

Appendix N - Hydrology and Flood Assessment Report

Appendix N-1 - Hydrology and Flood Assessment Report - Quest 29



Quest 29 Open-Cut Mine
Redevelopment

Catchment Hydrology and Flood Risk

Volume 1

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Photograph Cover Sheet: Rustler's Roost Pit looking north July 2021.

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
RRPA	Rustler's Roost Project Area
SILO	Scientific Information for Landowners
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 Quest 29 (Q29) open cut mines. Q29 is located on the Old Mount Bunday Station, Perpetual Lease (PPL) 1163 and McKinlay River Pastoral Station (PPL1184), approximately 100 km south-east of Darwin. PGO is a fully owned subsidiary of Hanking 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 impact assessment for Q29.

The site, as it is today, in care and maintenance, will be considered baseline 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 was 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 Tom's Gully Mine project, which lays in the middle reaches of Mount Bunday Creek (Surface Water & Erosion Solutions, 2019). The RORB hydrologic model (Laurenson, Mein, & Nathan, 2010) was used to determine design discharges that were used as input to the HEC-RAS model (Brunner, 2021) to assess flood inundation 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. Development of 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 postmining condition with changed pits and waste rock dumps (WRDs).
8. Develop a HEC RAS model to assess post-mining flood impacts.

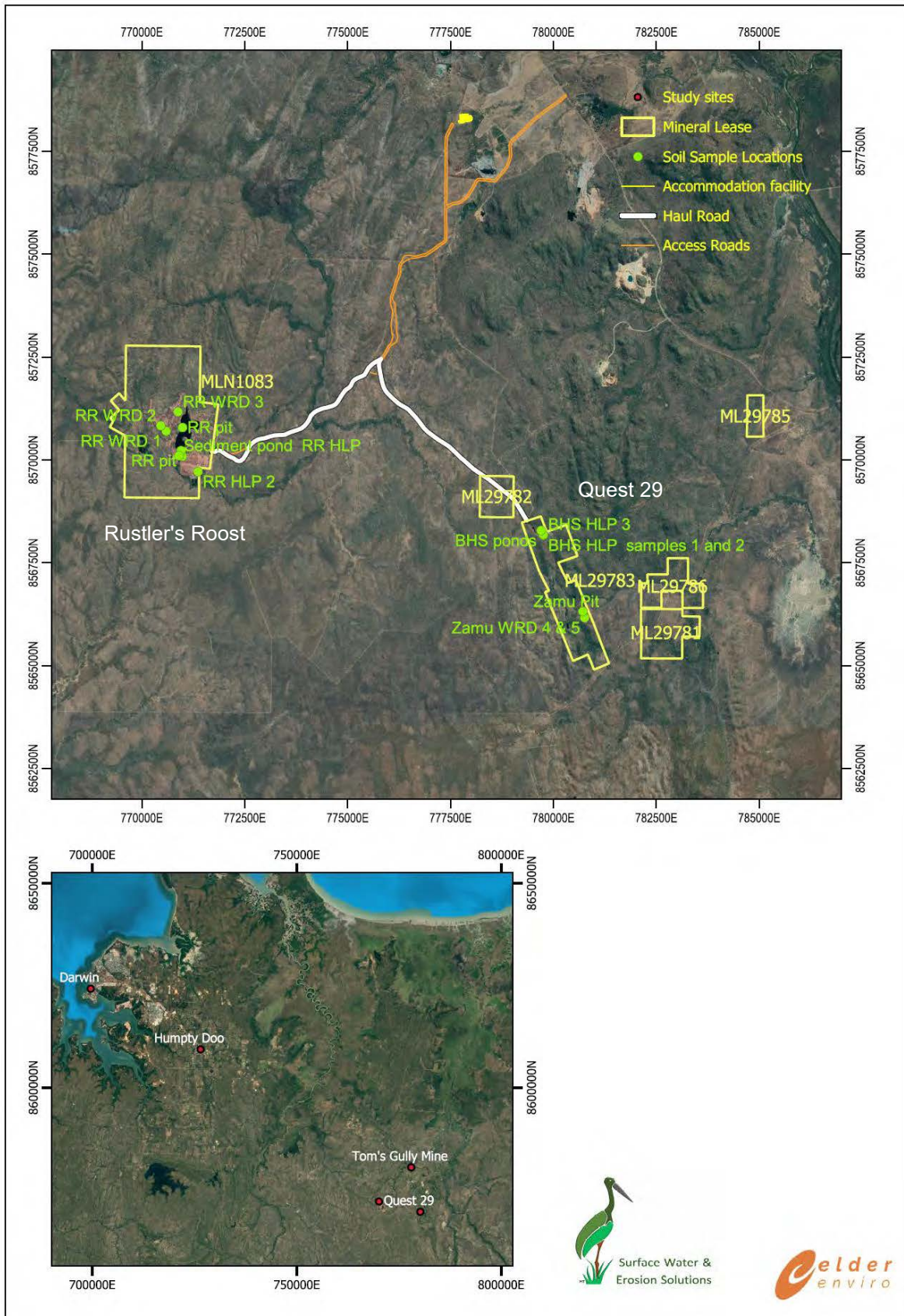


Figure 1-1. Study site location.

2 SITE DESCRIPTION

2.1 Historic and current land use

Q29 is located on Pastoral Leasehold land across five Mineral Leases – ML29785, ML29782, ML29783, ML29786 & ML29781 (Appendix A.2). Of these Mineral Leases, ML29783 is the only tenement that has had historical disturbance (aside from exploration drilling), across an area of approximately 21 ha.

The existing infrastructure and landforms on the site are listed below:

- Five open-cut pits (largest of the pits approximately 25 m depth, 280 m length and 50 m width).
- Five WRD's (largest of the WRDs approximately 10 m height, 280 m length and 80 m width).
- One heap leach pad (approximate dimensions 20 m in height, 200 m length and 200 m width).
- Heap leach ponds.
- Remaining infrastructure of the Carbon in-leach (CIL) processing tanks.

Q29 was operated as an open-cut gold mine from 1999 to early 2002. Under care and maintenance, the pastoral landowner of Old Mount Bunday Station has been engaged by PGO to assist in monitoring and managing the mining tenements in terms of weed, fire, and water management compliance requirements (EcOz 2021).

2.2 Proposed redevelopment

The Q29 mine development envelope encompasses 139.5 ha, of which 46.7 ha has been previously disturbed by past mining activities. The new mining proposal will require clearing of a further 26.16 ha of land.

The Q29 portion of the project involves open-cut mining and expansion of all existing open-cut pits, which will be conducted using a drill and blast technique. No new pits are proposed for development in the Q29 portion of the project.

Ore from Q29 will be processed at a new purpose-built facility located at the Rustlers 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 Rustlers Roost.

Waste rock at both sites will be deposited in surface WRDs and at Q29, also used to backfill several pits where mine scheduling permits. A new surface WRD is proposed to dispose of the waste from mining Zamu pit, with waste material from the remaining pits to be backfilled into Zamu pit and a portion of oxide material from BHS pit used for rehabilitation of the decommissioned heap leach facility.

The extent of proposed activities at Q29 is provided in Table 2-1.

Table 2-1. Proposed expansion of Q29 mining infrastructure

Description Area (Ha)	Proposed Disturbance (Ha)
Pits	28.2
WRDs	16.6
Leach Pond (decommissioned)	0
Leach Pad (decommissioned)	0
Miscellaneous Mining Infrastructure Area	0
Total	44.8
Quest 29 Development Envelope = 139.5 ha	

3 SITE CHARACTERISTICS

3.1 Climate

The Project is situated within the tropics and experience two distinct seasons, the dry season from May to September and the wet season from October to April.

Climate data were obtained from the BOM and SILO web sites.

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. 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.

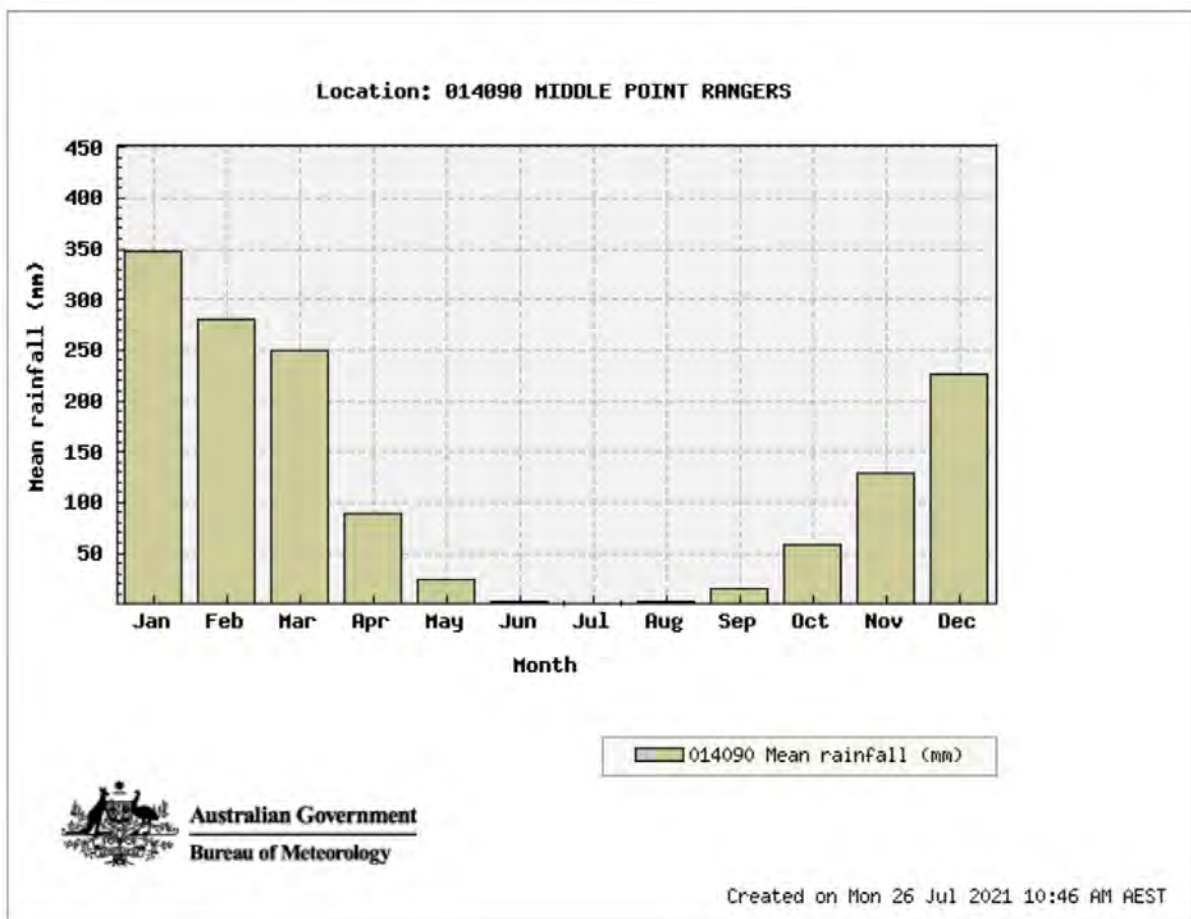


Figure 3-1. Mean monthly rainfall for BOM station 014090 Middle Park Rangers.

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.

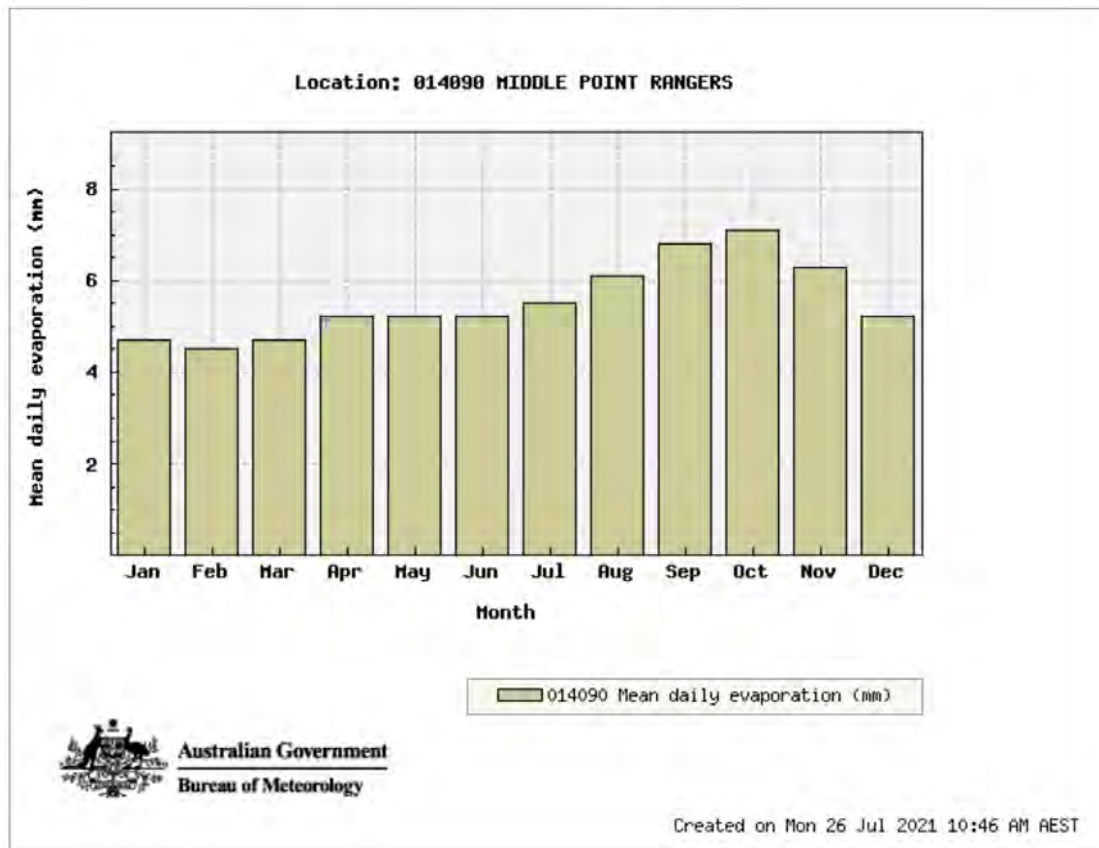


Figure 3-2. Mean daily evaporation for BOM station 014090 Middle Park Rangers.

3.1.2 SILO

Rainfall

Rainfall, for the study location, 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

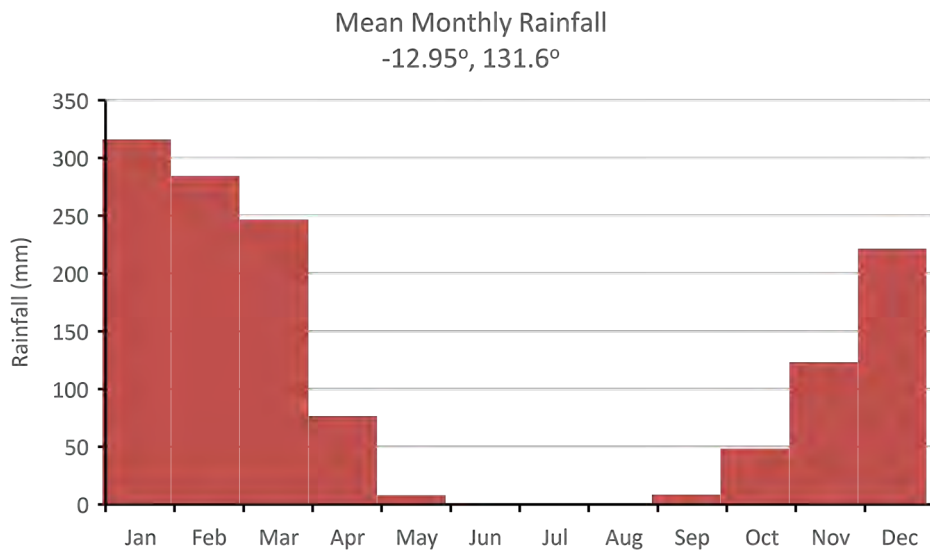


Figure 3-3. SILO mean monthly rainfall for the period 1 Jan 1900 to 17 Jul 2021

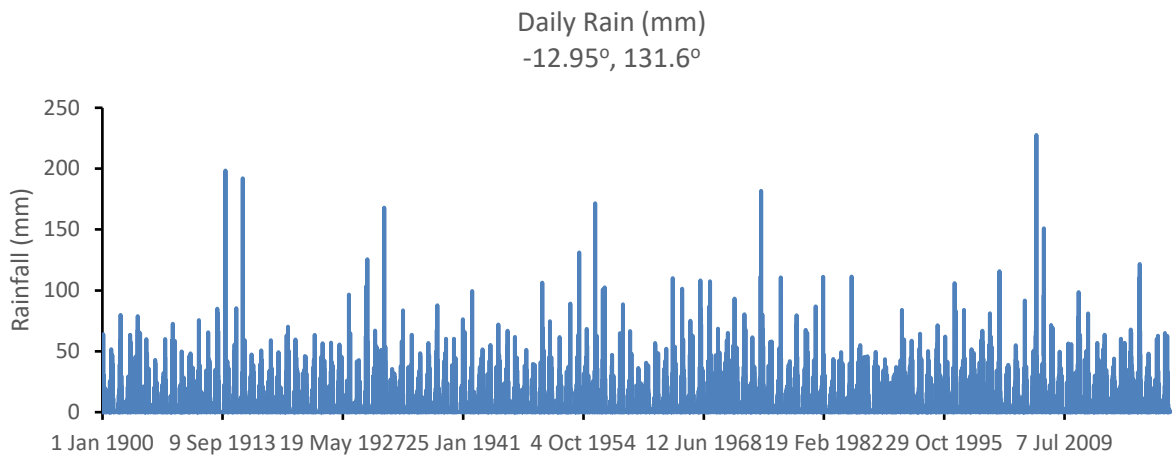
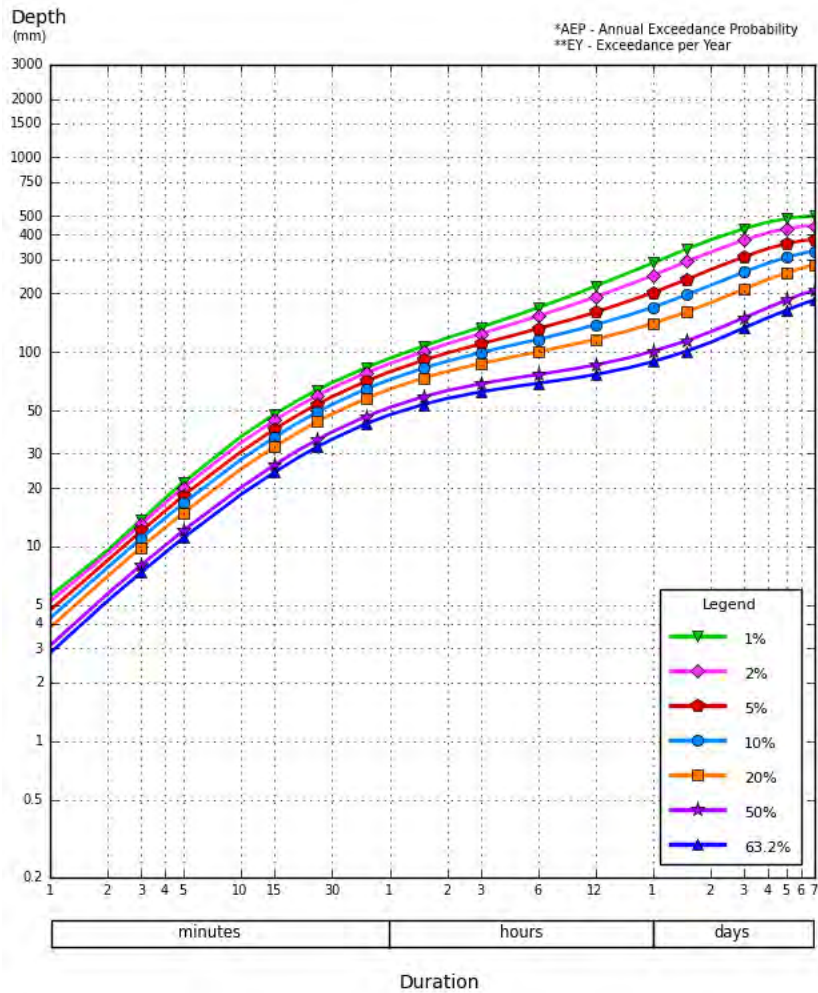


Figure 3-4 SILO daily rainfall 1 Jan 1900 to 17 Jul 2021.

Intensity Frequency Duration

BOM Intensity Frequency Duration (IFD) data, including those for rare events are shown in Figure 3-5



©Copyright Commonwealth of Australia 2016, Bureau of Meteorology (ABN 92 637 533 532)

Figure 3-5. BOM IFD for the study site including rare events.

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.

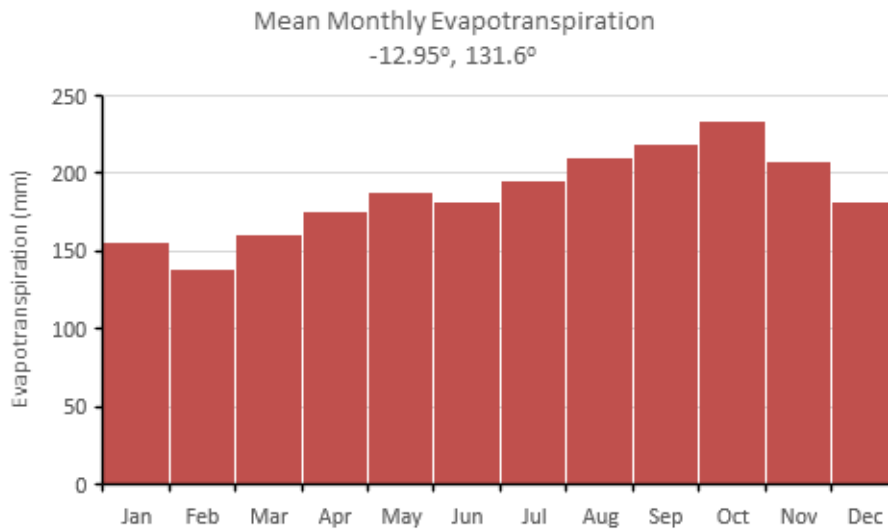


Figure 3-6. SILO mean monthly evapotranspiration.

3.2 Stream Catchments

Q29 is predominantly located in the McKinley River sub-catchment, which also flows into the Mary River system. A minor northern portion of Q29 is in the upper Mount Bunday Creek sub-catchment of the Mary River system.

The local catchment comprises 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).

The Q29 site is split into a north catchment (Q29N), draining into Mount Bunday Creek, with a surface area of 96.06 ha, and a south catchment (Q29S), with a surface area of 492.68 ha, draining into the McKinley River. Q29N and Q29S were delineated using the available 5 m DEM and aerial photography. Catchment analysis of the sites is shown in Appendix A.

4 DATA AVAILABILITY

4.1 Digital Elevation Data

A 5 m DEM of the current site was provided by PGO. It was hydrologically correct 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 data for the Q29 portion of the project area.

4.3 Water Level Data

There are no water level data for the Q29 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

A hydrologic model was developed for each of the catchments described above (Appendix A.1).

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 post-mining DEM was adjusted to include 2 m safety bunds around the final mine pits effectively preventing surface water entering or leaving. Only direct rainfall will enter the pits with the respect to surface water.

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 in 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 windows 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 Q29n and Q29S 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 %

This 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) (m). The lag time (t_L) equation, derived for NT conditions by Moliere, Boggs, Evans et al (2002), is:

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

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 were applied (Moliere, Boggs, Evans, Saynor, & Erskine, 2002).

5.2.5 Routing Parameters

Channel Lag

Channel lag was determined using Equation 1.

5.3 HEC-HMS MODEL input parameter values

The Q29 models were established to simulate continuous periods to determine long-term changes to the catchments because of pit expansion. There were no flow data or pit stage height data available for calibration, so parameter values were taken from previous studies in the region.

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). For the 0.96 km² Q29N catchment, the runoff ratio used was 0.34, and for the 4.7 km² Q29S catchment, the value was 0.26.

The 100y 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 Q29N was 0.9 mmh⁻¹ and 1.5 mmh⁻¹ for Q29S.

The HEC-HMS Q29N scenario simulations are shown in Appendix B.1.

The HEC-HMS calibration/validation for Q29S scenario simulations are shown in Appendix B.2.

Table 5-1. Calibration/Validation Results

Simulation Period	Scenario	CR (mmh ⁻¹)	HEC-HMS Discharge (GL)	HEC-HMS Qp (m ³ s ⁻¹)	Loss Ratio
Quest 29 North					
1-10-1930 – 30-9-1935	Current condition baseline	0.9	2.16	1.3	0.35
17-7-1921 – 17-7-2021	Current condition baseline	0.9	46.4	1.6	0.35
Quest 29 South					
1-10-1930 – 30-9-1935	Current condition baseline	1.5	8.10	3.4	0.26
17-7-1921 – 17-7-2021	Current condition baseline	1.5	167.1	5.0	0.26

The HEC-HMS parameters and adopted values are shown in Table 7-2. 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
<i>Canopy: Simple Canopy</i>	<i>Initial Storage (%)</i>	0	<i>default</i>
	<i>Max Storage</i>	2.5	<i>Fitted</i>
	Crop Coefficient	1	default
Loss: Deficit and Constant	Initial Deficit (mm)	36	ARR Data Hub
	Max Deficit (mm)	36	Fitted
	Constant Rate (mmh ⁻¹)	Q29N = 0.9, Q29S = 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 8-1).

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 8-1. 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 Q_p are given in Table 5-4.

Dewatering of the Zamu pit will begin in 2024. During pre-mining dewatering, water will be pumped from the Zamu Pit to the South Koolpin pit and the North Koolpin pit (Appendix C.1). During mining operations water will be pumped from the Zamu pit to North Koolpin, South Koolpin and Taipan pits (Appendix C.1). The highest Q_p during pumping ($2 \text{ m}^3\text{s}^{-1}$) is an approximate 24 % AEP event higher than the simulated Q_p of $1.3 \text{ m}^3\text{s}^{-1}$ a 40 % AEP event. This a short-term insignificant hydrologic change.

The same applies to the other dewatering scenarios.

Commencing in 2030, North Koolpin, South Koolpin and Taipan pits will be dewatered to the Zamu pit (Appendix C.2).

In 2031 Taipan will continue to be dewatered to Zamu Pit, and BHS Pit in Q29N will be dewatered to North Koolpin (Appendix C.3).

There are changes in Q_p at the catchment outlet (Table 8-2).

The proposed dewatering regime does increase peak flows at the catchment outlet for the short term. These are well within the range of natural/simulated peak flows.

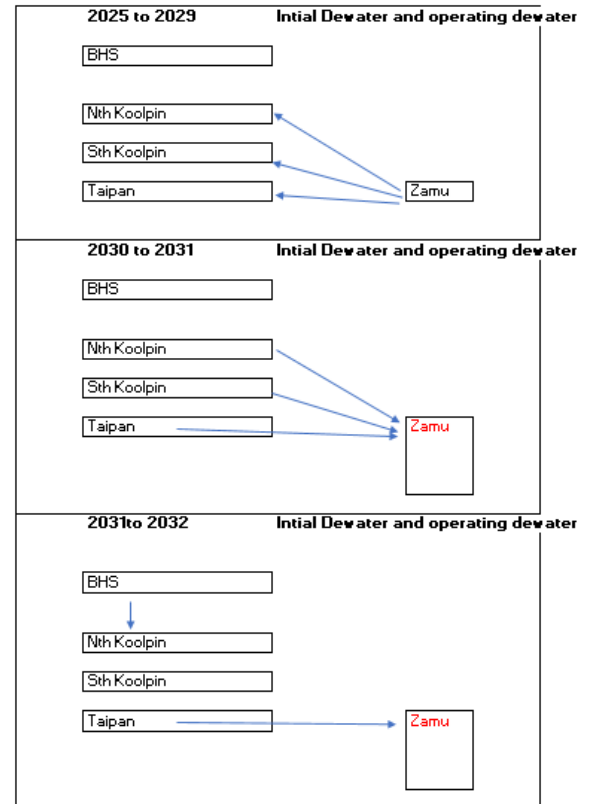
Mining Phase shedule and intial dewatering of pits

1 Initial dewatering of existing pits

Rustlers Roost Deposit	Start	Finish	KL water	Rate KL/day	L/s
RR Pit 2nd wet season	1/12/2021	30/04/2022	1,618,643	10,791	125
RR Pit 1st wet season	1/12/2022	30/04/2023	1,618,643	10,791	125

Q29 deposit	Start	Finish	KL water	Rate KL/day	L/s
South Koolpin	15/02/2029	30/04/2030	129,728	296	3
Zuma	15/12/2024	30/04/2025	103,612	763	9
Taipan	15/02/2029	30/04/2030	79,253	181	2
Nth Koolpin	15/02/2029	30/04/2030	35,278	80	1
BHS	15/03/2030	30/04/2031	21,637	53	1

destination
Mt Bundey Creek and Mariki creek
Mt Bundey Creek and Mariki creek
Zuma when mined
South Koolpin & Nth Koolpin
Zuma when mined
Zuma when mined
Nth Koolpin 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.

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

Period	Pits from	Pit to	Pump Rate (m³s⁻¹)	Baseline Discharge (GL)	Pump Scenario Discharges (GL) (% increase)	Baseline Qp (m³s⁻¹)	Scenario Qp (m³s⁻¹) (% increase)
15/12/2024-15/02/2029	Zamu	South Koolpin, North Koolpin, Taipan	0.009	5.02	5.63 (12.1)	1.31	2.0 (53)
01/7/2030-30/06/2031	South Koolpin, North Koolpin, Taipan	Zamu	0.003, 0.002, 0.001	1.71	1.78 (4)	1.0	1.3 (30)
01/07/2031-30/11/2031	BHS Taipan	North Koolpin Zamu	0.001 0.002	0.24	0.25 (4)	0.35	0.50 (43)

5.5 Environmental Flows

This environmental flow analysis was conducted using 100y simulations as follows:

1. The baseline condition as the site is represented today, used a 100y SILO rainfall record from 1921 to 2021,
2. For the site, in an undisturbed condition the RCP 4.5 climate model was applied to simulate the future 100 years, and
3. 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 2131.

The results for Q29N and Q29S are given in Table 5-5.

Table 5-5. Scenario Results – Impacts of Landform Changes with impact of RCP 4.5 Climate Model

Scenario	Site Condition	Baseline Discharge (GL)	Scenario Discharge (GL)	Baseline Qp (m ³ s ⁻¹)	Scenario Qp (m ³ s ⁻¹)
Quest 29 North					
Current condition baseline	Pre-mining	46.4	-	1.64	-
RCP 4.5 baseline	Pre-mining		49.5		1.73
RCP 4.5 post-mining	Post-mining		47.1		1.65
Quest 29 South					
Current condition baseline	Pre-mining	167.1	-	5	-
RCP 4.5 baseline	Pre-mining		178.2		5.4
RCP 4.5 post-mining-west tributary and South Koolpin routed through Taipan Pit with decant point elevations adjusted.	Post-mining		171.8		5.1
RCP 4.5 post-mining-west tributary routed between South Koolpin and Taipan Pits	Post-mining		172.7		6.9

For Q29N there is little difference between total discharge and Qp for the RCP 4.5 baseline and the RCP 4.5 post-mining landform condition. There is a reduction in total discharge which is due to the losses in refilling the BHS pit at the completion of mining.

The small reduction in Qp, 1.73 m³s⁻¹ to 1.65 m³s⁻¹ is due to the slight change in catchment area because of the heap leach pad rehabilitation where a part will drain to the Q29S catchment. In addition, the pit has a larger surface area and is bunded, reducing the runoff area of the catchment slightly.

In Q29S, there is an increase in total discharge and Q_p because of climate change during the next 100y. The post-mining landscape results in small changes to total flow due to the pits filling at the start of the simulations. For example, the South Koolpin pit (Figure 5-2), fills by 0.5 GL over about 40 years. Considering both Taipan and North Koolpin will also fill, this accounts for the losses in total discharge. Once filled there is little impact on total flows.

With respect to Q_p , if the west tributary in Q29S is routed between South Koolpin pit and Taipan pit, $Q_p = 6.9 \text{ m}^3\text{s}^{-1}$ for the simulation increases considerably from $5.4 \text{ m}^3\text{s}^{-1}$ for the pre-mining condition (Table 5-5). However, routing the channel through Taipan Pit reduced Q_p to a value closer to pre-mining conditions.

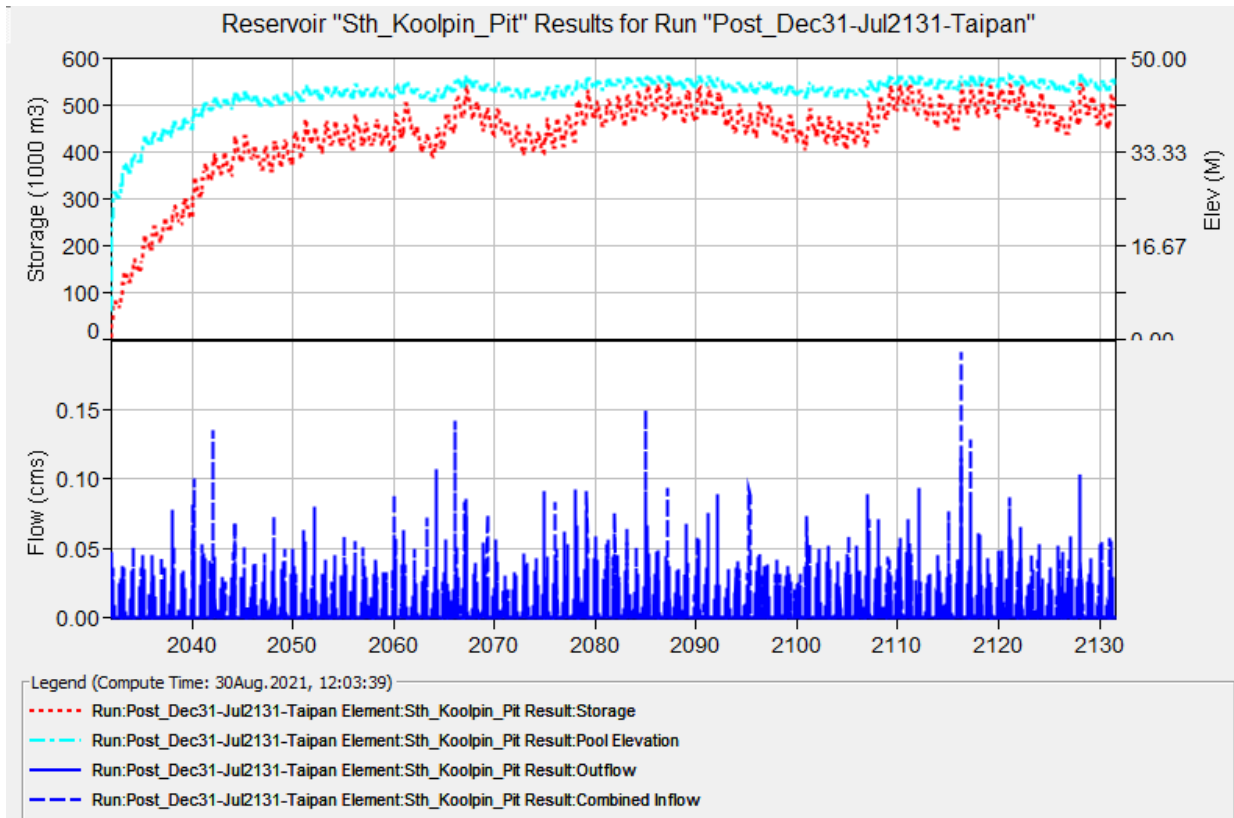


Figure 5-2. An example of pit filling post-mining. The figure shows South Koolpin pit filling post-mining from a level close to 0 m AHD and storage increasing by approximately 0.5 GL over about 3 decades.

5.6 Conclusions

There were no data available to calibrate the HEC-HMS model for Q29N and Q29S. 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 100y 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 100 years following mining. 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 Q_p at the catchment outlet during dewatering, these changes were transient and will have little effect on long-term catchment hydrology. Large flow changes will be managed by routing pumped water through various pits during operations.

Post-mining, there were reductions in the total flow for the 100y simulations, but this is due to the three pits remaining, filling during the first 30 to 40 years post-mining.

There is an increase in Q_p at the catchment outlet if the west tributary is routed between the South Koolpin pit and Taipan pit. However, if the creek is routed through the Taipan pit, as it is currently, there is slight reduction in Q_p . It is likely that historic mining and creek routing through the Taipan pit has reduced natural Q_p and routing the creek between South Koolpin and Taipan pits may return that part of the catchment to historic conditions.

This analysis indicated that mining and the planned water management during dewatering will have little impact on downstream environmental flows.

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.

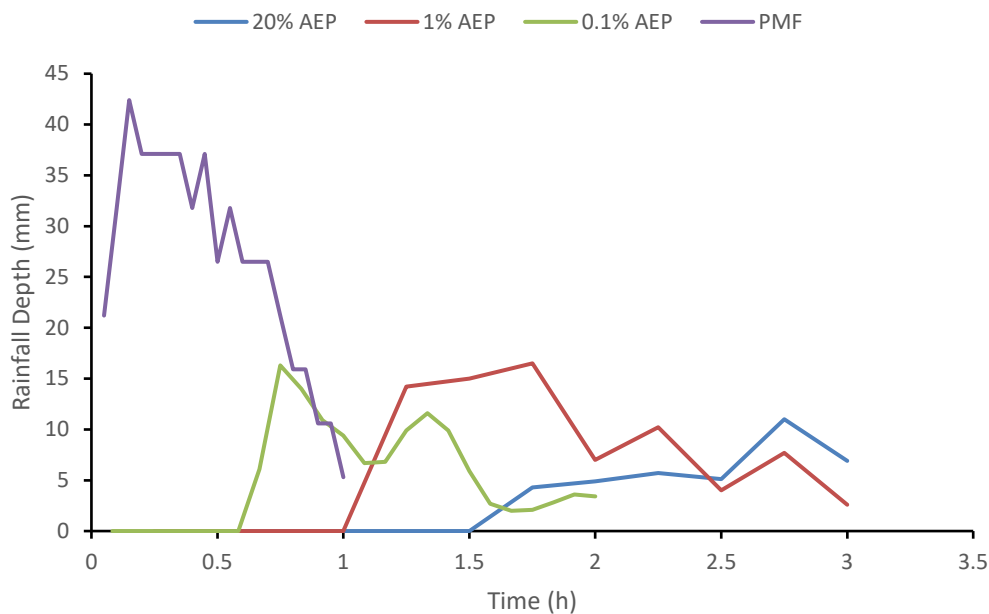


Figure 6-1. Design rainfall depths determined using RORB. These are used to determine hydrograph input to HEC-RAS for flood risk assessment.

6.1 Catchment Analysis

Information available for catchment analysis for the models comprises:

- 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 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 assess 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 Flood Inundation

As expected, the area of inundation increases from the 20% AEP event to the PMF event (Appendix D.1). There is a level of inundation at the toe of the heap leach cover and WRDs for all events. For the 1% AEP event, an event that has a 1% probability of occurring in any given year, water accumulates at the eastern side of the proposed WRD near North Koolpin Pit (See Appendix A for locations) to a depth >5m. For the PMF event, water depth in Taipan pit reaches a level of $\approx 47m$ with a level of $\approx 6m$ in the stream immediately downstream of the pit outlet.

6.3.2 Flow Velocity

The results are in Appendix D.2. The highest flow velocities are contained within the stream channels. For the 1% AEP the maximum in-channel velocity is in the main west tributary reaching $\approx 1.46 ms^{-1}$. Around the northern toe of the proposed WRD near North Koolpin. Flow velocity may reach $\approx 1.6 ms^{-1}$, but this can be controlled by appropriate drainage (see Erosion & Sediment Control Plan). For the PMF, flow velocities entering the Taipan Pit may reach $\approx 40 ms^{-1}$. This is a high-risk situation but the probability of it occurring is extremely low.

6.3.3 Flood Hazard

Flood hazard maps have been produced in accordance with ADIR (2017) (Appendix D.3). For the 1% AEP event, there is a flood hazard along the toe of the proposed WRD $> 2 m^2s^{-1}$. The flood hazard near the inlet of the Taipan pit is also high. High flood hazard is widespread for the PMF event.

6.4 Conclusions

This section assessed the risk to people, livestock, and wildlife during flood events.

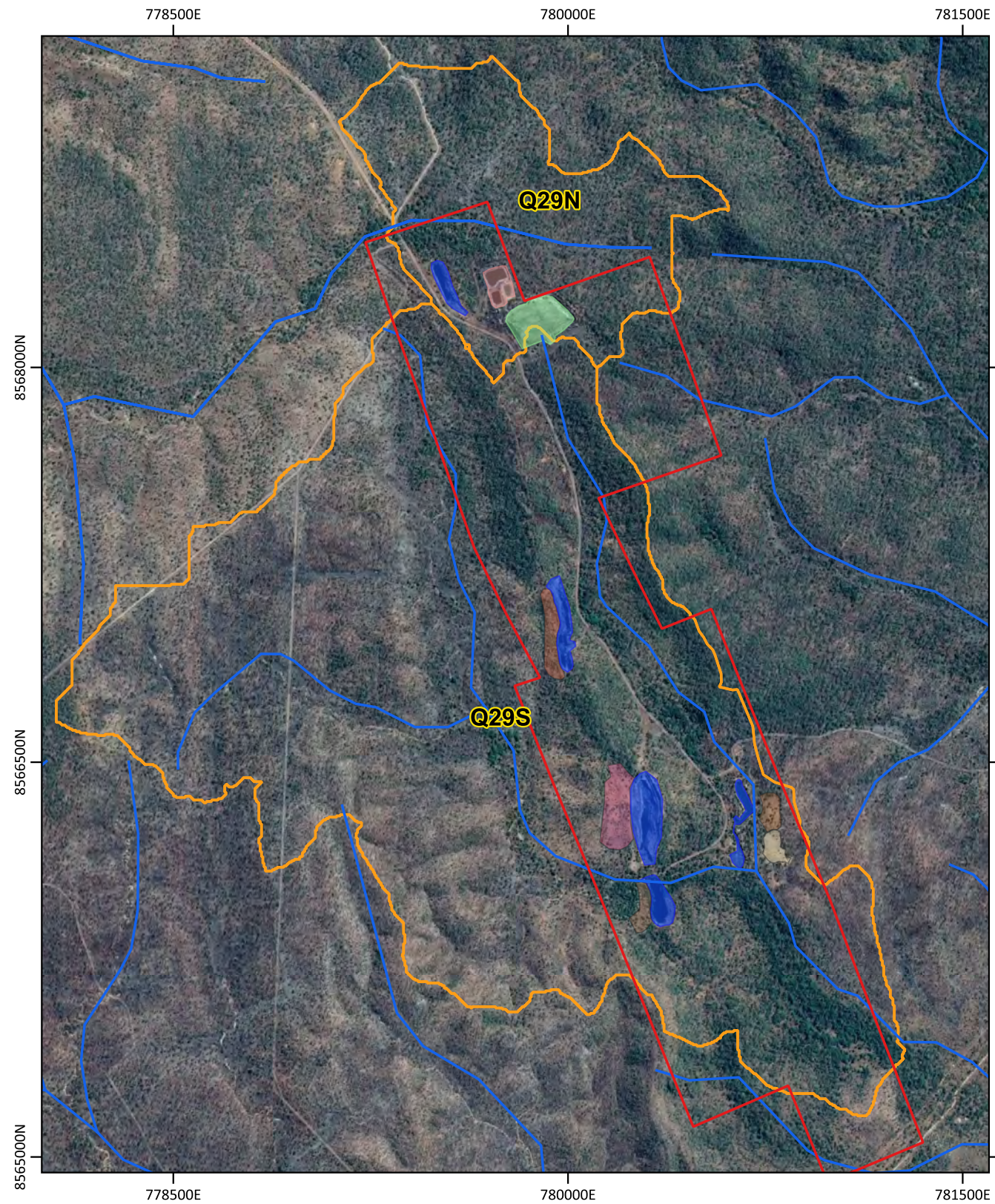
For the 1% AEP event, an event likely to occur within 100 years post-mining, there are flood risks, but these aren't widespread. For the PMF, an event likely to occur once every 5000 years, there is high flood risk in nearly every channel and around the Taipan pit. However, appropriate post-mine safety bunding to 2 m may ameliorate this.

In general, 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 Bunday. 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.

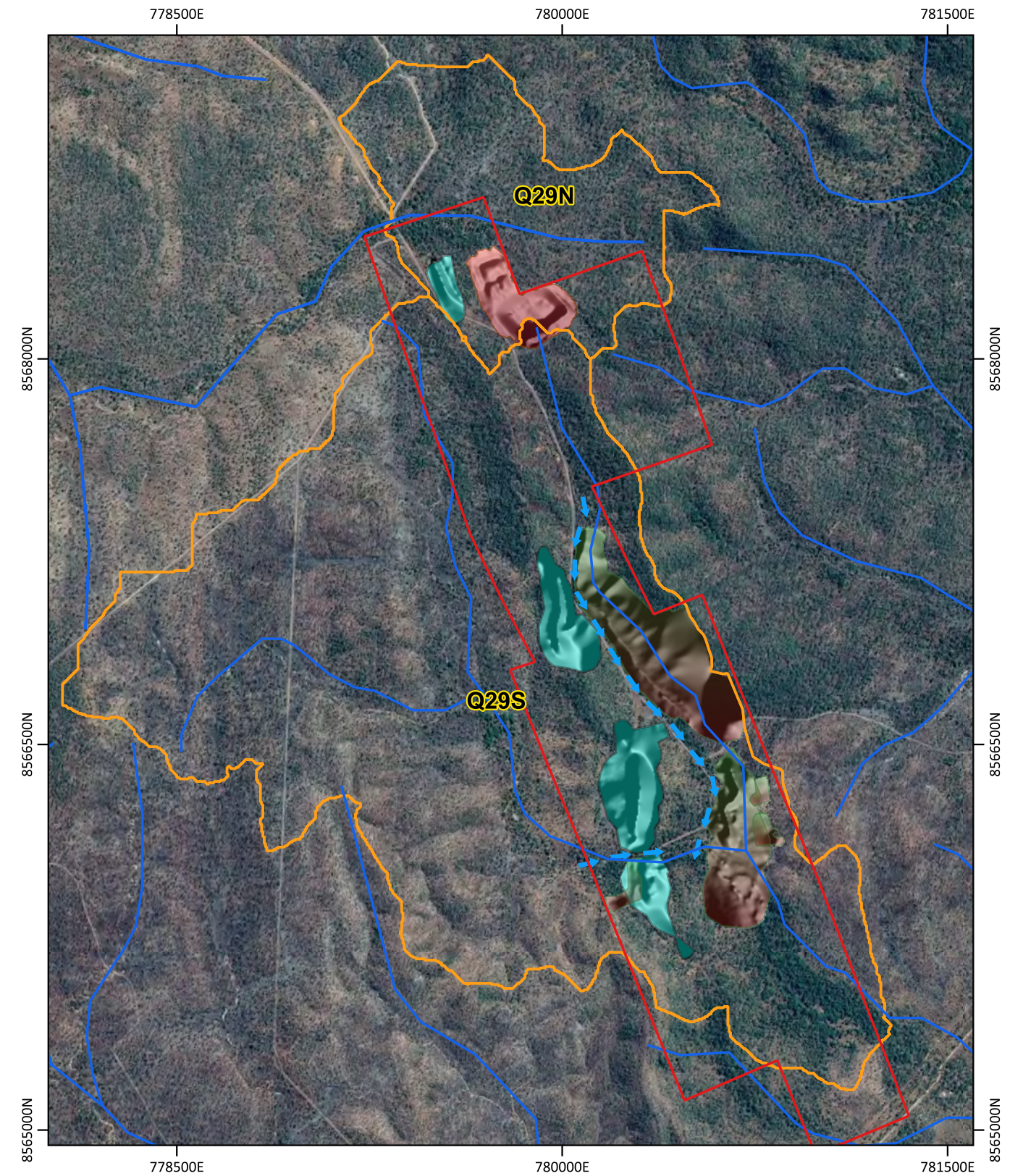
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8 APPENDICES

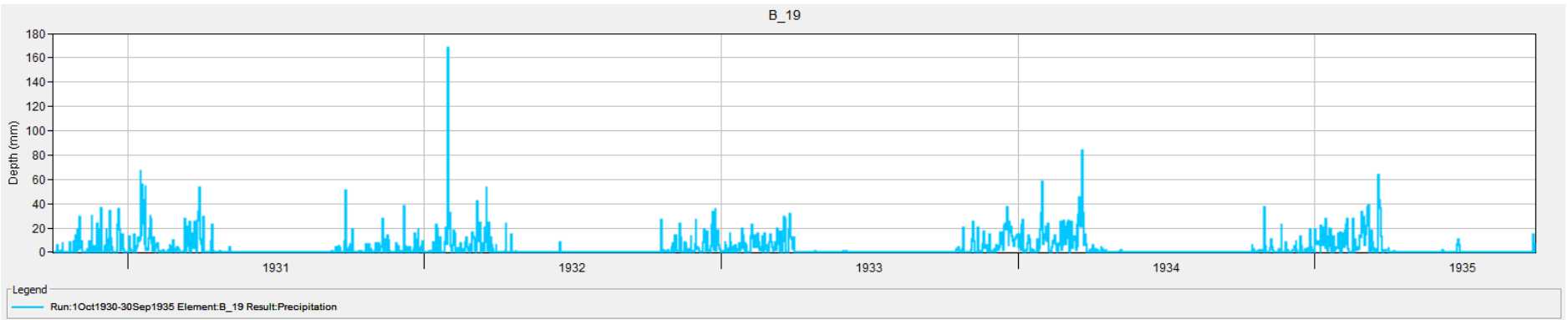
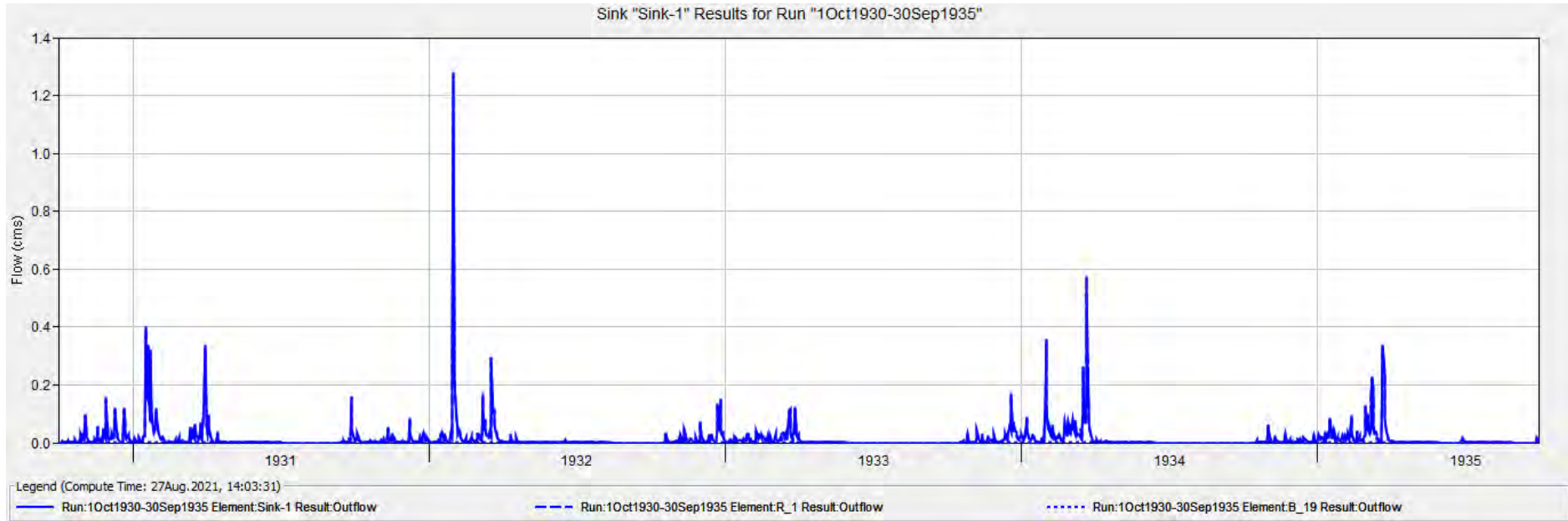
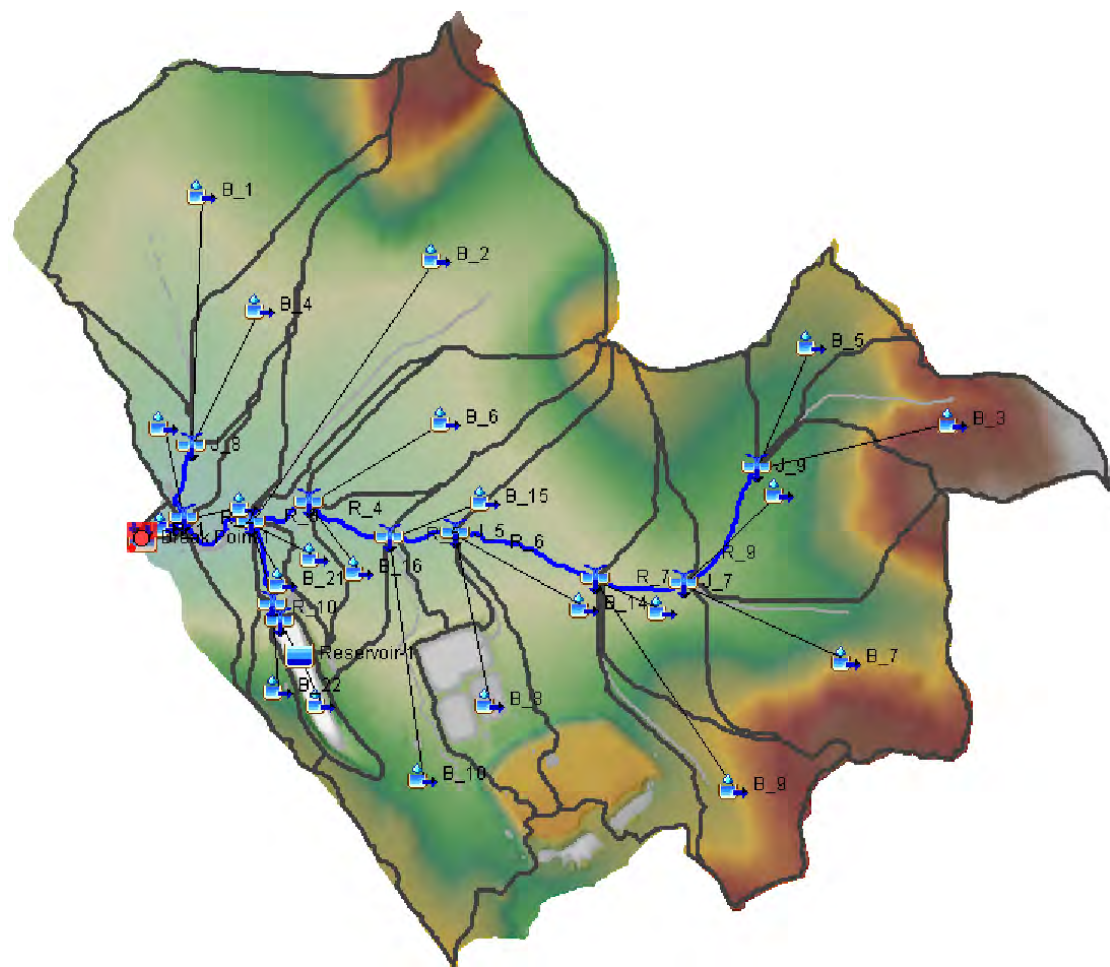


Above. Infrastructure layout for Q29 in it current condition



Above. Infrastructure layout

- | | | | | | |
|---------------------------------|---------------------------------|-------------------------------------|-------------------------------|-------------------------------------|---|
| Pre-mine Landform | Zamu WRD 1 | Heap Leach Ponds | Taipan Pit | Closure Landform | Mineral Lease Disturbed Area |
| Blue polygon: Sth Koolpin Pit | Pink polygon: Sth Koolpin WRD | Light green polygon: Heap Leach Pad | Blue polygon: Taipan Pit | Cyan polygon: Pit | Red outline: Mineral Lease Disturbed Area |
| Light brown polygon: Zamu WRD 2 | Blue polygon: Nth Koolpin Pit | Blue polygon: BHS Pit | Green polygon: WRD | Blue arrow: Pntial Stream Diversion | Blue line: Stream Line |
| Blue polygon: Zamu Pit | Orange polygon: Nth Koolpin WRD | Brown polygon: Taipan WRD | Red polygon: Heap Leach Cover | Yellow outline: Q29 Catchments | |



Above: HEC-HMS basin and reach model for the Quest 29 north catchment. The catchment is in the upper reaches of the Mt Bunday Creek. The current pit, heap leach pad and heap leach ponds are seen in the bottom left.

Top Right: The calibration event 1 Oct 1930 to 30 Sep 1935 using rainfall from the SILO data set. CR = 0.9 mmh⁻¹.

Upper Middle Right: Daily rainfall for the calibration event 1 Oct 1930 - 30 Sep 1935.

Lower Middle Right: Output showing the fitted total discharge and peak discharge (Q_p).

Bottom Right: Simulation results for the 1921-2021 series using CR = 0.9 mmh⁻¹ fitted to a runoff ratio of 0.35.

Project: Q29N_ken Simulation Run: 1Oct1930-30Sep1935
Sink: Sink-1

Start of Run: 01Oct.1930, 00:00 Basin Model: Quest 29N_Baseline
End of Run: 30Sep.1935, 00:00 Meteorologic Model: 1Oct1930-30Sep1935
Compute Time:29Aug.2021, 22:25:18 Control Specifications:1Oct1930-30Sep1935

Volume Units: MM 1000 M3

Computed Results

Peak Discharge:1.28 (M3/S) Date/Time of Peak Discharge31Jan.1932, 00:00
Volume: 2156.03 (1000 M3)

Project: Q29N_ken Simulation Run: Silo baseline 1921-2021
Sink: Sink-1

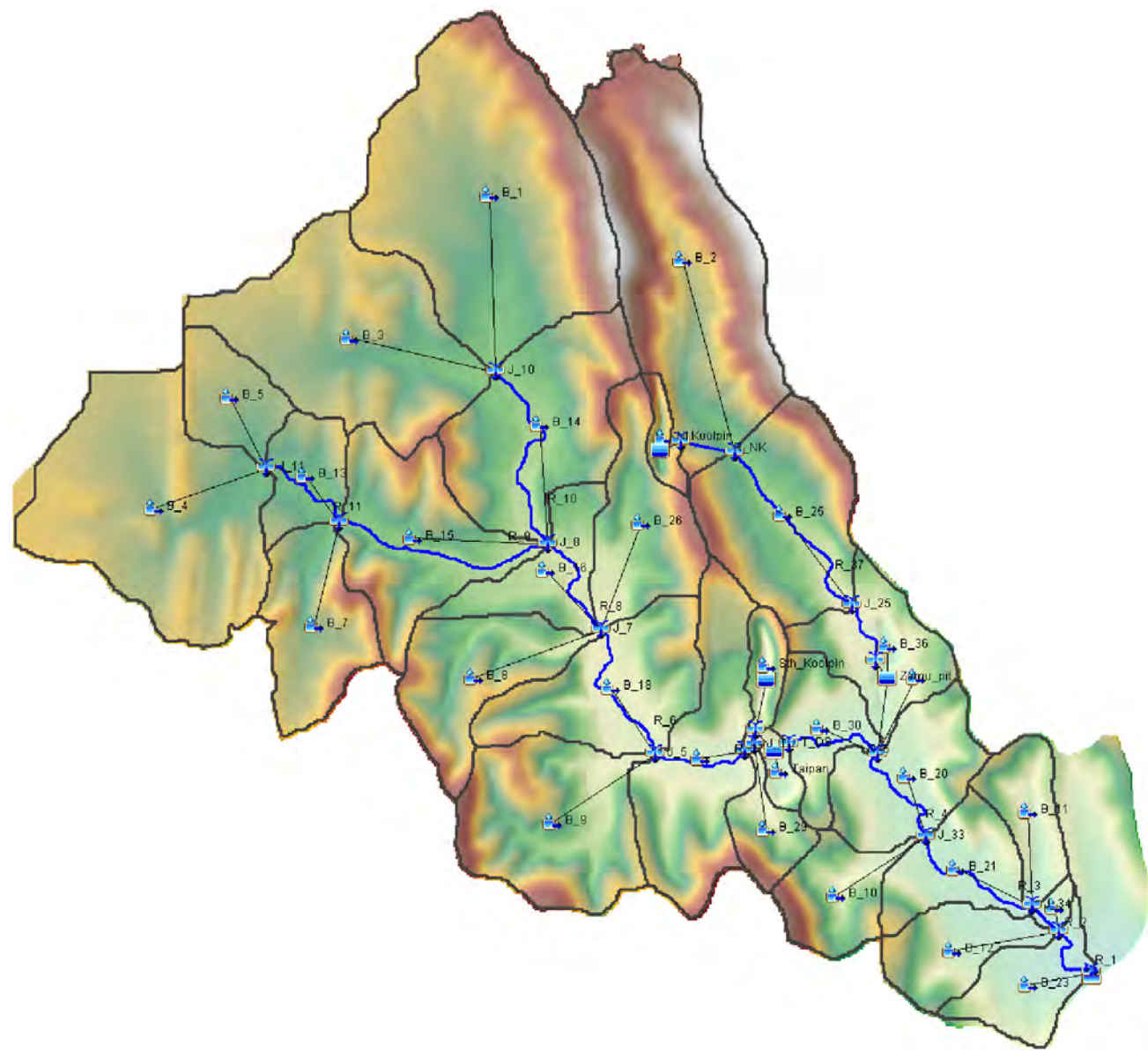
Start of Run: 17Jul.1921, 00:00 Basin Model: Quest 29N_Baseline
End of Run: 16Jul.2021, 00:00 Meteorologic Model: 100y_SILO
Compute Time:29Aug.2021, 22:17:41 Control Specifications:100y_SILO

Volume Units: MM 1000 M3

Computed Results

Peak Discharge:1.64 (M3/S) Date/Time of Peak Discharge26Apr.2006, 00:00
Volume: 46433.54 (1000 M3)

Appendix B.1		Project Quest 29 Open-Cut Mine Redevelopment -Catchment Hydrology and Flood Risk	Title HEC-HMS Calibration/Validation Q29N	Designed	Drawn	Checked	Sheet size	
								Sheet No.
				Date				Sheet of

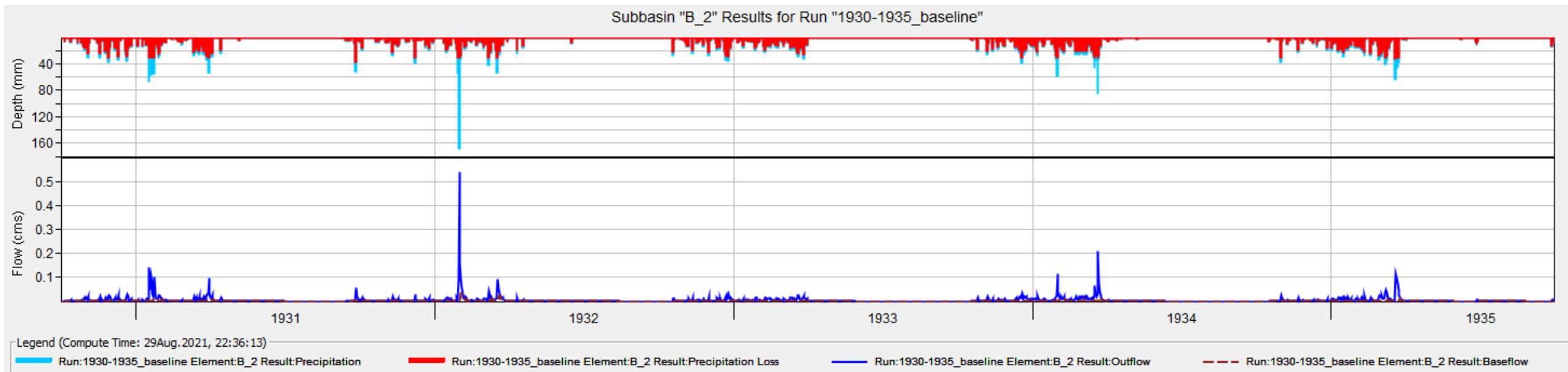


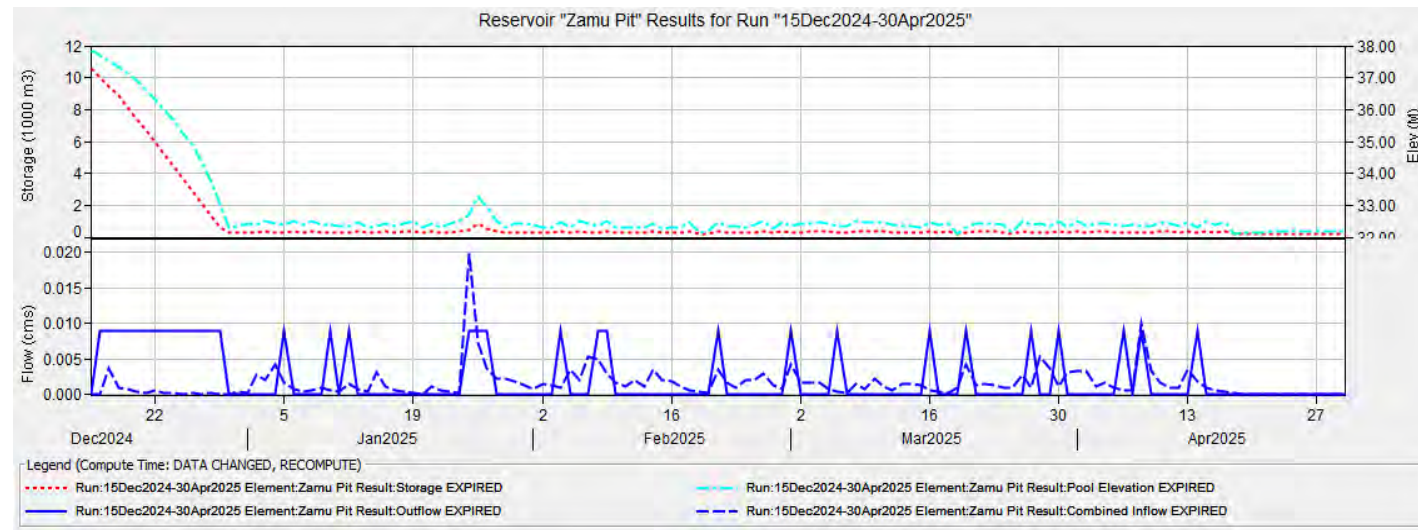
Top Left: HEC-HMS model for the Quest 29 South catchment. The catchment contains 4 pits - North Koolpin, South Koolpin, Taipan and Zamu.

Bottom Left: Output for basin B-2 for the baseline condition. CL = 1.5 mmh⁻¹ was fitted to a runoff ratio of 0.26.

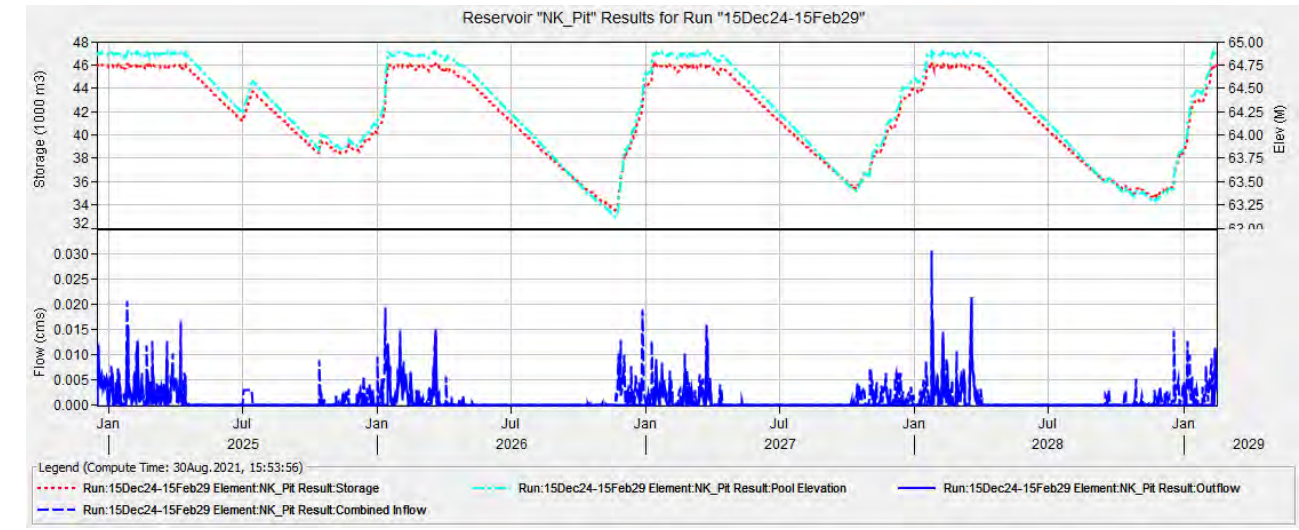
Below: Output for B-2 showing the various contributors to and Q_p.

Project: Q29S_pre-mine		Simulation Run: 1930-1935_baseline	
		Subbasin: B_2	
Start of Run:	01Oct.1930, 00:00	Basin Model:	Q29S_pre_change_baseline
End of Run:	30Sep.1935, 00:00	Meteorologic Model:	Silo_1Oct30-30Sep35
Compute Time:	29Aug.2021, 22:40:38	Control Specifications:	1930-1935_baseline
Volume Units: <input type="radio"/> MM <input checked="" type="radio"/> 1000 M3			
Computed Results			
Peak Discharge:	0.54 (M3/S)	Date/Time of Peak Discharge:	31Jan.1932, 00:00
Precipitation Volume:	2878.88 (1000 M3)	Direct Runoff Volume:	637.66 (1000 M3)
Loss Volume:	2241.12 (1000 M3)	Baseflow Volume:	83.92 (1000 M3)
Excess Volume:	637.77 (1000 M3)	Discharge Volume:	721.58 (1000 M3)

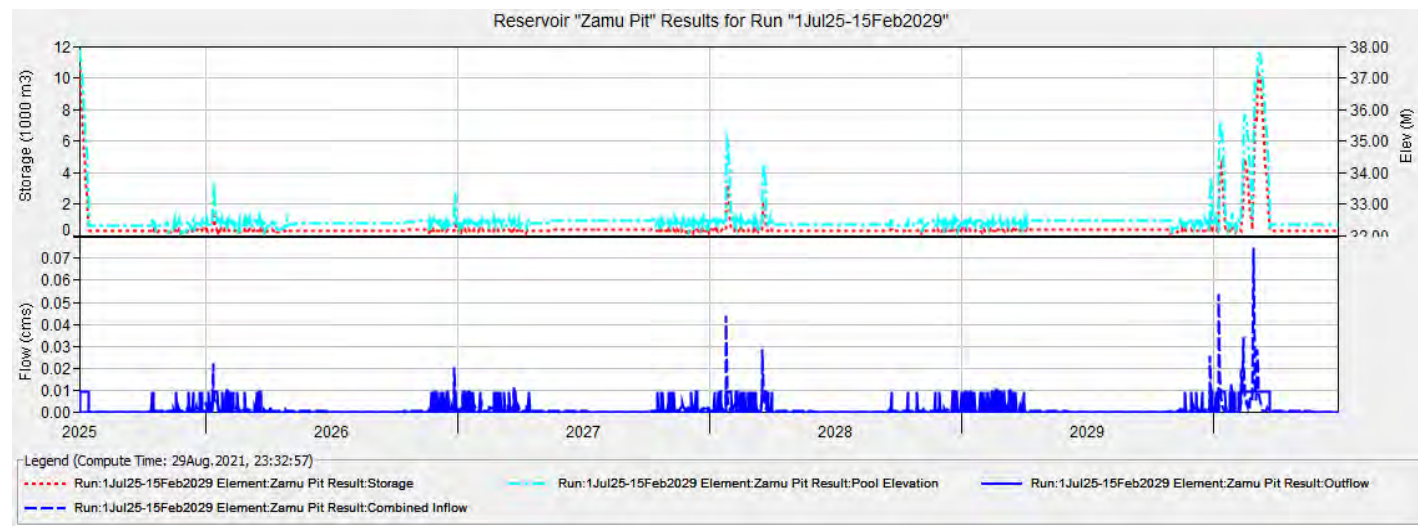




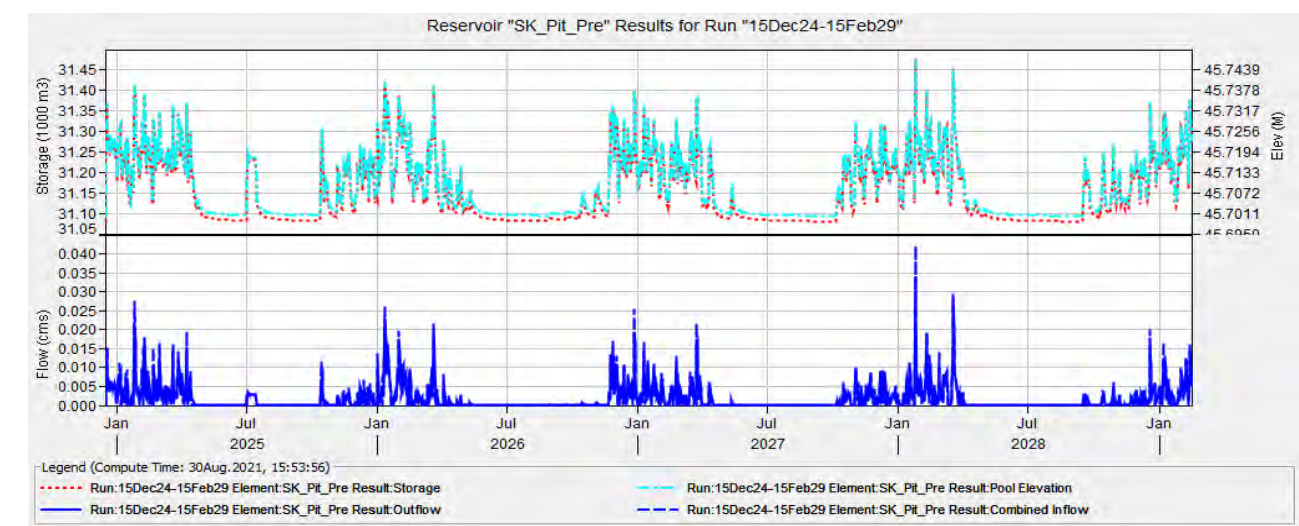
Above: Initial dewatering of Zamu pit Dec 2024 to Apr 2024.



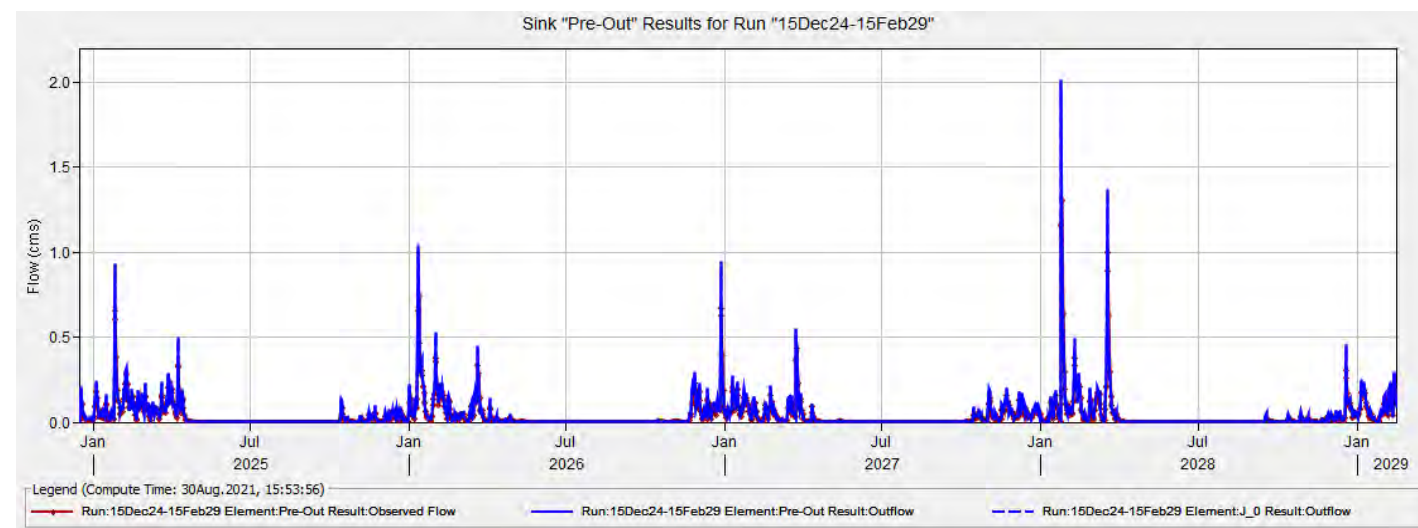
Above: Changes in pit water levels in North Koolpin pit during the Zamu dewatering phase.



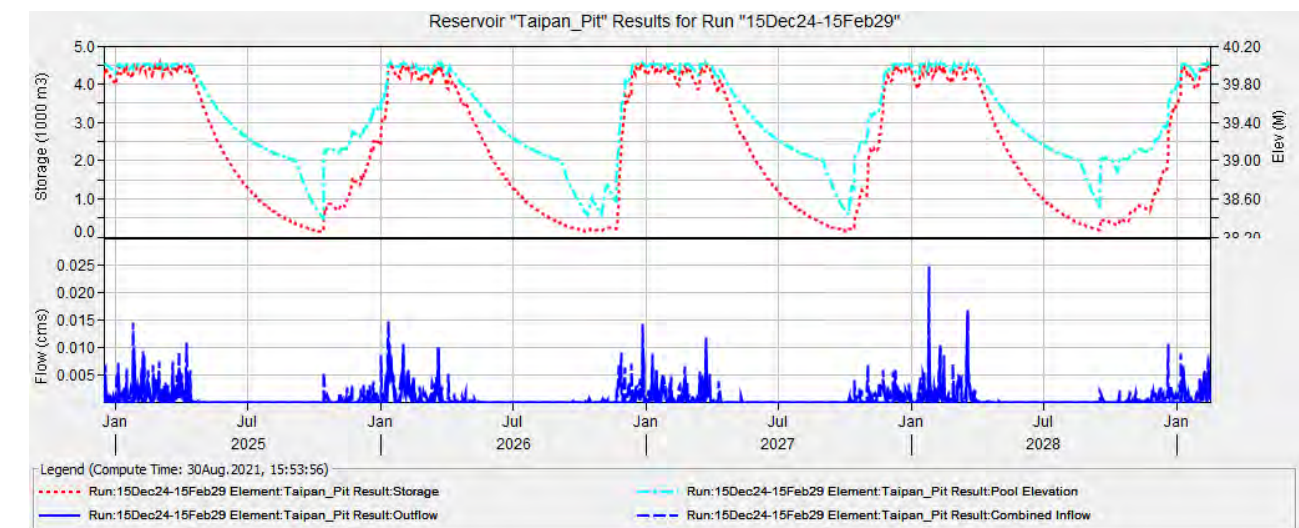
Above: Longer term dewatering of Zamu pit during mining operations. During this phase water is pumped to North Koolpin, South Koolpin and Taipan pits



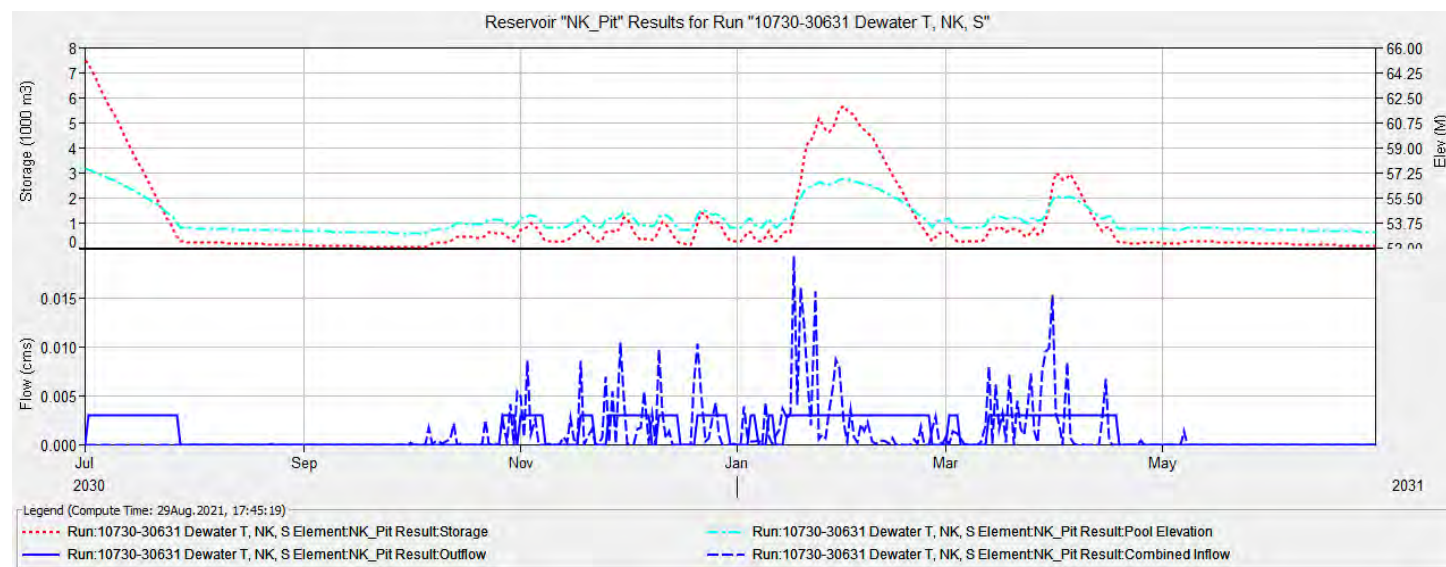
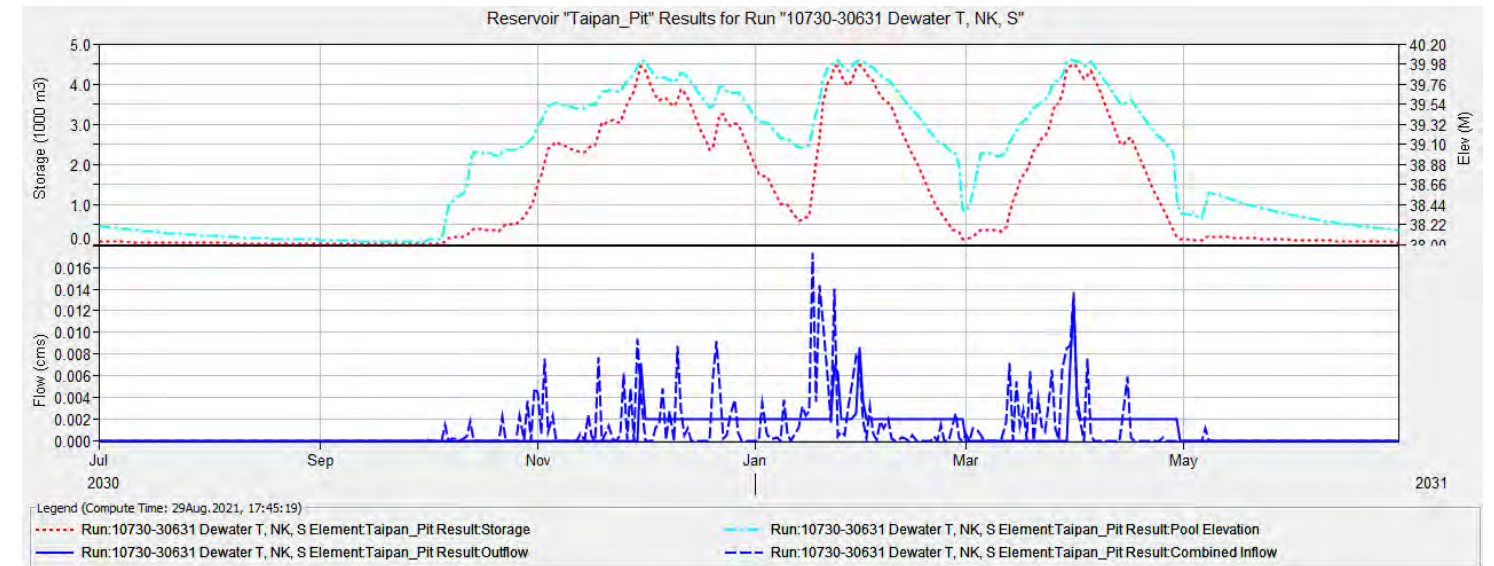
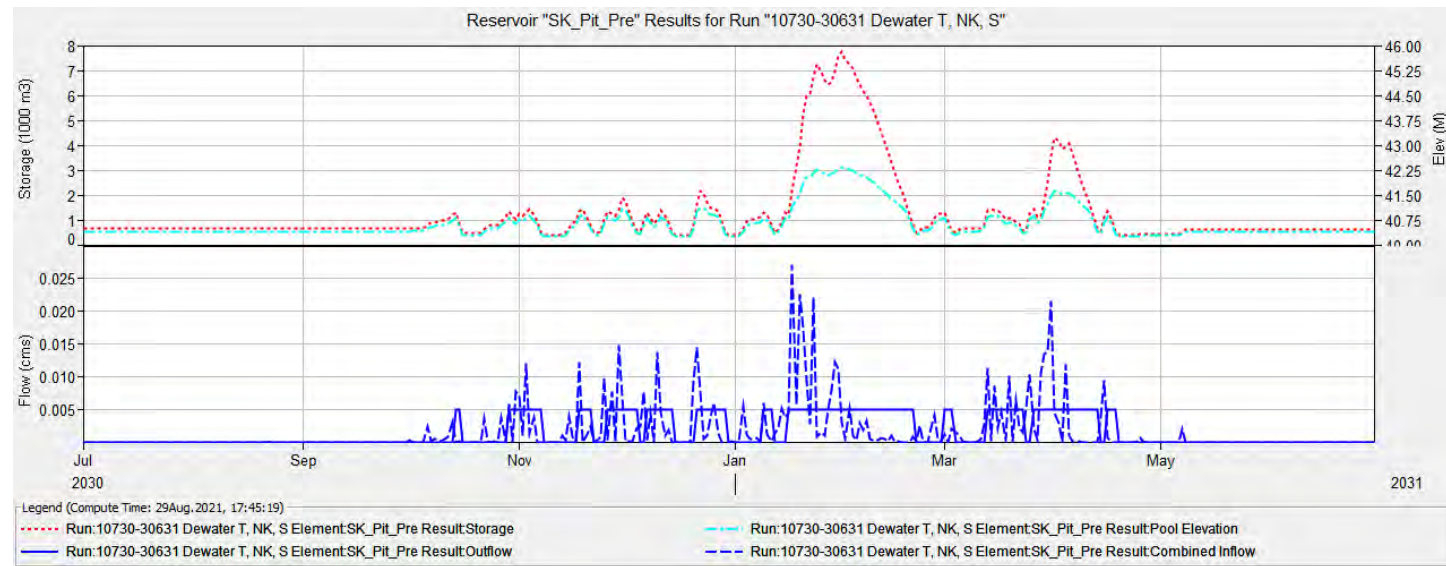
Above: Changes in pit water levels in South Koolpin pit during the Zamu dewatering phase.



Above: Simulated discharges at the catchment outlet during Zamu dewatering. Simulated peak discharges during dewatering are higher than the simulated discharges without dewatering. However, these are less than half the simulated peak discharge for the long term.

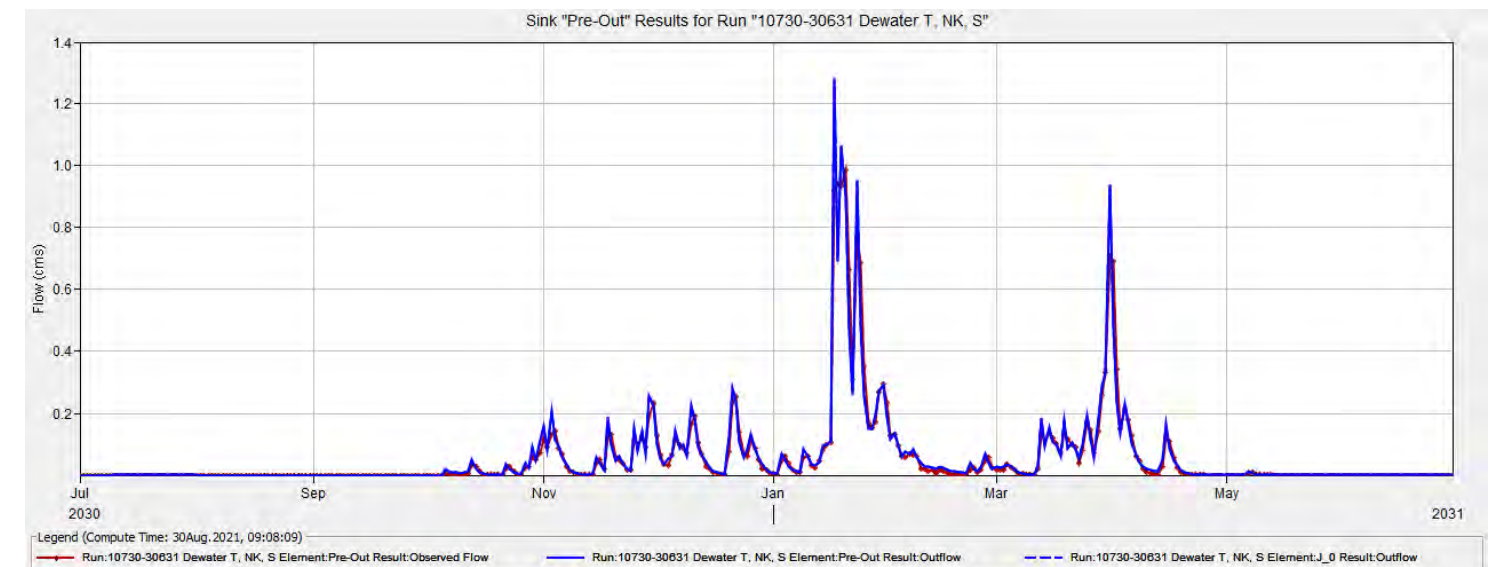
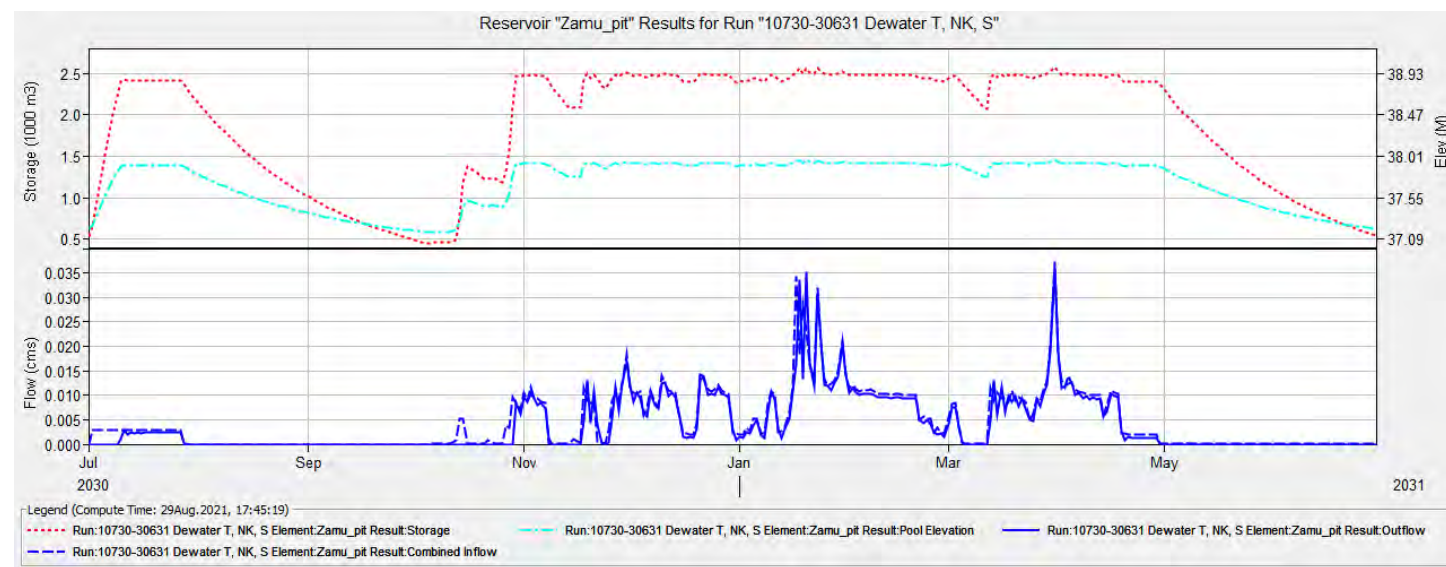


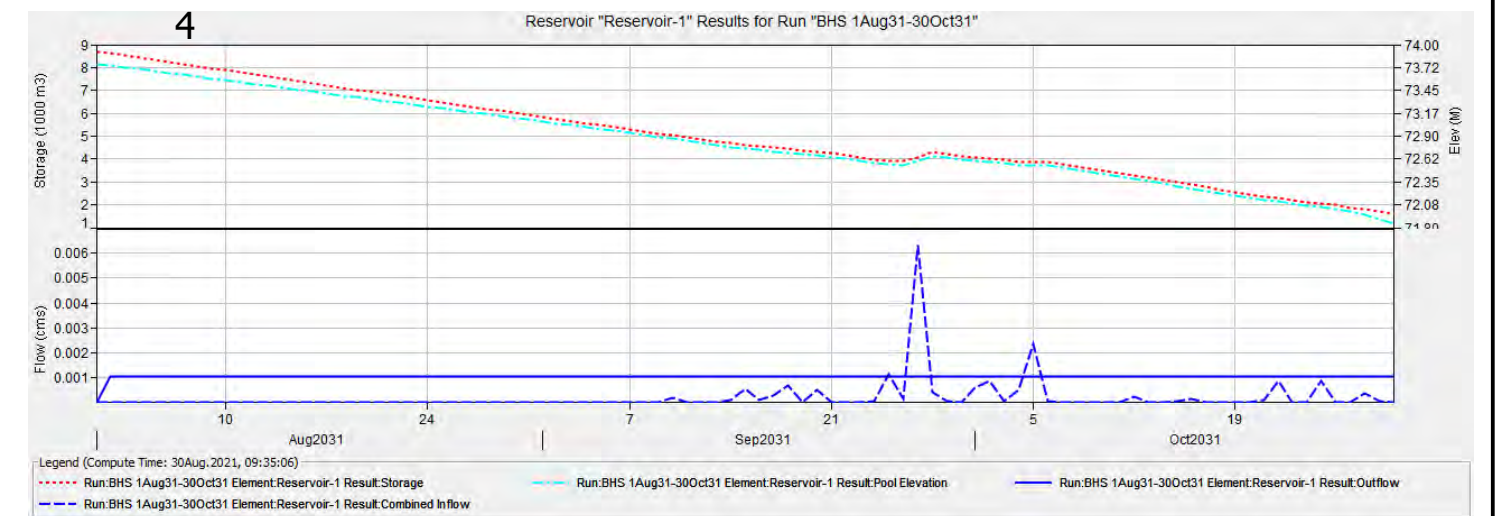
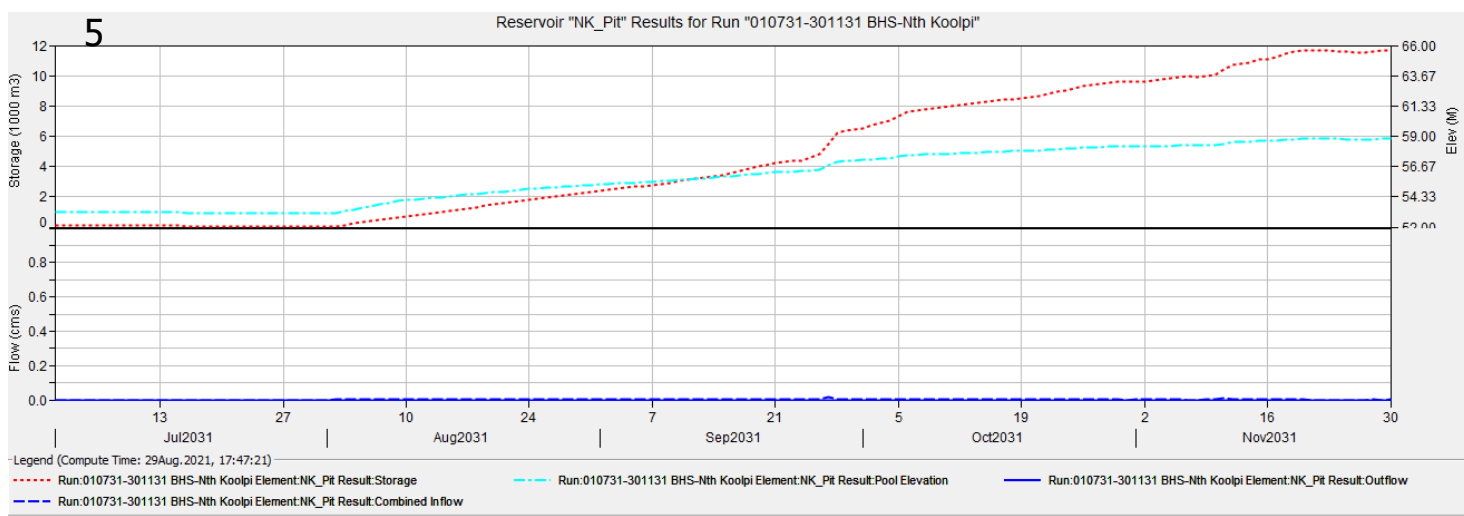
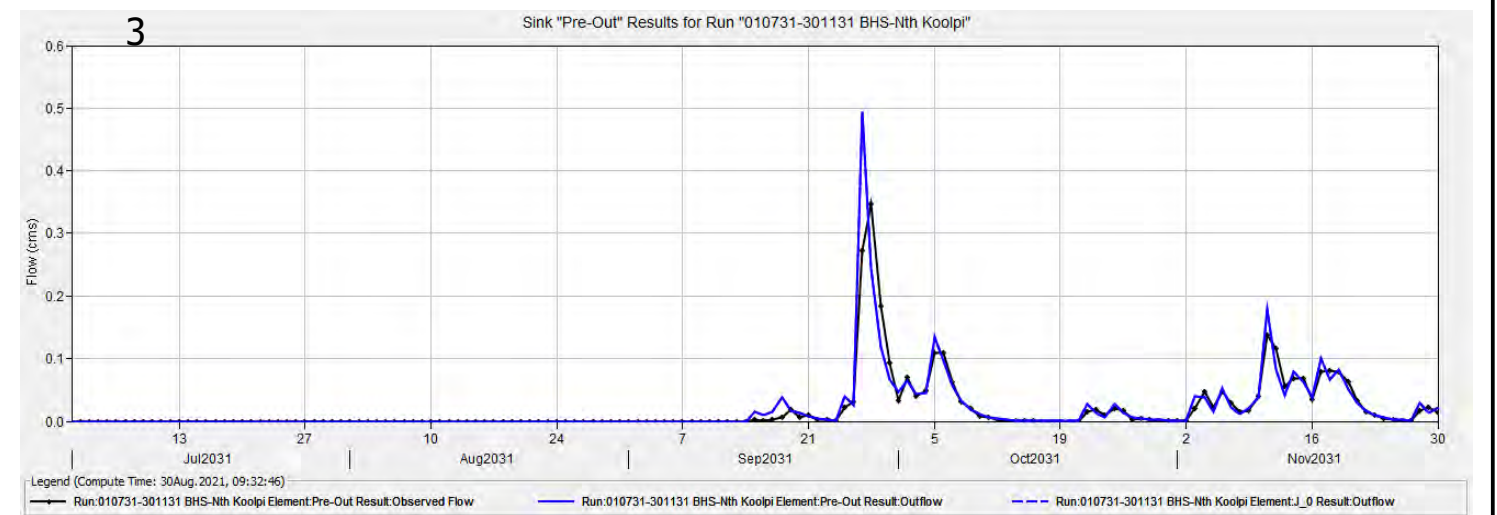
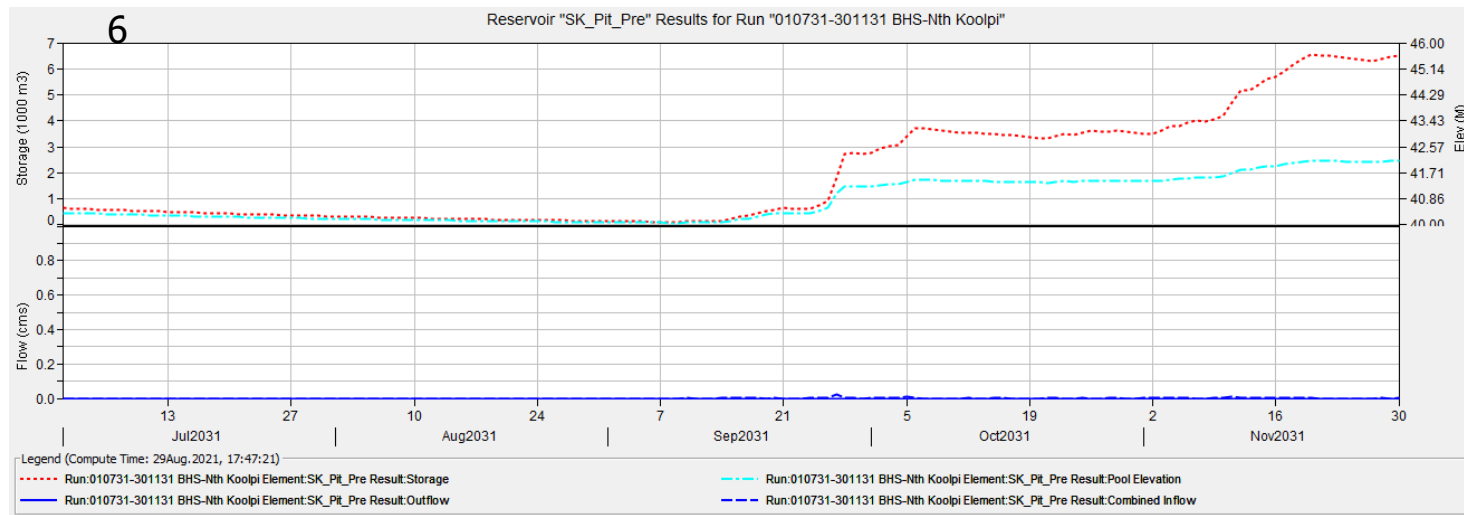
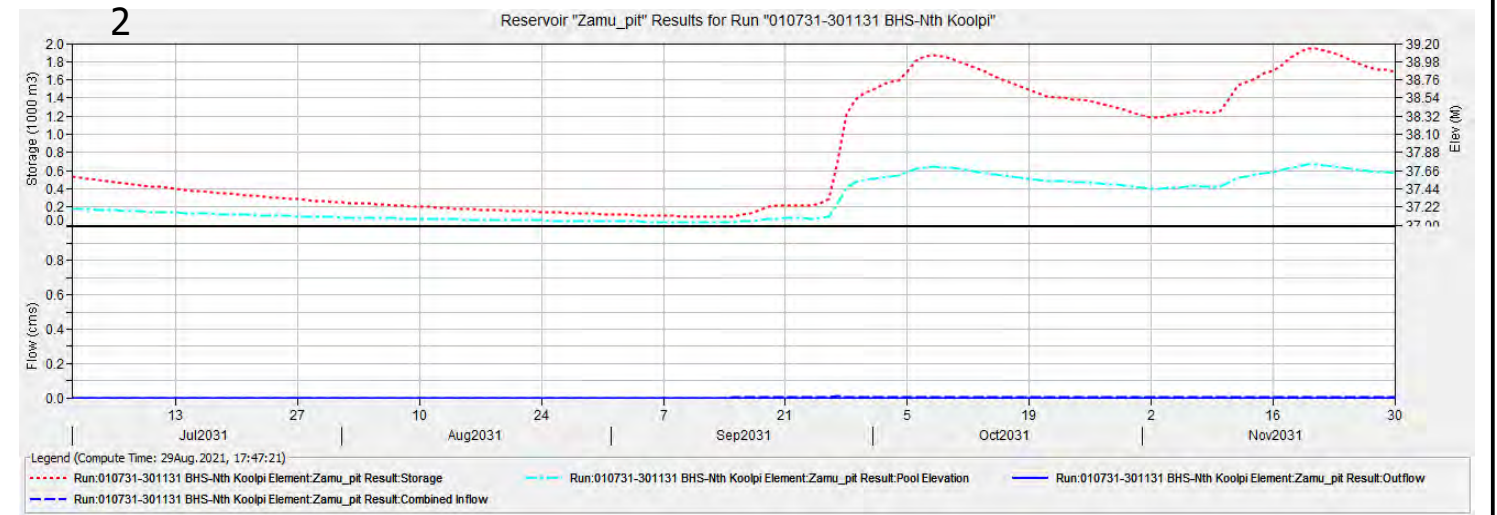
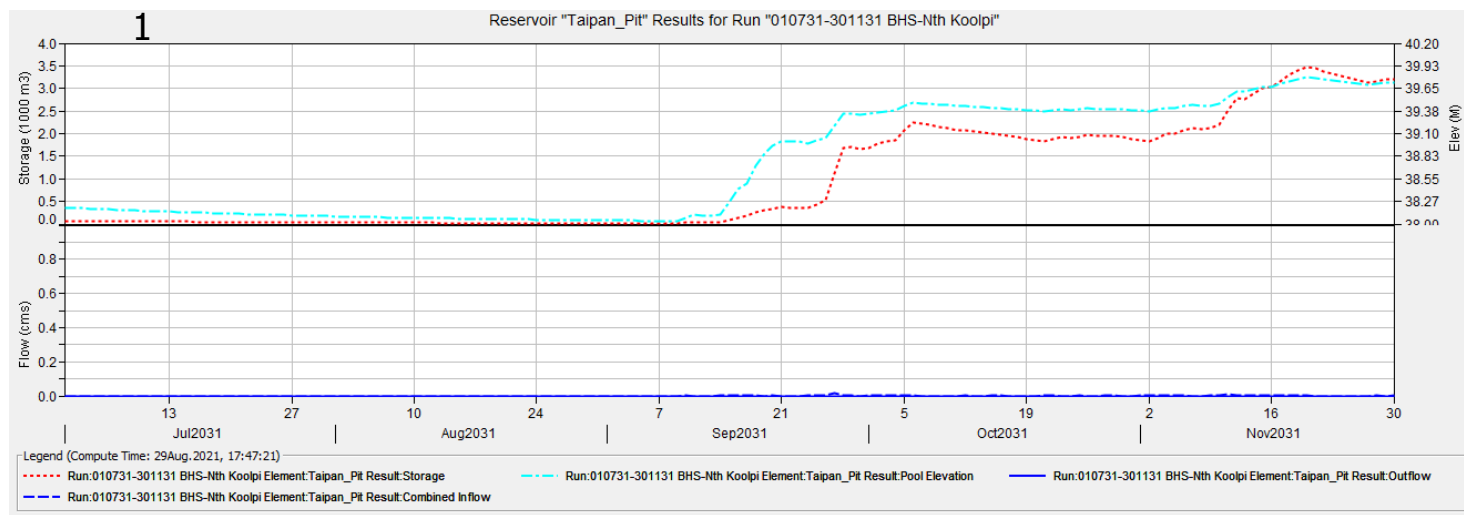
Above: Changes in pit water levels in Taipan pit during the Zamu dewatering phase.



Clockwise from above left:

1. South Koolpin pit changing water levels during its dewatering phase to Zamu pit. Pump rates are shown in lower view panel.
2. Taipan pit changing water levels during its dewatering phase to Zamu pit.
3. Discharges at the catchment outlet. Qp is higher than the simulated base line but this is only short term.
4. Zamu inputs during dewatering phase.
5. North Koolpin dewatering showing pump rates in lower view panel.





Clockwise from above left:

1. Final dewatering phase. Taipan pit pumped to Zamu.
2. Zamu pit receiving water from Taipan pit.
3. Discharge at the catchment outlet point. Qp increases but for the short term only.
4. BHS pit in Q29N pumped to North Koolpin.
5. North Koolpin pit receiving BHS but no output.
6. South Koolpin pit. Not receiving input.

