SOILWATER CONSULTANTS

RAVENSTHORPE GOLD PROJECT LANDFORM EVOLUTION MODELLING

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LIMITATIONS

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to undertake an erosion modelling study for the proposed Ravensthorpe Gold Project. This work was conducted in accordance with the Scope of Work presented to ACH Minerals ('the Client'). SWC performed the services in a manner consistent with the normal level of care and expertise exercised by members of the earth sciences profession. Subject to the Scope of Work, the erosion modelling study was confined to the RGP project area generally and specifically the three proposed closure landforms. No extrapolation of the results and recommendations reported in this study should be made to areas external to this project area or landforms different to those modelled. In preparing this study, SWC has relied on relevant published reports and guidelines, and information provided by the Client. All information is presumed accurate and SWC has not attempted to verify the accuracy or completeness of such information. While normal assessments of data reliability have been made, SWC assumes no responsibility or liability for errors in this information. All conclusions and recommendations are the professional opinions of SWC personnel. SWC is not engaged in reporting for the purpose of advertising, sales, promoting or endorsement of any client interests. No warranties, expressed or implied, are made with respect to the data reported or to the findings, observations and conclusions expressed in this report. All data, findings, observations and conclusions are based solely upon site conditions at the time of the investigation and information provided by the Client. This report has been prepared on behalf of and for the exclusive use of the Client, its representatives and advisors. SWC accepts no liability or responsibility for the use of this report by any third party.

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1 INTRODUCTION

Soilwater Consultants were engaged by ACH Minerals to carry out landform evolution modelling (LEM) for three proposed post mine landform designs at the Ravensthorpe Gold Project (RGP). The proposed project will develop three landforms which will remain after closure; a Northern waste rock landform (WRL), a Southern WRL and a tailings storage facility (TSF) This modelling was carried out to determine the long term behaviour of the landform designs with respect to surface stability. The modelling will allow for any design characteristics which may exacerbate erosion rates to be identified and the designs potentially modified prior to closure. The LEM has been undertaken using the SIBERIA landscape evolution model which has been used across many different sites to model erosion patterns and landform developments over large timescales.

1.1 SCOPE OF WORK

The following scope of work was carried out:

- Review of existing soil and waste material input data,
- Review and adjustment of the 3 closure landform designs,
- Determination of suitable input parameters for LEM modelling using the SIBERIA software,
- Calibration of input parameters using separate erosion models,
- Modelling of different material type and development scenarios for the 3 post mine landforms, and
- Summary of modelling output statistics and results.

1.2 EXISTING DATA

The existing soil and waste material data was largely collected during the course of two separate studies; a soil characterisation study conducted by Outback Ecology in 2004 and 2011, and a geochemical characterisation study conducted by Graeme Campbell & Associates (2004). A summary of their findings is presented here.

1.2.1 SOIL CHARACTERISATION DATA

The baseline soil sampling carried out provided data on the physical and chemical characteristics of the soil which will be utilised in rehabilitation of the post mine landforms. Surface soil sampling was undertaken at four different locations across the RGP site. The soils were broadly described as gravelly loams to clay loams with an underlying subsoil of medium clay which may be dispersive. The particle size data for the upper soil layer was reported as 9-27% clay (19% average), 54-87% sand (73% average) and gravel content between 0 and 37% (14% average).

1.2.2 WASTE CHARACTERISATION DATA

The relevant information for this study is the general description of geology and different waste rock lithologies which will form the landforms post mining. The soil / regolith profile in the mining area is approximately 40 – 45m thick and is comprised of an upper clay rich zone approximately 10m thick overlying saprolite. The underlying waste bedrock is dominated by fresh to slightly weathered Dacites.

The current mine plan estimates that approximately 28.5 million tonnes of waste rock will be generated during open pit mining, with the majority of this comprising saprolite, and the remainder largely composed of fresh Dacite.

2 CLOSURE LANDFORM DESIGNS

The three closure landform designs were supplied as a digital terrain model (DEM) in dxf format by ACH Minerals. The closure landform designs were for two WRL (North and South) and a TSF. The northern and southern WRL have similar design characteristics, with 10m high 18° batters, separated by wide berms generally 10m or more in width (Figure 2.1). The TSF has a single continuous outer embankment surface which also has a slope of 18°. The TSF outer embankment varies in height from less than 2m to a maximum of approximately 23m (Figure 2.2). The two WRL designs were modified by adding a small 2 m high berm at the edge of the upper surface to prevent water runoff occurring onto the batters from rainfall which fell on the top surface. Additionally all three designs were gridded on a 2m resolution with each grid node randomly varied ± 5 cm to simulate natural surface variability.

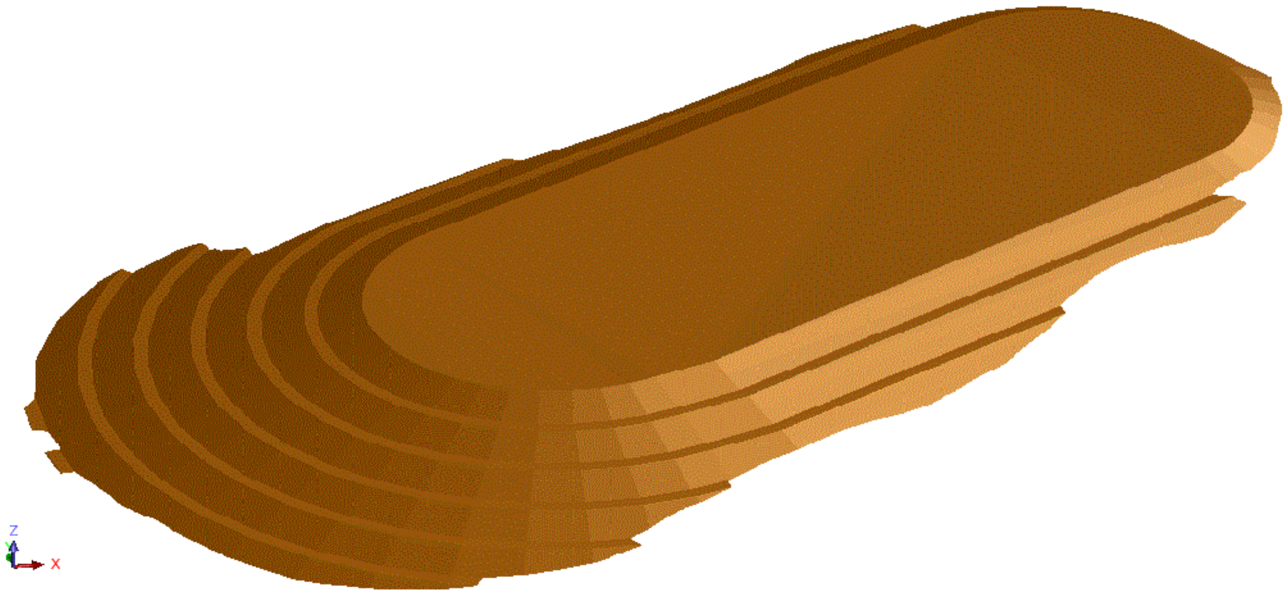


Figure 2.1: DEM of North WRL closure design

Figure 2.2: DEM of TSF closure design

3 SIBERIA MODELLING INPUT PARAMETERS

The determination of the response of landforms to long term erosion forces has generally been carried out using landform development models. There are several different landform development models in use however the SIBERIA model which was developed by Professor Garry Willgoose (1989) is widely accepted as the most robust and well developed example.

The SIBERIA model works to model channel network growth and elevation evolution by integrating and applying a number of erosional processes identified at small scales to a larger scale data set, in this case a gridded digital elevation model (DEM). Using the DEM a drainage direction is assigned to each grid node, with these directions then used to determine the catchment area contributing to each node. A number of equations have been developed which describe the various erosion processes.

The two processes which are central to predicting the volume of sediment lost and added to each grid node are the runoff process, modelled by;

$$Q_c = \beta_3 A^{m_3}$$

Where Q(q) is the discharge per unit width (m3/yr), and B_3 and m_3 are calibrated input parameters relating to the runoff rate and area respectively. This then feeds into the fluvial sediment transport process, modelled by;

$$q_s = \begin{cases} \beta_1 q^{m_1} S^{n_1} - q_{st} & \beta_1 q^{m_1} S^{n_1} > q_{st} \\ 0 & \beta_1 q^{m_1} S^{n_1} \le q_{st} \end{cases}$$

where S is the maximum slope (m/m) and B_1, m_1 and n_1 are calibrated input parameters. This equation holds provided q_{st} is below a critical threshold. As all of these parameters interact within the modelling process, a large number of input integers can result in the same output result. Therefore in order to simplify the calibration method m_3 and B_3 can be set to 1, with the remaining parameters modified by calibration.

3.1 CALIBRATION METHOD

Where the landform area (slope angle and length) are identical to the landform area for which erosion data is available for calibration, only the fluvial sediment transport process input parameters require adjustment. As physical erosion data for the materials which will be used at the RGP are unavailable, the SIBERIA model was calibrated using a combination of two separate erosion prediction methods. The first method used to calibrate the input parameters was the Revised Universal Soil Loss Equation (RUSLE) developed by Renard *et al.* (1997).

The soil material properties available (particle size distribution) were used to estimate the K-factor (erodibility) whilst the rainfall specific to the site was fitted to the R-factor (erosivity) and the C factor was estimated based on gravel content and vegetation properties (e.g. litter, canopy cover).

The SIBERIA input parameters can be adjusted directly using the output from the RUSLE equation; however there is no method to introduce specific climate events into the different input parameters of either SIBERIA or RUSLE. Therefore the watershed erosion prediction project (WEPP) was utilised as a secondary calibration method.

3.2 WEPP INPUT PARAMETERS

The input parameters required by WEPP include particle size information (% sand, % clay), organic content, effective hydraulic conductivity (K_{eff}), interrill erodibility (K_i), rill erodibility (K_r), and soil critical shear stress (τ_C). The basic soil information such as particle size is provided by baseline studies (Outback, 2004), with the remainder of the parameters given initial values based on experience of laboratory scale measurement of similar soil types. Basic 2D slope files simulating the range batter slopes within the three landform designs were used to calibrate the interrill and rill erodibility parameters, with the remainder staying constant. These parameters were adjusted using the results from RUSLE.

The WEPP input parameters were calibrated utilising a standard CLIGEN file (Section 2.3). Once the calibration was complete, the CLIGEN file was modified to include a single probable maximum precipitation (PMP) event within the 100 yr data set.

3.3 CLIMATE DATA

A synthetic climate file was generated using the CLIGEN stochastic weather generator (Yu, 2003), and was used in the WEPP model to simulate 100 years of rainfall, runoff, and erosion for calibration purposes. Data from the following weather stations was imported into CLIGEN to generate this file (BOM station #09961, Hopetoun North and BOM station #010633 Ravensthorpe):

- 0.5 hourly rainfall data (Dec 1995 – July 2018), and
- 30 year set of daily values for rainfall, maximum and minimum temperatures and solar radiation.

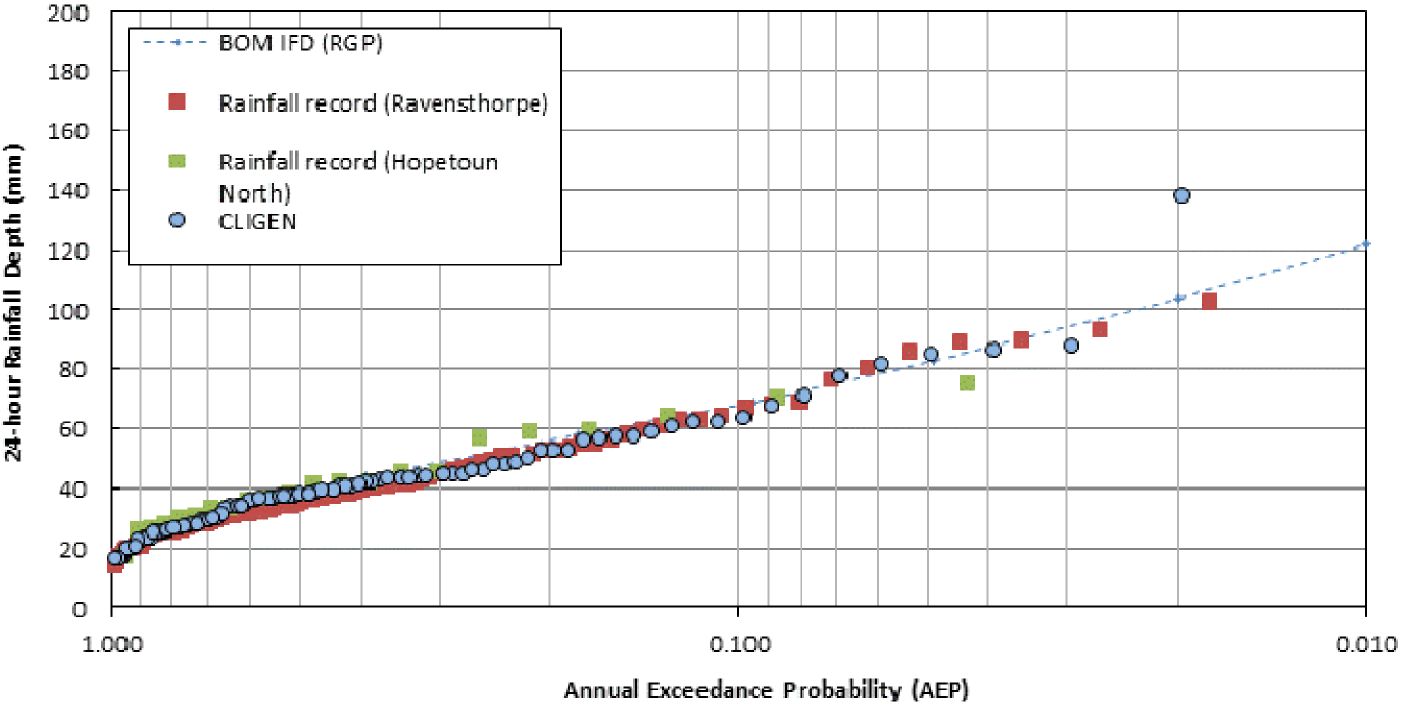
These weather stations are located approximately 20 km south (Hopetoun North) and 15 km northwest (Ravensthorpe) of the RGP area.

Figure 3.1a and Figure 3.1b demonstrate that the 100-year synthetic CLIGEN file used in this calibration method is generally consistent with the available climate data from the region. Figure 3.1a depicts the frequency of 24-hour storm depths, and demonstrates that the storm intensities predicted by CLIGEN are generally consistent with the available monitoring data, including the Intensity-Frequency-Duration (IFD) curves supplied by the Bureau of Meteorology (BOM, 2018). For the more extreme storms (i.e. AEP < 0.03), the CLIGEN predicted greater rainfall intensities than are indicated by the actual climate record, and this is likely to result in a calibrated erosion rate greater than the rates that will actually be experienced (i.e. this will result in a “conservative” erosion estimate).

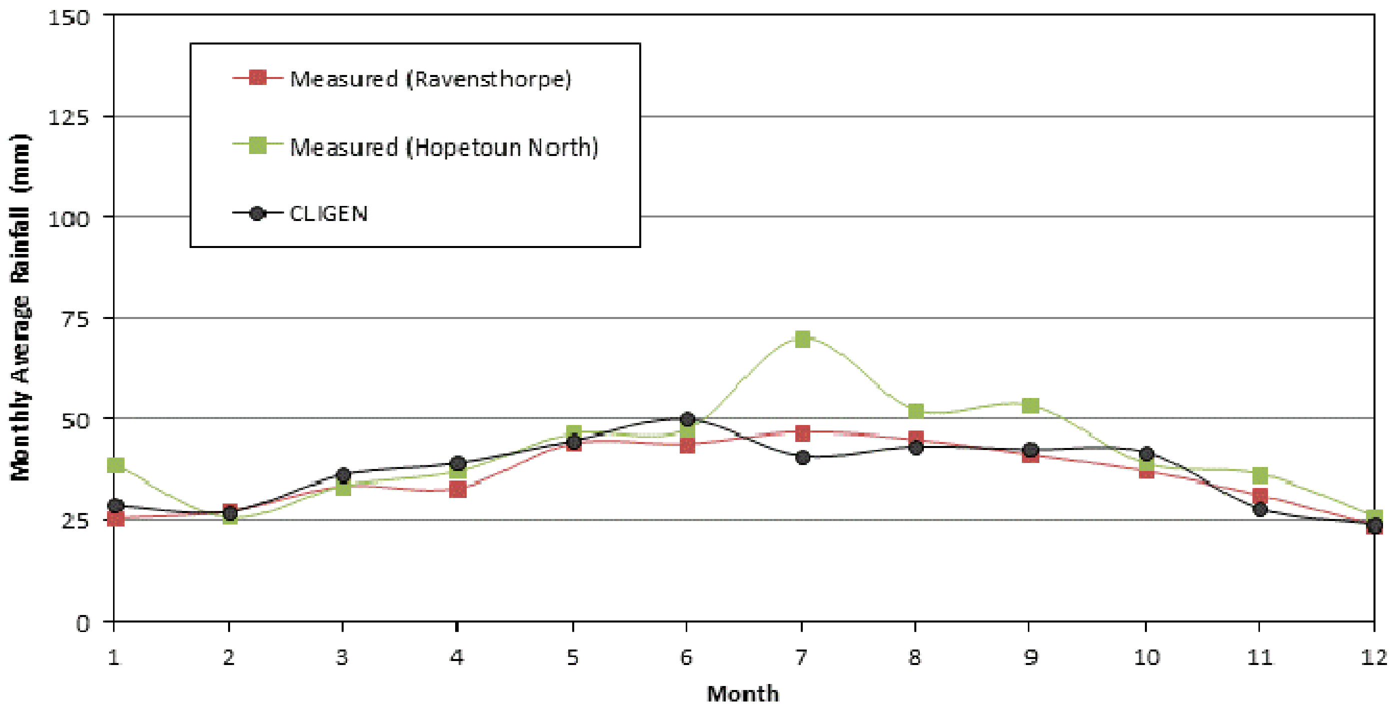
Figure 3.1b depicts the average monthly rainfall depth within the CLIGEN file, and shows that it generally falls within the range of monthly averages derived from Hopetoun North and Ravensthorpe. Where the CLIGEN monthly average fell outside of the range of local data, it fell below the upper limit of the measured average. This results in a slightly lower total annual rainfall depth of 431.2 mm/year in the CLIGEN file, as compared to the measured average annual rainfall depth of 458.4 mm/yr from both of the BOM climate stations. When considering only the Ravensthorpe data, the annual long term average rainfall is much closer, at 433.3 mm/yr.

Figure 3.2 illustrates the annual total rainfall for both the CLIGEN file and measured data sets. It demonstrates that the annual total rainfall depths of the CLIGEN file is slightly higher than the average of the measured data, and that year-to-year variability is similar.

a)



b)



ACH MINERALS	Figure 3.1: a) 24-hour and b) mean monthly rainfall data	soilwater GROUP
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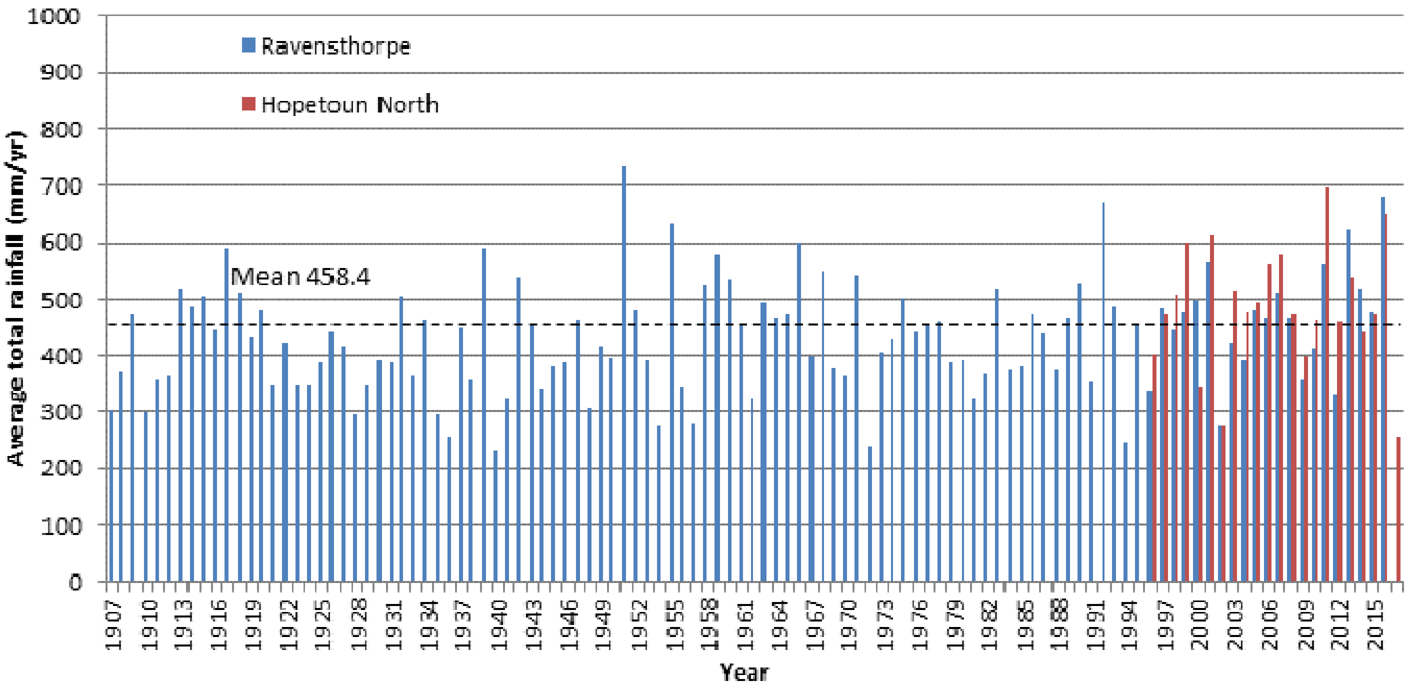

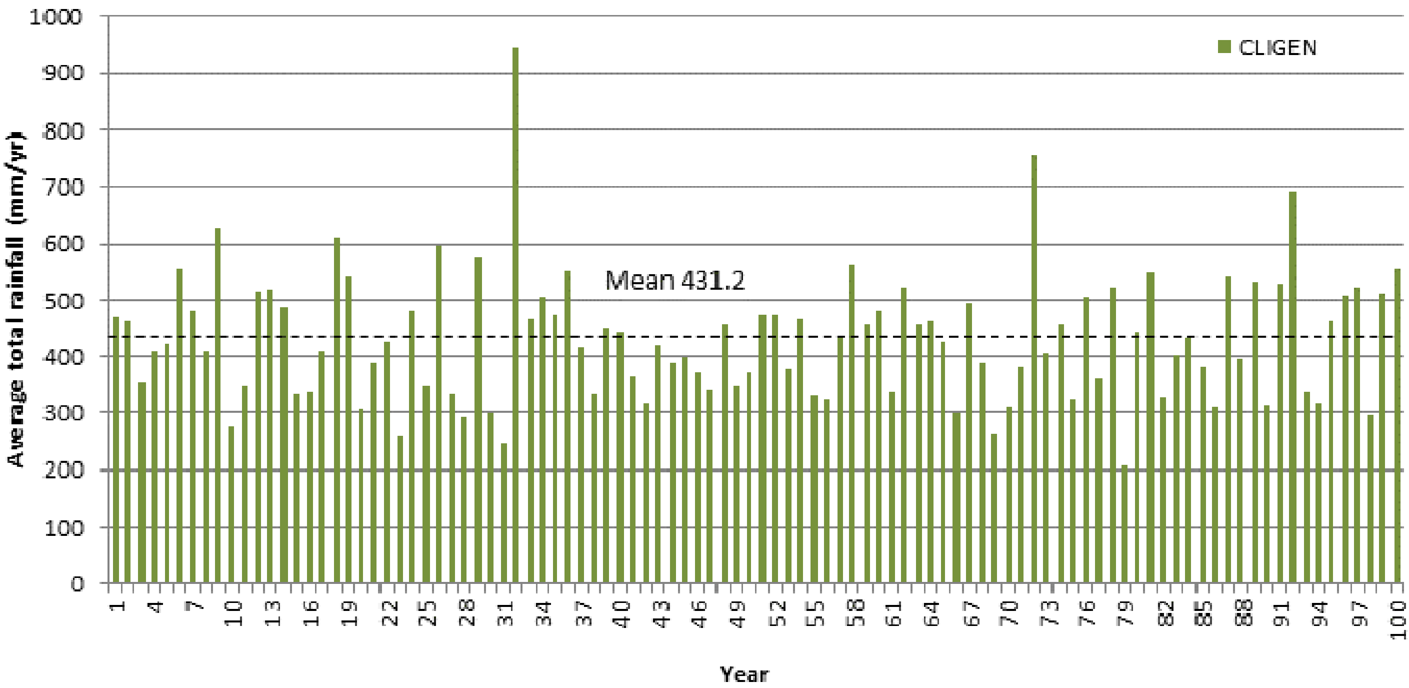

ACH MINERALS	Figure 3.2: Annual rainfall data	soilwater GROUP
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3.4 PMP CALCULATION

The PMP is defined as the theoretical maximum precipitation for a given duration under modern meteorological conditions and was calculated using the generalised short duration method (BOM, 2003), which is suitable for the small sized catchments of the landforms being modelled.

The RGP is located within the intermediate zone for calculation purposes and so was given a maximum duration of 5 hours by linear interpolation. It was estimated that 70% of the catchments which would exist once the landforms were built could be considered rough, with the remaining 30% considered smooth. The moisture adjustment factor for the RGP area is 0.65.

The PMP rainfall depth was then calculated using the following equation.

$$\text{PMP depth} = (S \times D_S + R \times D_R) \times \text{EAF} \times \text{MAF}$$

Where;

- S= smooth terrain percentage (0.3),
- R = rough terrain percentage (0.7),
- D_S and D_R are initial rainfall depths read from the generated depth-duration-area curves (900 and 940 respectively),
- EAF is the elevation adjustment factor for the RGP region (1 – no adjustment required), and
- MAF is the moisture adjustment factor for the RGP region (0.65)

This method estimates that the PMP for a 1 square kilometre area at the RGP is approximately 600 mm. This rainfall amount was randomly added to a single day within the 100 yr CLIGEN data file (year 32).

3.5 CALIBRATED SIBERIA PARAMETERS

Four separate SIBERIA parameters sets were calibrated using the combination of RUSLE and WEPP described above. These four modelling scenarios corresponded to two different surface material types and two different vegetation responses. In summary:

- Soil material with no additional stabilisation with 30% cover establishment.
- Soil material with no additional stabilisation with 70% cover establishment
- Soil material and stable fresh waste rock (50:50 mix) with 30% cover establishment.
- Soil material and stable fresh waste rock (50:50 mix) with 30% cover establishment.

The first scenario is conservative and simulates the effective under performance of vegetation establishment over the modelled time span. A cover establishment of 70%, which includes leaf litter and canopy cover is considered to represent a well-established vegetation community within the region.

The addition of fresh rock to the soil material cover has been modelled through modification of the soil parameter inputs in RUSLE and WEPP. Although the model calibration method, based on baseline soil particle size data, is suitable for the interrogation of conceptual design suitability, it is recommended that direct measurements are made of the different soil materials erodibility and surface runoff / permeability characteristics. This will allow increased confidence in the input parameters and the final modelled erosion results.

In all four scenarios, the landform initially underwent a 5 year model run with no cover to simulate the time required for root establishment and appreciable leaf litter etc. to develop. Following this, the output DEM was used to run a further 495 years of simulated erosion using the input parameters shown in Table 3.1.

Table 3.1: SIBERIA modelling input parameters

	Topsoil – no cover	Topsoil – 30% cover	Topsoil - 70% cover	Topsoil & rock – no cover	Topsoil & rock – 30% cover	Topsoil & rock – 70% cover
B_1	0.0150	0.0015	0.0005	0.0040	0.0008	0.0001
m_1	1.50	1.40	1.40	1.40	1.20	1.20
n_1	2.00	1.50	1.50	1.50	1.25	1.25

4 MODELLING RESULTS

Modelling of the landforms under each of the different scenarios above was carried out using SIBERIA, with the following outputs derived from the modelling:

- 250 and 500 year outputs,
- Average erosion rates for each output year, and
- Comparison of the landform elevation at each output time to the original DEM

Whilst modelling to longer timescales could be carried out, the nature of the inputs precludes this. As the inputs are based on adjustments calibrated to other erosion and landform evolution framework equations, the generalisations which are assumed in the parameter derivation become less acceptable as timescales grow. With this in mind a limit of 500 years has been set. The images derived from the comparison of each output year against the original DEM for each of the three landforms and various scenarios modelled has been included at the end of this report as Appendix A. All images have been given a vertical exaggeration of x 2 in order to highlight changes in elevation to viewers.

4.1 NORTH WRL DISCUSSION

The results from the modelling of the North WRL are summarised in Table 4.1, erosion mass has been calculated assuming a bulk density of 1.8 g/cm^3. As discussed each of the models were first subjected to a 5 year period of erosion with modelled 0% cover to simulate the initial period post final earthworks and prior to substantial vegetation establishment. As the cover input also takes into account gravel content this is considered to be a conservative start to the modelling as the baseline soil data across the site indicates that gravel contents average 14%.

The results show that the erosion rates where utilising only the topsoil material on the surface of the WRL are high, with large maximum erosion depths which are likely to exceed the maximum returned depth of the cover material. The modelled surface erosion rates where a cover material consisting of a 50:50 mix of topsoil and a fresh waste rock material are significantly lower, with the average gully depths modelled where vegetation establishment is high (i.e. cover of 70%) not significantly changing from the 250 year output to the 500 year output. This indicates that the surface is largely stable, with the gullies in particular not changing appreciably from the depths established during the initial 5 years of erosion.

Table 4.1: Summary of modelling results for the North WRL design

Material mix	Cover %	Model length (yr)	Max erosion depth (m)	Ave. gully depth (m)	Ave. erosion depth (mm/yr)	Ave. erosion (t/ha/yr)
Topsoil	30	250	3.7	1.1	2.8	50
		500	5.2	1.3	3.0	55
	70	250	3.1	0.8	2.0	36
		500	4.2	0.9	2.1	37
Topsoil and fresh rock (50:50 mix)	30	250	2.4	0.5	0.8	15
		500	3.3	0.5	1.1	20
	70	250	1.3	0.1	0.2	3.8
		500	1.7	0.1	0.2	3.5

The images of the elevation change shown in Appendix A illustrate the effectiveness of the added crest bund. It can be seen that the erosion depths on the upper most lift are considerably smaller than those calculated in the remainder of the lifts. This suggests that the design lacks an effective barrier or check to erosive forces between the different batter levels on the lower lifts.

4.2 SOUTH WRL DISCUSSION

The results from the modelling of the South WRL are summarised in Table 4.2.

The results from modelling the various scenarios are similar to those obtained for the North WRL, with erosion rates derived from the topsoil material models being significantly higher than the material stabilised by the addition of the fresh rock material. Interestingly, although the average gully depths and erosion rates are similar to the North WRL, which is to be expected given the similar overall batter angles and lengths, the maximum erosion depth is considerably higher. When looking closely at the change in elevation data sets it can be seen that the maximum erosion rates were consistently seen on the northern side of the WRL. This is thought to be a consequence of the overall geometry of the design, which has a concave shape in this region. This slope shape results in concentration of surface flow, where with increased length down slope each individual node has progressively larger upstream catchment flowing through it than similarly placed nodes on the other flanks of the WRL. The increase in upstream catchment results in a larger erosive force being applied to these specific nodes, accounting for the larger maximum erosion depth when compared to the North WRL design.

Table 4.2: Summary of modelling results for the South WRL design

Material mix	Cover %	Model length (yr)	Max erosion depth (m)	Ave. gully depth (m)	Ave. erosion depth (mm/yr)	Ave. erosion (t/ha/yr)
Topsoil	30	250	4.7	0.9	3.0	53
		500	5.4	1.1	3.1	56
	70	250	4.2	0.7	2.1	39
		500	4.9	0.8	2.4	42
Topsoil and fresh rock (50:50 mix)	30	250	3.8	0.4	0.7	13
		500	4.2	0.4	0.9	16
	70	250	2.5	0.1	0.2	3.4
		500	2.9	0.1	0.1	2.5

Increased erosion rates can be seen at top of each of the batter slopes where the berms meet the batter in both of the WRL designs (Appendix A). As this increased erosion occurs at the top of the slope it is almost certainly caused by localised depressions in the berm crest (introduced by design roughness). This has the effect of starting nodes at the beginning of the modelling cycle with a higher erosion rate than adjacent nodes, due to larger upstream catchments. This causes the node to lose progressively more sediment than adjacent nodes as the modelling continues.

4.3 TSF DISCUSSION

The results from the modelling of the South WRL are summarised in Table 4.3.

The modelling results show that in general the erosion rates derived from modelling the TSF design are similar to but slightly higher than those which were obtained from the two WRL designs. This is likely to be a result of both slightly higher lift heights in places, along with erosion occurring to a small extent on the gently sloping beach area. Although the top surfaces of the two WRL were given random roughness to provide a starting point for node calculation and upstream assessment the designs were initially flat and during the modelling these portions of the landforms represented a neutral area for overall erosion and sediment movement.

Table 4.3: Summary of modelling results for the TSF design

Material mix	Cover %	Model length (yr)	Max erosion depth (m)	Ave. gully depth (m)	Ave. erosion depth (mm/yr)	Ave. erosion (t/ha/yr)
Topsoil	30	250	1.7	0.9	3.1	57
		500	3.0	1.1	3.1	55
	70	250	0.9	0.7	2.5	45
		500	1.4	0.8	2.4	44
Topsoil and fresh rock (50:50 mix)	30	250	0.9	0.4	0.5	9.5
		500	1.2	0.4	0.4	8.0
	70	250	0.8	0.2	0.2	4.1
		500	0.9	0.2	0.3	5.8

The maximum erosion depth reported was considerably lower than both of the WRL designs, with a maximum depth of only 3.0 m recorded after 500 years of low cover using a topsoil cover material mix. In comparison the two WRL designs had maximum erosion depths of over 5 m after 500 years of these conditions. This is considered to be due to the much lower overall height of the design, which has a maximum height of 22 m whereas the two WRL designs have maximum heights of 58 m (North WRL) and 46 m (South WRL). As discussed the berms are considered to provide valuable additional stability, particularly in the critical early years of vegetation establishment by minimising the potential for excessive surface flow velocity to develop. However in the longer term these areas are modelled to be more susceptible to higher erosion rates prior to significant cover establishment.

5 CONCLUSIONS & RECOMMENDATIONS

The results of LEM carried out for the three closure designs proposed for the RGP show that the type of material mix used as a cover material will be critical to achieving long term stability post mining on each landform. The modelling carried out indicates that using the topsoil material available on site by itself will result in high erosion rates, with sediment loss likely to exceed the returned soil volumes on each of the closure landforms in the long term. The modelled movement of sediment is lower where considerable vegetation establishment is modelled to have occurred, but still considered to be excessive. Furthermore, the modelled instability of the topsoil on the batter slopes is likely to impede vegetation establishment, meaning that the likelihood of achieving higher cover percentages will be reduced.

The modelled erosion rates where cover material was assumed to consist of fresh waste rock and topsoil in a 50:50 mixture were significantly lower, with the stabilising effect of the rock modelled to cause erosion rates to drop by an order of magnitude where vegetation establishment was assumed to be successful. Therefore it is recommended that where possible, resistant fresh waste rock material is utilised in combination with stockpiled topsoil material on the outer surface of the WRLs and TSF, in particular on the batter slopes and berm crests to maximise the materials resistance to long term erosion and enhance landform stability.

All three designs showed generally uniform erosion across the design surface. The exception to this was the lower northern slopes of the South WRL, which showed elevated erosion rates in comparison to other areas of the South WRL. This was interpreted to be caused by the concave design of the WRL slopes in this area, which causes a convergence of surface water flows in this region. This caused maximum modelled erosion depths to approach 3 m in this area under most stable scenario, indicating that this area may see localised slope instability and excessive sediment loss even where vegetation establishment is successful. It is recommended that the design of the South WRL be modified where appropriate to minimise areas where significant concavity can result in surface water flow concentration and accumulation.

The other area of interest in the designs is the interface of batter and berm. As discussed (Section 4.2) this area of both the WRL designs appears to experience higher erosion rates than other areas. This indicates that over time as the berm areas become filled with sediment the initially separate lift areas may become hydraulically connected, which will then increase erosion rates as erosion is occurring over longer slope lengths. Although these features do tend to erode and ‘fail’ in time, their crucial design element is in ensuring slope stability in the early stages of vegetation establishment. The berms are considered to provide valuable additional stability, particularly in the critical early years of vegetation establishment by minimising the potential for excessive surface flow velocity to develop (i.e. minimise overall slope length).

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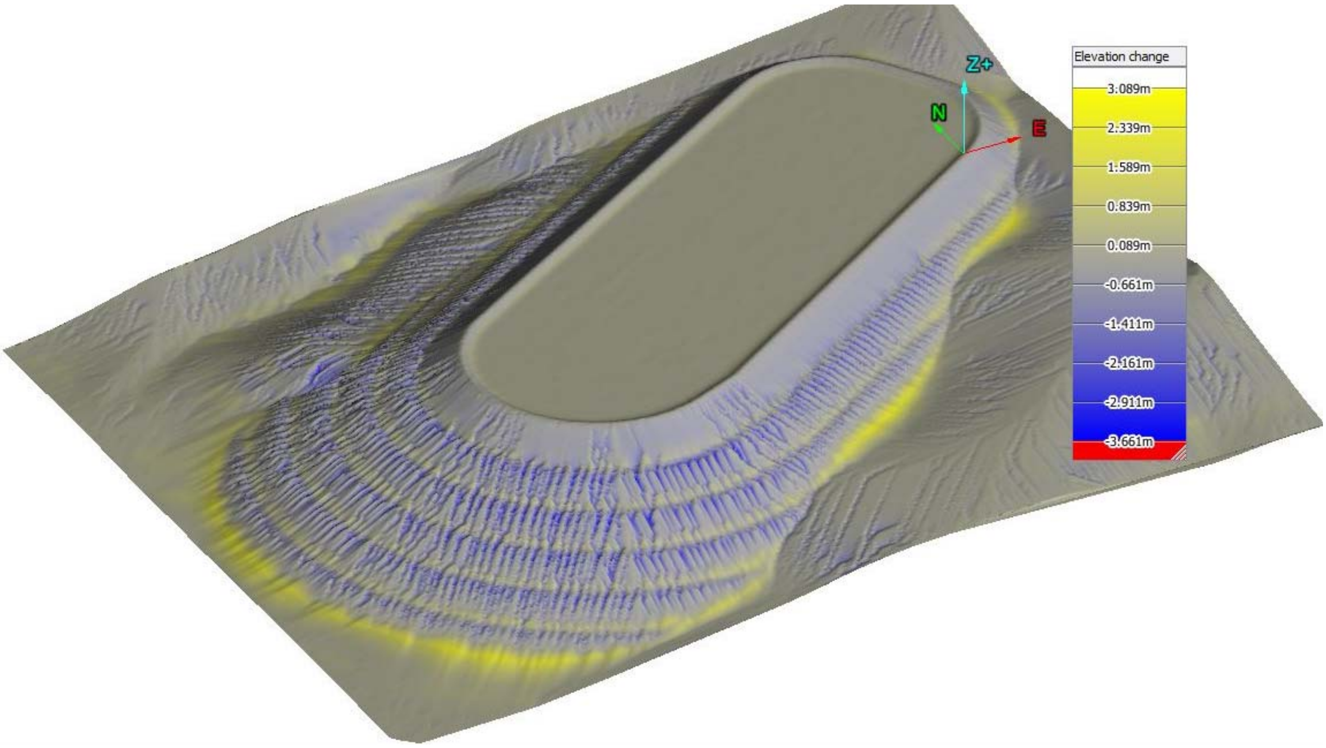
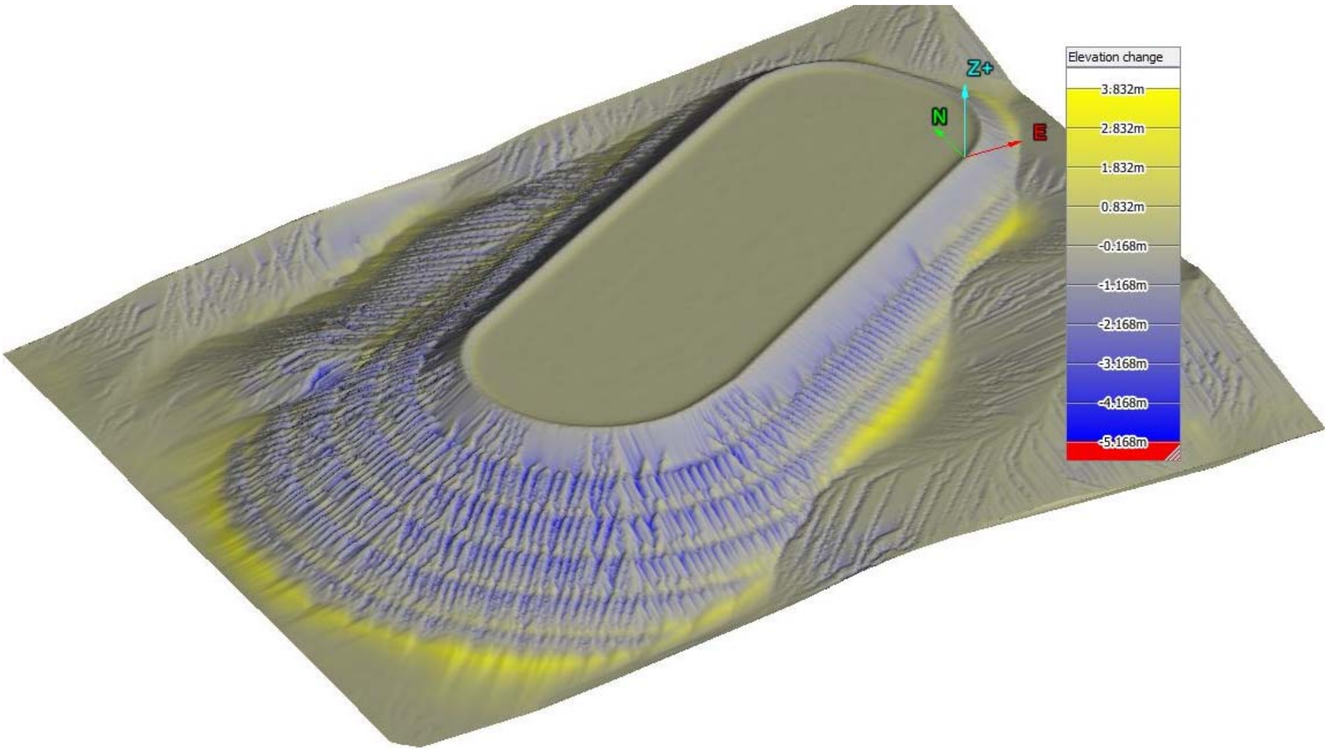
APPENDIX A
SIBERIA MODELLING RESULTS

North WRL modelled erosion with topsoil layer and 30% cover

250 year output

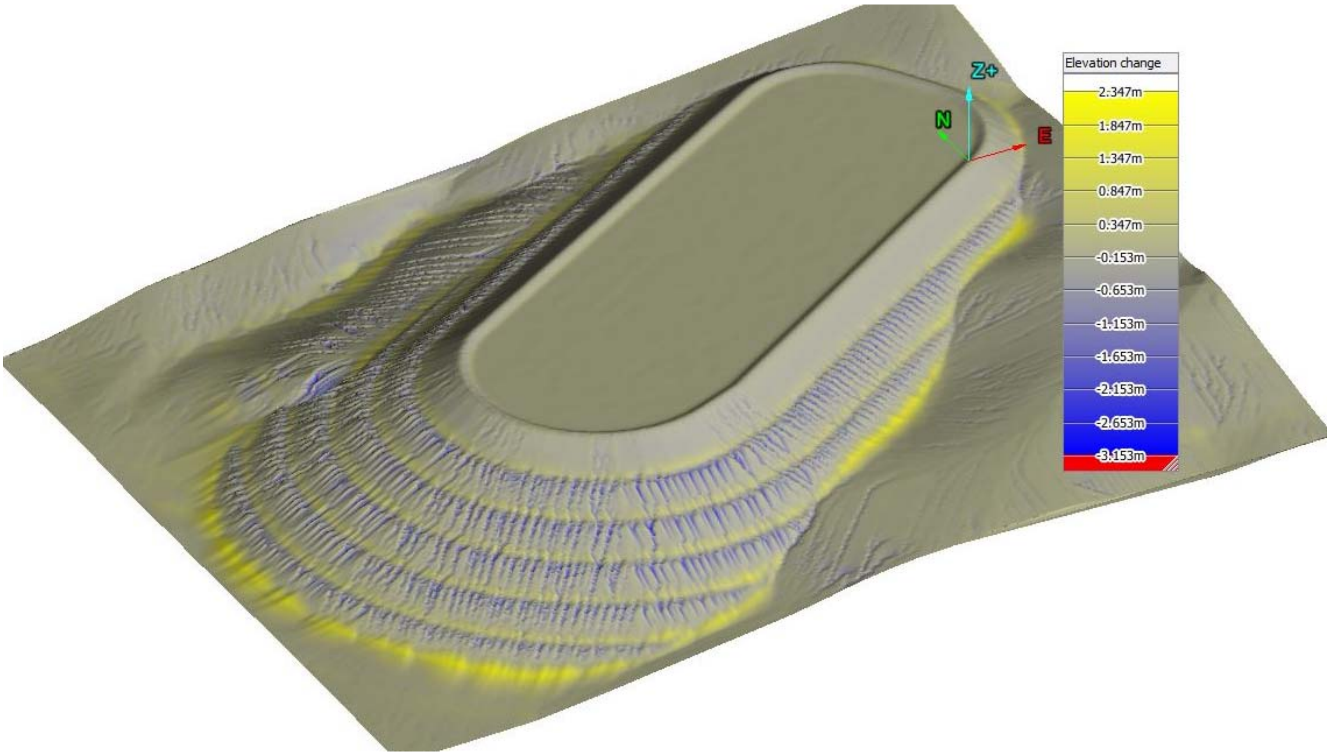


500 year output

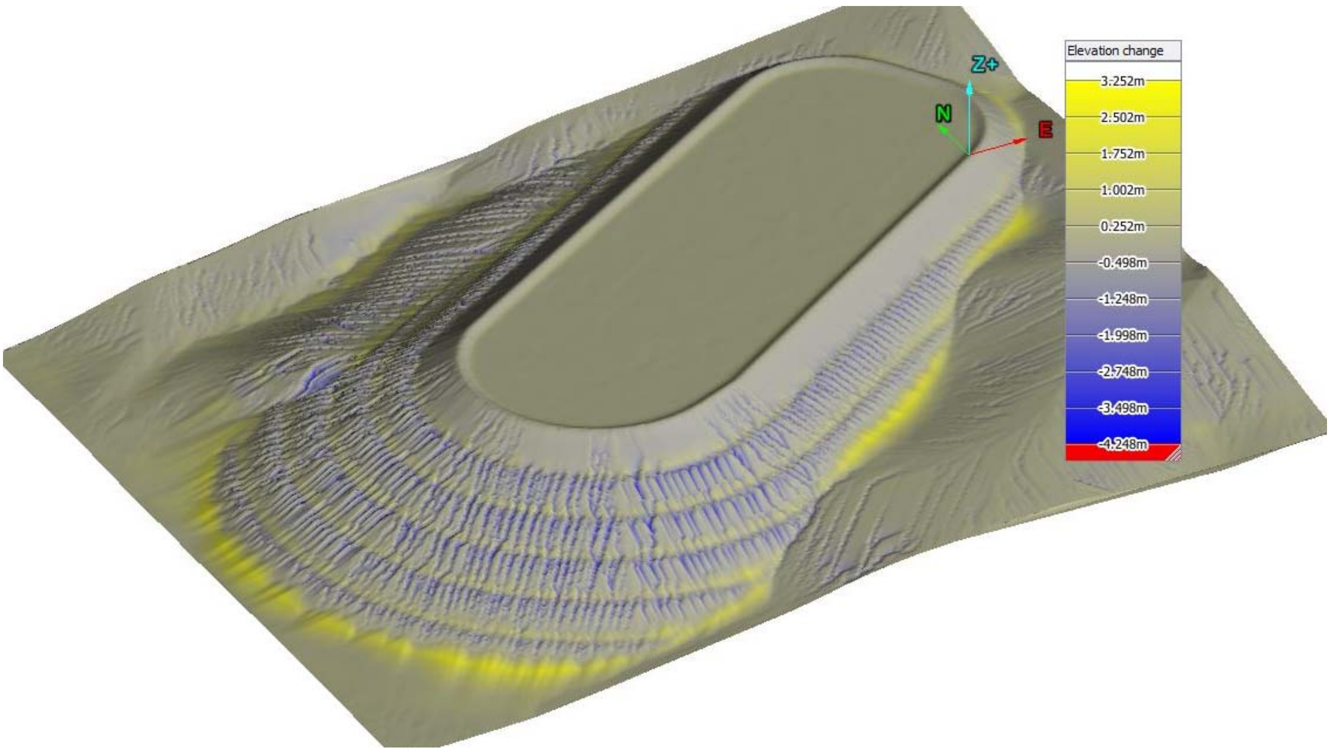


North WRL modelled erosion with topsoil layer and 70% cover

250 year output

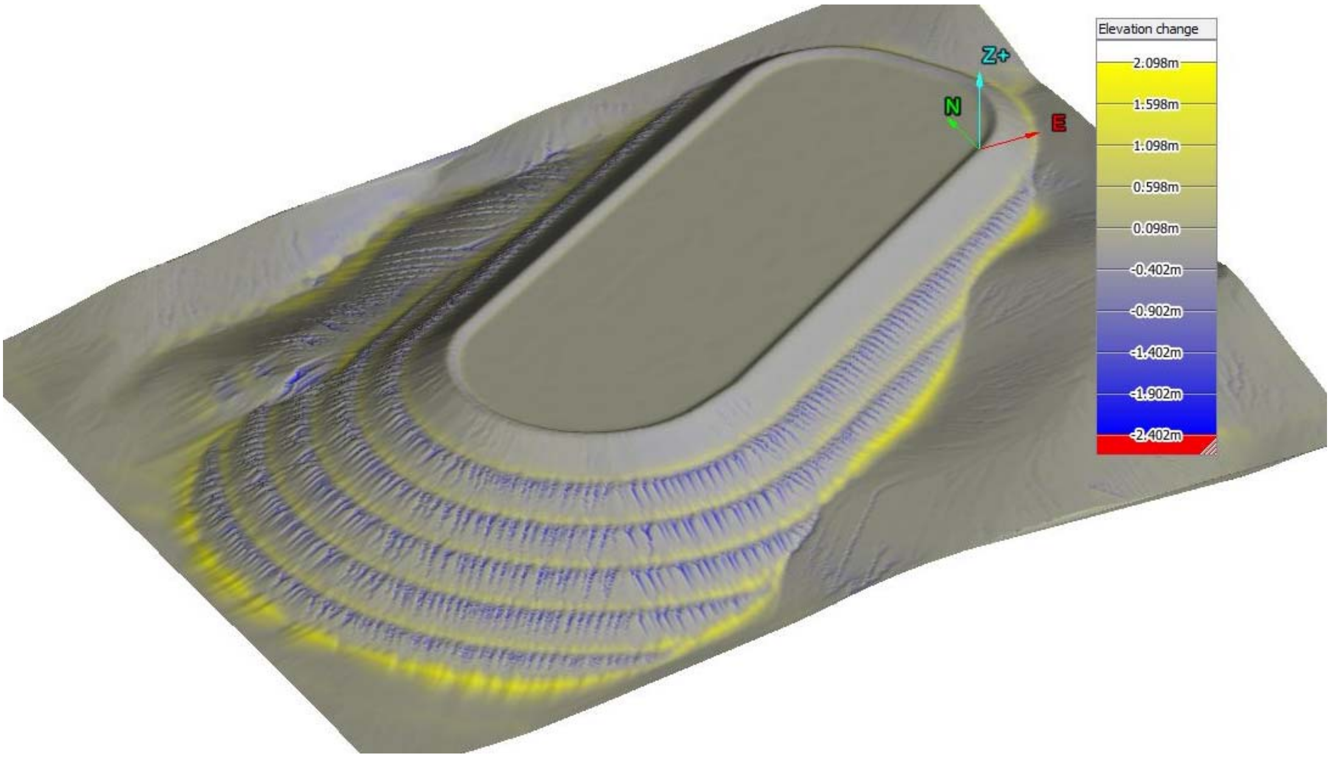


500 year output

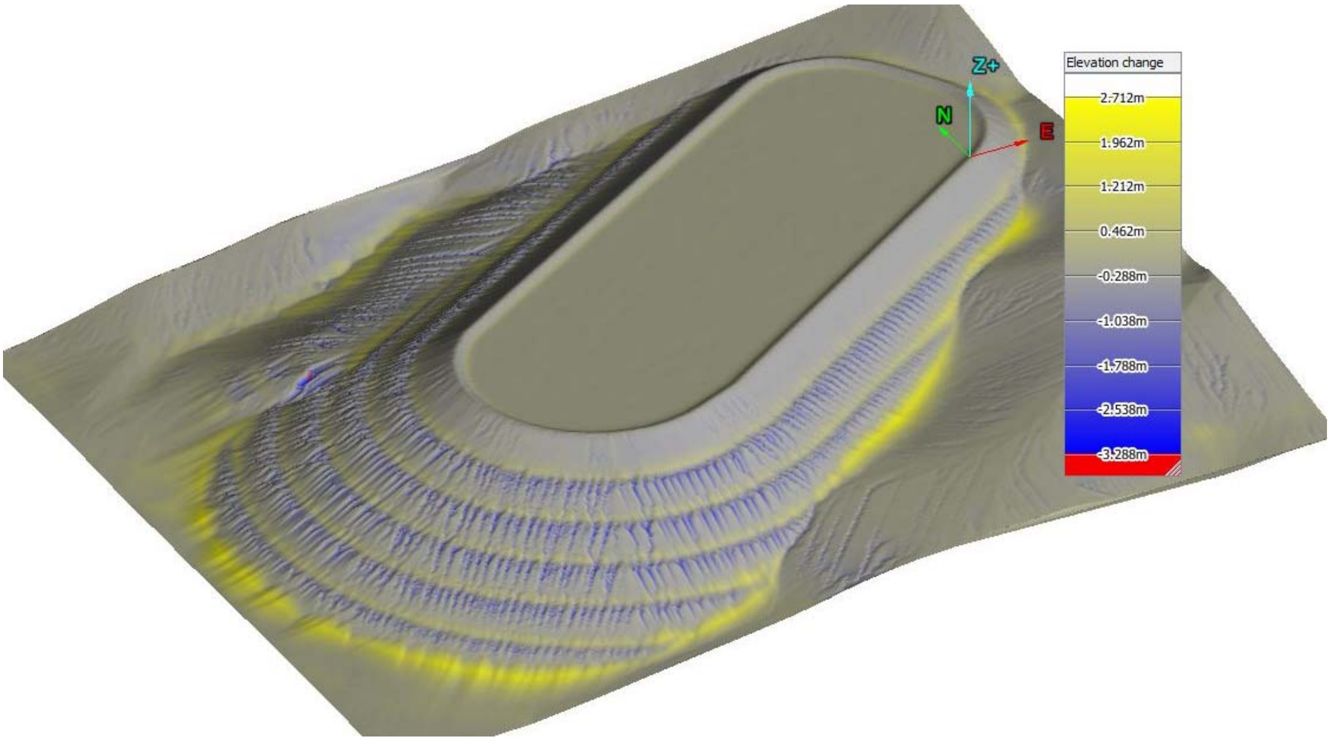


North WRL modelled erosion with topsoil and fresh rock layer (50:50 mix) and 30% cover

250 year output

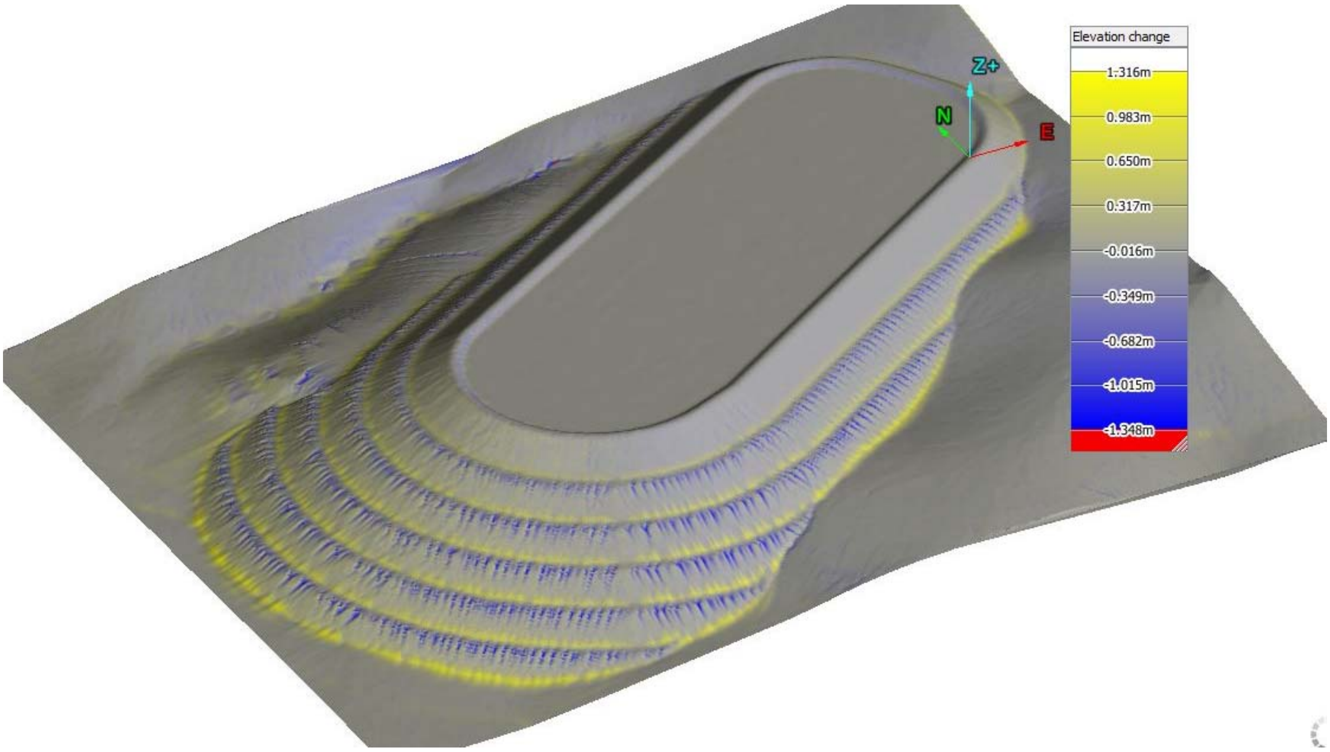


500 year output

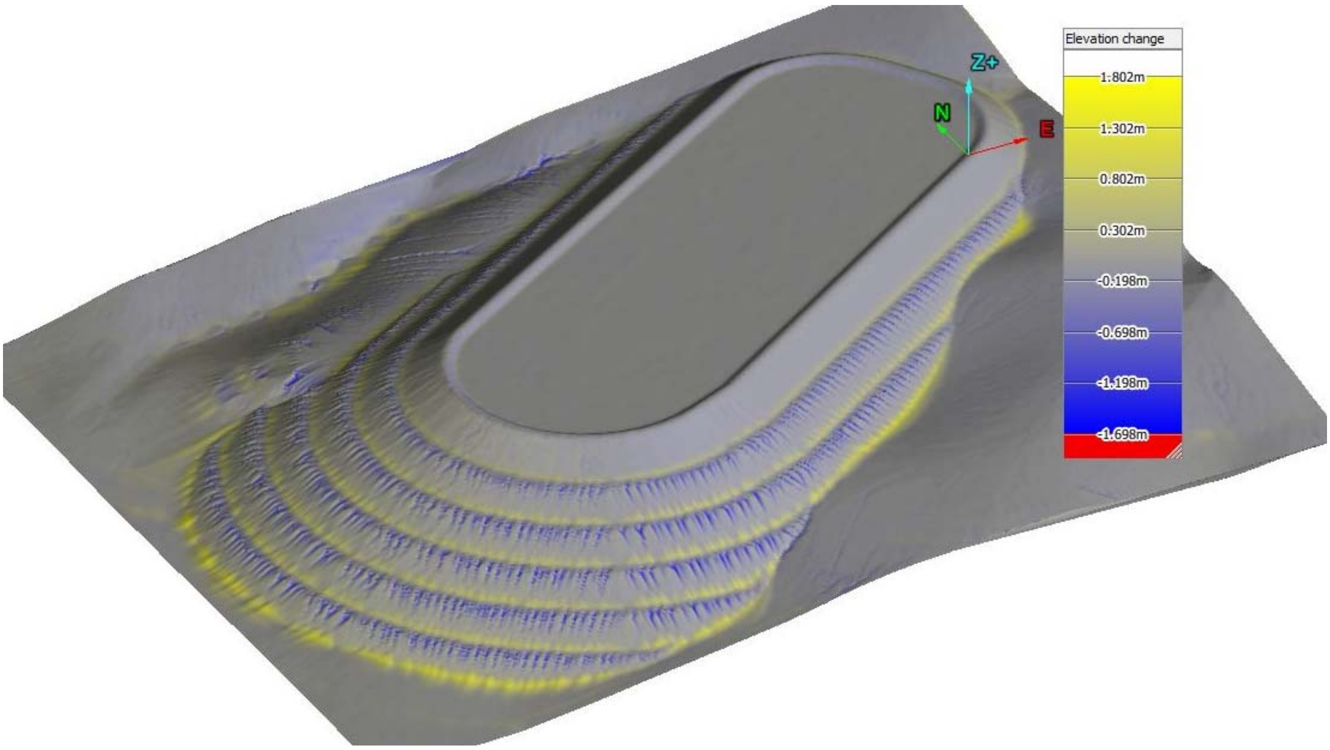


North WRL modelled erosion with topsoil and fresh rock layer (50:50 mix) and 70% cover

250 year output

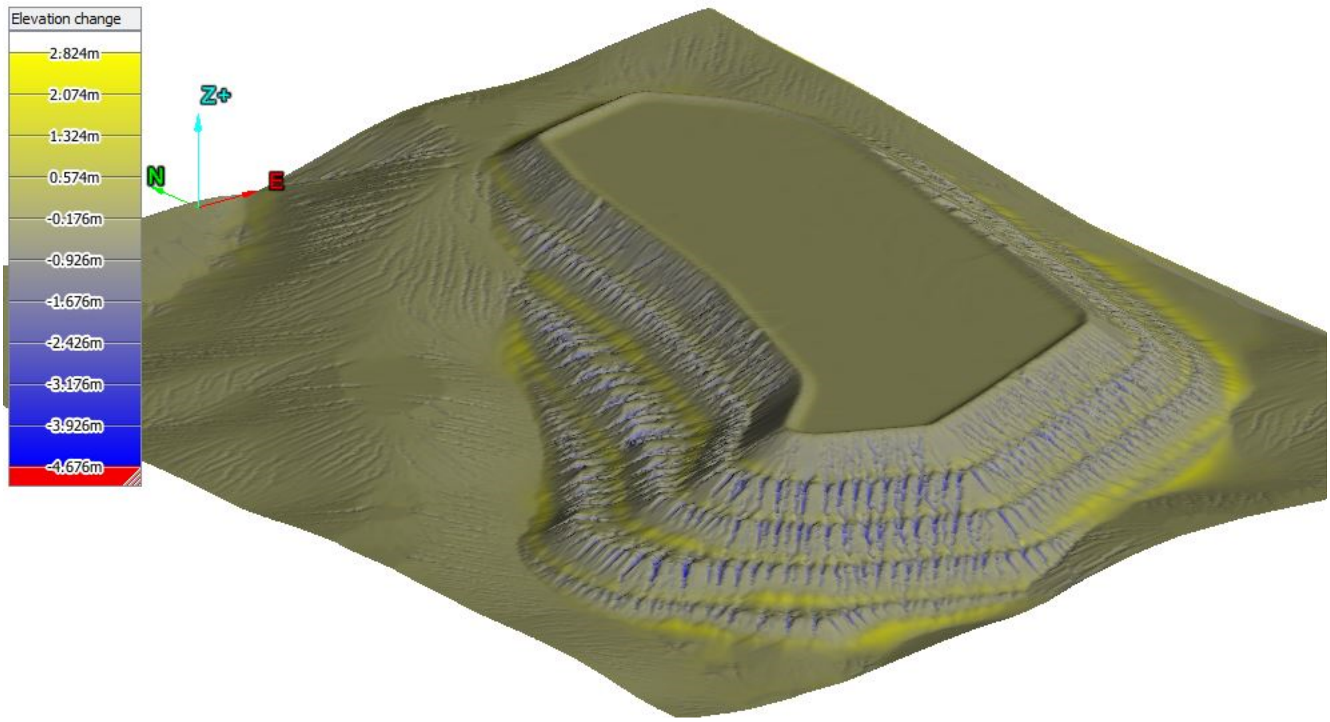


500 year output

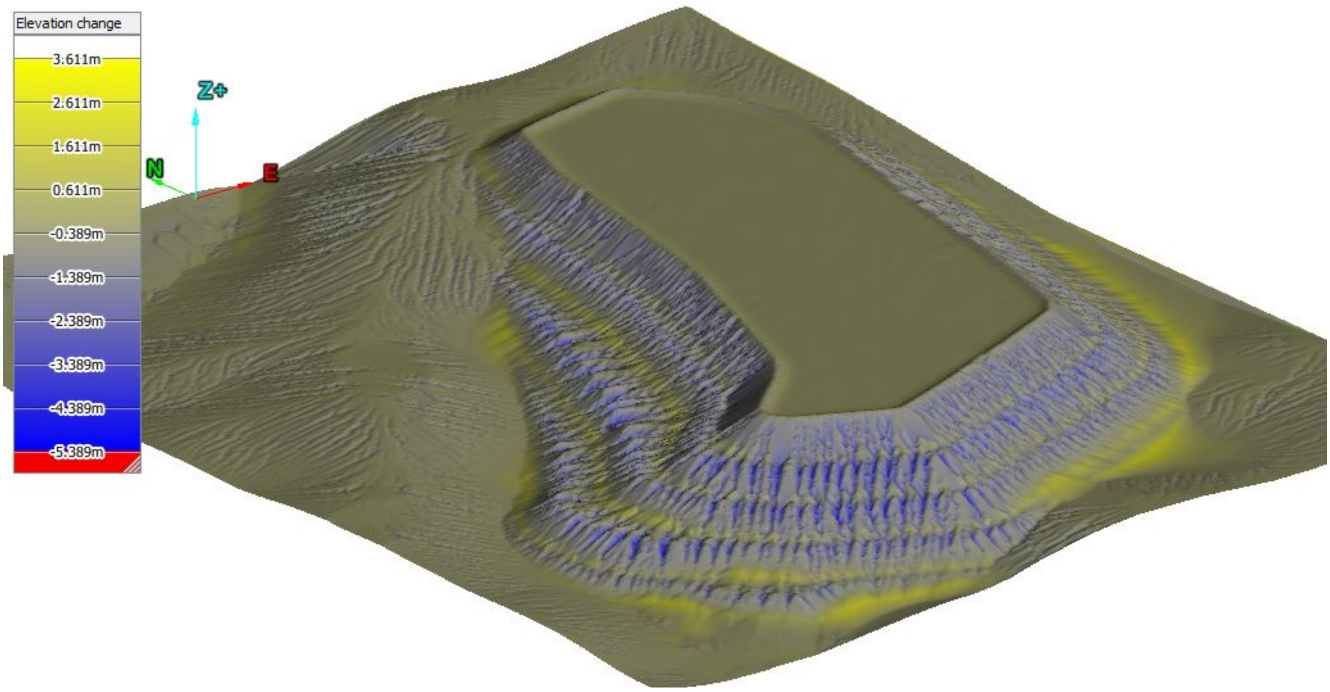


South WRL modelled erosion with topsoil layer and 30% cover

250 year output

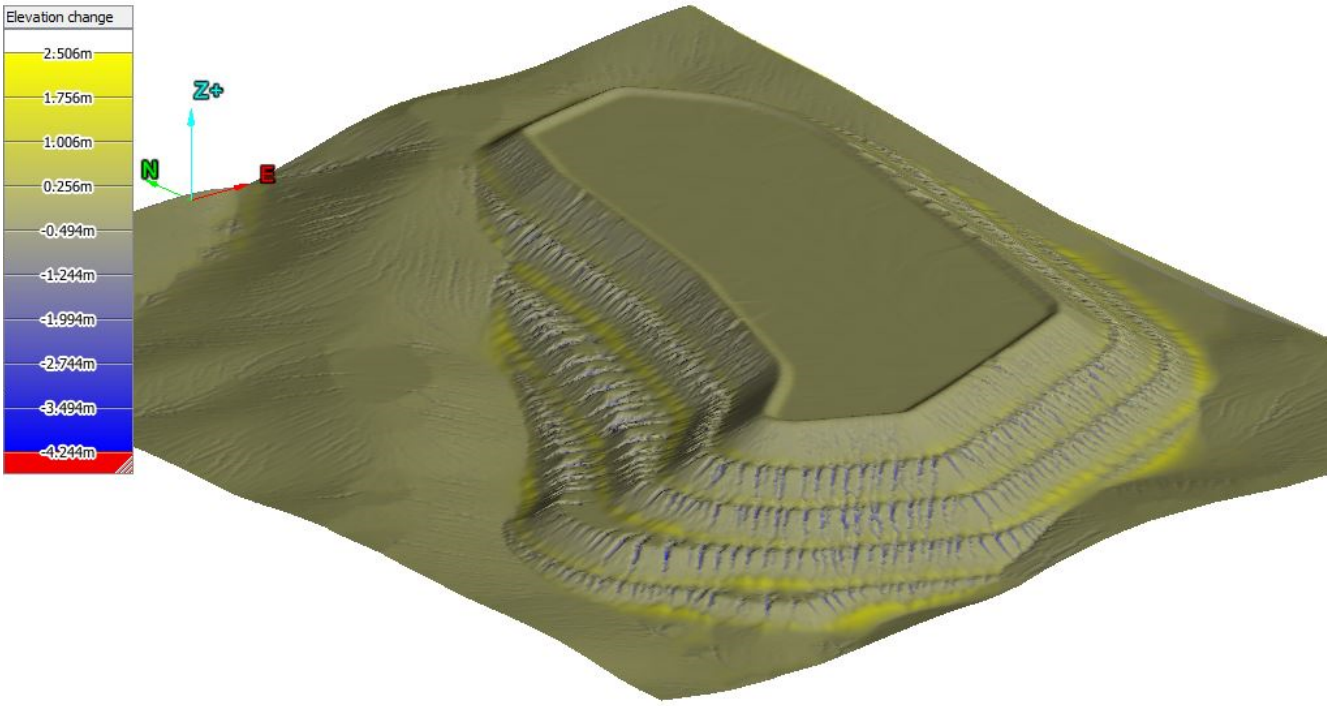


500 year output

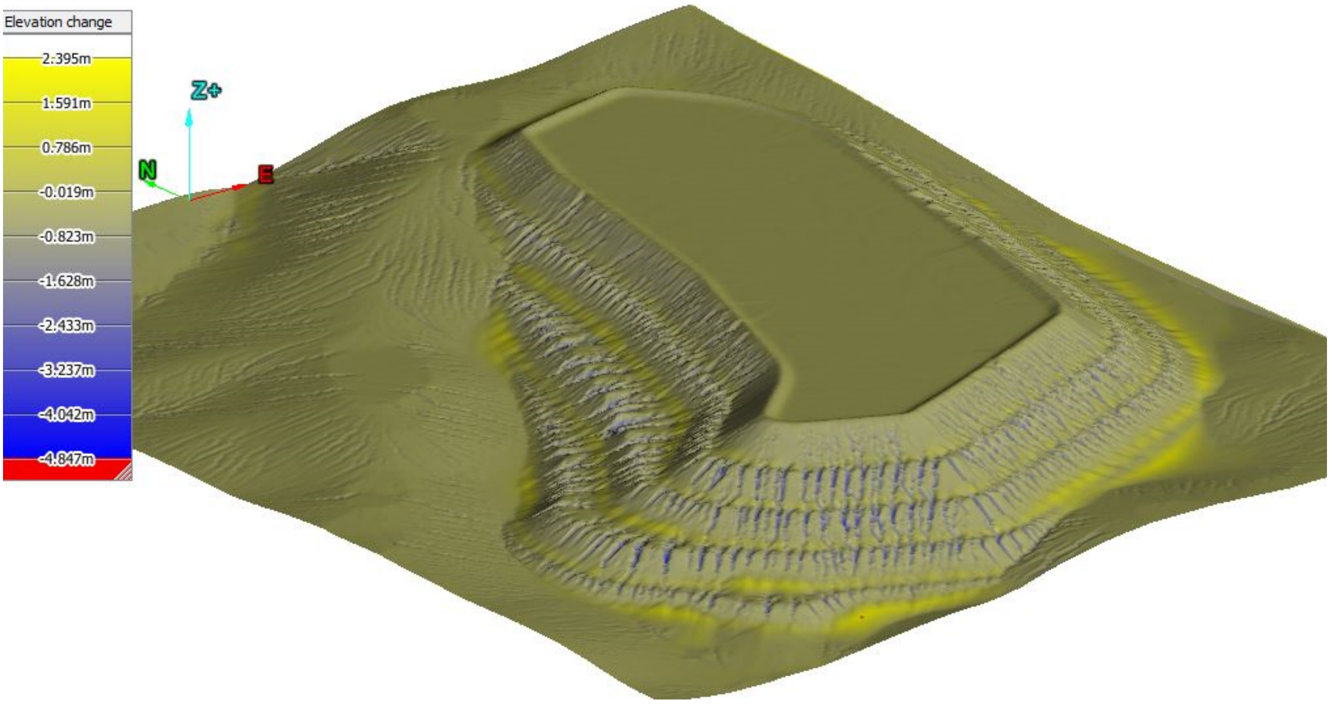


South WRL modelled erosion with topsoil layer and 70% cover

250 year output

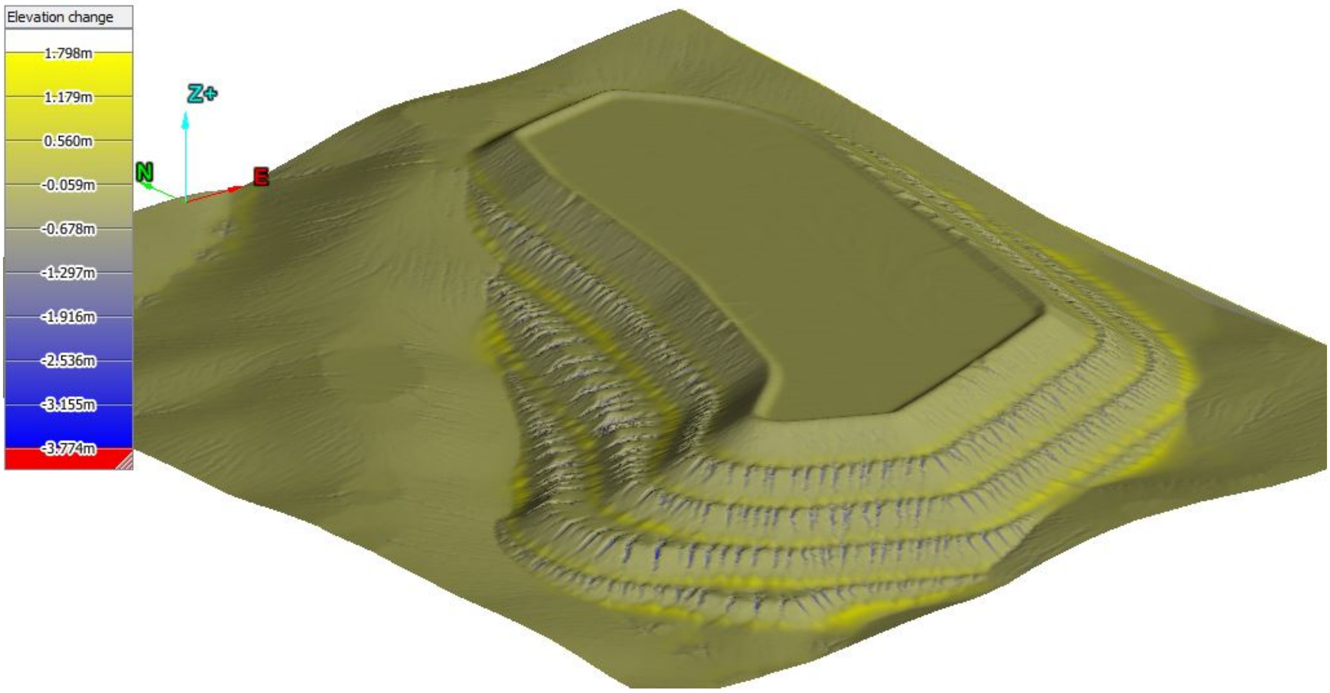


500 year output

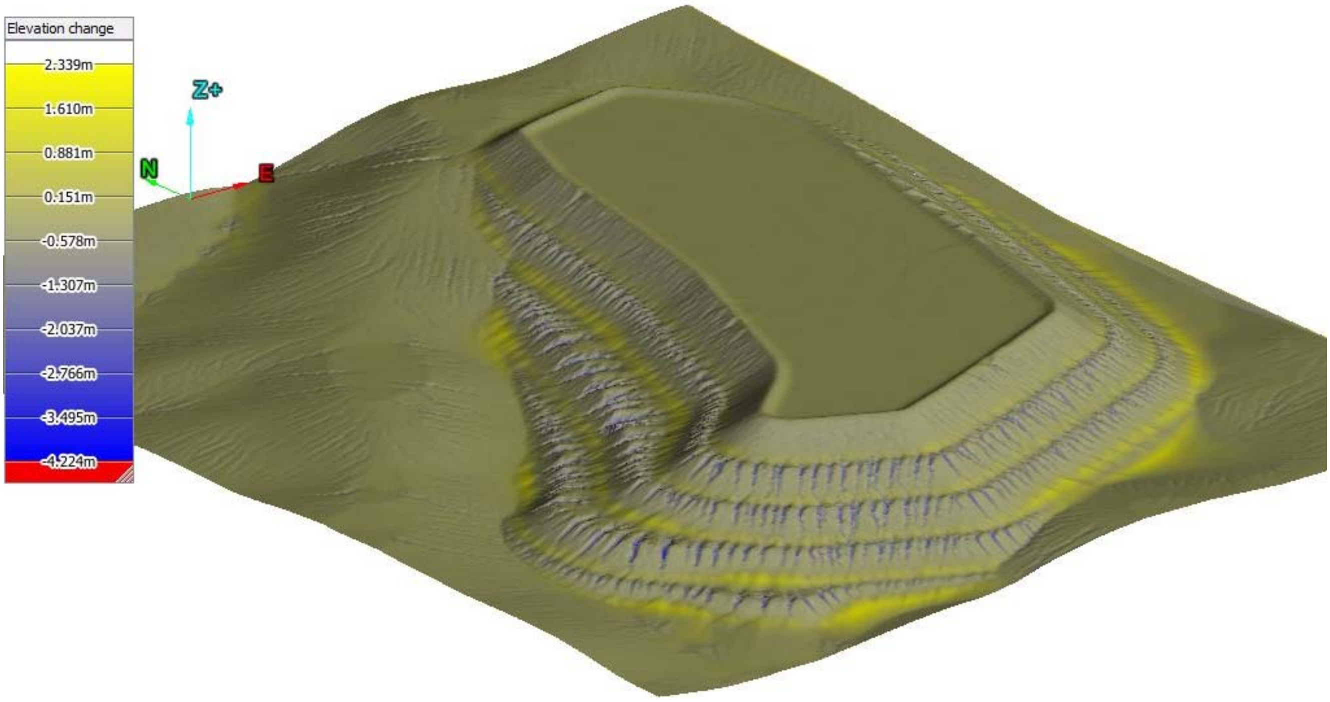


South WRL modelled erosion with topsoil and fresh rock layer (50:50 mix) and 70% cover

250 year output

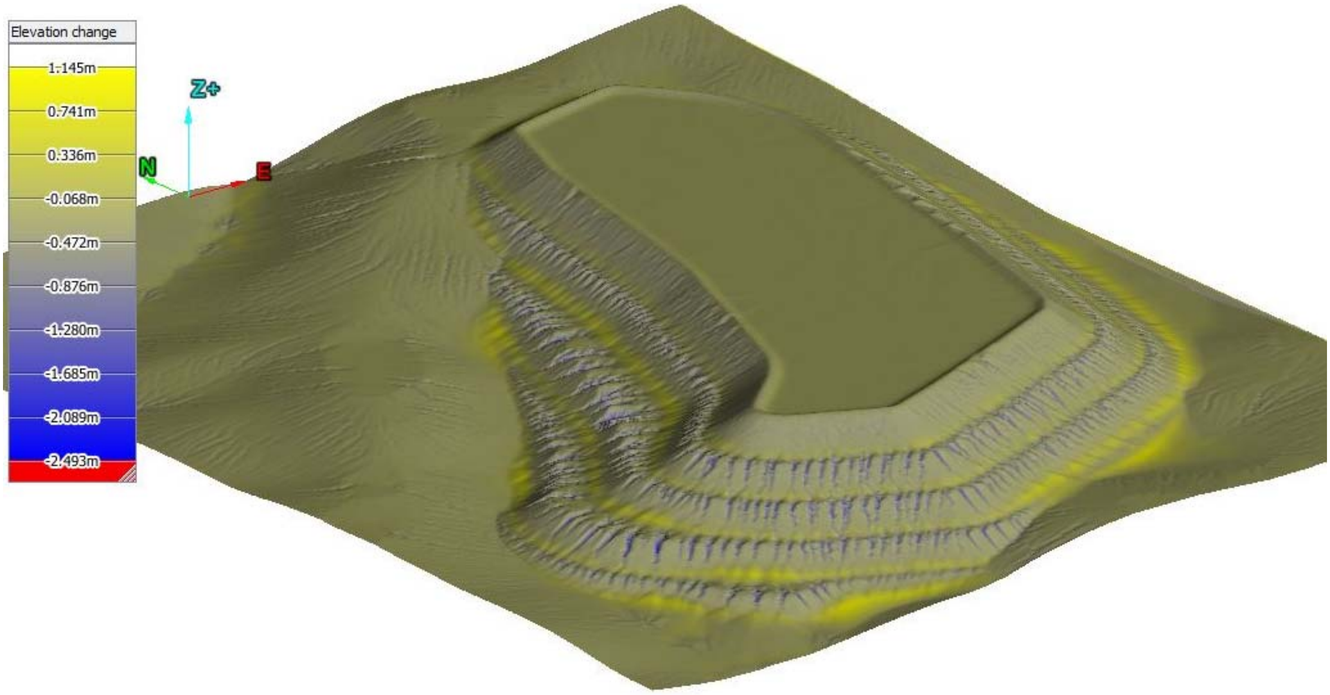


500 year output

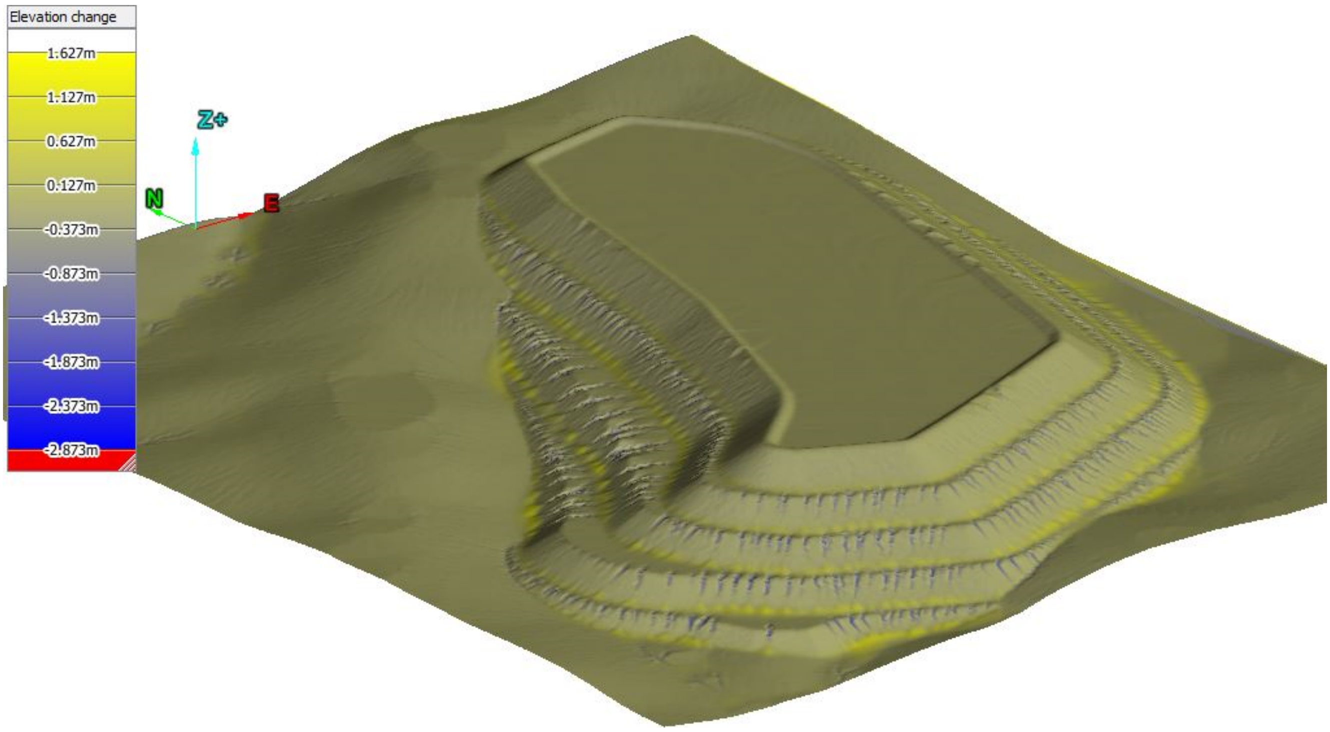


South WRL modelled erosion with topsoil and fresh rock layer (50:50 mix) and 70% cover

250 year output

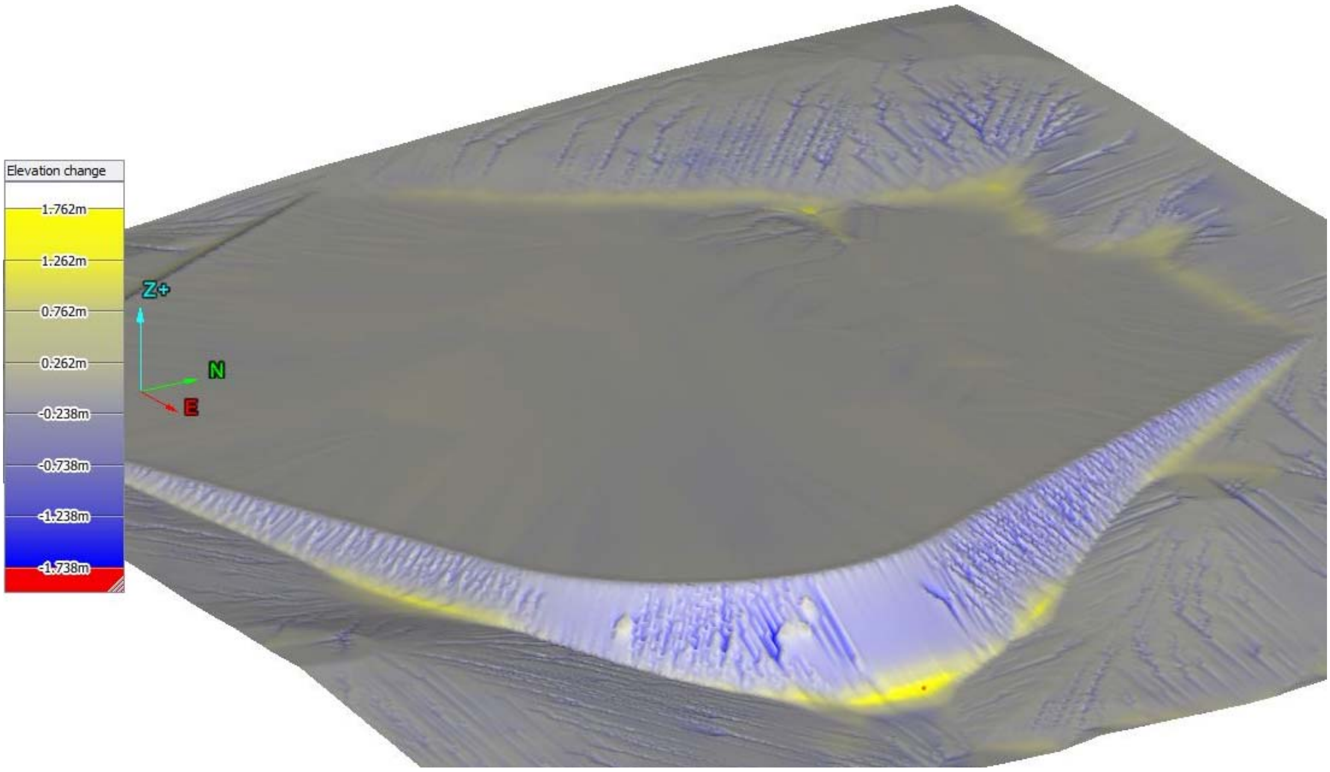


500 year output

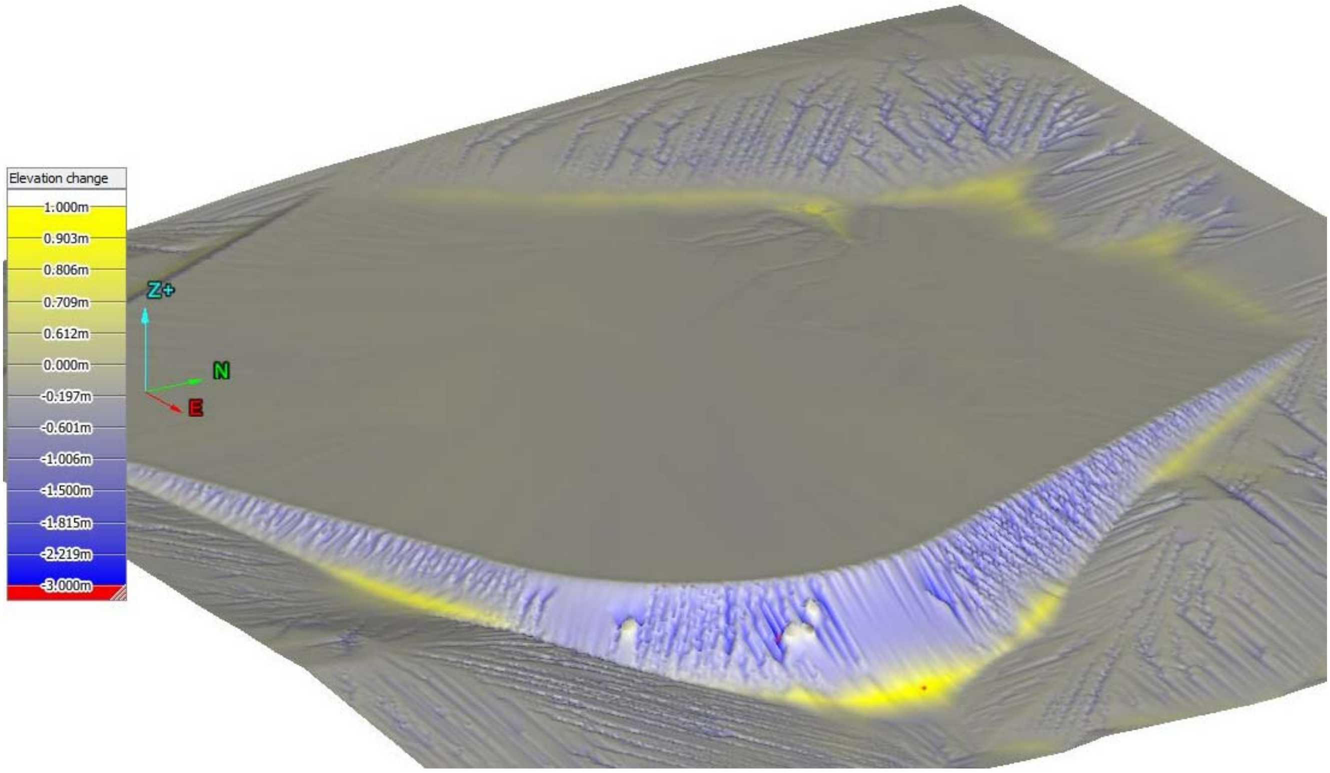


TSF modelled erosion with topsoil layer and 30% cover

250 year output

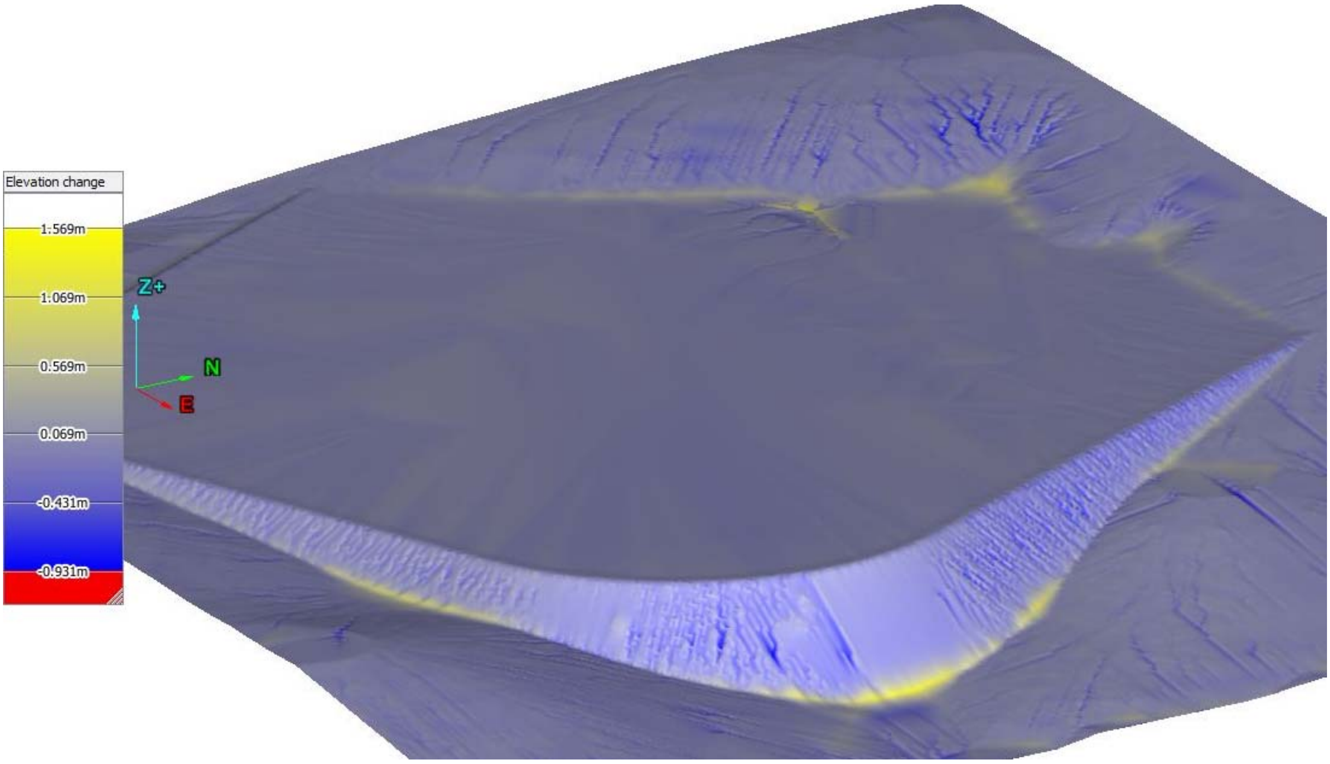


500 year output

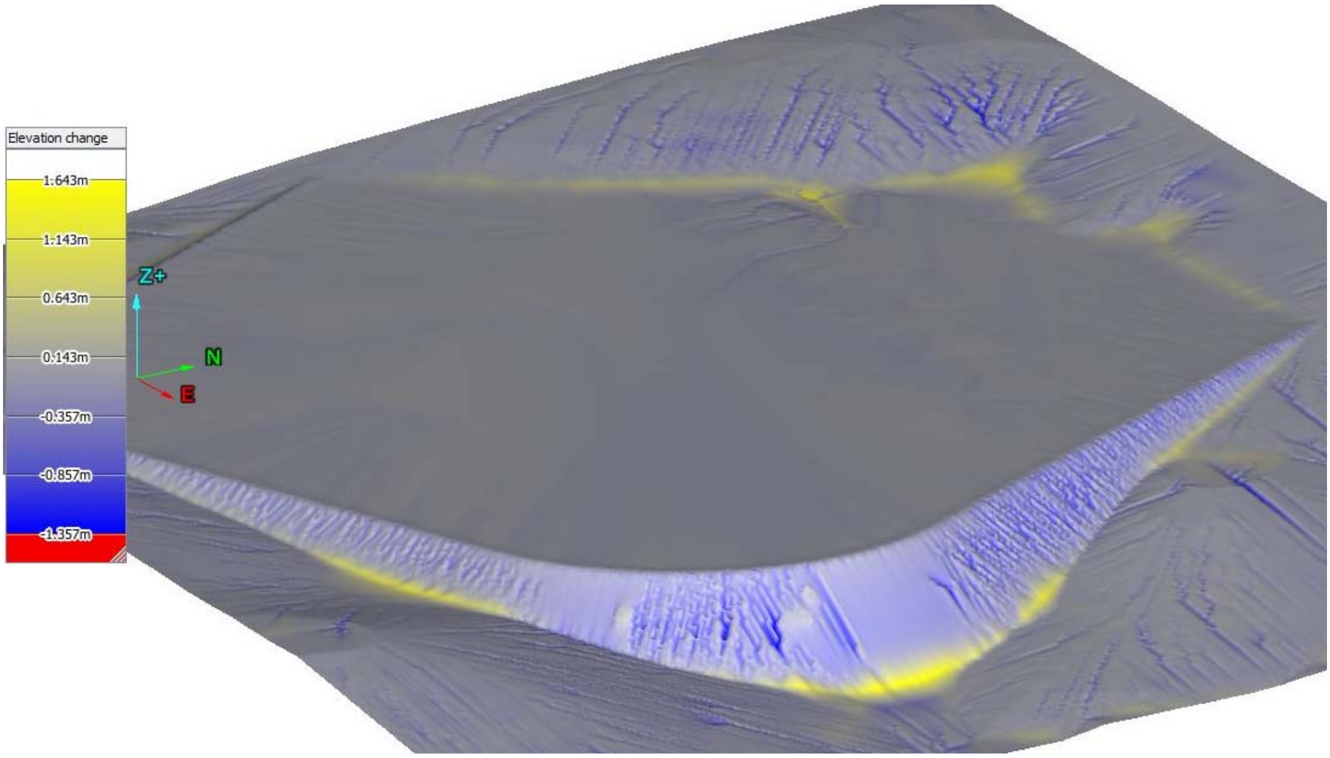


TSF modelled erosion with topsoil layer and 70% cover

250 year output

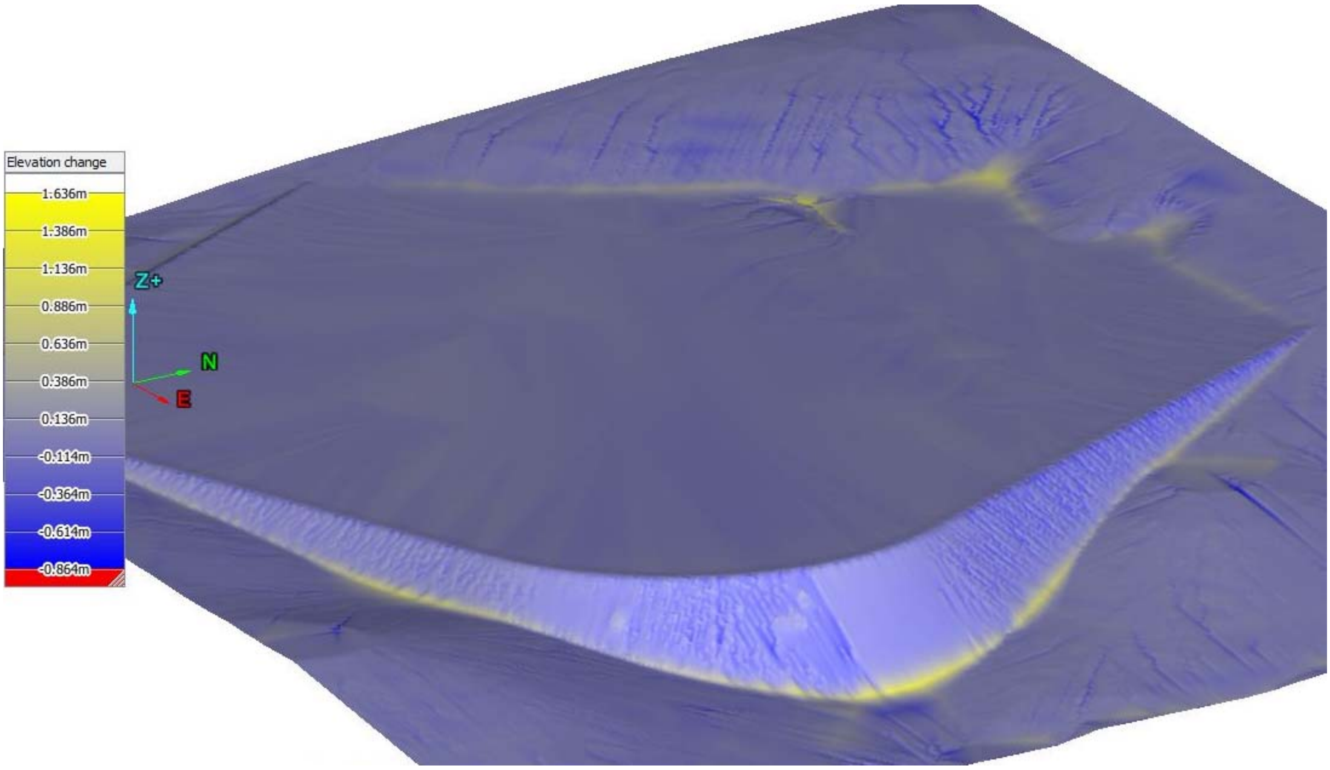


500 year output

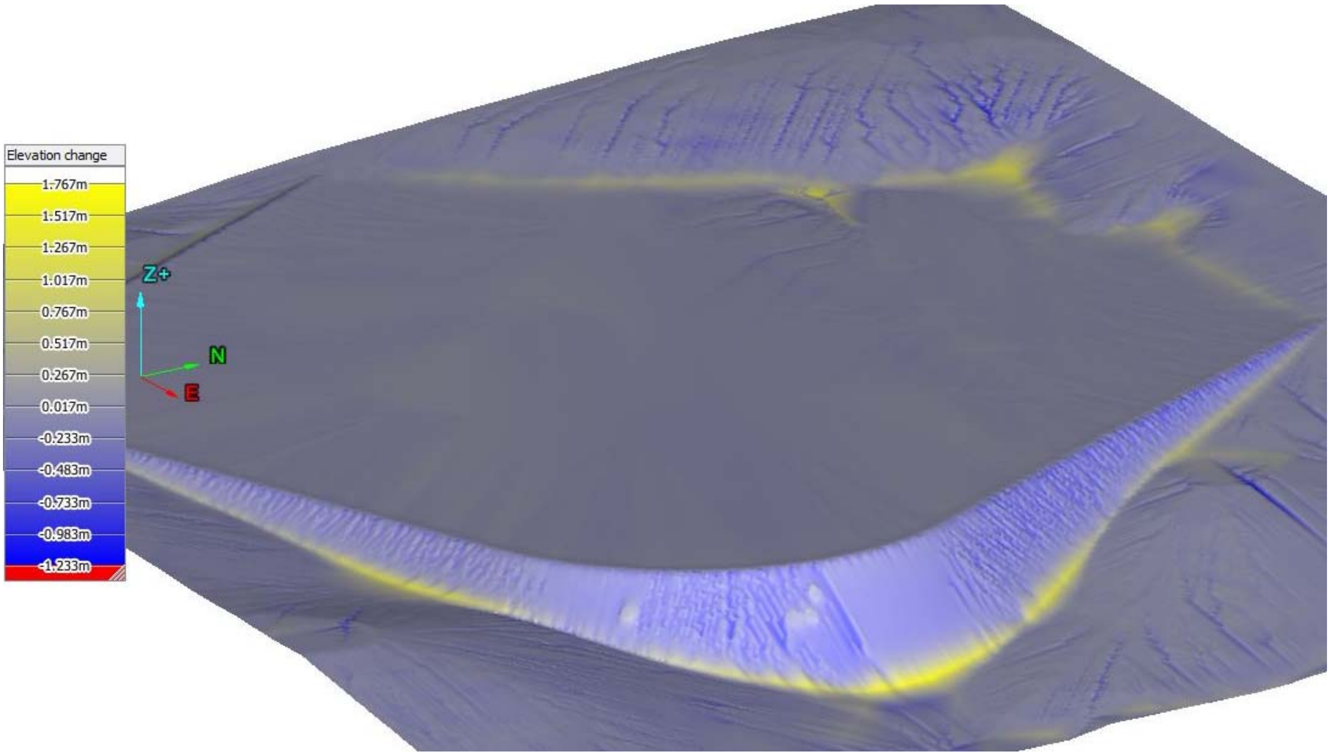


TSF modelled erosion with topsoil and fresh rock layer (50:50 mix) and 70% cover

250 year output

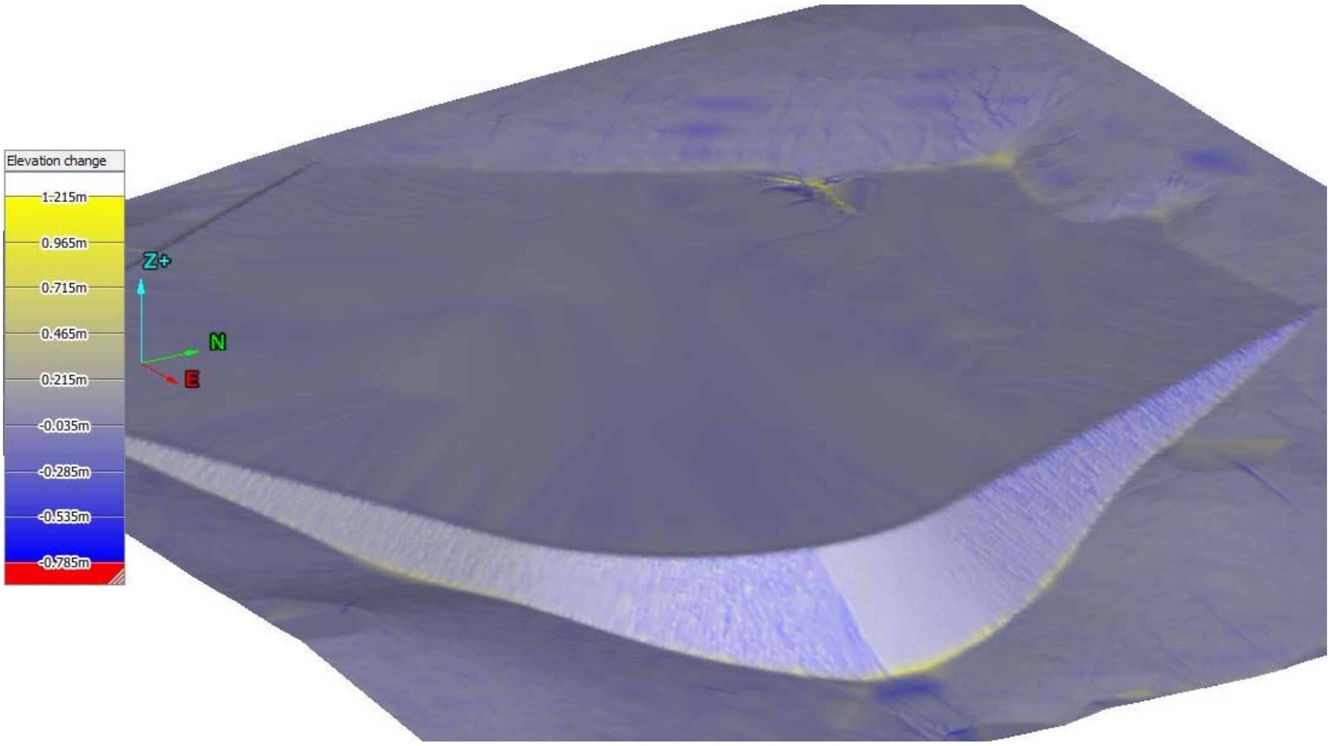


500 year output



TSF modelled erosion with topsoil and fresh rock layer (50:50 mix) and 70% cover

250 year output



500 year output