Image Resources
Bidaminna Project Hydrology Report

Prepared for

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EXECUTIVE SUMMARY

Bidaminna is a beach strand mineral sand deposit located on Vacant Crown Land on the Swan coastal plain 100 km north of Perth and 15 km WSW of Regan's Ford. Image Resources is seeking approval for development of a dredge mining operation at Bidaminna.

This report covers surface water-related matters in support of an environmental impact assessment, focussing on flood risk management and high flow conditions. Project impacts during low flow conditions are typically dominated by surface water -groundwater interactions which are more thoroughly addressed in the Bidaminna Project groundwater report (MWES, in prep.).

The deposit is a typical beach strand mineral sand, elongate in the NNW-SSE direction (parallel to the west coast). The proposed mine has an overall length of about 6900 metres and width 200-700m. Mining will progress linearly along the deposit which is situated beneath a gently west-sloping planar ground surface at an elevation of 57-60 m AHD.

The deposit extends south from the south bank of the lower Moore River. The DWER river gauging station 617001 (Quinn's Ford) has been operating on the Moore River since 1969. The March 1999 Moore River flood event constitutes a 1:100 year event in terms of basin scale rainfall and flow rate frequency. It estimated that the 1:100 year level peak flow will be contained within the lower flood plain at about 56 m AHD immediately north of the mine site. Above this level the higher flood plain is very wide and flooding beyond this (i.e. as far as the Orange Springs Road at the project site) is unforeseeable.

Local landform is the Bassendean Sands system which reaches a peak elevation of 100 m AHD, forming a local catchment boundary about 4 km east of the site. The western side of Bassendean Sands, on which the project is situated, is a nearly planar, 0.3% west-sloping surface. There is no indication of concentrated surface water flow west on the slope. Within the project area, "geomorphic wetlands" classed as "dampland" vegetative areas, were found to have no particular hydrological characteristics locally.

The project site is elevated and well drained. The site is not prone to flooding from the Moore River. No discernible hydrological features will be impacted by the mine as it progresses along the deposit. At the broad scale, the project does not pose a risk to the downstream surface water environment. Potential point sources of contamination are excluded from this assessment and will need to be identified and managed.

The post closure rehabilitation should restore the background surface elevation such that the westward slope is continuous across the site.

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CONTENTS

TABLES

FIGURES

1. INTRODUCTION

Image Resources is seeking approval for development of a dredge mining operation at the Bidaminna mineral sand deposit near Cowalla. This report covers surface water-related matters in support of an environmental impact assessment.

Bidaminna is a beach strand mineral sand deposit located on the Swan coastal plain 100 km north of Perth. The site is located 21 km east of the coastal town of Ledge Point. From the Brand Highway the site is 15 km WSW of Regan's Ford via Orange Springs Rd which follows the south side of Moore River. From there the narrow deposit extends about 7 km to the south (Figure 1).

This document focuses on flood risk management and high flow conditions. Project impacts during low flow conditions are typically dominated by surface water -groundwater interactions which are more thoroughly addressed in the Bidaminna Project groundwater report which is currently in preparation by MWES for Image Resources.

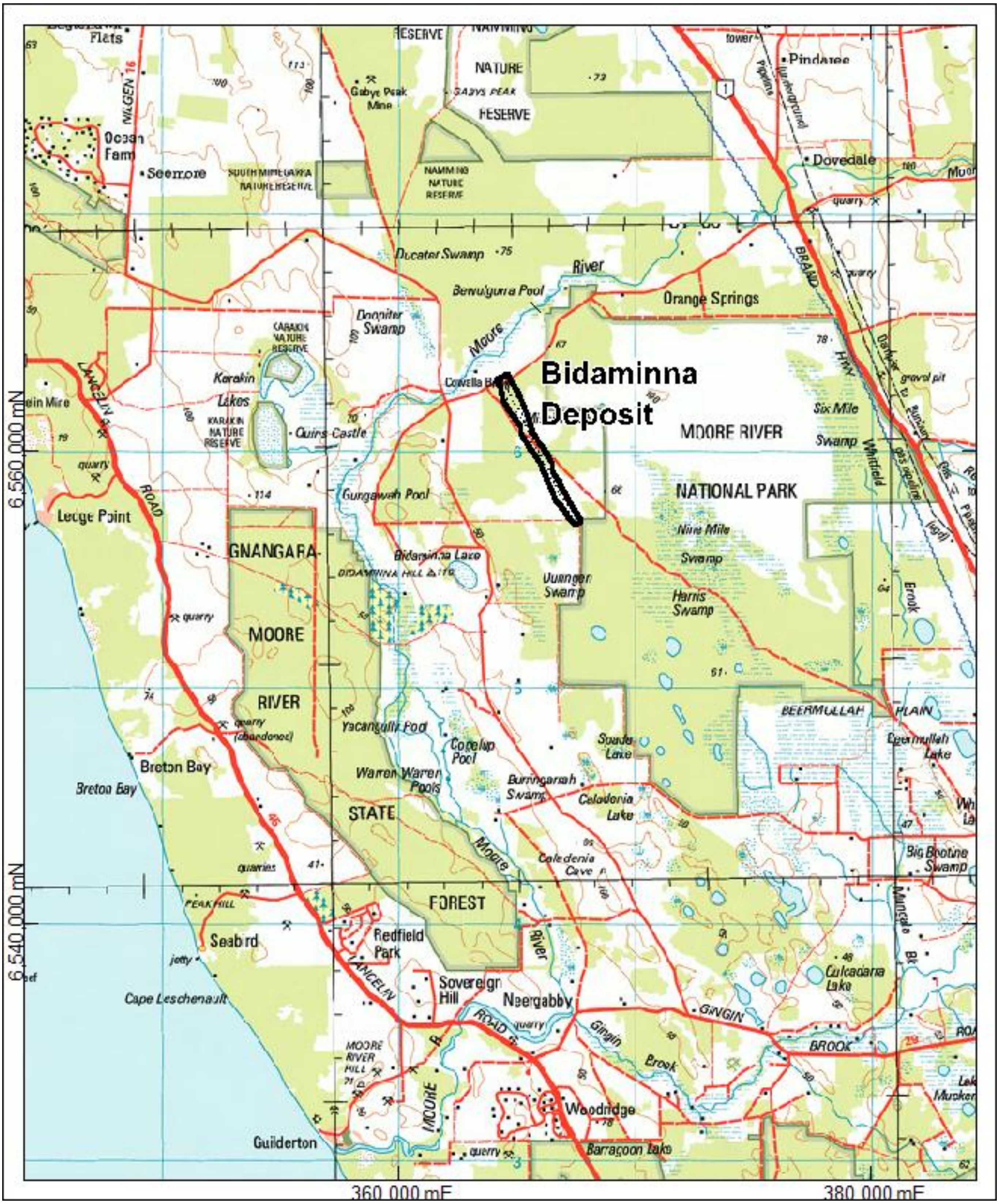
2. BIDAMINNA PROJECT

The Bidaminna project is located on vacant crown land across two exploration tenements. The northern portion of mineralisation (roughly half), which is open to the north, is located on E70/2844. The southern portion of Bidaminna mineralisation is located on E70/3298.

The deposit contains a dredge mining mineral resource estimate of 102 MT at 2.2% total heavy minerals. The interpreted strandline mineralisation covers a strike length of 9.5 km and consists of two strandlines, stacked one on top of the other. The upper strandline ranges in width from 90 to 345 metres and has an average thickness of 11.7 metres. The lower strandline ranges in width from 150 to 650 metres and has an average thickness of 9.1 metres. Depth of mineralisation ranges from as shallow as 12 metres at the top of the upper strandline, to 66 metres at the bottom of the lower strandline.

The deposit is a typical beach strand mineral sand, elongate in the NNW-SSE direction (parallel to the west coast). The proposed mine has an overall length of about 6900 metres and width 200-700m. Mining will progress linearly along the deposit which is situated beneath a gently west-sloping planar surface at a ground elevation of 57-60 m AHD.

Figure 1 – Bidaminna Project Regional Location Plan



3. BASELINE CONDITIONS

3.1. CLIMATE

The climate type is Mediterranean, with hot dry summers and cool wet winters, similar to Perth but slightly drier and sunnier. Mean monthly temperature maxima range from 18 to 32 degrees and minima from 8 to 18 degrees. Annual rainfall is about 667mm, with monthly totals averaging in the range 10 (December) to 120 mm (July). Annual pan evaporation is 2032 mm on the BoM continent-wide grid, with monthly averages ranging from 70 to 300 mm.

Rainfall intensity is described by the intensity-frequency-duration (IFD) statistics downloaded from the Bureau of Meteorology (BoM) Design Rainfall Data System, 2016 and summarised in Table 1.

Table 1 – Rainfall IFD Statistics (mm)

Average Recurrence Interval (ARI/Years)	10	20	50	100	200	500
Duration	Rainfall Total (mm)					
24 hour (1 day)	68.7	82	102	120	137	164
30 hour	72.7	86.5	108	127	147	179
36 hour	75.9	90	112	132	154	188
48 hour (2 days)	80.7	95.3	119	139	163	199
72 hour (3 days)	87.4	102	126	147	172	209
96 hour (4 days)	92.5	107	131	151	176	212
120 hour (5 days)	97.1	112	135	154	178	214
168 hour (7 days)	107	121	142	159	181	217

Longer term rainfall patterns are described by the SILO database of daily climate statistics on a 0.05 degree interval grid (https://www.longpaddock.qld.gov.au/silo/gridded-data/) for the period 1889 to 2020 (131 complete years). The local grid point data set shows the following notable statistics:

- Maximum monthly rainfall 416 mm
- Four monthly totals exceeding 300 mm
- 10% probability that in any year, one month total exceeds 245 mm
- The last year of significantly greater than average rainfall was 1999 (905 mm).
- Recent (2000-2020) annual rainfall averaged 579 mm (13 % below the longer term average)
- Recent (2000-2020) monthly totals have not exceeded 179 mm

3.2. *REGIONAL PHYSIOGRAPHY*

Physiographic zones are strongly linear and parallel to the west coast. The western Swan Coastal Plain is about 38 km wide with undulating surface elevations mostly 20-100 m AHD. The plain includes three broad geomorphic units formed in Quaternary near shore deposits. To the west, the coastal belt includes Quindalup Dunes and Tamala Limestone. The central Bassendean Dunes include the Bidaminna Project area. To the east is the Beermullah Plain. There are numerous wetlands within the alluvial and aeolian deposits, particularly to the east side of the Plain and adjacent to the Moore river where it meanders across the plain.

The Dandaragan Plateau forms the eastern boundary to the Swan Coastal Plain at the Gingin Escarpment. The Brand Highway locally follows the foot of the escarpment. The Dandaragan Plateau is formed on older Mesozoic shales and sandstones with rounded landforms at elevation up to about 250 m AHD.

Further east is the north-south oriented Darling Escarpment which marks the western edge of the Archaean Yilgarn Craton. The Bindoon-Moora Road follows the Darling Escarpment. To the east lies more steeply incised hill country which rises very gradually east on the continental massif.

3.3. *REGIONAL VEGETATION AND LAND USE*

The project site is situated on Vacant Crown Land (VCL) and along with much of the surrounding area is undeveloped and botanically diverse sandplain heathland including Banksia woodland. To the east of the site is the Moore River National Park, to the northeast the Namming Nature Reserve and to the southwest the Gnangara Moore River State Forest. Regionally extensive areas of floodplain and wetlands support larger and more diverse vegetation. Large wild or controlled fires have occurred regularly across the site and Moore River National Park.

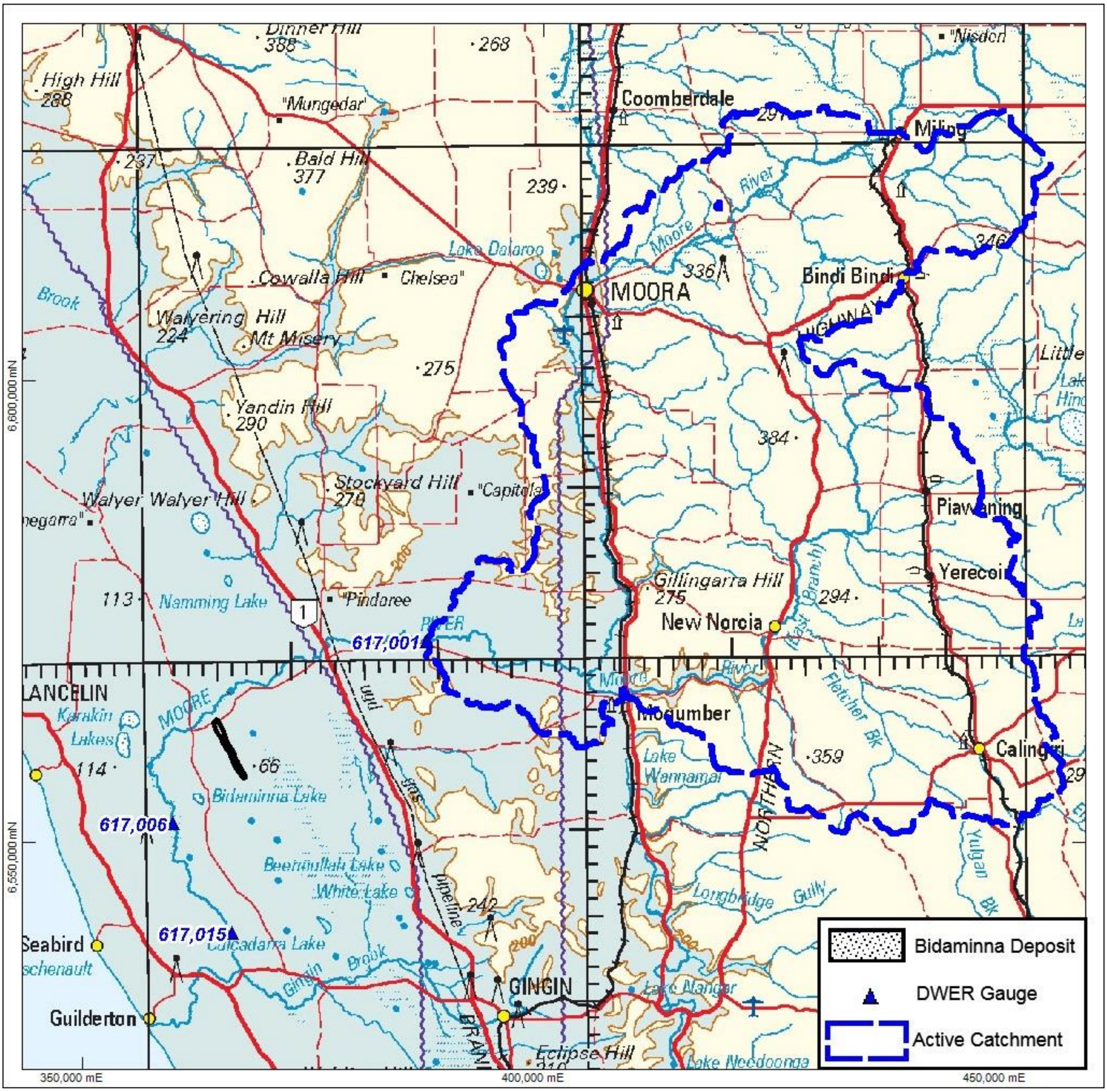
There are extensive freehold properties along the Moore River and further west of the site. These are largely cleared and used for grazing or irrigated agriculture.

3.4. *REGIONAL HYDROLOGY – MOORE RIVER*

The deposit extends south from the south bank of the lower Moore River, which from its mouth at Guilderton extends 220 km NNE and has a catchment area of 13,630 sq. km.

A large portion of the northern upper catchment comprises nearly flat and poorly drained plateau country or drains west to the tributary Coonderoo River. These areas generate very little runoff to the lower Moore River. The lower Swan Coastal Plain river reaches also receive relatively little runoff.

Figure 2 – Moore River Catchment – Active/Higher Yield Area



The majority of streamflow past Bidaminna originates from the middle of the Moore River catchment as shown in Figure 2. This active (high yielding or efficient) part of the catchment has a surface area of 3412 sq. km which is mostly cleared of native vegetation and used for unirrigated cropping and grazing. The north branch of the Moore River rises northeast of Moora, then flows south at the base of the Darling Scarp where it merges with the East Branch at Mogumber before flowing west across the Dandaragan Plateau and eastern Swan Coastal Plain. The confluence with Gingin Brook is 12 km upstream from the River mouth.

The DWER river gauging station 617001 (Quinn's Ford) has been operating on the Moore River since 1969. The site is located 24 km east (upstream) from the Bidaminna Project at a cease to flow elevation of about 102 m AHD. The following general notes apply to the 51 years of near complete flow records:

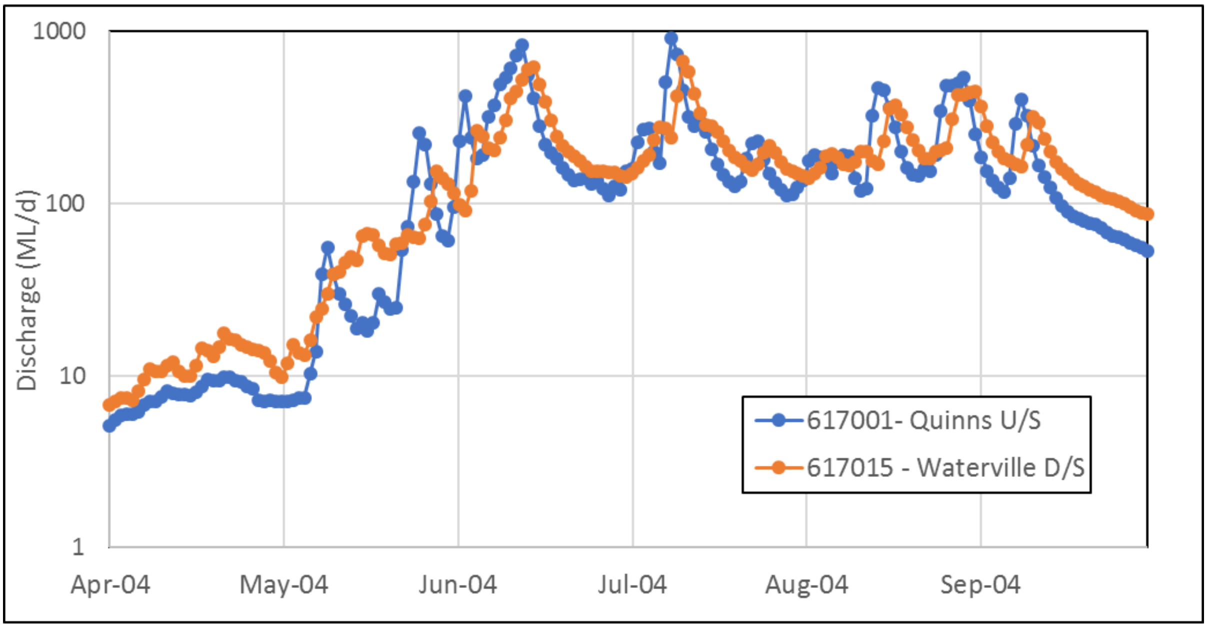
- Mean annual flow = 54 GL (54,000 ML or 54 M kL)
- Range of annual flow = 1 to 362 GL (max in 1999)
- Strong seasonality: 88% of total flow in 5 months May to September
- Mean annual flow from 2000 = 36 GL (only 3 years exceeding long term average)
- Max. flow rate = 446 cumecs (22/3/1999)
- Events with max. flow rate > 150 cumecs = 4
- Events with max. flow rate > 100 cumecs = 11
- Events with max. flow rate > 50 cumecs = 29

The statistics and hydrology of flood events are detailed further in Section 3.6 below.

Baseflow occurs all year round at Quinn's Ford (Figure 2, DWER gauge location 617001), demonstrating groundwater discharge to the river on the Dandaragan Plateau reach. Across the Swan Coastal Plain the river may be gaining (groundwater discharge) at low stage and losing at high stage (groundwater recharge).

Flow between upstream gauging station 617001 and downstream 617015 (Figure 2) for a typical rainfall year (2004 - dry summer/autumn, 470 mm May-August, moderate spring) is shown in Figure 3. The downstream flow rate exceeds the upstream rate during periods of low and receding flow, whilst rising and peak flow rates are greater upstream. These variations relate primarily to river channel storage rather than surface-groundwater exchange. Low flow during April averaged 90 L/sec upstream at 617001 and 130 L/sec downstream at 617015. The total annual flow volume was only marginally greater (0.5%) at the downstream gauging station, which indicates minimal net yield (ground or surface water) from the reaches between the two gauging stations.

Figure 3 – Moore River Flow Rate in Typical Wet Season



Early explorers (1850's) found the Moore River to be fresh and suitable for drinking. However, land clearing for agriculture has increased river salinity and the river is now mostly brackish to saline. The increased salt concentrations have been identified as a potential threat to groundwater quality in the Superficial aquifer downstream of Cowalla Bridge (Stelfox 2005). Seasonal salinity variations in the Moore River at 617001 for the period 1993-2002 are described in Mayer et al. (2005). Groundwater dominated summer flow had a salinity of 4500 mg/L while winter runoff from higher in the catchment was about 8000 mg/L. The volume weighted average salinity was 7200 mg/L.

3.5. LOCAL HYDROLOGY

Local surface topography is shown in Figure 4. The Bassendean Sands landform system reaches a peak elevation of 100 m AHD, forming a local catchment boundary about 4 km east of the site. The western side of Bassendean Sands, on which the project is situated, is a nearly planar, 0.3% west-sloping surface, with widely-spaced, fixed and mostly transverse dunes, up to 10 m in height. There is no indication of concentrated surface water flow west on the slope.

Immediately north of the deposit the Moore River has a slightly incised and meandering form. There is a 12 metre wide inner tree-lined channel with a cease to flow level estimated at about 51 m AHD (From Image Resources regional 1 metre contour data set and groundwater levels). The inner channel lies within a meandering lower level floodplain/channel with a width of about 120 metres. There is a main higher floodplain at 56 m AHD with a local width of 1600 metres. On the north bank the flood plain terminates abruptly against high dunes. On the south bank, a series of minor terraces rises onto the west-sloping planar surface.

Apart from the Moore River, surface drainage features are poorly developed or absent in the vicinity of the project. Surface drainage is limited by the coarse sandy substrate, low surface gradients and incoherent landform which is partitioned by dunes at a variety of orientations.

The site is isolated from the large swamplands of the eastern Swan Coastal Plain (Six Mile, Nine Mile and Harris Swamps) by the high Bassendean Sands dune deposits. At an elevation of 60-70 m the Beermullah Plain has limited drainage of local rainfall and the input of minor creeks discharging from the Gingin escarpment. To the west of the site the larger lakes (Karakin, Bidaminna Lakes) are at the elevation of the Moore River (about 38 m AHD) and may be remnant oxbows or overflows of the River.

Several small lakes or swamps are located within the higher country of the Bassendean Sands, typically where intersecting dunes trap overland flow runoff and build up a clay substrate. The closest notable such feature is Mission Lake, located 3 km upslope from the centre of the deposit and inside the Moore River National Park. All surface water bodies are largely seasonal which may fill with water at the end of winter. Monitoring has shown large seasonal variability of water salinity which varies inversely with water level (Kern, 1997).

Figure 5 shows the deposit on recent aerial imagery along with named hydrological features. Also shown are "Geomorphic Wetlands" (WA Govt. spatial data set DBCA-019) which remain locally as per the original vegetation maps presented by Hill et al (1996). The same areas are also mapped as aquatic groundwater dependent ecosystems in the Bureau of Meteorology spatial mapping system (http://www.bom.gov.au/water/groundwater/gde/map.shtml).

Figure 4 – Ground Elevation

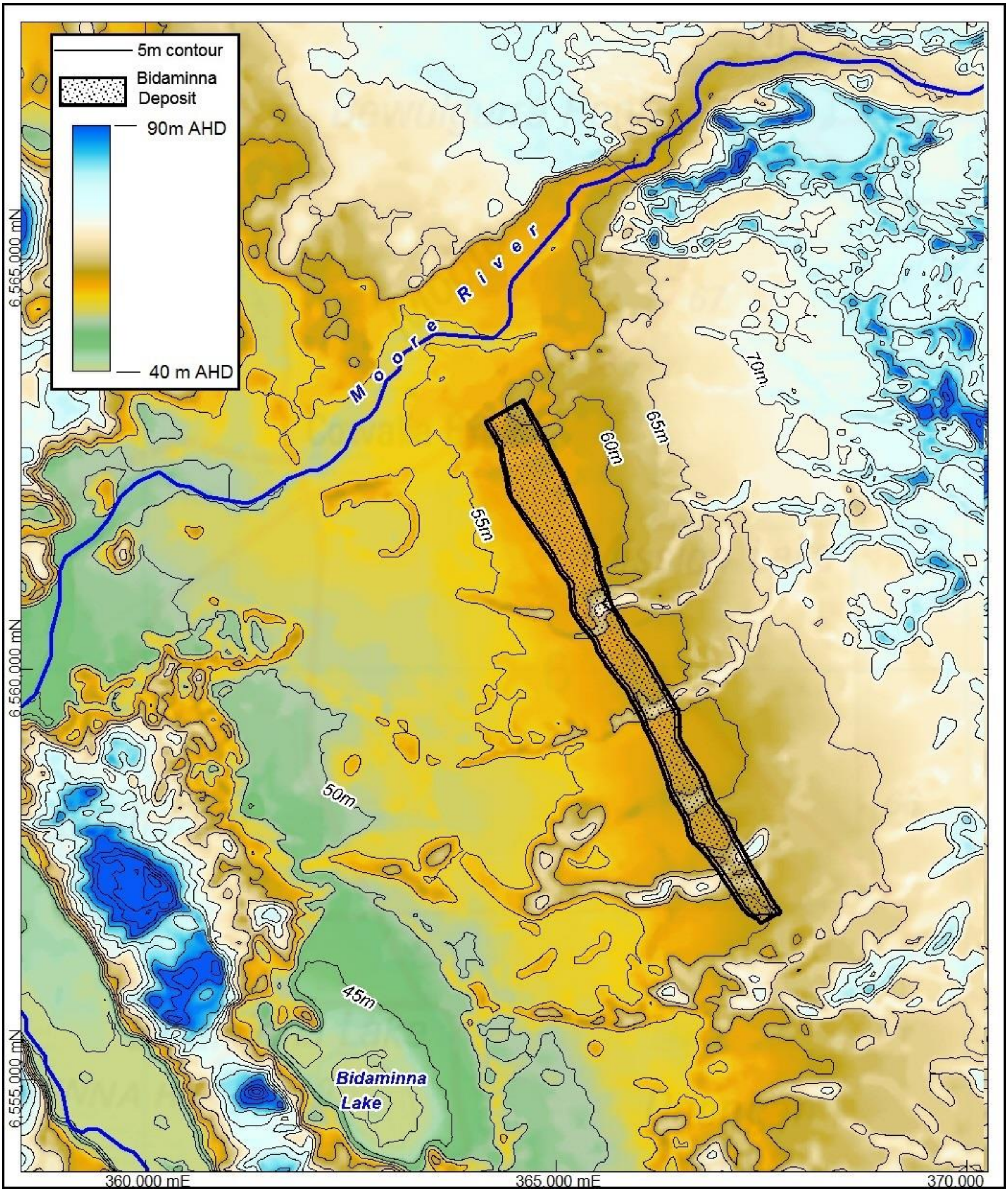
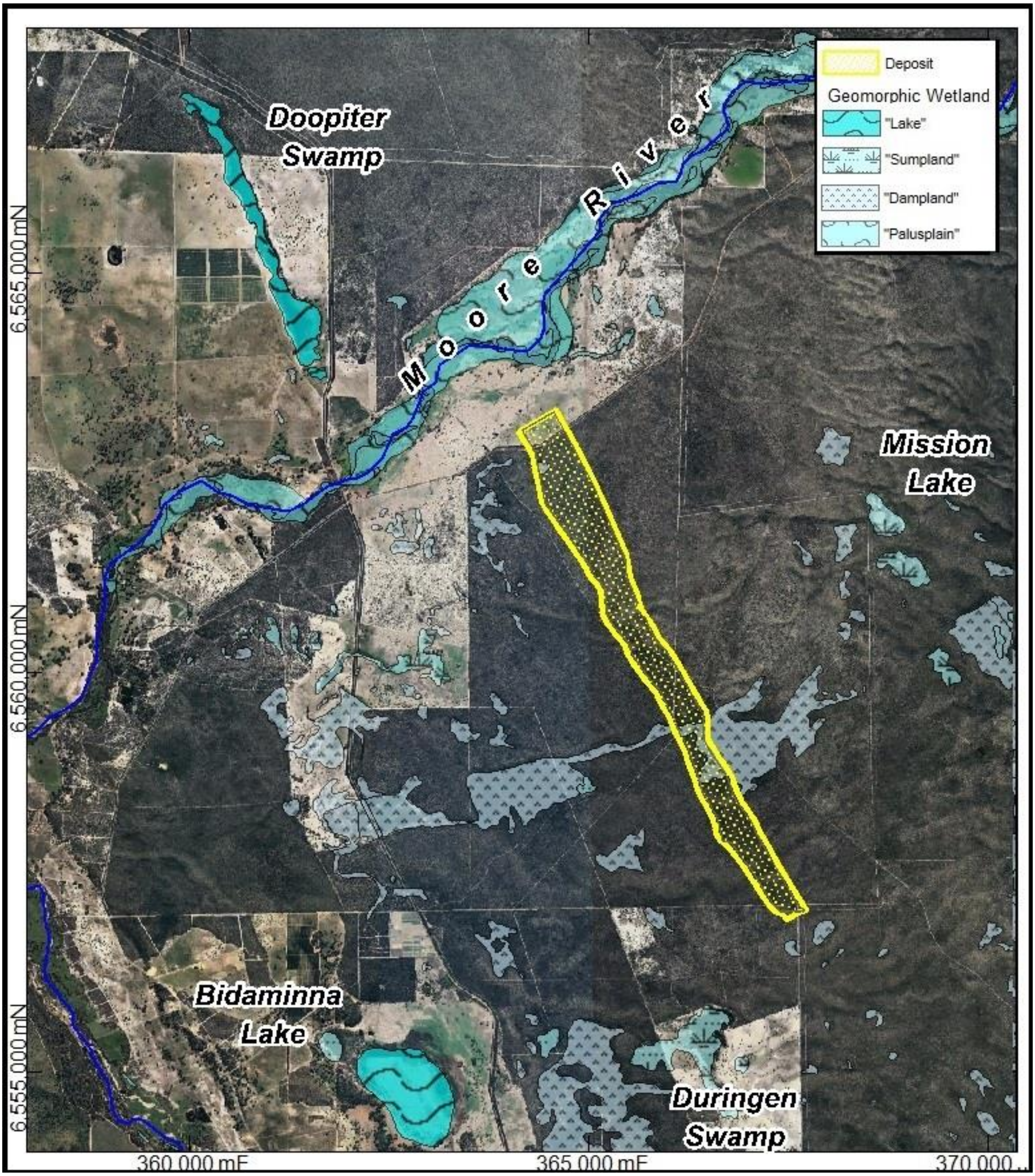


Figure 5 – Local Hydrology



Baseline field reconnaissance was undertaken in the local catchments on 16 June 2021. Field inspection confirmed the absence of any indication of concentrated surface water flow across the site. The areas mapped as “dampland” overlapping the project deposit (Figure 5 - south centre of deposit) were found to have no particular hydrological characteristics. The controls on the mapped vegetation zone perhaps relate to some combination of soil variations, fire history and other parameters.

On 16/6/21, there was a small pool in Mission Lake, with a water level of about 64 m AHD. The Lake is a hydraulically isolated, interdunal claypan swale, unconnected to broader surface or groundwater systems. The flow rate in the Moore River at Cowalla Bridge was estimated at 2 cumecs,(173ML/ day) whilst DWER data showed that the flow rate upstream at the 6170001 gauging station was 0.8 cumces (69ML/ day) and receding.

3.6. MOORE RIVER FLOOD RECORDS

The DWER gauging station locations are shown in Figure 2 and summarised in Table 2.

Table 2 – DWER Stream Gauging Sites

Site Ref	Site Short Name	Easting	Northing	Start	End
617001	Quinns Ford	387225	6571755	06/05/1969	Ongoing
617006	Bennies Road	359800	6552100	17/05/1996	01/10/2003
617015	Waterville Rd	366139	6540209	12/05/2000	Ongoing

Daily flow records (daily maximum and daily average) for Quinns Ford and Waterville Rd were partitioned into flow events (flow rate peaks separated by more than 10 days). The statistics of larger flow events are summarised in Table 3 below.

Table 3 – Flood Events

Station	617001	617015
Start	6/05/1969	12/05/2000
End	21/02/2021	19/05/2021
Days	18496	7678
Years	50.6	21.0
Max. Daily Max.	446	66
Max. Daily Mean	294	62
Events Max. >25	116	8
Events Max. >50	29	2
Events Max. >100	11	0
Events Max. >150	4	0

For Quinns Ford (617001) the event flow maximum exceedance probability (excluding low frequency events) is shown graphically in Figure 6 (excluding low frequency events for which sample period is insufficient).

Figure 6 – Flow Frequency at Quinns Ford Gauging Station

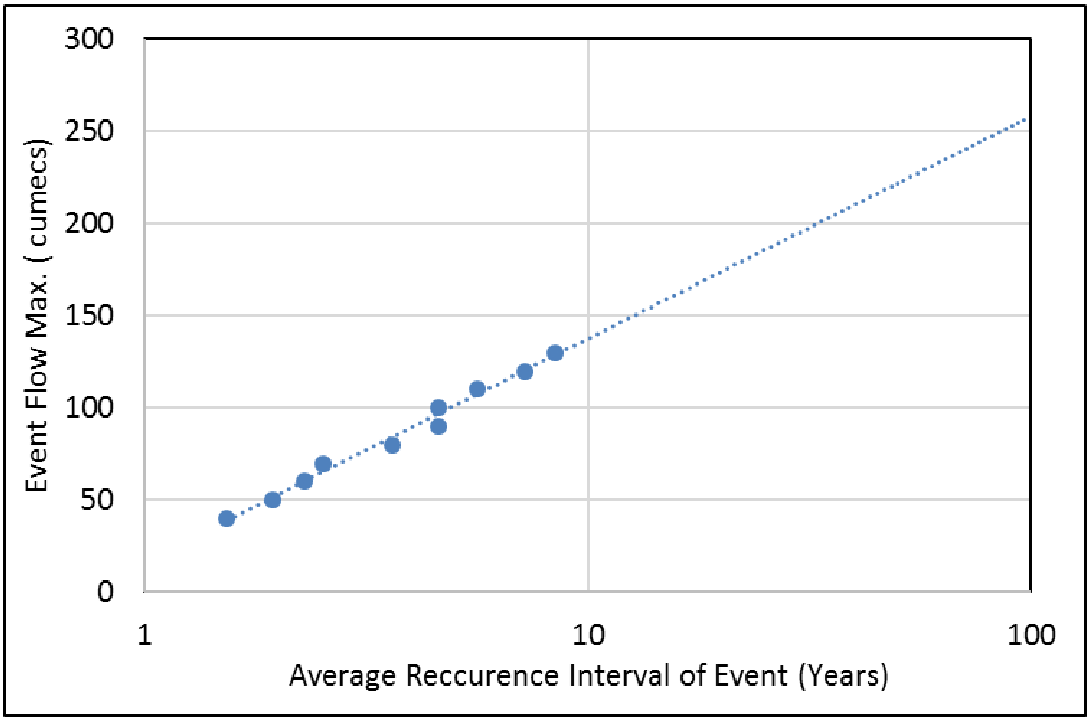


Table 4 presents a comparison of the date and magnitude of large flows at 617001/Quinns Ford (24 km upstream of the site) and 617015/Waterville Rd (29 km downstream) for the period over which both stations were mostly operational. Note the lag and attenuation of the flood peaks on the Swan Coastal Plain river reaches

Table 4 – Peak Flows at Upstream and Downstream Gauging Stations

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617001 Peak		617015 Peak		Lag (days)	Ratio (617015 / 617001)
Date	Max. Flow (cumecs)	Date	Max. Flow (cumecs)		
19/07/2000	30	21/07/2000	24	2	81%
23/08/2003	109	25/08/2003	66	2	61%
12/06/2005	33	20/06/2005	25	8	75%
19/08/2005	32	21/08/2005	24	2	76%
14/01/2006	133	16/01/2006	45	2	34%
1/08/2008	27	3/08/2008	22	2	84%
22/07/2009	35	26/07/2009	26	4	74%
20/08/2009	31	24/08/2009	26	4	84%
2/08/2015	42	6/08/2015	25	4	61%
18/07/2016	35	20/07/2016	24	2	69%
4/08/2015	33	6/08/2015	25	2	77%
5/08/2018	83	7/08/2018	57	2	68%
31/08/2018	50	2/09/2018	43	2	85%
No data reported		4/08/2021	41	n.a.	

The 617001/Quinn's Ford was not reporting from early 2021(at the time of writing), however the downstream gauge recorded a peak flow rate of 41 cumecs which has a frequency of about 1:2 years based on the longer term records from Quinn's Ford

3.7. RAINFALL RECORDS FOR LARGE FLOW EVENTS

The DWER Rainfall data relating to largest and selected very large flow events was extracted from the SILO database of daily climate statistics (Daily rainfall on a 0.05 degree interval grid) , (https://www.longpaddock.qld.gov.au/silo/gridded-data/). Daily rainfall totals for three data points : near Moora (near centroid of North Branch active catchment area), near New Norcia (East Branch) and near the project site for days preceding the peak flow at shown in Table 5

Table 5 – Catchment Rainfall for Large Flows at Quinns Ford

Date	Event Max. (cumecs)	Moora SILO Rainfall					New Norcia SILO Rainfall				
		Rainfall total (mm) for days prior to Event Peak Date									
		0	1	2	3	4	0	1	2	3	4
22/03/1999	446	0	45.9	53.8	38.5	0	0	63.4	35.9	28.7	0
12/07/1995	318	3	42.6	1.8	3.1	9.8	4.5	49.2	3.6	3.2	14.3
26/07/1983	270	15.9	24	24.8	0	0	16	28.2	37	0	0
2/08/1974	142	0.6	15.7	2.8	8.1	17.2	2.4	10.4	4.9	9.5	23.9
14/01/2006	133	3.4	66.2	5.3	0	0	0.5	69.1	0.8	0	0
25/07/1988	126	10.4	23.7	0.4	0	0	4	30.8	3.7	0	0
30/07/1975	110	18	22.1	5.2	11.8	0	6.2	20.3	7.5	21.8	0

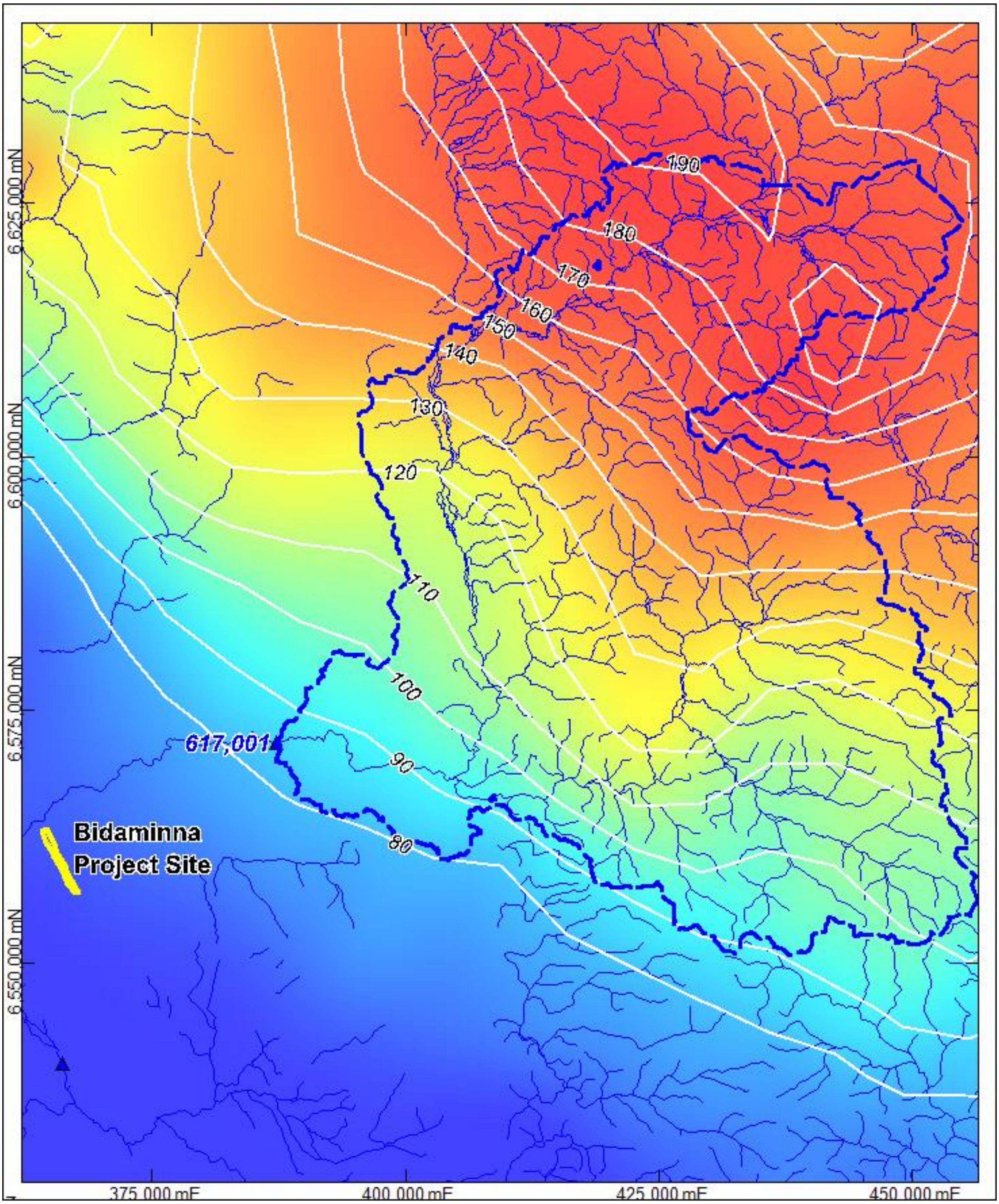
Note that, for the 24-hour time step the daily rainfall totals (24 hours to 9am , centred at 9pm the preceding day) lags the peak flow (midday) by 15 hours, in addition to the number of prior days listed in the table. The data demonstrates that the catchment response at 617001 is to event rainfall totals over about 3 days. From Table 4, there is an additional approximately 2 day lag between rainfall and peak flow at 617015/Waterville Rd.

The March 1999 flow event with a station 617001 peak flow rate of 446 cumecs on 22 March was substantially larger than any other in the record. SILO grids of 24 hour rainfall totals show that was in response to rainfall over three preceding days (72 hours to 9am on 21 March). The 72 hour totals for the active catchment area are shown in Figure 7 and are in the range 90-190. The mid-value and catchment centroid total (135 mm) equates to a return period of about 70 years (Table 1).

Considering that large parts of the catchment received >170 mm (> 1:200 year ARI) and allowing for rainfall spatial variability imposed by catchment size and shape (relative to weather systems), at the catchment scale the March 1999 rainfall approximates a 1:100 year ARI over the 72 hour duration.

Using the 24 hour data set and disaggregating the 135 mm total at the active catchment centroid across the three preceding days (19^{th} = 35 mm, 20^{th} = 45 mm and 21^{st} = 55 mm), maximum runoff catchment runoff occurred late on the 20^{th} . The 617001 (Quinns Ford) response time was 1.5-2 days and the 617006 (Bennies Rd) peak was about 1 day later.

Figure 7 – March 1999 Flood - 72 hour Rainfall Contours (mm)



4. FLOOD RISK

The March 1999 flood event approximates a 1:100 year event in terms of basin scale rainfall and flow rate frequency. The measured peak flow rate of 446 cumecs is a suitable benchmark for assessment of project flood risk from the Moore River. The River floodplain cross section directly north of the deposit was determined using the Image Resource 1 m contour data (Figure 8).

Figure 8 – Moore River North of Project Site

The flood level for this section line was calculated using the Manning Equation (Maidment, 1993) as follows:

$$Q = (A\ R^{0.67}\ S^{0.5}) / n$$

where:
Q = flow rate (cubic metres/seconds or cumecs)
A = cross-sectional area (sq. m)
n = Manning roughness coefficient
R = hydraulic radius = average depth
S = channel slope (m/m)

A peak flood level of 56 m AHD would be contained within the lower level floodplain. The cross sectional area below this level is 570 sq. m and the hydraulic radius 1.4 m. The long section channel gradient was estimated at least 1m/km. Assuming a Manning coefficient of 0.05, the flow rate is calculated at 445 cumecs similar to the peak for the March 1999 event further upstream.

On this basis it estimated that the 1:100 year level peak flow will be contained within the lower flood plain at about 56 m AHD immediately north of the deposit. Above this level the higher flood plain is very wide and flooding beyond this (i.e. as far as the Orange Springs Road at the project site) is unforeseeable. To the south of Orange Springs Road, the minimum ground level on the project site is about 57 m and hence is not prone to flooding from the Moore River.

For the remainder of the pit perimeter, stormwater ingress from extreme rainfall can be prevented and diverted by an eastern bund to a height of at least 0.5 m above ground.

5. ENVIRONMENTAL RISKS AND IMPACTS ASSESSMENT

The project site is elevated and well drained. The site is not prone to flooding from the Moore River.
No discernible hydrological features will be impacted by the mine as it progresses along the deposit. At the broad scale, the project does not pose a risk to the downstream surface water environment.

Potential point sources of contamination are excluded from this assessment and will need to be identified and managed.

The post closure rehabilitation should restore the background surface elevation such that the westward slope is continuous across the site.

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Report Limitations

MWES Consulting (MWES) have prepared this report for the use of Image Resources in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty expresses or implied, is made as to the professional advice included in this report.

MWES has made no independent verification of this information beyond the agreed scope of works and MWES assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information reviewed at the time of our investigations that information contained in this report as provided to MWES was false.

This report was prepared in June 2021 and is based on the conditions encountered and information reviewed at the time of preparation. MWES disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any context.
Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels; can change in a limited time. Therefore, this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.