Millipede and Centipede Landform Stability Assessment

Toro Energy Limited
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1 INTRODUCTION

Toro Energy Limited (Toro) has requested Landloch to conduct a preliminary investigation of the long term erosional stability of the materials and rehabilitated landforms proposed for use in closure of the backfilled pit areas of the Millipede and Centipede Uranium project (the Project).

The Project is located approximately 15km south east of the Wiluna township (Figure 1). There are six individual deposits within the Project area, as well as processing infrastructure (Figure 2). Overburden will be mined using conventional truck and shovel methods, and surface mining techniques will be used to extract the target resource. The mine life is estimated at 16 years.

![Map](image)

**Figure 1:** Location of the Toro Energy Uranium Project (Source: Toro Energy).

Once the ore has been extracted, the pits will be backfilled with tailings and waste, capped with a competent rock layers, and the landform will reconstructed as closely as possible to the natural existing landform and capped with stockpiled soils. The different soil materials will also be replaced as closely as possible to its original location.

The Project is currently in the proposal phase, and this preliminary landform investigation is based on information obtained from reports from previous studies of materials and landforms, as well as from additional grab sampling conducted as part of this assessment. This report will consider the feasibility of the proposed closure plans for the rehabilitated landform, and make recommendations for improving them where possible.
Figure 2: Layout of the Millipede and Centipede mine area (Source: Toro Energy).

2 OBJECTIVE AND SCOPE OF WORKS

The objective of this assessment is to develop a preliminary understanding of the characteristics of the main soil rehabilitation materials in terms of their long term erosional stability. This is necessarily done in association with information on the proposed final rehabilitated landform shapes.

To achieve this objective while the Project is in the proposal stage, the following tasks were completed:

- Examine previous reports on the topsoils of the Project.
- Obtain grab samples of the main soil types of the Project to further characterise their chemical and physical attributes, with special focus on materials from within the proposed pit disturbance areas and material attributes pertaining to erosional stability.
- Use the available soils data to assess the suitability of the soils for rehabilitating the backfilled pit areas.
- If suitable, use the available soils data to assign WEPP1 erosion model parameters for similar soils using Landloch’s extensive material parameter library of Western Australian arid zone soils.
- Examine the existing Centipede and Millipede undisturbed surface to obtain typical surface shape profiles to derive the range of potential rehabilitated

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1 Water Erosion Prediction Project.
landform shapes that the soils will be applied to, assuming that rehabilitation is to reconstruct the premining surface shape.

- Use WEPP to simulate long term erosion for a range of rehabilitated landform shapes using climate data from the region.
- If necessary, use the SIBERIA landform evolution model to assess the long term change of the rehabilitated landform surface. This will useful in assessing the risk of erosion features (e.g., gullies) intersecting underlying encapsulated waste.

This assessment assumes that the rehabilitated pit areas will be surrounded by 1:100 year flood levees and that any erosion that may occur will be generated solely by runoff generated on the surface of the rehabilitated pits, and not by any run on from surrounding upslope catchment areas. This assessment also does not consider the long-term stability of the flood levee.

3 EROSION ASSESSMENT OVERVIEW

3.1 Materials considered

Previous studies (Outback Ecology, 2008; Outback Ecology, 2011) examined the topsoil resource to a depth of approximately 1.5m and mapped different soillandscape associations. The main soil types within the disturbance footprint are the dune sands, lake fringe, and flats. The dune sands are red sandy, well draining, low salinity soils that form elevated features in comparison to the surrounding landscape. The lake fringe soils surround Lake Way and are saline, loamy sand, poorly structured, with pH ranges of 7 – 8.4 and associated with low relief. The flat soils are located further inshore from Lake Way and are a variety of soils associated with drainage lines, depression area clay pans, and large extents of calcareous flats that dominate the Centipede West site. The calcareous flats are red alkaline sandy loams of low salinity and are potentially dispersive. The clay pans are associated with landscape depression evaporation pans and are alkaline, relatively fine textured, and highly sodic.

The disturbance area (M53/336 and M53/1095) between Millipede/Centipede and Centipede West has not been directly soil surveyed, but it can be observed that it is comprised mainly of the dune sand, lake fringe, and clay pan soil types identified in Outback Ecology (2008).

Landloch investigated three main materials from the Centipede and Millipede deposit that is planned to be used to rehabilitate the backfilled pits. Grab samples of these materials were supplied to Landloch by Toro for assessment:

- **TE1** – Lake Playa. This is a material found at low relief areas on the fringes of Lake Way.
- **TE2** – Millipede clay pan. This material is found in low relief depression areas.
- **TE3**. Dune sand. These are red coarse sandy dune features that are positioned approximately 5-10m above the surrounding low relief landscape.

The grab samples were collected from a short transect that originated from the clay pan across the sand dune to the playa lake (Figure 3).
3.2 Basic material properties

Subsamples of the fine fraction (particles with diameters <2mm) of each grab sample were sent to a third party NATA accredited laboratory for analysis of:

- pH\textsubscript{1.5};
- Electrical conductivity (EC\textsubscript{1.5});
- Exchangeable cations (Ca\textsuperscript{2+}, Mg\textsuperscript{2+}, K\textsuperscript{+}, Na\textsuperscript{+});
- Effective cation exchange capacity;
- Exchangeable sodium percentage; and
- Particle size distribution (clay, silt, fine sand, coarse sand).

The materials’ pH and electrical conductivity (EC) were measured using a 1 part soil to 5 parts deionised water solution. Materials with EC\textsubscript{1.5} > 0.3dS/m were pre-treated prior
to assessment of exchangeable cations to remove dissolved salts (increasing the accuracy of the exchangeable cation analyses).

3.3 WEPP erodibility parameters

In the WEPP model (Flanagan and Livingston, 1995) used in assessing batter erosion potential in this report, erodibility\(^2\) is described via a number of specific parameters:

- Interrill erodibility (\(K_i\));
- Rill erodibility (\(K_r\));
- Critical shear for rill initiation (\(\tau_c\)); and
- Effective hydraulic conductivity (\(K_s\)).

Interrill erodibility (\(K_i\)) describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows. Rill erodibility (\(K_r\)) describes the detachment of particles by shear stresses caused by concentrated surface flows. Critical shear for rill initiation (\(\tau_c\)) is the shear stress applied by concentrated surface flows above which particle detachment in rills rapidly increases. Within WEPP, effective hydraulic conductivity (\(K_s\)) defines the rate of water movement through a defined soil profile in response to wetting by rainfall, and is derived through analysis of a material’s steady infiltration and runoff rates. Effective hydraulic conductivity is different to saturated hydraulic conductivity.

Typically, WEPP erodibility parameters are derived from data collected using either field-based or laboratory-based experimental methods involving the application of:

- Simulated rain to a surface and measurement of runoff and sediment in runoff to obtain estimates of \(K_i\) and \(K_r\); and
- Surface water flows to obtain estimates of \(K_s\) and \(\tau_c\).

These parameters are then used in WEPP computer simulations of runoff and erosion in determining a range of landform design options. For this preliminary assessment, the data from the basic material properties listed in Section 3.2 was used to match the Centipede soils to existing Landloch WEPP material files. More details on how the WEPP model is parameterised and the construction of a suitable climate file is contained in Appendix A.

3.4 Definition of acceptable erosion rates

The concept of acceptable or tolerable soil loss is widely mentioned in literature, but it appears to have little relevance to minesite rehabilitation. Tolerable soil loss is traditionally defined as a rate of erosion such that land productivity is not reduced, and is therefore of greatest relevance to agricultural situations. For mining, unacceptable erosion is more closely aligned to requirements to:

\(^2\) Although the concept of “erodibility” is broadly understood, its precise meaning can vary considerably within the framework of some erosion prediction models.
• Keep problematic materials encapsulated in the long-term;
• Limit requirements for future remediation works;
• Enable vegetation establishment; and
• Meet visual amenity goals set by stakeholders.

Currently, there is no widely applied methodology for assessing what is an acceptable erosion rate for rehabilitated mining lands.

Landloch’s approach to landform design acknowledges that limiting rill and gully erosion are of particular importance for mine rehabilitation, as their presence increases the risk of exposure of underlying materials and is often considered to have unacceptable visual amenity that leads to requirements to undertake remediation works. Further, slopes dominated by rilling or gullying can have erosion rates orders of magnitude greater than non-rilling slopes and produce considerably more sediment that can have adverse off site impacts. With these things in mind, Landloch’s designs aim to create slopes on which rilling will be minimal or absent. Such slopes will have little potential to become heavily gullied in the future. If rilling and gullyng is avoided, the slope should be erosionally stable in the long term.

Landloch has considerable experience in modelling erosion, and assessing erosion processes and rates in the field. Landforms designed with a predicted long term average annual erosion rate (averaged over the whole slope) less than 5 t/ha/yr, together with a predicted maximum long term average annual erosion rate (at any point on the slope) less than 10 t/ha/yr exhibit a low tendency to rill. These erosion threshold values were adopted in this report to differentiate between acceptable and unacceptable slope options.

These threshold values align with soil loss tolerance guidelines reported by Li et al (2009) for soils that overlie more hostile subsurface materials and where soil tolerance rates were set to limit their exposure; soil loss tolerance values of 2.5-7.5 t/ha/y are reported for soil profiles 25-50cm thick. To date, observations made by Landloch on several sites indicate that this erosion threshold definition has produced batters with low rilling potential that have been consistent with rehabilitation success (DRET, 2009).

3.5 General input conditions and assumptions

WEPP runoff and erosion simulations were conducted on the materials using the following general model settings:

• Rill spacing was set at 5m for the Project soils.
• Surface roughness was set at 3cm for all materials, consistent with the value used when calibrating the model runoff predictions using the rainfall simulator infiltration data.
• No allowance was made for the effects of vegetation on erosion.
• No allowance was made for water from upslope in the catchment discharging onto the rehabilitated slopes, nor for rising flood waters from Lake Way.
4 RESULTS

4.1 Basic material characteristics

Results of the analysis of the grab samples for the lake playa (TE1), clay pan (TE2), and dune sand (TE3) is shown in Table 1.

Table 1: Characterisation data of the Millipede soil material.

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Unit</th>
<th>TE1</th>
<th>TE2</th>
<th>TE3</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH&lt;sub&gt;1.5&lt;/sub&gt;</td>
<td>pH units</td>
<td>8.09</td>
<td>8.4</td>
<td>7.58</td>
</tr>
<tr>
<td>Electrical Conductivity (EC&lt;sub&gt;1.5&lt;/sub&gt;)</td>
<td>dS/m</td>
<td>0.58</td>
<td>7.09</td>
<td>0.06</td>
</tr>
<tr>
<td>Exchangeable Cations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>meq/100g</td>
<td>4.04</td>
<td>10.2</td>
<td>1.81</td>
</tr>
<tr>
<td>Magnesium</td>
<td>meq/100g</td>
<td>0.40</td>
<td>2.39</td>
<td>0.28</td>
</tr>
<tr>
<td>Potassium</td>
<td>meq/100g</td>
<td>0.05</td>
<td>0.72</td>
<td>0.00</td>
</tr>
<tr>
<td>Sodium</td>
<td>meq/100g</td>
<td>0.25</td>
<td>11.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Aluminium</td>
<td>meq/100g</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Cation Exchange Capacity</td>
<td>meq/100g</td>
<td>4.75</td>
<td>24.8</td>
<td>2.18</td>
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<tr>
<td>Exchangeable Sodium Percentage</td>
<td>%</td>
<td>5.35</td>
<td>46.17</td>
<td>3.64</td>
</tr>
<tr>
<td>Particle Size Distribution of Fine Fraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sand 0.2-2.0mm</td>
<td>%</td>
<td>29.4</td>
<td>26.4</td>
<td>38.8</td>
</tr>
<tr>
<td>Fine Sand 0.02-0.2mm</td>
<td>%</td>
<td>67.3</td>
<td>43.2</td>
<td>59.6</td>
</tr>
<tr>
<td>Silt 0.002-0.02mm</td>
<td>%</td>
<td>0.0</td>
<td>3.8</td>
<td>0.0</td>
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<tr>
<td>Clay &lt;0.002mm</td>
<td>%</td>
<td>3.3</td>
<td>26.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Dispersion Potential</td>
<td>Class</td>
<td></td>
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<tr>
<td>Fizz test (HCl)</td>
<td>x</td>
<td>√</td>
<td>x</td>
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</table>

Material pH is consistent with a range common for mineral soils in the Goldfields region, tending to be alkaline to moderately alkaline.

The EC values are low for TE3, high for TE1, and extremely high for TE2. Being a material that fringes a playa lake, TE1 has been previously reported as being extremely saline (4.25-9.99dS/m). The result in Table 1 is lower likely because the sample was a taken from the surface. Nevertheless, TE1 materials should be considered saline. The salinity values of TE2 and TE3 are consistent with values for surface materials previously reported.

The particle size distribution (PSD) for the three soils shows that TE1 and TE3 are very similar, being dominated by the sand fraction (96.7% and 98.4% respectively). TE2 has a finer texture and is 30.4% clay and silt.

TE1 and TE3 have ESP percentages below the 6% threshold, and this coupled with their low clay content would render that as having a low risk of clay dispersion. TE2 on the other hand has a very high ESP value (46.2%), is ~27% clay, and presents a significant dispersion risk. It was noted that when the TE2 grab sample arrived at Landloch’s erosion assessment facility, the nature of the material was a massive blocky crumb. The samples required sieving before forwarding to the laboratory, and the Landloch technicians report that the material had to be broken up using a hammer, indicating a tendency for hardsetting. Soils that a prone to dispersion and hardsetting tend to support limited
vegetation. If placed within the rehabilitation landform such that water is allowed to pond on them, dispersive soils can also lead to tunnelling and exposure of underlying materials.

The TE2 sample has displayed hard setting properties and has been analysed as having very high salinity and a high potential to disperse. It is for these reasons that Landloch would not recommend any use of the clay pan soil as a sheeting material for the back filled pit areas. If their use is necessary, they should be restricted to use in areas of low relief and where there is low risk of ponding or exposure of underlying materials via tunnel erosion. This material was not considered further in the erosion assessment.

TE1 and TE3 cannot be distinguished in terms of their physical characteristics and will therefore be treated as one material and denoted in this report as ‘Toro Sand.’ It is noted however that the high salinity of the TE1 material may limit the range of species that can be established on the lake playa materials.

4.2 WEPP file selection and WEPP parameters

Based on the results in Section 4.1, a search was conducted of Landloch’s WEPP materials’ database to select a comparable material. The best match was from another dune sand material that landloch had fully characterised. It had a pH of 6.5, low salinity, and a PSD that was dominated by sand (97.3%), which puts it between the TE1 and TE3 soils. The selected WEPP file will also be termed ‘Toro Sand.’

The WEPP parameters for the Toro Sand are listed in Table 2. The effective hydraulic conductivity value for the material is quite high which is typical of a sand dominated material. Also typical of sand (which is a structureless and un-cohesive material) are the values for interrill, rill, and critical shear. These values indicate that this material would be highly erodible if subjected to concentrated surface water flows.

<table>
<thead>
<tr>
<th>Material</th>
<th>Effective hydraulic conductivity, $K_e$ (mm/h)</th>
<th>Intermitt erodibility, $K_i$ (kg.s/m²)</th>
<th>Rill erodibility, $K_R$ (s/m)</th>
<th>Critical shear, $τ_c$ (Pa)</th>
</tr>
</thead>
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<tr>
<td>Toro Sand</td>
<td>260</td>
<td>1,760,710</td>
<td>0.0561</td>
<td>6.5</td>
</tr>
</tbody>
</table>

The erodible characteristics was observed when conducting the laboratory characterisation of the dune sand material termed in this report the ‘Toro Sand’ (Figure 4). When a concentrated flow was applied to the test flume surface, the dune sand was readily eroded.
Figure 4: Characterisation of rill erodibility of the dune sand in Landloch test flumes.

4.3 WEPP climate file used

The Wiluna climate file was used for long term erosion simulation in WEPP. Nearby climate files from Mt Keith and De Grussa were also used for comparison model runs to check the WEPP results.

4.4 Landscape surface determination

The planned final rehabilitated land surface shape will be a reconstruction of the existing natural surface. Therefore, the existing natural surface was used to determine the range of slope gradients and lengths to consider in the WEPP model simulations. CAD files of the Centipede and Millipede pits as well as the existing land surface were supplied to Landloch by Toro (Figure 5).

The files were imported into the ESRI GIS software where a digital elevation model (DEM) was constructed of the land surface with the pit outlines overlaid. Transects of the existing surface profile were created within the pit boundaries; numbers 1 – 8 for the western pit and 9 – 14 for the eastern pit (Figure 6). The transects were created perpendicular to the contour lines.
Figure 5: Millipede and Centipede proposed pit boundaries.

Figure 6: Transect lines (numbered) used to obtain profile information from the DEM.
The profile information showed that this is a very low relief and low gradient landscape. The lake playa and clay pan soils correspond to low lying areas in the landscape (491-492m ASL). The only areas of significant gradient were those associated with the dune sand material (492-501m ASL), where the largest elevation change was 9m and the steepest gradient was 4.23° (transect 11), and the largest slope length was 1,319m (transect 10). Transect 11 was selected as the ‘worst case’ profile to model due to its ‘large’ slope height and gradient (Figure 7). The other transect graphs are contained in Appendix B.

![Graph showing elevation and footprint](image)

**Figure 7:** Transect 11 profile. The gradient of the steepest section (shown by the line between the red dots) is 4.23°.

### 4.5 WEPP model runs

The WEPP input parameters have been listed in Section 3.5. The Toro Sand material was assessed for its long term erosional stability for a profile containing a relatively steep dune section above a low relief section of lake fringe (Figure 7). This runoff and erosion simulation did not yield any runoff or erosion. This result is due the very high hydraulic conductivity of the Toro Sand material. Even though the sand is quite erodible, there were no rainfall events in the climate sequence considered that were large enough to saturate the soil profile and cause runoff and hence erosion.

Additional land surface shapes were further examined long term erosional stability. A range of single linear slopes were simulated with slope gradients ranging from 12° to 18° and slope height ranging from 11 to 20m. These shapes (height and gradient) greatly exceed the shapes planned to be used when rehabilitating the backfilled pits. Again, WEPP predicted that no erosion would occur for these profiles.
4.6 Sensitivity analysis

The predicted stability of the Toro Sand is due to the high effective hydraulic conductivity value estimated for this material (260mm/hr). The sensitivity of WEPP model predictions of erosion to hydraulic conductivity was assessed. WEPP was run for a 20m high 18° single linear batter slope of Toro Sand with the $K_e$ value reduced from 260mm/hr to 100mm/hr. Again this simulation resulted in no predicted erosion. $K_e$ was then reduced and the model run until runoff was predicted. A $K_e$ value of 75mm/hr was required as input for erosion of the batter to be initiated. Further reducing $K_e$ value to 30mm/hr resulted in average erosion rates of 4.4 t/ha/yr and maximum erosion rates of 5.9 t/ha/yr, which are still below the acceptable erosion rates defined in Section 3.4.

The same simulations were also repeated with different climate sequences from within a 200km radius of the Project site, and all resulted in no erosion.

Is is concluded that if the rehabilitated Toro pits sheeted with dune sand or lake playa material of adequate depth to approximately the shape of the existing natural surface, these landforms will be erosional stable in the long term.

5 SIBERIA LANDFORM EVOLUTION MODELLING

The WEPP model has shown that for the rehabilitated landform there will be little runoff and erosion for the Toro Sand at the anticipated elevations and gradients. Therefore simulating landform evolution using the SIBERIA model is not necessary and will not provide any information on the long term stability of the Project.

6 DISCUSSION

6.1 Estimations of effective hydraulic conductivity for Toro sand material

The predicted erosional stability of a Toro Sand material is due to the material having a high infiltration capacity that is not exceeded by rainfall in the region of the Project. Reducing the $K_e$ value by more than half still did not result in any predicted erosion. To further validate that the assigned effective hydraulic conductivity of the Toro Sand was not unrealistically high, Landloch conducted an internal literature review of other similar arid zone sand materials.

Landloch has studied a sand dominated material from a mine site approximately 300km east of Leonora in the WA Goldfields. This material had higher clay contents (6-19%) and a coarse sand fraction of approximately 51-64%. The conclusion of this study once $K_e$ values were greater than 30mm/hr, minimal runoff occurs for a 40m high 14° batter slope in arid WA.

Aeolian sand material was studied from a mineral sand operation in South Australia. These sandy materials were approximately 75-90% sand and 10-25% clay. Effective hydraulic conductivity values ranged from 33-70mm/hr. The predicted erosion for a 300m long slope of approximately 6° slope was 0.6 t/ha/yr, well below the acceptable threshold of 5 t/ha/yr.

Another similar material was a saline slurry from a mineral sands operation in western NSW. The particle size data for this material was 96% sand and 3% clay. Laboratory
estimations of saturated hydraulic conductivity \((K_{sat})\) was 1,300mm/hr. Although \(K_{sat}\) and \(K_s\) are not the same measure, the very high \(K_{sat}\) value does indicate that very large amounts of water can be infiltrated into the sand dominated material.

\(K_{sat}\) value was also assessed using the ROSETTA model. This model estimates soil hydraulic properties through surrogate soil data such as soil texture and bulk density. The PSD information for the TE1 and TE3 sample were inputted to the model and a bulk density of 1.4g/cm\(^3\) used (previous reports stating a bulk density range of 0.9 - 1.9g/cm\(^3\) for site soils). The model returned a hydraulic conductivity of 300mm/hr.

## 7 CONCLUSIONS

Landloch undertook a preliminary landform stability assessment for the Toro Project based on grab samples of the lake playa, clay pan, and dune sand topsoils that have been targeted for use to rehabilitate the waste landforms at closure. The soils data showed that the lake playa and dune sand materials are not distinguishable and was considered as the same material (‘Toro Sand’) for the WEPP model runs. The clay pan material was very high in salinity and ESP and showed hard setting properties. The clay pan material should not be used as a sheeting material and should be returned to its low landscape position at closure, or not used at all for rehabilitation as only the most highly adapted halophytic plants would grow in this medium.

A WEPP soil file was selected that most resembled the Toro Sand, and this was run for the highest and steepest profile from the Project and this resulted in no predicted erosion. The model was re-run to consider a 20m high and 18° batter configuration (far in excess of any proposed Project closure shape) and no predicted erosion resulted. This is due to the high infiltration rate of the Toro Sand that means there are few rainfall events that lead to runoff from the soil. A review of previous erosion studies conducted by Landloch on similar dune materials, ROSETTA model estimations of hydraulic conductivity, and Landloch’s previous experience with assessing erosion for similar sandy materials has concluded that when a range of effective hydraulic conductivity values consistent with those measured for other similar materials are used within WEPP to predict runoff, the potential for runoff and subsequently erosion remains low. A very low effective hydraulic conductivity setting of 30mm/hr for the 20m high and 18° batter configuration still resulted in erosion rates below the acceptable thresholds. Based on the samples supplied and these preliminary modelling results, use of dune sand and lake playa soils at suitable depths for the reconstructed landform surface will be eresionally stable.

The above findings are based on one grab sample from each of the main materials found at the Project. The lake playa sample provided to Landloch was low in salinity, while previous reports indicate that it is high in salinity. It is recommended that a more comprehensive material and erosion assessment be undertaken once the Project commences so as to more thoroughly characterise the materials for factors not considered in this preliminary study such as surface sealing and interactions with underlying waste and other capping materials. Wind erosion will also be significant in the arid zone for a sandy material, and this could also be considered in a more comprehensive erosion assessment.


APPENDIX A

A.1 Rainfall and overland flow simulation

Interrill and rill erosion were determined by employing the following methodology:

1. Interrill erosion was measured by applying a simulated "storm" with known rainfall intensity to test plots (Figure A.1). Runoff rates and sediment loads were recorded and used to derive rainfall related parameters.
2. Rill erosion was measured by applying overland flow to flumes (Figure A.2). Sediment in runoff were measured and used to derive rill related parameters.

![Rainfall simulator installation](image)

**Figure A.1:** Laboratory-based rainfall simulator installation.
A.2 Computer simulation of erosion of landform batters

A.2.1 The WEPP model

The WEPP model was used in this project for simulations of runoff and erosion (Flanagan and Livingston 1995). It was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for hillslopes and catchments. WEPP is a simulation model with a daily input time step, although internal calculations can use shorter time steps. Plant and soil characteristics important to erosion processes are updated every day. When rainfall occurs, those plant and soil characteristics are considered in determining the likelihood of any runoff. If runoff is predicted to occur, the model computes sediment detachment, transport and deposition at points along the slope profile.

The erosion component of the WEPP model 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 the soil’s critical shear stress, and when the sediment load of the flow is below transport capacity. Deposition in rills is computed when the sediment load is greater than the capacity of the flow to transport it. Adjustments to soil detachment are made in WEPP to incorporate the effects of canopy cover, ground cover, and buried residue.
A.2.2 WEPP climate file

WEPP requires both daily climate observations of rainfall, temperature, and solar radiation, and sub-daily data (e.g. 6-minute) of rainfall to create the long-term climate sequence. For each day of simulation, WEPP requires ten daily weather variables:

- Precipitation (mm),
- Precipitation duration (hr),
- 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 the list above) are of particular importance because previous studies have shown that predicted runoff and soil loss are most sensitive to these precipitation variables.

Very few sites around the world have complete historical weather data of these variables, and data must be sourced from various locations and combined in a way that is justifiable. Landloch’s approach is to develop synthetic weather sequences that statistically preserve the mean and variations in the historical observations from nearby weather stations. This approach allows for missing data points to be patched with values that do not skew the data set statistically.

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.

Daily climate data were sourced from the Australian Bureau of Meteorology (BoM) through the SILO Patched Point data facility.

Using the data set, the following CLIGEN parameter values were computed and used to develop the synthetic climate sequences:

- 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 were assembled to create a CLIGEN parameter file for the site. Wind data (used to calculate soil evaporation) were not synthesised by CLIGEN because Priestley-Taylor’s method for estimating the potential evaporation (that does not require wind speed) will automatically be used by WEPP. A 100-year climate sequence was generated using CLIGEN version 5.1.
APPENDIX B. LANDFORM TRANSECT PROFILES

Graphic Profile 1

Graphic Profile 2

Graphic Profile 3

Graphic Profile 4

Graphic Profile 5

Graphic Profile 6

Graphic Profile 7

Graphic Profile 8