Appendix 17.

SLR Consulting Australia (2020h) *Rum Jungle Mine Closure Remediation – East Branch Finniss River – River Reinstatement and Flooding Report.* Report to the Department of Primary Industry and Resources, Northern Territory.

NORTHERN TERRITORY GOVERNMENT

Department of **Primary Industry and Resources**

RUM JUNGLE MINE CLOSURE REMEDIATION

East Branch Finniss River - River Reinstatement and Flooding Design Report

Prepared for:

NT DPIR - Mines Division
GPO Box 4550
Darwin, NT, 0801

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with NT DPIR - Mines Division (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
680.10421.90060-R02-v1.0 Issued for Implementation	12 June 2020	Peter Cupitt	Paul Delaney / D O'Toole / DPIR	Danielle O'Toole
680.10421.90060-R02-v1.0 Issued for External Peer Review	26 May 2020	Peter Cupitt	Paul Delaney	Danielle O'Toole

EXECUTIVE SUMMARY

The former Rum Jungle Mine includes two large pits, known as the Main Pit and Intermediate Pit, which were constructed within the existing floodplain of the East Branch Finniss River (EBFR). To accommodate historic mining, a river diversion was constructed to the south of the two pits, and flood bunds established for flood control. Since initial closure of the mine site, drainage structures allow a portion of flows from the EBFR to run into and through the Main and Intermediate Pits but the bulk passes through the main made diversion structure to the south of the Pits – East Finniss Diversion Channel (EFDC).

Remedial solutions for the site have been developed in consultation with the Traditional Owners (TO) of the land, the Kungarakan and Warai peoples and involved a multi-disciplinary owners and consultant team. Important objectives are to restore the EBFR to its original alignment, provide a naturalistic watercourse which is long term stable preserves cultural aspects of the site and allows for aquatic organisms to recolonise and utilise the site's aquatic features.

Key features of the project relevant to the water course, flooding and riparian zones include:

- Restoring the original alignment of the EBFR. This will involve the reconnection and reconstruction of the flow path that safely conveys water through the Main Pit lake, the original riverbed, the Intermediate Pit lake and then out to the main channel of the EBFR (K. Martin-Stone, 2019);
- Removal of the existing man-made inlet and outlet structures; opening of the surrounding man-made embankments to provide an unimpeded natural flow path;
- Provide adequate floodplain conveyance so that flood levels are not increased at cultural significant sites upstream of the Main Pit;
- Inclusion of a defined alignment for low flows which can be successfully revegetated and emulate the nearby natural creeks, while avoiding highly geometric channel forms;
- Inclusion of very shallow slopes along the floodplain where slow moving water will allow for native fish passage;
- Provision of erosion protection in the form of designed rip rap infilled, submerged and underlain with a sandy soil growth medium;
- Establishment and maintenance of native trees, shrubs and grasses within the riparian zone;
- Backfilling of the Main Pit to create a shallow lake;
- Retention of the Intermediate Pit as a deep lake; and
- Potentially back-filling of the existing river diversion should the reconstructed flow path be sufficiently stable to support long term full flows. The decision making for this process is planned to occur after the completion of the Main Pit Backfilling works are complete.

Whole of site remediation will be carried out as described in (SLR, 2020c). Key steps for restoring the EBFR to its former alignment are outlined below.

EXECUTIVE SUMMARY

- The EBFR realignment works would commence immediately and prior to the Main Pit backfilling operations. This is to provide the longest possible period for vegetation to establish before river flows are re-introduced to the former river alignment. Research has concluded that a period of 10 years is required for trees, shrubs and grasses to establish in the riparian zone to withstand large flood flows (Karen White, Darcy Moar, Ross Hardie, D. B. & R. L., 2014). For this reason, the return of the EBFR to its original alignment may be performed progressively over approximately 5-8 years however this timeframe may vary according to the progress of the revegetation. The flow from the EBFR may therefore be split between the existing diversion and the realignment for some time or permanently.
- Flows would be progressively increased through a regulation structure at the inlet of the Main Pit.
- The existing river diversion will remain fully functional while the Main Pit is being backfilled. A temporary crossing will be constructed across the diversion for a haul road. The crossing would be removed during the river diversion backfilling.
- The capping material for the Main Pit has been designed to safely pass the 1% AEP flood event without bed scour.
- The bedding material of the flow path of the EBFR river realignment would be designed to safely pass the 1% AEP flood event without bed scour. The vegetation will be required to maintain the stability of the growth media within this flow path.
- Irrigation water for the establishment of the realignment vegetation would be supplied by the water treatment plant.
- The haul road crossing over the newly constructed channel would be constructed after the WSF’s are completed.
- The re-establishment of vegetation in the realignment will govern the timing and extent of flow splitting between the existing and former EBFR flow path. Continual monitoring will be necessary before an informed decision can be made.

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APPENDICES

1 Introduction

A cornerstone cultural objective for rehabilitation of the former Rum Jungle Mine site is to restore the East Branch of Finniss River (EBFR) to its pre mining alignment, which runs through the Main and Intermediate Pits and fill the current manmade EBFR diversion which is not long term stable and geometrically uncharacteristic of the EBFR. The key environmental objective is to cease polluting the EBFR. Additional details can be found in the Draft EIS (NT-DPIR, December 2019).

This report documents objectives and design rationale for the river diversion, construction sequencing requirements, and integration with other rehabilitation activities. It also describes the existing and post rehabilitation flood behaviour for flows along the EBFR and the designs implemented to prevent erosion. The passage of aquatic organisms requires a baseline flow rate for a portion of the season along with landscape and landform nuances to be built up from the foundation design provided in this report. These are described at a high level within this document. Further detail on these elements can be found in the Draft EIS (NT-DPIR, December 2019).

1.1 Project Background

The Northern Territory Government (NTG), represented by the Department of Primary Industry and Resources (DPIR), proposes the rehabilitation of the former Rum Jungle Mine site (the Project), located 6 km northwest of Batchelor, Northern Territory (NT). The project location and regional setting are shown on **Figure 1**.

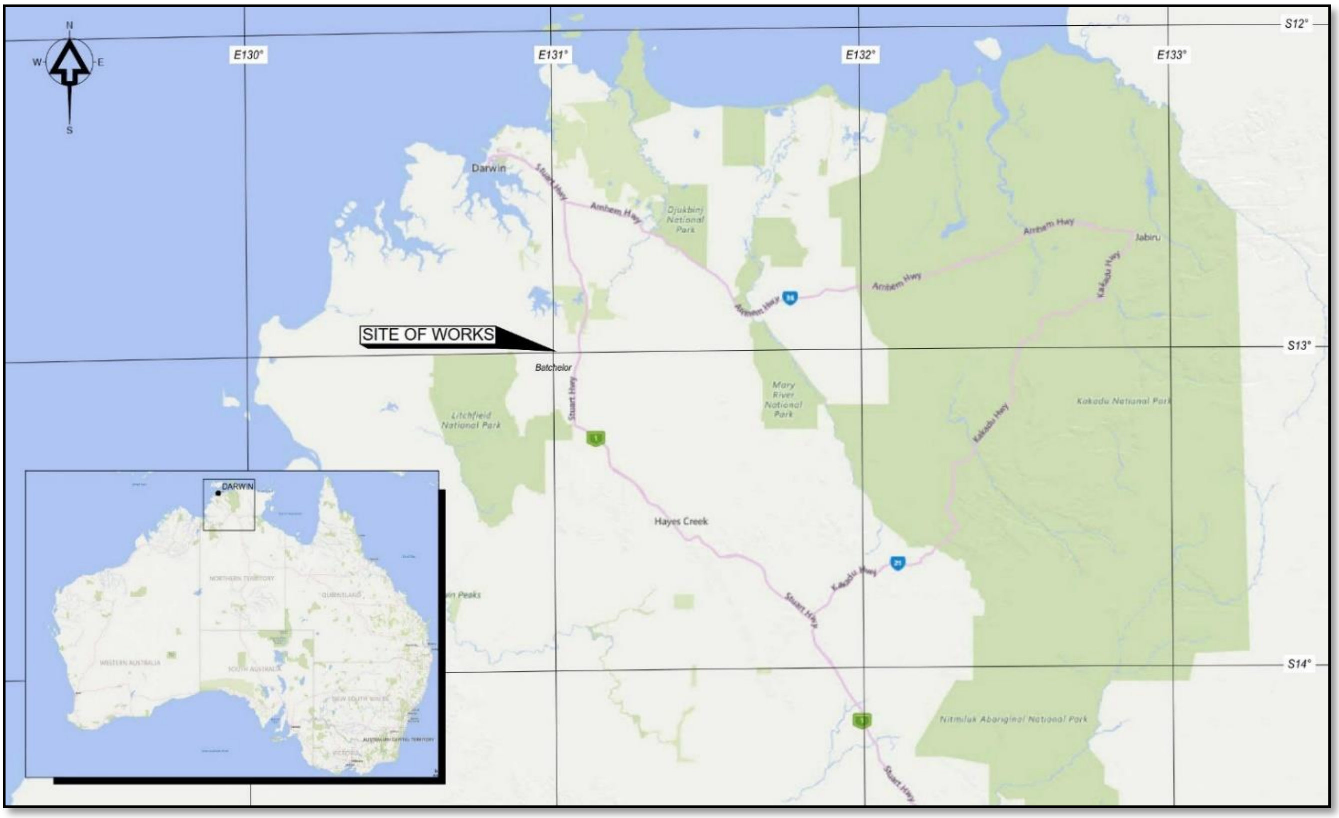

Figure 1 Project Location

The former Rum Jungle mine was rehabiliated in the 1980s, however recent studies indicate that not only has the site deteriorated and needs further rehabilitation, but that the traditional Aborignal owners cultural requirements have not been met. Since 2009, the NTG and the Australian Government have been working under a National Partnership arrangement to complete investigative work to inform a rehabilitation plan, deliver site maintenance and continue environmental monitoring. The results of these programs have been used to develop an improved rehabilitation strategy that is consistent with the views and interests of traditional Aboriginal owners and that meets contemporary environmental and mined land rehabilitation standards.

The Project's high-level objectives are two-fold and focus on environmental remediation and restoration of cultural values of the site as described below:

Improve the environmental condition onsite and downstream of site within the East Branch Finniss River (EBFR). This includes the following key outcomes:

- Improved surface water quality conditions within EBFR in accordance with locally derived water quality objectives (LDWQOs) (Hydrobiology, 2016).
- Achieve chemically and physically stable landforms (RGC, November 2019).
- Support self-sustaining vegetation systems within rehabilitated landforms (Hydrobiology, 2016).
- Develop physical environmental conditions supportive of the proposed Land Use Plan (Hydrobiology, 2016).

Improve site conditions to restore cultural values. This includes the following key outcomes:

- Restoration of the flow of the EBFR to the original course as close as possible (K. Martin-Stone, 2019).
- Remove culturally insensitive landforms adjacent to sacred sites (NT-DPIR, December 2019).
- Return living systems including endemic species to the remaining landforms (Hydrobiology, 2016).
- Preserve Aboriginal cultural heritage artefacts and places (NT-DPIR, December 2019).
- Isolate sources of pollution including radiological hazards (EcOz, 2019a).
- Maximise opportunities for Traditional Owners (TO) to work onsite to aid reconnection to country (NT-DPIR, December 2019).

1.2 Current Site Condition

Historic mining and rehabilitation activities have altered the landscape within the former Rum Jungle Uranium Field, most prominently seen at the Rum Jungle site. Further rehabilitation will see a final landscape that, whilst still altered, has improved functionality and reduced environmental and cultural impact. The Rum Jungle complex is a typical example of an open pit legacy mining site of which there are many examples across Australia's landscape. Rum Jungle features, including the manmade flow diversion around open pits and between waste rock dumps (WRDs) are show in **Figure 2**.

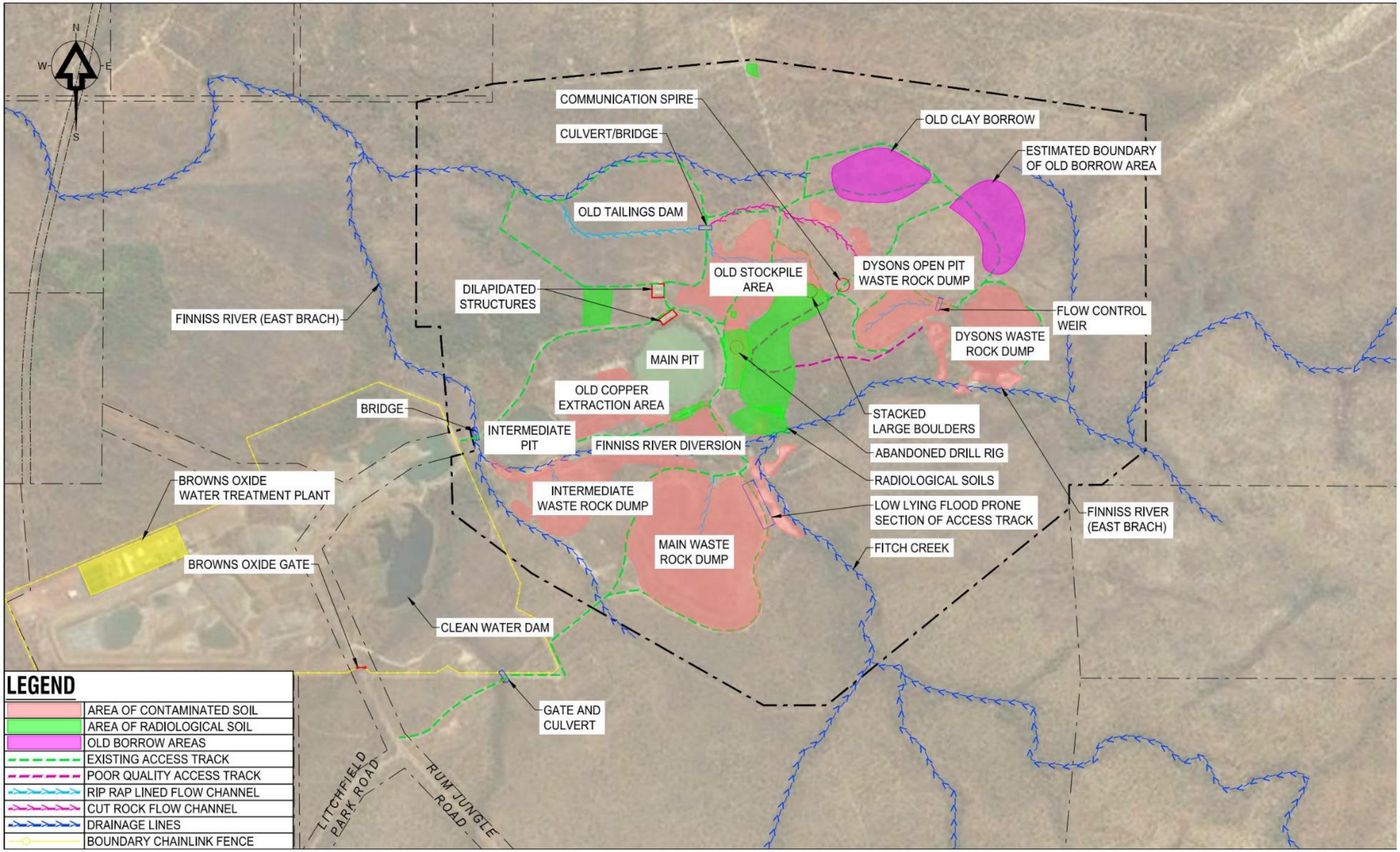

Figure 2 Existing flow paths with the manmade diversion channel flowing south of the two open pits

The most significant contamination mechanism at the Rum Jungle site is the impact to ground and surface waters by Acid Metalliferous Drainage (AMD). The primary AMD sources are the sulphide-bearing waste rock in the historic WRDs, leached low-grade ore and contaminated soils placed in shallow zones of Dyson's Pit during initial rehabilitation in 1984/85. Further groundwater contamination has occurred due to metalliferous liquor lost during an experimental heap leach operation from 1965-1971 in the Copper Extraction Pad area.

The key objective of the rehabilitation project is to improve water quality within the EBFR and Finniss River proper. Copper is the primary Contaminant of Concern as described in the Draft EIS Rum Jungle Rehabilitation (NT-DPIR, December 2019). Impacts to the cultural landscape of historic activities are related to the course of the EBFR and the general environmental health onsite.

For comprehensive detail on the site condition, studies into the contamination processes, details regarding the contamination pathways and receptors; the reader is referred to the Draft EIS Rum Jungle Rehabilitation (NT-DPIR, December 2019). Significant work has been completed over recent years to characterise site conditions and to establish an agreed vision for future land use with Traditional Owners.

1.3 Historical EBFR Condition

The Finniss River has been shaped by the intense monsoonal rainfall which are responsible for high rates of sediment delivery from an eroding sand bearing geology. The EBFR is an intermittent stream within a distinct channel that dries to a number of pools in the mid to late Dry season depending on the amount of rainfall in the preceding Wet season. The bed is typically broad with low, earthy banks 1 to 3 m high with many sandy to rocky mid-stream shoals. The riparian corridor typically merges rapidly with surrounding Eucalypt woodland areas with little to no surrounding floodplain areas (Hydrobiology, 2016).

Figure 3 EBFR typical channel sectional profile

Figure 3 is an example of the unmodified river system upstream of the mine site. It is likely to have been typical of the original EBFR which passed through the pits. The historical flow path of the EBFR pre-mining was estimated from historical photographs and is plotted in **Figure 4** (K. Martin-Stone, 2019).

Figure 4 Original course of the East Branch Finniss River (K. Martin-Stone, 2019)

The river immediately upstream of the Main Pit entrance and downstream of the iron bridge crossing of the EBFR is virtually unaltered. The design objective is to restore the flow path in between to pre mining conditions with the pits retained as permanent lakes.

2 Design Objectives for Flooding and River Reinstatement

2.1 Objectives

Remedial solutions for the site have been developed in consultation with the Traditional Owners and involving a multi-disciplinary consultant team. The agreed collective objectives are as follows:

- Ensure no increase in flood levels upstream of the Main Pit;
- Convert the Main Pit into a permanent shallow lake;
- Retain the Intermediate Pit as a deep lake;
- Remove the manmade concrete culverts from each of the pits;
- Facilitate aquatic organism passage by ensuring zones of low velocity along the flood fringes at varying flood heights and resting places at intervals with zero velocity;
- Inclusion of a defined low flow alignment which follows the original alignment for which can be successfully revegetated and have the appearance of nearby natural creeks, while avoiding highly geometric engineered channel forms; and
- Work towards backfilling the existing manmade EBFR diversion channel to restore the EBFR to its original alignment though the Main and Intermediate Pits;

To achieve the above goals, the following design specific aspects are to be implemented during the Main Pit backfilling phase:

- Comply with water quality requirements during the construction;
- Provide flood immunity of mine site infrastructure during the rehabilitation earthworks project;
- Provide a temporary crossing of the EBFR diversion channel with an earthen embankment containing appropriately sized pipes for flood transmission to safely pass a 20% AEP (1 in 5 year ARI) without overtopping;
- provide a passage for fish with a natural river bed through the crossing by means of installing a low flow arch 2.3m in width bedded onto the existing bedrock platform. The floor of the arch is therefore the original creek bed and as close to natural conditions as possible. Current research has shown that the EBFR contains a chemical barrier to fish migration (Hydrobiology, 2016) which will reduce as the project progresses due to the progressive treatment of groundwater. This may improve the required conditions;
- Backfill the Main Pit with waste rock and line the finished surface with inert material to2m below the lowest seasonal surrounding groundwater level. Profile main pit lake crests to improve aesthetics, stability and provide vegetation substrates; and
- Divert out of catchment surface drainage away from the construction zone where feasible.

The following design specific aspects are to be implemented on the site post Main Pit backfilling:

- Comply with water quality requirements during the construction;
- Provide a naturalistic watercourse which is long term stable;
- Include very shallow slopes along the floodplain where slow moving water will allow for aquatic organism utilisation and passage; and
- Design the surface with an erosion potential to safely withstand a 1% AEP (1 in 100-year ARI) flood event without bed scour.

2.2 Water Quality Objectives

Water quality objectives for the project are developed by Hydrobiology which identifies Locally Derived Water Quality Objectives (LDWQO) for water quality (Hydrobiology, 2016). These are also discussed in detail in the SLR Report on the Water Treatment Facility Design Report (SLR, 2020a).

2.3 Construction phase requirements

2.3.1 Main Pit backfilling

Backfilling of the Main Pit will likely result in AMD impacted water which will not meet the water quality limits suitable for release to the EBFR. The Intermediate Pit water will also likely require treatment prior to release to EBFR. Water in these pits will be managed through:

- lowered operating levels maintained by a pump and treat operation;
- treatment in a designated water treatment plant; and
- untreated waters use for dust suppression and moisture conditioning on WSF construction zones of the site and treated waters on haul roads and revegetation irrigation if required.

Additional details are provided in the Draft EIS (NT-DPIR, December 2019) and SLR Water Treatment Facility Design Report (SLR, 2020a) with some important aspects summarised below.

2.3.2 Construction operating levels in pits

To prevent overtopping of the pits during a major flood event and to ensure the pits act as sinks to the surrounding groundwater; the following freeboards would be maintained throughout the backfilling operation by a pump and treat operation.

Table 1 Construction operating levels in the pits

Pit	Outlet Culvert Weir Level (m AHD)	Construction Operating Level Range (m AHD)	Drawdown depth from dry season level (m)
Intermediate	57.82m AHD	49 to 50	7.5 to 8.5
Main	59.95m AHD	58 to 59	0 to 1

2.3.3 Surface water diversion

Where practical, surface water runoff would be diverted away for the Main and Intermediate Pits to reduce the volume of water to be treated in the WTP. The inlet of the Main Pit and the outlet of the Intermediate Pit would be sealed to prevent inflow from the EBFR. The inlet of the Intermediate Pit and the outlet of the Main Pit would remain open to prevent local runoff from flooding the construction zone.

Temporary earth bunds are required to the south west of the Main Pit to divert surface runoff away from the pit. With the water diversion measures in place, the contributing catchment to the Main Pit would be approximately 17.6Ha and the Intermediate Pit 21.2Ha.

2.3.4 Erosion Sediment Controls

Additional water from site construction areas with ground disturbance would be managed in accordance with an Erosion and Sediment Control Plan (SLR, 2020b). Relevant aspects of this strategy are:

- Runoff from the West WSF would discharge directly into the Main Pit.
- Additional impacted water from sediment dams may be pumped or trucked back to the Main Pit, but the average (24 hour/7 day) rate across the wet season should not exceed 15L/s.

3 Construction Sequencing

3.1 General

Remediation of the landform is currently scheduled over a period of 10 years with a possible further 8 years of groundwater decontamination. Since the EBFR will be realigned to pass through the Main Pit, and the Main Pit will be backfilled to create a shallow lake, then the water course construction works will need to coordinate with works in the Main Pit and allow compliance with the LDWQO requirements. Key construction sequencing requirements for restoring the EBFR to its former alignment are outlined below.

3.1.1 Backfilling of the Main Pit

While the Main Pit is being backfilled to create a shallow lake, it should be isolated from flood flows along the EBFR. This would require:

- The existing EBFR diversion remain functional;
- The inlet to the Main Pit be sealed to prevent EBFR inflow. If required, a control structure installed on the culvert could be used to ‘top up’ water levels in the Main Pit;
- The bunds and drainage infrastructure southwest and northwest of the Main Pit be constructed to prevent out of catchment runoff entering the Main Pit;
- The outlet should remain open as potential surcharge flows would enter the Intermediate Pit which is artificially lowered; and
- A temporary crossing of the EFDC be constructed for backfill material haulage.

3.1.2 Construction of Re-alignment Watercourse

The permanent diversion of the EBFR should be constructed along its permanent alignment, to the extent practically compatible with other remediation works. Approximately 10 years may be required to allow time for the establishment of vegetation across the floodplain before the full EBFR flood flows are diverted (Karen White, Darcy Moar, Ross Hardie, D. B. & R. L., 2014), however partial flows may be allowed to pass after 5-8 years of revegetation progression. The decision making for this will take place in the future based on revegetation and stability monitoring of the newly reconstructed landform.

The following works would be carried out during the construction of the re-alignment of the EBFR. Coordination would be required with these activities:

- Bulk earthworks to remove the contaminated soils within the former copper heap leach area;
- The construction of the north south haul road to the west of the Main Pit;
- The construction of the road embankment with DN600 RCP to the northwest of the Main Pit; and
- The construction of the embankment crossing of the EBFR diversion.
- The culverts into and out of the Intermediate Pit would be removed and modifications to the manmade embankments completed.
- The outlet culvert and surrounding embankment of the Main Pit would be removed and armoured with rip rap and granular soil infill.

The following works would be carried out after the construction of the EBFR re-alignment:

- A regulation structure on the culvert inlet to the Main Pit would remain in place during the vegetation establishment period. This structure would allow some flow to pass through the re-alignment during the vegetation establishment period;
- The local diversion bunds would be removed to allow local runoff to enter the diversion riparian zone;

The EBFR flows will be introduced progressively over seasons, the monitoring of the channel vegetation and stability will indicate if and when 100% of flows can be safely returned to this pathway. If the re-alignment is deemed safe to accept the full flow, then the following works would be carried out after the vegetation establishment period:

- The regulated culvert inlet to the Main Pit and surrounding embankment would be removed and armoured with riprap and granular soil infill;
- The EBFR diversion would be backfilled.

3.1.3 Water Quality Verification

Prior to placement of the clean fill cap the Contractor will be required to ensure the water quality in the pit satisfies the LDWQO. Full flows from the EBFR will not pass through the Main Pit lake or newly formed channel during the vegetation establishment period of this landform.

3.1.4 Opening up Main Pit to EBFR

Progressive introduction and increase of EBFR flows to the Main Pit lake and reinstated channel should take place at a rate directed by the performance of the newly constructed landform. An adaptive management approach should be taken whereby performance of the landform directs the management of flows throughout the newly constructed channel.

The permanent full flows through the Main Pit will be opened up to the EBFR only when vegetation and landform stability allow this. This will involve removal of existing embankment and drainage structures at the upstream side of the Main Pit.

Works to open up the Main Pit to the EBFR should be carried out during the dry season due to flooding safety risk and the risk of works eroding during the construction period.

3.1.5 Filling of existing diversion

Once the Main Pit is opened up to the full EBFR, then works on the existing EBFR can commence. The backfill should be carried out during the dry season due to flooding safety risk and the risk of severe erosion during the construction period.

4 Estimation of Flood Flows

4.1 Hydrological Context

The Project area sits within the headwaters of the Finniss River catchment; the majority of the Project footprint is within the EBFR sub-catchment, the exceptions being Mt Burton and Mt Fitch which are adjacent to the West Branch of the Finniss River, and the low permeability borrow area which is adjacent to Meneling Creek (which flows into the West Branch of the Finniss River).

The EBFR is an intermittent stream which drains north-west, joining the Finniss River approximately 8km downstream of the Rum Jungle site. Base flow is generally not established until sustained monsoonal rains arrive. The Finniss River is a perennial river that flows to Fog Bay. During the Wet season the river often overbanks whilst during the Dry season the river typically consists of a series of pools about 1m in depth connected by shallower sections.

4.2 Reparameterization of the RAFTS model

SLR was engaged to peer review a flood estimation model of the Rum Jungle catchment prepared by Water Technologies in 2013 (Water Technology, 2018). Parameters in the Water Technology's hydrological model were calibrated to a flood frequency curve prepared by the Department of Land and Resource Management at a gauging station 5.6kms downstream of the site on the Eastern branch of the Finniss River (the station was referred to as GS8150097). Over 50 years of flow data was available at the gauging station. The largest was estimated to have an exceedance probability of 2% AEP (1 in 50-year ARI).

SLR concluded that while the Water Technologies RAFTS model parameters were adjusted to provide a match to the peak flow on the flood frequency curve it was likely to overestimate flood flows during more extreme events. With the benefit of LiDAR data, it appears the bed slope used in the Manning's equation derivation of the rating curve calculation was twice as steep as the actual bed slope. In addition, a comparison of the LiDAR data and original surface contour by SLR showed a mismatch up to 6m in some overbank areas.

Accordingly, with the benefit of LiDAR data and high-resolution surface imagery, SLR was able to reparametrize the Runoff And Flow Training Simulation (RAFTS) model to include more realistic topographical and surface parameters from which behaviours of extreme events could be more confidently extrapolated.

SLR was also given access to gauged hyetograph rainfall and real time river depth data recorded from 2014 at the same gauging station which was not available to Water Technology. This data enables the model parameters to be further refined to simulate the runoff measured from the application of the gauged rainfall.

An important factor which should be emphasised is the recent change to the design rainfall estimates between 2013 and 2020. The release of the revised Australian Rainfall and Runoff in 2016 (Ball, J., Babister, M., Nathan, R., Weeks, W., Weinmann, E., Retallick, M., & Testoni, I., 2019) saw a reduction in rainfall intensities in the Batchelor region of up to 39% compared to the design estimates in Australian Rainfall and Runoff in 2013 used in the Water Technologies study. **Table 2** summarises the comparison,

Table 2 Comparison of rainfall estimates for the 1% AEP event 1987 ARR to 2016 ARR

Duration (mins/hours)	ARR 1987 Rainfall Intensity (mm/h)	ARR 2016 Rainfall Intensity (mm/h)	Change
5	361	259	-39%
10	276	221	-25%

Duration (mins/hours)	ARR 1987 Rainfall Intensity (mm/h)	ARR 2016 Rainfall Intensity (mm/h)	Change
30	166	140	-19%
1	111	93.8	-18%
2	68.2	59.8	-14%
3	49.9	45.6	-9%
6	29.1	28.8	-1%
12	17.9	18.7	4%
24	12.3	12.4	1%
48	8.9	8.2	-9%
72	6.96	6.4	-9%

Therefore a 1 in 200 AEP event post 2016 would be in the vicinity of a 1 in 100 year ARI event pre 2016.

4.2.1 Critical catchment parameters

The hydrological factors which play a critical role in the simulation include:

1. Sub-catchment areas;
2. Vectored average slope;
3. Flow path representation;
4. Surface roughness Manning's n; and
5. Soil losses.

With access to Light Detection And Ranging (LiDAR) survey data, factors 1 to 3 were accurately represented in the revised model using digital means. With access to high resolution digital imagery in combination with a site surveillance visit, factor 4 was applied with confidence. The 5th factor was estimated through a combination of:

- insitu soil testing;
- verification against the latest Australian Rainfall and Runoff Data Hub (https://data.arr-software.org/) catchment loss recommendations; and
- model calibration.

In situ soil samples were analysed at three locations within the upper catchment. A USDA textural classification (Appendix A, (Rawls, W. J., Brakensiek, D. L., & Miller, N., 1983)) at each of the sites showed the upper soil profile to be a sandy clay loam at all three sites, refer Figure 5. Based on the USDA guidelines (Appendix A, (Rawls et al., 1983)) the recommended saturated hydraulic conductivity (akin to continuing loss) would be approximately 3mm/h for a sandy clay loam.

In the absence of site-specific data, ARR provides estimates of catchment losses based on local factors and calibrated studies nearby. Australian Rainfall and Runoff Data Hub (https://data.arr-software.org/) recommends a continuing loss of 4mm/h for this catchment. The actual continuing loss would be somewhere in between the two values and is refined through calibration.

The EBFR depth gauging performed by the Department of Land and Resource Management over the last 40 years has shown an unusual behaviour catchment behaviour. Gauge GS8150200 located immediately downstream of the EBFR diversion drain has recorded runoff for a period of one month before gauge GS8150097, located 5.6kms downstream. This is most likely the result of the river alluvial materail soaking the early monsoonal rains before excess runoff is realised. This phenomenon makes use of gauged data to derive the initial soil loss difficult as it defined as the rainfall loss before excess runoff is realised. An estimate of the initial loss was made using the USDA soil classification for a sandy clay loam which is predominant throughout the upper catchment. The residual saturation is a measure of the residual soil saturation quantity until saturation is achieved after the pore volumes of the displacing fluid have flowed through a particular portion of the soil. It's approximately 60% of the void space between the field capacity and wilting point of soils. For a sandy clay loam this figure is approximately 0.068 x soil depth. Spade excavation within the catchment showed a topsoil profile to be approximately 300mm. **Figure 5** provides a visual of the sandy loam topsoil. The initial loss would therefore be approximately 20mm of rainfall before excess runoff is realised (refer Appendix B).

Figure 5 Sandy clay loamy top soils are consistent throughout the undisturbed catchment

In the absence of specific catchment data, ARR2016 provides estimates of initial losses based on calibrated studies nearby (refer **Figure 6**). An initial loss of 38mm is recommended for this catchment in the absence of site-specific data according to the weighted average of 15 calibrated flood studies in the region (http://rffe.arr-software.org/).

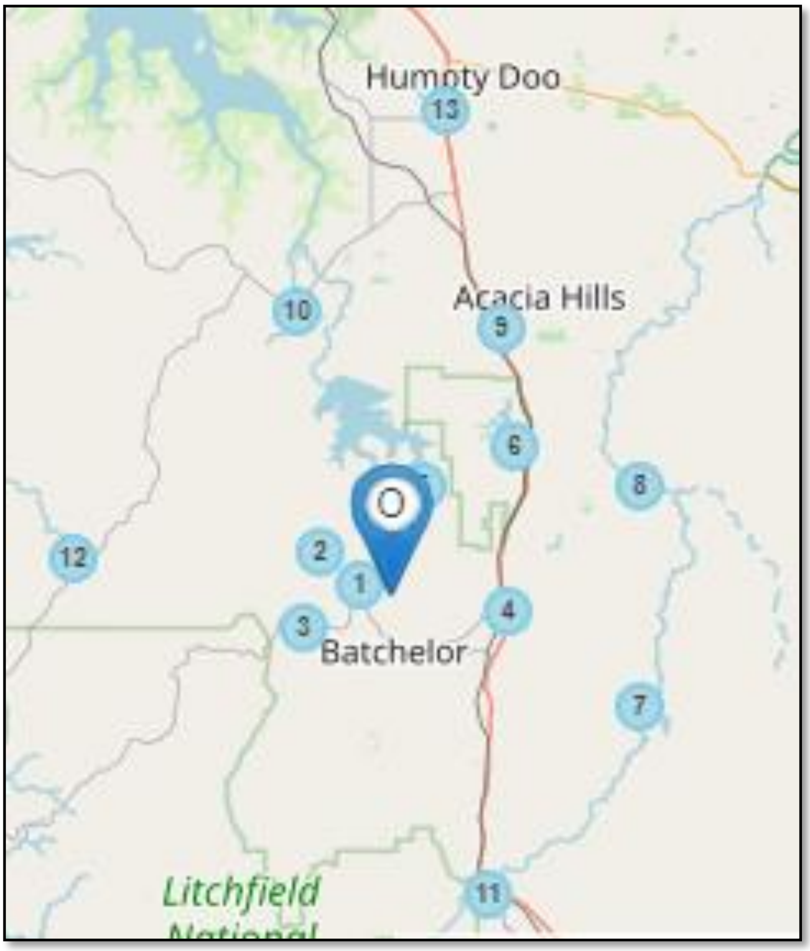

Figure 6 Location of regional calibrated studies relative to the Rum Jungle catchment (http://rffe.arr-software.org/)

Table 3 summarises the recommended catchment infiltration parameters and corresponding data sources. The actual figure will most likely lie between the two recommendations and would be confirmed through calibration against gauged rainfall and flow gauging data.

Table 3 Infiltration parameters

Parameter	ARR2016 data hub estimation	USDA Insitu soil testing estimation
Initial loss	38mm	20mm
Continuing loss	4mm/h	3mm/h

4.3 Calibration

Calibration is the process of adjusting catchment parameters such that the model simulates the catchment response and runoff volume when it receives rainfall. Continuous gauged rainfall and flow gauging data in the form of a rainfall hyetograph and a streamflow hydrograph are required for calibration. Gauged rainfall and runoff data for this catchment was available from 1965 however both rainfall and river depths were only recorded once every 24 hours. This is inadequate for calibration which requires rainfall and flow recorded against time at least hourly.

A tipping bucket rain gauge was installed in Batchelor in January 2014. A tipping bucket gauge records the time after 0.2mm of rainfall is collected. Unfortunately, the records are incomplete and often the gauge failed during the rainfall event.

The flow gauge on the EBFR at GS8150097 started recorded the river level against time from December 2013. The flow gauging data contains only one complete event from 14st October 2014 to the 19th January 2015.

There has therefore only been one period between December 2014 and January 2015 with complete data on where both gauges.

4.3.1 Calibration Results using Gauged Rainfall

Figure 7 presents a series of hydrographs produced by the model when compared to the gauged flows for a series of gauged rainfall events. The infiltration parameters were adjusted until the best match was achieved. An initial loss of 20mm and a continuing loss of 3.2mm/hour produced the best fit between the gauged and modelled hydrographs.

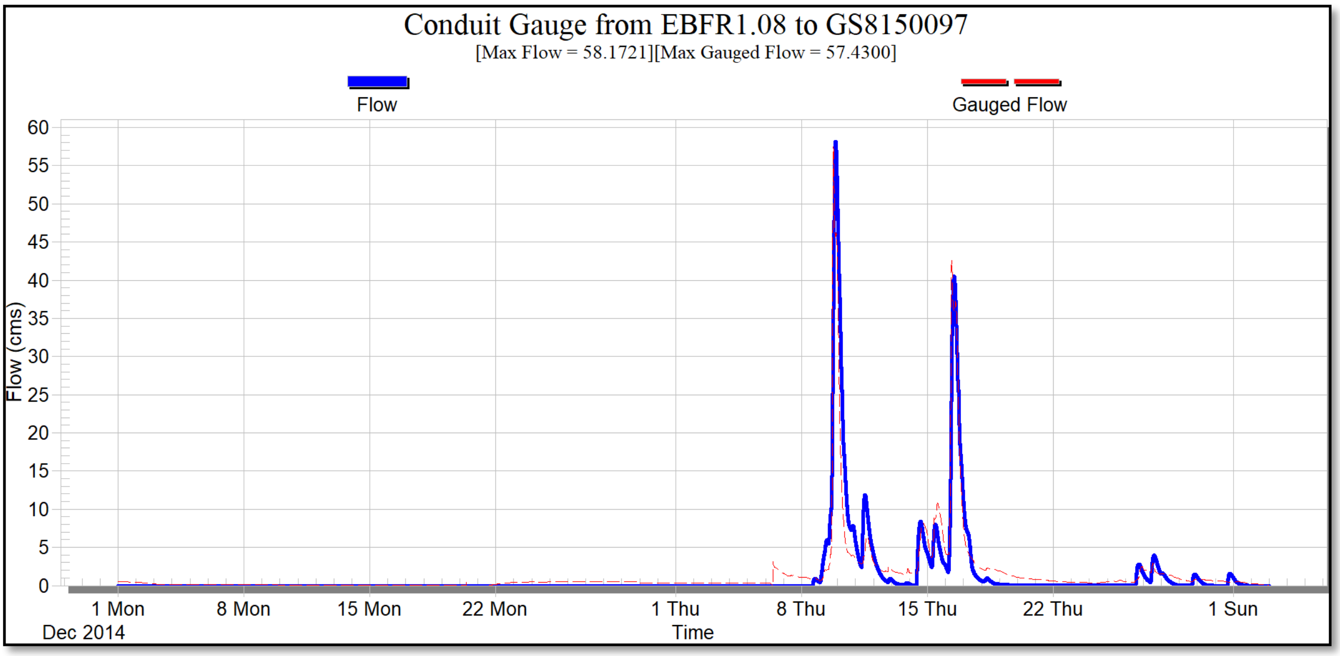

Figure 7 Calibration event with complete rainfall and runoff data, Dec 2014 to Jan 2015

The SLR RAFTS model shows a near perfect catchment response and hydrograph volume providing confidence in the runoff predictions.

As indicated previously other events contained incomplete rainfall and/or runoff data. A reasonable but not ideal fit has been achieved for an event at the end of January 2015 to mid March 2015, refer **Figure 8**. The tipping bucket failed at the end of January therefore supplying less rainfall to the model to simulate the required catchment response. The flow gauge then failed in February making it impossible to perform a satisfactory calibration.

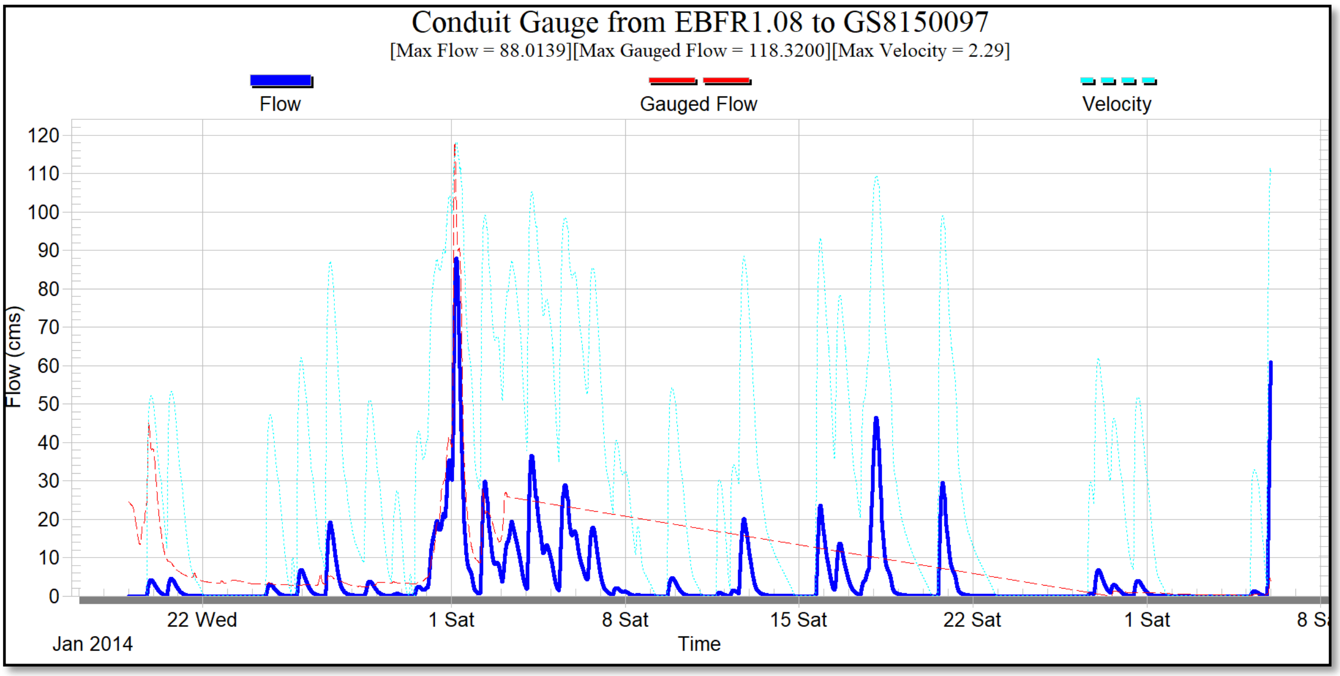

Figure 8 Calibration event, with a common failure of the rainfall and/or flow gauge

4.4 Regional Flood Frequency Estimation of the Catchment Peak Flow

The Regional Flood Frequency estimation is a technique based on data from 853 gauged catchments throughout Australia which were updated with the release of Australian Rainfall and Runoff in 2016 (Ball, J., Babister, M., Nathan, R., Weeks, W., Weinmann, E., Retallick, M., & Testoni, I., 2019). A Bayesian generalised least squares regression method is used to regionalise the catchment parameters. **Table 4** is a guide to the expected peak flood estimates from the Rum Jungle catchment at the gauging station GS8150097 located 5.6kms downstream of the site. The calibrated model would be expected to produce similar values to the expected discharge.

Table 4 Regional flood frequency estimation at gauge GS8150097, ARR 2016 (Ball et al., 2019)

AEP (%)	ARI (years) approximate equivalent	Expected Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
50	2	41.9	20.4	86.4
20	5	79.7	40.9	157
10	10	113	55.1	234
5	20	153	68.2	338
2	50	216	84.7	541
1	100	274	97.0	750

According to the Regional Flood Frequency estimation, a peak flow of approximately 274 m^3/s should be expected at gauging station GS8150097.

Figure 9 shows the peak flow from the EBFR lying central to the peak flow from 15 other flood studies performed in the region.

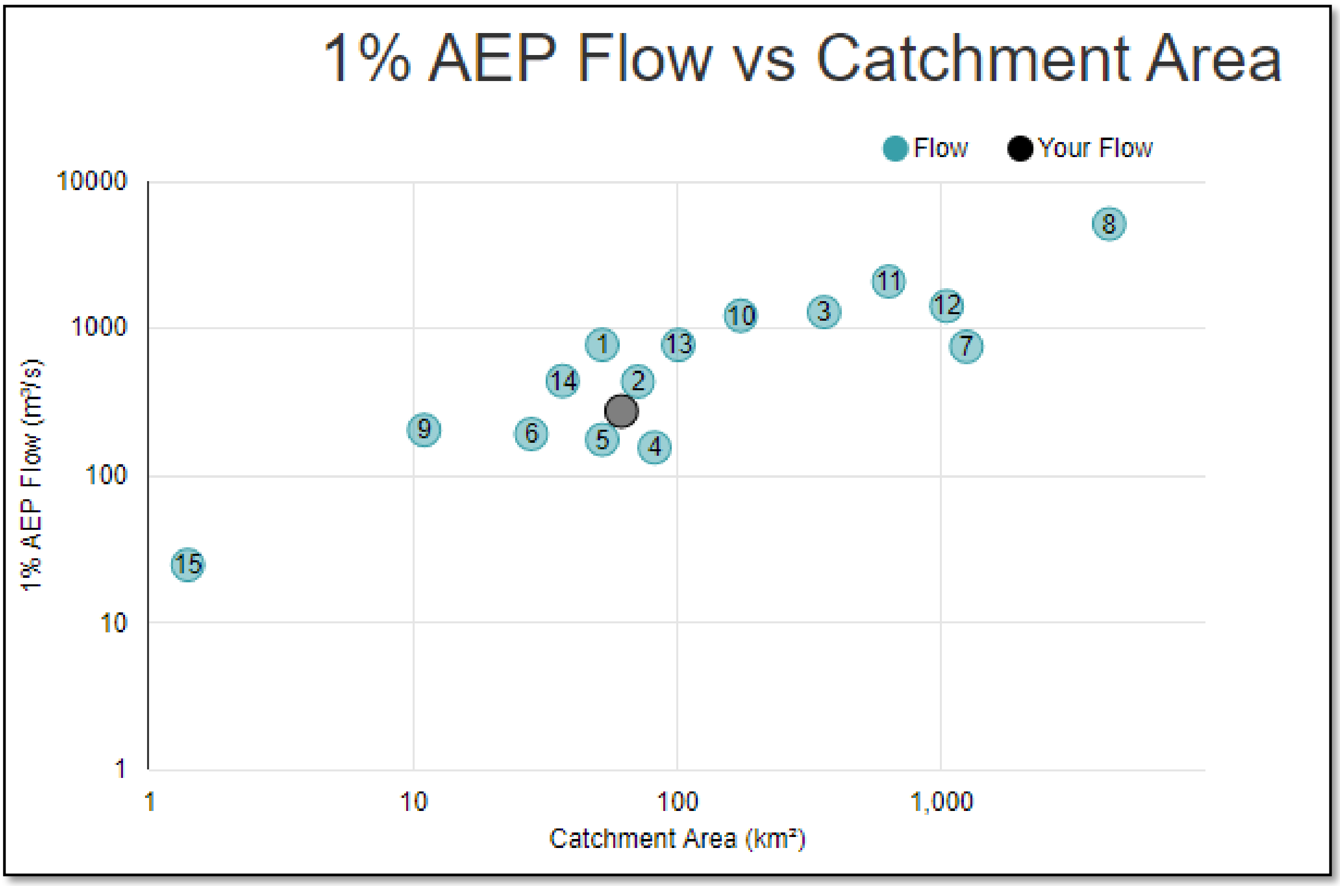

Figure 9 Peak flow from the EBFR relative to 15 other flood studies performed in the region (http://rffe.arr-software.org/)

4.5 Modelled Peak Flow Estimates

The recent edition of Australian Rainfall and Runoff (Ball et al., 2019) recommends a different approach to the previous version to defining the peak flow from a catchment. Rather than identifying the peak flow for certain duration storm it recommends simulating an ensemble of rainfall temporal patterns for every rainfall duration between 5 minutes and 7 days (290 different storm events) and determining the maximum of the ensemble means.

Figure 10 is a box and whisker graph showing the peak flow at gauge GS8150097 for 200 of the potential 290 different storms with varying durations and temporal patterns. The maximum of the ensemble means occurs during a 9-hour duration storm with a peak flow of 258m^3/s whereas the maximum of the maximums occurs during a 48-hour storm with a peak flow of 346m^3/s.

4.6 Comparison of Catchment Peak Flows

Table 5 compares the model predictions compared to the Regional Flood Frequency Analysis. The Regional Flood Frequency Analysis should be compared against the model's estimation of the maximum of the mean flow at gauge GS8150097. The estimate in from the Water Technology's study (Water Technology, 2018) has been included for comparison.

Table 5 Comparison of model predictions

SLR RAFTS model Maximum of the ensemble means, 1% AEP	SLR RAFTS model Maximum peak flow, 1% AEP	Regional Flood Frequency Analysis recommendation, 1% AEP	Water Technology's Peak Flow, 1 in 100 year ARI
258 m^3/s	346 m^3/s	274 m^3/s	763 m^3/s

The SLR RAFTS model is 6% lower than the Regional Flood Frequency estimation providing confidence in the model predictions. The Water Technologies peak flow is not a fair comparison as design events of 2013 are not comparable to 2020 due to the changes to Australian Rainfall and Runoff in 2016 (Ball, J., Babister, M., Nathan, R., Weeks, W., Weinmann, E., Retallick, M., & Testoni, I., 2019).

4.7 Flood Analysis

Flood behaviour over the site has been determined from the SLR SWMM model for the site. SWMM incorporates an interconnected one-dimensional (1D) and two-dimensional (2D) analysis of flows. Due to the large catchment, the 2D analysis has been restricted to upstream of the Main Pit and downstream to the site boundary.

Peak flooding depths of inundation for the 1% AEP event are shown in **Figure 11** and **Figure 12** for:

- The existing site (note the bathometry of the pits to the floor was excluded in the modelling); and
- The rehabilitated site with design river reinstatement in place (note the final pit bathometry was included in the modelling).

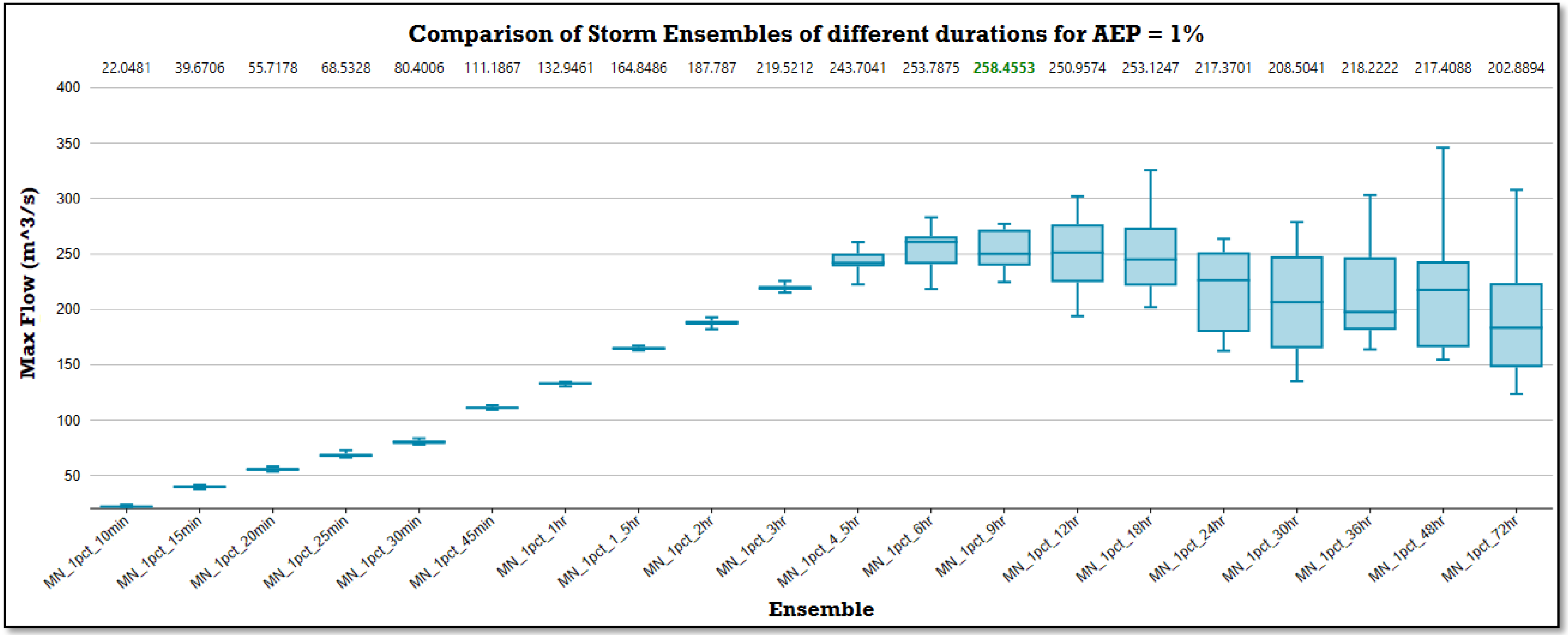

Figure 10 Peak flow in cumecs at gauge GS8150097 of ensembles with a range of storm durations

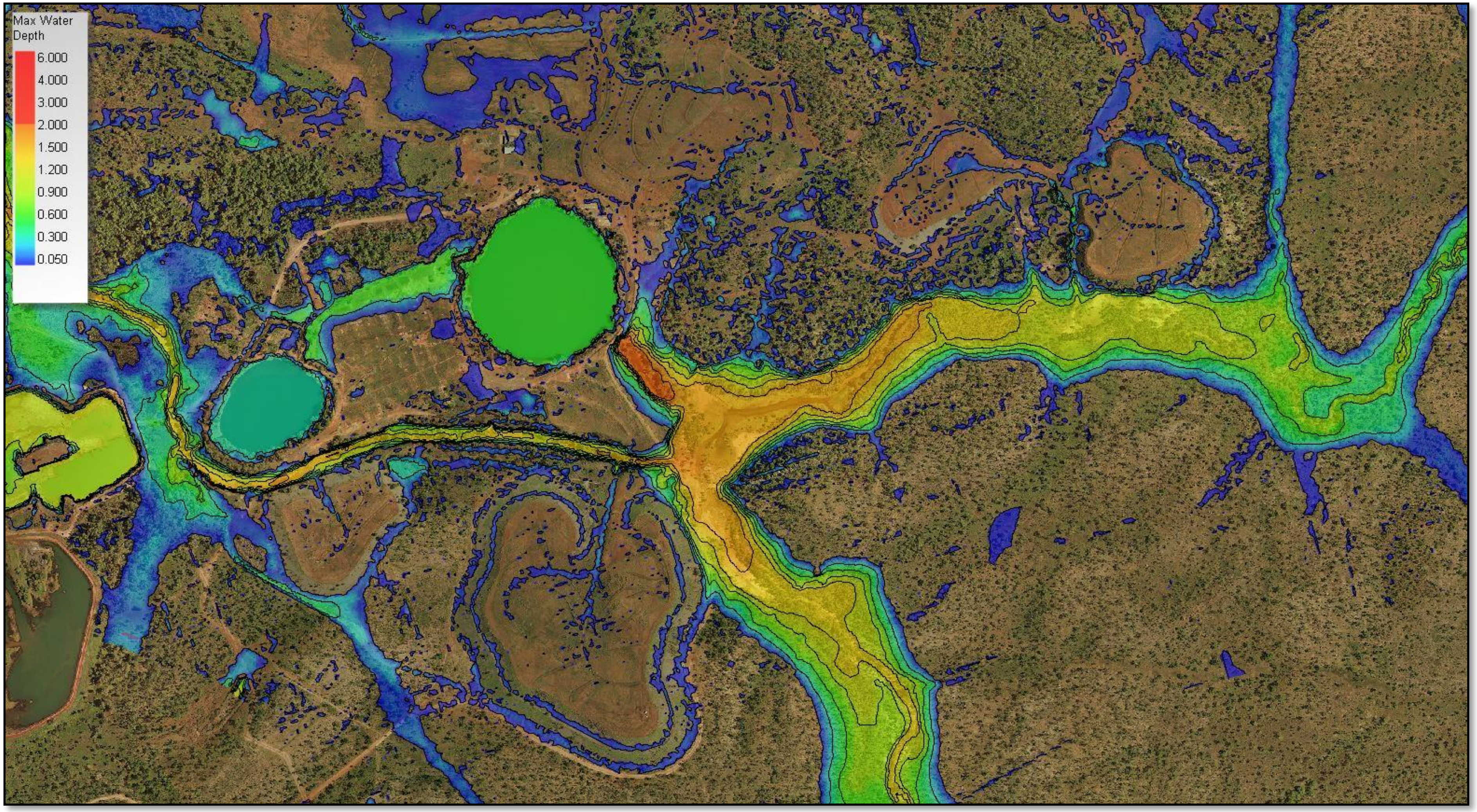

Figure 11 **1% AEP flood extent on the existing site (depths in metres & scale excludes depth to pit floors)**

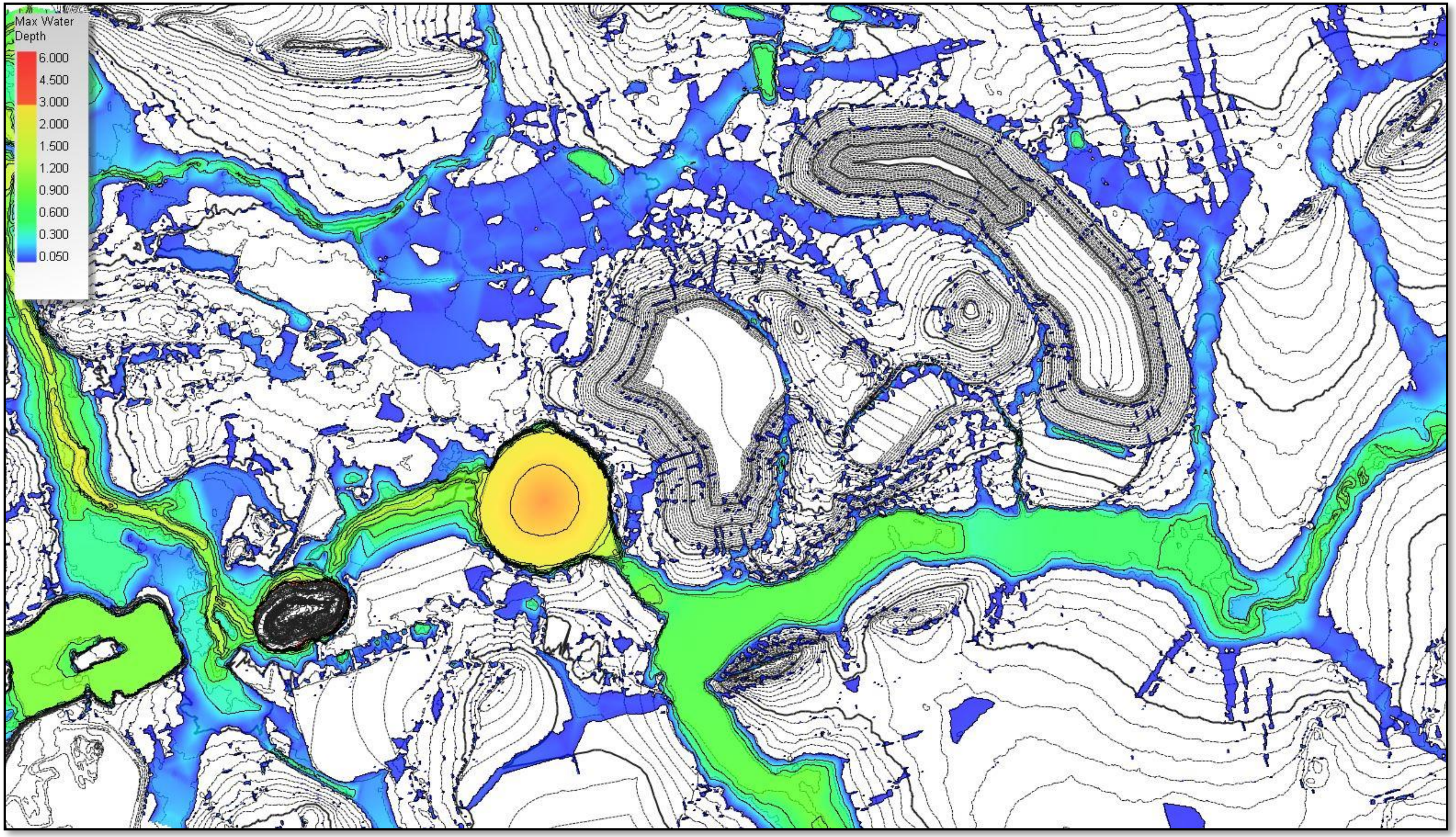

Figure 12 **1% AEP flood extent post reinstatement works (depths greater than 6m excluded from display for clarity)**

5 Design of River Reinstatement

5.1 Design Rationale

The river reinstatement has included consideration of the following priorities:

1. Isolate waste rock materials stored within the Main Pit from erosion processes.
2. Realign the EBFR to satisfy cultural needs.
3. Create a landform that allows for revegetation and establishment of riparian/aquatic organism utilisation
4. Create a landform with improved visual amenity that will allow for ecological processes until such time as baseline geomorphological processes can be reinstated.
5. Replicating, as far as practicable, the morphological and hydraulic characteristics of the existing and adjacent EBFR flow path and thereby maintain aquatic habitat values and allow aquatic ecological processes;
6. Establish vegetation in the riparian zone which is compatible with adjacent undisturbed riparian zones and complies with the EIS; and
7. Provide a subsurface condition that is long term stable to erosion and a surface condition which is suitable for native vegetation regrowth;

It is critical to note that the purpose of this design report is to provide a suitable foundation design for construction purposes. It is recognised that this EBFR restoration process on site will require monitoring, maintenance and management over a timeframe that extends beyond the scope of this design report and the project construction phase. The rationale for the design elements provided here must be considered in the context of the dynamic watercourse processes of erosion and sedimentation, water flow and flooding regime, the seasonal cyclic nature of aquatic organism utilisation and the vegetation cycles that respond to the physical processes mentioned here.

The design presented here corrects the alignment of the water course, describes a stream bed and flood plain design that has low erosion rates and suitable flow rates to allow revegetation and aquatic organism utilisation. It is recognised that the Main Pit lake will act as a sediment trap for some time therefore isolating the downstream channels from receiving the majority of the available sediment loading. The lack of sediment replenishment is recognised as a long-term landform risk and as such, the Project owner's management framework will need to incorporate appropriate monitoring of this element and committed to an Adaptive Management approach to mitigating future impacts.

5.1.1 Alignment

The historical flow path of the EBFR pre-mining was estimated from historical photographs and is plotted in **Figure 4** (K. Martin-Stone, 2019). The reinstatement design has relied on this alignment to define the low flow path which exactly follows the original alignment. It is critical to note that the Intermediate Pit outlet position should be discussed with the neighbouring mine operator to ensure that the outlet does not impact on their operations. This small portion of the design may need refinement pending the outcomes of this consultation work.

5.1.2 Stream Bed - form

The designed form of the watercourse includes a low flow channel which seeks to replicate stream beds in surrounding 'reference' watercourses, which have bed widths of 3 to 5m of granular material comprising gravels sand and humus.

The bed is intended to be a slightly sinuous channel lightly incised into the surrounding floodplain. The channel geometry does not have a fixed dimension or constant slopes. Construction will need to be based on the digital terrain model.

By following the original alignment, overbank slopes will be replicated to those immediately upstream in undisturbed areas.

5.1.3 Stream Bed – materials selection

The selection of stream bed materials seeks to provide a surface which is not dissimilar to adjoining creeks which have areas of coarse sand deposits interspersed with stone, and areas of exposed bed rock as shown in **Figure 13.**

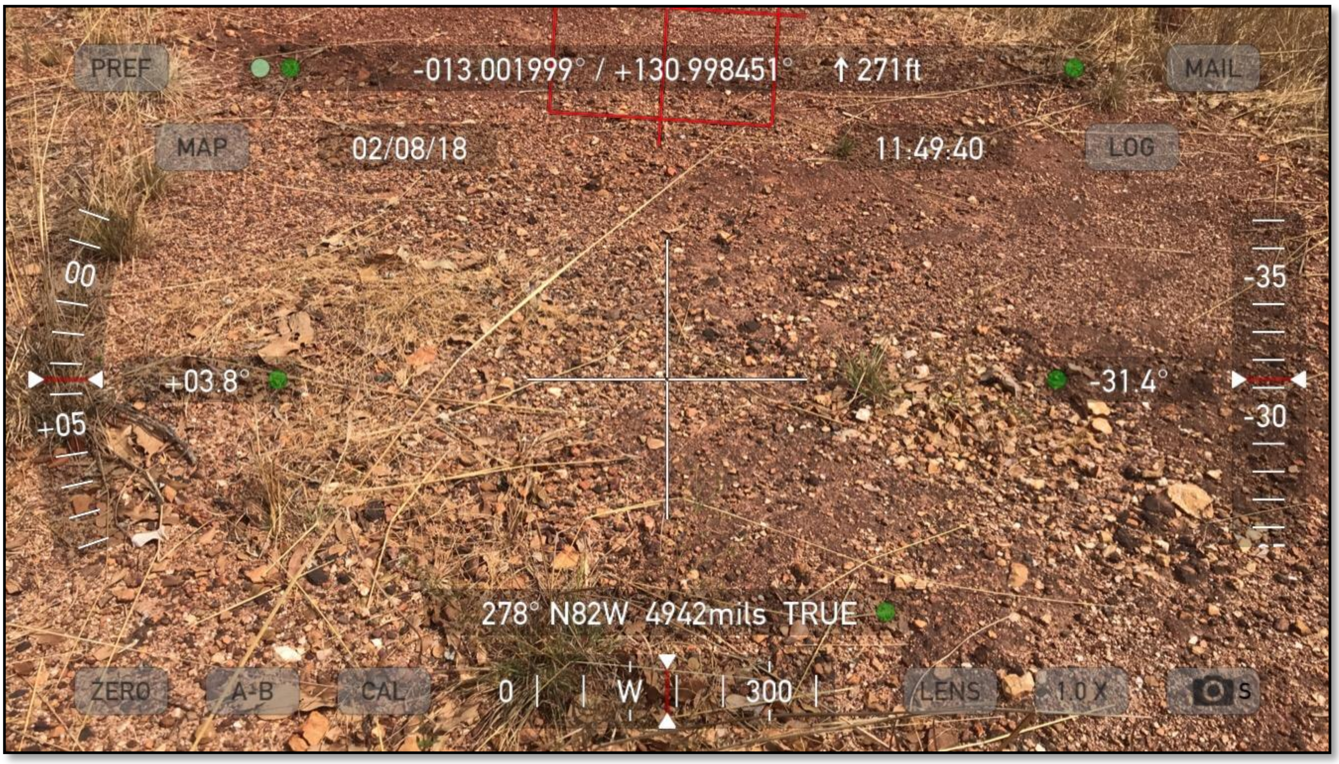

Figure 13 Typical stream bed materials

The detailed design drawings (refer **Section 6.2**) indicate several types of material along the stream bed which are a mix of:

- Soils and organic matter to provide nutrients and assist moisture retention to encourage the establishment of vegetation;
- Fine to coarse sands and gravels to provide resistance to movement where fluid shear stresses are low; and

- The incorporation of rip-rap stone in areas of higher shear stress with a mix of sandy soils and organic matter filling the voids to promote vegetation growth and bind the finer graded material.

The long-term establishment of vegetation in areas of higher shear stress will bind the finer material between the larger rip rap stone. The root matter surrounding the rip rap will serve as a robust matrix to shear stresses when exposed to flood flows.

The distribution of different materials is based on predicted shear stresses during a 1% AEP flood when the channel is in an unvegetated state. There has also been some rationalisation of zones and increase in rip-rap sizing near the entry to pit lakes.

Shear stresses have been determined from Storm Water Management Model (SWMM) modelling, and sanity checked by hand calculations using bed slope and flow depth as inputs. **Table 6** summarises the thresholds applied:

Table 6 Rip rap rock sizing according to induced shear stress (Pa)

Shear Stress (Pa)	D50 (mm)	D max (mm)
32	50	100
96	150	230
144	230	360
192	300	460

Rip rap has been sized based on Queensland Urban Design Manual (QUDM) design tables and checked using Shields entrainment function for threshold of movement with the F* values as recommended by (Henderson, F.M., 1966).

The low flow area of the river diversion has increased thickness of growth medium to encourage the establishment of denser vegetation along the watercourse and its banks.

Resource salvaging is planned during other scopes of work for this project including recovery of boulders from borrow pits, preservation of large woody debris and other items that can be incorporated into the microscale landscaping requirements of this EBFR restoration. Some materials may need to be imported at the direction of the Superintendent.

All site revegetation works are the responsibility of the Owner and this includes the riparian and aquatic revegetation needs for the EBFR restoration works. The Owner is to engage a locally experienced revegetation expert who will co-ordinate with TOs, project aquatic ecologists and other specialists to establish the revegetation needs for the EBFR restoration works. Priorities will include:

1. Provision of suitable rest points, habitat and nutrition for aquatic organisms.
2. Provision of suitable habitat and nutrition for riparian organisms.
3. Culturally and ecologically appropriate plant species.

5.1.4 Floodplain Form

The shape of the floodplain has been set at low grades so that overbank flows are wide and slow moving. This seeks to replicate the existing landform. **Figure 14** is a cross section of the undisturbed EBFR immediate upstream of the site. It shows a flat low flow channel typically 30m wide composed of sandy soils interspersed in large boulders and covered is sparse grasses. The overbanks on both sides are set at very low slopes typically between 1 in 10 and 1 in 25. This would make for low velocities on the fringes during large floods.

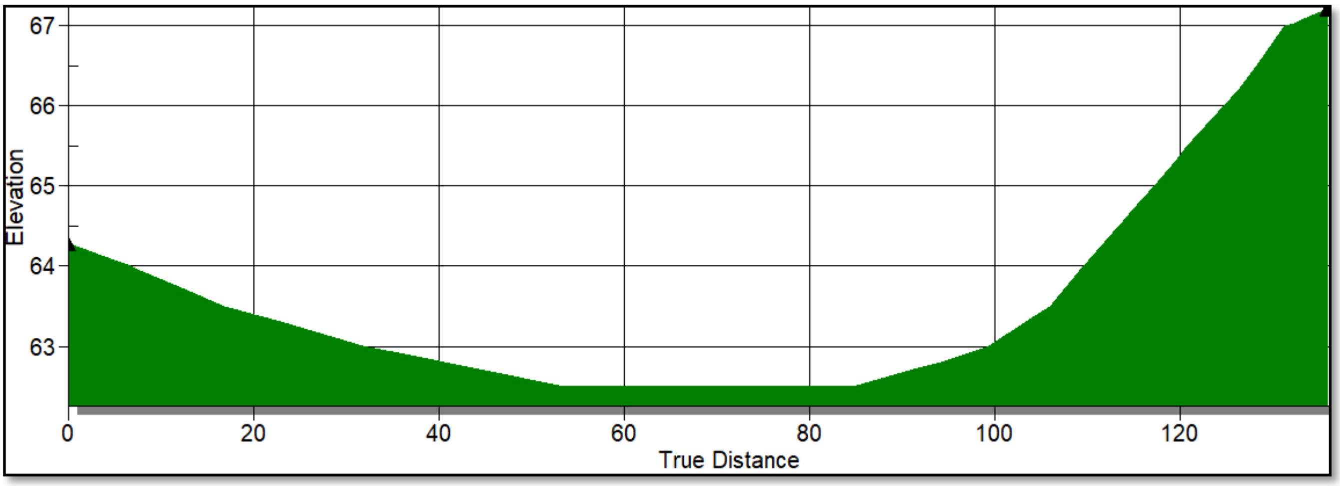

Figure 14 Typical cross section immediately upstream of the site (distance & elevation in metres)

5.1.5 Fish Passage 'Furniture'

Details around installation of natural features designed as rest points within the topography including boulders, banks, pools, logs and snags and revegetation works are to be established by the Owner and are not part of this contract. For the purpose of this report, the earthmoving contractor is to provide quotation to install the base engineering design along with a schedule of rates for smaller earthworks needs as defined by the Superintendent.

5.2 Main Pit Bed Inert Cap Design Verification

The inert cap and the final bathometry of the Main Pit has been designed to provide a long-term stable seal during major flood events. The depth, side embankment slope, entry and exit conditions have provided the hydraulic conditions to facilitate sediment settlement and recirculation. The capping material is well graded and self-sealing to accommodate the anticipated 5.6m of consolidation over the next 170 years.

5.2.1 Inert Capping Material Grading

The compilation of particle size distribution of the granular capping material is provided in **Table 7.**

Table 7 Particle Size Distribution – Main Pit Capping

Analyte	% Gravel	% Sand	% Fines
Count	14 Samples (14 x SLR)		
Mean	33	43	24
Maximum	56	55	35

Analyte	% Gravel	% Sand	% Fines
Minimum	13	33	11
Standard Deviation	9.8	6.2	6.6

he compiled particle size distribution curves are shown in **Figure 15.** All samples tended to plot within the sandy gravel to gravelly sand brackets as shown in the curves with the statistical breakdown below. The D_{50} value (50% passing diameter) is considered to be 1 mm.

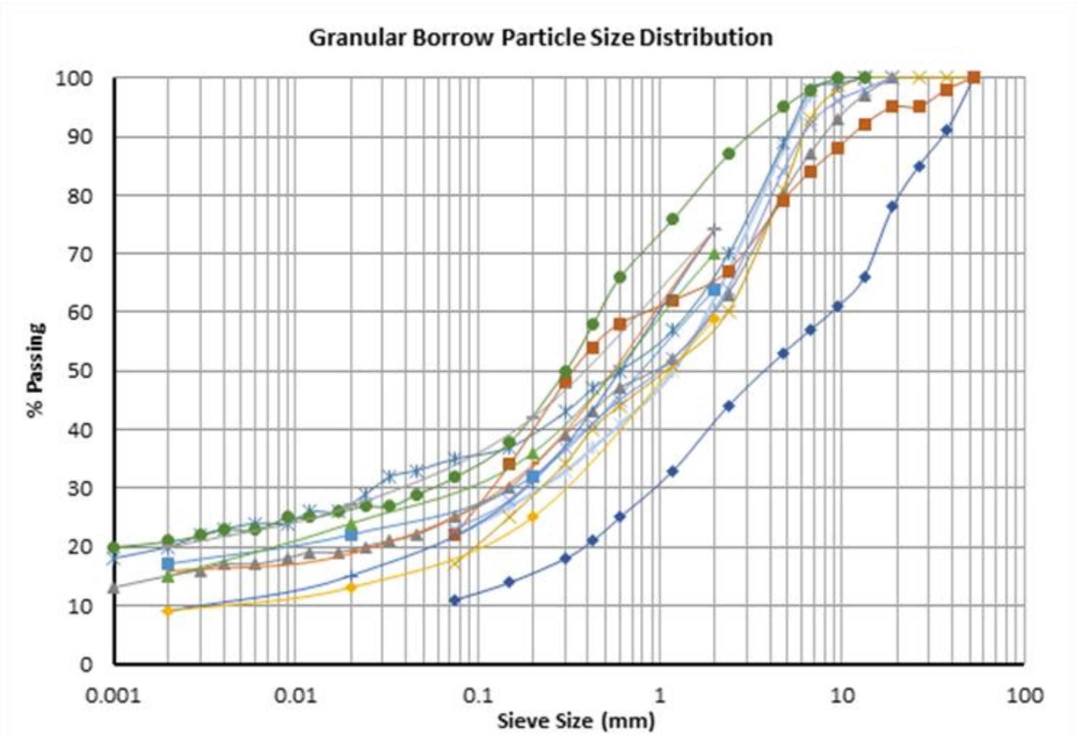

Figure 15 Particle size distribution for Main Pit waste rock capping material

5.2.2 Main Pit Bathometry

The surface level of the capping material at completion will have a cross sectional profile as detailed in **Figure 16**. At completion, the lowest bed level would be RL57m AHD increasing to a crest level of RL59m AHD with a 1 in 160 bed slope over a diameter of 300m then steepening to 1 in 50 slope to the outer rim. The incoming bed slope to the Main Pit (shown on the left of **Figure 16**) has a 1 in 125 slope which will ensure velocities entering the pit remain very low for all magnitude floods.

Settlement modelling has confirmed the bed level will drop asymptotically over time to a steady state of RL51m AHD within a century.

The storage volume of the Main Pit to RL 59m AHD would be approximately 112ML.

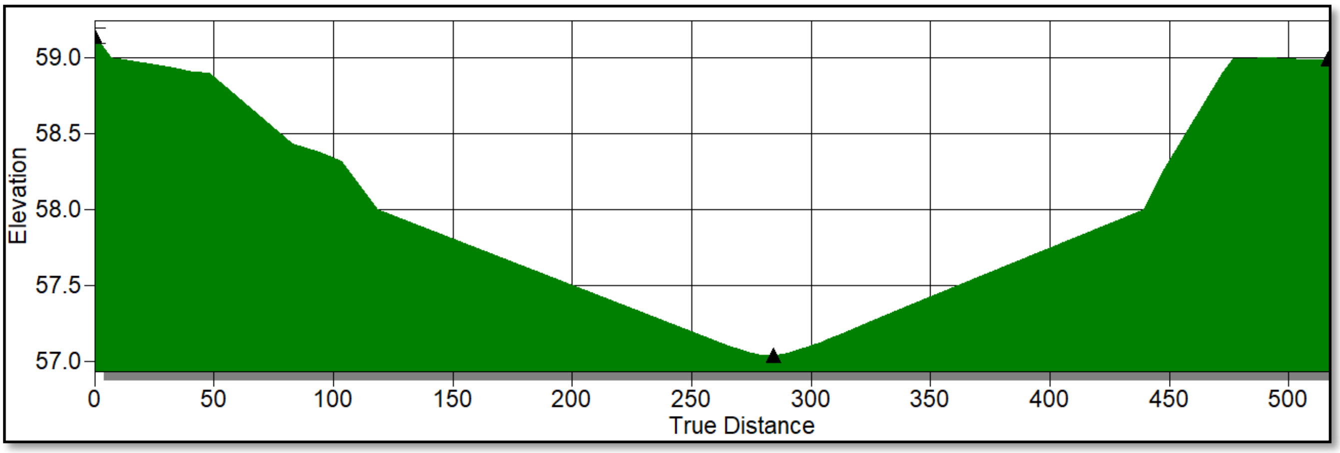

Figure 16 Final bathometry of the Main Pit (dimensions in metres)

The water level of the Main Pit currently varies between RL 59.5 and RL 61m AHD depending on the season. The surrounding groundwater tracks a similar pattern but varies between RL58m and RL62m AHD between the seasons. Refer **Figure 17**.

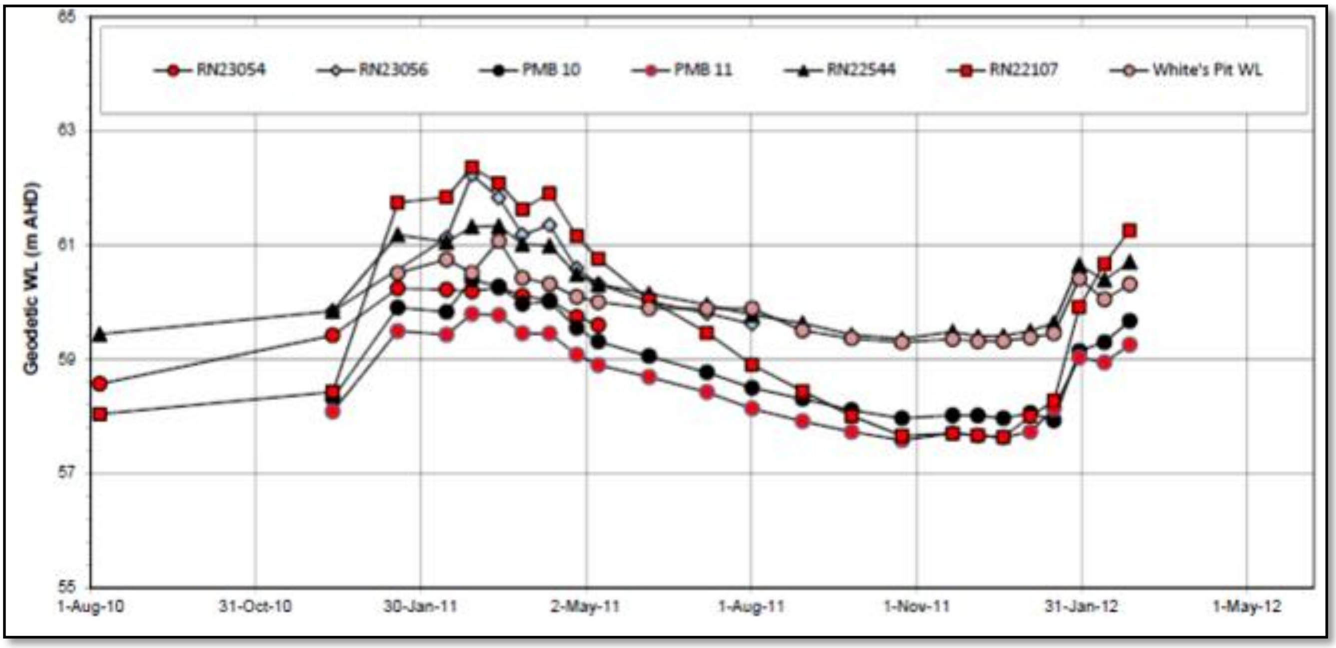

Figure 17 Seasonal water level in Main Pit

With a spillway level of RL59m AHD, and a hydraulic connection to the surrounding groundwater it is expected the seasonal water level on the Main Pit will remain relatively static between RL 58.5 and RL 59m AHD. Hydraulic modelling has confirmed the water level would peak at RL 61.9m AHD during a 1% AEP flood.

5.2.3 Pit Velocities and Bed Stability

Figure 18 shows the maximum velocity attained over the profile depth in the Main Pit during a 1% AEP flood event. Flood flows from the EBFR enter the Main Pit in a north westerly direction and pass over the centre of the Pit towards the spillway. A large portion of the flow is split in opposite directions as it strikes the opposite bank which then hugs the outside of the Pit to return to the inlet. This bi-cyclic movement would serve to slow incoming flows from the EBFR and deposit entrained sediment in the pit.

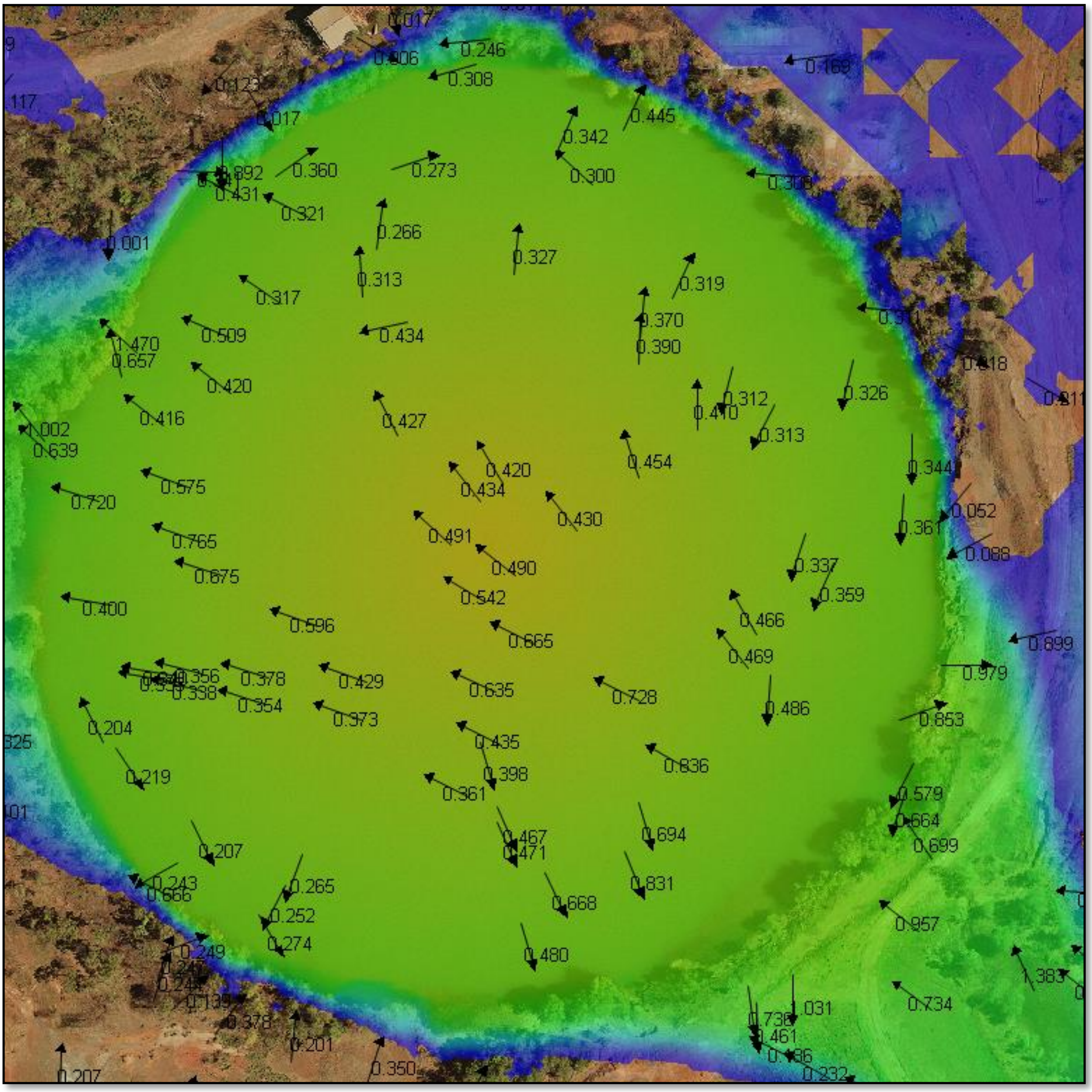

Figure 18 Peak velocities in the Main Pit during a 1% AEP flood post capping

Table 8 lists the erosion potential of soil with a range of coverings under long term saturation conditions (Landcom, 2004).

Table 8 Critical velocity for saturated soil erosion (Landcom, 2004)

Material	Critical velocity (m/s)
Bonded plastic fibres	4.0
Kiku yu	2.0
Jute mesh	1.5
Bare soil	0.4

Assuming a conservative assumption of bare soil the critical velocity for soil movement would be 0.4m/s. The velocities identified in the 2D model are average across a section. The bed velocity would actually be half this velocity based on the variation in velocity over the 2m depth water profile. Refer **Figure 19**.

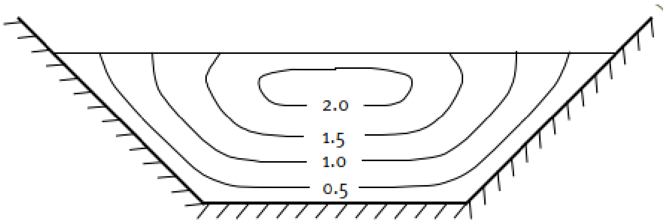

Figure 19 Bed velocity to average sectional velocity ratio (Department of Science, I. T. and I., 2015)

The peak velocity at the bed level would therefore vary between 0.4 and 0.2m/s. This is well within the conservative calculations (Landcom, 2004). The material on the Main Pit floor would therefore remain intact for all event including major flood events.

5.2.4 Sedimentation

A Stoke's settlement calculation on the granular capping particles >1mm estimates a settlement time of 4.6 minutes. At an average 1% AEP flood flow velocity of 0.5m/s, the travel time from the inlet and outlet of the pit would be approximately 11 minutes. More than 50% of the entrained sediments would settle to the floor before reaching the centre of the Main Pit. Particles between 1mm and 0.2mm diameter would settle before reaching the opposite bank. Based on these calculations over 70% of the entrained sediment would drop to the floor before existing the Main Pit. The Main Pit would therefore serve as an efficient sediment trap with only a fraction of the entrained sediment remaining in suspension during very large floods.

The re-alignment watercourse has been designed to be long term stable without a live sediment load to replenish lost material. This is because the Main Pit lake will remove sediment loads from the water prior to entering the river re-alignment. Based on Wasson's regional relationship, approximately 500 to 1,000m^3 of sediment would be deposited into the Main Pit annually. As the storage volume at completion is approximately 112ML (112,000m^3) and a consolidation of up to 5.6m would occur over 170 years the Main Pit is unlikely to totally silt up in a millennium.

5.2.5 Pit Lake Outlet

The outlet from the Main Pit has been designed at an extremely low grade (0.14%) so that water flows slowly in a subcritical regime, which means that there is low levels turbulence which may initiate sediment/stone movement along the re alignment creek bed.

A sill of thicker and coarser rip-rap has been provided at the Main Pit discharge to provide some long term control on pit levels and the flow distribution across the spillway.

5.3 Phased closure of diversion

The decision for total or partial closure of the existing diversion would be made following a long-term monitoring of the regrowth in the river re-alignment. The preference is to slowly introduce EBFR flows into the revegetated areas 5 to 8 years after completion. The robustness of the vegetation, soil and rock matrix will determine if the total EBFR flows can be returned to the re-alignment or if they should be permanently split between the diversion and re-alignment. If the later is to occur, then additional erosion protection would be required in the diversion channel to ameliorate the existing scour.

6 List of Supporting Documentation

6.1 Design Reports

This EBFR design report is intended as a standalone report, however it forms part of a wider rehabilitation strategy for Rum Jungle and it is recommended that it be read in conjunction with the documentation listed in the Bibliography. Particular reference should be made to the overarching Detailed Engineering Design Report (SLR, 2020c).

6.2 Design Drawings

A summary of drawings associated with these design works is given in **Table 9**.

Table 9 Supporting Design Drawings

Drawing No.	Title
680.10421.RFR.D01	Reinstatement of 'EBFR' General Arrangement
680.10421.RFR.D02	Reinstatement of 'EBFR' Existing and Final Contour Planning
680.10421.RFR.D03	Reinstatement of 'EBFR' Sections – Sheet 1 of 2
680.10421.RFR.D04	Reinstatement of 'EBFR' Sections – Sheet 2 of 2
680.10421.RFR.D05	Reinstatement of 'EBFR' Details – Sheet 1 of 2
680.10421.RFR.D06	Reinstatement of 'EBFR' Details – Sheet 2 of 2
680.10421.RFR.D07	Reinstatement of 'EBFR' Flood Inundation and WSF Position

7 Bibliography

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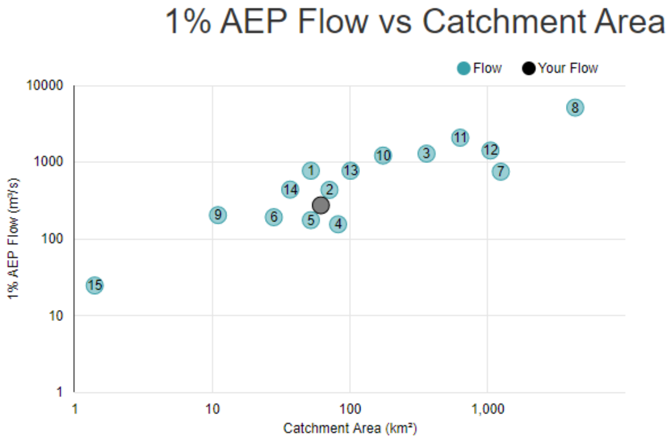
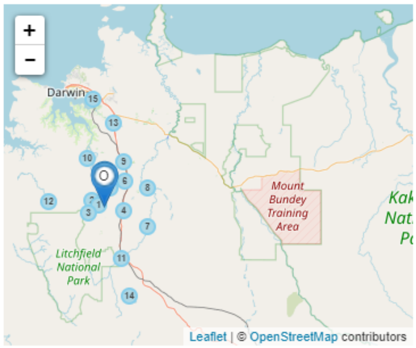
APPENDIX A

ARR2016 Data Hub and Regional Flood Frequency Estimation

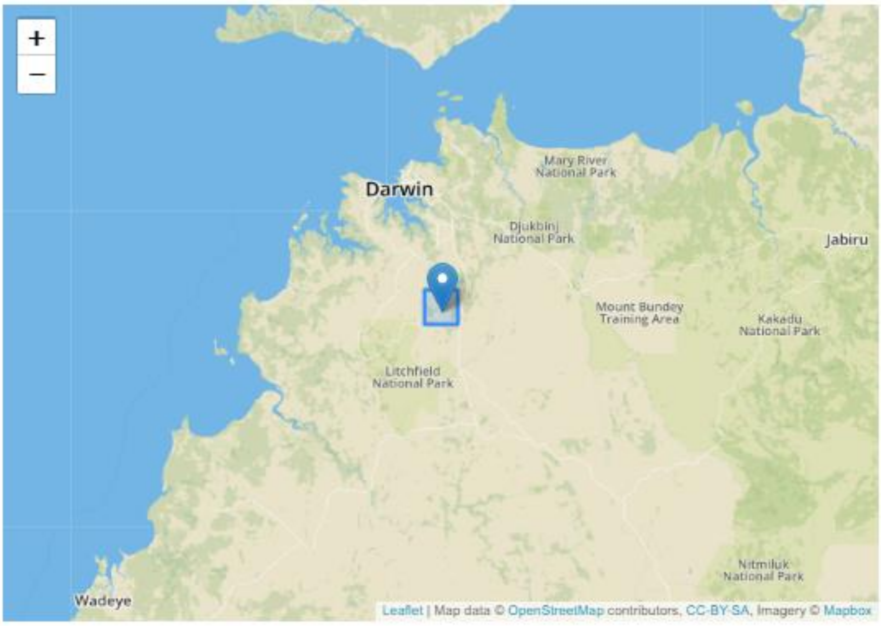




Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	131.026
Latitude	-13.001
Selected Regions (clear)	
Storm Losses	show



Data

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR DIRECT USE** in urban areas

ID	20812.0
Storm Initial Losses (mm)	38.0
Storm Continuing Losses (mm/h)	4.0

Layer Info

Time Accessed	14 May 2020 09:36PM
Version	2016_v1

Catchment Name	EBFR
Latitude (Outlet)	-13.00194
Longitude (Outlet)	131.028823
Latitude (Centroid)	-13.001235772
Longitude (Centroid)	131.026363581
Catchment Area (km^2)	61.45
Distance to Nearest Gauged Catchment (km)	3.39
50% AEP 6 Hour Rainfall Intensity (mm/h)	12.778287
2% AEP 6 Hour Rainfall Intensity (mm/h)	25.795095
Rainfall Intensity Source (User/Auto)	Auto
Region	Top End NT and Kimberley
Region Version	RFFE Model 2016 v1
Region Source (User/Auto)	Auto
Shape Factor	0.04*
Interpolation Method	Natural Neighbour
Bias Correction Value	-0.186

APPENDIX B

USDA Soil Physical Properties

USDA Textural Classification	Total Porosity/Saturation θ_s (cm^3/cm^3)	Effective Porosity/Saturation θ_e (cm^3/cm^3)	Field Capacity Saturation θ_f (cm^3/cm^3)	Wilting Point Saturation θ_{wp} (cm^3/cm^3)	Residual Saturation θ_r (cm^3/cm^3)	Bubbling Pressure Geometric Mean ψ_b (cm)	Pore Size Distribution Arithmetic Mean λ (cm/cm)	Saturated Hydraulic Conductivity (multiply by 0.5 for GA methods) K_s (cm/h)	Wetting Front Suction Head (Capillary Head) ψ_f (cm)
Sand	0.437	0.417	0.091	0.033	0.02	7.26	0.694	23.56	4.95
Loamy sand	0.437	0.401	0.125	0.055	0.035	8.69	0.553	5.98	6.13
Sandy loam	0.453	0.412	0.207	0.095	0.041	14.66	0.378	2.18	11.01
Loam	0.463	0.434	0.27	0.117	0.027	11.15	0.252	1.32	8.89
Silt loam	0.501	0.486	0.33	0.133	0.015	20.79	0.234	0.68	16.68
Sandy clay loam	0.398	0.330	0.255	0.148	0.068	28.08	0.319	0.30	21.85
Clay loam	0.464	0.390	0.318	0.197	0.075	25.89	0.242	0.20	20.88
Silty clay loam	0.471	0.432	0.366	0.208	0.040	32.56	0.177	0.20	27.30
Sandy clay	0.430	0.321	0.339	0.239	0.109	29.17	0.223	0.12	23.90
Silty clay	0.479	0.423	0.387	0.250	0.056	34.19	0.150	0.10	29.22
Clay	0.475	0.385	0.396	0.272	0.090	37.30	0.165	0.06	31.63

(Rawls, W. J., Brakensiek, D. L., & Miller, N., 1983)

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