Rio Tinto

Resource Development

Marillana Creek regional flow balance and catchment hydrology

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Introduction

The Marillana Creek catchment is located in the eastern Pilbara of Western Australia, approximately 90 km northwest of Newman. The principal land use in the region is pastoral cattle production, with a long history of cattle grazing. Other regional land uses include the traditional use of land by Aboriginal groups, tourism, conservation and mining.

Mining activities, such as the Rio Tinto Iron Ore Hamersley Iron (RTIO) Yandicoogina and BHPBilliton IronOore (BHPBIO) Yandicoogina mining operations, focus on the excavation of the Greater Yandicoogina orebody, a continuous Tertiary channel iron deposit (CID) palaeochannel. The CID consists mainly of coarse sand to gravel size pisolitic deposits, which have subsequently been cemented in a goethite matrix. The CID follows a similar flow path to contemporary Marillana Creek, such that the deposit is positioned adjacent to and crosses beneath Marillana Creek at several locations.

The mine voids will be positioned adjacent to and intercepting local tributaries to Marillana Creek, Marillana Creek floodplain and possibly Marillana Creek proper; such that some of the voids may collect or divert tributary flows, while others may only collect local surface water runoff and incident rainfall. Due to the low waste to ore ratio, the cessation of mining will leave of a series of voids where mining has been undertaken. The mine voids may be partially backfilled with waste material, may expose the groundwater table or they may be partially filled to the surface to restore surface water flows. Consequently, when mine closure and rehabilitation activities are completed the hydrological regime of the Marillana Creek catchment will be altered.

This report describes the surface water hydrological regime in Marillana Creek pre-mining. One cumulative impact case study for a theoretical post-mining landscape is also presented to highlight the changes to the hydrological regime that are likely to result from mining within the Marillana Creek catchment.

Regional setting

1. Catchment description

The Marillana Creek catchment (Figure 1) occupies 2,230 km^2 and extends west from the confluence with Weeli Wolli Creek to within about 20 km of the Great Northern Highway. The headwaters rise from the high relief areas of Hamersley Range where the Creek drains in an east and north easterly direction into the Munjina Claypan. The Munjina Claypan has an internally draining catchment area of approximately 274 km^2. It is subject to periodic inundation following rainfall events and has the potential to retain surface water flows for lower magnitude flood events (≤ 1 in 10 year average recurrence interval (ARI) was calculated as described later in the report). Surface water in excess of the internal holding capacity of the basin flows south east past the Flat Rocks gauging station, forming Marillana Creek proper and the start of the lower Marillana Creek catchment.

The lower Marillana Creek drains in an easterly direction through the existing BHPBIO and RTIO Yandicoogina operations. The flow path is a topographically controlled creek with a flood plain 70 m to 150 m wide. Within the flood plain sections of the creek are braided with a dominant low flow channel naturally forming only in the lower third of the catchment. The flood plain widens to flat 400 m to 600 m wide downstream of the RTIO Yandicoogina Junction Central (JC) and Junction South East (JSE) deposits (the active mining areas), before converging with Weeli Wolli Creek, 8 km before emerging into the Fortescue Valley.

The Marillana Creek sub-catchment encompasses over half of the larger Weeli Wolli Creek catchment, and is believed to contribute approximately 50 percent of the flood flow into the Fortescue Valley via Weeli Wolli Creek[1]. Flow into Fortescue Valley terminates within the upper Fortescue River catchment at Fortescue Marsh, an extensive saline wetland.

Major tributaries of the Marillana Creek catchment include Iowa Creek, Lamb Creek, Phil's Creek and Yandicoogina Creek. As for most parts of the Pilbara, the normal condition for these watercourses is dry. Creek flow is ephemeral, occurring only after significant and intense rainfall events. However, there is evidence of subsurface flow through the creek alluvials, with springs located in the upper catchment areas of the lower catchment and hydraulic connection of the regional groundwater table to the Marillana Creek alluvials (Kirkpatrick and Dogramaci, 2009) supplying subsurface base flow to support water sensitive vegetation species such as *Melaleuca argentea* (Cadjeput) (Biota, 2010).

2. Sensitive areas and receivers

Locations with heritage or environmental significance are colloquially referred to as sensitive areas or sensitive receivers. These are locations that require special consideration of the direct and cumulative impact of all mining activities due to their high heritage or environmental value. Sensitive areas also includes important infrastructure, such as powerlines, which if disturbed or damaged could impact on personal or environmental health and safety.

With respect to surface water, sensitive areas may be impacted where modifications to the creek morphology or hydrologic regime adversely influence the significance of the site; For

[1] This is difficult to verify due to the absence of long term, coincident gauging in Fortescue Marsh and its tributaries.

example, where a minor change in topography diverts flows to flood a previously undisturbed area. Thus modelling activities presented in this report are designed to ensure the surface water (hydrological and hydraulic) conditions are resolved at these locations in order to assess the impact or risk. The sensitive areas identified around RTIO Yandicoogina sites, considered at time of writing this report, are illustrated in Figure 1.

Numerous heritage sensitive areas were identified following archaeological and ethnographic surveys in close proximity to the mine area and adjacent to creek lines. The impact of surface water management activities on heritage sites will be undertaken on a site specific basis at each stage of development, prior to disturbance, throughout the life of the mine in accordance with the Yandicoogina Cultural Heritage Management Plan (CHMP). For more information on the significance of the sites please refer to the CHMP.

No Threatened Ecological Communities listed under the Environmental Protection and Biodiversity Conservation Act 1999 or by CALM are known to occur in the immediate Yandicoogina mine area.

In the Marillana, Yandicoogina and Weeli Wolli Creek systems, unconfined alluvial aquifers recharged by creek floodwater support significant stands of riparian vegetation, including *Eucalyptus camaldulensis*, *E. victrix* and *M. argentea*. These vegetation communities are somewhat dependent on water stored within the alluvial aquifer, sections of which are dewatered as part of the BHPBIO Yandicoogina and RTIO Yandicoogina mining operations.

Currently, abstracted groundwater is discharged upstream from both mines to supplement water supply to communities impacted by dewatering activities. In order to minimise impacts to these sensitive receivers it is necessary to maintain water supply by irrigating vegetation along Marillana Creek. Within the RTIO tenements, irrigation activities are performed by discharging abstracted groundwater into the Marillana Creek flood plain adjacent to the JC and JSE deposits. Future similar impacts are likely to be ameliorated by discharging abstracted, surplus groundwater adjacent to the Junction South West (JSW) and Oxbow deposits. The result of dewatering discharge activities have not been assessed in this document.

Impacts to infrastructure are considered with each local modification to the topography, as part of mine planning design review procedures.

As part of the Rio Tinto *Way We Work*, the management and impact of proposed mine activities on sensitive areas in or adjacent to Pilbara creeks are considered as part of the option analysis. This ensures community expectations are embedded into the options for managing floods or modifying the creek, as part of the site surface water management.

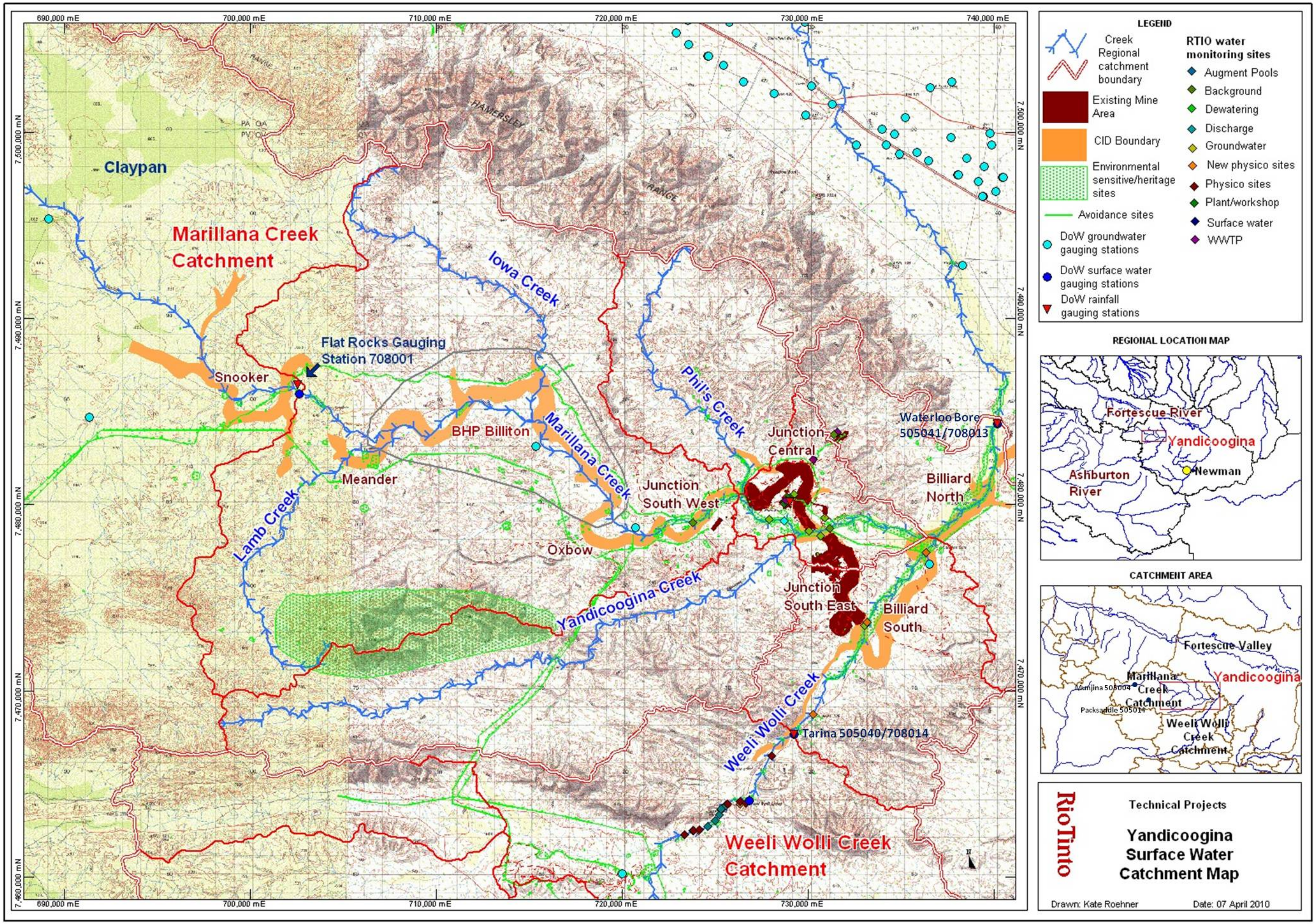

Figure 1: Catchment overview of Marillana Creek.

3. Rainfall

3.1 Recorded rainfall

In general, Pilbara rainfall is characterised by low intensity, frequent events related to localised thunder storms and tropical upper air disturbances, and occasional high intensity falls associated with tropical cyclones. Rainfall data relevant to the Marillana Creek catchment and surrounding environs has been recorded at gauges as illustrated in Figure 1 within the catchment at:

- Flat Rock (Western Australian Department of Water (DoW) rainfall gauge 505011),
- Munjina (DoW rainfall gauge 505004),
- Packsaddle (DoW rainfall gauge 505014), and
- RTIO Yandicoogina mine site,

Outside the catchment (up and downstream respectively of the confluence with Weeli Wolli Creek) at:

- Tarina (DoW rainfall gauge 505040), and
- Waterloo Bore (DoW rainfall gauge 505041).

A summary of the data from the individual rainfall gauges is presented in Appendix A.

Using the Köppen classification scheme[2], based on temperature and rainfall, the Marillana Creek catchment is described as grassland: hot, persistently dry. As illustrated by summary Figures 2 and 3, rainfall is episodic and highly variable between years. The majority of rainfall occurs during the hottest months, between December and March. Winters are dry and mild in comparison with lighter, winter rainfall expected in June/July each year.

Across the rainfall gauges the recorded individual annual rainfall variability is very high, with an average differences of 100 mm or ~25% of the annual average rainfall noted between yearly totals. The averaged annual rainfall for the above gauges is observed to increase by 1.5 mm per year (Figure 4) over the 35 year period 1975 to 2009 with biennial fluctuations (+200/-130 mm) in annual rainfall. Beyond the simple linear increase, decadal rainfall averages exhibit a 28 year cyclic pattern, with decadal average rainfall peaking in 1980 and 2006, with an associated trough in 1993. If this trend continues it suggests the catchment can expect suppressed rainfall for the next 14 years.

[2] http://www.bom.gov.au/lam/climate/levelthree/ausclim/koeppen2.htm

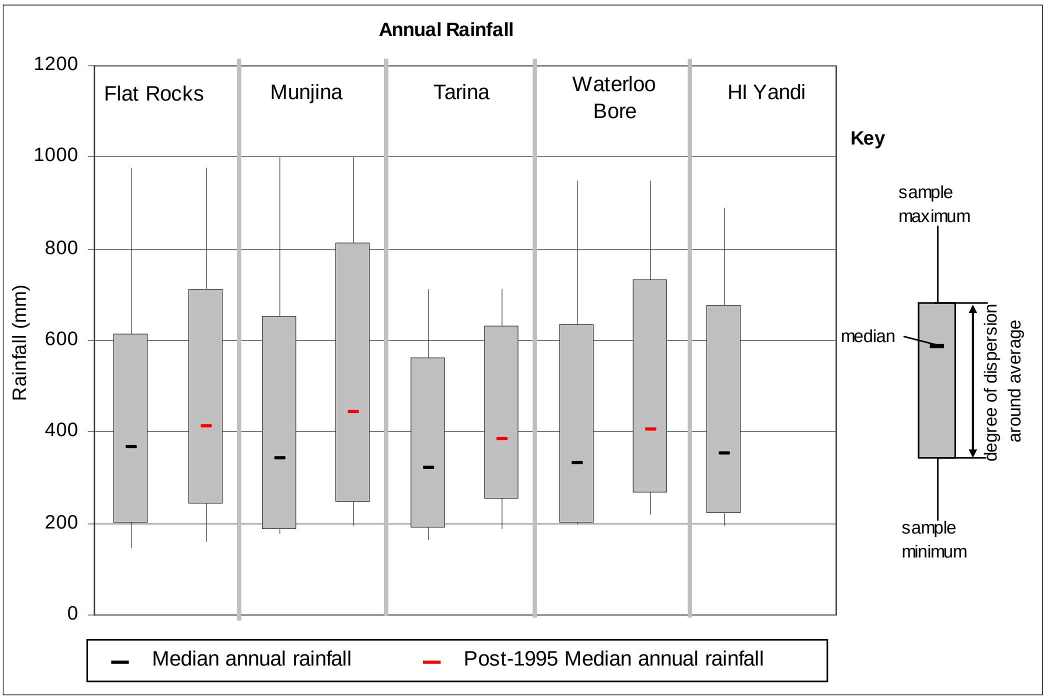

Figure 2: Annual rainfall data statistics for selected rainfall gauging stations.

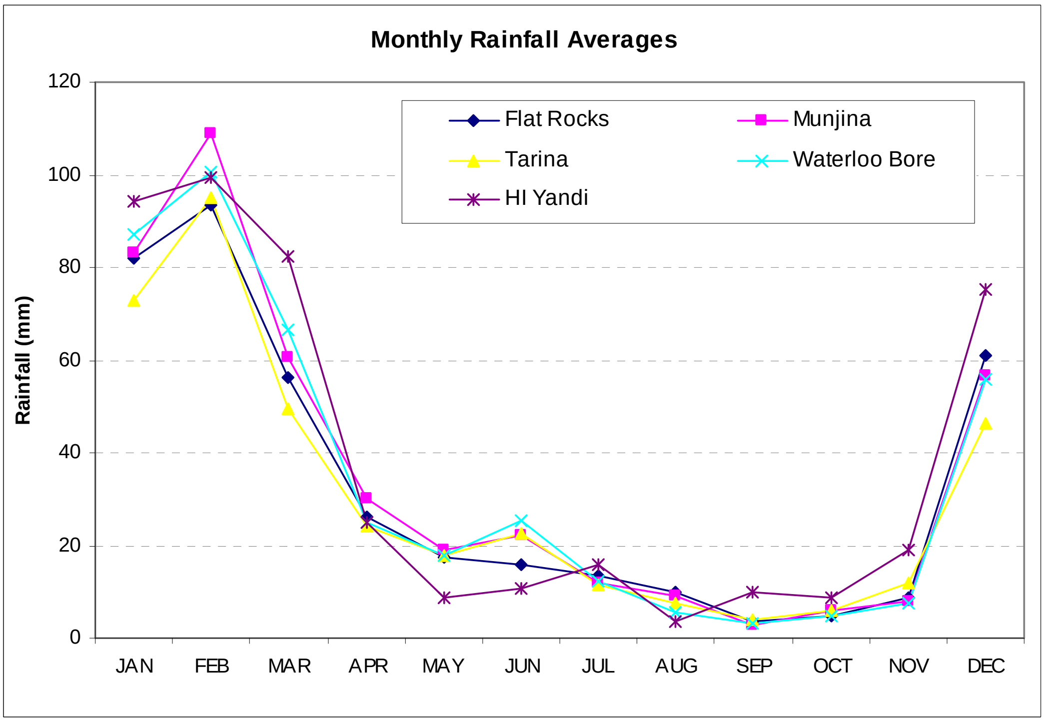

Figure 3: Average monthly rainfall for selected rainfall gauges.

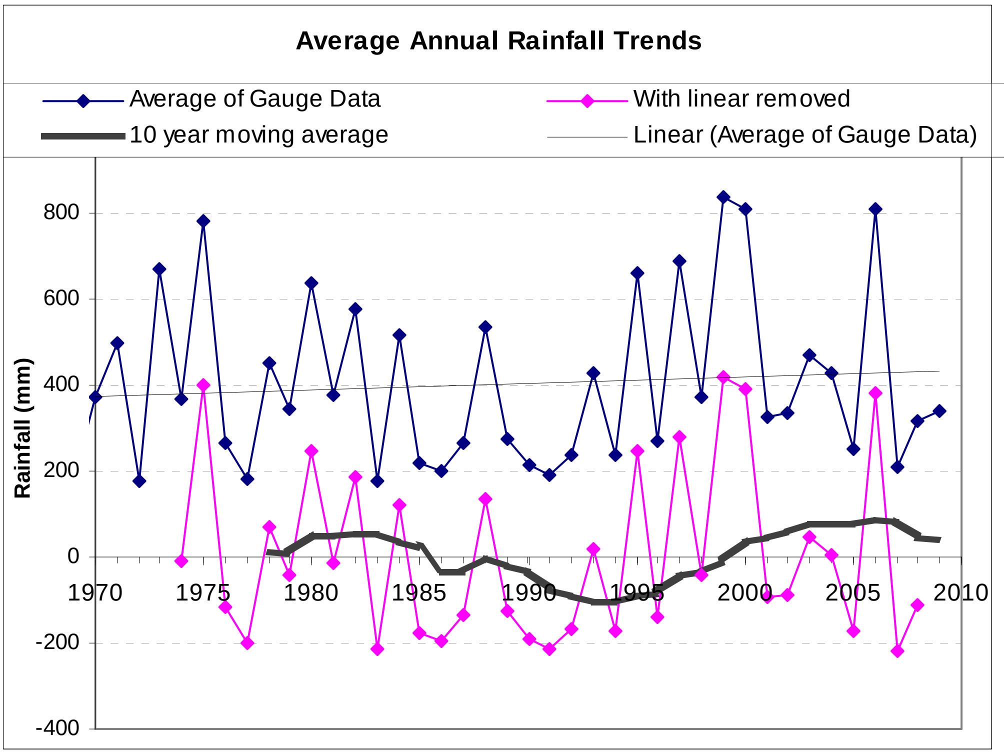

Figure 4: Trends in rainfall data for the Marillana Creek catchment rainfall data.

3.2 Cyclonic rainfall

At least eight cyclones have passed within 50 km of the catchment within the Bureau of Meteorology cyclone path recording period (1906 to 2010), producing larger than normal monthly rainfall as listed in Table 1.

Table 1: Tropical cyclones that have passed within 50 km of the Marillana Creek catchment with corresponding monthly rainfall from Munjina and Flat Rocks rainfall gauges.

Cyclone	Monthly rainfall (mm)			
	Munjina rain gauge		Flat Rocks rain gauge	
	Cyclone	Median	Cyclone	Median
Unnamed in February 1925	N/A	N/A	N/A	N/A
Unnamed in January 1939	N/A	N/A	N/A	N/A
Unnamed in December 1954	N/A	N/A	N/A	N/A
Unnamed in February 1957	N/A	N/A	N/A	N/A
Joan in March 1965	N/A	N/A	N/A	N/A
Kerry in January 1973	214.5	49.9	39.7	48.3
Dean in January/February 1980	172.6	79.4	224	80.9
Connie in January 1987	125.2	49.9	90.3	48.3
Rachel in January 1997	256.8	49.9	307	48.3
John in December 1999	240	30.3	240	36.3
Wylva in February 2001	107.4	79.4	106.2	80.9
Chris in February 2002	193.4	79.4	189.5	80.9

Large cyclones that passed more than 100 km away from the catchment, such as Joan in November 1975 which produced 549.1 mm at Munjina, have also generated significant rainfall.

3.3 Daily rainfall

Generally rainfall is unreliable and highly variable, with a large percentage of the annual rainfall occurring over short periods associated with thunderstorm activity and occasional cyclonic lows moving inland from the coast. Daily rainfall statistics are presented in Table 2.

Table 2: Daily rainfall statistics by month, based on RTIO Yandicoogina rainfall gauge 1998 to 2009.

Month	Probability of rainfall occurring				Rainfall statistics when rain occurs		
	Min days	Max days	Mean days	Standard deviation	Median	Standard deviation <10 mm	Standard deviation
January	3	31	10.0	5.4	2.3	2.5	23.3
February	5	28	11.0	4.7	3.4	2.8	14.7
March	2	30	9.0	5.3	3.2	3.0	16.8
April	0	20	6.0	3.4	2.2	2.4	8.3
May	0	8	1.5	1.6	1.8	2.6	7.8
June	0	12	2.0	2.4	1.9	2.6	5.5
July	0	13	1.5	2.8	1.2	2.1	15.3
August	0	5	0.0	1.3	1.7	3.0	5.0
September	0	5	0.0	1.2	0.7	0.5	18.3
October	0	14	1.5	3.1	0.9	2.2	6.5
November	0	17	4.5	3.1	1.2	2.5	6.9
December	0	23	6.0	4.3	2.2	2.7	33.0

A simple statistical analysis of the 24 hour (daily) rainfall shows that:

- 50% of 24 hr rainfall was ≤2 mm
- 80% of 24 hr rainfall was ≤10 mm;
- 90% of 24 hr rainfall was <20 mm;
- 98% of 24 hr rainfall was <50 mm; and
- 3 events in 11 years with a daily rainfall total >100 mm.
- 53% of the daily rainfall is >5% of the total monthly rainfall;
- 25% of the daily rainfall is >20% of the total monthly rainfall; and
- 10% of the daily rainfall is >50% of the total monthly rainfall.

3.4 Design rainfall

3.4.1 ARR Intensity-Frequency-Duration Design Analysis

Intensity-frequency-duration (IFD) curves were calculated for the Yandicoogina area following the Australian Rainfall and Runoff (ARR)(2001) guidelines (Figure 5). The curves provide estimates of rainfall intensities and durations for individual annual recurrence intervals (ARI) rainfall events.

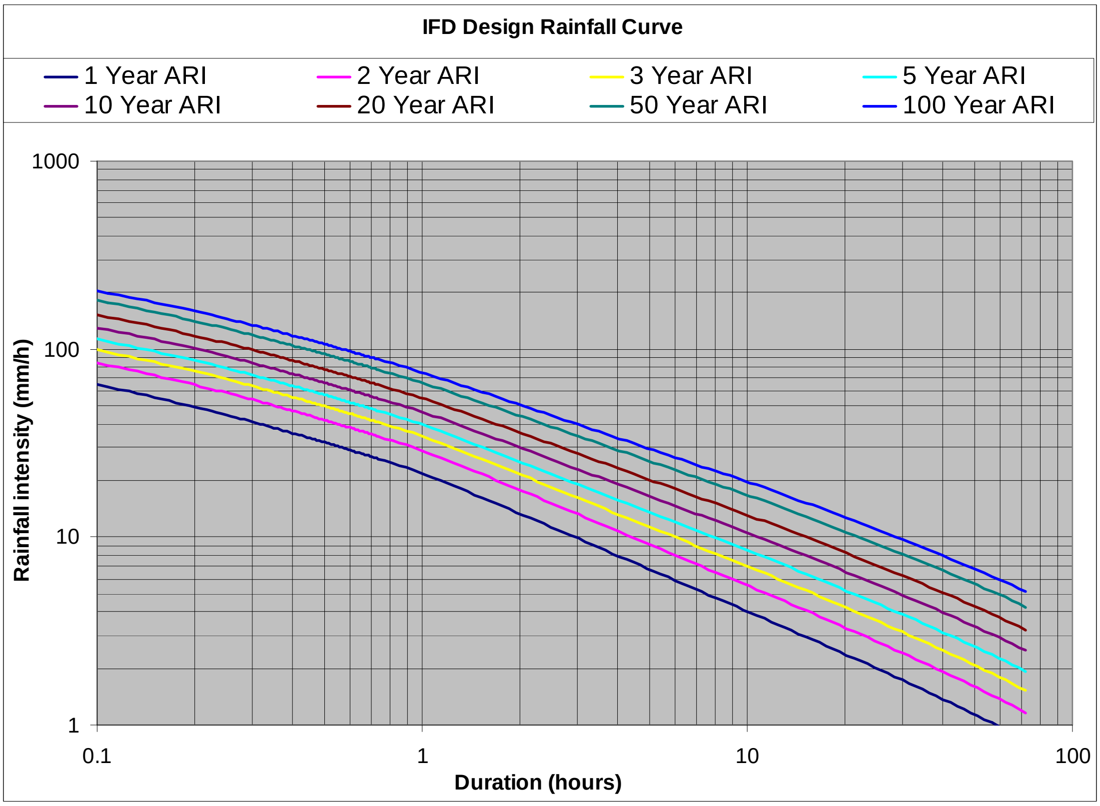

Figure 5: Intensity-Frequency-Duration (IFD) Design Rainfall Curves for Yandicoogina.

ARI (Average Recurrence Interval) is the average or expected value of the period between the exceedance of a given event. This period is itself a random variate. Annual exceedance probability is the probability of a given event within a period of one year.

For the purpose of following engineering protocol, IFD values generated in accordance with ARR guidelines are applied to engineered structures.

3.4.2 CRC FORGE methodology rare design rainfalls

Flood design criterion in Australia is guided by ARR (2001). However research published by the Water Resources Division, Department of Environment West Australia (2004)[3] more accurately reflects Western Australian hydrometeorological conditions for rare design rainfalls for annual exceedance probability (AEP) of 0.02 (2%) to the credible limit of extrapolation.

For the location latitude -22.7284, longitude 119.0563, the approximate centre of the Marillana Creek catchment, the following areal design rainfalls (Table 3) were extracted from the published CRC FORGE (Durrant and Bowman, 2004) values.

For the purpose of assessing environmental values, rainfall values generated in accordance with CRC FORGE methodology are applied for the most accurate representation of natural condition.

[3] The CRC FORGE methodology published by the Water Resource Division, Department of Environment Western Australia is a modification of the CRC FORGE methodology developed by Nandakumar et al. (1997).

Table 3: CRC FORGE areal rainfall quantiles (in mm) and extrapolated areal rainfall quantiles (in mm) to peak maximum precipitation (PmP) AEP 0.0005.

AEP	Duration (hour)							
	24	30	36	48	60	72	96	120
0.02	179	191	202	221	228	235	237	241
0.01	200	214	227	249	256	262	268	271
0.005	233	250	265	290	298	305	311	314
0.002	282	303	321	353	362	369	376	379
0.001	324	348	369	405	415	424	431	435
0.0005	371	399	423	463	475	484	492	496

4. Evaporation

The average annual pan evaporation (Bureau of Meteorology, Australia) is approximately 3,200 mm. Pan evaporation rates are indicative of the amount of water evaporating from bare ground or open water with a constant water supply.

RTIO Yandicoogina site weather station sheltered (dry-bulb) potential evaporation statistics collected between April 2004 and November 2008 are shown in Table 4. The average annual evaporation rate was 1,800 mm/year (site dry bulb data). This value represents an evaporation rate that would be similar to the evaporation rate of a dam sheltered from winds.

Table 4: Evaporation rates (site dry bulb data) (mm/day) for Yandicoogina (2004 to 2008)

Month	Average (mm/day)	Standard deviation (mm/day)	Minimum (mm/day)	Maximum (mm/day)
January	4.1	2.9	0	17.1
February	5.3	2.4	0.3	13.9
March	4.8	2.1	0.3	12.4
April	5.4	3.3	0	17.7
May	5.1	2.3	0.6	13.5
June	5.4	2.7	1.2	14.9
July	4.9	2.5	0	13.8
August	3.7	2.1	0	13.2
September	4.5	2.7	0	13.5
October	4.7	3.5	0	16.3
November	5.7	3.3	0.5	16.3
December	5.4	3.2	0	17.3

Evaporation from land surfaces covered by vegetation is better estimated by evapotranspiration. The average point potential evapotranspiration (ET) rate estimated for the region by Bureau of Meteorology (BoM) is approximately 3000 mm/year. Point potential ET is the ET that would take place, under the conditions of unlimited water supply, from an area so small that the local ET effects do not alter local air mass properties. Based on the information provided by BoM, point potential ET may be taken as a preliminary estimate of evaporation from small water bodies such as shallow water storages, which may include surface water pools within a creek system.

All of the evaporation rates greatly exceed the mean annual rainfall, keeping the landscape typically arid.

4.1 Climate change

A climate change study for the Pannawonica to Yandicoogina region was conducted in 2007 by independent consulting group Environmental Modelling and Prediction P/L Australia, exclusively for the internal use of Rio Tinto. The results predicted a reduction in annual rainfall of 31% for the period 1970 to 2079. The impact is likely to be felt more in the increasing frequency of drier years with the 12 driest years predicted by the ensemble mean of the climate models to all occur in the future climate period beyond the year 2035 with most of these beyond 2050.

The climate modelling predicted a decline in the number of tropical cyclones passing within 150km of the mine site in the historical period starting in 1970, from 3.0 per decade down to around 2.0 tropical cyclones per decade by the start of the 2060 decade. While the impact of a tropical cyclone or tropical depression could still trigger significant river and flash flood events in the future, it is likely that these events will gradually become spaced further apart.

The climate change modelling predicts temperatures in the Yandicoogina region to continue to increase, with maxima temperatures increasing by 0.047°C per year, minima temperatures increasing by 0.041°C per year and mean temperatures increasing by 0.042°C per year. Increasing temperatures and reduced annual rainfall as a result of climate change are expected to contribute to reduced water availability. This is likely to increase the frequency of multiple dry years in succession (drought), with rainfall reductions across all months leading to annual rather than seasonal water availability problems.

The climate modelling also predicted a potential increase in severe thunderstorm activity in the form of severe wind squalls. The increase in severe thunderstorms implies the potential for increasing storm intensity, leading to the frequency of flash floods increasing over time.

5. Gauging data

Marillana Creek contains one gauging station, Flat Rocks (WRC number 708001), located approximately 25 km upstream of the Oxbow and JSW deposits and upstream of the BHPBIO Yandicoogina mine. The Flat Rocks station has been the subject of several studies including Woodward-Clyde (1995) and Gilbert and Associates (2003) *in* BHPBilliton (2004, 2005). Flavell (1999) *in* BHPBilliton (2004) noted the catchment upstream of the gauging station exhibits hydrological characteristics inconsistent with regional trends. This is likely to be the result of a small flood retention area, the Munjina Claypan, upstream of the gauging station. Consequently catchment characteristics derived from the Flat Rocks gauge, which is positioned downstream of the Munjina Claypan, is unlikely to reflect regional trends.

Daily flow data for the gauging station was available for the period 16 August 1967 to 19 May 2005 (with occasional missing data). The rating curve for the Flat Rocks gauging station produced by the Western Australia Department of Water is shown in Figure 6.

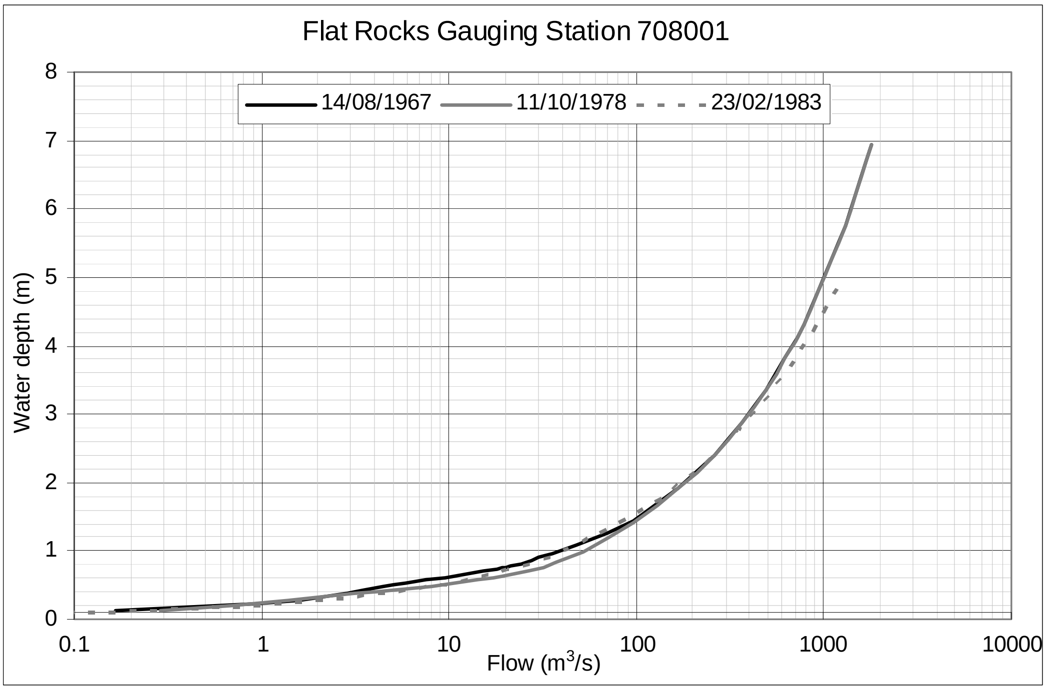

Figure 6: Flat Rock gauging station rating curve.

6. Flows due to cyclonic activity

There is a common misperception in the Pilbara that cyclonic activity produces creek flow. Table 5 lists cyclones that have passed through or within 100 km of the Marillana Creek Catchment since 1970 and the resulting peak flow events as recorded at Flat Rocks. As Table 5 shows, the presence of a cyclone alone does not necessarily indicate either excessive rainfall (rainfall greater than a normal storm event) or trigger a flood event. Equally, the rainfall volume (mm) received does not define the magnitude of the peak flow (m^3/s) and is not proportional to the total volume (l) of water generated.

Table 5: Tropical cyclone occurrence within 100 km of the catchment with associated rainfall and flow characteristics.

Tropical Cyclone	Monthly rainfall (mm)	Peak flow rate (m3/s)	Monthly volume (ML)
SheliaSophie in January 1971	N/A	25	317
Kerry in January 1973	39.7	796	42,338
Joan in December 1975	478.5	1,327	14,4287
Amy in January 1980	221.9	N/A	0
Dean and Enid in January/February 1980	224.0	N/A	225
Emma in December 1984	83.5	23	206
Connie in January (February) 1987	90.3 (101.9)	27 (58)	686 (1096)
Kirsty in March 1996	15.2	0	0
Rachel in January (February) 1997	307 (208.4)	319 (76)	11,940 (8,043)
John in December 1999	240.0	503	19,623
Wylva in February 2001	106.2	39	1,196
Chris in February 2002	189.5	127	1,948
Unnamed in January 2003	233.5	726	29,536

As an example of the complexity of the rainfall-flood relation, in December 1999 following Tropical Cyclone John the rainfall gauge at Flat Rocks recorded 240 mm of rainfall for the month, a peak flow event of 503 m^3/s and flood volume of 20 Gl. In the subsequent 3 months, an additional 776 mm of rainfall was recorded, however, the peak flows were all less than 140 m^3/s and the total additional 3 month flood volume was less than 18 Gl.

7. Flood frequency analysis

Flood frequency analysis (FFA) of annual wet season (October to September) peak flows was undertaken on the Flat Rocks peak annual flow data. The analysis was performed using the US Army Corps of Engineering HEC-SSP Statistical Software Package following the United States of America Bulletin17b methodology. The annual peak flows are presented in Table 6 and the results of the analysis are presented in Figure 7 and Table 7.

Note many of the flood peak values have been determined from theoretical rating curves.

Table 6: Flat Rocks peak annual flows (derived from hourly instantaneous flow measurements).

Wet Season	Date	Peak (m3/s)	Wet Season	Date	Peak (m3/s)
1968	Feb-1968	137	1990	Jan-1990	92
1969	Feb-1969	81	1991	Jun-1991	1
1970	May-1970	0.4	1992	Jan-1992	78
1971	Feb-1971	375	1993	Jan-1993	66
1972	Feb-1972	4	1994	Dec-1993	56
1973	Jan-1973	796	1995	Feb-1995	865
1974	Dec-1975	1327	1996	Apr-1996	6
1975	Feb-1975	3	1997	Jan-1997	319
1976	Mar-1976	369	1998	Oct-1997	0
1977	Mar-1977	3	1999	Dec-1998	83
1978	Jan-1978	174	2000	Dec-1999	503
1979	Mar-1979	119	2001	Feb-2001	39
1980	Mar-1980	17	2002	Feb-2002	127
1981	Jan-1981	31	2003	Jan-2003	726
1982	Feb-1982	106	2004	Feb-2004	72
1983	Apr-1983	81	2005	Nov-2004	4
1984	Mar-1984	209	2006	Jan-2006	102
1985	Mar-1985	85	2007	Mar-2007	28
1986	Feb-1986	5	2008	Jan-2008	191
1987	Feb-1987	58	2009	Mar-2009	88
1988	Feb-1988	194	2010	Feb-2010	3
1989	Apr-1989	22			

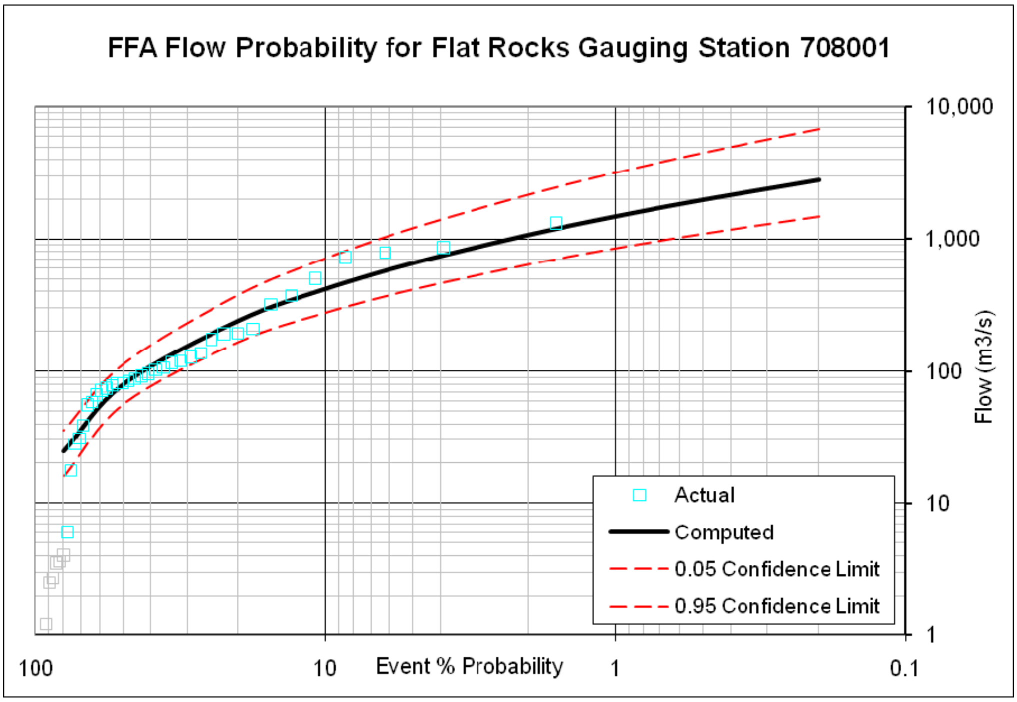

Figure 7: Flood frequency analysis of Flat Rocks gauging station. Peak flows less than 5 m³/s were considered to be outliers.

Table 7. Flood frequency analysis values based on peak hourly flow rates at Flat Rocks gauging station as presented in Figure 7.

Average recurrence (years)	Exceedance chance (%)	Computed curve (m^3/s)	0.05 confidence (m^3/s)	0.95 confidence (m^3/s)
500	0.2	2,800	6,800	1,500
200	0.5	2,000	4,500	1,100
100	1	1,500	3,200	860
50	2	1,100	2,200	650
20	5	660	1,200	420
10	10	420	710	280
5	20	240	380	170
2	50	79	110	56
	80	25	36	16
1.1	90	13	20	8
	95	8	12	4
	99	3	5	1

8. Existing flood conditions

8.1 Modelling approach

The RTIO Yandicoogina deposits are positioned adjacent to and extend under Marillana Creek. A flood plain study was undertaken to define the 1 in 100 year ARI flood plain extents and flow characteristics of Marillana Creek adjacent to these deposits.

Floodplain hydraulics were assessed using the steady state model in Hydrologic Engineering Centers River Analysis System (HEC- RAS) one-dimensional hydraulic computation program for networked natural and constructed channels, interfaced with the geographical information system ArcGIS through HEC-GeoRAS. The programs were used to calculate flood velocities, flood water levels and subsequent floodplain extents for the 100 year peak flow volume of 2500 m^3/s. This peak flow volume was derived using the methodology described in Section 9.

The digital terrain input for the model was generated from detailed 1 m contour data and supplementary point elevation data, extracted from August 2004 and August 2008 survey information. In areas where 2008 data were available, the older 2004 data was clipped away and replaced with the newer data to provide a better representation of the current mine development and infrastructure locations. The extent of the 2004 and 2008 topographic surveys is illustrated in Figure 8. It should be noted that the topographical data of the more recent mine and road infrastructure, including the BHPIO railway bridge, were not captured by the 2004 data. As a result, additional, interpolated elevation values were required to generate a representative digital terrain model.

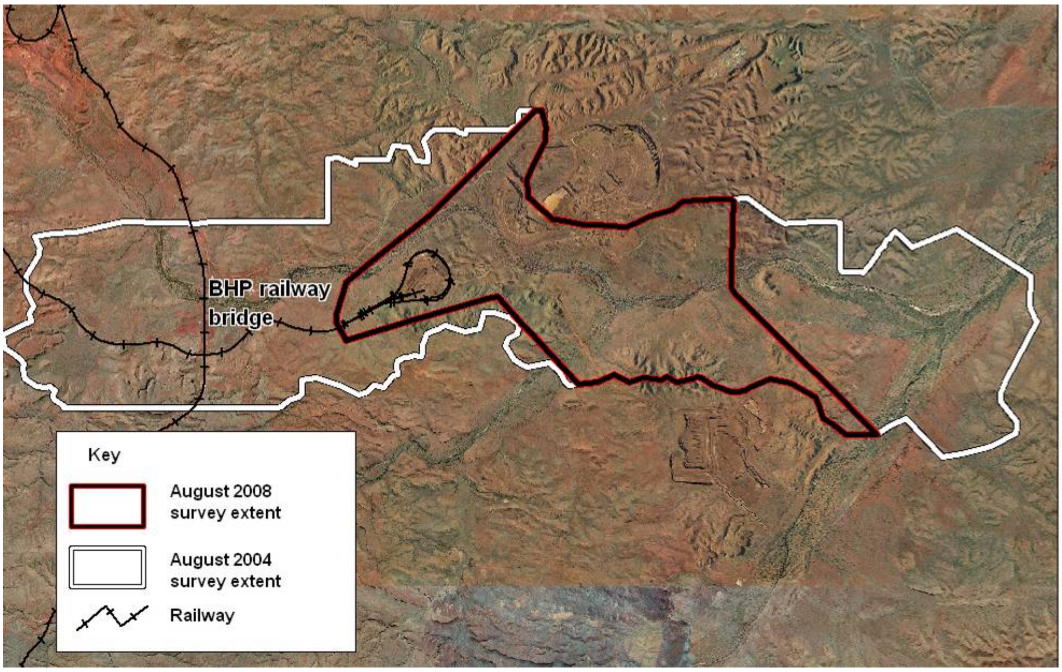

Figure 8: Extents of the 2004 and 2008 topographic survey

Polygons of Manning's (surface roughness) coefficient (*n*) were delineated (Figure 9) to map the change in surface roughness across the floodplain. The Manning's coefficient values range from 0.022 (representing built-up areas and road infrastructure) to 0.065 (representing more vegetated conditions within the creek channel). The change in surface roughness were captured by the cross sections and imported into the model.

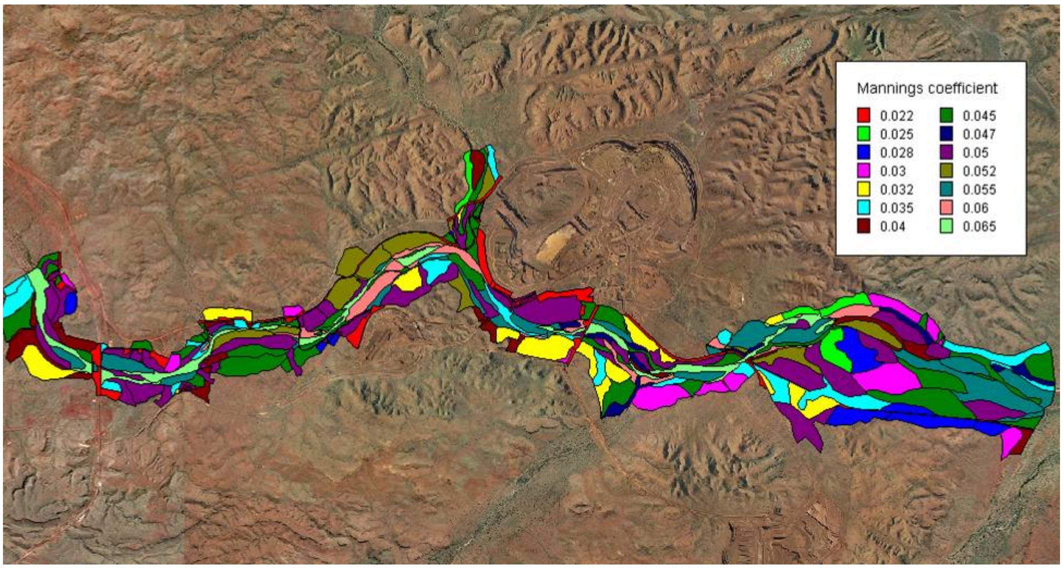

Figure 9: Manning's coefficient across the Marillana Creek floodplain.

Existing bridge crossings along Marillana Creek, including the BHP rail bridge, were incorporated into the model. Configurations of the bridge crossings were extracted from topographic survey information where available; otherwise were estimated from aerial photographs. Bridge locations along the Creek are illustrated in Figure 10.

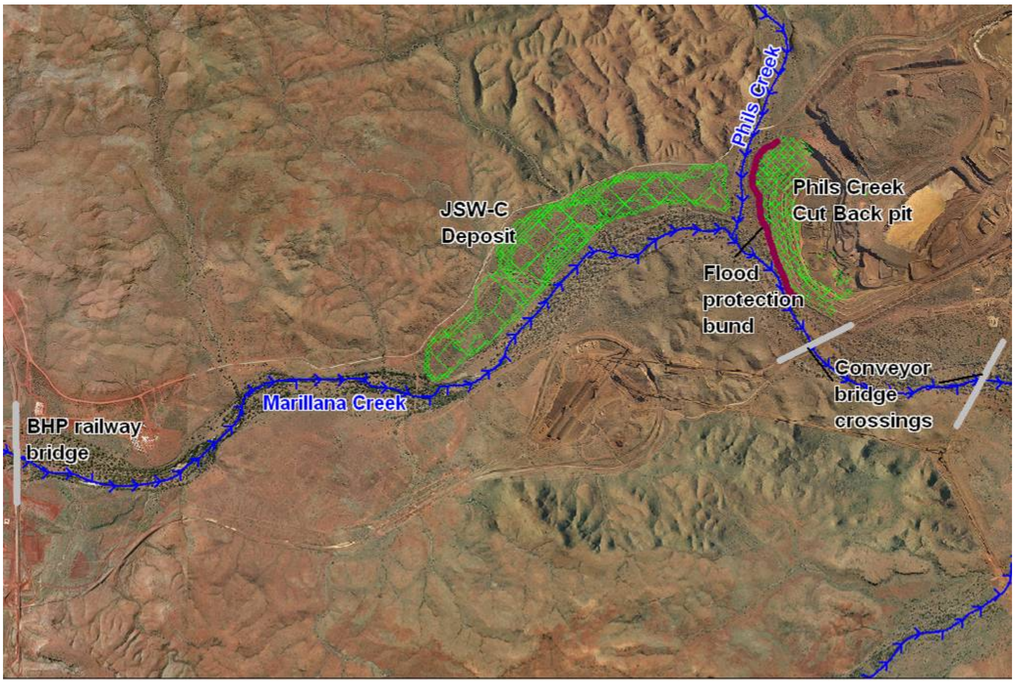

Figure 10: Flood protection bund and bridge crossing locations (green shaded areas illustrate the Yandicoogina 5 year mine plan)

A simple levee of infinite height was positioned along the edge of the Phils Creek cut back pit (Figure 10), to represent the Phils Creek cut back flood berm currently under construction.

8.2 100 year ARI hydraulic conditions

The 100 year flood extent and the average cross sectional velocity distribution along Marillana Creek and Phil's Creek are illustrated in Figure 11. Local catchment floodplains, including the Yandicoogina Creek catchment, were not incorporated into the model. Back water development was noted to occur at the confluences, contributing to the width of the floodplain. The average maximum channel depth for a 100 year ARI flood event was 4.2 m with an average cross sectional velocity of 1.8 m/s. Velocity increased to nearly 5 m/s at bridge crossings due to constriction of flows and alteration of the flow directions by bridge piers and embankments.

As illustrated in Figure 11, the conceptual pit outline of the RTIO Yandicoogina Oxbow deposit is outside the Marillana Creek 100 year ARI flood plain. However, this deposit straddles a tributary to Marillana Creek that was not modelled in this assessment.

The northern tip of a RTIO Yandicoogina JSW-A conceptual pit outline is located within of the 100 year floodplain. Within this area, the maximum modelled water depth was 2.5 m with a maximum velocity of 1.3 m/s along the edge of the proposed pit. A flood protection levee along the north eastern pit edge of JSW-A will be required to prevent flooding from Marillana Creek.

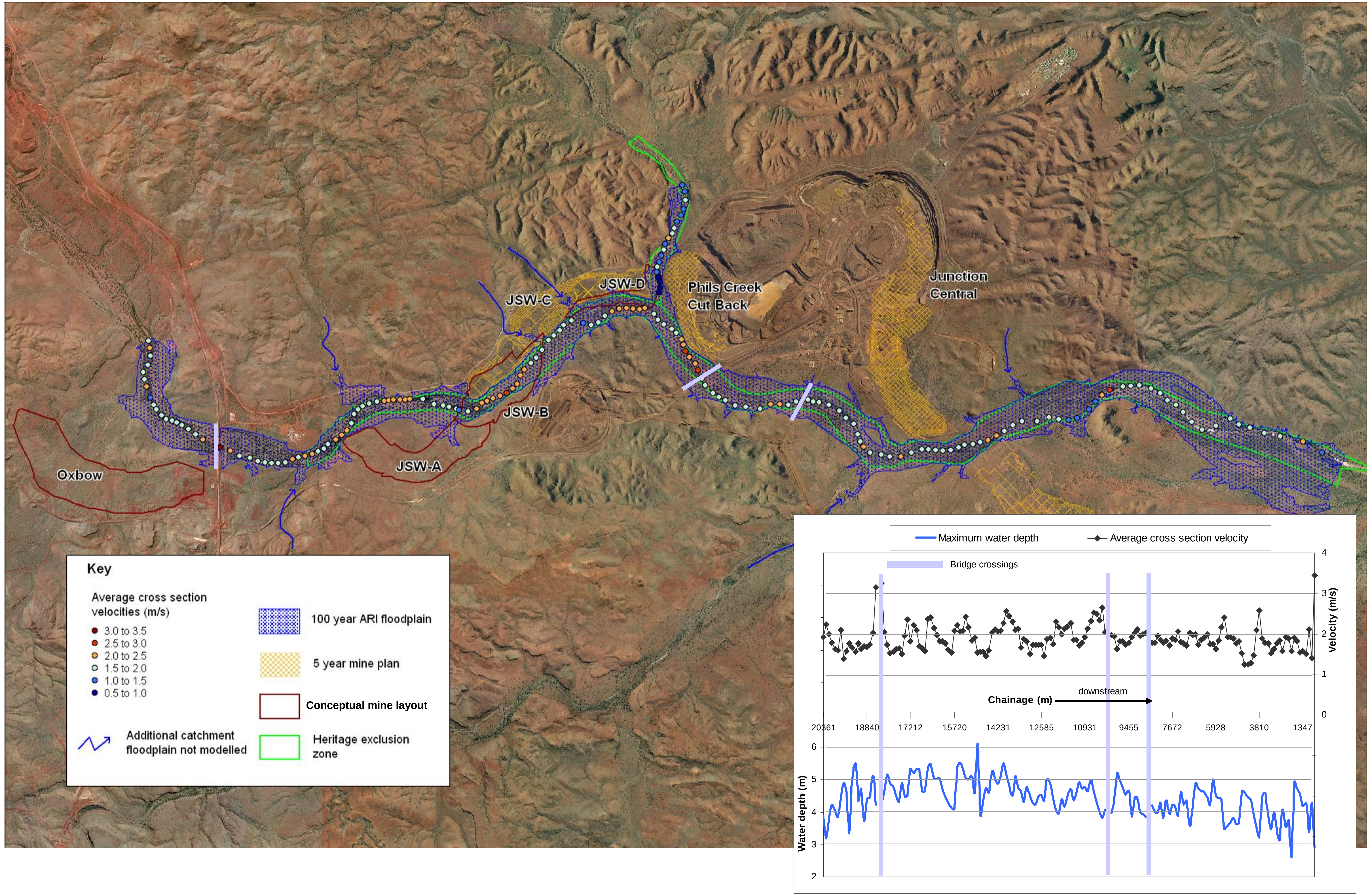

Figure 11: 100 year ARI flood extent and average cross sectional velocity distribution down Marillana Creek. The long section insert, starting upstream (Oxbow) heading east, illustrates the range of velocities and water depths identified through the modelling. Points in the long section align with the mapped average cross section velocities dots on the larger plan image.

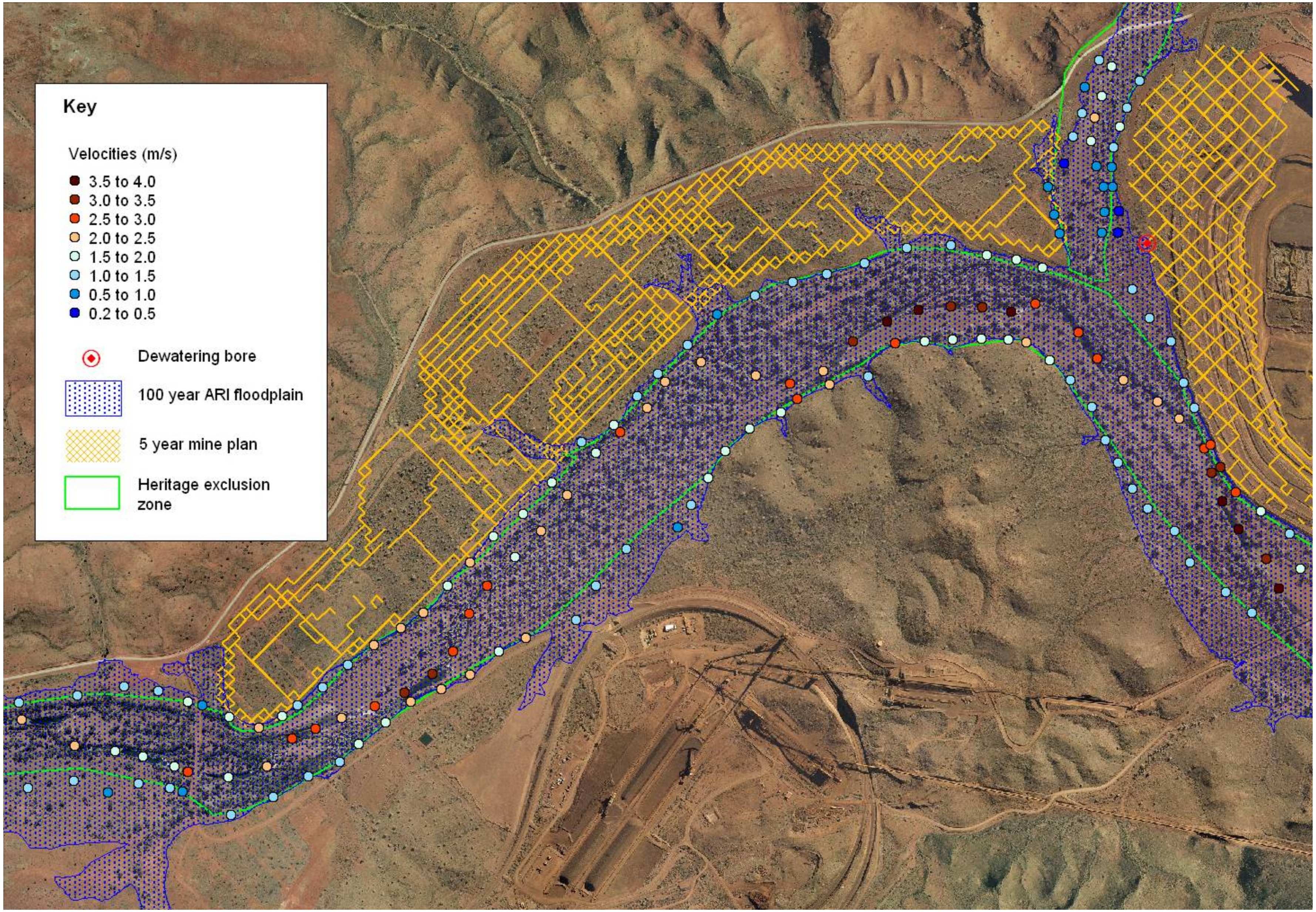

Figure 12: 100 year ARI flood extent, as illustrated in Figure 8, with additional local velocity information for the JSW-C and Phils Creek pit mine area.

Figure 12 illustrates the 100 year flood extents and velocity distribution past a RTIO Yandicoogina JSW-C conceptual pit outline and active areas of the RTIO Yandicoogina JC deposit. The current five year mine planned activity areas, shown in Figure 12, will mine areas close to and within the Marillana Creek 100 year flood plain, necessitating flood protection.

Along the southern edge of the mine area (Figure 13) the maximum water depth of Marillana Creek during a 100 year ARI flood event was 3.6 m with a maximum velocity of 2.5 m/s. Rock armour along the protection levee will be required to minimise damage from scouring during a flood event. Between the current and expansion areas (Figure 14) in the Phil's Creek tributary, the maximum water depth on the perimeter of the illustrated mine activities was 1.7 m with a maximum velocity of 1.4 m/s. A flood protection levee or alternative management activity will be required to protect the mine areas from the inrush of water from Phil's Creek.

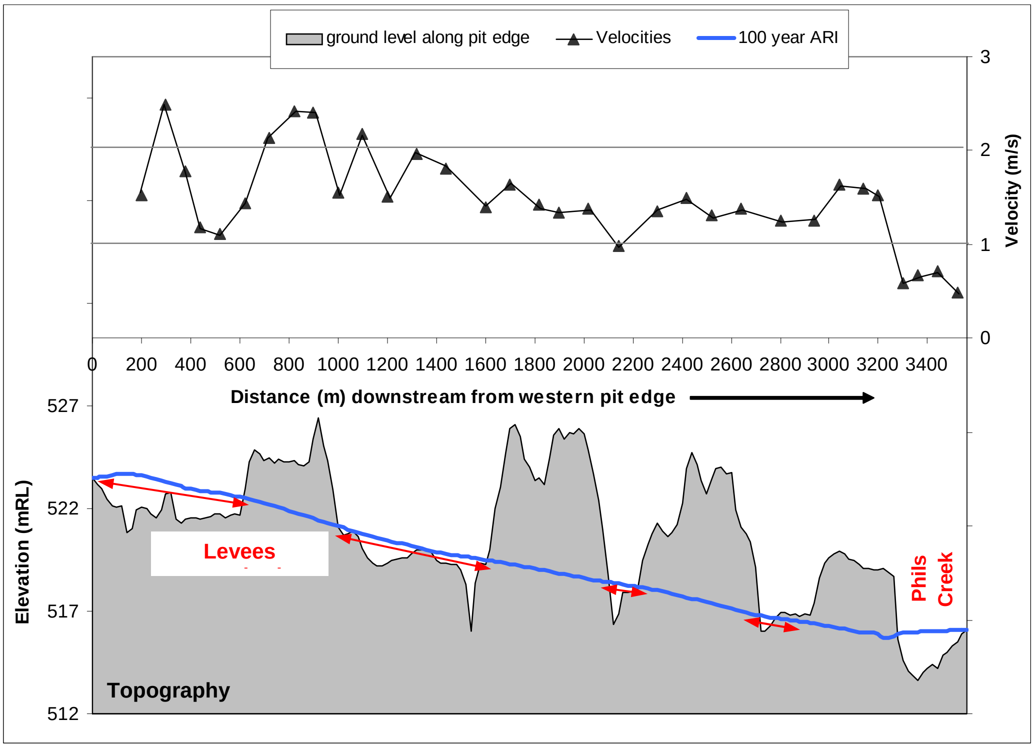

Figure 13: Flood conditions during a 100 year ARI flood event, along the southern boundary of the JSW-C mine area adjacent to Marillana Creek. (Long section shown west to east)

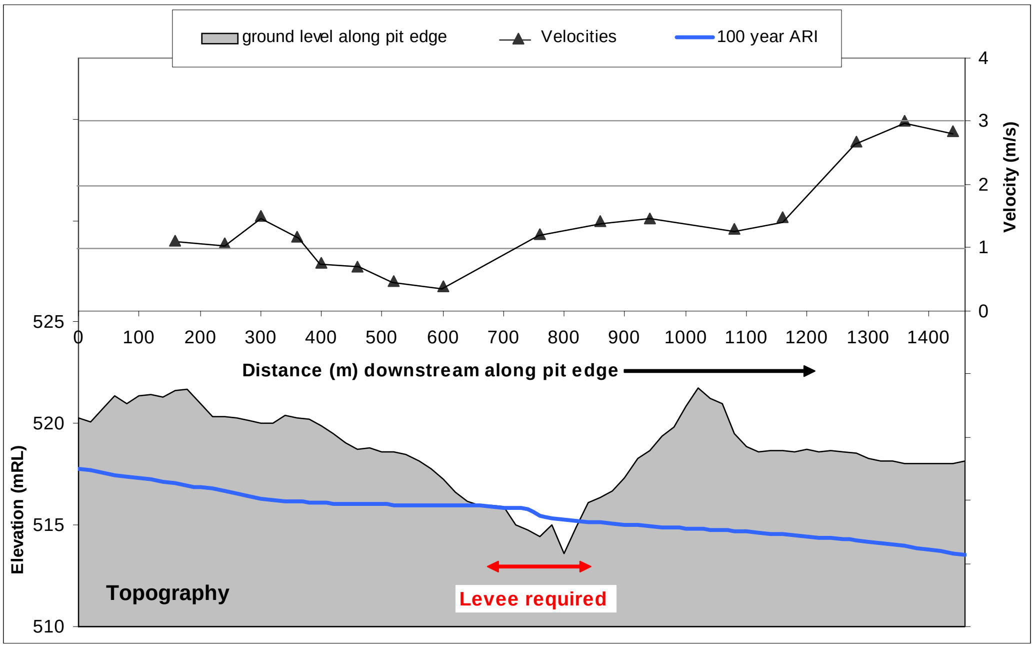

Figure 14: Flood conditions during a 100 year ARI flood event, along the eastern boundary of the JSW-C mine area adjacent to Phils Creek. (Long section shown north to south, junction of Phil's Creek and Marillana Creek)

9. Post mining (theoretical) flood conditions

9.1 Overview

Existing flow conditions, including the creek morphology and surface drainage patterns, of the Marillana Creek system are modified by development in the catchment, notably the RTIO RTIO Yandicoogina and BHPBIO Yandicoogina mine operations. For example, surface water flow direction and existing flow paths in creeks are altered by the construction of diversion structures which re-route water, conveyor bridges and associated earthworks that constrict large flows and road crossings which impound flows. In addition, local catchments have been and will continue to be truncated as a result of mine development. This reduces tributary flow to Marillana Creek, which in the future may alter Marillana Creek's peak flow volume, total volume of water conveyed and/or duration of flow events.

The following theoretical modelling activity was undertaken to provide a better understanding of the influence of truncating tributary flow and catchment runoff on the flood behaviour in Marillana Creek at selected locations: immediately downstream of the BHPBIO Yandicoogina operations prior to the RTIO Yandicoogina Oxbow deposit and at the catchment outlet terminus of Marillana Creek at the Weeli Wolli confluence. This theoretical modelling exercise may not accurately represent the closure conditions for all of the deposits adjacent to Marillana Creek, and thus does not represent the definitive Marillana Creek flow conditions post mining.

9.2 Hydrological modelling

Hydrographs were generated for the 2, 5, 10, 20, 50, 100, 200 and 500 year ARI storm events for pre and post mining conditions using the RORB Version 6 program (SKM, 2010). RORB is a general runoff and stream flow routing program used to calculate flood hydrographs from rainfall and other channel inputs.

For the purpose of the model, the Marillana Creek catchment was divided into 17 sub-areas (Figure 15) and catchment characteristics for individual sub-area, represented by the area (A, km^2), mainstream length (L, km), equal area slope (Se, m/km) and parameters k_c and m, were derived based on Flavell et al. (1983) $k_c = 0.35(A^{0.67})$.For the purpose of this study, an 'average' *m* value of 0.8 was adopted for each sub-area group. This information is summarised in Table 8.

Parameters that describe the retention characteristics of the Munjina Clayplan (k_s and m_s) were defined in accordance with RORB user guidelines, such that the storage (S)-discharge (Q) relationship was defined by $S = 3600 k_s Q^{m_s}$,based on the storage area and outlet characteristics of the retarding basin (Table 8).

Selection of the initial and continuing loss values followed the ARR (1980) runoff routing guidelines, as presented in Table 9. Results are tabled in Appendix B.

Table 8: Catchment characteristics input parameters for Marillana Creek RORB model.

Sub-areas		Area (km^2)	Stream length (km)	Equal area slope (m/km)	k_c	m
A	Upper Marillana Creek	134.2	21.3	6.2	23.10	0.8
B	Upper Marillana Creek	258.7	31.2	4.8	23.10	0.8
C	Upper Marillana Creek	126.9	15.6	8.1	23.10	0.8
D - E	Upper Marillana Creek	284.0	46.8	0.4	20.10	0.8
F	Upper Marillana Creek	141.2	15.1	3.7	9.65	0.8
G	Upper Marillana Creek	245.7	28.6	3.0	19.72	0.8
H	Upper Marillana Creek	164.6	20.8	5.6	19.72	0.8
I	Herberts Creek	64.9	11.0	7.8	27.18	0.8
J	Lamb Creek	112.8	22.8	6.7	27.18	0.8
K	Iowa Creek	155.4	24.5	5.0	27.18	0.8
L	Marillana Creek	106.5	19.5	10.0	27.18	0.8
M	Oxbow	83.9	11.3	11.0	27.18	0.8
N	Phil's Creek	99.1	18.7	5.4	27.18	0.8
O - P	Yandicoogina Creek	205.6	42.1	5.7	15.23	0.8
Q	Junction Central	45.3	9.6	10.0	15.23	0.8

Munjina Claypan retention characteristics

Storage area (km^2)	Effective length of outlet spillway (m)	Weir coefficient of outlet spillway[4]	ks	ms
17.5	300	2.00	68.37	0.67

Table 9: Initial and continuing loss values for individual ARI events

ARI (year)	2	5	10	20	50	100	200	500	PMP
Initial value (mm)	22	40	52	47	32	10	0	0	0
Continuing loss (mm)	5	5	5	5	5	5	5	5	5

[4] Source: RORB Version 6 user manual Table 2-5

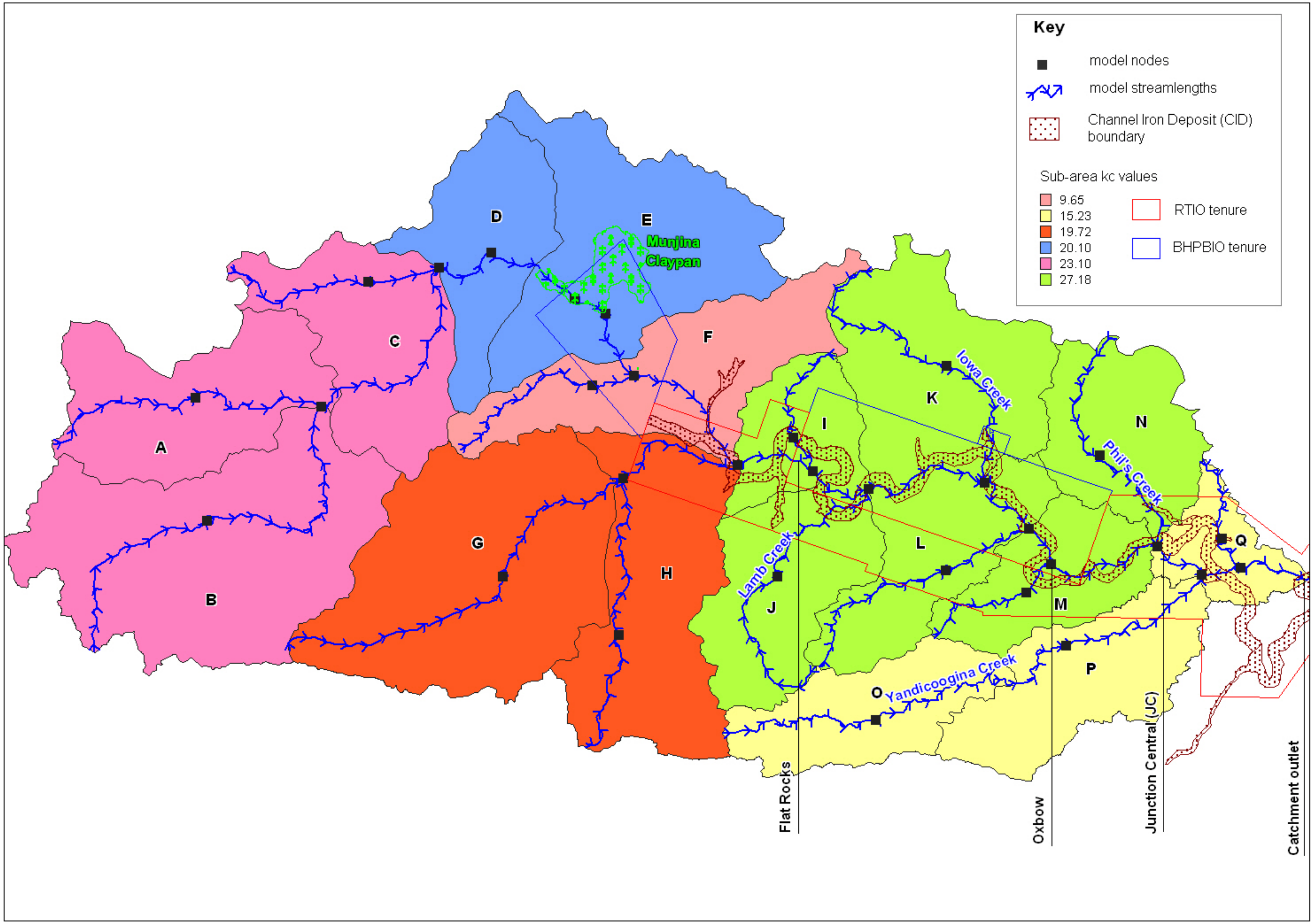

Figure 15: Marillana Creek catchment pre-mining RORB model configuration

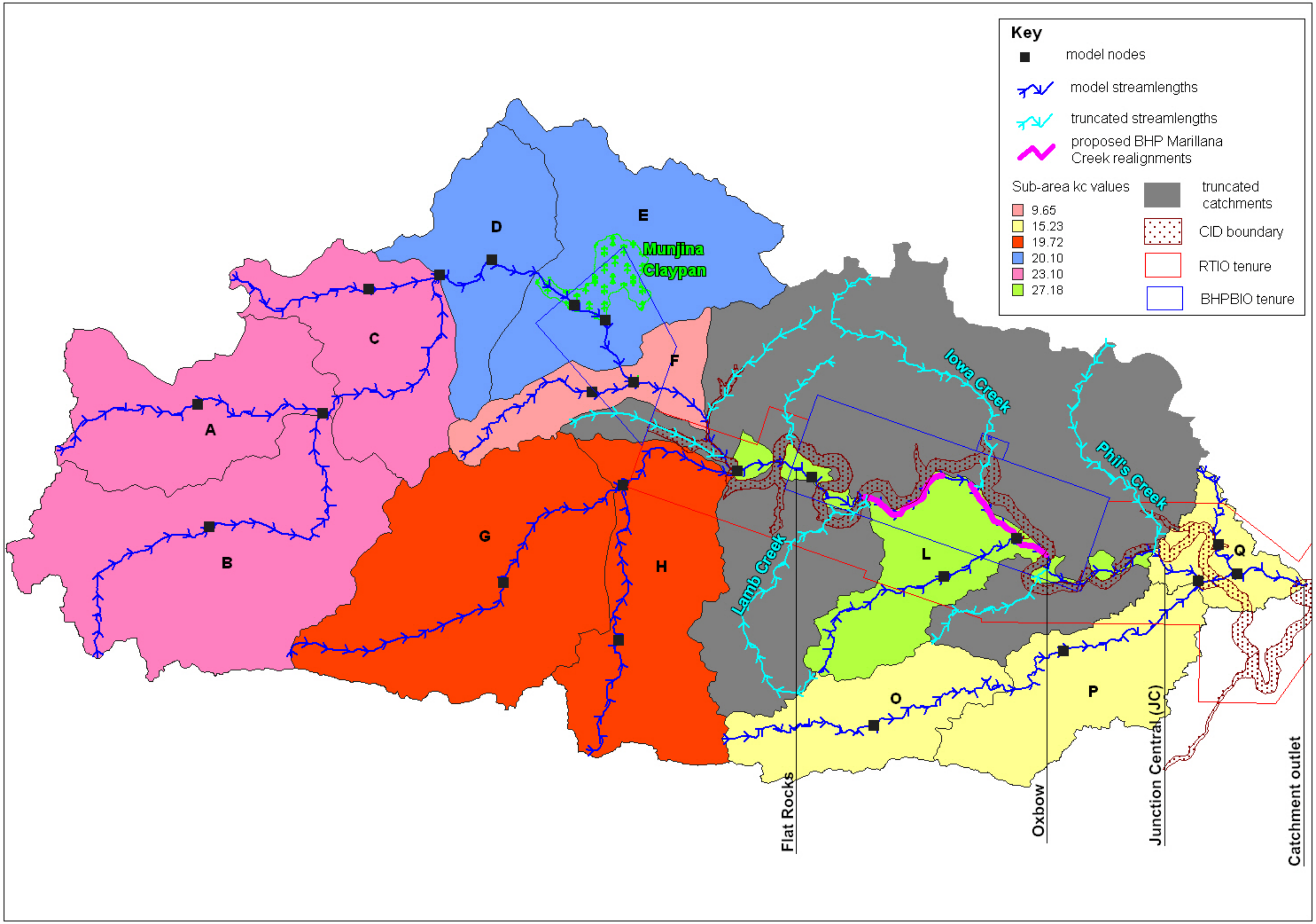

Figure 16: Marillana Creek catchment post-mining RORB model configuration.

The results showed that Munjina Claypan, located upstream of the mining activities, retained small volumes of water, reducing peak discharges for smaller rainfall events (1 in 10 year ARI and lower) and delayed the time to the event peak (Figure 17). The retention effects of the claypan are less prominent for larger storm events. For example, model results suggested the claypan has the effect of dampening peak discharges for the 10 year 12 hour and the 100 year 24 hour events by approximately 70 % and 20 %, respectively.

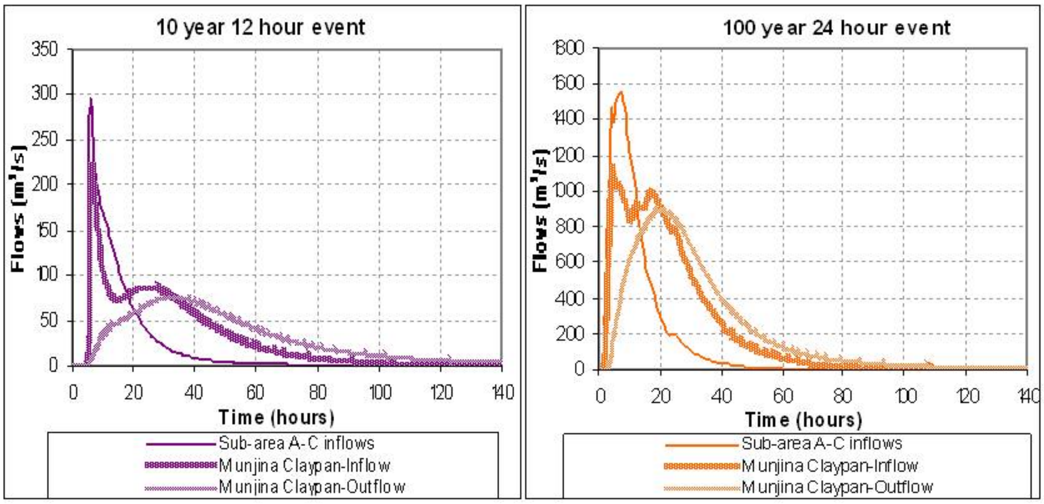

Figure 17: Hydrographs for the 10 year 12 hour and 100 year 24 hour events illustrate the typical retention characteristics of the Munjina Claypan.

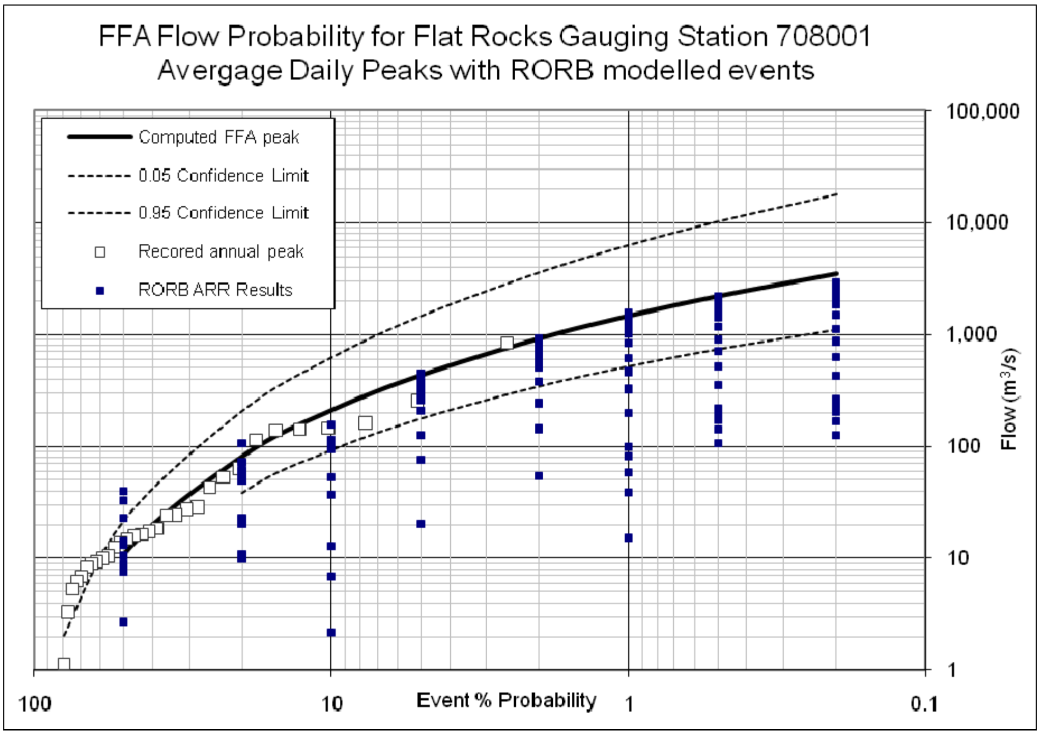

Figure 18. Flood frequency analysis of average daily peak flow volumes with peak flow values for considered average recurrence interval and duration rainfall patterns.

The modelled maximum flow peaks compared favourably with a flood frequency analysis of average daily recorded flood peaks (Figure 18) at the Flat Rocks flow gauge, downstream of the Munjina Claypan. The peak flows for the ARI events mimics the pattern of the observed flow data, producing a slight dip in the values around the 1 in 10 year ARI (10% probability) flows due to the storage effects of the Munjina Claypan. However, there is a notable difference between the modelled peak flow and observed values for 1 in 5 year ARI events. The difference may be attributed to uncertainties associated with the input parameters, such as kc, m and initial/continuing loss values, leading to an inaccurate representation of the flow characteristics for lower rainfall events. For example, a lumped value of the parameter kc was used to describe channel storage characteristics for all ARI events. Nevertheless, the resultant correlation and general agreement between the observed and modelled results for events with less than 20 % probability provides confidence in the modelled flood volumes and provides a baseline for the development of the post-mining model.

It is recognised that the catchment characteristics above the Flat Rocks gauging station are not representative of the catchment characteristics downstream of the gauge. As the target areas for the model are predominantly located downstream of the gauge, extensive parameterisation and calibration was not undertaken for this modelling exercise. As additional data becomes available in the future, it is expected that additional flow modelling and parameterisation would be undertaken prior to formalising closure and rehabilitation management plans.

Post mining catchment conditions (Figure 16) were simulated by removing catchment areas from the model, to simulate terminated tributary flows and catchment runoff upstream of the mapped Marillana Creek channel iron deposit (CID). It was assumed:

- Creek systems originally flowing over the mapped CID terminate into (future) pit voids.
- Insufficient materials are available for backfill pits to create a free draining surface, thus all pits act as infinite capacity voids;
- There are no interruptions to flows once water is within the main Marillana Creek channel;
- The proposed realignments of Marillana Creek at the BHPBIO mine operation (BHPBIO, 2005) behave as a fluvial system in a similar manner to the existing creek system, i.e. similar hydrology, channel hydraulics and geomorphology are maintained;
- The diversion bund and channel around the north eastern perimeter of the JC pit are permanent and runoffs originating from the northern catchments are diverted around the pit and returned to Marillana Creek southeast of the mine;
- Catchment characteristics and subsequent model parameters remain unchanged from pre-mining parameters.

As there is the potential for some creek systems to be reinstated by back filling pit voids and given that the voids are not of infinite storage capacity, this model is likely to reflect to the potential worst case scenario for Marillana Creek.

The truncated catchments summed to approximately 590 km^2, which contribute to 26.5 % of the total catchment area of the Marillana Creek system. The model results suggested that RTIO and BHPBIO operations could potentially reduce the overall catchment area contributing to flow in Marillana Creek by approximately 16.5 % and 10 %, respectively.

Hydrographs for modelled 10 year and 100 year ARI flood events pre and post-mining are illustrated in Figure 19. The results suggest there is a potential reduction in peak discharges and total flow volumes under post-mining catchment conditions, with an average drop of approximately 23 % in peak discharge at Flat Rocks, 46 % at Oxbow and 46 % at the catchment outlet and approximately 6 % reduction in total flow volumes at Flat Rocks and 26 % at Oxbow and 26 % at the catchment outlet for all ARI storm events.

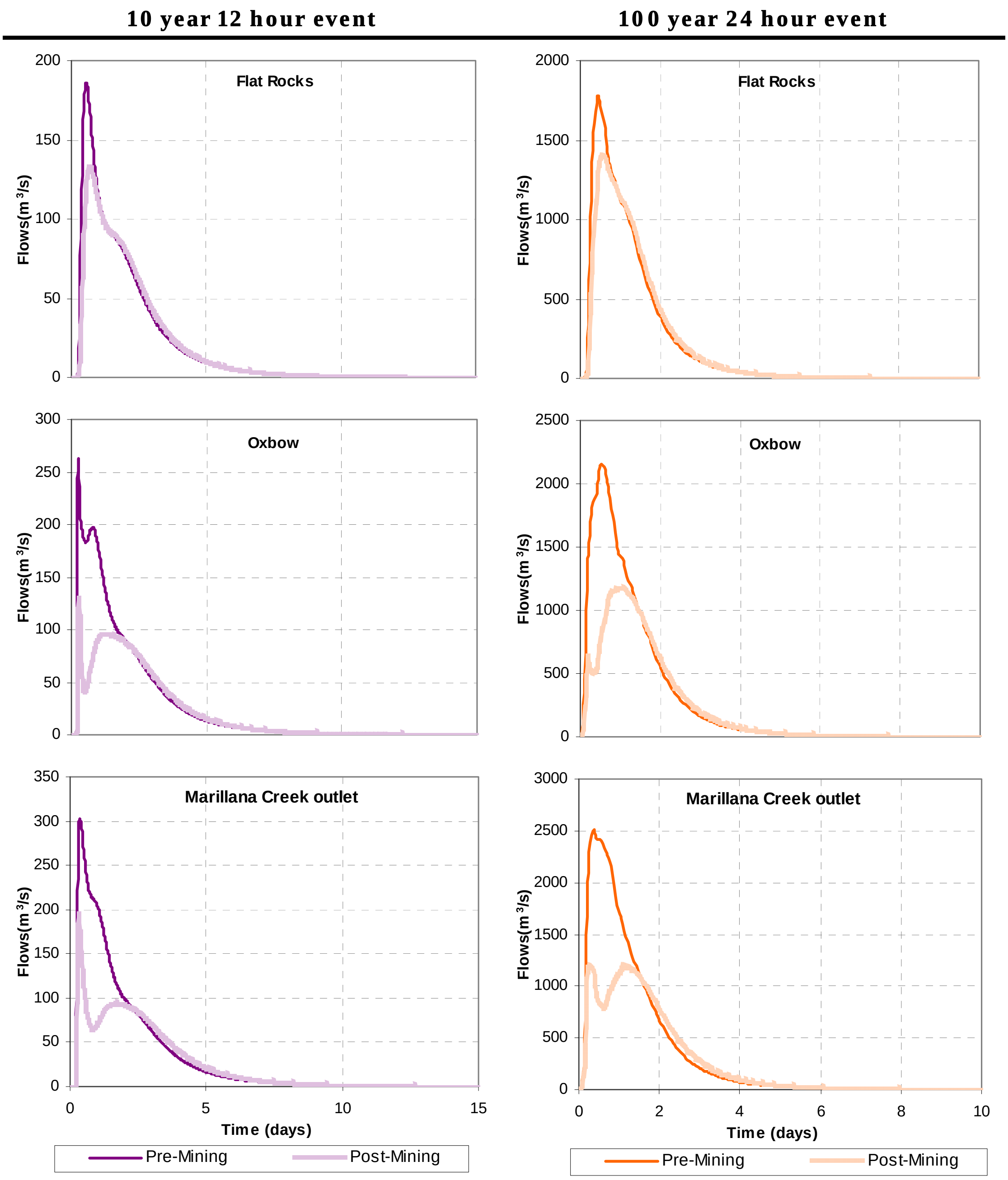

Figure 19: Hydrographs for the 10 and 100 year ARI events, pre and post-mining, at Flat Rocks, Junction Central and the catchment outlet

Table 10 compares the difference in event frequency to generate similar peak flow volumes under pre and post-mining conditions. The modelling suggests that the truncation of local creeks identified in Figure 16 change the flood frequency and thus lower flood potential within Marillana Creek. For example, the bank full flow conditions at the terminus of Marillana Creek were estimated to be comparable to a 10 year ARI flood event (i.e. a 10 year flood event is contained within the creek banks). Under post-mining conditions the peak flow volume required to produce similar bank full conditions corresponds to an approximate 20 year event.

Table 10: Exceedance probabilities and associated ARIs for the modelled peak flow volumes at the Marillana Creek catchment outlet under pre and post-mining catchment conditions.

Post-mining catchment conditions		Post-mining peak flow volumes (m^3/s) at catchment outlet	Pre-mining catchment conditions	
Exceedance probability (%)	ARR (year)		Exceedance probability (%)	Approximate ARR (year)
0.2	500	2500	1.0	95
0.5	200	1800	1.6	61
1	100	1200	3.0	33
2	50	740	5.5	18
5	20	420	8.0	12
10	10	200	22	4
20	5	140	31	3
50	2	52	74	1

10. Flow duration within Marillana Creek

10.1 Overview

Long term stream flow time series are often required to characterise the flood regime, duration and response of a catchment to historical rainfall events. Most commonly used runoff and stream flow routing programs, including RORB, are limited to simulating discrete storm events with the assumption that for example a design rainfall event of a certain ARI will result in a design flood with the same ARI. Without reverting to a complex two dimensional flow model to simulate a stream flow time series, for which the complex inputs were not available, an alternative piece-wise, event based methodology was employed.

Historical events were first classified using 15-minute rainfall data from the 37 year (1972 to 2009) Flat Rocks gauging records. The observed rainfalls and durations were compared with the design rainfalls generated for the Yandicoogina area and each storm event was assigned with an ARI in accordance with ARR guidelines. The time series of stream flow data was subsequently simulated by coupling the historical rainfall events with the similar intensity, simulated, event based flood hydrographs from RORB to recreate the stream flow time series at the Flat Rocks gauging station. The result was a theoretical stream flow time series at Flat Rocks.

The theoretical time series was subsequently compared with the observed time series from Flat Rocks gauging station. Disparity between the sequence were expected as the RORB hydrographs were not designed to accommodate antecedent conditions, for example where small storm events following larger storm events generate runoff when no runoff would be produced if the catchment was dry before the small storm. This disparity was expressed as the event scaling factor, defined by the difference between the theoretical and observed event durations.

Due to the absence of gauging data in the Lower Marillana Creek catchment, a simulated stream flow series was generated for the Lower catchment and to the catchment outlet of the creek system. The time series were based on the modelled flood hydrographs at each location coupled with the storm events classified from the Flat Rocks gauging station multiplied by the Flat Rocks event scaling factor. Underlying this approach is the assumption that the simulated long term stream flow pattern at Flat Rocks is valid for the Lower Marillana Creek catchment.

10.2 Simulated stream flow series

A comparison between the observed and simulated historical stream flow time series at Flat Rocks is presented in Figure 20. The average flow duration per storm event derived from the observed stream flow sequence is 73 days, which is comparable to the value (86 days) estimated from the simulated sequence. This finding suggests the model is capable of predicting the duration of a discrete flood event with accuracy of approximately 15 %.

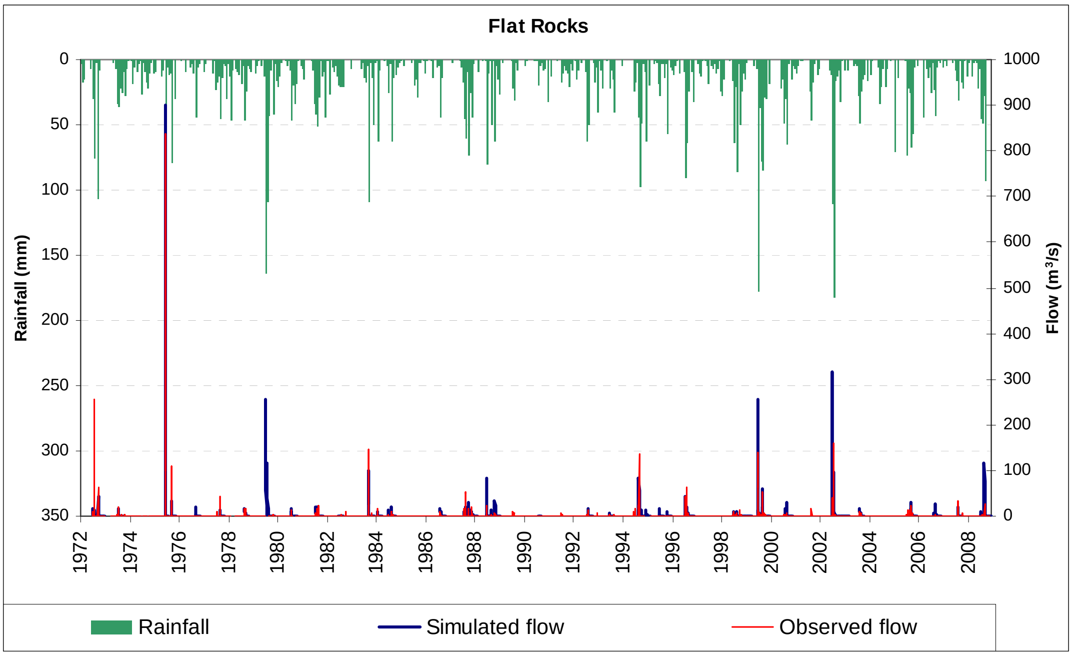

Figure 20: A comparison of the observed and raw simulated historical stream flow time series at Flat Rocks from 1972 to 2009.

Based on the observed stream flow sequence at Flat Rocks, it was determined that Marillana Creek flowed on average 213 days per year (the range varies from 15 days in 1986 to 366 days in 2000). It was also observed that creek flow was almost constant between 2000 and 2004, with over 350 flow days recorded per year at the Flat Rocks gauge during that period. 2000 was a particularly wet year (under the influence of significant cyclonic activities) with over 970 mm of rainfall recorded at the Flat Rocks gauging station. Below average rainfall 346 mm and 395 mm (annual average rainfall at Flat Rocks is 406 mm) was recorded in 2001 and 2003 but continuous flow was observed potentially resulted from saturated antecedent catchment conditions.

However, the simulated sequence did not replicate the flooding characteristics of Marillana Creek under wet antecedent conditions, hence significantly underestimates the number of flow days that could be expected in the creek system. From the simulated sequence an average of 85 days of flow per year, ranging from 0 to 202 days, at Flat Rocks was estimated compared to the average 213 days derived from the observed sequence.

In order to provide a more realistic representation of the historical flow sequence and to account for wet antecedent catchment conditions, an event scaling factor was applied to the simulated stream flow time series. This correction factor defines the ratio of the duration of flows generated from a storm event under wet and dry antecedent catchment conditions. By comparing the observed and simulated stream flow sequence, it was determined that on average the flow duration would extend approximately 2.6 times longer than the event based duration due to rainfall following the initial storm event. Hence an event scaling factor of 2.6

was applied to modelled events. It is important to note that this correction factor is specific to the flood characteristics of the upper Marillana Creek catchment.

The number of flow days per year at Flat Rocks, for the period 1974 to 2008, derived from the observed, simulated and the corrected stream flow sequences are listed in Appendix C. A comparison between the observed and corrected flow duration sequences is provided in Figure 21. The average number of flow days, 202, estimated from the corrected sequence is comparable to the 212 days estimated from the observed stream flow data. However the discrepancy between the two sets of data between 2001 and 2004, due to the absence of significant storm events during those periods, highlights the failure of the approach to predict flow under low rainfall conditions.

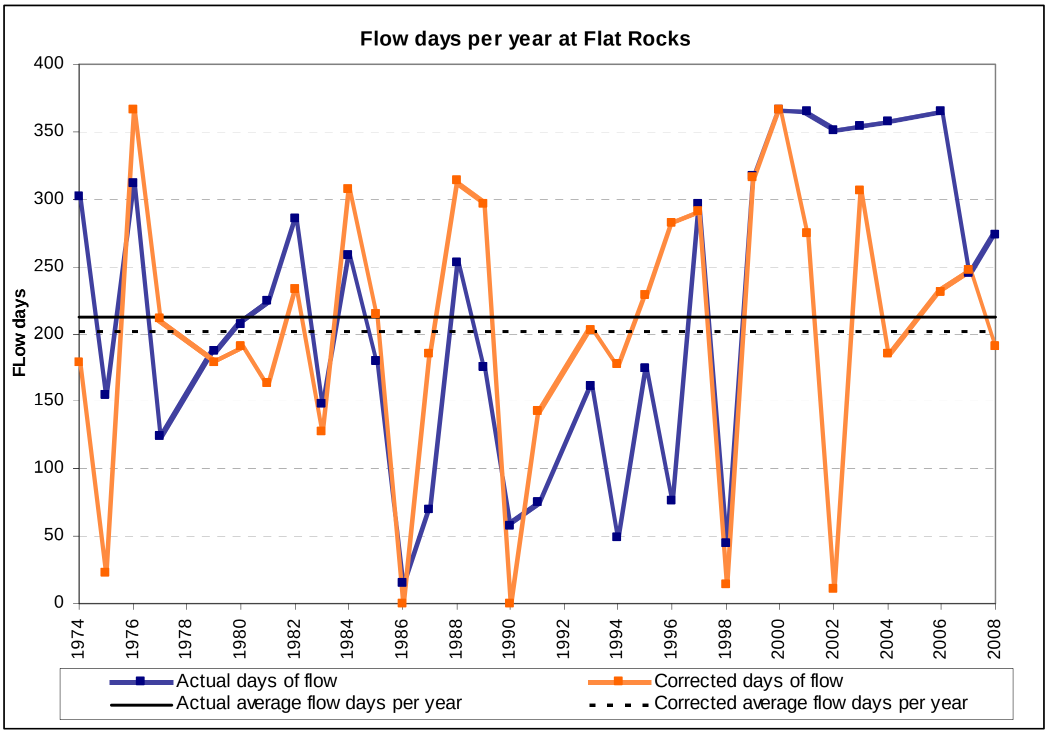

Figure 21: A comparison between the observed and corrected flow day sequences at Flat Rocks, for the period 1974 to 2008.

The event scaling factor was subsequently applied to the modelled stream flow series at Oxbow (Figure 22) and at the Marillana Creek catchment outlet (Figure 23). Consequently by extrapolating the flow series results from Flats Rocks to the theoretical Oxbow and Marillana Creek outlet locations as modelled using RORB and applying the event scaling factor, it was determined that Marillana Creek would flow for approximately 210 days per year at Oxbow and approximately 215 days per year at the catchment outlet.

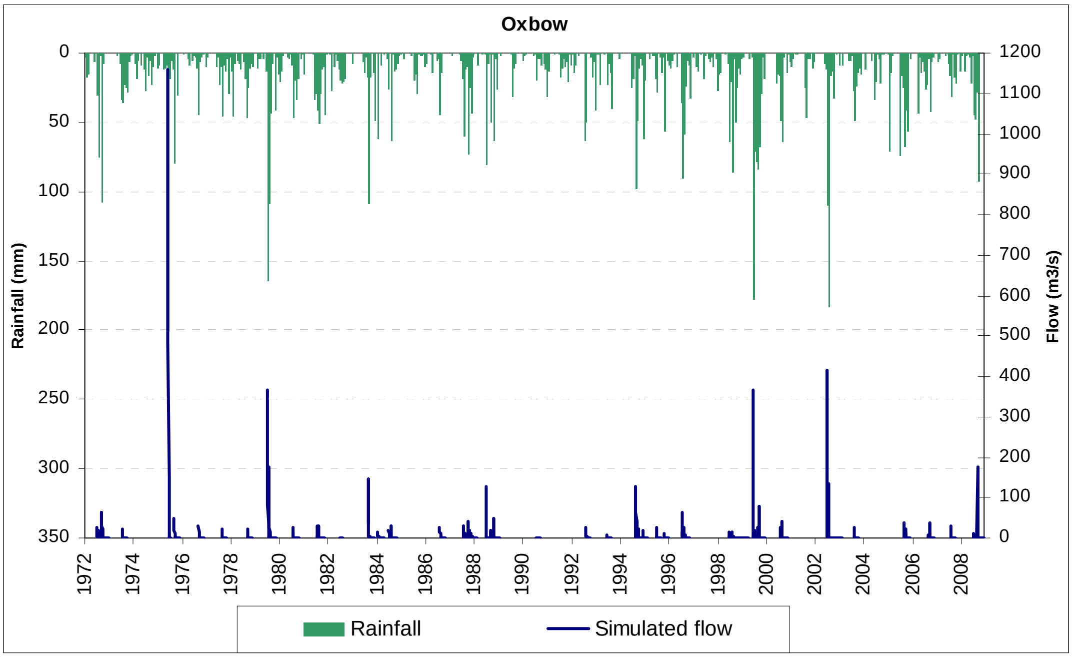

Figure 22: Simulated historical stream flow time series at Oxbow from 1972 to 2009.

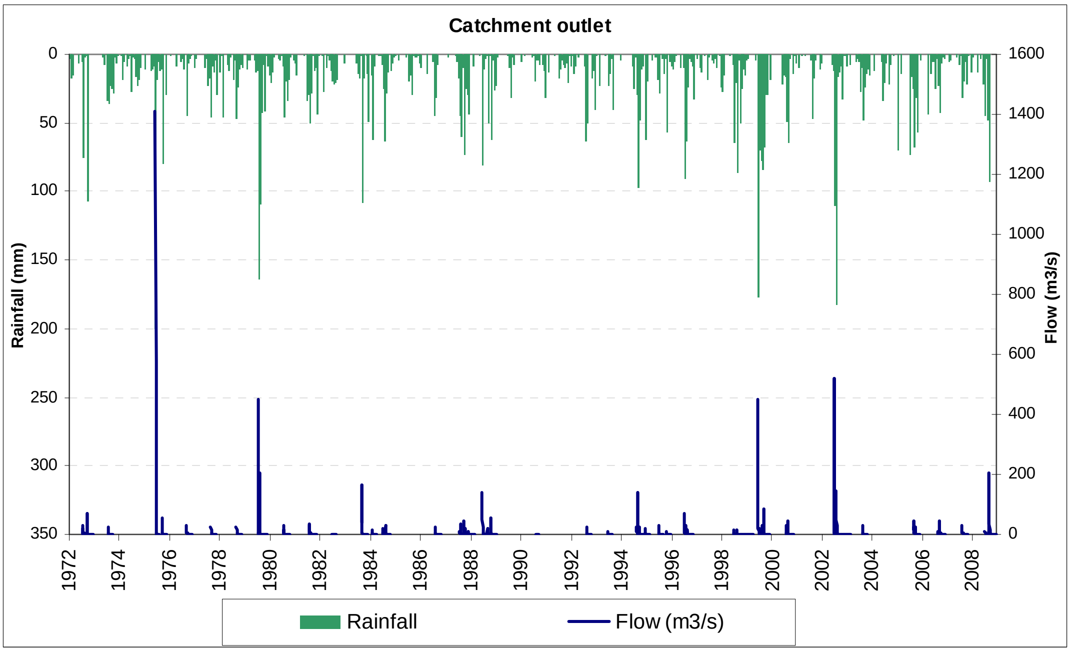

Figure 23: Simulated historical stream flow time series at the Marillana Creek catchment outlet from 1972 to 2009.

10.3 Event scaling factor caveats

The response of a catchment to rainfall is dependent on a combination of factors including the magnitude of the rainfall events occurred, the duration and interval in which the rainfall events occurred and the degree of catchment saturation as a result of preceding rainfall events or groundwater levels. For the time series modelling an event scaling factor was defined in order to incorporate the influence of these factors on modelled event based flood duration. This approach produced a reasonable estimation of flow duration, such that the technique may be used for estimating duration in other ungauged Pilbara catchments.

However it is unlikely that a single average correction value could accurately or adequately capture the non-linear flooding characteristics of the catchment. One of the recommendations to improve the outcomes of the time series modelling is to adopt a spatial hydrologic modelling approach incorporating antecedent conditions. However this type of modelling approach is complex, generally data intensive and requires long term rainfall and evaporation data, and observed stream flow sequence for calibration purposes. It may therefore be infeasible to use in the general absence of long term hydrologic data in Pilbara catchments.

Alternatively, prior to adopting a spatial modelling approach, improvements to the hydrometric network and refinement of the *kc* and *m* modelling parameters for gauged areas in the Marillana Creek catchment would improve flow duration prediction.

10.4 Natural catchment flow duration conclusions

For the Pilbara, ephemeral watercourses are presumed to be dry, with no base flow and flow occurring only after significant and intense rainfall events. However the study demonstrated that ephemeral Marillana Creek could and had sustained water flows during rainfall dry periods, where continual creek flows were recorded at Flat Rocks gauging station between 2000 and 2004. It was likely that the catchment was saturated as a result of above average rainfall in 2000 (Flat Rocks had recorded over 970 mm of rainfall in 2000, the highest annual rainfall recorded in its 37 year, from 1972 to 2009, gauging period). The saturated creek bed would have sustained interflow (the oblique lateral movement of water through the creek bed), which enabled water to return to the surface as surface water flow, due to sudden change in creek bed topography, during rainfall dry periods.

Another possible contributing factor to sustained surface flows in the creek system is the presence of the retention basins (the Munjina Claypan and some minor retention basins located in Sub-areas G and H) in the upper catchment, which has the potential to retain small volumes of water. The stored water is likely to contribute to the soil water store within the creek system and therefore sustain creek interflow and subsequently surface flow during the dry season.

11. Implications for cumulative impacts assessment

Cumulative impact assessment is the analysis of all impacts on an area resulted from one or more activities as they accumulate over time and space. Cumulative effects can result from an accumulation of effects from multiple activities or from a combination of effects from one activity. In either case, cumulative effects are likely to be larger in magnitude, greater in significance and/or greater in spatial extent than is the case with individual effects (IPENZ, 2000).

The cumulative effects of mining and interventions by RTIO Yandicoogina and BHPBIO Yandicoogina mine operations in the Marillana Creek catchment have altered the flooding characteristics and flood frequency of the creek system. Activities such as construction of diversion structures and haul/access road crossings have modified the existing surface flow direction and pattern; existing pits and development of future pits have and are likely to truncate local catchments thus reducing flow contribution to Marillana Creek. These changes in surface flow regime may result in reductions to peak and total flow volumes and reduction in flooding potential of the creek. Event durations remained more or less unchanged for most modelled ARI events, suggesting under post-mining conditions the average flood duration and the average number of flow days per year for the Marillana Creek catchment would be comparable to that pre-mining.

Flood regime change is likely to affect sections of the creek that support riparian vegetation such as *Eucalyptus camaldulensis* (River Red Gum), whose existence is associated with surface flooding characteristics (CSIRO, 2004) and the frequency of over bank flow conditions during flood events. An example of such location is illustrated in Figure 24. Figure 24 shows a typical cross section of the downstream section of Marillana Creek and the associated modelled flood levels for the 20 and 50 year ARI events under pre and post-mining conditions. The riparian vegetation communities identified in the figure are common species found within the downstream section of Marillana Creek, based on the vegetation survey conducted in the area.

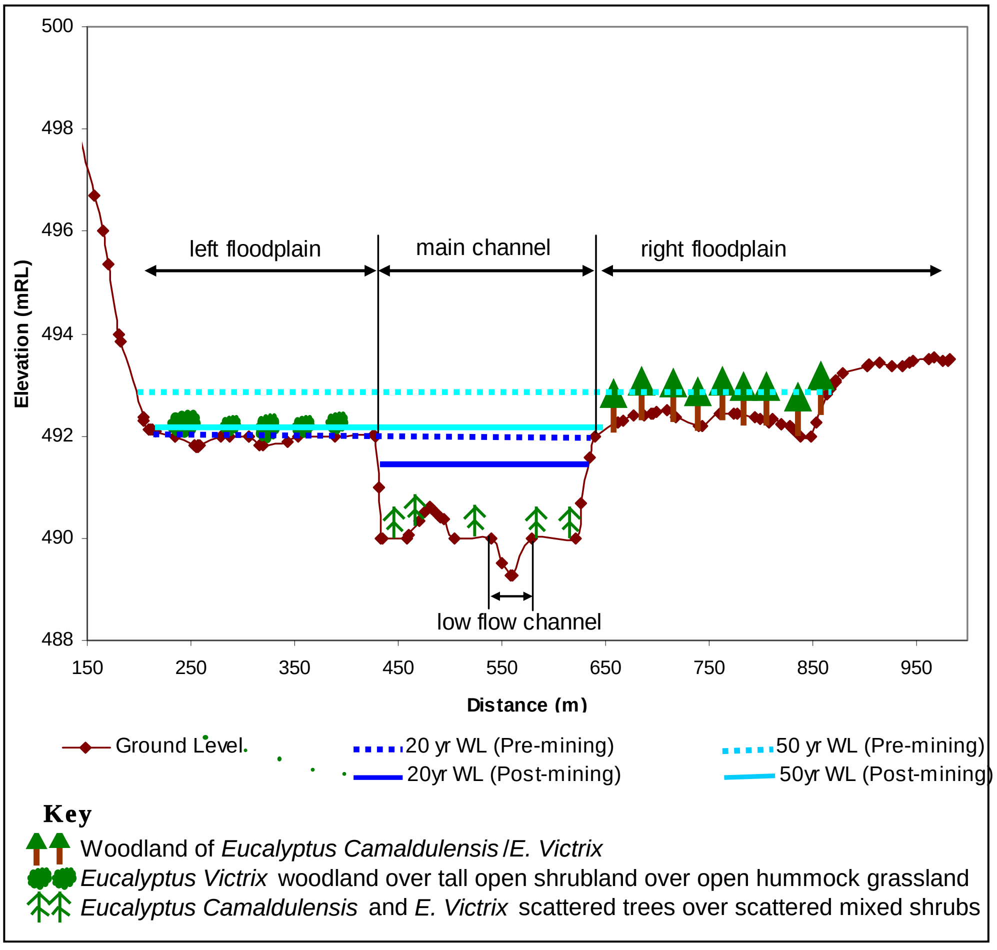

Figure 24: Typical cross section and riparian vegetation at the downstream section of Marillana Creek and associated flood levels for the 20 and 50 year ARI events under pre and post-mining conditions. The right floodplain would no longer be flooded during a 50 year ARI storm event under post-mining conditions. Similarly the left floodplain would not be flooded during a 20 year ARI storm but during a 50 year event under post-mining conditions.

Under natural flood conditions, the left bank of the creek system would be inundated by 1 in 20 and greater flood events. Under post-mining conditions, the left floodplain would only be flooded during a 50 year ARI event. This modification to the flood regime will result in less water being available for flood dependent regeneration of riparian ecosystems and would over time alter the creek ecology and potentially the biodiversity of riparian environments. An example of the deterioration of riparian vegetation as a result of flood regime change and reduced flooding was observed in the Murray River catchment. Changes in river flow patterns of the Murray River resulted from large scale dam building has led to the decline in riparian tree health, including reduced tree growth rate, accelerated mortality and minimal regeneration (CSIRO, 2004). Further work is therefore required to identify creek sections that are potentially "at risk" or sensitive to flood regime change for future preservation or rehabilitation.

One management option proposed to minimise impacts on the Marillana Creek catchment is to backfill all pits to the original surface topography at closure to maintain local catchment flow contribution to Marillana Creek. This management option is often not feasible as there is insufficient waste material available at closure to create a free draining surface within the mine void.

An alternative option is to reinstate only the intersected creek tributaries via diversions or land bridges to allow continuation of flows to Marillana Creek. However, it is understood that the fresh water supply from creek runoff may also be used to reduce pit lake salinity resulting from exposed groundwater. Consequently it is acknowledged that a balance between surface water supply and ground water quality must be developed as part of a regional closure strategy. However, based on the existing alignment of the CID and previous assumptions, by reinstating key tributaries across or around the (theoretical) pit voids it was estimated that approximately 4 % for the Lamb Creek catchment, 3 % for Iowa Creek catchment and less than 2 % for the Phils Creek catchment areas and corresponding flows would be terminated. Hence re-establishing the truncated creek systems without complete backfill of the pit voids would return most if not all local surface water flow volumes contributing to the Marillana Creek system to pre-mining conditions.

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Appendix A

12. Rainfall data

Yandicoogina (HI mine)

The average monthly rainfall for RTIO Yandicoogina is provided in Figure 25. The average annual rainfall for the period 1998 to 2009 was 449 mm, with annual rainfall recorded between 195 mm and 890 mm.

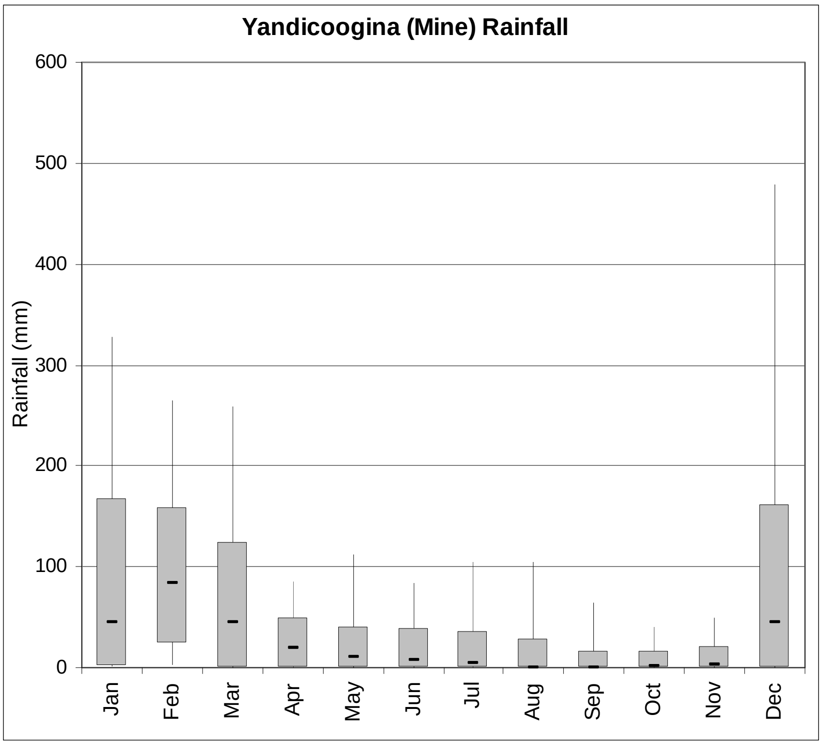

Figure 25: Monthly rainfall statistics for Yandicoogina.

Flat Rock rainfall

The average monthly rainfall for Flat Rock is provided in Figure 25. The average annual rainfall for the period 1974 to 2009 was 395 mm, with annual rainfall recorded between 148 mm and 976 mm.

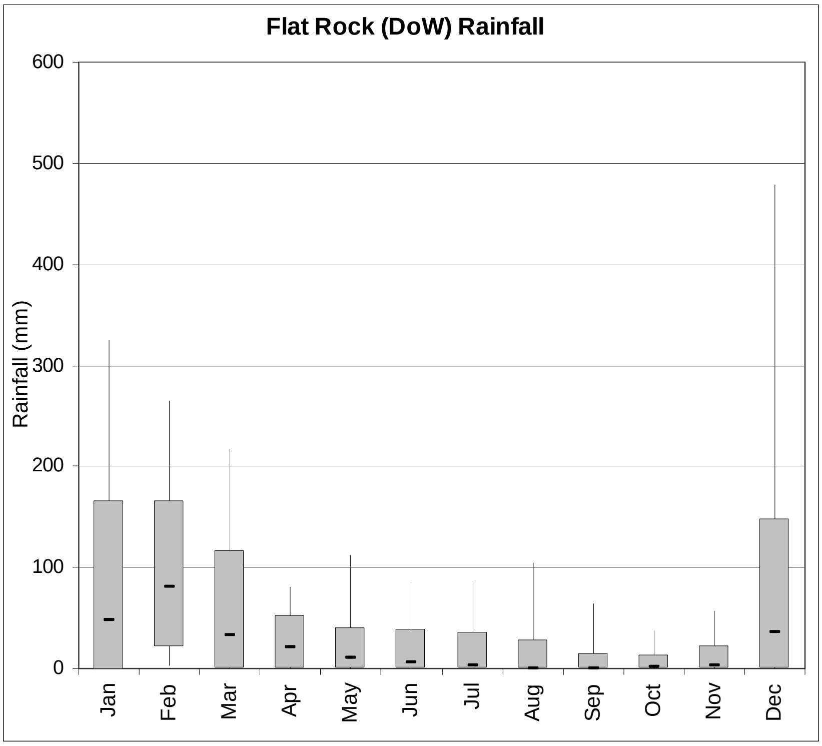

Figure 26: Monthly rainfall statistics for Flat Rock rainfall gauge.

Munjina

The average monthly rainfall for Munjina is provided in Figure 25. The average annual rainfall for the period 1969 to 2009 was 418 mm, with annual rainfall recorded between 176 mm and 1002 mm.

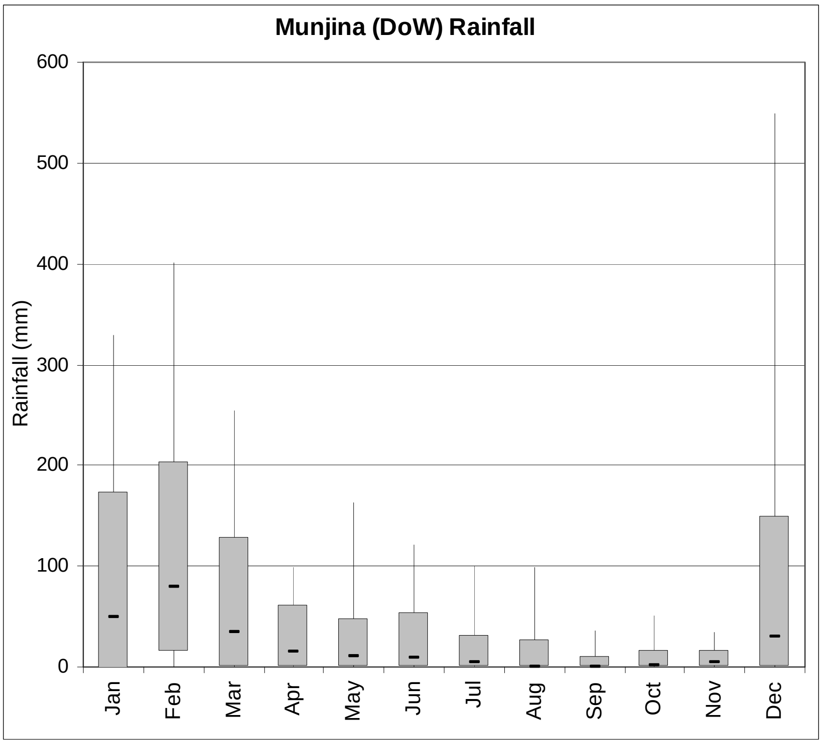

Figure 27: Monthly rainfall statistics for Munjina rainfall gauge.

Packsaddle

The average monthly rainfall for Packsaddle is provided in Figure 25. The average annual rainfall for the period 1978 to 1999 was 322 mm, with annual rainfall recorded between 89 mm and 862 mm.

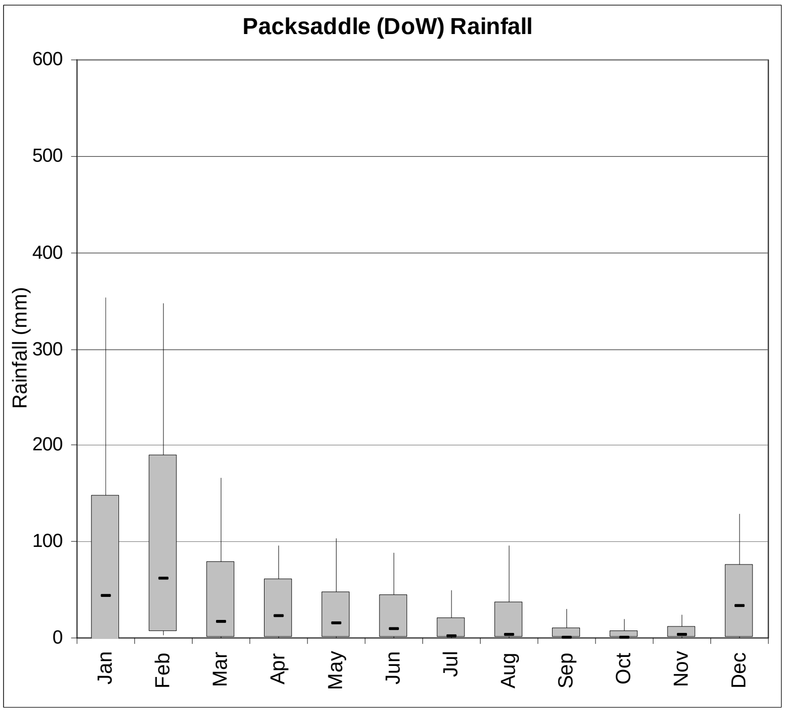

Figure 28: Monthly rainfall statistics for Packsaddle rainfall gauge.

Tarina

The average monthly rainfall for Tarina is provided in Figure 25. The average annual rainfall for the period 1985 to 2009 was 373 mm, with annual rainfall recorded between 163 mm and 711 mm.

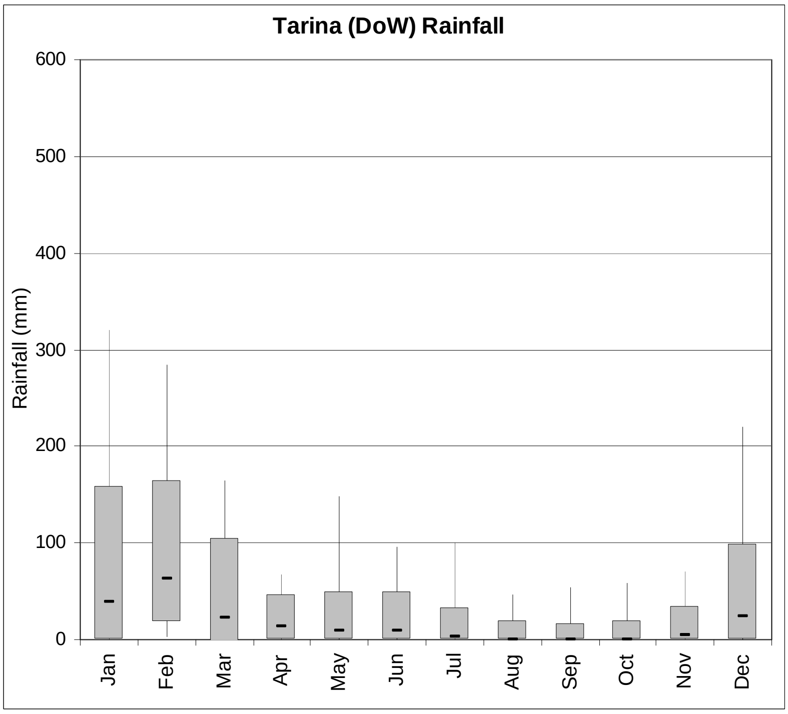

Figure 29: Monthly rainfall statistics for Tarina rainfall gauge.

Waterloo Bore

The average monthly rainfall for Waterloo Bore is provided in Figure 25. The average annual rainfall for the period 1985 to 2009 was 415 mm, with annual rainfall recorded between 214 mm and 950 mm.

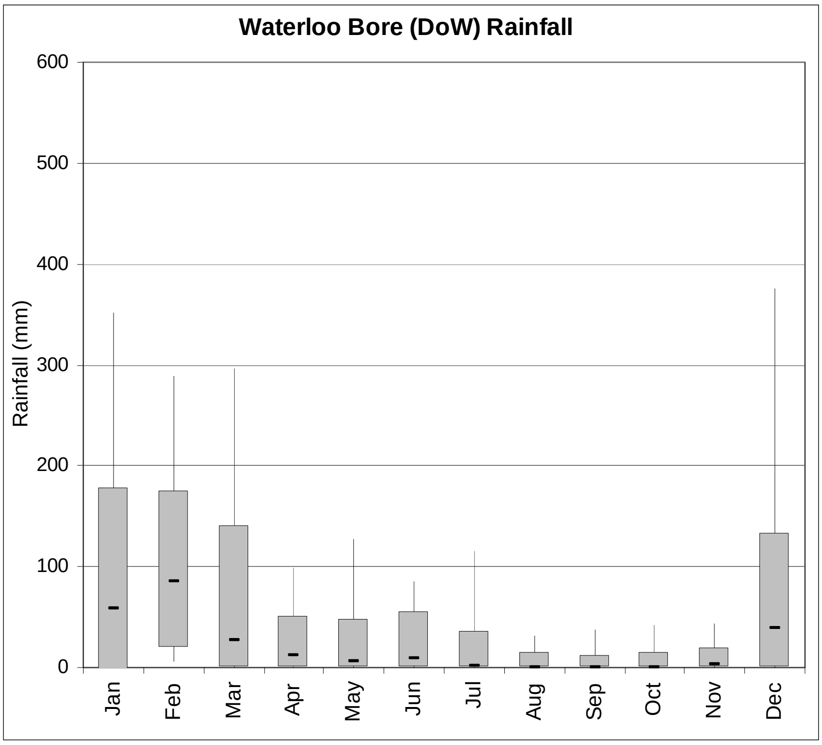

Figure 30: Monthly rainfall statistics for Waterloo Bore rainfall gauge.

13. Peak flow volumes pre and post-mining conditions

Peak flow volumes and results comparison at selected locations along Marillana Creek under pre and post-mining conditions.

						Pre-mining peak flow volumes (m^3/s)									
ARI (year)	Rainfall Source	Burst Rain(mm)	Duration (hr)	Areal reduction factor	ARF*Rainfall (mm)	Munjina Claypan Inflow	Munjina Claypan - Outflow	Flat Rocks	Lamb Creek	Iowa Creek	At Oxbow	Phil's Creek	At Junction Central	Yandicoogina Creek	Marillana Creek outlet
2	ARR	54	9	0.87	47	63	18	48	39	27	73	28	52	53	79
5	ARR	90	12	0.89	80	160	51	130	100	67	180	70	140	130	210
10	ARR	112	12	0.89	100	220	75	190	140	97	260	100	200	190	300
20	ARR	175	24	0.92	161	390	230	530	180	170	580	170	580	330	800
50	ARR	227	24	0.92	209	660	500	1000	360	300	1200	280	1200	560	1500
50	CRC FORGE		24		179	490	340	730	260	220	840	210	850	410	1100
100	ARR	270	24	0.92	249	1100	890	1800	560	500	2200	500	2200	960	2500
100	CRC FORGE		24		200	820	580	1200	420	360	1400	370	1400	690	1800
200	ARR	317	24	0.92	292	1600	1300	2500	700	690	3100	690	3100	1300	3500
200	CRC FORGE		24		233	1200	880	1800	540	520	2100	520	2100	990	2500
500	ARR	385	24	0.92	354	2000	1800	3300	870	880	4200	880	4200	1700	4600
500	CRC FORGE		24		282	1500	1200	2400	680	670	2900	670	3000	1300	3300

PMP[5]	CRC FORGE		24		372	2100	1900	3600	930	950	4500	940	4600	1800	5000

						Post-mining peak flow volumes (m^3/s)									
ARI (year)	Rainfall Source	Burst Rain(mm)	Duration (hr)	Areal reduction factor	ARF*Rainfall (mm)	Munjina Claypan Inflow	Munjina Claypan - Outflow	Flat Rocks	Lamb Creek	Iowa Creek	At Oxbow	Phil's Creek	At Junction Central	Yandicoogina Creek	Marillana Creek outlet
2	ARR	54	9	0.87	47	63	18	34	-	-	34	37	23	53	52
5	ARR	90	12	0.89	80	160	51	91	-	-	91	92	63	130	140
10	ARR	112	12	0.89	100	220	75	130	-	-	130	130	93	190	200
20	ARR	175	24	0.92	161	390	230	390	-	-	390	290	280	330	420
50	ARR	227	24	0.92	209	660	500	810	-	-	810	670	640	560	740
50	CRC FORGE		24		179	490	340	560	-	-	560	450	430	410	540
100	ARR	270	24	0.92	249	1100	890	1400	-	-	1400	1200	1100	960	1200
100	CRC FORGE		24		200	820	580	940	-	-	940	770	740	690	860
200	ARR	317	24	0.92	292	1600	1300	2000	-	-	2000	1700	1700	1300	1800
200	CRC FORGE		24		233	1200	880	1400	-	-	1400	1200	1100	990	1200
500	ARR	385	24	0.92	354	2000	1800	2700	-	-	2700	2400	2300	1700	2500
500	CRC FORGE		24		282	1500	1200	1900	-	-	1900	1600	1600	1300	1700
PMP[6]	CRC FORGE		24		372	2100	1900	2900	-	-	2900	2600	2500	1800	2700

5 Probable Maximum Precipitation

6 Probable Maximum Precipitation

ARI (year)	Rainfall Source	Peak flow volumes (m^3/s)									Total volumes (m^3) (x 10^6)									Event duration (days)								
		Flat Rocks (Pre-mining)	*Flat Rocks (Post-mining)*	% Difference	Oxbow (Pre-mining)	*Oxbow (Post-mining)*	% Difference	Catchment outlet (Pre-mining)	*Catchment outlet (Post-mining)*	% Difference	Flat Rocks (Pre-mining)	*Flat Rocks (Post-mining)*	% Difference	Oxbow (Pre-mining)	*Oxbow (Post-mining)*	% Difference	Catchment outlet (Pre-mining)	*Catchment outlet (Post-mining)*	% Difference	Flat Rocks (Pre-mining)	*Flat Rocks (Post-mining)*	% Difference	Oxbow (Pre-mining)	*Oxbow (Post-mining)*	% Difference	Catchment outlet (Pre-mining)	*Catchment outlet (Post-mining)*	% Difference
2	ARR	48	*34*	-29	73	*37*	-50	79	*52*	-35	9	*9*	-6	13	*9*	-26	15	11	-26	71	*72*	1.4	75	*76*	1.3	77	*80*	3.9
5	ARR	130	*91*	-29	180	*92*	-50	210	*140*	-35	20	*19*	-6	27	*20*	-26	33	24	-26	87	*73*	-16	92	*77*	-16	94	*97*	3.2
10	ARR	190	*130*	-28	260	*130*	-50	300	*200*	-35	27	*25*	-6	37	*28*	-26	44	33	-26	88	*89*	1.1	92	*93*	1.1	94	*98*	4.3
20	ARR	530	*390*	-26	580	*290*	-49	800	*420*	-47	63	*60*	-6	88	*65*	-26	100	77	-26	88	*89*	1.1	92	*94*	2.2	95	*98*	3.2
50	ARR	1000	*810*	-23	1200	*670*	-45	1500	*740*	-51	120	*110*	-6	170	*120*	-26	200	150	-26	88	*89*	1.1	91	*94*	3.3	93	*98*	5.4
50	CRC FORGE	730	*560*	-24	840	*450*	-47	1100	*540*	-50	89	*84*	-6	120	*91*	-26	150	110	-26	88	*89*	1.1	92	*94*	2.2	94	*98*	4.3
100	ARR	1800	*1400*	-21	2200	*1200*	-45	2500	*1200*	-53	190	*180*	-6	270	*200*	-26	310	230	-26	88	*89*	1.1	91	*92*	1.1	93	*95*	2.2
100	CRC FORGE	1200	*940*	-23	1400	*770*	-46	1800	*860*	-51	140	*130*	-6	190	*140*	-26	220	160	-26	88	*89*	1.1	91	*94*	3.3	97	*98*	4.3
200	ARR	2500	*2000*	-20	3100	*1700*	-44	3500	*1800*	-49	260	*250*	-6	360	*270*	-26	430	310	-26	87	*88*	1.2	91	*92*	1.1	93	*95*	2.2
200	CRC FORGE	1800	*1400*	-22	2100	*1200*	-46	2500	*1200*	-51	190	*180*	-5	260	*190*	-26	310	230	-26	88	*89*	1.1	91	*92*	1.1	93	*95*	2.2
500	ARR	3300	*2700*	-19	4200	*2400*	-43	4600	*2500*	-47	340	*320*	-6	470	*350*	-26	560	410	-26	87	*88*	1.2	90	*91*	1.1	92	*95*	3.3
500	CRC FORGE	2400	*1900*	-20	2900	*1600*	-44	3300	*1700*	-50	250	*240*	-6	350	*260*	-26	410	300	-26	87	*88*	1.2	91	*92*	1.1	93	*95*	2.2
PMP	CRC FORGE	3600	*2900*	-19	4500	*2600*	-43	5000	*2700*	-46	370	*350*	-6	510	*380*	-26	600	440	-26	87	*88*	1.2	90	*91*	1.1	92	*95*	3.3

Appendix C

14. Observed versus modelled flow duration

The number of flow days per year at Flat Rocks, Oxbow and the Marillana Creek catchment outlet, for the period 1974 to 2008.

Year[7]	Flat Rocks			Oxbow		Catchment outlet	
	Observed days of flow	Estimated days of flow	*Corrected days of flow*	Estimated days of flow	*Corrected days of flow*	Estimated days of flow	*Corrected days of flow*
1974	302	69	*179*	72	*187*	75	*195*
1975	155	23	*23*	23	*23*	23	*23*
1976	312	126	*366*	142	*366*	144	*366*
1977	124	71	*211*	74	*232*	77	*245*
1979	187	69	*179*	72	*187*	75	*195*
1980	207	74	*191*	77	*201*	80	*206*
1981	225	44	*164*	46	*174*	50	*180*
1982	286	99	*233*	102	*241*	105	*249*
1983	147	40	*128*	44	*153*	46	*159*
1984	258	163	*307*	172	*307*	176	*307*
1985	180	101	*215*	104	*222*	107	*230*
1986	15	0	*0*	0	*0*	0	*0*
1987	70	71	*185*	74	*192*	77	*200*
1988	253	202	*314*	206	*324*	208	*330*
1989	175	183	*297*	187	*307*	189	*312*
1990	58	0	*0*	0	*0*	0	*0*
1991	75	55	*143*	59	*153*	61	*159*
1993	161	89	*203*	92	*210*	95	*218*
1994	49	50	*178*	54	*187*	56	*192*
1995	174	117	*229*	121	*237*	123	*237*
1996	76	128	*282*	135	*292*	140	*298*
1997	297	112	*291*	116	*302*	118	*307*
1998	45	14	*14*	14	*14*	14	*14*
1999	317	127	*316*	131	*336*	133	*341*
2000	366	136	*366*	140	*336*	159	*366*
2001	365	100	*275*	104	*292*	106	*298*
2002	351	11	*11*	11	*11*	11	*11*
2003	354	111	*306*	116	*319*	118	*324*
2004	358	71	*185*	74	*192*	77	*200*
2006	365	89	*231*	92	*239*	95	*247*
2007	245	95	*247*	99	*257*	101	*263*
2008	274	77	*191*	80	*198*	83	*206*
Average	**213**	**85**	***202***	**89**	***210***	**91**	***215***

[7] Missing years are due to incomplete gauging record at Flat Rocks