Appendix N-2 - Hydrology and Flood Assessment Report - Rustler's Roost

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Rustler's Roost Open-Cut Mine Redevelopment

Catchment Hydrology & Flood Risk Assessment

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ACRONYMS & ABBREVIATIONS

AEP	Annual Exceedance Probability
ARR-DH	Australian Rainfall and Runoff Data Hub
BOM	Bureau of Meteorology
CPEng	Chartered Professional Engineer
CPESC	Certified Professional in Erosion and Sediment Control
DEM	Digital Elevation Model
ESCP	Erosion and Sediment Control Plan
IECA	International Erosion Control Association
IFD	Intensity Frequency Duration
LOM	Life of Mine
LP3	Log Pearson 3 statistical distribution
ML	Mineral Lease
MMP	Mining Management Plan
NSE	Nash-Sutcliffe model efficiency coefficient
NT	Northern Territory
Q29	Quest 29 Project Area
RPC	Representative Concentration Pathway
RR	Rustler’s Roost Project Area
SILO	Scientific Information for Landowners
TGUM	Tom’s Gully Underground Project
TSF	Tailing Storage Facility
WRD	Waste rock dump

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1 INTRODUCTION

1.1 Background

Primary Gold Limited (PGO) propose to redevelop and expand the Rustler’s Roost open cut mine. Rustler's Roost is located on the Old Mount Bundey Station, Perpetual Lease (PPL) 1163, approximately 100 km south-east of Darwin. PGO is a fully owned subsidiary of Hangking Australia Investment Pty Ltd. The location of the project area is shown in Figure 1-1.

PGO have engaged Surface Water & Erosion Solutions to conduct catchment hydrology flood impact assessment of the Rustler's Roost Project Area (RRPA).

The site, as it is today, in care and maintenance, will be considered base line against which post-mining conditions will be assessed. It will also be the baseline against which dewatering of the pits, i.e., pumping to downstream locations, will be assessed.

The long-term catchment hydrology assessment were conducted using the HEC-HMS hydrologic model (US Army Corps of Engineers, 2020). A HEC-HMS model was previously used to assess the catchment hydrology of the nearby Toms Gully Mine project which lays in the middle reaches of Mount Bundey Creek (Surface Water & Erosion Solutions, 2019). The RORB hydrologic model (Laurenson, Mein, & Nathan, 2010) was used to determine design flood discharges for the site which were used as input to the HEC-RAS model (Brunner, 2021) to assess flood inundation and risk.

1.2 Scope and purpose

This assessment is divided into the following parts:

1. Desktop analysis of aerial photographs and digital elevation models (DEM) to determine catchment configurations.
2. Collation of existing hydrological data.
3. Develop a GIS for terrain analysis and derivation of hydrologic parameters.
4. Development and calibration of HEC-HMS catchment hydrologic model for 1921 to 2021 to assess current baseline.
5. Assess climate change scenarios for the baseline condition.
6. Develop a HEC-HMS model to assess changes in hydrologic regimes during the dewatering process.
7. Develop a HEC-HMS model to assess changes in the hydrologic regimes and for the post-mining condition with changed pits and waste rock dumps (WRDs).
8. Develop a HEC RAS model to assess post-mining flood impacts.

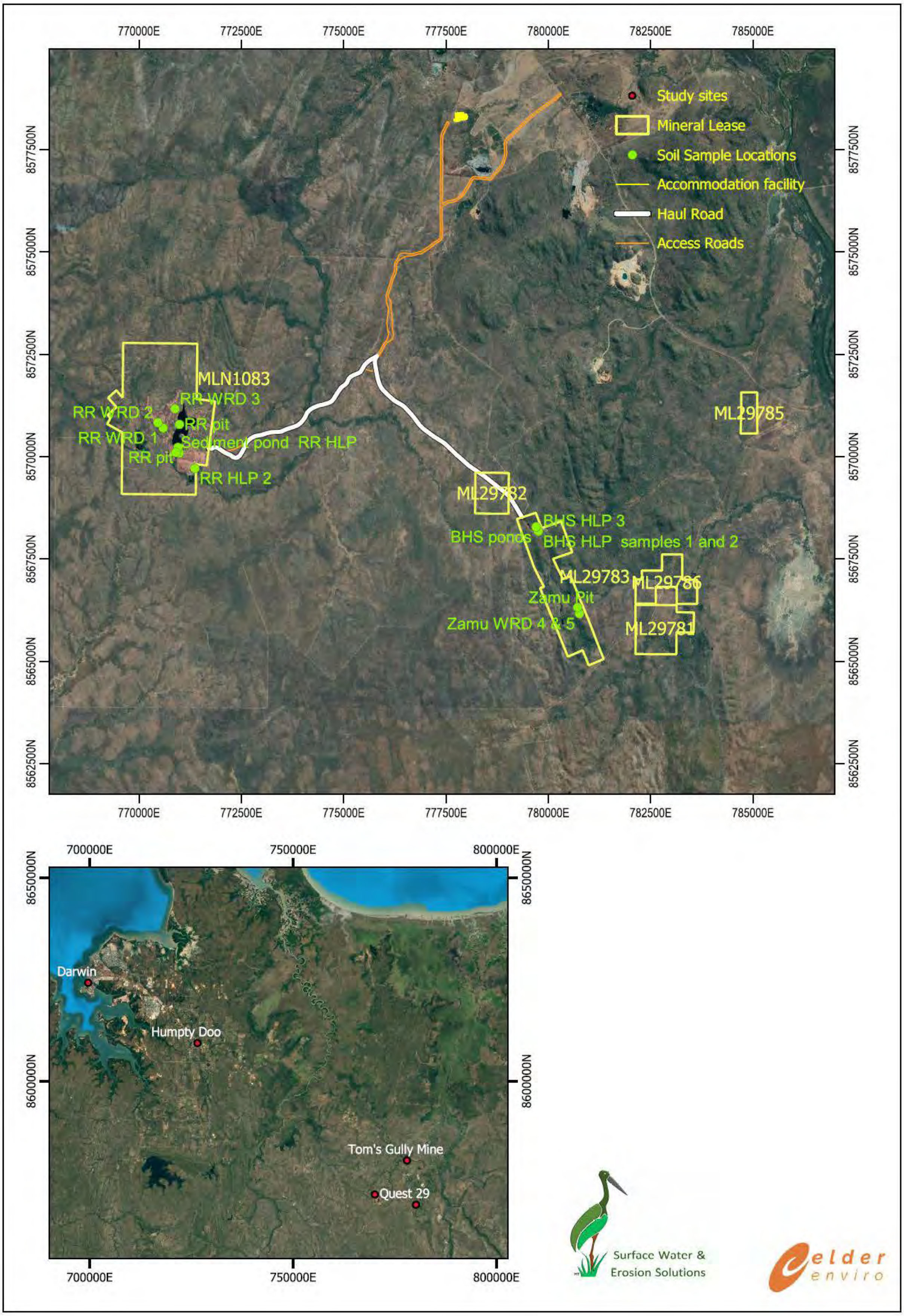

Figure 1-1. Study site location.

2 SITE DESCRIPTION

2.1 Historic and current land use

RRPA is located on Mineral Lease 1083 (MLN1083) which covers approximately 756 ha. Rustler's Roost has been in care and maintenance since 1998, with exploration works being conducted by PGO in 2003, 2017 to 2018 and more recently during 2020.

The infrastructure and landforms that remain on the site are listed below.

- WRD (approximate dimensions 30 m in height, 1,000 m length and 400 m width).
- Associated open pits that have flooded and are considered one pit (approximate dimensions 50 m, 1,000 m length and 300 m width). The pit lake currently holds approximately 3.16 GL of water based on the post mining pit shell dxf. and has a current water level 56.90 mAHD (surveyed on 3 November 2020).
- Annie's Dam - an existing pastoral dam and a potential raw water resource for the proposal with nominal water storage capacity of 0.29 GL (GRES 2018).
- Two heap leach pads (total approximate dimensions 20 m in height, 600 m in length and 450 m width) and heap leach ponds.
- Remnants of old processing plant. In 1997 most of the plant, buildings and other mining infrastructure were removed, apart from three large tanks and some concrete footings.

2.2 Proposed redevelopment

Details of the proposed redevelopment of the sites are provided in Section 1 and Section 4 of the draft EIS (CDM Smith, 2021)

The RRPA mine development envelope will encompass 611.0 ha, of which 277.6 ha has been previously disturbed by past mining activities. The new mining proposal will require clearing of a further 333.4 ha of land.

The proposal involves open-cut mining and expansion, which will be conducted using a drill and blast technique.

In addition to RRPA ore, ore from nearby Quest 29 (Q29) satellite pits) will be processed at a new purpose-built facility located at the Rustler's Roost site to produce gold bullion. The existing unsealed access track will be upgraded to accommodate haulage of ore from Q29 to the processing facility at Rustler's Roost.

At Rustler's Roost, most of the waste rock material will be deposited within two surface WRDs (located partially over the historic WRD to the north-west of the main pit) and a portion backfilled into the two new minor pits (Annie's Dam pit and Annie's Oakey pit) and the main pit..

Mined ore will be processed using a Carbon in Leach (CIL) processing method, which extracts gold from the ore by mixing with a cyanide solution. Tailings produced from the processing facility will be deposited in a tailings storage facility (TSF) to be constructed as part of the proposal.

The extent of proposed activities at RRPA is provided in Table 2-1.

Table 2-1. Proposed expansion of RRPA mining infrastructure

Description Area (Ha)	Proposed Disturbance (Ha)
Open Pit	76.1
WRD	92.0
Heap Leach Pad (decommissioned)	0
Heap Leach Pond (decommissioned)	0
TSF	243.0
Annie's Dam	4.4
Processing Plant and ROM	38.1
Miscellaneous Mining Infrastructure Area	6.6
Total	**460.2**
Rustler's Roost Development Envelope = 611.0 ha	

3 SITE CHARACTERISTICS

3.1 Climate

Q29 and RRPA are situated within the tropics and experience two distinct seasons, the dry season from May to September and the hot and humid wet season from October to April.

Climate data were obtained from the BOM and SILO (Jeffery, Carter, Moodie, & Beswick, 2001).

3.1.1 BOM

Rainfall

Bureau of Meteorology (BOM) daily rainfall records are available for station 014090 Middle Point Rangers where data have been collected since 1957. The average annual rainfall of 1420 mm with the greatest average monthly rainfall during January (350 mm). Cyclones and monsoons can occur during the wet season from October to April and very little rain falls during the dry season from May to September. Mean monthly rainfalls are shown in Figure 3-1.

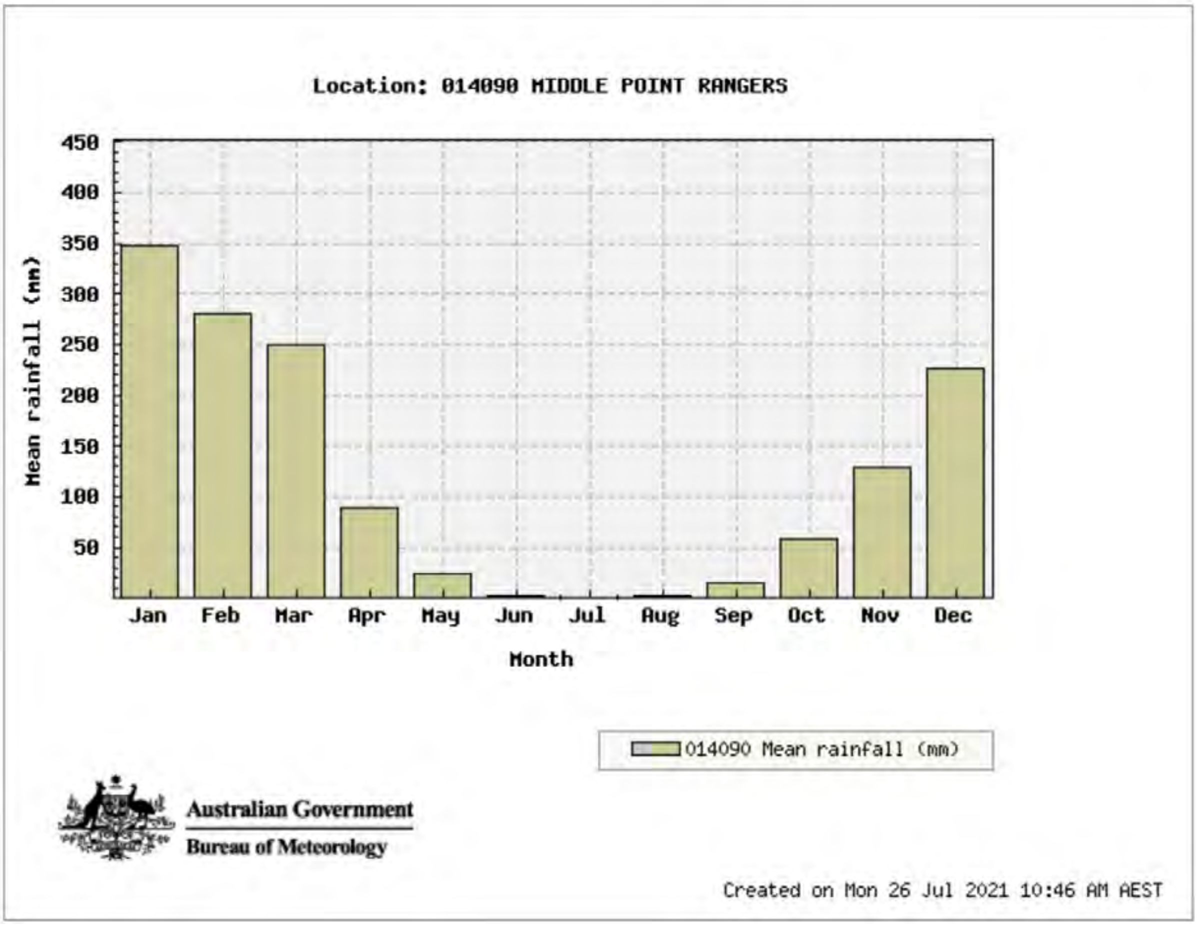

Figure 3-1. Mean monthly rainfall for BOM station 014090 Middle Park Rangers.

Intensity Frequency Duration

BOM IFDs, including those for rare events are shown in Figure 3-2

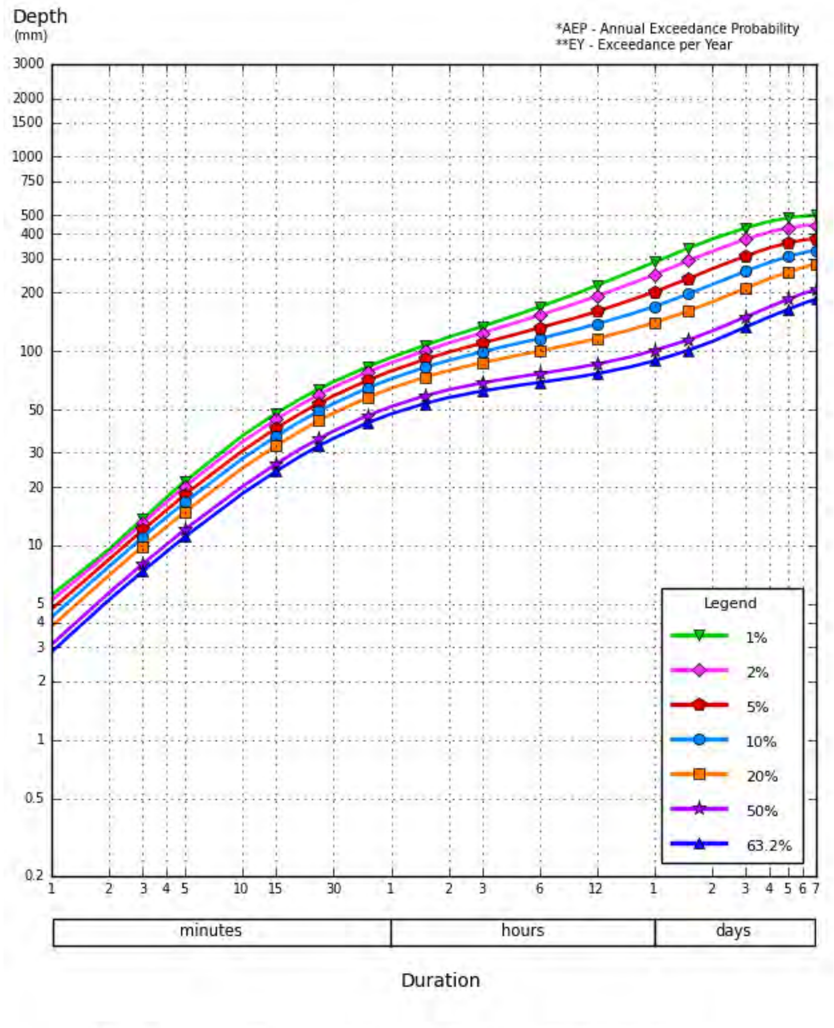

Figure 3-2. BOM IFD for the study site including rare events.

Evaporation

The mean daily evaporation at Middle Point Rangers BOM site, measured by class A evaporation pan from 1965 to 1998, is shown in Figure 3-3.

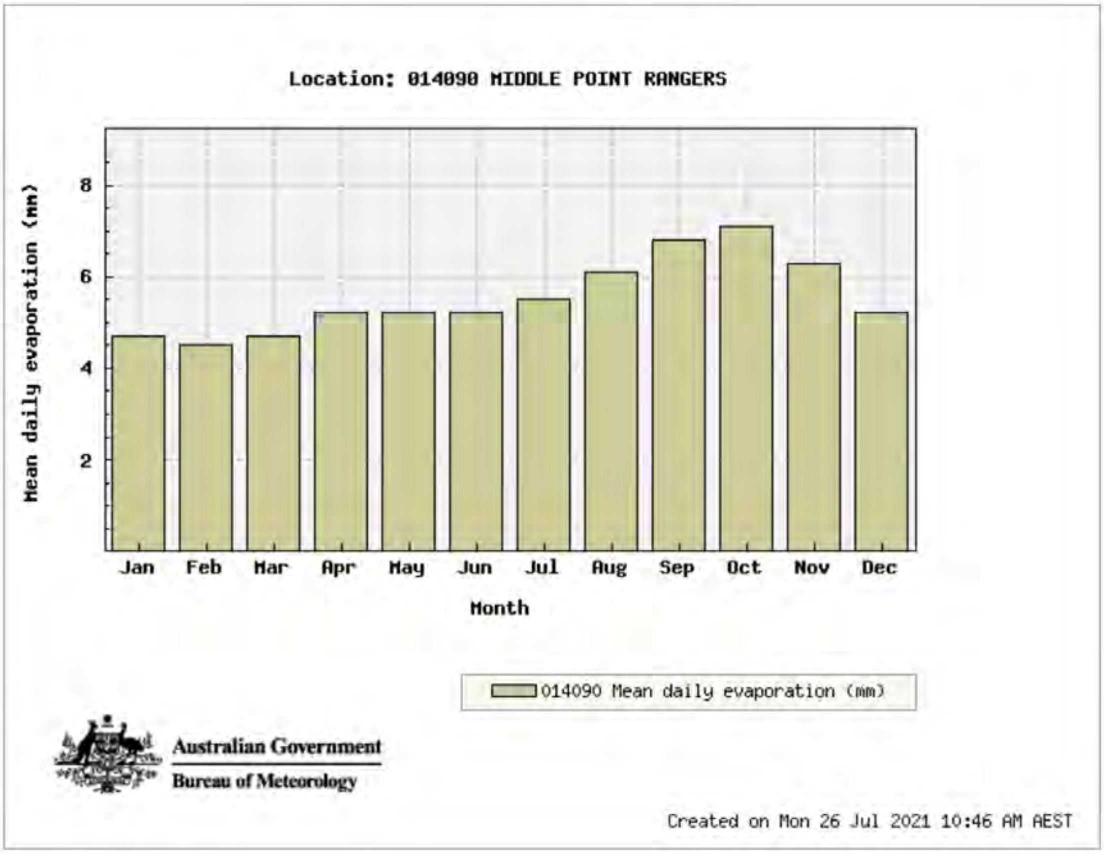

Figure 3-3. Mean daily evaporation for BOM station 014090 Middle Park Rangers.

3.1.2 SILO

Rainfall

Rainfall for the period 1 Jan 1900 to 16 Jul 2021 was obtained from the SILO site (Jeffery, Carter, Moodie, & Beswick, 2001). Mean monthly rainfall is shown in Figure 3-4. Daily rainfall is shown in Figure 3-5

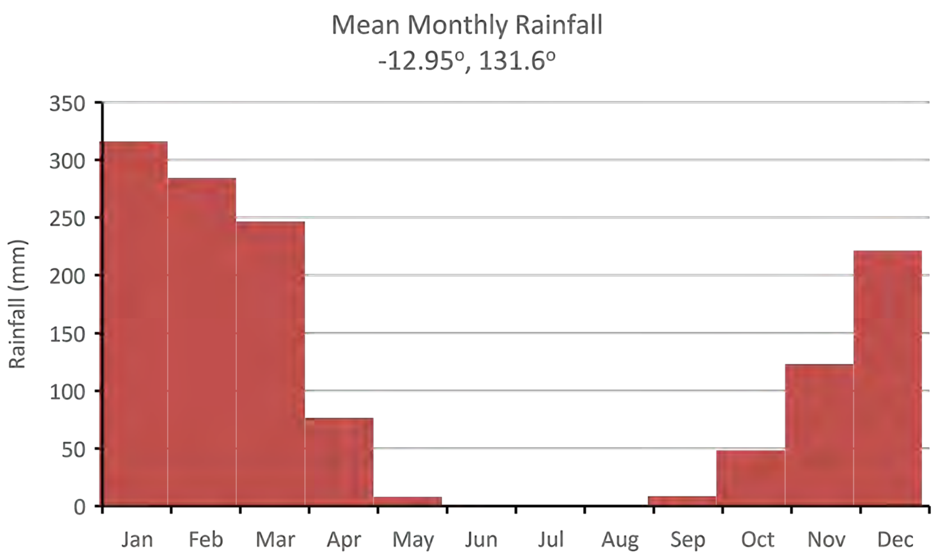

Figure 3-4. SILO mean monthly rainfall for the period 1 Jan 1900 to 17 Jul 2021

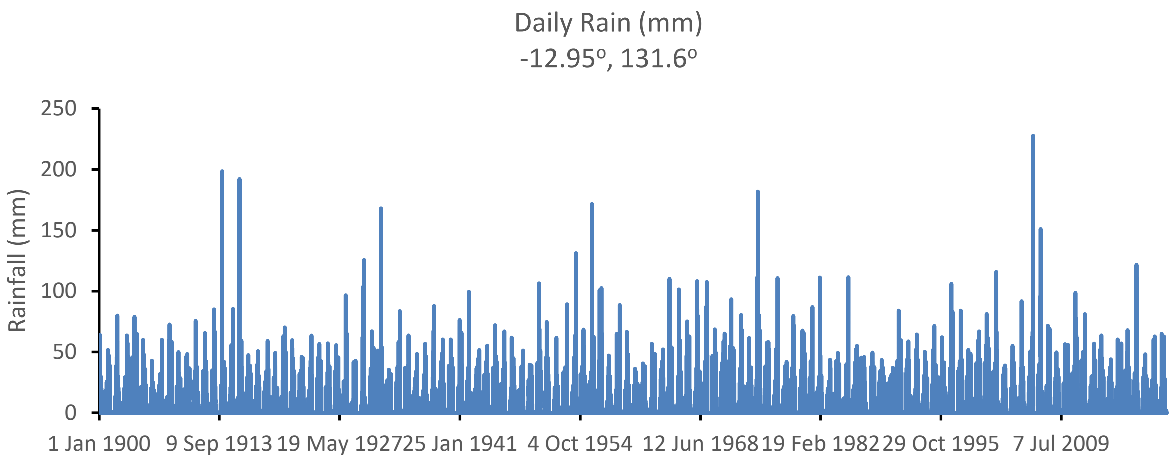

Figure 3-5 SILO daily rainfall 1 Jan 1900 to 17 Jul 2021.

Evapotranspiration

Evapotranspiration at the site, for the period 1 Jan 1957 to 16 Jul 2021 was obtained from the SILO site (Jeffery, Carter, Moodie, & Beswick, 2001). Mean monthly evapotranspiration is shown in Figure 3-4.

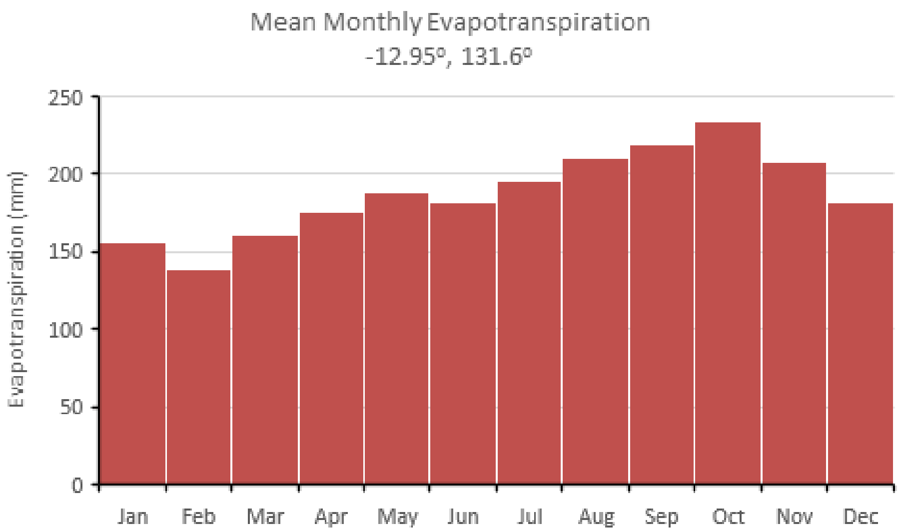

Figure 3-6. SILO mean monthly evapotranspiration.

3.2 Stream Catchments

The Rustler's Roost site is on the catchment divide and in the headwaters of Marrakai Creek and Mount Bundey Creeks and the mineral lease extent is 9.35 km^2. Both creeks are ephemeral, flowing only through the wet season with the annual receding hydrograph continuing into the dry season.

The Rustler's Roost site has internally draining catchments reporting to the pit and the proposed TSF comprising 3.34 km^2 and externally draining catchments reporting to Marrakai and Mount Bundey Creeks comprising 6.01 km^2.

The local catchment is comprised of ridges and dissected hills that are drained by small step rivulets (CDM Smith 2019). Stream flows in these upper areas of the catchments are ephemeral, with flows occurring for only a few weeks-months each year throughout the wet season, in response to rainfall events (EcOz 2021).

4 DATA AVAILABILITY

4.1 Digital Elevation Data

A 5 m DEM of the current site was provided by PGO. It was hydrologically corrected using the GIS analysis available in HEC-HMS. The proposed pit expansions and WRDs were merged with this DEM and 2 m safety bunds placed around the mined-out pit to represent the post-mining condition.

4.2 Stream Flow Data

There were no stream flow data for the RRPA.

4.3 Water Level Data

There are no monitored water level data for the RRPA catchment.

4.4 Rainfall Data

There were no long-term rainfall data for the site. BOM gauges are available across the region and SILO long-term rainfalls for the site were obtained The SILO data set was used in HEC-HMS modelling.

5 LONG-TERM CATCHMENT HYDROLOGY

5.1 HEC-HMS Hydrologic Model Setup

The RRPA site is hydrologically complex and required several HEC-HMS models (Appendices A.1, A.2, C.1 and C.2).

The HEC-HMS model comprises a basin model, meteorological model, control specification, time series data (rainfall, discharge, stage) and paired data (cross sections, volume/elevation curves, area/elevation curves).

5.1.1 Basin Model

The provided pre- and post-mining 5 m x 5 m DEMs were used in this study.

The GIS tool embedded in HEC-HMS was used to identify the drainage channels, delineate the sub-basins, and reaches and insert junctions. The physical characteristics: area, slope, reach length and channel cross sections were derived, and used to determine transform and routing parameter values for the models. These properties were determined for each sub-basin and reach.

5.1.2 Meteorological Models

The SILO data were used as input hyetographs required for the catchment model. Time windows of data were extracted for the simulated water-years and scenarios. An annual evapotranspiration factor of 6.1 mmd^{-1} obtained from SILO was applied to each catchment except the pit catchments.

5.1.3 Control Specifications

These are the time windows for a simulation period and link the time windows in the rainfall, discharge, stage, and paired data time windows.

5.1.4 Time Series Data

These data are time series of the SILO daily rainfall.

5.1.5 Paired Data

Paired data are the relationships between water elevation and surface area and water elevation and volume which are required to fit changes in water elevation in a water body.

Cross sections using the pit decant points are also input in this area along with the head-discharge relationship for the pumps.

5.2 HEC-HMS Model Parameters

During calibration, model parameters which cannot be assigned precise values, based on available information and catchment measurements, are iteratively adjusted until model results achieve an optimal fit with observed data. A common approach for model calibration is to fit the predicted hydrograph to the hydrograph observed by stream gauging within the modelled catchment. Once a good fit has been obtained, these values are applied to another rainfall event with the intention of obtaining a well-fitted simulated hydrograph for that event to validate the calibrated parameter values.

Since there were no stream flow data available to calibrate or validate the RRPA models, realistic parameter values were taken from previous studies, the Australian Rainfall and Runoff Data Hub (https://data.arr-software.org/) and through fitting a runoff ratio to regional values.

The HEC-HMS input parameters include the canopy method, loss, transform, baseflow and routing.

5.2.1 Canopy Method

A canopy method should be used for continuous simulations and in this study is used with the Deficit and Constant Loss method discussed below. A simple canopy method was used. Precipitation is intercepted and once the storage capacity is full, excess precipitation falls to the ground surface. Potential evapotranspiration empties the storage.

5.2.2 Loss Method

This method is suitable for continuous simulations. The method allows the soil layer to dry between rain events as the canopy extracts soil water.

Initial Deficit (ID)

This is the deficit at the start of a simulation and is the amount of rain required to fill the soil layer storage.

Maximum Storage (MS)

This is total amount of water that a soil can hold. In this study it was considered equal to the ID value.

Constant Rate (CR)

This is the loss in mmh^{-1} that continues throughout a storm event and is applied regardless of the length of simulation. The value is commonly fitted iteratively in hydrologic modelling.

Impervious %

The is the percentage of the catchment that is impervious.

5.2.3 Transform Method

The transform method was used to calculate runoff from rainfall. The parameter value, lag time (min), was determined from catchment properties of mean channel slope (S_c) and stream length (L) (km). The lag time (t_L) equation, derived for NT conditions by Moliere, Boggs, Evans et al (2002), is:

$$t_L = 0.57 L^{0.983} S_c^{-0.187} \qquad \text{(Equation 1)}$$

5.2.4 Baseflow

Recession Method

This method performs the calculation of subsurface flow within a catchment. It approximates the typical behaviour observed in a catchment when channel flow recedes exponentially after a storm event.

For this study parameter values determined for an 8.46 km^2 subcatchment of the East Alligator River NT, were applied (Moliere, Boggs, Evans, Saynor, & Erskine, 2002).

5.2.5 Routing Parameters

Channel Lag

Channel lag was determine using Equation 1.

5.3 HEC-HMS MODEL input parameter values

The RRPA models were established to simulate continuous periods to determine long-term changes to the catchments because of pit expansion.

5.3.1 Calibration and Validation of Best-Fit Model Parameters

The most sensitive parameter is CR. To obtain a realistic value, CR was calibrated using a runoff ratio for the catchment. The runoff ratio used was derived for similar sized catchments in the region (EnviroConsult Australia Pty Ltd, 2018b). The derived runoff/loss ratios are shown in Table 5-1.

The SILO rainfall record was used. The scenarios conducted to fit the models to the runoff ratios by varying CR were:

1. 1 Oct 1930 – 30 Sep 1935 to calibrate the model, and
2. 17 Jul 1921 – 16 Jul 2021 to validate the model.

5.3.2 Results

The calibration/validation time series and results are shown in Table 5-1.

The chosen CR value for RRPA was 1.5 mmh^{-1} for RRPA.

Table 5-1. Calibration/Validation Results

Simulation Period	Scenario	CR (mmh^{-1})	HEC-HMS Discharge (GL)	HEC-HMS Qp (m^3s^{-1})	Loss Ratio
Rustler's Roost East					
1-10-1930 – 30-9-1935	Current condition baseline	1.5	24.9	14.8	0.24
17-7-1921 – 17-7-2021	Current condition baseline	1.5	528.6	18.8	0.25

The HEC-HMS parameters and adopted values are shown in Table 5-2. These parameter values were used in the pre- and post-mining modelling scenarios.

Table 5-2. HEC-HMS parameter values applied to the Quest 29 catchment hydrology models.

Method	Parameter	Value	Source
Canopy: Simple Canopy	*Initial Storage (%)*	*0*	*default*
	Max Storage	*2.5*	*Fitted*
	Crop Coefficient	1	default
Loss: Deficit and Constant	Initial Deficit (mm)	36	ARR Data Hub
	Max Deficit (mm)	36	Fitted
	Constant Rate (mmh^{-1})	1.5	Fitted
	Impervious (%)	18	(Moliere, Boggs, Evans, Saynor, & Erskine, 2002)
Transform: SCS Hydrograph	Lag (min)	Equation (3.1)	(Moliere, Boggs, Evans, Saynor, & Erskine, 2002)
Baseflow: Recession	Recession Constant	0.58	(Moliere, Boggs, Evans, Saynor, & Erskine, 2002)
	Ratio to Peak	0.25	(Moliere, Boggs, Evans, Saynor, & Erskine, 2002)
Routing: Lag	Lag Time (min)	Equation (3.1)	(Moliere, Boggs, Evans, Saynor, & Erskine, 2002)

5.4 Assessment of Hydrologic Regime Changes

Model scenario simulations were conducted to assess changes to the baseline condition due to mine site changes, climate change and dewatering (Table 5-3).

For these scenarios the site's condition, as it is today, was considered as baseline. The HEC-HMS model was calibrated for this condition and a 100y simulation conducted using SILO rain from 1921 to 2021. The catchment discharge was used as baseline for future scenarios. The 100y SILO rainfall was then used for the dewatering scenarios from 2024 to 2031 with the RCP 4.5 climate change model applied. A post-mining scenario was conducted from the end of mining 2031 to 2131. For the post-mining scenario, the simulation was conducted for the current landform with a climate change factor applied. This scenario was considered baseline for the future. The same rainfall was used for the post-mining landform scenario commencing in 2031 as the end of mining. The scenario outputs were assessed against the baseline.

Table 5-3. HEC-HMS modelling scenarios.

Scenario	Landform Condition	Simulated Period	Climate Change Model
Impacts of Landform Change			
RCP 4.5 baseline	Pre-mining	1/12/2031 – 17/7/2131	RCP 4.5
RCP 4.5	Post-mining	1/12/2031 – 17/7/2131	RCP 4.5

5.4.1 Climate Change Model

The RCP is a greenhouse gas concentration trajectory adopted by the International Panel on Climate Change of which, there are 7. RCP 4.5 is considered an intermediate scenario (https://ar5-syr.ipcc.ch/topic_futurechanges.php) which will result in a mean sea level rise and the inability of some plants and animals to adapt (https://ar5-syr.ipcc.ch/topic_futurechanges.php). The RCP 4.5 climate model was applied to the dewatering phase of the operation and the post-mining scenarios. The 100y SILO rainfall from 1921 to 2021 was increased relative to the climate change model in accordance with the percentages provided by the ARR Data hub (Babister, Trim, Testoni, & Retallic, 2016).

5.4.2 The influence of dewatering on downstream flows

Dewatering scenarios were conducted to assess change in downstream flows. Scenarios were conducted in accordance with the schedule in Figure 5-1. The RCP 4.5 model was applied to these scenarios and assessed against simulated flows in the pre-project landscape. This assesses the effect of expansion and pumping on existing conditions.

The changes in total discharge and Qp are given in Table 5-4.

Dewatering of the RRPA pit will begin on 1/12/2021 and continue through the wet season to 30/4/2022. It will recommence following the 2022 Dry Season on 1/12/2022 and continue until 30/4/2023. During pre-mining dewatering, water will be pumped to Annie's Dam in Marrakai Creek and to Mount Bundey Creek (Appendix B.1). The second phase of dewatering will commence on 1/12/2022 and continue through the wet season to 30/4/2023. The water will be pumped to Annie's Dam in Marrakai Creek and Mount Bundey Creek (Appendix B.1).

The proposed dewatering regime has a minimal effect on Mountt Bundey Creek with slightly increased flows and Qp. The pump discharge is diluted by catchments size. The Marrakai Catchment modelled was not as extensive as Mount Bundey Creek, so the pump discharge increased total flow by ≈31% at the model domain outlet and Qp increase by ≈10%. However, as the flows progresses downstream to the broader catchment, they will be diluted by catchment size. There is no risk of increased scour from increased Qp as the baseline Qp for the Annie's Dam catchment is 5.3 m^3s^{-1} (Table 8-3) compared with the Qp of the pump affected discharge of 2.5 m^3s^{-1}.

Table 5-4. Pit dewatering assessment showing changes in total discharge and Qp at the catchment outlet influenced by dewatering.

Period	From	To	Pump Rate (m^3s^{-1})	Baseline Discharge (GL)	Pump Scenario Discharges (GL)	Baseline Qp (m^3s^{-1})	Scenario Qp (m^3s^{-1})
1/12/2021 – 30/4/2022	Existing Pit	Mount Bundey Creek	0.0725	4.1	4.4	2.9	2.6
1/12/2022 – 30/4/2023	Existing Pit	Mount Bundey Creek	0.0725	3.2	3.2	1.9	1.9
1/12/2021-30/4/2023	Existing Pit	Annie's Dam	0.0725	1.9	2.5	0.68	0.75

Mining Phase shedule and intial dewatering of pits

1 Intial dewatering of existing pits

Rustlers Roost Deposit	Start	Finish	KL water	Rate KL/day	L/s	destination
RR Pit 2nd wet season	1/12/2021	30/04/2022	1,618,643	10,791	125	Mt Bundey Creek and Mariki creek
RR Pit 1st wet season	1/12/2022	30/04/2023	1,618,643	10,791	125	Mt Bundey Creek and Mariki creek
Q29 deposit	**Start**	**Finish**				
South Koolpin	15/02/2029	30/04/2030	129,728	296	3	Zuma when mined
Zuma	15/12/2024	30/04/2025	103,812	763	9	South Koolpin & Nth Koolpin
Taipan	15/02/2029	30/04/2030	79,253	181	2	Zuma when mined
Nth Koolpin	15/02/2029	30/04/2030	35,278	80	1	Zuma when mined
BHS	15/03/2030	30/04/2031	21,637	53	1	Nth Koopin when mined

2 Mining Overview schedule

	Finacial ye	Finacial ye	Finacial ye	Finacial ye	Finacial ye	Finacial ye	Finacial ye	Finacial years	Finacial years
RR	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**	**2030-31**	**2031-32**
RR Pit	start 1/3/2024								31/10/2031
	Finacial ye	**Finacial ye**	**Finacial ye**	**Finacial ye**	**Finacial ye**	**Finacial ye**	**Finacial ye**	**Finacial years**	**Finacial years**
Q29	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**	**2030-31**	**2031-32**
South Koolpin								1/07/2030 to 30/06/2031	
Zuma			1/07/2025				30/06/2030		
Taipan								1/07/2030	30/11/2031
NTh Koolpin								1/07/2030 to 30/06/2031	
BHS									1/08/2031 to 30/10/2031

3 Post Mining Phase

Rehab and monitoring	Start	Finish
Rehab plant and both sites	1/01/2032	31/12/2032
All pits Monitoring	1/11/2031	30/10/2036

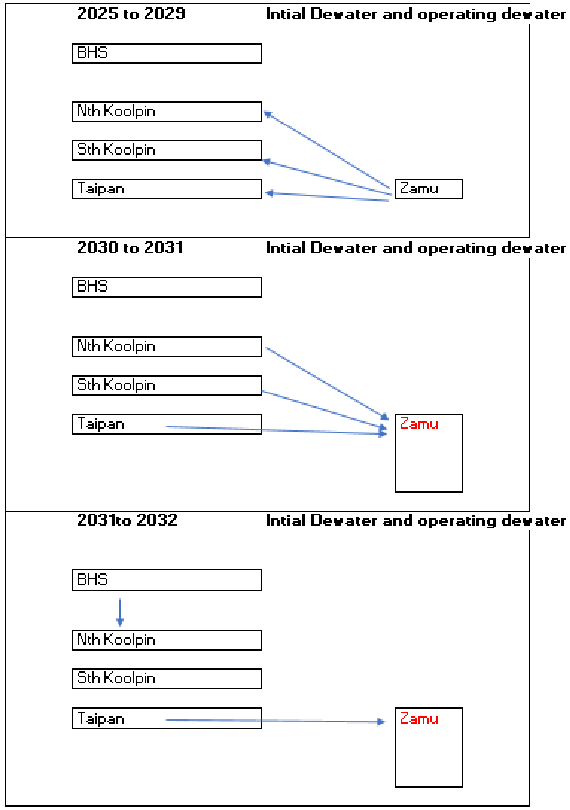

Figure 5-1. Proposed pit dewatering and mining schedule and pit water recycling.

5.5 Environmental Flows

Erskine et al (2003) in their study of the Daly River, NT considered that to maintain environmental health of the system extractions should be less than 20%. This could be applied to losses from the system from mining.

This environmental flow analysis was conducted using log-term simulations as follows:

1. For the site, in an undisturbed condition for the future, used the same SILO rainfall record with the RCP 4.5 climate model applied to simulate the future 100 years, and
2. The rainfall in 2 above was used in the post-mining HEC-HMS model to assess changes occurring to total flow and Qp resulting from changed catchment conditions resulting from mining.

The simulation ran from 2031 at the end of mining to 2121.

The results are given in Table 5-5.

5.5.1 Rustler's Roost East

Simulations show the effects of climate change post-mining (Appendix A.1) where it is seen pit water level rises because of applying the RCP 4.5 climate model.

The pre- and post-mining models are shown in Appendix A.1 and A.2. There is a 10% loss in total flow and 6.6% loss in Qp in the RCP 4.5 post-mining landform condition. These losses are mainly due to refilling the pit over several decades post mining. However, simulations for the water years 2080 and 2119 (Appendix A.2) as the pit water reached equilibrium, showed that the losses had reduce by several % Table 8-3. The TSF increases the post-mining east catchment area, but based on the provided DEM, water level does not reach a spillway level and therefore the TSF does not contribute to downstream flow.

5.5.2 Annie's Dam Catchment

Annie's Dam catchment is the catchment most affected by mining operations. The proposed TSF consumes almost 50% of the current Annie's Dam catchment Appendix C.1. As a result, total flow decreases by 38% and Qp decreases by 34% (Table 8-3). However, the Annie's Dam model domain is small, and it is in the head waters of the very large Adelaide River catchment. It is unlikely that these reductions in flows will have an adverse impact on downstream waterways.

5.5.3 Small Catchments

The RRPA site is located on a catchment boundary and therefore sheds water in several directions. To the north of the pit are several small sheet-flow catchments that will be affected by WRD placement (Appendix C.2). Because of earthworks, WRD placement and drainage change, some catchments gain area and some loose area. Therefore, between the pre- and post- scenarios some lose flow and others gain. The changes in total flow and Qp of these catchments are shown in Table 8-3.

Table 5-5. Scenario Results – Impacts of Landform Changes with the RCP 4.5 Climate Model applied to rainfall

Period	Scenario	Site Condition	Baseline Discharge (GL)	Scenario Discharge (GL)	Baseline Qp (m^3s^{-1})	Scenario Qp (m^3s^{-1})	Percentage change (Total discharge) (Qp)
Rustler's Roost East (Appendix A.1 & A.2)							
1/12/2031-16/7/2131	RCP 4.5 baseline	Pre-mining	518.6		19.9		
	RCP 4.5 post-mining	Post-mining		470.8		18.6	-10 (-6.6)
1/10/2080-30/9/2081	RCP 4.5 baseline	Pre-mining	5.9		8.7		
	RCP 4.5 post-mining	Post-mining		5.8		9.2	-2 (+5.7)
1/10/2119-30/9/2120	RCP 4.5 baseline	Pre-mining	4.8		4.1		
	RCP 4.5 post-mining	Post-mining		4.4		3.8	-6.4 (-7.4)
Annie's Dam Catchment (Appendix C.1)							
1/12/2031-16/7/2131	RCP 4.5 baseline	Pre-mining	119.7		5.3		
	RCP 4.5 post-mining	Post-mining		73.6		3.5	-38 (-34)

Period	Scenario	Site Condition	Baseline Discharge (GL)	Scenario Discharge (GL	Baseline Qp (m^3s^{-1})	Scenario Qp (m^3s^{-1})	Percentage change (Total discharge) (Qp)
Upper West (North WRD) (Appendix C.2)							
1/12/2031-16/7/2131	RCP 4.5 baseline	Pre-mining	9.4		0.14		
	RCP 4.5 post-mining	Post-mining		14.8		0.75	+37 (+81)
North (Appendix C.2)							
	RCP 4.5 baseline	Pre-mining	55.6		2.5		
	RCP 4.5 post-mining	Post-mining		37.6		2.2	-33 (-12)
Northwest (North WRD) (Appendix C.2)							
	RCP 4.5 baseline	Pre-mining	28.3		1.4		
	RCP 4.5 post-mining	Post-mining		37.6		1.6	+25 (+12.5)
Middle West (North WRD) (Appendix C.2)							
	RCP 4.5 baseline	Pre-mining	15.0		0.76		
	RCP 4.5 post-mining	Post-mining		14.8		0.75	-1 (-2)

5.6 Catchment Hydrology Conclusions

There were no data available to calibrate the HEC-HMS model for RRPA. However, several studies in the region have produced robust model input parameter values. Applying these values resulted in runoff ratios for the model that represents regional values.

The parameterised model was used to assess hydrologic changes due to pit dewatering, mining operation and landform changes. A long-term SILO rainfall record was used to conduct simulations and the outputs taken as baseline conditions.

The RCP 4.5 model was applied to the same rainfall, and this was considered baseline conditions for the period following mining which would be affected by climate change. This same rainfall was used to assess catchment changes during dewatering and post-mining.

Simulations showed, that although there were changes to total discharge and Qp at the catchment outlet during dewatering, these changes were transient and will have little effect on long term catchment hydrology.

Post-mining, there were reductions in the total flow for the long-term simulations, but this is due to pit filling with direct rainfall over several decades. This rainfall is lost to the surface water system.

Only Annie's dam catchment exceeds a maximum 20% reduction in flow which is required for river health, but this is because nearly 50% of Annie's dam catchment is consumed by the proposed TSF. Otherwise changes to the site will not affect flows to the extent that the environmental health of the streams will be threatened.

6 FLOOD RISK ASSESSMENT

Flood inundation and flood hazard for the 20% AEP, 1% AEP, 0.1% AEP and PMP design rainfall events were assessed using the HEC-RAS model. The RORBwin model was used to determine the design event discharge hydrographs used as inputs to HEC-RAS.

RORBwin is a rainfall excess model which generates flow with the application of excess rainfall over defined sub-catchment areas. RORB was used to generate rainfall hyetographs for the design events in accordance with the Australian Rainfall & Runoff Guidelines 2019. The significant parameters in RORBwin are 1) Initial Loss (IL), which is abstracted from the beginning of the rainfall event; 2) Continuing Loss (CL), which is applied at a constant rate over the duration of the rain event, 3) the routing parameter kc; and 4) the hydrograph exponent m (recommended value 0.8). In this study regional parameter values were taken from the ARR Data Hub (Babister, Trim, Testoni, & Retallic, 2016).

The rainfall loss parameter values used in this study were initial loss (IL) 44 mm, and continuing loss (CL) 4.5 mm/h, which have previously been fitted for this region (Babister, Trim, Testoni, & Retallic, 2016). Ensemble simulations, embedded in RORBwin and using the above parameter values and BOM IFD curves (Figure 3-2), were run to determine the most probable rainfall (Figure 6-1) and discharge for the 20% AEP, 1%AEP, and 0.1%AEP. For the PMP event IL = 0 mm and CL = 0 mmh^{-1}.

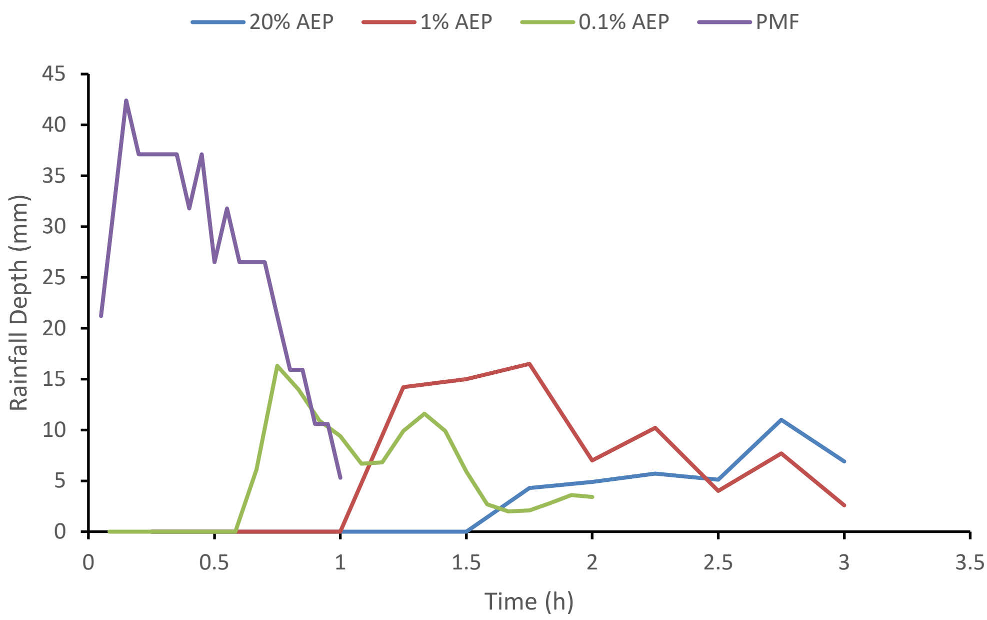

Figure 6-1. Design rainfall depths determined using RORB. These are used to determine hydrograph input to HEC-RAS for flood risk assessment.

6.1 Catchment Analysis

Information available to create the RORBwin catchment model comprise:

- High-resolution 2 m digital elevation model (DEM) covering the immediate study site, which was used for catchment and streamline delineation,
- Lower resolution GeoScience Australia 30m hydrologically corrected DEM, used for areas outside this coverage,
- 2 m post-mining digital elevation model (DEM) created using Lidar data for detailed coverage of the mine site,

- GIS-based topographic information for defining waterways and waterbodies, and
- Google Satellite aerial photography accessed through Quantum GIS (QGIS).

6.2 Flood Inundation and Flood Hazard Modelling

6.2.1 HEC-RAS

HEC-RAS was used to model flood inundation on the site. The following scenarios were simulated:

1. Local inundation in the post-mine catchments due to design rainfall events,
2. Local flood hazard in the post-mine catchment in accordance with the Australian Disaster Resilience Guideline 7-3 Flood Hazard (AIDR, 2017).

The model meshes were constructed from available topographic and bathymetric data. The mesh for post-mining scenarios were constructed from the pre-mining DEM merged with mining infrastructure created from the design drawings.

6.2.2 Model Roughness Parameter

The roughness parameter describes the ground surface condition which affects the behaviour (velocity and depth) of flow in the model. The roughness parameter used in HEC-RAS is Manning's n. The Manning's n values are set as 0.04 for channel and channel bank and 0.06 for floodplain and other regions. These values were selected from the typical ranges of 2D roughness parameters (Ball, et al., 2019).

6.3 Flood Inundation and Hazard Modelling Results

This section assesses risk based on flood hazard (m^2s^{-1}) calculated as depth x velocity (AIDR, 2017) and inundation, the depth of water (m). The spatial distribution of these were determine from the HEC-RAS modelling.

6.3.1 20% AEP Event

The Hazard and inundation maps for the 20% AEP event are shown in Appendix D.1. There is a minor hazard around the toe of the North WRD where the hazard is between 0.5 and 1 m^2s^{-1}. There is little risk of inundation other than that expected for over bank flow <0.2m.

6.3.2 1% AEP Event

The results are in Appendix D.2. the main flood hazard risk is a small area around the toe of the north WRD with minor risk elsewhere. The extent of risk has increased compared with the 20% AEP event.

Inundation risk is minor. However, there are areas of inundation with depths as much at 2 m contained in the TSF and in the north flowing reach of Marrakai Creek that drains the external TSF wall to the east.

6.3.3 0.1% AEP Event

The results are in Appendix D.3. The area around the toe of the North WRD has now reached a high risk >2 m^2s^{-1}. This covers an area of ≈0.7 ha. This could be managed by adjusting the flow path in this area during rehabilitation. There are high risk areas in the northeast tributary and in the TSF. But the flow in the tributary is probably no more than would be expected during such an event.

6.3.4 PMP Event

The results are in Appendix D.4. This type of event may occur about once in every 5000 years. The results show that the highest class of risk is present in nearly every streamline, almost completely along the eastern toe of the Northern WRD, at the northern toe of the southern WRD, and over large areas in the TSF. If this occurs when the tailings are dry, it may result in scour along the inner wall. High levels of inundation, >3m, are present along the toes of the north and south WRDs. They also occur in the TSF and may release through the spillway.

6.3.5 Conclusions

This section investigated whether direct rainfall and runoff from the mine site increases the risk to people, livestock, and wildlife during flood events. There is little risk to humans as access to the site is through fences and locked gates. The broader area of the mine site is entered from the Arnhem Highway through fenced private property and through the quarry at Mt Bundey. All remaining water bodies will be bunded. Wildlife would be familiar with flooding in the creeks; therefore, the main safety risk lies with livestock (principally beef cattle). However, it is likely the site will be fenced reducing the risk to cattle.

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