

FINAL REPORT

Maud Creek Mine Site Flood Study

Prepared for
Terra Gold

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42213799



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1.1 Background

Terra Gold Mining Ltd proposes to recommence mining operations at Maud Creek, near Katherine, in the Northern Territory (NT). Maud Creek is an existing open pit mine that is currently under Care and Maintenance. The proposed operations will involve the construction of an underground mine with an access portal and decline. All mined ore will be transported via road trains to Union Reefs Gold Mine (URGM) for processing and treatment. Figure 1 shows the location of the Maud Creek project area in a regional context.

The pit lies adjacent to Gold Creek, a tributary of Maud Creek, which itself flows into the Katherine River approximately 13 Km North of the site (see figure 1). Gold Creek and Maud Creek confluence approximately 2 km north of the existing Maud Creek Pit, both Creeks have the potential to inundate the surrounding area. Figure 2 details the characteristics of the Maud Creek site.

The existing pit is bunded around its perimeter. However, the pit may be at risk of inundation from flood waters generated by the two creeks. Flooding at the Maud Creek site may also be exacerbated if the Katherine River is in flood.

With the potential re-opening of the pit and the development of underground workings, a flood study was required to estimate the potential risk of pit inundation and gauge the extent of the potential flood area during selected rainfall events. This study concentrates on the potential flood risk caused by:

- 1:100 year Annual Return Interval (ARI) event (a large flood event).
- 1:500 year ARI event (a rare flood event).
- Probable maximum Flood (PMF), considered an extreme event.

The key objective of this assessment is to reconsider the flood risk posed to the Maud Creek Pit and surrounds. To achieve this objective, the following scope of work is proposed.

1.2 Scope of Work

The scope of works will include the following:

- Review of previous hydrology reports on the Maud Creek site and surrounding areas.
- Update of meteorological data.
- Calculate flows for the 1:100, 1:500 year ARI events and the PMF using recommended methods
- Produce a representative hydraulic model of the Maud Creek site
- Identify the likelihood of the current pit bund being over topped by the estimated flood events.

-
- Estimations of the possible impact on the Maud Creek site from flooding of the Katherine River will be made. Katherine River design flood levels will be used in this analysis.
 - Production of a report and maps detailing the flood area in relation to the site plan and identification of potential areas at risk.

2.1 Estimation of Flows

Methods recommended for the ungauged catchments in the Northern Territory in Australian Rainfall and Runoff (AR&R) have been utilised. Design flood flows were estimated for three locations along Gold Creek and Maud Creek in the vicinity of the mine site. Flows were estimated for 1:100, 1:500 ARI events and the Probable Maximum Flood (PMF).

Catchment areas for Gold Creek and Maud Creek were also derived using 1:50000 scale topographical maps. These maps were the most detailed available for the estimation of the Maud Creek catchment area. Table 1 highlights the estimated catchment areas for both Creeks up until their confluence. It also estimates a combined catchment area up to a natural hydraulic structure, which has been taken as the downstream boundary for the hydraulic model.

Table 1: Estimated Catchment Areas

Reach	Catchment	Catchment Area (Km²)
Gold Creek	A	33
Maud Creek	B	244
Total catchment (to d/s boundary of model)	C	282

2.1.1 ARI Events

Several methodologies for estimating peak flows for the 1:100 and 1:500 year ARI events were considered. These were suggested in AR&R for the estimation of flows in ungauged catchments in the Northern Territory. The three methodologies considered were;

- The Rationale method
- Use of the Alligator River Envelope curves
- Use of regression relationships derived from flood frequency analysis of gauged catchments in the vicinity of Gold and Maud Creek.

Use of the Alligator River Envelope curves was not pursued after a telephone conversation with Lakshman Rajaratnam (21/06/07), Senior Water Resources Engineer at the land and water division of the Department of Natural Resource, Environment and The Arts (formerly the DLPE). The Alligator River Envelope Curves are no longer used by the department due to more up to date methods such as the Flood Frequency assessment conducted by KBR-Halliburton. After estimating flows using both the Rationale Method and the Flood Frequency Method (as described in the Halliburton-KBR report *Alice Springs-Darwin Railway Regional Flood Frequency Assessment*) the Rationale Method was adopted as the results it produced were more conservative.

2.1.2 Rational Method

The Rational Method is a universally accepted simplistic method to calculate the peak flood flows of selected events from an average rainfall intensity of the nominated event. The Rational Method incorporates the intensity of the rainfall, the area of the catchment and a coefficient of runoff.

The coefficient of runoff for a catchment depends on the following inter-related factors:

- Soil type and permeability;
- Land vegetation type, density and slope; and
- Intensity of rainfall.

The Rational Formula used for the estimation of the peak discharge is:

$$Q = 0.00278 C I_{t_c,Y} A$$

Where

Q = Peak discharge (in m³/s);

C = A dimensionless run-off coefficient;

I = Mean rainfall intensity (mm/hour) of a storm of the design ARI and duration equal to the time of concentration, t_c;

A = Catchment area (ha);

The relevant equation to calculate t_c is given below (AR&R, 1987).

$$t_c = \frac{58.5xL}{A^{0.1}xS^{0.2}}$$

The Rational runoff Coefficient was interpolated from the values given in AR&R for the Northern Territory. The typical lithology of the Maud Creek area is that of rock overlain by thin soils. Based on the interpolation of the coefficients given in AR&R for the Northern Territory and the nature of the soil, a coefficient of 1.0 was assumed for a 1:100 year ARI event. This value was also used in the calculation of the 1:500 ARI event and the PMF.

C = Coefficient 1.0

The peak rainfall intensity data for 1 hour, 12 hour and 72-hour durations for 2 and 50-year ARI's, geographical factors for 2- and 50-year ARI's, and average regional skewness were obtained from AR&R (1987). The rainfall intensities (mm/hour) for different durations and ARI's between 1 and 100 years

were then computed for Gold Creek and Maud Creek to calculate peak discharges for a 1:100 year ARI event.

2.1.3 1:500 Year ARI event

To estimate the 1:500 ARI event, guidance given in AR&R – *Estimation of large floods (2001)* was followed and used to interpolate the 1:500 year ARI rainfall event utilising other estimated rainfall intensities including the 1:100 year ARI event and Probable Maximum Precipitation (PMP). The estimated rainfall intensity was then applied to Rational Method to give design flows for a 1:500 year ARI event.

2.1.4 PMF

The PMF was derived utilising the Generalised Short Duration Method (GSDM) for Gold Creek and the Generalised Tropical Storm Method (GTSMR) for Maud Creek. These two methodologies were used as the design storm events varied in duration for each catchment. From these calculations the PMP for each catchment was estimated. From this value, rainfall intensity was derived and used in the Rational Method to produce the PMF flows.

2.1.5 Verification of Flows

There are no rainfall gauges with sufficiently long enough records located within area of the Maud Creek site or the catchments of interest. However, a review of daily records from pluviometers in adjacent areas would suggest that the rainfall intensities being used to calculate flows are higher for 1:50 year events. Records at the stations do not go back 100 years so no actual rainfall events can be considered as having a 1:100 ARI.

Gold Creek and Maud Creek are not gauged. Gauged records from surrounding catchments extend back to 1957. This limits the confidence when extrapolating flows for estimation of 1:100 year ARI events. Results from the flood frequency analysis, which are based on flow data from 16 gauging stations within the Katherine area, when extrapolated to 1:100 ARI events, are lower than the Rational Method estimates.

The flows used to model the 1998 Katherine River flood, highlighted in the *Katherine River Flood Study (2000)*, included estimated flows from the entire Maud Creek catchment. These flows were estimated at approximately 1800 m³/s. When compared to the 1:100 ARI flows estimated using the Rational Method, they would suggest that the Rational derived flows are conservative.

The verification of flows for 1:500 and PMF flows are not viable using local data.

2.2 Estimation of Flood Elevations

A hydraulic model representing the Maud Creek site was developed using the modelling package HEC-RAS and a Digital Elevation Model (DEM) of the mine site and surrounds. Cross sections were produced along the reaches of Gold Creek and Maud Creek at, approximately, 200 m intervals. Cross sections were also inserted where a significant topographical change occurred. The cross sections represented not only the River channel itself but also the potential floodplain of both creeks. The final downstream boundary of the model was taken at a natural hydraulic structure. At this point, the channel steepened and narrowed which could possibly cause flood flows to back up, increasing the flood elevations at the Maud Creek site.

It has been assumed that there are no permanent access roads to the pit that cross either Gold Creek or Maud Creek. If an all weather access road was proposed and crossed either Creek, then a detailed assessment on its impact on flows and flooding in either of the creeks would need to be undertaken as this would likely exacerbate flooding.

Figure 3 shows a typical Gold Creek cross section. It shows the main creek channel marked by the bank station points. The rest of the cross section details the potential floodplain. The hydraulic model was developed to assess the potential routing of the design flood event and therefore try and estimates the extent of any flooding and the depths of flooding along the cross-sections.

Channel and Floodplain roughness were estimated using limited photographs at various locations along both Creeks and using aerial photographs. Using the criteria produced by Chow and highlighted by French (1985) roughness coefficients were estimated. The coefficients also allow for observed moderate tortuosity of the Creeks. The values used in the Hardcastle and Richards report *Flood study for Gold Creek Diversion (1998)* were also considered.

2.2.1 Potential Influence of a Flooding Katherine River

Maud Creek is a tributary of the Katherine River. There may be potential for the Katherine River to exacerbate flooding at the Maud Creek site if it was also in flood via the ‘backing up’ of Maud Creek flood waters.

To estimate any potential impact of the Katherine River on flood elevations at the Maud Creek site, predicted flood elevations from the January 1998 flood (the worst recorded flood on record) were used in the HEC-RAS model to show any potential effect. The flood was estimated to have an ARI of 1:155 years. The various flood depths were taken from the *Katherine River Flood Study (2000)*. The Katherine River flood levels were entered in to the downstream boundary condition of the HEC-RAS model

Further sensitivity analysis was also carried out on the potential impact of Katherine River flood levels on Maud Creek flood elevations.

2.3 Flood Mapping

Flood depths and extents produced in the HEC-RAS model were exported back into the DEM. Depths and extents between each cross section were then interpolated and compared to topographical relief. The flood boundary is where the ground surface and flood depth intersect.

3.1 Estimated Flows

Table 2 shows estimated design flows developed using the Rational Method for each nominated flood event at each of the three locations along Gold Creek and Maud Creek. As would be expected, the PMF flows are significantly higher than those of the 1:100 and 1:500 year ARI events. The PMF is estimated to have an annual exceedence probability of least a $1 \text{ in } 10^7$ years. These flows have then been used in the HEC-RAS hydraulic model to produce flood elevations for the Maud Creek site.

Table 2: Estimated Flows

Node	Reach	1:100 (m ³ /s)	1:500 (m ³ /s)	PMF (m ³ /s)
1	Gold Creek	296	352	1569
2	Maud Creek	1424	1560	5223
3	Combined catchment	1513	1646	6173

3.2 Flood Elevations

3.2.1 100 Year ARI Event

Table 3 compares Maud Creek pit bund elevations to Gold Creek 1:100 ARI flood levels. It clearly shows that the Pit bund is not over topped during a 1:100 year flood event. The water surface level gets within 2.22 m of the top of the bund at Cross section 1941.

Table 3: Current Pit Bund Elevations Compared to Flood Elevations for a 1:100 Year ARI Event

HEC-RAS Cross section Ref	Maximum Pit Bund Elevation at Cross Section (mAHD)	Maximum Flood Elevation at Cross Section (mAHD)	Variation (m)
1941	145.96	143.74	2.22
1437	147.01	141.90	5.11
1322	147.20	141.53	5.67

Figure 4 shows a modified HEC-RAS schematic view of the location of the referenced HEC-RAS cross sections.

3.2.2 1:500 Year ARI Event

The 1:500 year ARI event water elevations are higher than those of the 1:100 year ARI event as would be expected. However, as table 4 shows, the water surface elevations are below the top of the bund. The water surface level at cross section 1941 gets within 2.06 m of the top of the bund.

Table 4: Current Pit Bund Elevations Compared to Flood Elevations for a 1:500 Year ARI Event

HEC-RAS Cross section Ref	Maximum Pit Bund Elevation at Cross Section (mAHD)	Maximum Flood Elevation at Cross Section (mAHD)	Variation (m)
1941	145.96	143.90	2.06
1437	147.01	142.06	4.95
1322	147.20	141.68	5.52

3.2.3 PMF

Table 5 compares the pit bund elevations to flood elevations estimated for the PMF. Again the water surface levels do not exceed the height of the pit bund. However, the variation between the elevation of the pit bund and water elevation is vastly reduced. At cross section 1941, there is only a 0.07 m difference between the maximum height of the pit bund and the water surface elevation of the PMF. With such a small variation between the water surface elevation and the height of the pit bund any wave action that may occur due to high winds associated with a cyclonic event would likely be sufficient to overtop the pit bund.

Table 5: Current Pit Bund Elevations Compared to Flood Elevations for the PMF

HEC-RAS Cross section Ref	Maximum Pit Bund Elevation at Cross Section (mAHD)	Maximum Flood Elevation at Cross Section (mAHD)	Variation (m)
1941	145.96	145.89	0.07
1437	147.01	145.12	1.89
1322	147.20	145	2.20

3.2.4 Katherine River Flood

Floods in the Katherine River were analysed to assess their impact on flood levels in Maud Creek. As there is no gauging station near the confluence of Maud Creek and the Katherine River, data from a longitudinal profile for the January 1998 estimated Katherine River flood has been used in the HEC-RAS model to assess the impact floods in the Katherine River have on flood levels in Maud Creek. This flood was estimated to be a 1:155 ARI event. The Confluence between Maud Creek and the Katherine River is shown in Figure 5.

Several predicted flood elevations were used at different Average Mean Thread Distances (AMTD) along the Katherine River. These corresponded to the approximate location of the confluence between Maud Creek with the Katherine River. These flood levels were taken from the *DLPE Katherine River Flood Study (2000)*

As table 6 shows, the selected Katherine River flood levels do not influence the estimated flood elevations at the Maud Creek Site. Further sensitivity analysis would suggest that flood levels at Maud Creek would only be influenced if flood levels of 144 mAHD or greater were experienced at the confluence of Maud Creek and the Katherine River. This would be highly unlikely.

Table 6: Impact of Predicted Katherine River Flood elevations for the January 1998 Flood

Katherine River AMTD (m)	Water Level (mAHD)	Increase in Flood Elevation at the Maud Creek Site (m)
35000	109	0
40000	110.5	0
45000	113	0
50000	115.5	0

The relief of the Maud Creek Site and the surrounding landscape suggests that the site would not be inundated by the flood waters of the Katherine River.

3.3 Flood Map

Figure 5 shows the area that would be inundated in a regional context. Figure 6 highlights the extent of the flooding caused by each of the selected flood events for entire hydraulically modelled area. Figure7 focuses on the Maud Creek site. It shows that the pit is not inundated by any of the flood events and highlights those areas of the site at risk of flooding during these events. It also shows that an existing spoil heap would be reached by all of the design flood events. The dark blue represents the extent of the

estimated PMF flood, the turquoise the extent of the 1:500 year ARI flood and the light blue the extent of the 1:100 ARI flood event.

4.1 Conclusions

4.1.1 Review of Previous Reports

The list of previous hydrology reports on Maud Creek and surrounds are listed under references. The relevant data has been used for this flood study.

4.1.2 Update of Meteorological data

Meteorological data has been updated. The rainfall data was extended to include records up to June 2007 where possible.

4.1.3 Estimated design flows

Flood flows for 1:100 and 1:500 year ARI events and the PMF for Gold Creek Maud Creek have been calculated and estimated as follows:

Node	Reach	1:100 (m³/s)	1:500 (m³/s)	PMF (m³/s)
1	Gold Creek	296	352	1569
2	Maud Creek	1424	1560	5223
3	Combined catchment	1513	1646	6173

4.1.4 Hydraulic Model

A representative hydraulic model for the Maud Creek site was developed using the modelling package HEC-RAS. This was used to estimate flood flow elevations for the various design floods. Flood maps of the site show the extent of inundation caused by the various design flood events.

4.1.5 Pit Inundation

The water levels associated with the design flood events were analysed in relation to the current pit bund elevation. We conclude that of the design floods none will over top the bund. The bund elevation is therefore adequate protection against floods

4.1.6 Katherine River flood influence

The impact of simultaneous flood events in the Katherine River and Maud Creek was evaluated and found that an observed 1:155 year flood event will not impact on design flood levels around the Maud Creek project site.

4.1.7 Flood Maps

This report contains flood maps showing inundation areas around Maud Creek for various design flood events

4.1.8 HEC-RAS Model

The flood levels have been estimated using peak flows in a steady state hydraulic model. This assumes that the Peak flows from all the catchments occur at the same time and constantly. In reality, catchments are likely to behave in different ways depending on their size and characteristics. The flood is more likely to flow as a 'wave' rather than at a constant flow. For example, a 1:100 year ARI Katherine River flood wave is unlikely to converge at the same point and time as a 1:100 year ARI Maud Creek flood wave, as the Katherine River catchment is many times larger than the Maud Creek catchment. However, for the estimation of design levels, the steady state approach offers conservative results that allows for the possible worse case scenario and confidence in the results.

4.2 Recommendations

4.2.1 The Pit

Maud Creek Pit is not inundated by any of the flood events, although caution with the PMF results has been suggested. A review of pit bund levels should be undertaken to ensure bund height is greatest at the location where the highest flood water levels are anticipated.

An investigation into the bund design should be undertaken to see if it is suitable to act as a water retaining structure for such flood events. Outside of the bund, suitable measures should be implemented to protect it from scouring as the bund redirects natural flow from Gold Creek under flood conditions.. The investigations on the stability of the bund should be undertaken utilising the results estimated in this report.

4.2.2 Other areas affected by floods

The structure and composition of the waste dump should be considered as flooding could interact with wastes stored in the dump. Where possible, infrastructure should not be built in the estimated flood plain of the 1:100 year ARI flood event. If infrastructure is constructed in the flood plain, suitable flood

mitigation should be incorporated in to its design such as raised floor levels in buildings. Flood management plans, such as the instigation of early warning systems and safe evacuation routes, should also be considered.

5.1 References

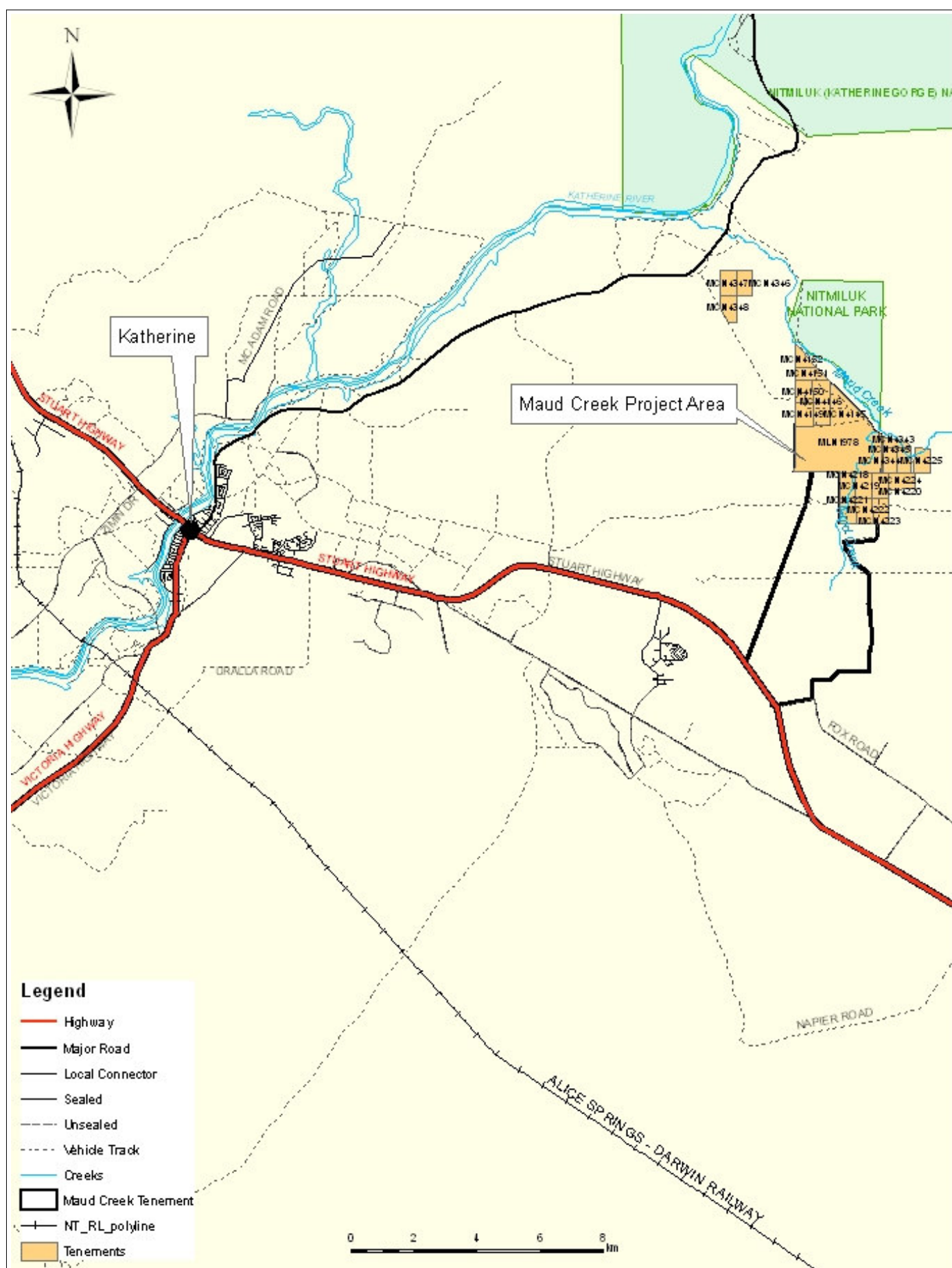
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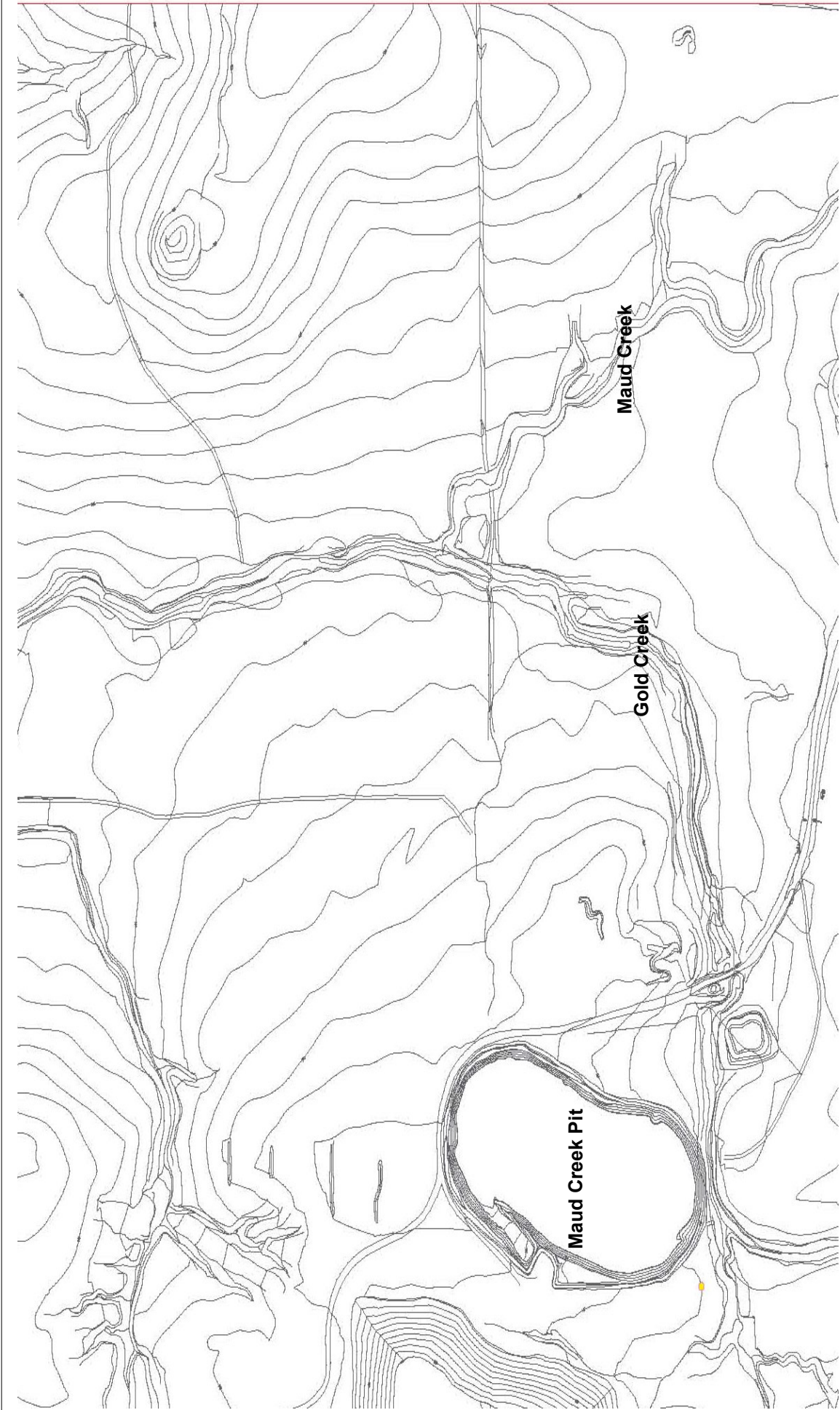
The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between June to July 2007 and is based on the information reviewed and received from Terra Gold Limited at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

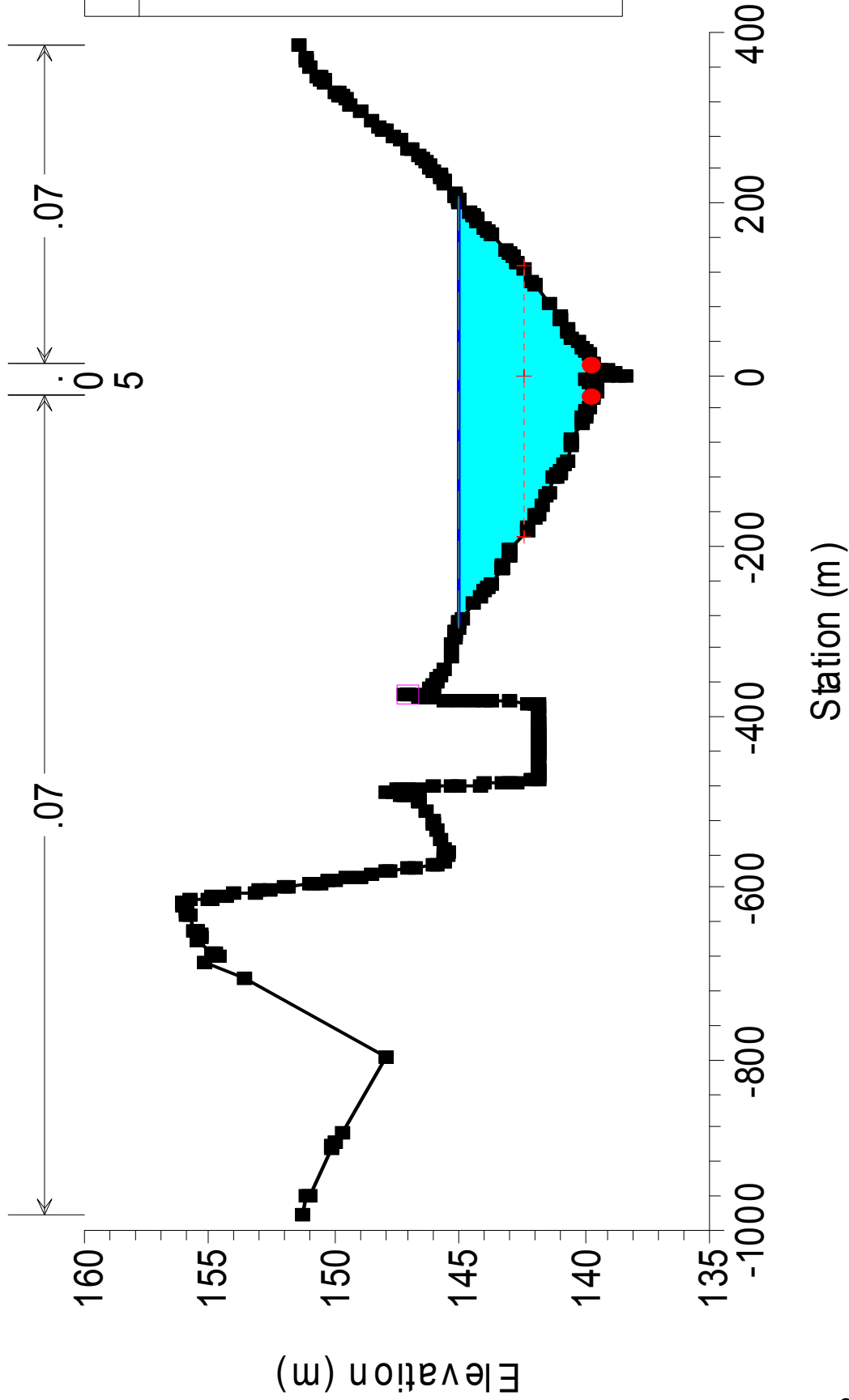
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Source:		Project:		Title:	
Client:		Maud Creek Flood Study		Maud Creek Project Area	
Terra Gold Ltd					
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		Job No: 42213799	File No: 42213799.srf	Figure: 1	A4

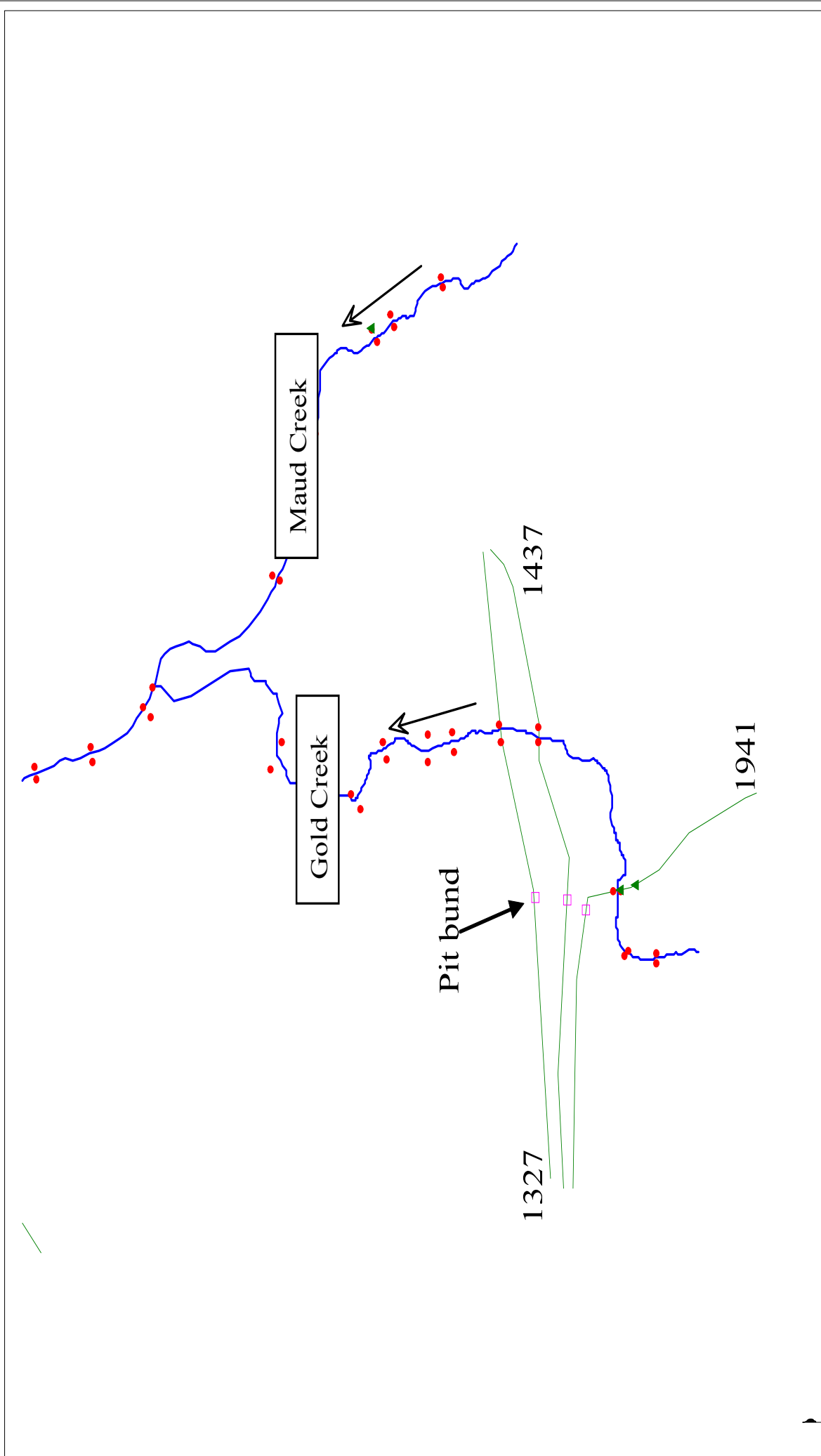


Terra Gold Ltd	Maud Creek Flood Study			HEC-RAS Schematic Showing the Location of Specific Cross-Sections	
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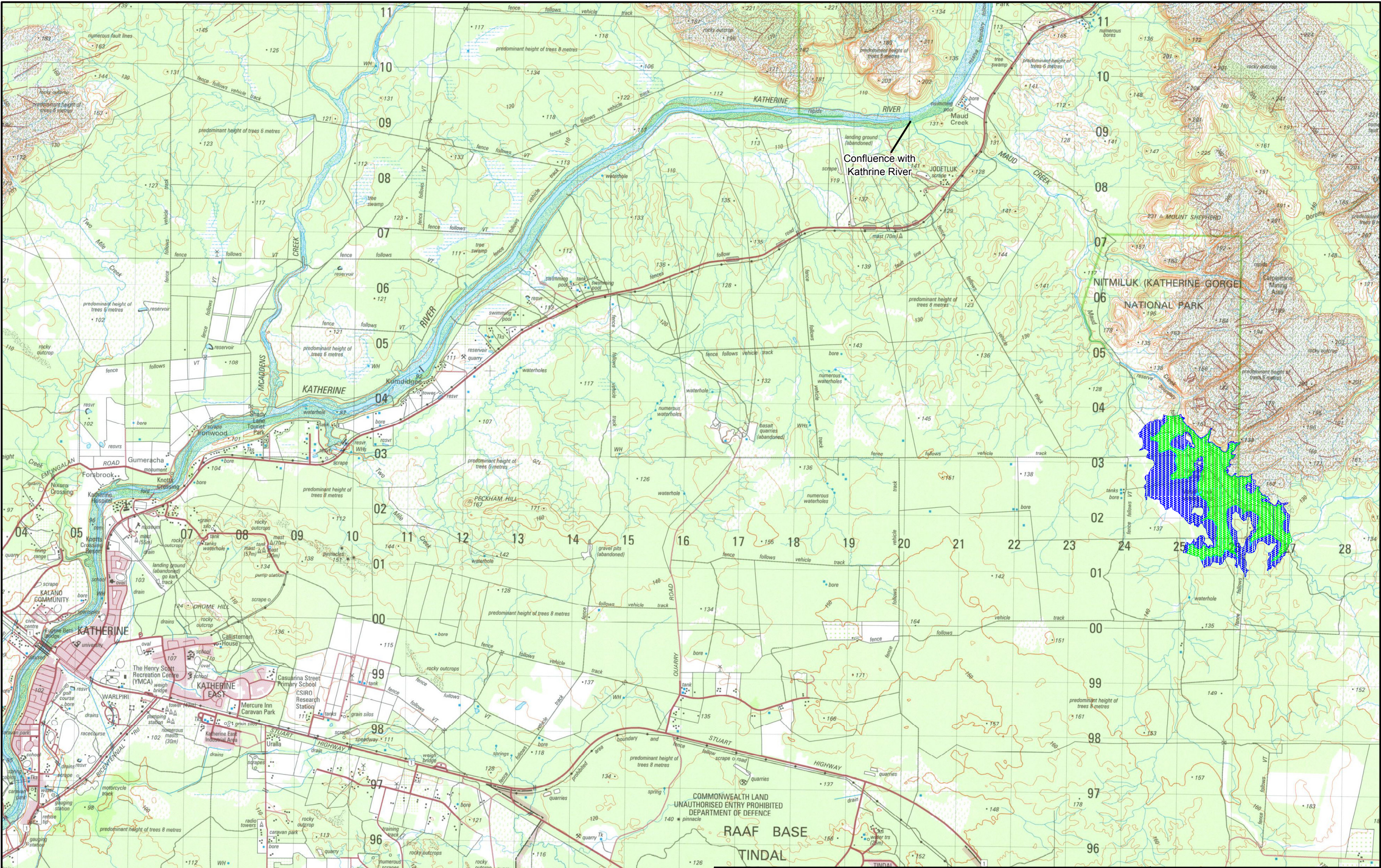


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	Drawn: DB	Approved: AM	Date: 12/07/07	Figure: 3	Rev: A
Job No: 42213799			File No.: Fig3.srf		





Terra Gold Ltd	Maud Creek Flood Study			HEC-RAS Schematic Showing the Location of Specific Cross-Sections	Figure: 4	Rev A
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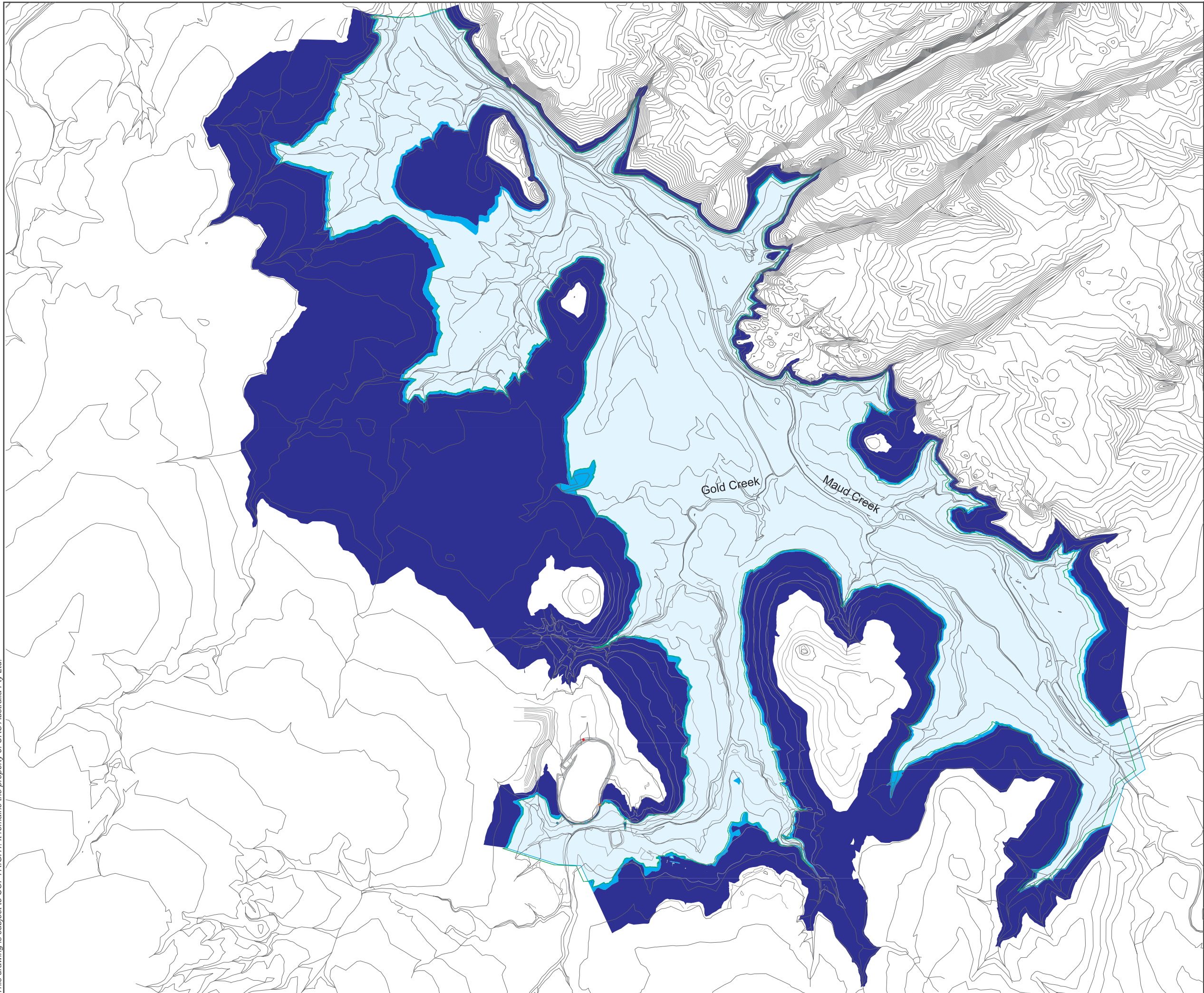


Legend

- 100 Year Flood Event
- 500 Year Flood Event
- Predicted Maximum Flood Event

Client	CLIENT NAME	Project Maud Creek			Title Flood Event Extents			
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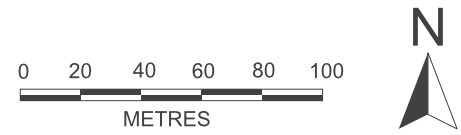
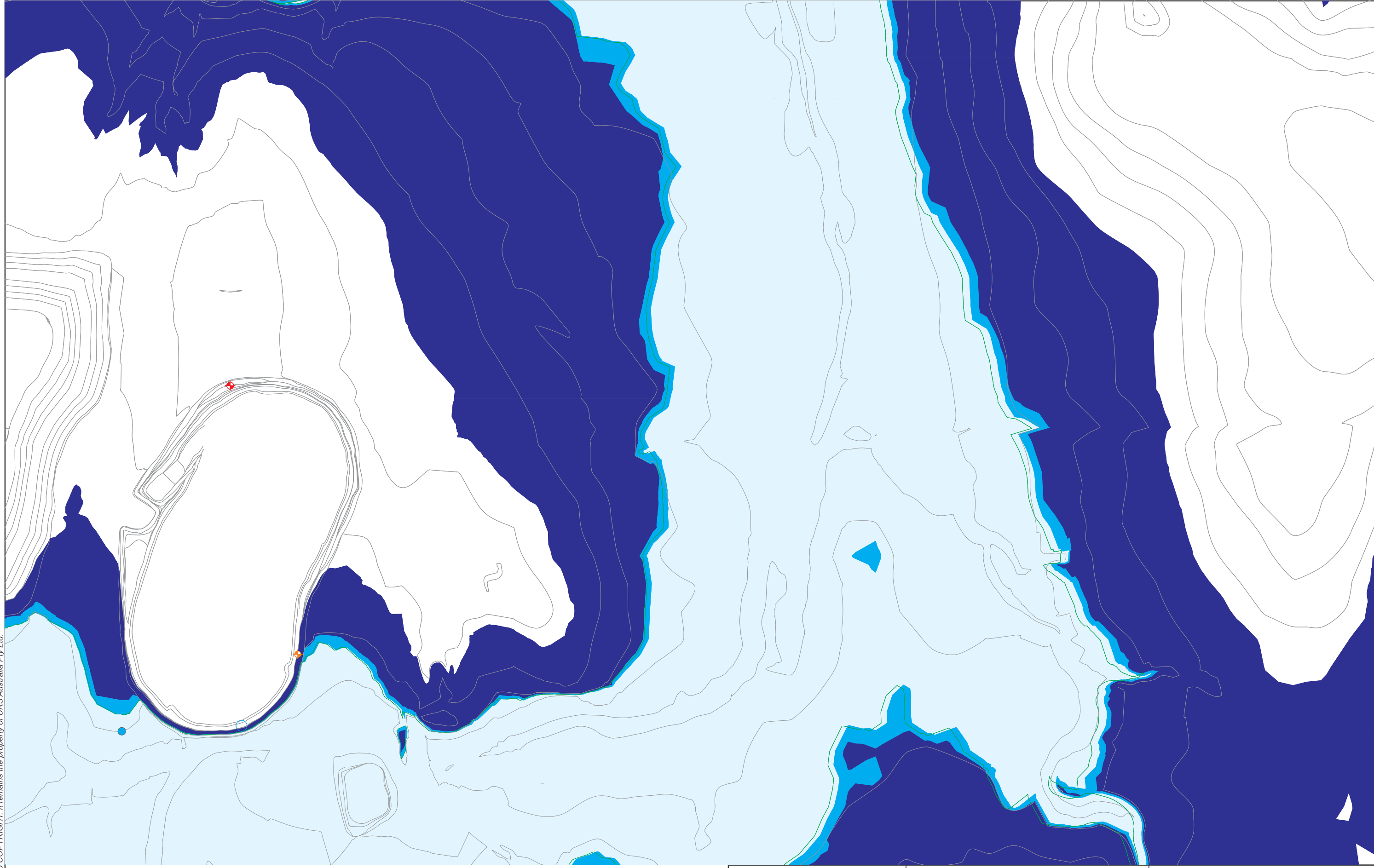
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Job No. 42213799	File No. : \$\$FILE	
Client	Terra Gold Ltd	
Project	Maud Creek Flood Study	
Title	Total Flood Area Map	
Figure: 6		Rev. A A3
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Client Terra Gold Ltd		Project Maud Creek Flood Study		Title Site Flood Map	
		Drawn: TDR	Approved: TDR	Date: 31/07/2007	Rev. A
		Job No.: 42213799	File No.: \$\$FILE	Figure: 7	A3