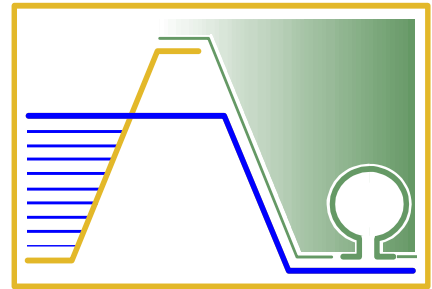


APPENDIX F: SURFACE WATER STUDY

Report on:



FLOOD ASSESSMENTS FOR THE GAWIB RIVER AT LANGER HEINRICH URANIUM MINE

metago
Environmental Engineers
(Australia) Pty Ltd

Prepared for

LANGER HEINRICH URANIUM LTD

**PROJECT NO. 336-001
REPORT NO. 1/08**

NOVEMBER 2008

- * *Tailings dam engineering and management*
- * *Municipal and industrial waste management*
- * *Risk based environmental control*
- * *Environmental Management Systems*
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- * *Environmental impact assessment*

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Report on:

FLOOD ASSESSMENTS FOR THE GAWIB RIVER AT LANGER HEINRICH URANIUM MINE

Prepared for

LANGER HEINRICH URANIUM LTD

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NOVEMBER 2008

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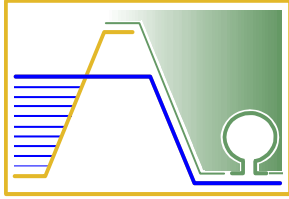
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Appendix 1: HEC RAS Modelling Report



metago

Environmental Engineers (Australia) Pty Ltd

A B N 18 078 578 864

Project No. 336-001

November 2008

Report No. 1/08

FLOOD ASSESSMENTS FOR THE GAWIB RIVER AT LANGER HEINRICH URANIUM MINE

1 INTRODUCTION

Langer Heinrich Uranium mine (LHU) is located approximately 85km WNW of Walvis Bay, Namibia. The ore body is located in a paleochannel which for the most part tracks the course of the Gawib River. Mining of the ore body must, of necessity, take place in the river channel. Management of flood water is essential in order to minimise contamination of fresh water as well as to minimise the impact on mining production.

The processing plant has been located within the river channel and is susceptible to flooding. Diversion structures have been constructed within the river channel to ensure that flood water is routed around the processing plant but these structures severely reduce the width of the channel. The existing Tailings Storage Facility (TSF 1), along with a lift currently under construction (TSF 1 Phase 2) and a proposed additional facility (TSF 1 Extension) are located adjacent to the channel.

To minimise the risk of contamination as well as damage to the mining facilities a flood assessment is required which will:

- Estimate the size of flood detention facilities which may be required to contain all but the most extreme floods.
- Determine the dimensions of flood protection structures as well as the nature of erosion protection required for these structures in the event of extreme event floods occurring during the operating life of the mine.

This report documents the flood assessments which have focused on the following activities:

- Derivation of a representative rainfall record.
- Development and calibration of a probabilistic storm water management model.

- Simulating floods and flood events using the model.
- Assessing flood detention capacity requirements from the simulation results.
- Evaluating flood protection requirements.

This work documented in this report is based on available rainfall records from Rössing Uranium Mine as well as gauging stations within 80km of the mine. It is important to note that these records are of less than 20 years duration. Catchment boundaries have been determined from 1:50,000 maps, and surficial cover characteristics have been estimated from available aerial photography and Google Earth images.

In developing this report reference has been made to a report entitled *Determination of Floodlines* prepared by Knight Piesold Consulting for GRDMinProc at the time of mine design in October 2005.

2 TERMS OF REFERENCE

The terms of reference for this report are as follows:

- Carry out flood predictions for the mine site
- Determine flood detention storage capacities for a range of flood recurrence intervals
- Determine the locations and dimensions of flood protection works
- Document the above in a report.

3 RAINFALL DATA

3.1 ISOHYETS

Figure 3-1 below demonstrates that annual rainfall and rainfall variability in Namibia in the area surrounding Langer Heinrich vary in a regular manner with distance the coastline. As only limited rainfall data was available from the Langer Heinrich site directly, data from a nearby site with comparable climatic conditions was substituted to provide a longer rainfall record.

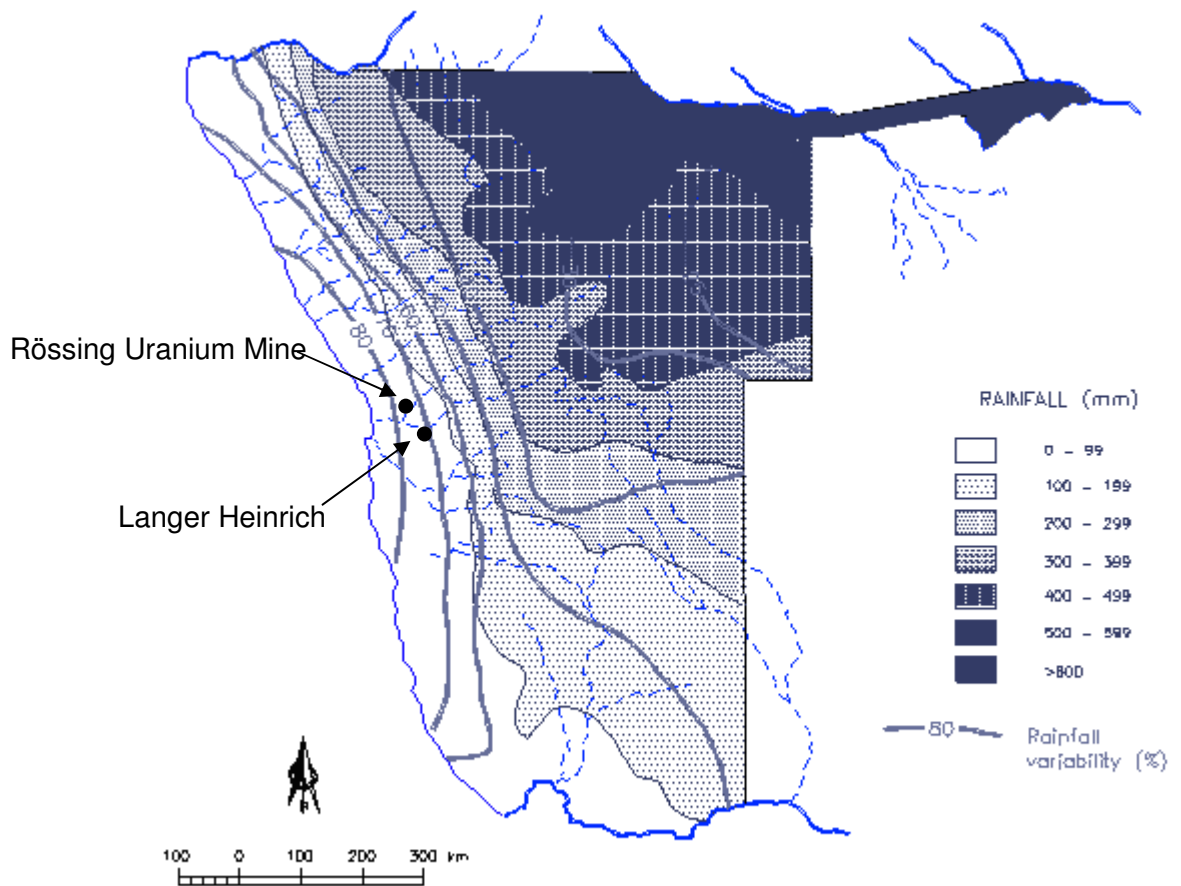


Figure 3-1: Rainfall variation with distance from the Namibian coast

Rössing mine was selected for this purpose as the longest representative rainfall record available. Figure 3-1 demonstrates that relative to the outlined rainfall regions, Rössing may be expected to fit the required climatic criteria.

3.2 AVAILABLE GAUGE DATA

Modelling of flood events has focused on assessing the catchment response to isolated rainfall events of duration less than 24 hours, and hence has been dependent on the availability of daily rainfall records. Available rainfall data used to derive a representative rainfall record is summarised as follows:

- Daily rainfall data from LHU, recorded between December 2005 and April 2008
- Daily rainfall from Rössing recorded between 1987 and the present recorded at four different stations

3.3 EVALUATION OF SPATIAL DISTRIBUTION OF RAINFALL FOR RÖSSING

Rainfall at Rössing was recorded at four locations covering an area of approximately 24 km², shown below in Figure 3-2.

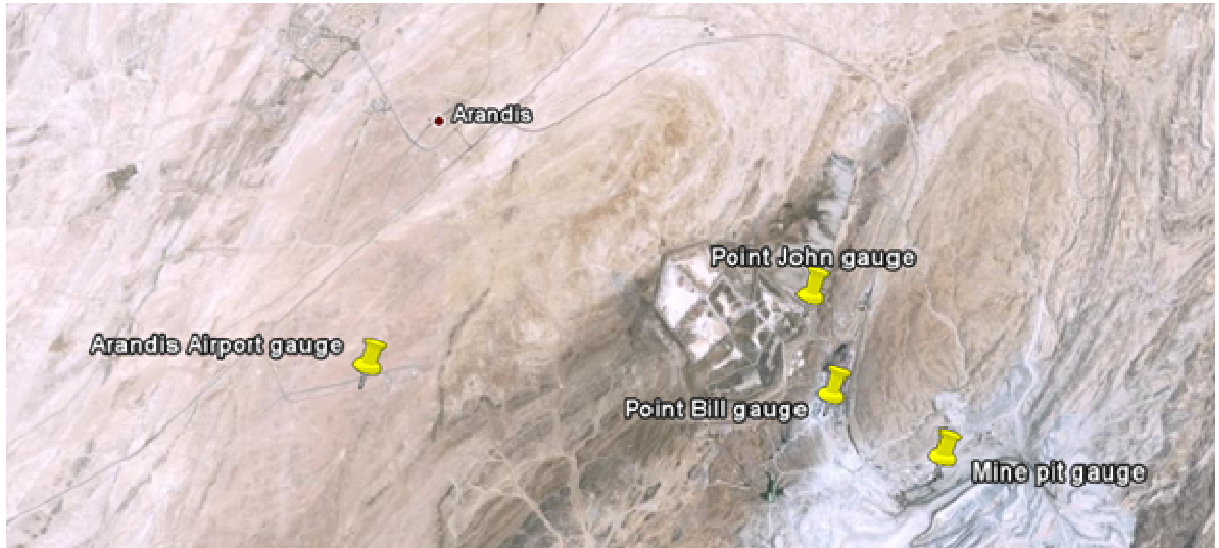


Figure 3-2: Locations of Rössing rain gauges

As the area covered by the Rössing gauges was similar to the extents of the catchment above Langer Heinrich, the Rössing data was also used to assess the likelihood that a rainfall event on one part of the catchment would be experienced over the whole catchment. Analysis of the data showed that this was the case for the majority of rainfall events experienced, particularly for events with an average intensity greater than 4 mm over the area of the catchment. The manner in which this has been incorporated into the model is discussed in more detail in later sections.

4 DEVELOPMENT OF LONG TERM RAINFALL DATA

4.1 EXTRAPOLATION TO A 1000 YEAR RECORD

The 30 year daily Rössing Rainfall record was extrapolated to a 1000 year rainfall record using SCL (Stochastic Climate Library), a library of stochastic models developed by the Australia Bureau of Meteorology for generating climatic data. The resulting data was used to produce statistics on the probability of severe rainfall events, suggesting that there was a 10% probability of exceeding 6mm of rain in a single day and a 1% probability of exceeding 17mm of rain in a day. The 27mm of rain that was measured in April has a 0.3% probability of being equaled or exceeded. The 1 in 10,000 case used to assess the most extreme realistic conditions as a basis for safety factors produced a total rainfall depth estimated at 40mm in a single event.

This data was also used in assessing the probability distribution used to generate rainfall figures for simulation purposes described below.

4.2 FITTING AN EXTREME EVENT PROBABILITY DENSITY FUNCTION

As noted previously, representative rainfall data was available for the region for a period of less than 20 years duration. In order to extrapolate data for simulation purposes described below, rainfall data for all days on which precipitation was recorded was fitted to the gamma distribution. This distribution was selected due to its convincing match to the rainfall patterns observed, having the desired characteristics of varying over positive values between zero and infinity with the majority of values close to zero.

Precipitation on days where positive rainfall was recorded was an average of 3.15 mm with a standard deviation of 4.72. Figure 4-1 below shows the comparison between the actual records from Rössing and Langer Heinrich and those produced by the gamma distribution.

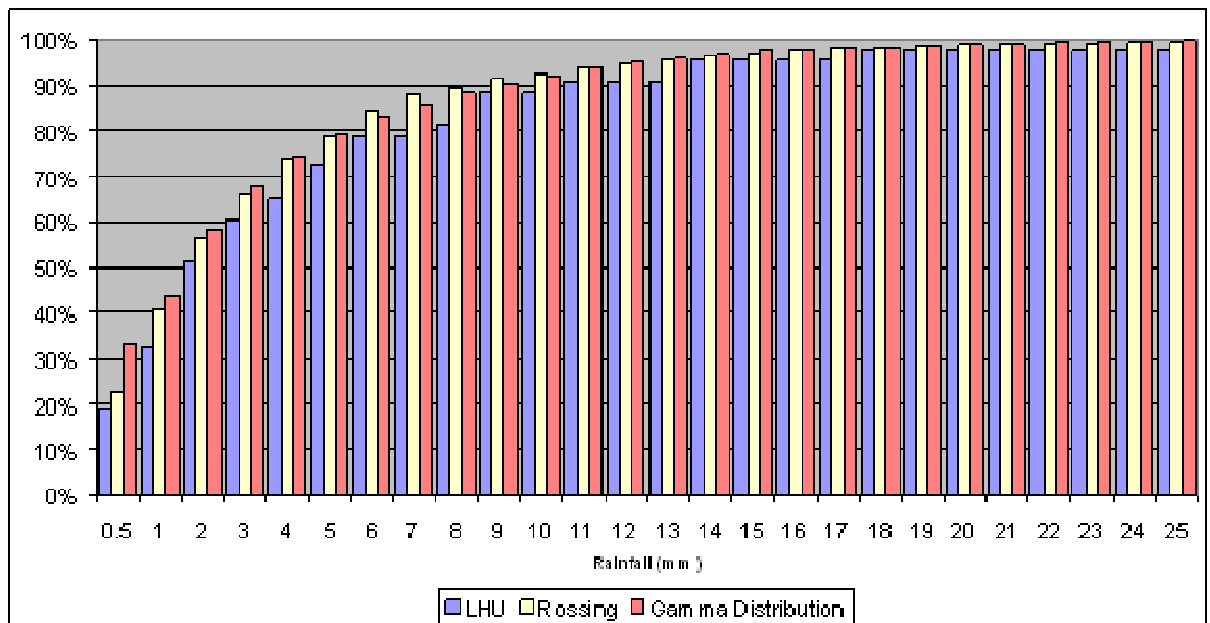


Figure 4-1: Comparison of values generated by gamma distribution to the available rainfall record

5 DEVELOPMENT OF THE STORMWATER MANAGEMENT MODEL

5.1 BASE MODEL – SWMM

Modelling of storm flow through the catchment above the mine site was performed using EPA SWMM (Storm Water Management Model). SWMM uses the Kinematic wave method of flood routing to allow storm water flow to be modelled based on a schematic model of sub-catchments and connecting channels in response to rain events of a specified intensity and duration. Output includes results defining the total outflow at the river mouth as well as data on maximum flow velocities and depths occurring in links during the simulated period.

5.2 CATCHMENT CHARACTERISTICS

The river catchment above the processing plant has been outlined and divided into nine sub-catchments, shown below in Figure 5-1. Catchments are linked by n river branches. The catchment areas are outlined in Table 5-1.

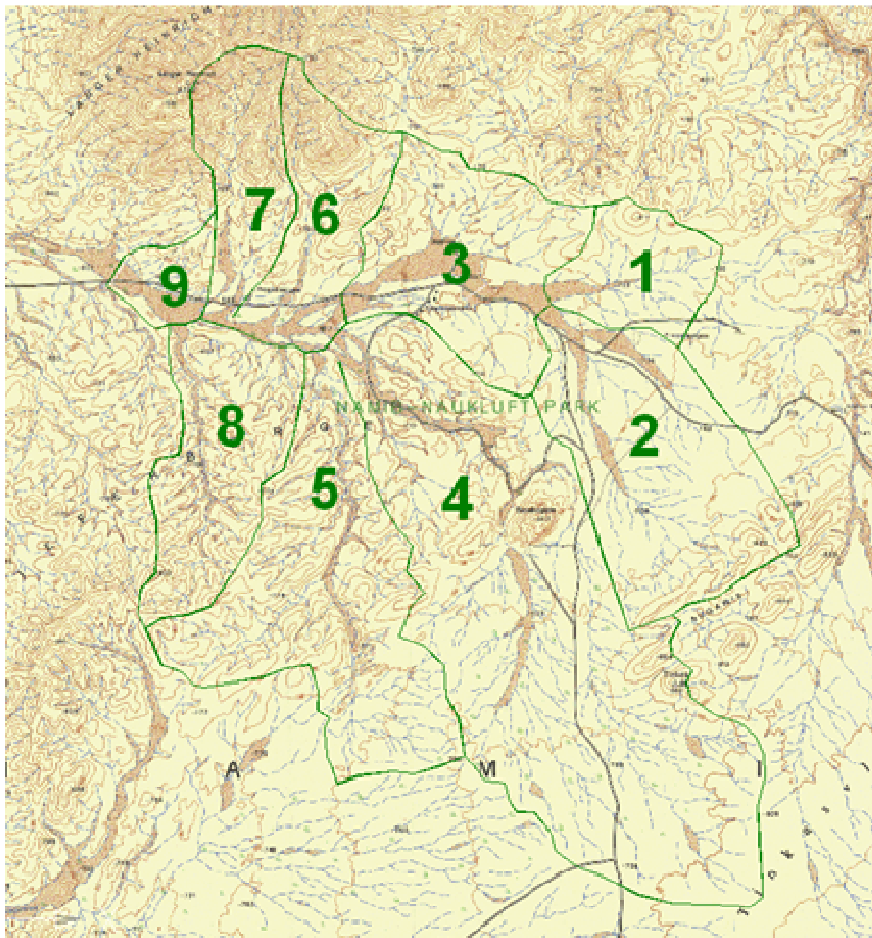


Figure 5-1: Sub-catchments on the Gawib River basin, numbered from upstream to downstream

Table 5-1: Sub-catchment characteristics

Sub-catchment No.	Area (ha)	Assumed Impermeable area (%)	Width (m)	Average slope
1	339	10	1460	3.38
2	1000	10	2100	2.88
3	764	10	2200	4.6
4	2520	20	3350	2.65
5	1200	70	1900	3.14
6	500	50	1050	12.2
7	400	60	1100	16.3
8	645	90	1500	5.69
9	149	0	1200	10.6

5.3 DEVELOPMENT OF PROBABILISTIC MODEL

Due to the limited availability of data defining the Langer Heinrich rainfall record, past flood conditions and catchment characteristics, significant uncertainty exists regarding a number of factors which will influence flood forecasts for the region. This issue has been dealt with by defining the uncertain variables in terms of probability distributions and running a large number of simulations of flood events. In order to produce statistical data on the magnitude of flood events, a spreadsheet-based model was developed to randomly generate flood and catchment parameters within a realistic range for input into SWMM, and to collate results. Each individual simulation run was designed to represent one 'day', on which a rainfall event had a certain probability of occurring. If rain occurred, values would then be generated representing the precipitation depth and other relevant parameters.

5.3.1 Assumptions

- Precipitation has been viewed as a series of discrete events, ie, flow in river between rainfall events has been assumed to be negligible.
- Based on the available rainfall record, rain was found to occur on an average 5% of days per year. It has hence been assumed for modelling purposes that on any randomly selected day, there is a 5% probability of occurring.
- Total rainfall does not vary significantly over different parts of the catchment during the same storm event, ie, the rainfall recorded is the average depth recorded over all parts of the catchment which experienced rainfall. This is similar to what is evident from the Rössing data which is gathered over a total area similar to the LHU catchment.

5.3.2 Analysis algorithm

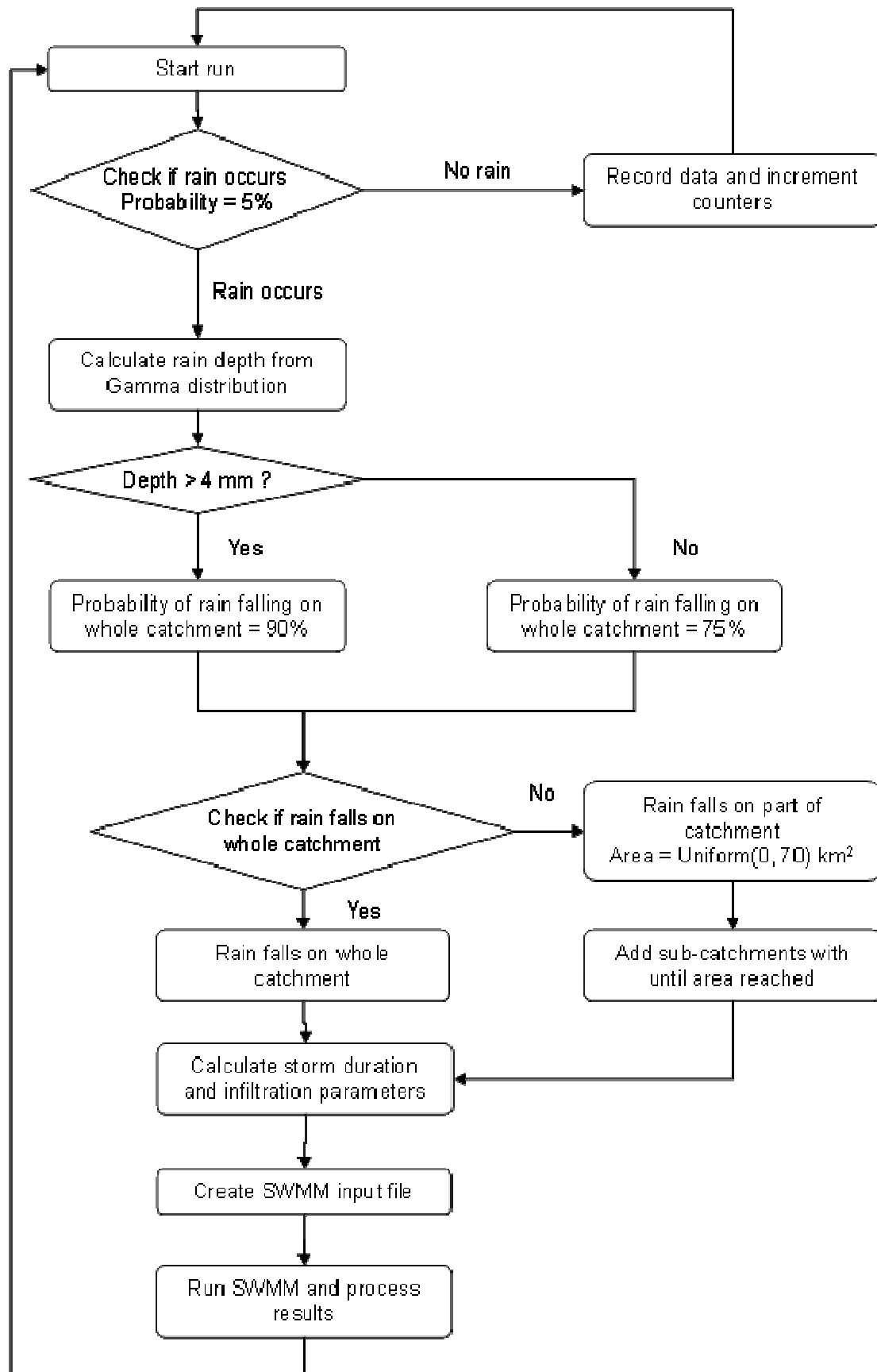


Figure 5-2: Flow chart demonstrating the Excel model algorithm

5.4 CATCHMENT AND FLOOD PARAMETERS

Probability distributions have been used to describe the variability of the total depth of rainfall, the duration and area of the event, and also the percentage of the storm area which passed over the catchment. The probability distributions are summarised in Table 5-2 below.

Table 5-2: Storm parameters

Parameter	Distribution	Avg	Std Dev	Min	Max
Precipitation	Gamma	3.15mm	4.72mm	-	-
Storm duration	Exponential	30 min	-	-	-
Storm area	Exponential	78 km ²	-	-	-
% of storm area over catchments	Uniform	-	-	0%	100%

Other than for the gamma distribution the probability distributions have been selected on the basis of maximisation of entropy to ensure minimum bias.

Based on the Rössing data discussed in Section 3.2, it was deduced that a rainfall event could be expected occur over all sub-catchments in between 75 and 90% of storms, with the probability increasing with the event's intensity. For remaining rainfall events occurring over only part of the catchment, the number of sub-catchments over which it occurred has been simulated by generating the storm area from a uniform distribution, and then randomly selecting an initial sub-catchment number between 1 and 9, comparing its area to the total storm area, and then adding adjacent catchments in a clockwise direction until the full area is accounted for.

Infiltration has been modelled using the Green-Ampt method; however, significant uncertainty exists regarding the exact infiltration parameters which would apply to the catchment area. In attempt to incorporate the effect of this area of uncertainty, infiltration parameters have been generated from a uniform distribution with bounding values representative of the soil type found in the catchment. The ranges used are summarised in Table 5-3.

Table 5-3: Infiltration parameters

Parameters	Distribution	Min	Max
Suction head	Uniform	50	90
Conductivity	Uniform	0.001	0.01
θ_D	Uniform	0.3	0.45
Impermeable area	Uniform	70% * sub-catchment avg.	130% * sub-catchment avg.

6 CALIBRATION OF THE STORM WATER MANAGEMENT MODEL

6.1 AVAILABLE RAINFALL AND FLOOD INFORMATION FOR THE CALIBRATION

A recent storm over the river basin that occurred in April 2008 provided data which was used in calibrating the model. A precipitation depth of 26 mm was recorded during this period, and it was evident from the flow patterns and wet areas upstream of the plant that the storm only occurred over sub-catchments 9, 7, and part of catchment 6. The total outflow from storm was estimated at 170-200 ML based on survey measurements of the water level in the pit.

6.2 CALIBRATION RESULTS

The calibration of the model was checked running a SWMM simulation with the above rainfall data input over the appropriate catchments. The final calibrated run using the parameters listed above in Section 5.4 produced a total predicted outflow of 200 ML, assuming that the majority of sub-catchment 6 experienced rainfall. Based on this result, the model was deemed sufficiently accurate for further modelling.

7 PROBABILISTIC SIMULATIONS AND RESULTS

7.1 FLOOD PEAK

Results from probabilistic simulations using the model described above over 50,000 iterations/simulations are summarised below in Table 7-1.

The simulations indicate that floods in the 99th percentile of rainfall events, or roughly once in 200 years, can be expected generate an outflow volume of the order of 3,000ML.

Table 7-1: Simulation results

ARI (years)	AEP	Precipitation (mm)	Outflow volume (ML)	Max flow rate (m ³ /s)
2	39%	15	450	50
5	18%	21	800	100
10	9.5%	26	1000	150
20	5%	31	1400	200
50	2%	38	2000	300
100	1%	44	2500	400
200	0.5%	46	3000	550

8 DESIGN OF FLOOD PROTECTION STRUCTURES

8.1 GENERAL

The floods predicted in Section 7.1 above will flow down the river channel towards the existing LHU mine as shown in Figure 8-1 below. Critical LHU site infrastructure must therefore be modified or protected to minimise the likelihood that damage occurs during storm events. These modification or protection works consist of:

- Modifying site infrastructure adjacent to the existing pit to ensure flow is directed into the pit without overtopping into the process plant area (refer Section 8.2 below).
- Storage of the flood (where possible) within the existing pit (refer Section 8.3 below).
- Construction of a spillway if necessary to allow the flood to overtop the pit in major events without damaging critical site infrastructure (refer Section 8.4 below).
- Erosion protection of the downstream toe of the TSF 1 and TSF 1 Extension embankments (refer Section 8.5 below).
- Relocation of the existing tailings delivery pipelines (as proposed by LHU).

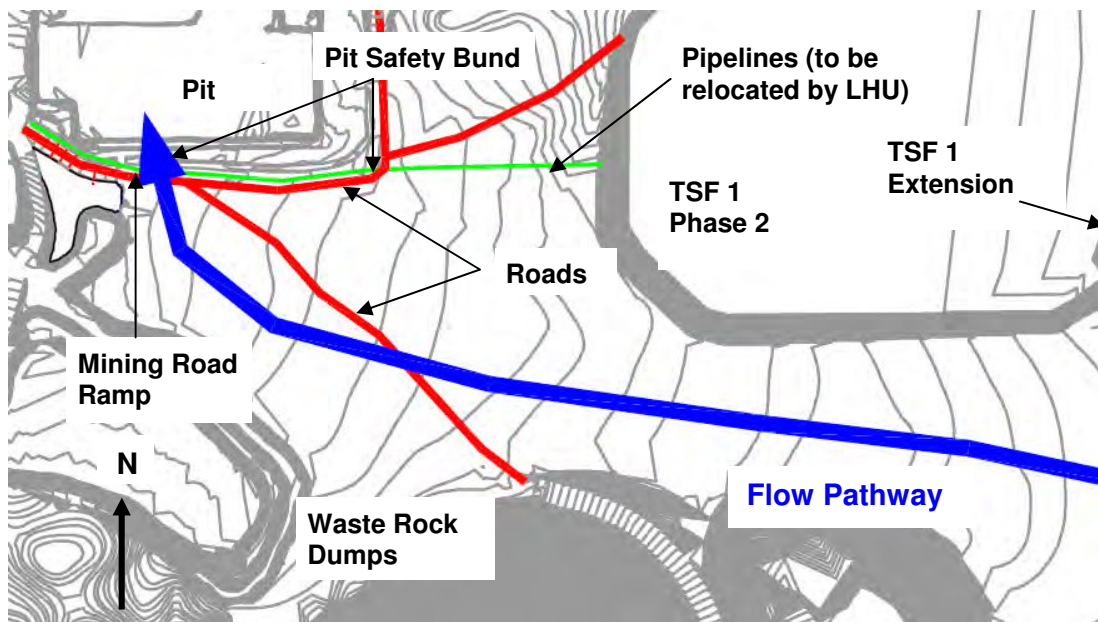


Figure 8-1: Flow Pathway

8.2 FLOOD PROTECTION OF THE PROCESSING PLANT

Flood modelling has been conducted using the US Army Corps of Engineers programme HEC-RAS so as to develop a flood diversion strategy to divert water flowing towards the LHU process plant area into Pit A. The modelling is described in detail in Appendix 1 and a summary is presented below.

Proposed modifications to the existing site layout as developed from the modelling are located directly south of the existing pit, adjacent to an existing mine road ramp, waste rock dump, and the pit safety bund. The area, together with proposed modifications to accommodate the flood, is shown in Figure 8-2 below. A typical section through the modified pit safety bund and ramp is shown in Figure 8-3 below. Proposed modifications to the existing site layout are as follows:

- Raising of the existing ramp: The current ramp has a crest elevation of approximately RL 629m, where it joins other mine roads at a four-way intersection. The ramp needs to be raised to a crest elevation of RL 632.5m to ensure a minimum 1m freeboard against overtopping and flooding of the processing plant area should a 1 in 200 year flood occur. The ramp should be sloped at 1V:13H to tie in with the existing road at the four-way intersection and at the same time retain safe sight distances. Safety bunds should be constructed on either side of the modified ramp as required by LHU policy.
- Cuts through the Pit Safety Bund: A series of three cuts in the pit safety bund are required, with base width of 10m at approximately 30m centres, so as to allow flood water to enter the pit. It is anticipated that these cuts would be scoured to the required width naturally in the course of a flood.
- Filling of Area between Ramp and Waste Rock Dump: It is proposed that the area between the existing waste rock dump and the ramp be filled with waste rock material to an elevation of at least RL 632.5m to ensure a minimum of 1m freeboard during the 1 in 200 year flood. The area may be filled higher than this elevation at LHU's discretion.

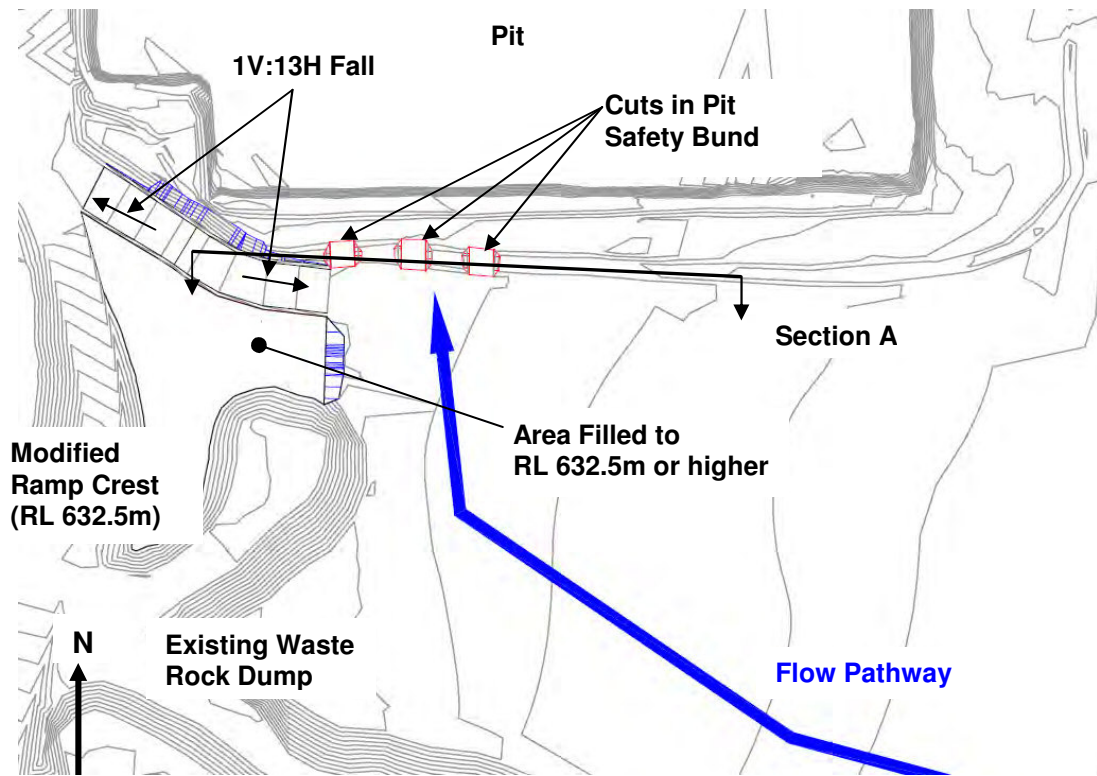


Figure 8-2: Proposed Site Layout Modifications – Plan

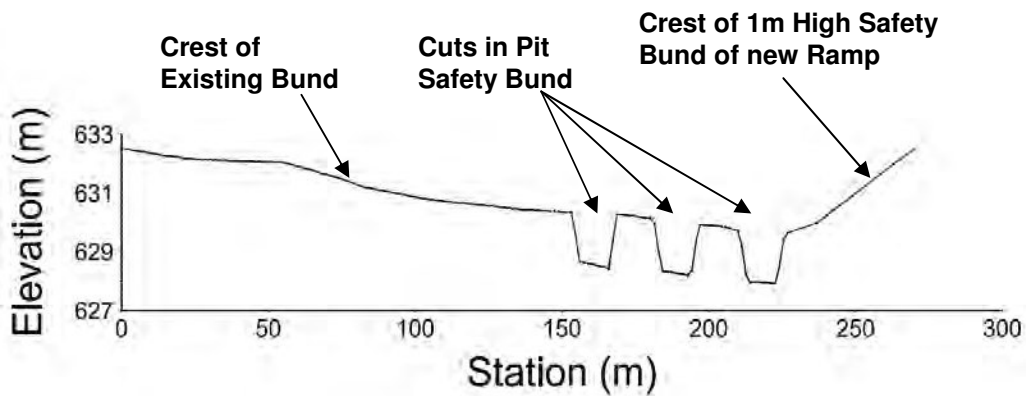


Figure 8-3: Section A of Proposed Site Layout Modifications

8.3 FLOOD DETENTION IN PIT

It is proposed to make use of mined-out Pit A to capture and contain the flood water. This water will then be used as make-up water in the processing plant and will offset Namwater. As outlined in Section 8.2 above, a flood diversion strategy has been

prepared to ensure that water is directed into the pit. This section addresses the issue of the capacity of the pit.

The location of the pit relative to key site infrastructure is shown in Figure 8-4 below.

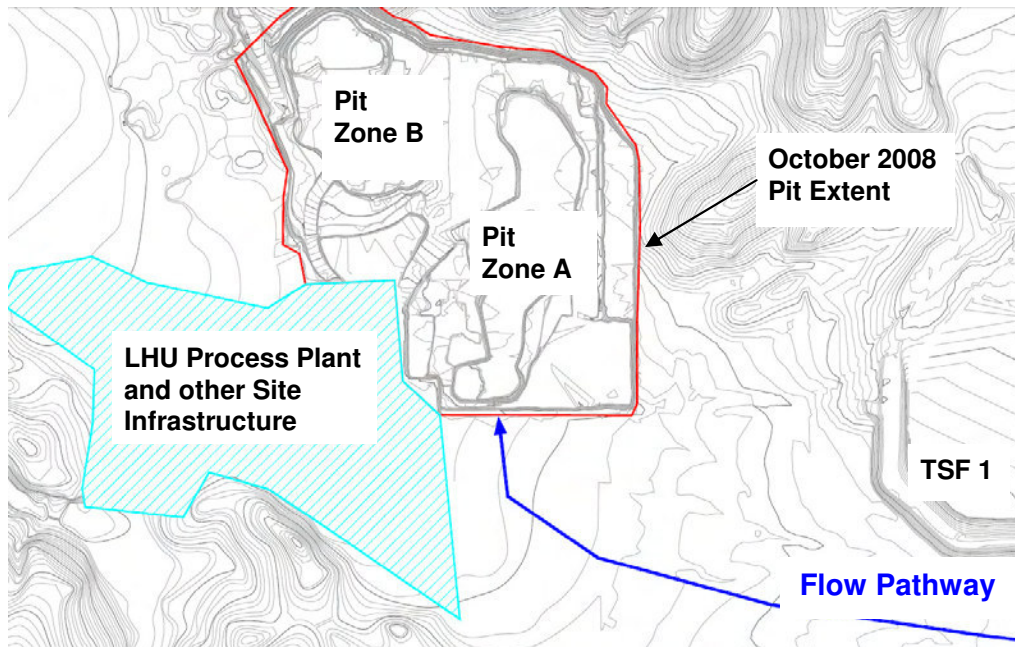


Figure 8-4: October 2008 Pit

The October 2008 pit survey provided by LHU indicates a potential pit storage capacity of 2,832,354 m³. Therefore based on the results documented in Table 7-1 above, the existing pit has the capacity to store up to at least the 100 year ARI event. The annual probability of spillage is therefore less than 1%. This probability will decrease as expansion of the pit continues in the course of mining.

It should be noted that while the current pit being mined in two zones (A and B) as shown on Figure 8-4 above, the ridge that separates the pits is significantly lower than the outside crest of the combined pit. Therefore the pit will act as a single storage unit prior to spilling.

8.4 PIT SPILLWAY REQUIREMENTS

As discussed in Section 8.3 above, there is an annual probability of spillage from the pit of less than 1%. In order to assess the result of the pit overtopping, the pit survey was merged with the existing site contours, and the lowest point around the pit (where spilling of the pit would occur) was identified in order to assess the potential consequences. The route of a spill from the lowest location is shown in Figure 8-5 below.

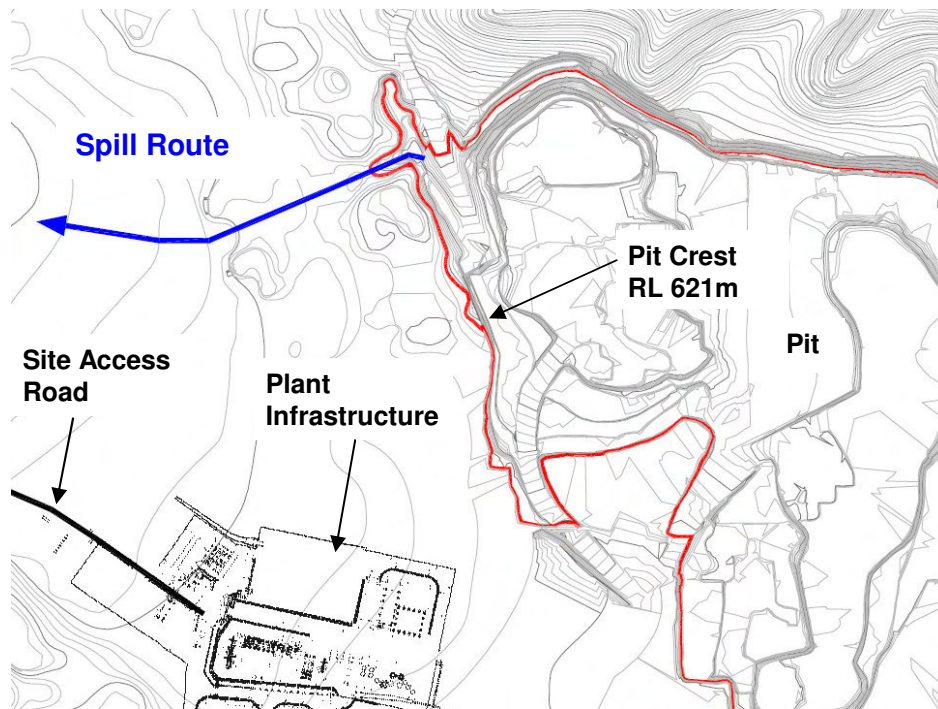


Figure 8-5: Existing Pit Spill Route

From Figure 8-5, it can be seen that a spill from the pit would naturally flow down the existing valley, and avoid critical site infrastructure. Based on this examination of the current site layout, a spillway from the pit is not required.

8.5 TSF EROSION PROTECTION

The existing TSF 1, currently being raised (TSF 1 Phase 2), and a planned TSF 1 Extension facility are located adjacent the flood pathway.

As part of the HEC RAS modelling conducted within the Appendix 1 report, the proposed final toes of TSF 1 and the TSF 1 Extension were incorporated into the site geometry. The HEC RAS modelling indicated that for the 200 year ARI event, water is expected to flow adjacent the TSF 1 Phase 2 toe to a maximum depth of 1.33m. Therefore erosion protection of this toe to a minimum depth of 3m has been specified in the TSF 1 Phase 2 Construction drawings prepared by Metago.

Based on the modelling, water levels are not expected to reach the toe of the TSF 1 Extension embankment.

9 CONCLUSIONS

Based on the studies conducted, the following conclusions can be made:

- Rainfall records from Rössing mine were assessed and found to be the most appropriate available for use in the flood assessment at LHU. These records have been extrapolated to a 1000 year rainfall record, which has been used to produce statistics on the probability of severe rainfall events on the catchment above the LHU site.
- Modelling of the catchment above the LHU site has been performed using the EPA SWMM (Storm Water Management Model). Due to significant uncertainties in modelling inputs a probabilistic model has been developed to randomly generate flood and catchment parameters within a realistic range for input to the SWMM.
- Calibration of the model has been conducted based on a storm event on site in April 2008. The calibration indicated the model was suitable for use.
- Estimated runoff peak flows and total runoff volumes as predicted by SWMM have been used in assessing flood control and diversion structures.
- HEC RAS modelling of proposed diversion works to direct stormwater flow into the pit has been used to determine modifications to the site layout to accommodate the flood peaks.
- The current pit can accommodate storms exceeding the 100 year ARI event. The resulting annual probability of the pit is therefore less than 1%.
- In the event of stormwater spilling from the pit, the flow from the spill would follow the existing water course and flow into the pit areas downstream of Pit A and B. The flow will not pose a risk to existing site infrastructure and it is not necessary to provide a purpose constructed spillway.
- HEC RAS modelling of the flood adjacent to the proposed final TSF toes indicates that for the 200 year flood event water levels may reach up to 1.3m in depth immediately adjacent to the TSF 1 Phase 2 embankment toe. It would be prudent to provide erosion protection to a minimum height of 3m up the slope face along the toe of the TSF. Water levels are not expected to reach the toe of the TSF 1 Extension embankment.

10 RECOMMENDATIONS

Based on the study described above, the following it is recommended that consideration be given to the following actions:

- Construction of the plant diversion works as specified in this report should begin as soon as is practicable in order to reduce the probability of a major event occurring prior to these remedial measures being undertaken.
- Relocation of the tailings pipeline as outlined by LHU should take place as soon as is practicable.
- A detailed as-built survey of the works as constructed should be prepared to allow verification of the adequacy of the works for flood diversion.
- Erosion protection rock to a minimum height up the slope face of 3m should be placed along the toe of the TSF 1 Phase 2 Embankment.

Dr G I McPHAIL PrEng MIEAust CPEng RPEQ

For and on behalf of

Metago Environmental Engineers (Australia) Pty Ltd

METAGO ENVIRONMENTAL ENGINEERS (AUSTRALIA) PTY LTD

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APPENDIX REPORT 1: HEC-RAS MODELLING

Prepared for

LANGER HEINRICH URANIUM LTD

Revision	Date	Description	Issuer
R0	24 Sep 08	Working draft to Tad	GMcP
R1	29 Nov 08	Draft for comment	GMcP

**PROJECT NO. 336-001
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NOVEMBER 2008

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APPENDIX 1: HEC-RAS MODELLING

1 INTRODUCTION

In order to assess a potential strategy to divert and manage stormwater flowing towards the Langer Heinrich Uranium Mine (LHU) in the event of a storm of serious magnitude, modifications to the existing site topography were modelled using Autocad Land Desktop and the performance of the modifications analysed using HEC-RAS, a river analysis program which defines the river pathway in the form of a series of cross-sections. Storm and flood data has been derived from daily records for LHU and adjacent sites, as detailed in the main report, *Flood Assessments for the Gawib River at Langer Uranium Mine*. Consideration has also been given to the potential impact on mine infrastructure from both the flood and the proposed Works.

2 FLOOD CONTROL OPTIONS

The objective of flood control was to direct all stormwater collected by the catchment in the event of a significant storm to the pit without damaging critical site infrastructure. In the current site layout, while flow does eventually enter the pit, there is significant risk of overtopping of a mine road ramp leading to inundation of the process plant area. A pit safety bund, as currently constructed, located directly adjacent the pit increases the likelihood of a build up of water in this area during major events. Also, the existing TSF 1 which is currently being raised (Phase 2), and a proposed TSF 1 Extension are directly adjacent to the route of flow.

The route of flow is shown in Figure 2-1 below, along with the relevant site infrastructure as discussed.

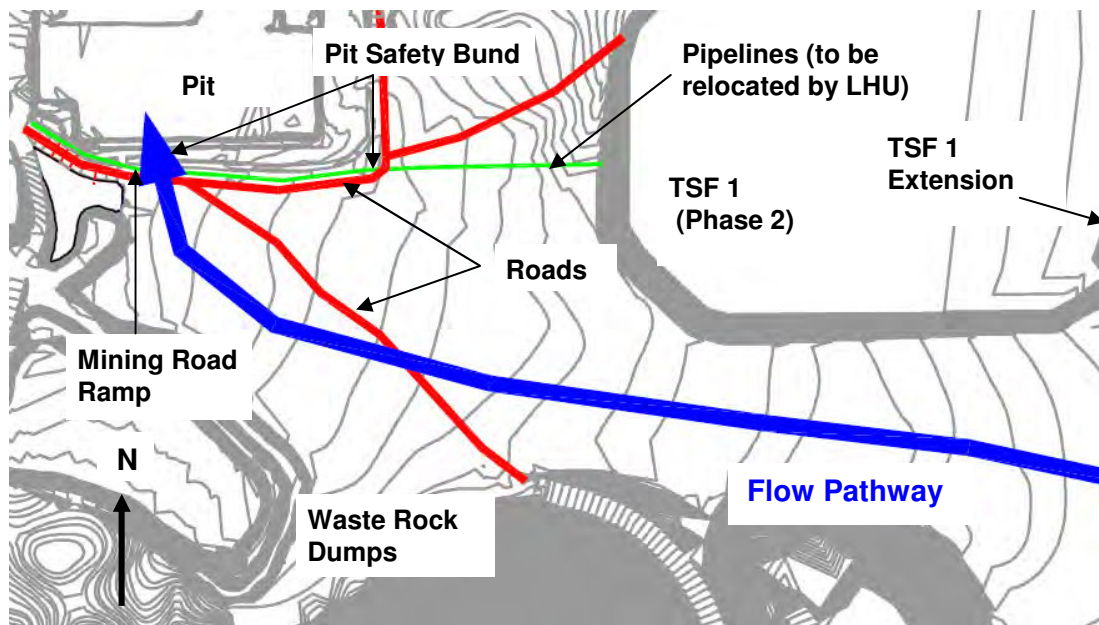


Figure 2-1: Flow Route

A large storm event took place in April 2008 on the LHU catchment, and followed the route as shown in Figure 2-1. Water built up behind the pit bund and eventually overtopped into the pit. Fortunately the water level did not reach an elevation where it overtopped into the process plant area.

In designing modifications to the site layout to ensure that flow reports to the pit and does not overtop the ramp into the process plant, consideration also needed to be given to the manner in which this would be accomplished in order to minimise impact on existing site infrastructure.

The relevant site infrastructure that could potentially be impacted is summarised as follows:

1. An existing mine road ramp is adjacent to the flow pathway, and needs to be increased in elevation to prevent overtopping. Construction will hence need to be undertaken in a manner which will allow continued use of this ramp. This has been incorporated into the design by limiting the slope of the ramp to not greater than 1V:10H.
2. A pit safety bund between the existing roadway and pit intersects the flow pathway. This bund cannot be removed in its entirety for safety considerations. However, a number of cuts through it would likely be acceptable to allow sufficient flow into the pit. It should be noted that in major storm events this bund would very likely be damaged and require repair.

3. Existing tailings delivery and water pipes cross the flow pathway. However, Metago understands that these are to be rerouted north of the pit by LHU.
4. A number of existing mine roads are located within the flood pathway. Any damage to these roads following major events would be repaired as necessary, as it is not practicable to protect them from major storm events.

In keeping with these requirements and restrictions, the proposed flood control measures were developed as follows:

Flow areas would be excavated through the Pit Safety Bund at regular spacing to allow flow to enter the pit and minimise “backing up” in the area. In a major event the pit safety bund may be severely damaged by erosion, however the sizing of the excavated areas has conservatively assumed that no damage has occurred. The crest elevation of the ramp would need to be raised to ensure flow does not overtop the ramp and enter the process plant area. A maximum slope of 1V:10H has been assumed for the modified ramp to allow vehicle access. The layout of the modified mine road ramp, pit safety bunds and fill area is shown in Figure 2-2, and a typical cross-section in Figure 2-3.

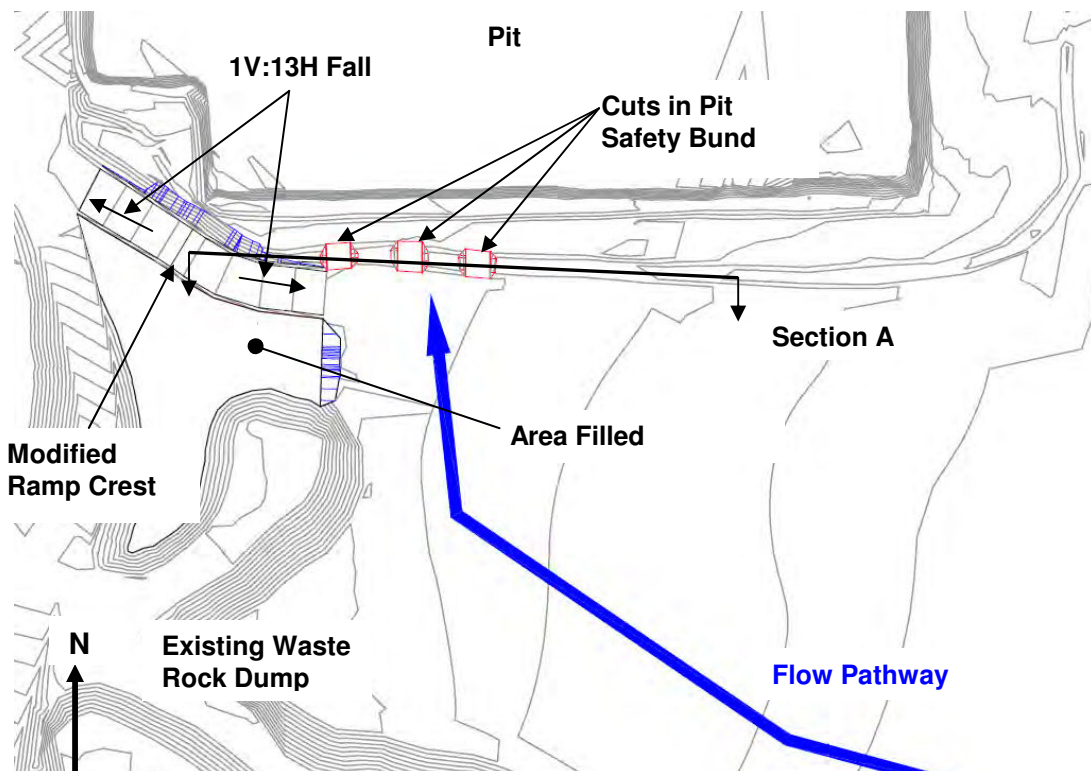


Figure 2-2: Plan View of Flow Route at the Entrance to Pit

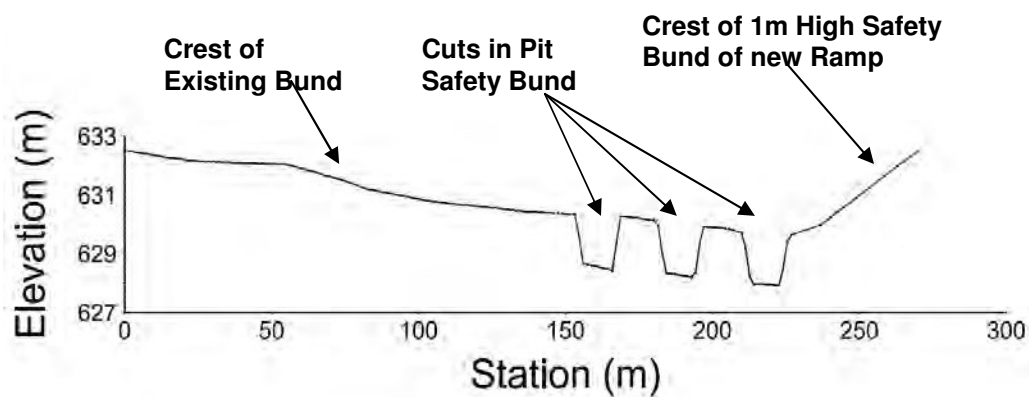


Figure 2-3: Section A through Cuts in Pit Safety Bund and Modified Ramp

Modelling of the flow for the modified layout is outlined in Section 4 below.

Additional to the infrastructure described above is the existing TSF 1 facility. A Phase 2 embankment raise (designed by Metago) is currently underway, while a TSF 1 Extension facility is to follow to the east, as shown on Figure 4-1. Modelling of the flow adjacent to these works as been conducted and is also outlined in Section 4 below.

3 DESIGN FLOODS

Floods of three magnitudes have been used to assess the efficacy of the proposed solution, each considering the catchment response to a rainfall event of less than 24 hours duration. Flood magnitude was derived as documented in the main report, based on daily rainfall data recorded close to Langer Heinrich. The magnitude of the outflow volume and flow rate were calculated using EPA SWMM (Storm Water Management Model).

Design floods with ARIs of 2, 20 and 200 years respectively have been selected for analysis. This ensured the analysis would include events having a variety of frequencies and associated risks. The design flood properties are outlined in Table 3-1.

Table 3-1: Design Flood Properties

ARI (years)	Expected damage	Failure risk	Max velocity(m/s)	Max depth (m)
2	Minimal	Negligible	2m/s	0.5
20	Repairable	Negligible	3m/s	1m
200	Major but structure remains	Low	5m/s	1.5m

Flow and rainfall statistics associated with the three cases are summarised in Table 3-2 below.

Table 3-2: SWMM outflow results

ARI (years)	AEP	Precipitation (mm)	Outflow volume (ML)	Max flow rate (m ³ /s)
2	39%	15	450	50
20	5%	31	1400	200
200	0.5%	46	3000	550

4 HEC-RAS MODELLING AND RESULTS

Modelling was performed using HEC-RAS, a channel analysis program developed by the US Department of Defense Army Corps of Engineers which is able to model flow through natural or artificial channels of varying profile. The inputs for the HEC-RAS modelling included:

- Flow data for the 2, 20 and 200 year ARI events as outlined in Table 3-2;
- Cross section data along the proposed flow route; and
- Assumed Manning's Roughness Coefficient (n) of 0.035 for the flow pathway.

The boundary conditions assumed for the HEC-RAS were:

- Upstream: Water Surface Elevation of RL 660m.
- Downstream: Critical Depth.

The locations of the cross-sections used for the model development, including key cross-sections are shown in Figure 4-1 below.

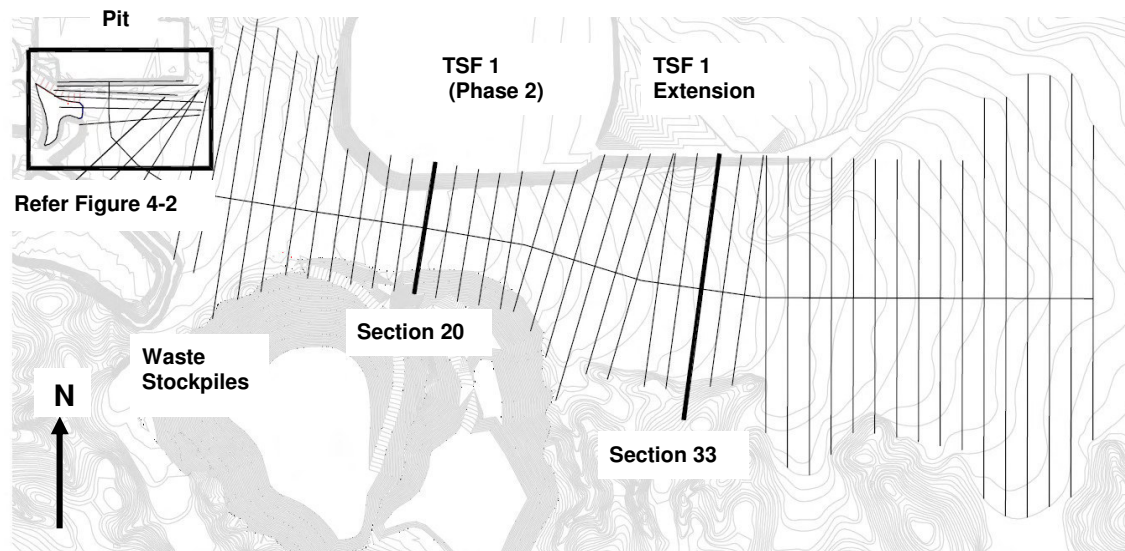


Figure 4-1: Cross-section locations for HEC-RAS

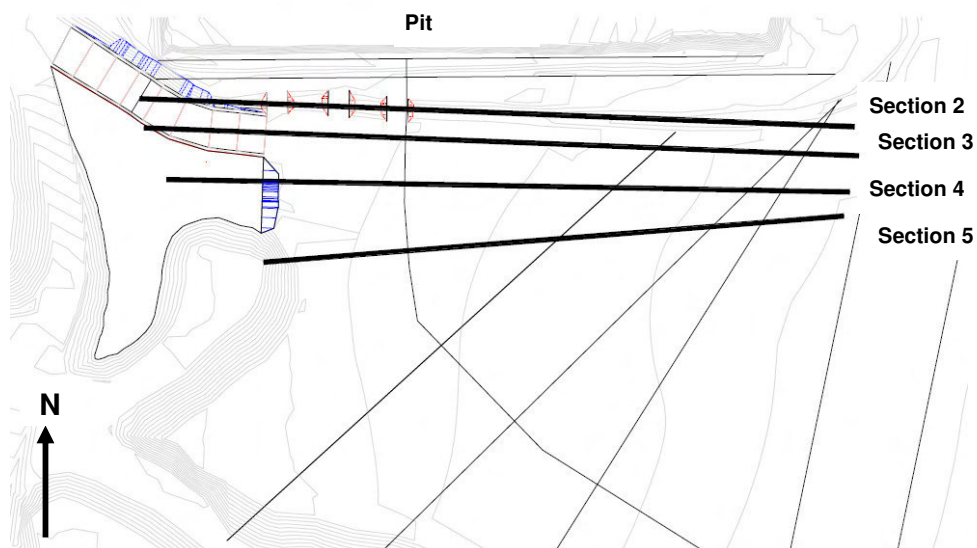


Figure 4-2: Cross-section locations for HEC-RAS at entrance to Pit

The initial model indicated that it would be necessary to modify the ramp and dump geometry directly adjacent to the pit rim. These modifications include:

- Raising of the existing ramp: The current ramp has a crest elevation of approximately RL 629m, where it joins other mine roads at a four-way intersection. The ramp must be raised to a crest elevation of RL 632.5m to ensure a minimum 1m freeboard. The ramp should slope to meet the existing four way intersection and existing road at 1V:13H on either side of the crest.

Safety bunds as required by LHU policy should be constructed on either side of the modified ramp.

- Cuts in Pit Safety Bund: A series of three cuts in the pit safety bund are required, with base width of 10m at approximately 30m centres.
- Filling of Area Between Ramp and Waste Rock Dump: The area between the existing waste rock dump and ramp is to be filled with waste rock material, to an elevation of at least RL 632.5m, to ensure a minimum 1m freeboard. The area can be filled higher than this elevation at LHU's discretion.

The modifications as described above are outlined in Figure 4-3 below.

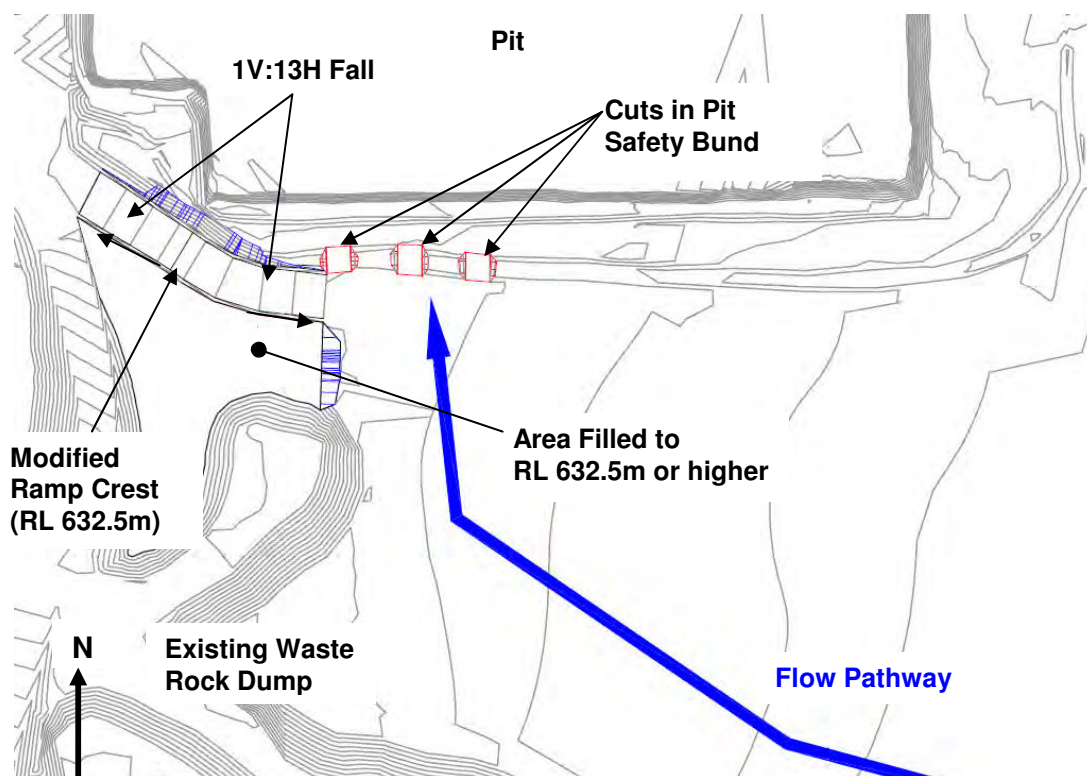


Figure 4-3: Proposed Site Layout Modifications

HEC-RAS simulations were then carried out on the proposed modifications outlined for the three design flows shown in Table 3-2 above. Typical output cross-sections showing the maximum water level for all three design events are shown in Figure 4-4 to 4-6.

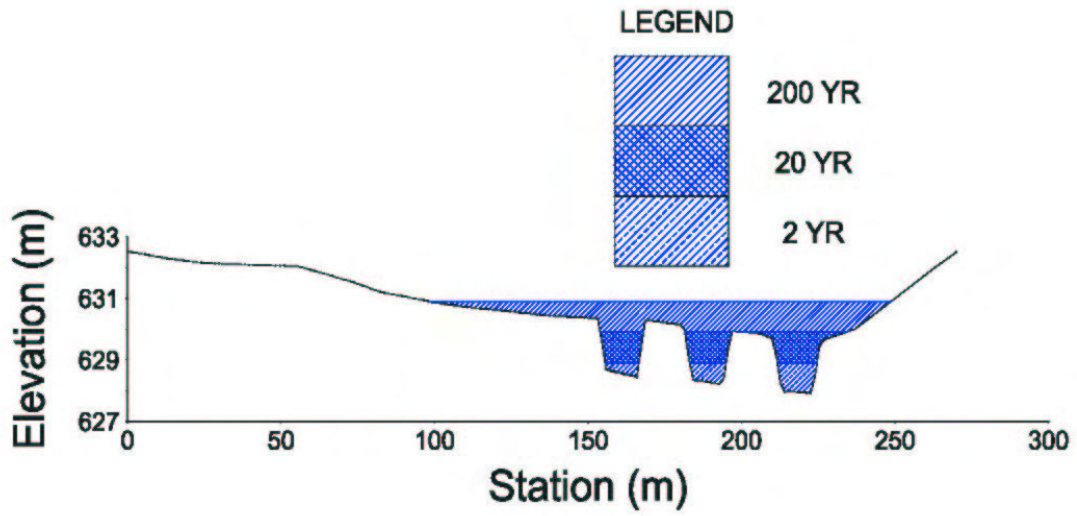


Figure 4-4: Section 2

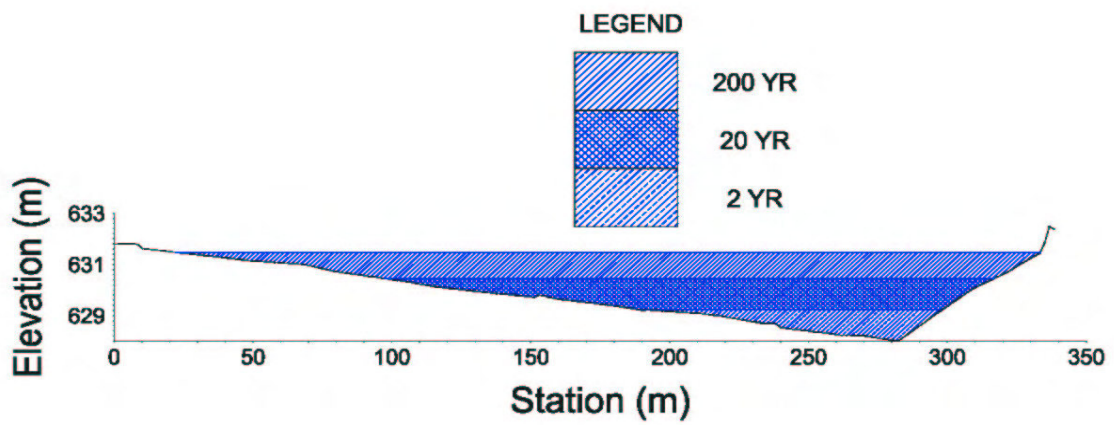


Figure 4-5: Section 3

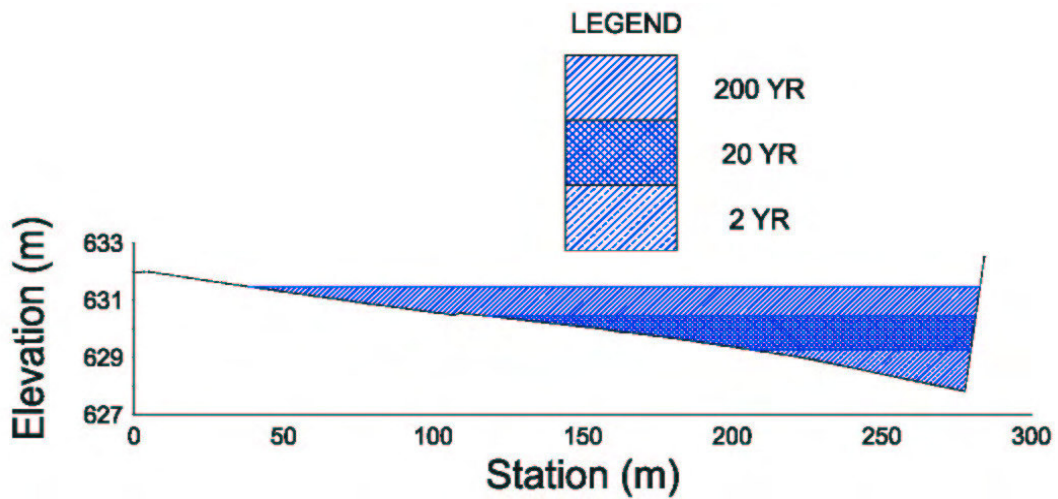


Figure 4-6: Section 4

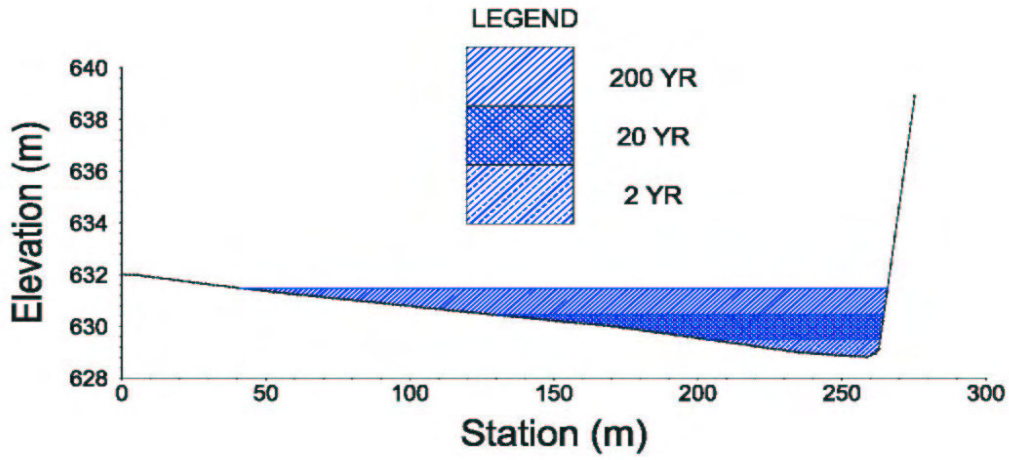


Figure 4-7: Section 5

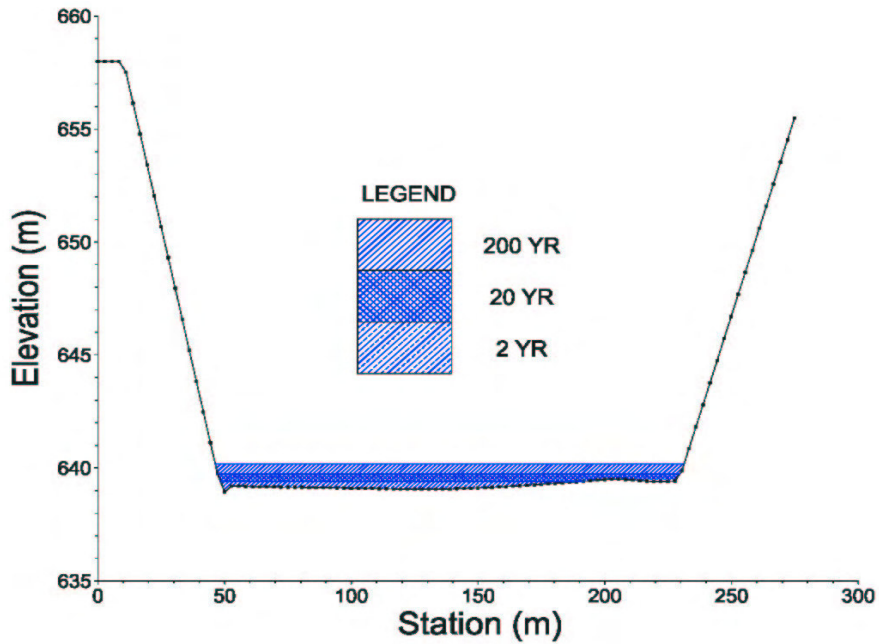


Figure 4-8: Section 20

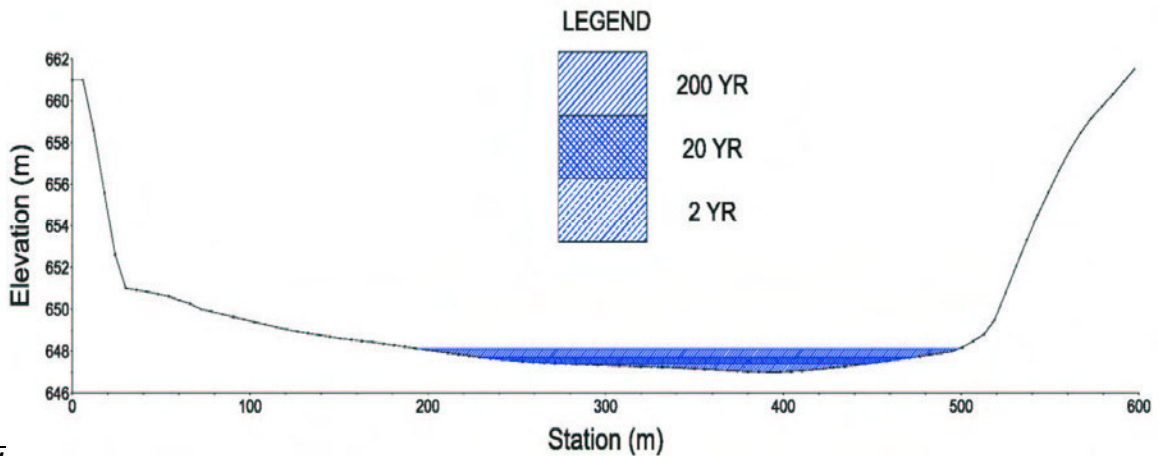


Figure 4-9: Section 33

Flow velocity and depths for the sections shown above are presented in Table 4-1 below.

Table 4-1: Flow Information

Section	ARI	Velocity (m/s)	Maximum Flow Depth (m)
2	2	2.40	0.98
	20	3.10	2.00
	200	3.33	2.97
3	2	0.78	1.23
	20	0.76	2.43
	200	1.03	3.47
4	2	0.98	1.45
	20	1.07	2.63
	200	1.37	3.66
5	2	2.02	0.70
	20	1.76	1.64
	200	1.84	2.67
20	2	1.10	0.46
	20	1.65	0.79
	200	2.51	1.33
33	2	0.96	0.42
	20	1.55	0.77
	200	2.20	1.11

As seen from the results above, the maximum water level expected in the area of the ramp and pit safety bund is **RL 631.5m**. The modifications to the site layout outlined above have been designed taking cognisance of this maximum modelled water level.

It should be noted that the modelling conducted assumes that the pit safety bund remains intact (other than the excavated cuts), which is a conservative assumption. In major events it is very likely that portions of the pit safety bund will be destroyed, thus lowering the maximum water level.

The modelling of the proposed Works indicates:

- The 2 year event will pass through the pit safety bund cuts, likely causing only minimal damage to the Works;
- The 20 year event will pass almost completely within the pit safety bund cuts, likely causing only minor, repairable damage to the Works; and
- The 200 year event will likely completely erode the pit safety bund, and damage the ramp and waste rock dump, however this damage will not be sufficient to lead to overtopping into the process plant area.

The HEC RAS modelling also indicated that for the 200 year ARI event, water is expected to flow adjacent the TSF 1 Phase 2 toe to a maximum depth of 1.33m. Therefore erosion protection of this toe to a minimum height of 3m up the slope face should be provided.

Based on the modelling, water levels are not expected to reach the toe of the TSF 1 Extension embankment.

5 SUMMARY AND CONCLUSIONS

The following conclusions have been made:

- Analysis of the flow rates associated with three design rainfall events have been calculated using SWMM simulation results documented in the main report.
- An option for directing flood water to the pit in the event of a serious rainfall event has been identified and modelled.
- The efficacy of this option has been assessed using HEC-RAS to model flow through the diversion pathway following construction.
- The relocation of the tailings delivery pipes within the flow pathway is required as soon as is practicable.
- Construction Works required to produce a site layout as recommended by the modelling have been outlined. They include:
 - Raising of the existing ramp to a crest elevation of RL 632.5m with slopes of 1V:13H;
 - Excavation of three cuts in the pit safety bund with base width of 10m at approximately 30m centres; and
 - Filling of the area between the ramp and existing waste rock dump to a minimum elevation of RL 632.5m.
- The modelling of the proposed Construction Works indicates:
 - The 2 year event will pass through the pit safety bund cuts, likely causing only minimal damage to the Works;
 - The 20 year event will pass almost completely within the pit safety bund cuts, likely causing only minimal damage to the Works; and

- The 200 year event will likely completely erode the pit safety bund, and damage the ramp and waste rock dump, however this damage will not be sufficient to lead to overtopping into the process plant area.
- Water levels are expected to reach up to 1.3m in depth adjacent to the TSF 1 Phase 2 embankment toe during a 200 year ARI event. Erosion protection to a minimum height of 3m up the slope face should be provided along the toe of the TSF. Water levels are not expected to reach the toe of the TSF 1 Extension embankment.

6 RECOMMENDATIONS

Based on the study conducted and outlined here, the following recommendations can be made:

- Construction of the Works should begin as soon as is practicable in order to reduce the probability of a major event occurring prior to these remedial measures being undertaken.
- Relocation of the tailings pipeline as outlined by LHU should take place as soon as is practicable.
- Mining safety personnel should review the ramp slopes recommended along with the proposed cuts to the pit safety bund in order to ensure these Works will not be in contradiction to LHU safety policies, or if a modification to the speed limit for the ramp is required.
- A detailed as-built survey of the Works as constructed should be conducted to allow Metago to model the as-built layout and verify its suitability for flood diversion.
- Erosion protection rock to a minimum height of 3m up the slope face should be placed along the toe of the TSF 1 Phase 2 Embankment.

APPENDIX G: AIR STUDY