9.2 1,000 YEAR LANDFORM EVOLUTION MODELLING

9.2.1 General

The Environmental Protection Authority (EPA) determined that the Venturex Sulphur Springs Project would be assessed under Part IV of the Environmental Protection Act 1986. As part of the Environmental Scoping Document (Assessment No 2/20) a list of required work was provided by the EPA. Item 32 on the work list was as follows:

"*Conduct long term (1000 years) Landform Evolution Modelling of behaviour and performance of landforms associated with containment systems including the TSF, modelled under a range of climatic events. Include the modelling of the appropriate Probable Maximum Precipitation (PMP) and associated Probable Maximum Flood (PMF) scenarios.*"

The modelling has been undertaken based on the TSF configuration (described in the preceding sections) using the SIBERIA software developed by Telluric Research for landform modelling.

SIBERIA produces a large scale model of catchment evolution involving channel network growth and elevation evolution. This model integrates a model of erosion processes, theoretically and experimentally verified at small scales, with a physically based conceptualisation of the channel growth process. Neither the properties of the channel network nor the properties of the hillslopes can be viewed in isolation. A crucial component of this model is that it explicitly incorporates interaction between the hillslopes and the growing channel network based on physically observable mechanisms. An important and explicit differentiation between the processes that act on the hillslopes and in the channels is made (Ref. 4).

The current design for the TSF is at a feasibility stage with limited data available on material characteristics etc. A site investigation has been undertaken (Refer Section 3) and the assumed parameters and material characteristics are based on this information and typical parameters from other sites with similar conditions.

9.2.2 Description of the TSF Area

9.2.2.1 Landform System

Flora and Vegetation surveys were undertaken across the site area by Astron Environmental in 2002 and M.E. Trudgen & Associates in 2006 respectively. Both of these documents were included in Appendix E "Environmental" in the CBH Resources Limited Bankable Feasibility Study in 2006 (Ref. 5).

These surveys classified the TSF area as “Boolgeeda Land System” using the classification from “Technical Bulletin No. 92 – An inventory and condition survey of the Pilbara region, Western Australia”, Department of Agriculture, 2004.

In the 2007 EIS review by Mattiske Consulting Pty Ltd (Ref. 6) the location of the current TSF (over the then proposed Evaporation Pond No 2) area was classified as containing primarily “Vegetation Alliance 13”. The critical information from these surveys and landform types can be summarised as follows:

- The area is covered with open to closed spinifex hummock grasslands (primarily Triodia Wiseana) with scattered Acacia shrubs;
- The ground has a stony mantle over the surface consisting of gravel fragments; and
- The vegetation is considered to be non-degradable (by livestock etc.) and the erosion potential is low.

Photographs taken during the site investigation (refer Appendix C) are consistent with the above classification.

9.2.2.2 Soil Classification

The test pits in the TSF area show that the soils have high concentrations of sand/gravel and cobbles/boulders. Typically the silt/clay content in the surface soils is less than 20-30%.

9.2.2.3 Potential Construction Materials

Five potential construction materials have been identified on the basis of the site investigation as follows:

i. Topsoil/Colluvium – this is considered to be a thin scattered material across the TSF area consisting of a clayey, sandy gravel material. This will be used in the rehabilitation as a final layer on the TSF cover and embankment faces;

ii. Colluvium surface layer – this is present across the TSF area consisting of material ranging from minor amounts of silts and clay through sand and gravel and up to cobbles and boulder sizes. This may be used in the upstream embankment zones and as part of the growth medium layer in the TSF cover;

iii. Clay/Silt material – this will be sourced from off site and will be used for the HDPE liner sub-base;

iv. Sand – this will be sourced from off site and will be used for drainage materials and the HDPE protection layer; and

v. Run of mine waste materials – mine waste will be used in the TSF downstream embankment and as a base material for the growth material layer. This will have a range of sizes depending on pit blast patterns but may have material ranging up to 500 mm to 800 mm particle size. This will be durable fresh rock material and only NAF material will be used in the TSF area.

9.2.3 Landform Modelling

9.2.3.1 Model Development

Based on the preliminary design for the TSF, the landform modelling study using the SIBERIA software was carried out to:

- Confirm that the resultant landform is geomorphically stable;
- Identify those issues associated with the cover design that affect the landform performance;
- Identify any potential TSF design changes which may mitigate long-term erosion issues;
- Establish, within an order of magnitude, the likely changes in the TSF landform over a 1,000 year period; and
- Identify the subsequent information required to refine the model in the feasibility study.

The determination of the long-term changes in the landform as a consequence of closing the TSF was completed over a 1000 year timeframe through consideration of the run-off and erosion sequences over that period and the changes in landform arising from those sequences.

The base case for the modelling was the TSF after closure, as per the preliminary design, with the barrier store and release cover system as described by O'Kane (Ref. 7). This design was built into the digital terrain model which was then incorporated into the software for processing. Climate data used was drawn from the historic data collected in the period 1889 - 2017 and processed through the SILO data drill. A 1000 year dataset was applied by taking the 100 year analysis and applying it 10 times in the SIBERIA model.

The SIBERIA software predicts the final shape of the landform each year over the 100 year climate model then re-applies that shape as the base case for the following year to predict the evolutionary transformation over a 1,000 year period. The key factors considered in the model are the catchment area, surface grade and channel network development.

The cover system adopted by O'Kane has a multi-layered cross-section designed to reduce infiltration into the tailings and lower the potential for acid generation from the tailings stored. Achievement of this objective requires the development of a barrier layer (low permeability material/HDPE) over which a well-graded granular non-acid forming (NAF) layer is placed to store and release retained moisture. The cross-section description includes the following range of dimensions for consideration at this stage of development:

- Low permeability soil liner – 200 mm;
- 1.0 or 1.5 mm HDPE liner;
- Protective sand layer –150 mm minimum;
- Well graded NAF layer – 1,560 mm to 2,650 mm; and
- Topsoil – nominal thickness.

The physical, chemical and erosion properties of these layers have not been described within the O'Kane report. The properties of each layer in the modelling were based on the preliminary information available from the site investigation.

The SIBERIA model displays the zones of erosion and the zones of sedimentation within and beyond the landform. It can also be used to assess the undisturbed landscape around the TSF to compare the naturally occurring evolution with the evolution that occurs in the formed structure.

The proposed materials are based on the preliminary site investigation. Development of the model, therefore, required parameters to be set in the model based on typical parameters. The parameters selected were based on the project experience of engineers within the KP office in Perth.

For modelling purposes, three zones were selected:

- The tailings cover surface, as described in this report;
- The TSF downstream embankment face, as located and designed in this report; and
- The undisturbed ground around the TSF.

9.2.3.2 Selection of Parameters

The following factors were assumed in determining the parameters to be applied to each zone:

- The relative age of the slope;
- Its cover characteristics;

- The particle size of materials within the zones; and
- The desired infiltration characteristics of the cover.

Consistent with O'Kane's report (Ref. 7), the tailings cover surface is assumed to have a thin topsoil layer over a positively draining storage layer/growth medium sloped at the beach angle of the tailings, therefore being a shallow slope. The growth medium will likely be constructed using non-acid forming (NAF) waste rock supplemented with local colluvium material which will allow some drainage at the surface.

The TSF embankment downstream face will have an outer face of a coarse material with a maximum particle size of 300 to 500 mm. It is expected that the infiltration will be improved while the erodibility of the TSF wall will be reduced by the presence of this coarse material. Topsoil will be placed over this material and mixed into the underlying material.

The undisturbed ground around the TSF (Boolgeeda Land System) is assumed to be relatively stable having been eroded for millennia and formed of scree overlying a coarse gravel material with some minor fines content.

Based on these assumptions, the database of erodibility parameters within the SIBERIA model and parameters used for other projects in similar areas, the following comparative values were applied to the SIBERIA software to produce a 1,000 year prediction of the landform constructed for the TSF taking into account the erosion that will occur progressively over that period.

Table 9.1: Assumed comparative values

Location	Erodibility (ß)	Coefficient (m_1)	Coefficient (n_1)
Undisturbed surface	0.000002	1.5	2.0
TSF embankment	0.0001	1.2	1.5
Tailings surface	0.08	2.0	3.0

The erodibility (ß) defines the estimated annual erosion due to rilling and the coefficients (m1 and n1) are representative of the discharge and slope respectively.

The erodibility factors selected reflect how each location is expected to perform given the materials that will form the impacted surface and the relative catchment areas. The existing undisturbed surface was assigned the erodibility expected of an 'old' land surface covered by a stony mantle and with the presence of rock outcropping described as 'stony soils'.

This area was given a moderate slope coefficient (n1), as it contains a range of different gradients, and a moderate discharge coefficient (m1), as the soil tends to be a sandy or sandy loam texture covered with the abundant stony mantle which will tend to slow any water flow across its surface.

The TSF embankment will have a downstream face consisting of cobbles and boulders with a small proportion of topsoil (less than 20% by volume) built into the surface matrix. The erodibility of this material is higher than the natural surface due to the fine particles lying between the cobbles and boulders. The embankment is steep and has been ascribed a lower slope coefficient consistent with that steepness. The discharge coefficient (m1) has also been reduced as the surface particle sizes will provide significant storage capacity before flow off the surface is high enough to dislodge surface material.

The tailings surface cover system is formed of particle sizes which are smaller than the rock mantle and the TSF embankment, and the erodibility of the material (ß) is much higher than the other surfaces. To be conservative an erodibility value at the top end of the expected range was selected. This is offset to a degree by the surface flatness which is likely to be less than five degrees. However, the flatness of the surface will increase the rate of discharge as it is likely to have less surface storage than the other two zones.

The relative values assigned are consistent with the comparative descriptions of the soil groups for the Pilbara (Ref. 6).

The model was developed using annualised data linked to a 100 year climate model which was rolled over to produce a model with 1000 years of continuous data. All modelled surfaces were considered to be a uniform material that was not penetrated beyond its depth through evolution of the landform. The TSF surface was modelled as being smooth with no surface disturbance and without vegetation.

9.2.3.3 Model Outputs

The model outputs for Years 0, 5, 10 and 1000 are shown in figures 9.1 to 9.4. From these outputs it is evident that gully erosion has commenced by Year 5 and has formed a distinct pattern by Year 1000. As shown in Figure 9.5, the indicated maximum depth on the tailings cover surface is about 0.3 m with rills to 0.4 m indicated on the TSF embankment downstream face. Erosion is also evident in the zone where the TSF abuts the hills around the valley in which it lays.

The balance of the TSF appears to lose about 0.2 m of surface material through sheet flow run-off.

Ground level outside the TSF area appears to remain static with some minor accumulation occurring in downstream areas or high erosion zones.

There do appear to be some areas of sedimentation formed outside the spillway or at the base of the TSF embankment. The maximum depth at the base of the embankment is about 1.5 m over a width of approximately 10 m from the original toe of the batter. At the base of the spillway, the depth is about 0.4 m over a width of 25 m from the outlet.

At the TSF embankment, the rilling occurs from the berm located mid-embankment as its storage capacity is exceeded. However, the rilling will be highly dependent on the type of material located in the transition area from the berm to the slope below the berm.

9.2.4 Modelling Conclusions and Recommendations

The pattern of rilling and sheet flow erosion on the tailings cover surface is consistent with expectations as it follows the patterns predicted to occur with the tailings profile developed in the facility where run-off is directed to the spillway in the final stages of TSF operation. The deeper erosion occurs where concentration of run-off develops, as expected.

The depth of erosion on the TSF embankment face is consistent with expected outputs in a SIBERIA model where an inter-batter berm is placed (Ref. 8). This erosion is expected to continue until the berm is effectively removed (Ref. 8).

The commencement of the erosion early in the life of the TSF after closure, as shown in figures 9.2 and 9.3, indicates that development of mechanical stability in the surface of the cover system will be critical to the surface stability until a vegetative cover is sufficiently developed to maintain the surface stability.

The site investigation indicates that the establishment of vegetation on the cover consistent with the current vegetation materials is viable. It should be noted that vegetation has a significant impact on overall erosion rates (Ref. 9) reducing rates by 50 to 60%.

9.2.5 Implications for TSF Design

The 1,000 year landscape evolution modelling was undertaken based on the current design of the TSF. There are three areas in which erosion effects occur as follows:

- On the surface of the cover area leading towards the spillway location;
- Around the perimeter of the cover where it interacts with the surrounding valley walls; and
- On the embankment face, in particular along the berm on the embankment face.

The following design modifications have been incorporated into the current design to reduce or mitigate these effects as follows:

- Cover surface – the depth of erosion on the surface area is about 0.15 m up to a peak value of around 0.3 to 0.4 m. The cover design from O'Kane (Ref. 7) has an overall depth of 2 to 3 m and thus the expected level of erosion will not expose the HDPE liner within the cover. Notwithstanding this, some additional modifications to the cover design are recommended as follows:
    i. Mix the topsoil layer into the surface zone of the growth medium layer;
    ii. Ensure that the surface zone (mixed topsoil/growth medium) has a base quantity (% of material) of gravel to cobble sized material present to improve erosion resistance; and
    iii. Restore the vegetation cover as soon as possible on completion of placement of the cover layers consistent with the existing moderately dense surface cover (as can be seen in the site investigation photographs of the TSF area).
- Edge of the cover against the valley sides – the model has an assumed flat surface which meets the sloping valley hillside. This relatively sharp interface focuses water flow and thus results in a localised erosion issue. During construction of the cover the edges of the cover around the perimeter should be shaped to extend up and integrate into the hillside face. In addition, coarser material will be added in these areas to improve erosion resistance. The design concept is to draw the water away from the edge of the cover out onto the surface and also to reduce local erosion by increasing the erosion resistance in this area;
- Embankment face and berm – the berm on the downstream face of the embankment has been provided in accordance with the current embankment facility guidelines; however the berm does act as a focus point for erosion in the post closure condition. The following changes to the embankment have been incorporated into the design:
    i. The downstream face of the last stage of the embankment will consist of large size erosion resisting material to reduce the erosion potential. The topsoil will be mixed with this coarse material;
    ii. The profile of the berm should be sloped to the outside edge so it will act as a velocity inhibitor for rainfall run-off but not store any water on the berm itself;

iii. The possibility of completely removing the berm as part of the post closure works should be assessed in more detail; and

iv. Vegetation establishment on the face of the embankment consistent with vegetation established on existing steeper hill faces in the area should be incorporated into the embankment on completion of the final embankment lift.