DSLP A, B, C waste materials from Leigh Creek.

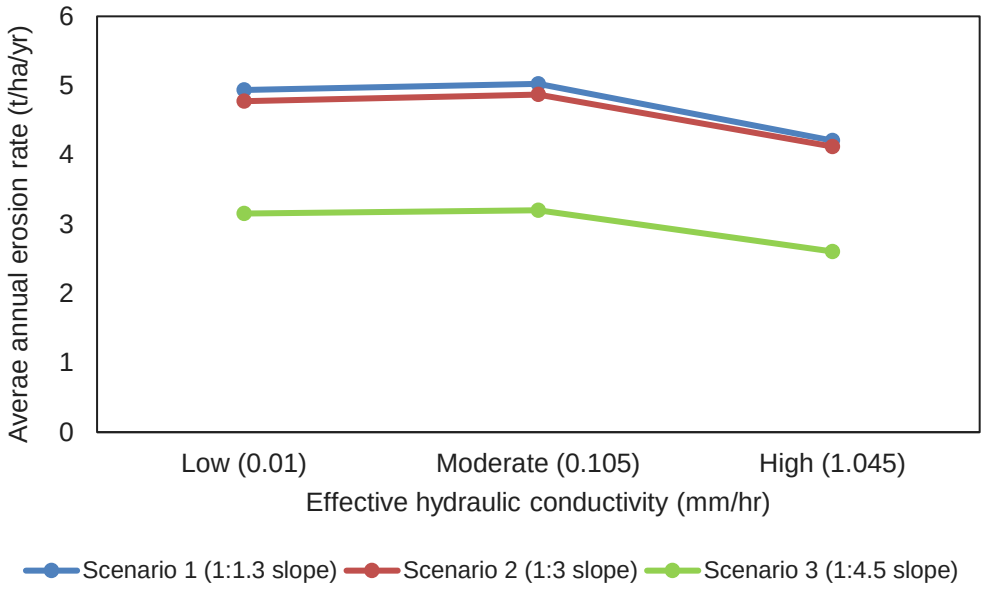

Figure A-1: Sensitivity assessment for effective hydraulic conductivity (K_e)

The predicted and model calculated effective hydraulic conductivity values were also compared for each of the three slope angle scenarios materials to assess the suitability of the predicted value for effective hydraulic conductivity (**Figure A-2**). The predicted and model calculated values for effective hydraulic conductivity were comparable for each slope angle scenario, indicating that the predicted value is adequate for the purpose of preliminary erosion simulation for the Leigh Creek cover materials, in place of specific laboratory tested properties.

A range of clay percentages were also tested to determine the impact on erosion rates for the Leigh Creek DSLP A, B, C waste materials, in consideration of the minimum 60% clay threshold required for use as cover materials (**Figure A-3**). The model simulations predicted lower erosion rates for materials with higher clay contents. These findings suggest the model simulations are consistent with the recommendations for management of 'spon com' waste for use of cover materials with higher clay content in waste landforms.

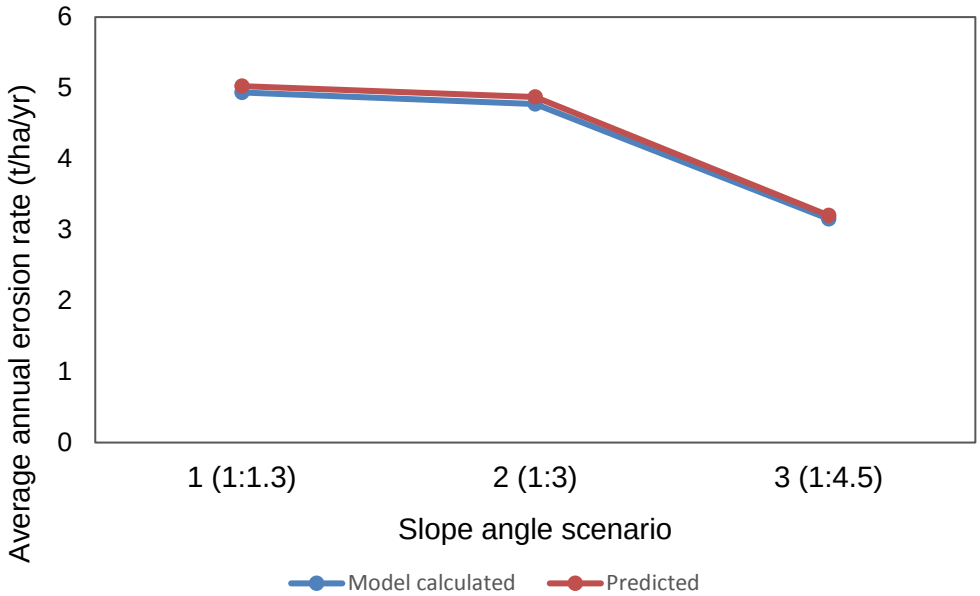

Figure A-2: Comparison of predicted versus model calculated effective hydraulic conductivity for simulating erosion rates

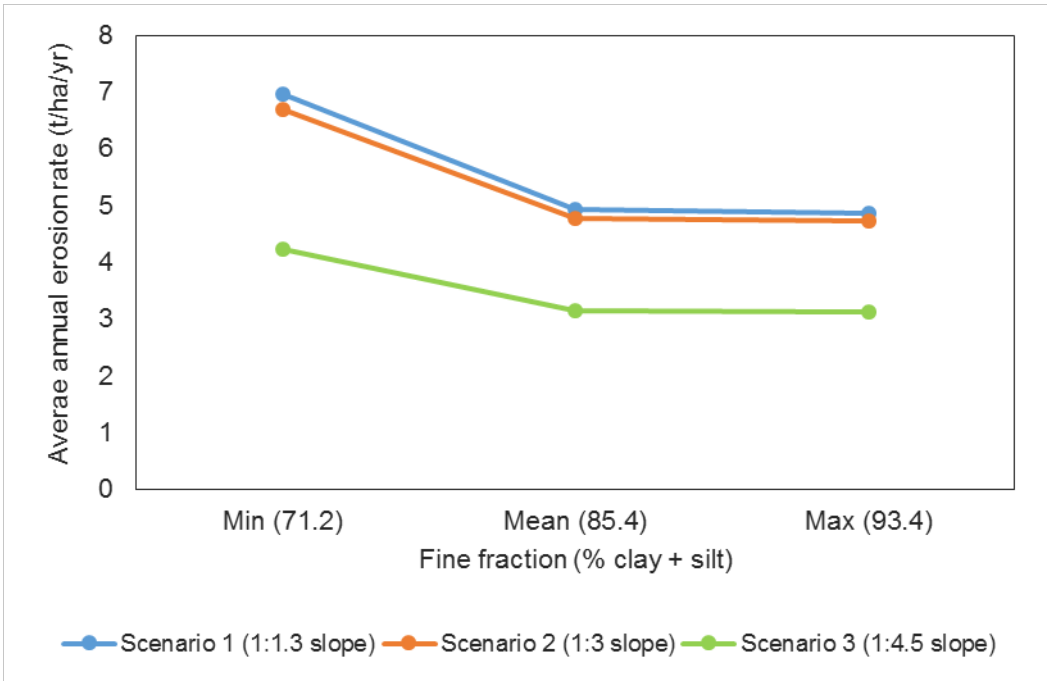

Figure A-3: Comparison of fine fraction percentages for simulation of Leigh Creek cover material erosion rates