

Memo

To	Helen Chernoff	Company	Ramelius Resources
From	Shirley Field	Job No.	514C
Date	09/12/2024	Doc No.	010b
Subject	Lake Roe Hydraulic Behaviour Desk Study		

Dear Helen,

Please find below our assessment of the ponding behaviour in the vicinity of the proposed Roe Mining Project.

1. BACKGROUND

Ramelius Resources' proposed Roe Mining Project is located in the Goldfields Region of Western Australia, approximately 100 km due east of Kalgoorlie and circa 45 km southwest of the Rebecca Gold Project. The Project is proposed to consist of the Bombora open-cut pits and underground mine, and Kopai Crescent open-cut pits. Both proposed mining areas are proximal to Lake Roe, with the pit footprint extending partially over the Lake Roe basin.

As part of the assessment for potential pit dewatering requirements, Ramelius has asked AQ2 to complete following:

- Characterise the ponding within Lake Roe with respect to frequency and duration of inundation.
- Estimate potential seepage rates from the lake to the underlying groundwater during ponding events.

To understand the hydrological behaviour at Lake Roe, the following was completed:

- Climate characteristics such as daily rainfall, evaporation, and temperature data were defined.
- Inundation events were identified from satellite imagery between 1993 and 2024.
- Inundation events and rainfall records were correlated to identify the climate drivers for inundation.
- Areas which are prone inundation were identified.
- Seepage analysis for the salt pans for different inundation events.
- Potential discharge location(s) for surplus dewatering were assessed, by estimating the rate at which ponded water can lose water to evaporation at different locations.

In addition to this assessment, the following additional works are being completed and will be reported separately:

- **Dewatering inflow assessment** to the proposed mine pits.
- **2D flood model of Lake Roe** to simulate ponding locations and flood distribution throughout Lake Roe from different runoff events.
- A **Lake Roe water balance** model to estimate flood levels for different design recurrence intervals.

2. CLIMATE

Nearby rainfall, evaporation and temperature climate data were assessed to aid in characterising Lake Roe's hydrological behaviour. The climate data used for this analysis was obtained from the Scientific Information for Land Owners project (SILO) (Jeffrey et al. 2001), as it provides temporally complete daily climate parameters from 1889 to the present, for any location in Australia to the closest 0.05° latitude/longitude (decimal degrees). SILO compiles all valid data for the input location and spatially interpolates, patches, and calculates long-term averages from nearby raw observational data to provide a complete dataset.

SILO data from Cowarna Downs station (BOM Station ID 12220) was considered the most representative analogue of the climatic conditions of the Lake Roe area based on proximity and observed data availability. The station is situated 40 km southwest of Lake Roe's centre (refer Figure 2.1), with rainfall records available between 1970s to 2010. A SILO rainfall dataset was obtained between 1970 and October 2024.

It was noted the Cowarna Downs station SILO dataset:

- Likely best represents Lake Roe's rainfall for 1970–2010, when actual measurements were taken at the weather station.
- Rainfall data outside these years would be interpolated from nearby stations and is likely to be less representative of Lake Roe catchment's rainfall.
- Used SILO's interpolation techniques to derive temperature and evaporation values as this was not recorded at the Cowarna Downs station. The nearest station this data was recorded was at Kalgoorlie 110 kms away.

The closest long-term weather station to the Lake Roe Project Area where rainfall has been recorded is Karonie weather station (BOM Station ID 12041), located approximately south-south-west 25 km away from Lake Roe's centre point; however, there are no observed data from 1990s onwards. Gindalbie station (BOM Station ID 12247), located 95 km northwest, has the largest timespan of observed data, but it was considered too distant to be a realistic analogue of Lake Roe's weather conditions. This weather station had recorded rainfall peaks which were greater in magnitude than Karonie and Cowarna Downs.

A summary of the Cowarna Downs station SILO dataset is as follows:

- Grid reference for the Cowarna Downs station location: -31.00933 degrees south and 122.35564 degrees east.
- Spanned period of 1970s to October 2024.
- Long-term average annual rainfall of 260.7 mm.
- Annual average Class A pan evaporation rate of 2,420 mm and an annual average Morton's shallow lake evaporation rate of 1,560 mm (from SILO interpolation at Cowarna Downs).
- Long-term average maximum temperature of 26 °C.
- Monthly average rainfall, Class A pan evaporation, Morton's shallow lake evaporation, maximum and minimum temperature (1970–2024) as shown in Figure 2.3.

The installation of a weather station at the site would be useful to provide site specific data for rainfall, evaporation and wind speed and direction.

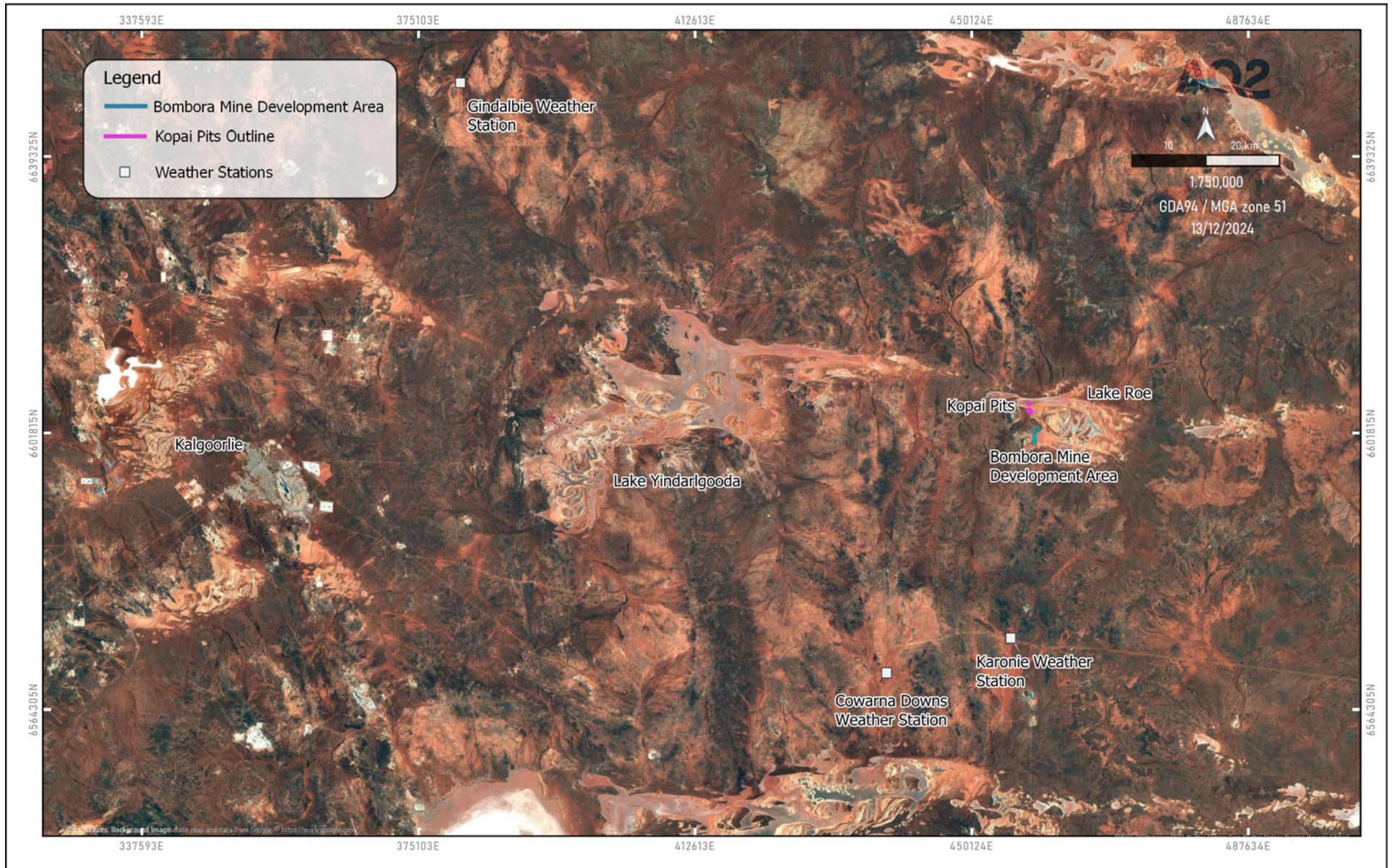


Figure 2.1 Regional Map of the Eastern Goldfields, including Lake Roe, Cowarna Downs, and Kalgoorlie

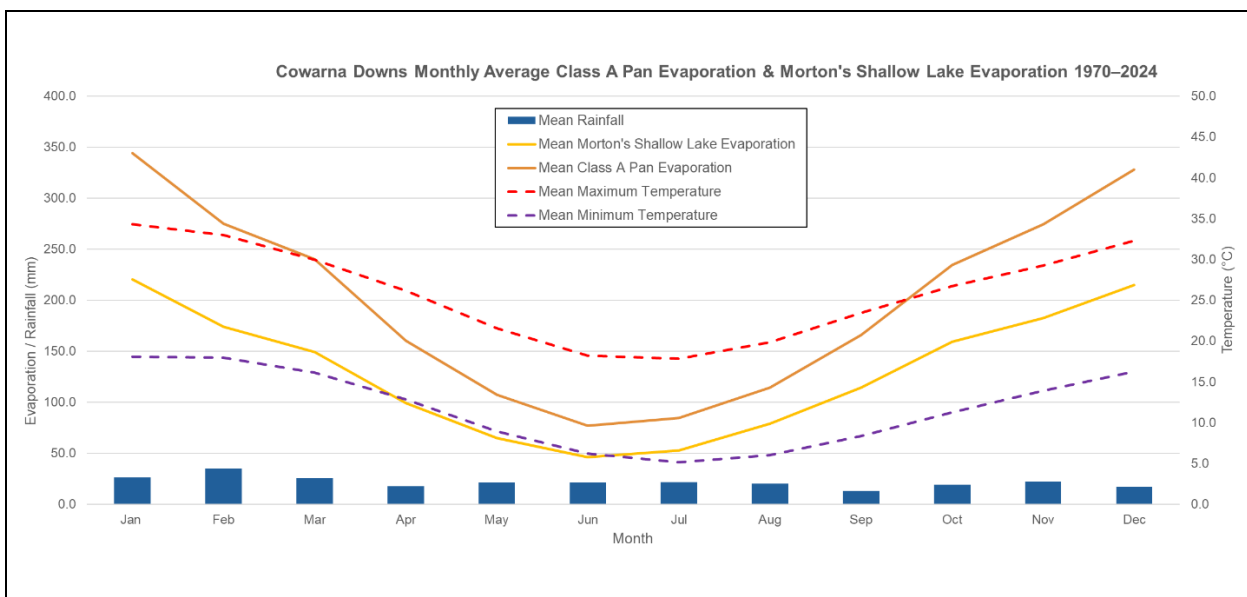


Figure 2.2 Cowarna Downs Monthly Average Climate Characteristics (1970–2024)

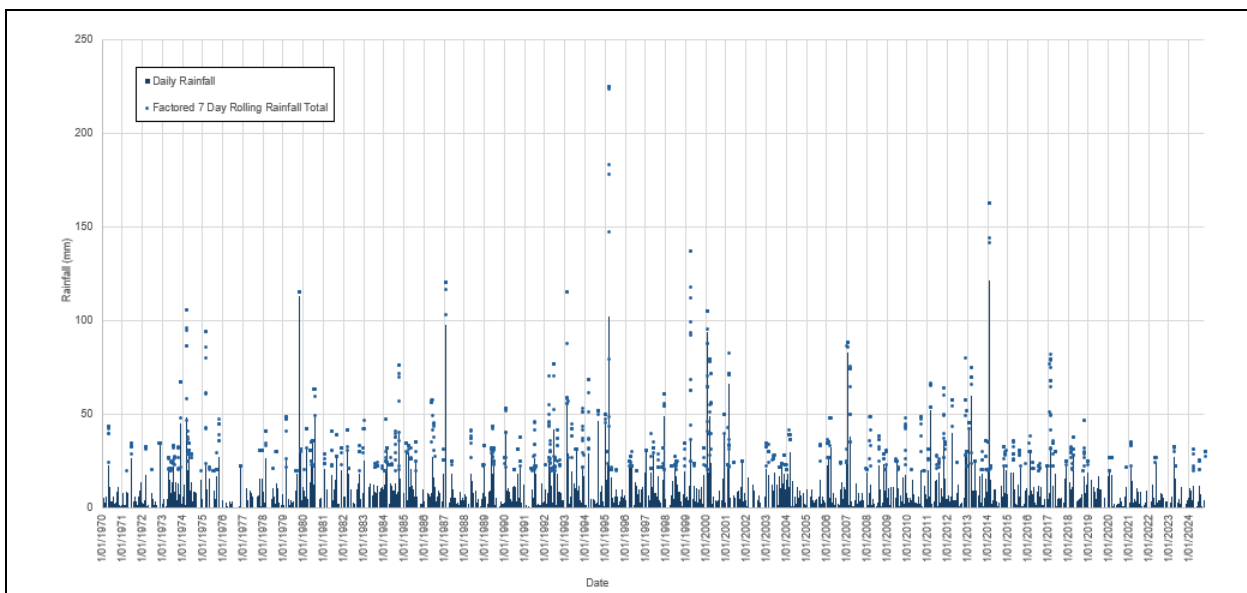


Figure 2.3 Cowarna Downs Rainfall Metrics (1970–2024)

3. SATELLITE IMAGERY ASSESSMENT

The Lake Roe inundation extents and frequency were estimated between 1993 and 2024 using satellite data, specifically true colour imagery and Normalized Difference Water Index (NDWI) data from Sentinel, Landsat and Google Earth. Data availability and aerial image quality varied considerably throughout the 1990 to 2024 study period. The inundation extents were compared to the Digital Elevation Model (DEM) of the lake to estimate ponding depths with time.

As shown in Figure 3.1, Lake Roe consists of a series of small salt pans that appear to be separated by (relatively) high points, some of which appear to be sand dunes, based on assessment of aerial imagery and LiDAR surface elevation data. Each of the small salt pans have a local low point where water may pool.

Figure 3.1 denotes the nominal names used within this study for some salt pans relevant to the assessment. The main catchment reporting to the lake comes from the western side of the lake, with other, smaller catchments reporting to the lake around the lake perimeter. Following large enough inflow events, the individual salt pans may become hydraulically connected.

Confidence in the estimated inundated depths (from observed satellite imagery) varies, and the date of recorded imagery may not coincide with the date of the actual peak inundation extent. Frequent Sentinel data between 2017 and 2024 provides the most reliable period for analyses. Between 2013 and 2017, Landsat (satellite) data are inconsistent with some gaps due to Lake Roe's eastern area falling on a different tile without imagery and satellite imagery strips (Landsat 7) giving an incomplete picture. Pre-2013, imagery from Landsat is less frequent, with data pre-2008 missing for extended periods and/or has insufficient resolution to confidently interpret. Notably, there is a Landsat data gap from late 2011 to early 2013, meaning that any lake inundation due to rainfall events during 2012 are not estimated.

3.1 Inundation Observations

The following observations were made at Lake Roe during the satellite imagery assessment:

- Catchment runoff responses causing at least some inundation in Lake Roe were generally observed when rainfall exceeded approximately 25 mm.
- In small inundation events where widespread flooding across the full lake is not prevalent (i.e., following rainfall depths in the order of 25 mm), the water levels Pan A were estimated. Appendix A presents the estimates of inundation water levels from satellite observations within salt pans B and D for reference.
- Visible widespread inundation across constituent salt pans was typically observed when a rainfall event occurred over multiple days, with total rainfall over the event exceeding 50 mm. Widespread inundation due to a large, singular rainfall day event could not be concluded as there were not any events where daily rainfall exceeded 50 mm within the rainfall data, notwithstanding this may be possible.
- The magnitude of inundation (water level) can vary between constituent salt pans; however, when widespread inundation is observed, the timing of the inundation is generally consistent across the lake.
- Rainfall in early 1995 and 2014 presents the largest rainfall events within the observation period, and these correlated with observations of large inundation events.
- Inundation responses in Lake Roe were generally observed 1 to 3 days after initial rainfall was recorded (noting that satellite observations are not available on a daily basis).

There is a level of uncertainty when correlating satellite observations and rainfall recorded at Cowarna Downs given the distance between the weather station and the lake. Rainfall is highly temporally and spatially variable in the Goldfields and it is likely the rainfall that occurs within the Lake Roe catchment differs from that recorded at Cowarna Downs. Larger events are likely to be more widespread than smaller events, but there is still likely to be a difference between the rainfall recorded at Cowarna Downs and the effective rainfall on the Lake Roe catchment (given the size of the Lake Roe and the Lake Roe, it is likely that rainfall will be variable over the catchment and lake as well). Given the limited spatial availability of rainfall records in the Goldfields, Cowarna Downs is still considered to best represent the rainfall that may have occurred within the Lake Roe catchment.

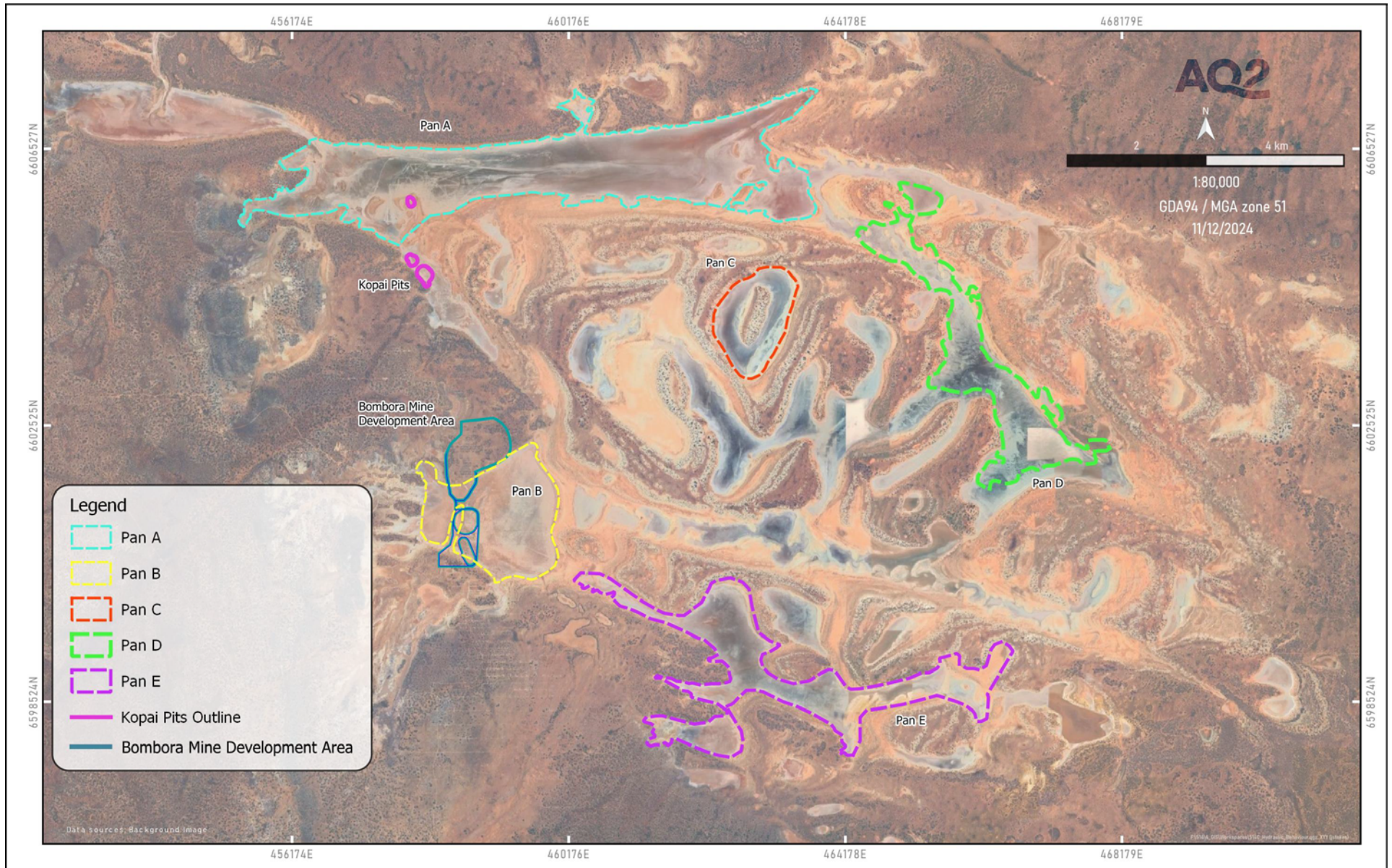


Figure 3.1 Lake Roe Study Area

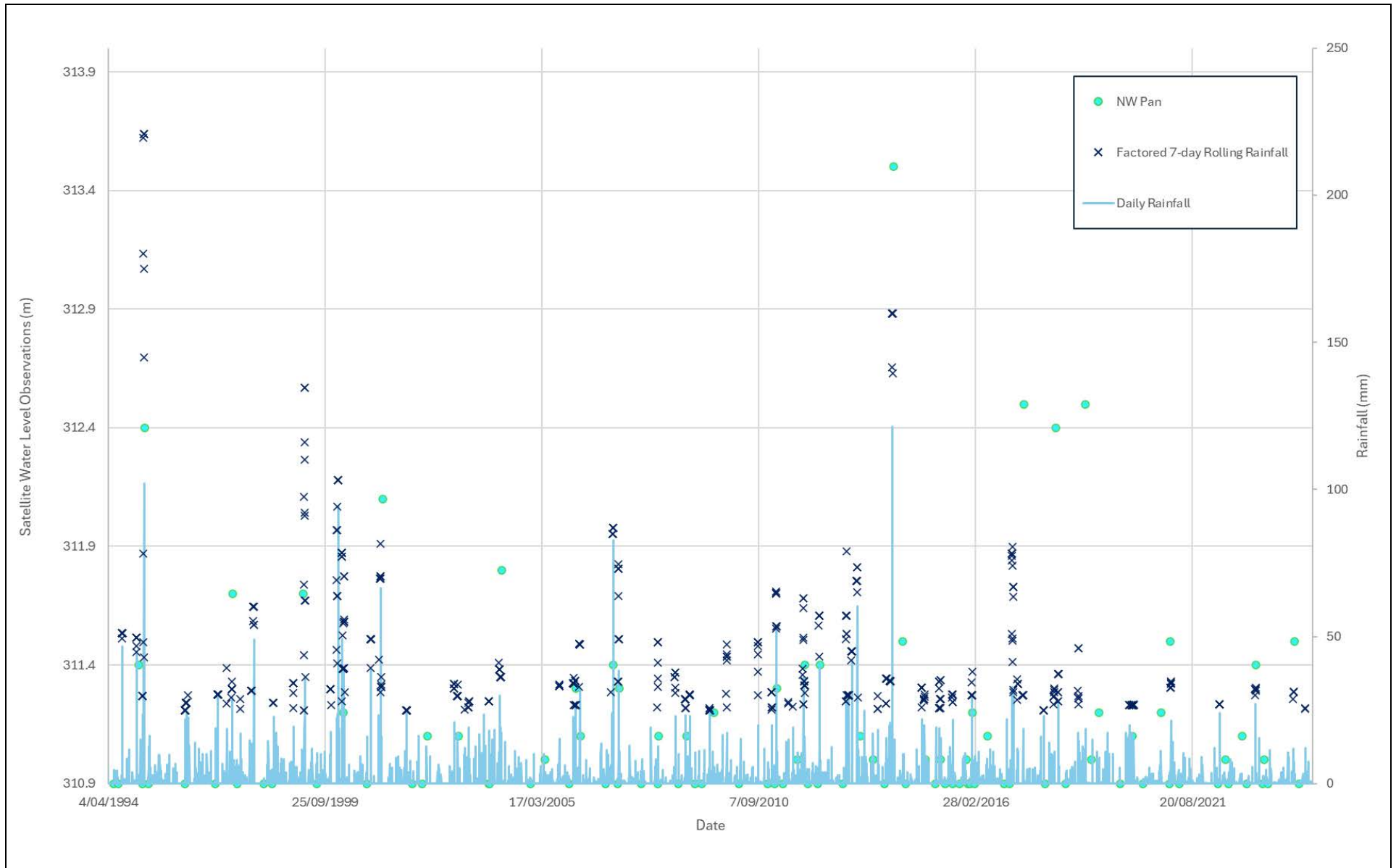


Figure 3.2 Lake Roe Inundation Depths (Pan A) vs Rainfall Data

3.2 Correlations to Intensity–Frequency–Duration (IFD) data

The observed rainfall events since 1993 were correlated with the available Bureau of Meteorology (BoM) intensity–frequency–duration (IFD) data for Cowarna Downs. The 63.2% AEP event (which approximates a large rainfall event which you would expect would happen every year) rainfall depths over 1–3 days of 31.1–38 mm (refer Table 3.1) correlates with the rainfall that results in smaller inundation events observed at Lake Roe in most years.

Larger, rarer rainfall events recorded typically since 1992 at Cowarna Downs (32 years inclusively), seemed to have occurred more frequently than the IFD data would suggest. This is shown in Figure 3.3, where factored rolling rainfall totals from the Cowarna Downs rainfall record are compared to the IFD curves. The plot indicates that, for example, there were 5 x 24-hr (1,440 minutes) duration rainfall events which exceeded the 5% AEP curve where it would be expected that ~2 events of this magnitude may occur in a 32 year period (noting the IFD curves presented do not account for climate change and are typically 10–15% less than what current climate conditions would suggest).

In the last 32 years, there were also 5–6 large inundation events observed in satellite imagery (equating to a 15–20% probability of occurring in a given year). Based on the IFD data, it would be expected that large inundation events would require more than 60 mm of rainfall to occur, which is close to what has been estimated from the inundation estimations (50 mm).

Table 3.1 Cowarna Downs intensity–frequency–duration (IFD) data

Duration	Duration in min	Annual Exceedance Probability (AEP)						
		63.20%	50%	20%	10%	5%	2%	1%
24-hour	1,440	31.1	37	58.6	76.2	96.1	125	150
30-hour	1,800	32.6	38.9	61.8	80.8	102	133	160
36-hour	2,160	33.8	40.4	64.5	84.5	107	140	168
48-hour	2,880	35.7	42.6	68.5	90.2	115	150	180
72-hour	4,320	38	45.5	73.7	97.5	125	163	195
96-hour	5,760	39.5	47.3	76.9	102	131	170	204
120-hour	7,200	40.5	48.6	79	105	134	174	209
144-hour	8,640	41.4	49.7	80.5	106	136	177	212
168-hour	10,080	42.1	50.5	81.6	108	137	178	213

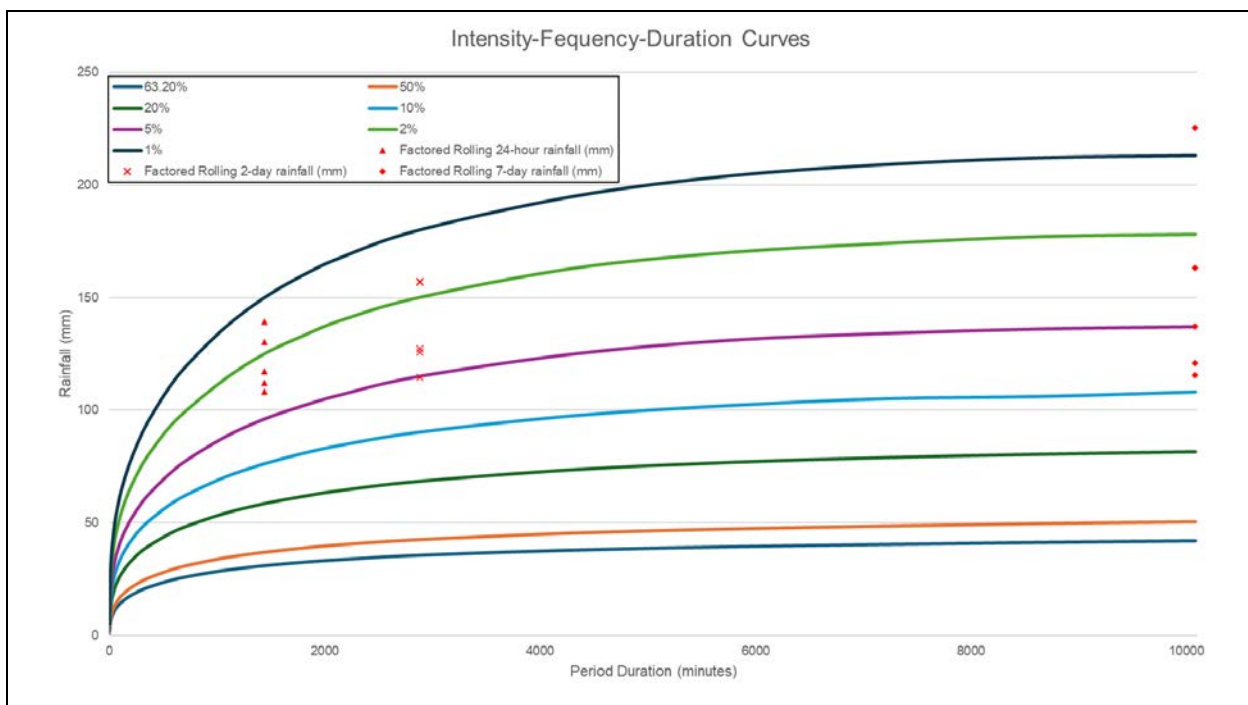


Figure 3.3 Cowarna Downs Intensity–Frequency–Duration (IFD) and Rolling Rainfall Data

4. SEEPAGE ASSESSMENT

Water level recession curves at Lake Roe were predicted following inundation events using a 1D water balance calculation and compared to the observed recession of standing water in the lake from the satellite imagery assessment. As shown in Figure 4.1, Figure 4.2 and Figure 4.3, three key inundation events were identified for assessment in years 1995, 2014 and 2017. The assessment was used to assess the potential **seepage from the lake to the subsurface**. During the circa 32 years period examined, Lake Roe hosted standing water for various lengths of time (typically in the order of months) after large rainfall events. The water level recession observed from satellite aerial imagery within Lake Roe is assumed to be driven by evaporation and (potentially) seepage into or from the subsurface; Figure 4.4, Figure 4.5 and Figure 4.6 show aerial true colour imagery of the May 2017 flood event's recession

The completed assessment is summarised as follows:

- A stage vs area relationship was derived for different salt pans from the provided LiDAR data.
- Satellite imagery was reviewed to identify periods of significant inundation within the salt pans, nominally years 1995, 2014 and 2017 were chosen as the best data for assessment.
- The inundation area within the salt pans was estimated during period that the lake level recedes when satellite imagery was available (typically in the order of weekly images, but many were unable to be used due to clouds, poor quality etc.).
- The stage area relationship was used to derive estimates of lake water levels with time during the recession period.
- A 1D water level balance calculation was completed using the following formula:

$$\text{Water Level} = \text{Water Level}_{\text{previous}} \mp \text{Rainfall} - \text{Evaporation} - \text{Seepage}$$
- The daily 1D water balance calculation used the following:
 - The water balance was set to start at the peak lake water observed following the rainfall event.
 - Daily evaporation losses from the lake in the 1D water balance calculation have been predicted using Morton's shallow lake evaporation estimates sourced from the SILO database for the site. These evaporation estimates vary on a daily basis based on meteorological observations.

- If a small rain event occurred during the water level recession period, the depth of rainfall was added to the running water level total. This assumed that no catchment runoff reported to the lake, with only incident rainfall on the lake surface reporting to the lake. If large rainfall events did occur during the recession, then the observations weren't used as the additional inflow would not be accounted for in the method prescribed above.
- A nominal seepage loss rate was applied and adjusted such that the modelled recession approximates the observed recession.

The **seepage rate** that enables water level predictions to approximate the observed recession of standing water within Lake Roe is approximately **3 mm/day**. Noting:

- It was difficult to interpret when Lake Roe was completely dry in the satellite imagery due to image quality, partial (or full) cloud cover and the frequency of imagery capture. The appearance of a salt crust on the lake floor in satellite photography was determined not to be a reliable indicator of the entire lake system being fully dry, as, on occasions, these observations concurred with periods where NDWI imagery indicates standing water.
- It is interpreted that groundwater does not contribute to inflow into the Lake Roe, and surface water recession / periodic standing water within the claypan(s) is solely accounted for by evaporative losses and seepage.
- There is a degree of uncertainty in the evaporation losses applied and in the estimation of lake inundation depths. Additionally, there is uncertainty in what the rainfall which falls on the lake is compared to what was measured at Cowarna Downs.

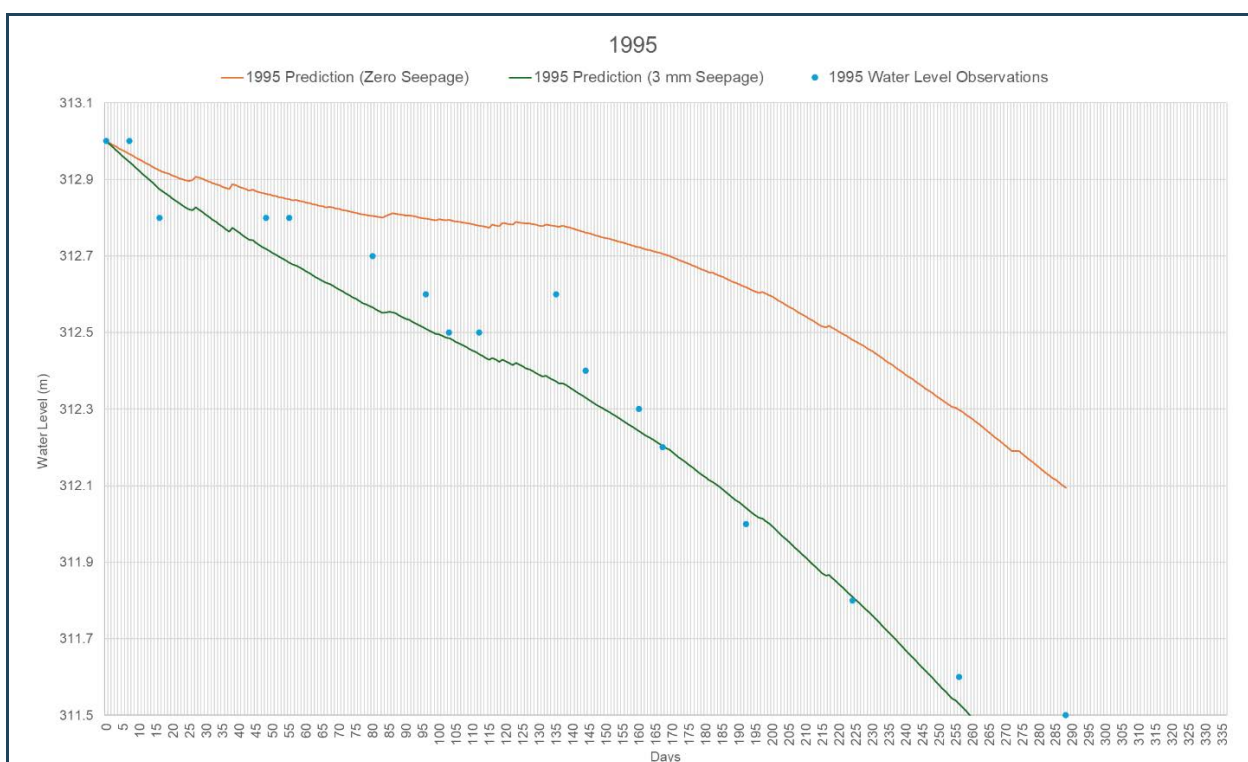


Figure 4.1 Observed vs Predicted Flood Recession Curves (March 1995)

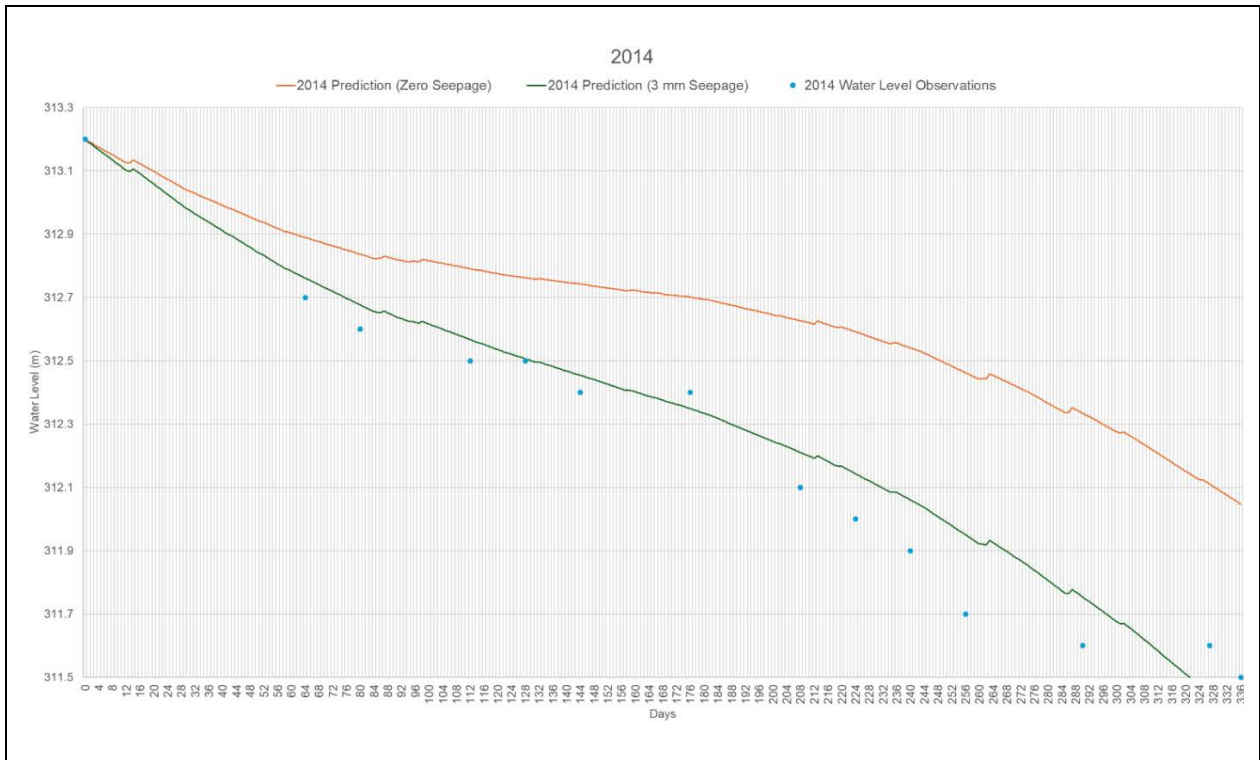


Figure 4.2 Observed vs Predicted Flood Recession Curves (January 2014)

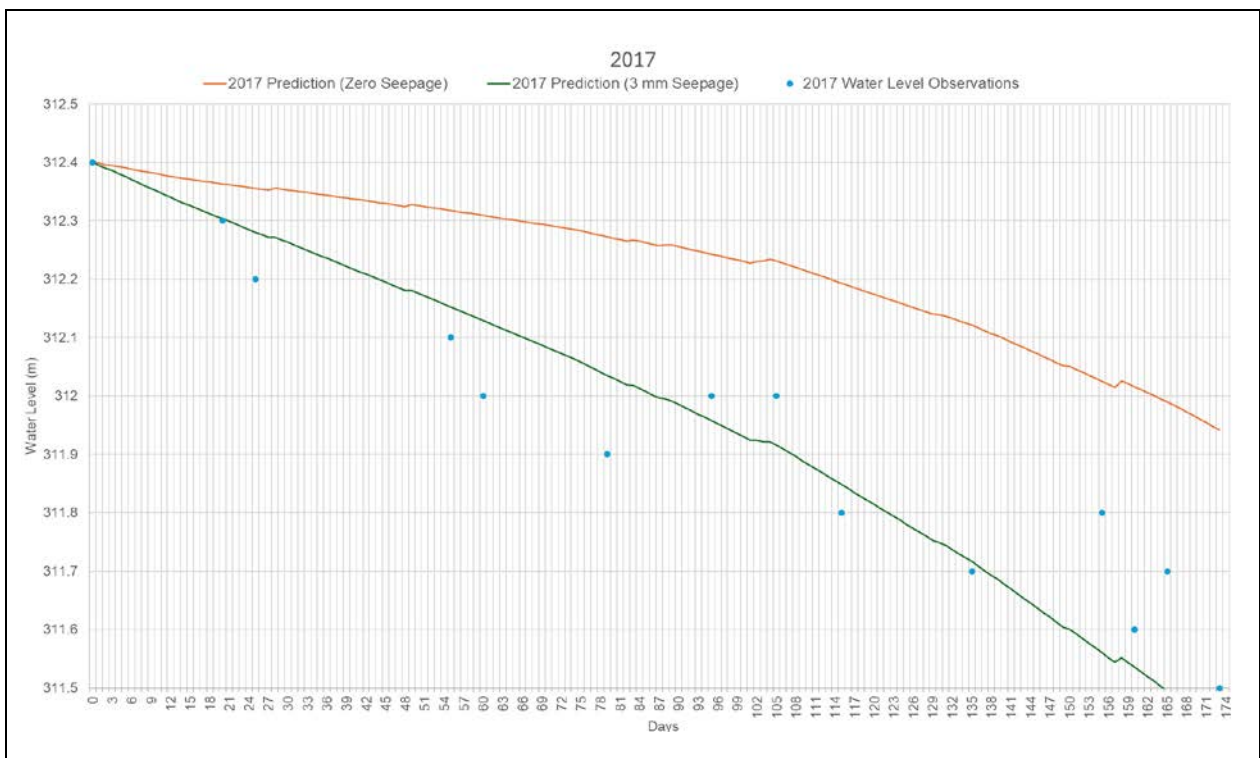


Figure 4.3 Observed vs Predicted Flood Recession Curves (May 2017)



Figure 4.4 True colour imagery for May 2017 flood event's peak inundation on 18 May 2017



Figure 4.5 True colour imagery for May 2017 flood event's partial recession on 07 June 2017

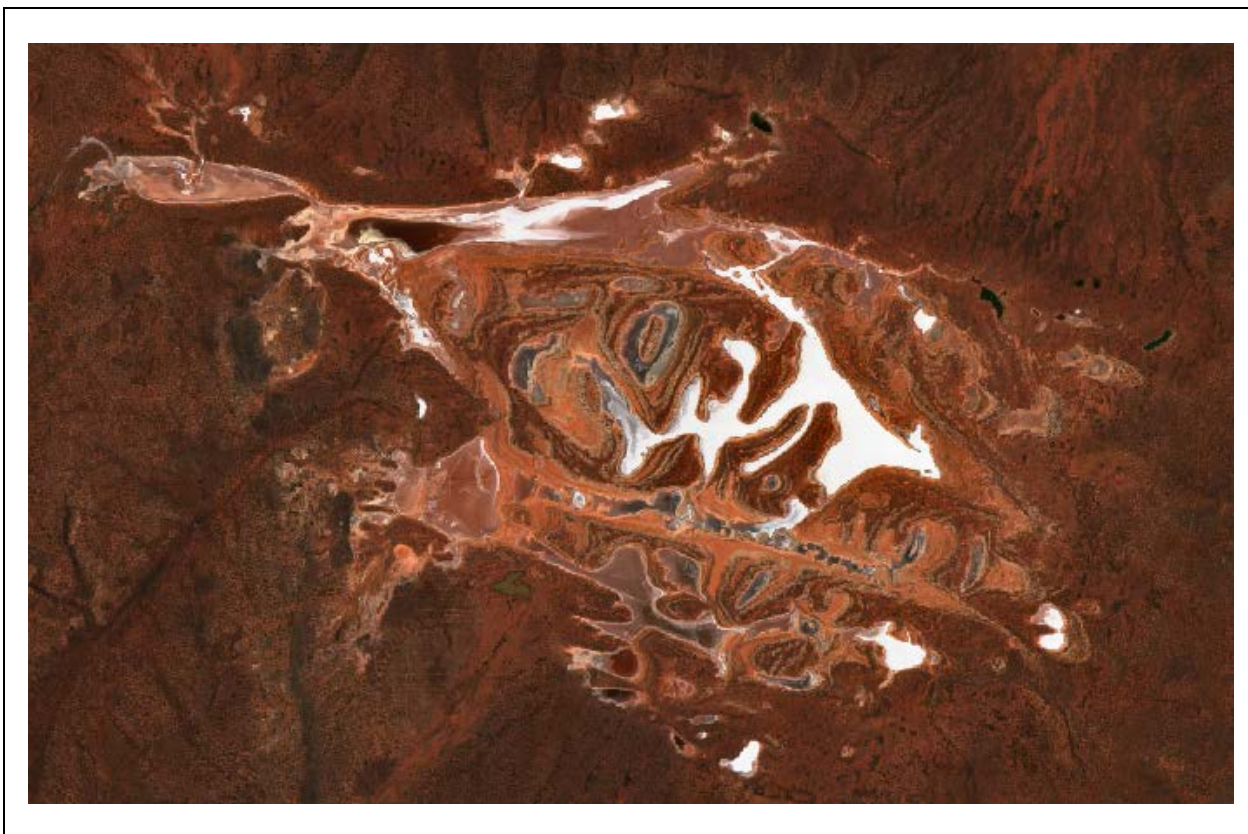


Figure 4.6 True colour imagery for 30 October 2017 flood event – recession

5. POTENTIAL DEWATERING DISCHARGE LOCATIONS

A number of potential locations to receive surplus dewatering have been identified and are shown in Figure 3.1. These locations have chiefly been identified for their proximity to the project area. For each of the potential receiving salt pans, the following has been estimated using the DTM/aerial imagery:

- Maximum storage/inundation elevation – it is assumed that any salt pan could only be filled to either:
 - 0.5 m below the vegetated shoreline of the salt pan.
 - 0.2 m minimum below the point at which the salt pan overtops to the adjacent salt pan (to confine the impact to a single pan).
- Maximum inundation surface area of the salt pan at the maximum inundation elevation.
- Maximum inundation storage volume of the salt pan at the maximum inundation elevation.
- Evaporative loss from the maximum lake surface based on Morton's Shallow Lake Evaporation rate in July, with a nominal reduction in this evaporation rate of 30% adopted to approximate the impact the salinity of the dewatering discharge may have on the evaporation rates.
 - Note that higher evaporation losses would occur during other months, such that the estimates of loss rates are conservative. If there is sufficient balancing storage in the salt pan, the annual average evaporation rate could be applied (rather than the July evaporation rate).

A summary of these characteristics for each salt pan is provided in Table 3.2. The assessment assumes no ponded rainfall within the lake. The advantages / disadvantages of the identified discharge locations are as follows:

- Option A (Pan A) – This pan is close to the proposed Kopai Pit development and provides a large area for storage/evaporation of surplus dewatering. The main disadvantage of this option is that the largest surface water catchments to Lake Roe discharge into this salt pan, and there is the potential

that accumulated salt will flow into the downstream pans during large runoff events (i.e., the impact won't be contained to the one pan). Additionally, the discharge of dewatering to this lake may result in recirculation to the Roe Pits, given their proximity to the lake.

- Option B (Pan B) – This pan is close to Bombora Pit development and would contain the surplus discharge to a smaller area compared to Option A. Similar to Option A though, the southwest pan commands a significant upstream catchment, and there is therefore the potential for accumulated salts to be transported to salt pans to the east. Additionally, the discharge of dewatering to this lake may result in recirculation to the Bombora Pits, given their proximity to the lake likely via the Lake Roe N-S fracture zone
- Option C (Pan C) – There is a number of salt pans which appear to be hydraulically isolated from the remainder of Lake Roe by sand dunes, including a roundly shaped pan, the smallest of the four options. Additionally, a cluster of pans situated between Pan B and Pan D have been discounted due to limited volume, all individually smaller than Pan C. These are located further away from the mining areas than Option A and B but may allow impact to be localised to pan. The choice of pan could be based on the rate of dewatering that needs to be managed, with different potential evaporative losses achievable at each pan based on their available surface area. Pan C has been nominally assessed for this option.
- Option D (Pan D) – Pan D could be filled to a depth of approximately 312 mRL (refer Figure 3.1), which is 0.2 m below the elevation of the saddle which separates Pan A and Pan D, to isolate impacts from discharge to this pan. Option D is the pan most isolated and furthest from both the Bombora Mine Development area and Kopai Pits. Option D is the main pan at the most downstream part of Lake Roe.
- Option E (Pan E) – An initial review of Pan E was completed but a comparison of lake shore elevations to the overflow point between consecutive salt pans indicated that it wouldn't be feasible to discharge to one salt pan and fill multiple areas. As such, the available evaporation area for Pan E was too small to consider further.

Environmentally, Option C is the preferred option for discharge as it would isolate the impact of dewatering discharge to the isolation Pan C (subject to confirmation that Pan C has no environmental value which differs from the rest of the lake). However, Option C provides the lowest potential for ongoing loss from the ponded water due to evaporation.

If impact containment is not a priority for the dewatering discharge, Option A may be preferred as it has the highest likelihood of accumulated salt being washed downstream into other parts of the lake during runoff events.

Discharge to Pan D is the furthest discharge option so may be the highest capital cost for discharge, but the benefit is the ponded water is furthest from the mine voids so has the lowest chance of recirculation into the pits.

Further assessments of discharge locations should consider the likely magnitude and duration of discharges to the lake, as well as the potential storage volume in each of the considered discharge locations. A water balance of the pan area could be completed, considering the stage/volume/area relationship of each of the pan options, to predict how each of the pans may fill with time.

Table 5.1 Dewatering Discharge Options

Target	Invert RL	Shoreline RL	Overflow Point RL	Max Inundation RL	Area (km ²)	Loss Potential m ³ /day	Loss Potential l/s
Option A	310.9	313	312.2	312.0	7.1	8,500	98
Option B	311.6	312.6	312.4	312.1	2.5	3,000	35
Option C	310.7	313.5	313.6	313.0	1.1	1,000	16
Option D	311.5	313	312.2	312.0	3.1	3,700	43

6. SUMMARY

AQ2 has completed an assessment of available climate data sources for Lake Roe area, a satellite imagery assessment of inundation and other hydraulic behaviour, estimations of potential discharge volumes, and a seepage assessment. Key findings are as follows:

- Pan A, adjacent to Kopai Pits, has been observed to hold runoff in most years. Significant inundation is observed to occur in the order of once every 5 years.
- Following significant inundation events, the lake may hold water for months.
- Seepage rate analyses indicate that in the order of 3 mm/day of seepage may occur from the lake bed when it is inundated.
- Five locations were considered for the discharge of surplus water from the project. Environmentally, Pan C is considered the most favourable, as it would confine the discharge to a single part of the lake. However, Pan C has the smallest surface area and therefore the lowest potential to lose discharged water via evaporation (in the order of 15-20L/s).
- Option D is furthest from the project area and allows for the containment of discharge in the most downstream part of the chain of salt pans that make up the Lake Roe system.
- Further assessment work should be completed on the discharge options when surplus water magnitudes and duration of discharge are estimated.

We trust that this assessment meets your requirements. Please contact us should you require further information.

Best wishes,

Shirley-Rose Field

Water Resources Engineer

Mark Nicholls

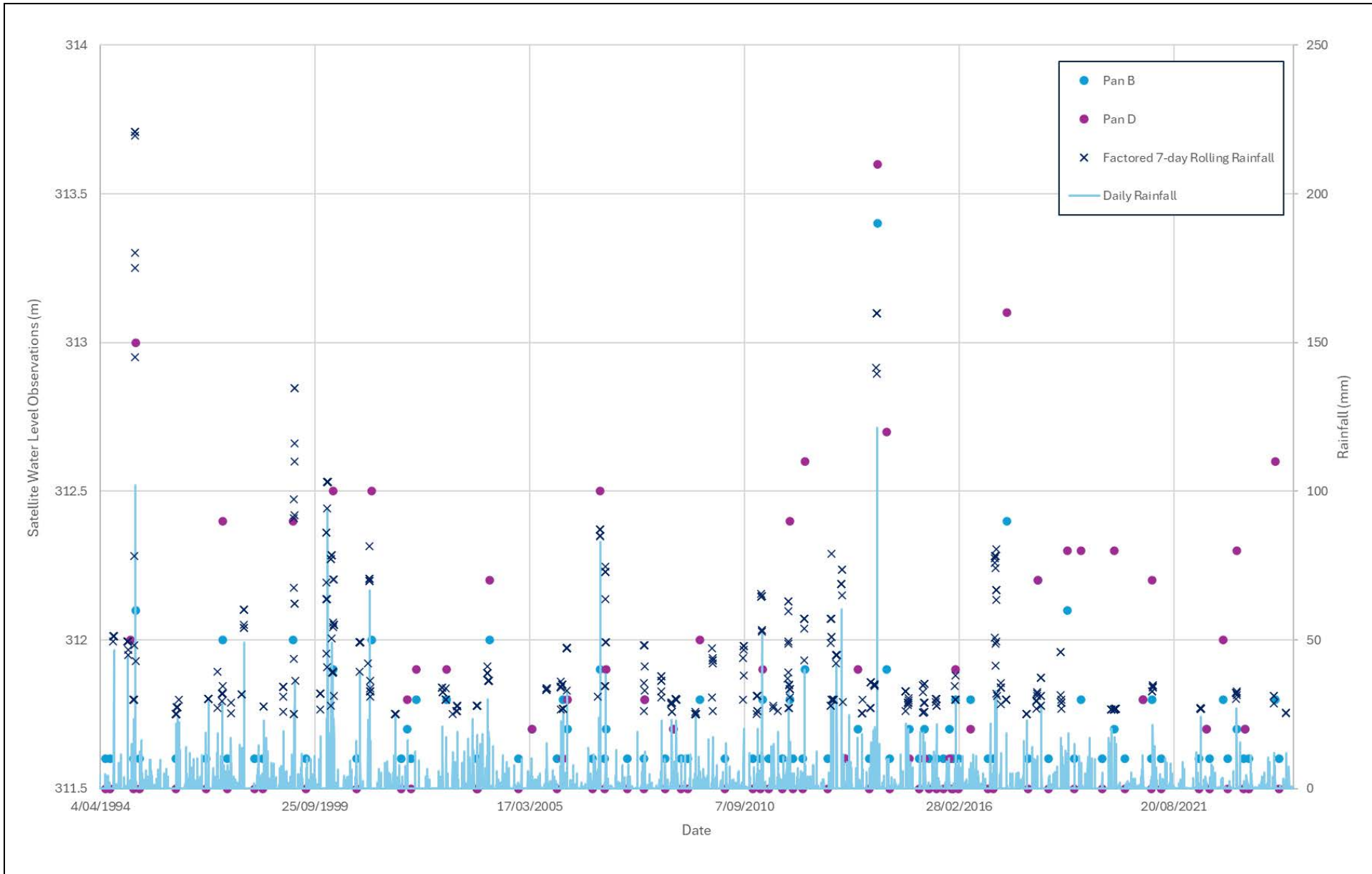
Consulting Water Resources Engineer

Author: SF/JS (06/12/2024)

Checked: MN (06/12/2024)

Reviewed: MN (06/12/2024)

Attached: Lake Roe Inundation Depths (Pans B and D)



Lake Roe Inundation depths (Pans B and D)