12.0 Surface Water

12.1 Overview

Aspects of surface water hydrology and water quality relevant to existing conditions and the open cut project are related to a wide spatial scale. These include the broad catchment context as well as local hydraulics of floods and low flows in the McArthur River. The operational management of water at the existing mine site and Bing Bong port also needs to be considered. The assessment of existing surface water relevant to the project covers the following aspects:

- Regional surface water systems, catchment context;
- Existing McArthur River hydrology;
- Local surface water systems;
- Hydraulic aspects of existing river morphology;
- Existing surface water quality; and
- Existing water management.

The impacts and proposed mitigation strategies for surface water management for the open cut project are presented for the following key aspects:

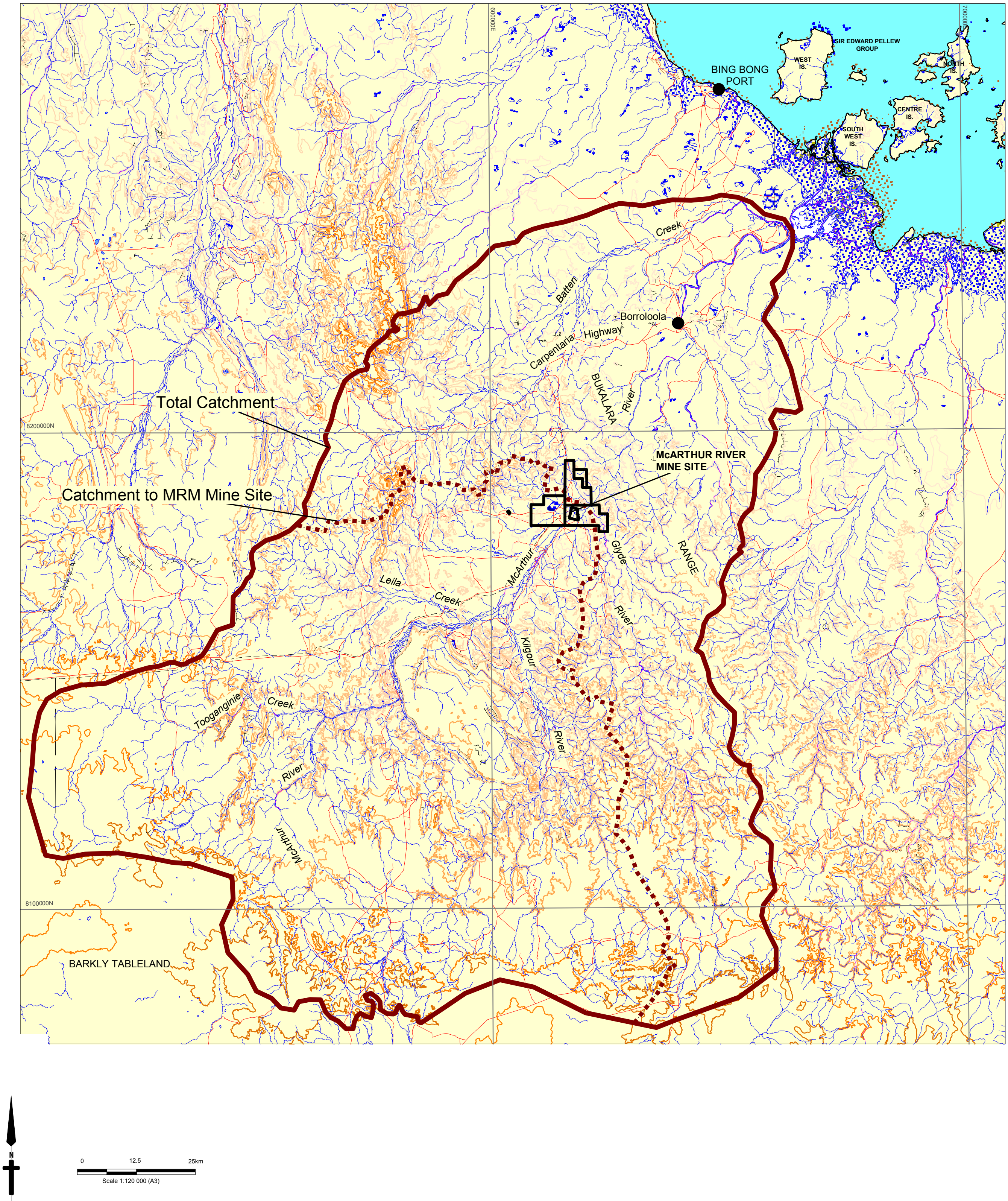
- Impacts on water management and mitigation;
- Stream realignment impacts and mitigation (including hydrology, geomorphology, sedimentation, fish passage, water quality, and flooding); and
- General construction impacts and mitigation.

12.2 Regional Surface Water Systems and Catchment Context

The McArthur River is the major surface water feature in the region and is relatively large for the tropical north of Australia, with a total catchment area of approximately 20,000 km^2. The catchment drains from the headwaters in the Barkly Ranges and flows north-east to the Gulf of Carpentaria at the Sir Edward Pellew Group Islands (Figure 12.1). The river falls more than 250 m over its 330 km course.

Approximately half of the river’s catchment is upstream of the mine site. The exclusion of the very small mine footprint (less than 10 km^2) from a 10,000 km^2 catchment will have no significant effect on river flows.

Major tributaries in the McArthur River Catchment include the Glyde River, Kilgour River, Tooganginie Creek, and Batten Creek.



Horizontal Datum: AGD84, Zone 53

Source: This product incorporates data which is:
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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

REGIONAL CATCHMENT MAP

Drawn: VH
Approved: CMP
Date: 15-02-05
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File No: 42625552-g-050.wor
Figure: **12.1**
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The MRM mine site is situated adjacent to the McArthur River, in the middle reaches of its catchment, between the confluences of the Kilgour and Glyde Rivers. The mine site is located approximately 120 km upstream of the river mouth, and approximately 5 km upstream of Bukalara Range. The river bed level in the reach near the mine site is between RL 15 and 19 m.

The existing underground mine is under the McArthur River floodplain, on the north-west side of the main channel. Other streams joining the McArthur River from the eastern side in the vicinity of the mine are Bull Creek and Emu Creek (which will be intercepted by the proposed river realignment) and Glyde River downstream of the mine. Local streams near the mine are shown on Figure 12.2.

12.3 Hydrology

12.3.1 General Hydrology

Climate statistics for the project areas are described in Section 8.1.

Streamflow throughout the McArthur River catchment is highly variable as a result of thunderstorm, cyclone or monsoonal rainfall. The greatest flows occur during the ‘wet season’ which generally extends from October to March. The major wet season flows occur in February and March, however early wet season floods have occurred in December and January and occasionally in November.

Stream flow typically dries up to a series of large isolated pools during the “dry season” between August and September. No flow periods are typically one to two months and can last up to six months. Arnol *et. al.,* (1983) mapped more than 1,000 waterholes and lagoons along the major streams and floodplains. Some tributaries have flow supplemented by natural springs, but this contribution to overall catchment streamflow is small. The size, and mean annual flow of key sub-catchments are presented in Table 12.1.

Table 12.1

Sub-catchments and Annual Flows of the McArthur River Catchment

Catchment	Catchment Area (km^2)	Mean Annual Streamflow (ML/year)
McArthur River at MIM pump site	10,400	487,000
Glyde River at McArthur River Junction	2,500	102,000
Barney Creek at McArthur River Junction	390	32,000
Surprise Creek at McArthur River Junction	100	7,000
Emu Creek at McArthur River Junction	60	2,900
Bull Creek at McArthur River Junction	74	3,600

Source: Estimated from information in Hollingsworth Dames & Moore (1992), Water Solutions Pty Ltd (2001), and Kellogg Brown and Root Pty Ltd (2002).

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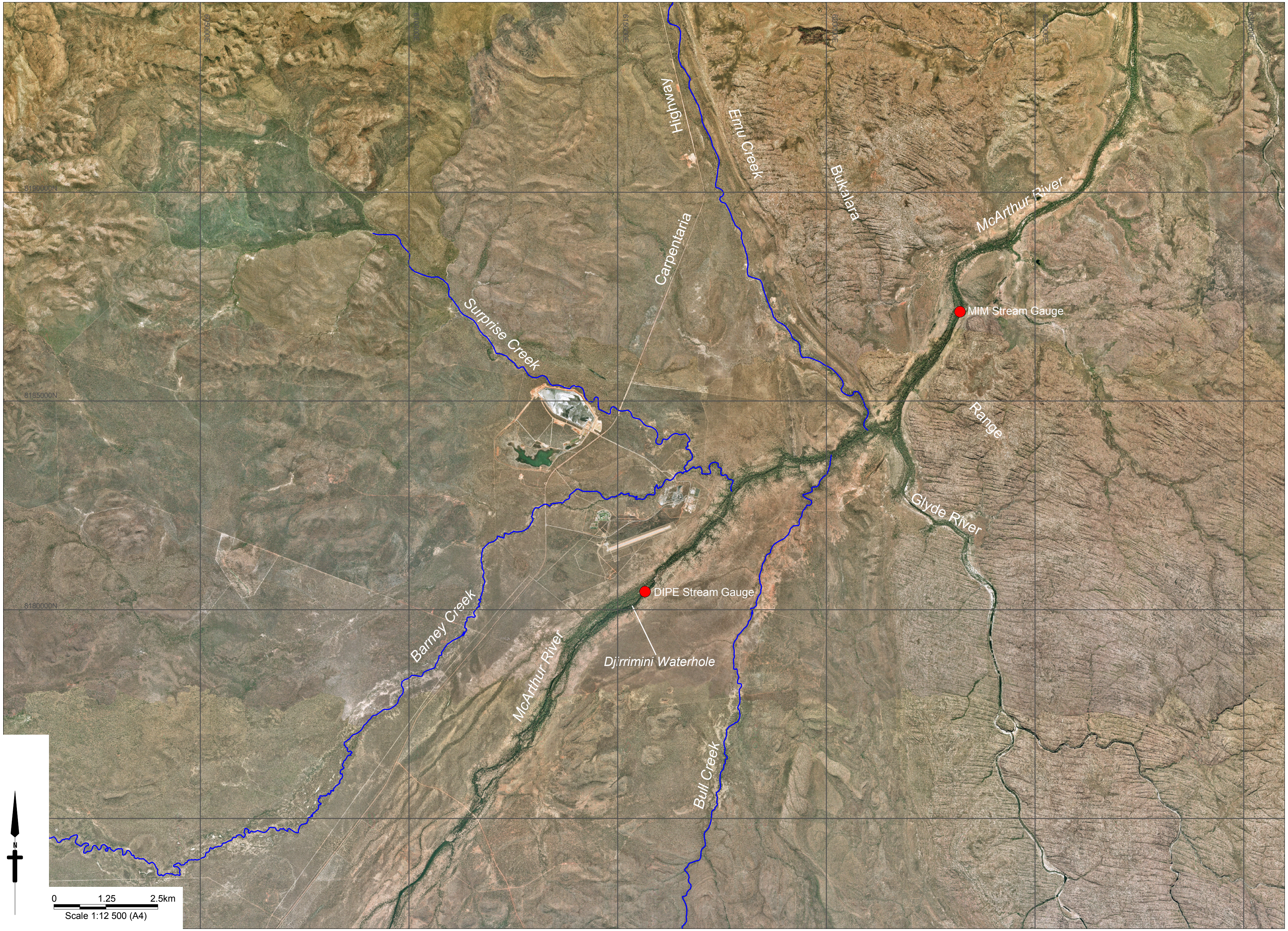

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

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LOCAL WATERWAYS AROUND MINE SITE

Figure: **12.2**

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12.3.2 Flood Hydrology of the McArthur River

Floods in the McArthur River are large and highly variable. Peak flow of up to 6,200 m^3/s was recorded during floods in February 1975 near the mine site (DIPE stream gauge – refer Figure 12.2). The floodplain is regularly inundated up to 5 m deep, and rises in flood levels of 5 to 7 m over 24 hours are not uncommon (Hollingsworth Dames & Moore, 1992). Flooding in the vicinity of the mine is influenced by a narrowing of the floodplain at the Bukalara Range, 3 km downstream of the confluence with Barney Creek (KBR, 2003).

On 7 January 2003, the largest flood in the past 15 years was observed and recorded at the mine site. The flood occurred from persistent rainfall over a seven day period, and a peak flood flow of 4,720 m^3/s was recorded near the mine (KBR, 2003). Design flood hydrology estimates of peak flood flows in the McArthur River have recently been updated by taking account of the 2003 flood event. Empirical relationships to estimate the likely peak flood flows at various locations along the river (related to catchment area) have also been reported by KBR (2003). Design peak flood estimates for the McArthur River are presented in Table 12.2, and peak flows for the 2003 flood event are presented in Table 12.3. A flood frequency plot of the design peak flood estimates is presented in Appendix K.

Table 12.2

McArthur River Floods – Design Peak Flow Estimates

Catchment Location	Catchment Area (km^2)	Peak Flood Flows (m^3/s)				
		Average Recurrence Interval (ARI) (years)				
		500[1]	100[1]	50	5	2
DIPE Stream Gauge (near upstream end of proposed realignment)	10,400	19,000	9,300	6,500	1,300	460
Downstream end of proposed realignment	11,160	20,000	9,700	6,800	1,400	480
MIM Stream Gauge (downstream of Glyde River confluence)	13,690	24,000	12,000	8,100	1,600	550

Source: adapted from Kellogg Brown and Root Pty Ltd (2003).

Table 12.3

Recorded and Estimated Peak Flows for the January 2003 Flood Event

Catchment	Catchment Area (km^2)	Peak Flow (m^3/s)
DIPE Stream Gauge (near upstream end of proposed realignment)	10,400	4,720[1]
Downstream end of proposed realignment	11,160	4,900[2]
MIM Stream Gauge (downstream of Glyde River confluence)	13,690	5,600[2]

[1] Recorded peak flows

[2] Estimated peak flows inferred from derived empirical equations reported by KBR (2003).

12.3.3 Wet Season Hydrology during Periods of Fish Movement

Biological studies (Section 13.5.4) have identified that the McArthur River channel supports fish migration between freshwater and estuarine reaches (to the north of the mine) mainly for breeding purposes. Characterisation of the existing hydrological conditions occurring during fish migration is therefore of interest to guide and evaluate the design and mitigation/management requirements to maintain fish migration in the proposed realigned channel.

Several studies of fish biology in the McArthur River have been undertaken however there is no published information on the specific behavioural patterns of fish migration correlated to river flow conditions. Anecdotal observations and knowledge among fish biologists and recreational fisherman suggests that the typical behavioural pattern of the diadromous species (those that migrate between freshwater and estuarine areas, mainly for breeding purposes) is downstream migration of adult fish in the early wet season (December to January) and upstream migration of juvenile fish in the late wet season (around April). These fish migration responses are unlikely to be specific to a certain month and rather are likely to be in response to flow events, or water temperature and other abiotic stimuli. Additionally, it is also believed that fish species do not migrate during peak flood periods particularly when flow velocities are high (Cotterell, 1998) and flood waters naturally carrying sediment load increase the water's natural turbidity.

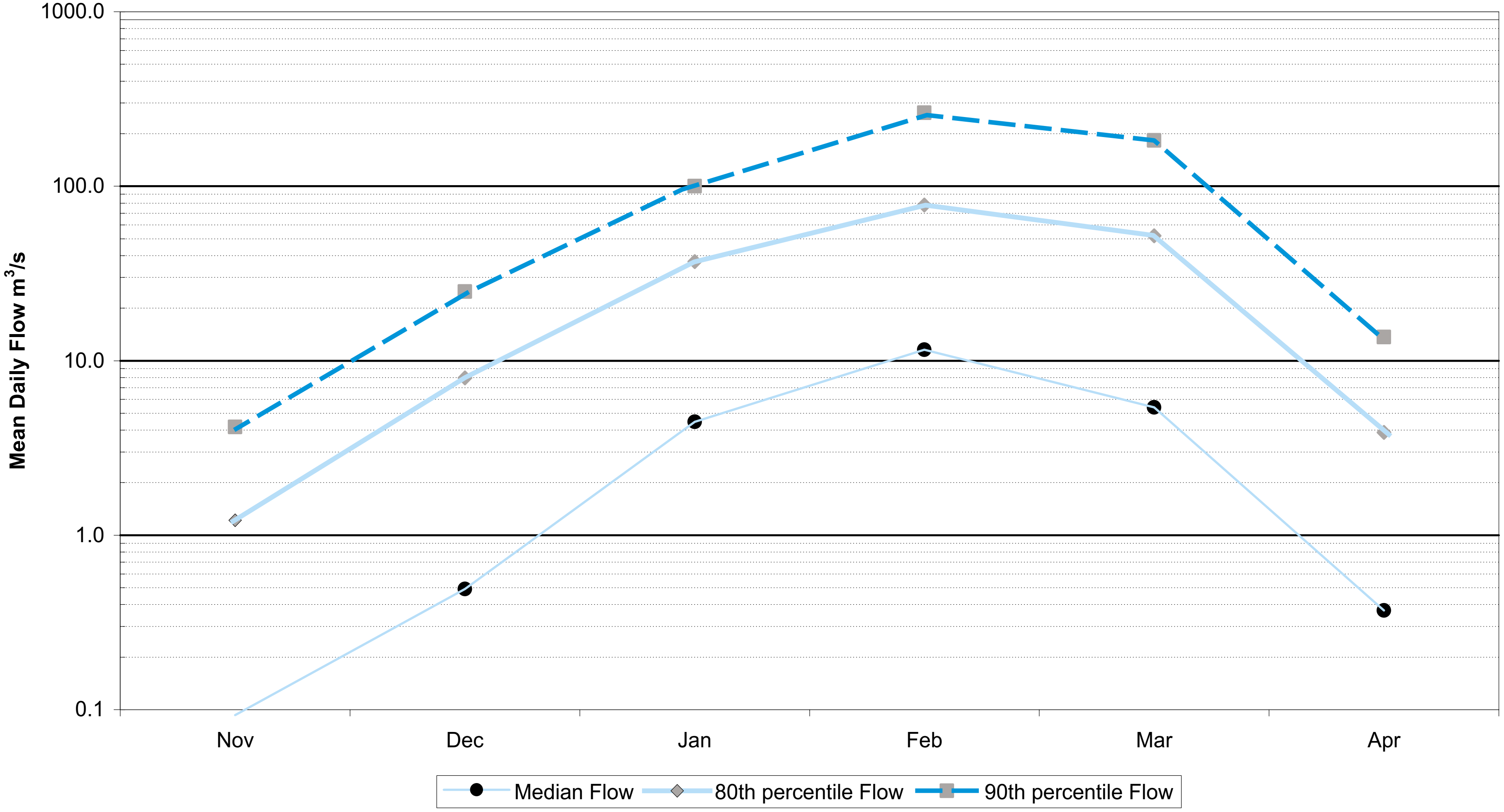
Streamflow data for the McArthur River recorded between 1970 and 2002 were assessed to characterise the variability of flow across wet seasons. The statistical flow duration data are presented in Table 12.4 and shown graphically on Figure 12.3. Recorded data at the DIPE stream gauge do not provide a continuous period of record, however the available data (Table 12.4) provide sufficient representation to characterise typical flow conditions.

Table 12.4

Daily Average Streamflow (m^3/s) in McArthur River during Wet Seasons
1970 to 2002 at DIPE Stream Gauge

Flow Statistic Description	Daily Average Streamflow (m^3/s)					
	Nov	Dec	Jan	Feb	Mar	Apr
Median Flow (50% of flows during month are below this flow)	0.1	0.5	4.5	12	5.4	0.4
80th Percentile Flow (80% of flows during month are below this flow)	1.2	8.0	37	78	52	3.9
90th Percentile Flow (90% of flows during month are below this flow)	4.2	25	100	264	183	14
95th Percentile Flow (95% of flows during month are below this flow)	13	54	324	588	388	25
Available daily flow data as % of total sample period	73 %	80 %	82 %	74 %	75 %	77 %

McArthur River - Monthly Variation of Daily Flows
DIPE Stream Gauge 1970 to 2002



MCARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

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STATISTICAL VARIATION OF DAILY RIVER FLOWS DURING WET SEASON

Figure: **12.3**
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12.4 Declared Beneficial Uses

As discussed in Section 12.7.1, the declared beneficial uses for the McArthur River and its catchment are “Aquatic Ecosystem Protection” and “Recreational Water Quality and Aesthetics”. There are no RAMSAR listed wetlands in the catchment.

Surface water resources in the catchment are limited to streamflow during the wet season and ponds during the dry season. There are no constructed storages of any substantial size in the catchment. The main economic uses of surface water are for livestock watering (sourced from run-of-river flows) and to support the local fishing and tourism industry. Minor surface water flow is intercepted on Barney and Surprise Creeks for reclamation and utilisation as process water at the MRM mine. An existing approval to abstract surface water from the McArthur River has not been utilised to date.

12.5 Local Surface Water Systems

12.5.1 Mine Site

At the MRM mine, existing mine infrastructure is located on a low hill (Mt Barney) between the confluence of several minor streams (Surprise Creek, Barney Creek) and the McArthur River.

Flows in Surprise Creek and Barney Creek are more variable than flow in the larger McArthur River. With smaller catchment areas contributing to these creeks, the magnitude of total annual streamflow and floods is less than the river. The creeks also have minimal base flow (sustained flows receding after moderate and large flow events).

The mine occupies a small portion of the sub-catchments of Surprise and Barney Creek, and the current operations have no significant impacts on the general flow hydrology of these creeks.

12.5.2 Bing Bong

The Bing Bong port facilities are located on dunes and beach ridges adjacent to tidal mud flats along the coastline of the Gulf of Carpentaria. The site does not intersect any natural drainage lines. The main drainage lines beyond the site are Mule Creek to the east and Bing Bong Creek to the north.

The area is subject to storm surges associated with cyclones. Surges of 3 to 4 m have been observed in the area and current infrastructure at the site has been designed to accommodate these extreme events.

12.6 McArthur River Geomorphology and Flooding

12.6.1 Overview

The existing geomorphology and flooding hydraulics of the McArthur River near the mine site have been assessed to ascertain the likely stability impacts of the proposed river realignment and associated mitigation strategies.

In general, geomorphology characterises physical features of the broad landscape and processes that form and modify the landscape. In this EIS, the surface water aspects of geomorphology relevant to the open cut project have focussed on the existing form of the river's main features (channel and floodplain) and the associated hydraulic and fluvial processes that sustain its current form and on-going development (fluvial geomorphology).

Fluvial geomorphology is a specific aspect of river form and behavior, including the processes that govern changes in the physical shape and form of rivers. Environmental variables such as geology, topography, soils, vegetation, hydrology and land use are relevant to the river forming processes. Assessing a river's fluvial geomorphology allows it to be viewed as part of a system rather than operating as a discrete environmental variable.

12.6.2 Morphological Features of the Broader McArthur River

Stream geomorphology of the McArthur River varies from a single main channel in the upper reaches of the catchment to braided channels and floodplain systems in the lower reaches from its confluence with Tooganginie Creek to the tidal limit just south of Borroloola.

For most of the year, small and moderate streamflow through the braided parts of the river system are confined to a single channel. During floods, the main channel overflows and spread across the floodplain into a series of minor channels (known as flood runners) on either side of the main channel.

Tidal influences extend 60 km up the McArthur River to near Borroloola. Tidal influences are less pronounced during the wet season when river levels are high. River flows discharge into the Gulf of Carpentaria near the Sir Edward Pellew Group of islands through a delta containing three main tidal channels and several anabranch channels. The delta and alluvial landforms are geomorphologic evidence of a long history of sustained natural sediment transport from the catchment to the coast.

12.6.3 Morphology of the Central Reaches of McArthur River

Assessment Methods

Available topographic and aerial photographic data, supported with field reconnaissance and photographs of the main river channel at various locations, were used to assess a 45 km reach of the McArthur River extending upstream and downstream of the mine site. The subject reach is generally the central reach in the broader catchment and is shown on Figure 12.4. Qualitative and quantitative parameters were assessed.

The qualitative assessment classified the stream characteristics including the main channel, benches and terraces (if any), the floodplain, density and type of vegetation, sediment deposition areas, location of scour, channel patterns (e.g. meanders, braiding), flood runners, and anabranches.

The quantitative assessment considered key hydraulic parameters. For this analysis, the sinuosity of the river, the shear stress and stream power along the channel for various flood flow rates were assessed. The river reach was analysed quantitatively using a mathematical hydraulic model for a range of flood flows (listed in Table 12.2). These quantitative assessment parameters have been used to determine the existing regime of the McArthur River such as its existing potential to aggrade or degrade the channel bed and/or banks. A detailed description of the mathematical hydraulic modelling is presented in Appendix K.

General Form of the Main River Channel

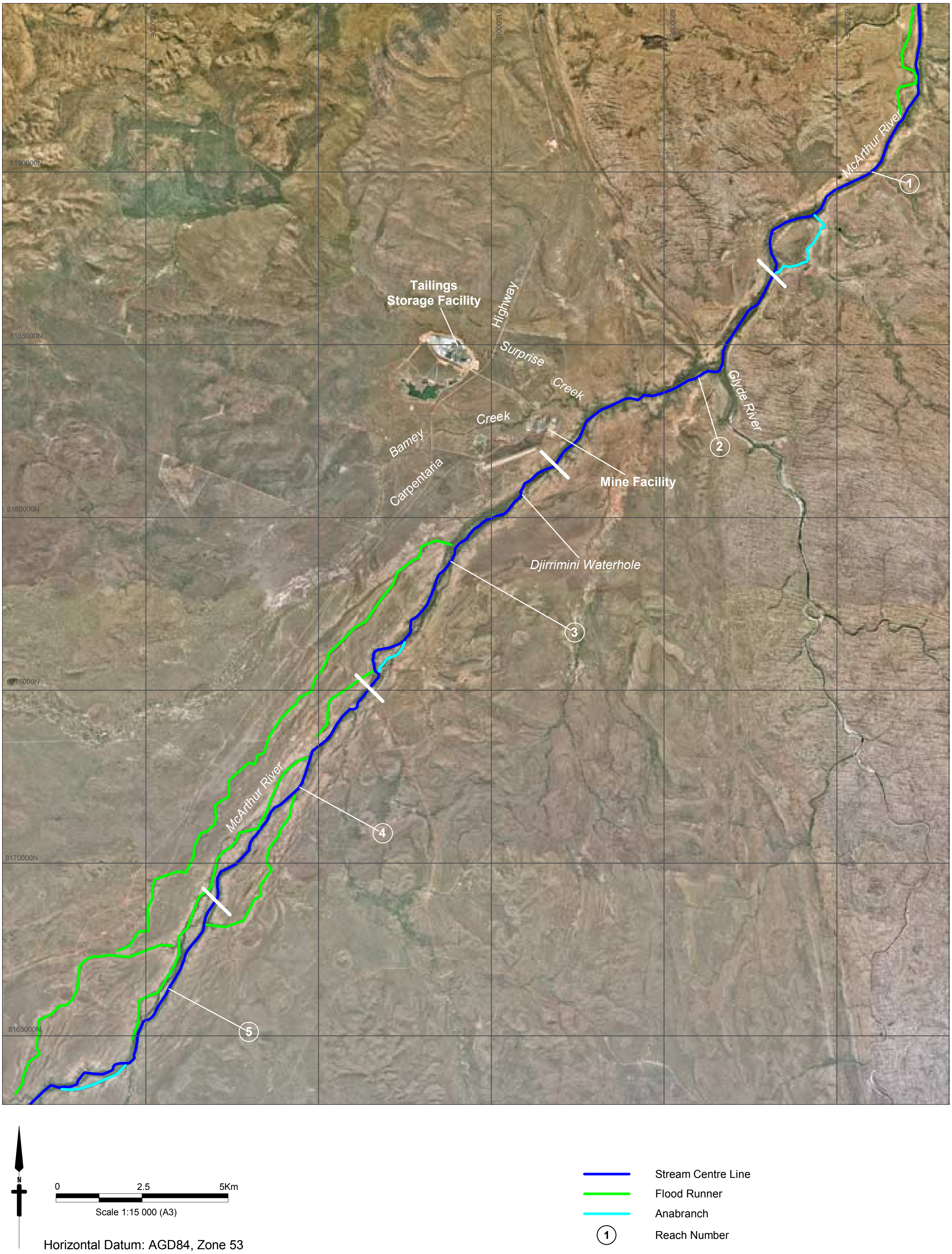
The 45 km stream reach was divided into five reaches of approximately the same stream length as shown on Figure 12.4. In general, several of the river reaches have similar features and can collectively be described.

The downstream reach (Reach 1 – 10.3 km) consists of a regular channel pattern (low sinuosity) due to the sedimentary bedrock where the river passes through the Bukalara Range. The main channel is well defined and deeply incised into the bedrock with small less defined floodplains. Relatively dense vegetation surrounds the main channel and relatively sparse vegetation exists across the adjoining floodplains. Key dimensions of the main channel in this reach are:

- Longitudinal bed slope is approximately 0.0003 m/m (1 in 3,000).
- 2-year ARI flood channel depth varying between 6 to 9 m.
- 2-year ARI flood inundation is approximately 100 m wide.
- A flood terrace for the 2-year ARI flood is present on one side, or spread across both sides of the main channel. The terraces are not continuous along the river and have typical inundation depths in the order of 2 to 5 m in small frequent floods (2 to 5-year ARI).
- Main flood channel top width is approximately 300 m and its overflows onto a restricted floodplain in floods between 2-year and 5-year ARI.
- The floodplain width does not vary significantly between the 5-year ARI flood and the very rare 500-year ARI flood events.

The upstream reach comprises the upper 35 km (Reaches 2 to 5) which includes the mine site and proposed channel realignment. The main channel through the upper reach consists of irregular sinuous meanders where the river passes over thin alluvium overlying bedrock beneath the river valley.

The main channel is generally well defined with a low flow channel incised in the bed of a major flood channel. Key dimensions of the main channel in Reaches 2 and 3 near the mine are:



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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

GEOMORPHOLOGICAL ASSESSMENT OF CENTRAL REACH OF McARTHUR RIVER

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Figure: **12.4**

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- The broad average longitudinal bed slope is approximately 0.0003 m/m (1 in 3,000) and the river bed is steeper (at 1 in 1,000 – as determined from field survey) in the local vicinity of the proposed channel realignment.
- 2-year ARI flood channel depth varying between 5 to 11 m. The channel entirely contains the 2-year ARI flood in some sections, while in other sections, secondary overflow channels (flood runners, braided channels and/or discontinuous hollows, and flood benches) assist the main low flow channel to convey these small floods.
- 2-year to 5-year ARI flood inundation varies between 100 m and 350 m wide.
- Main flood channel is approximately 300 m wide and overflows onto an extensive floodplain in floods greater than 2-year or 5-year ARI.
- The floodplain width varies significantly between the 50-year ARI flood (3 to 4 km) and very rare 500-year ARI flood events which inundate floodplain areas up to 6 km wide or more.

In Reach 2 (near the mine), the main channel has terraces adjoining the main low flow channel approximately 5 to 10 m above the bed. These terraces typically vary from 40 m to 80 m wide (KBR, 2005) and generally do not appear to be continuous along the river. Higher level terraces are also evident about 15 m above the river bed, and the main channel top width at flood levels which commence to overflow onto the broader floodplain is typically 200 to 250 m.

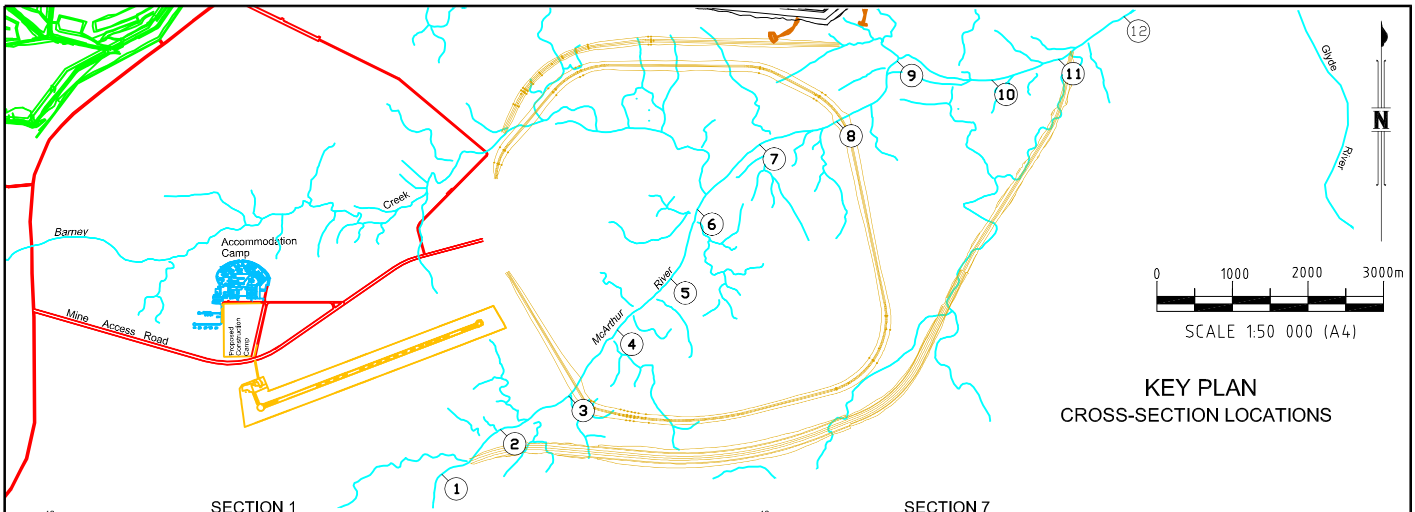
Main Channel – Local Reach

In the local reach of the McArthur River, the size and form of the existing river channel are of interest to ensure that the proposed channel realignment design reflects the natural form and size of the existing river. Detailed ground-based survey, field inspections and photographs were used to characterise the existing river channel. This information is presented in Figure 12.5.

The existing McArthur River channel in the reach that will be realigned can be characterised as:

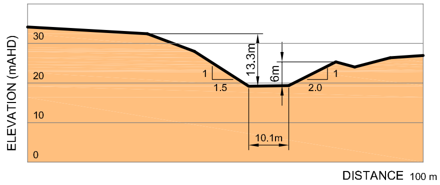
- Consistent trapezoidal channel section with flat bed and steep banks;
- Bed width in the range of 10 to 20 m;
- The slope of channel banks varies from 1(V) in 1.4(H) to 1(V) in 3(H), and typically at 1(V) in 2(H) for most of the channel length; and
- Channel depth to lowest terrace level in the range of 4 to 8 m above the bed, with the majority of terraces being at least 6 m above the river bed.

The bed of the low flow channel has minimal vegetation and primarily consists of a sandy-silty or clay bed with scattered large woody debris and snags at regular intervals along the reach (Figure 12.5). Sandy deposits along the river bed are generally loose (unconsolidated) and appear to be dynamic in response to individual flood and small flow events. The general channel bed substrate is shallow alluvial deposits of sand, silt, and clay overlying bedrock. In some locations such as near Djirrinmini Waterhole (Figure

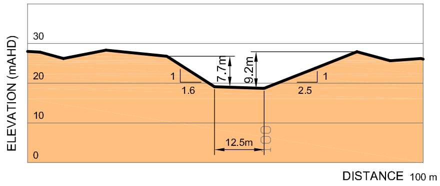


KEY PLAN
CROSS-SECTION LOCATIONS

SECTION 1



SECTION 2



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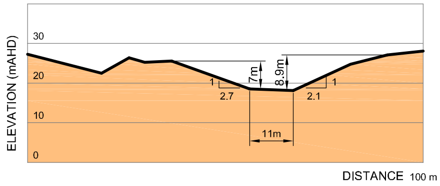

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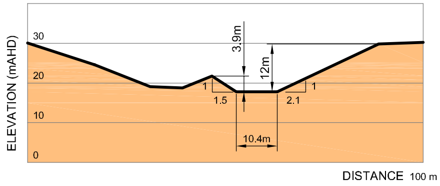

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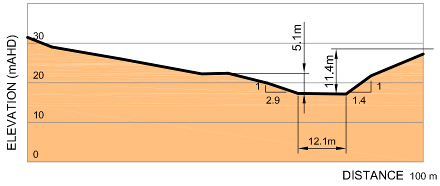

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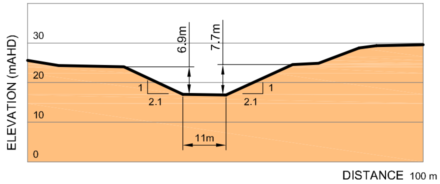

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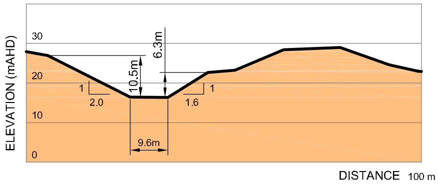

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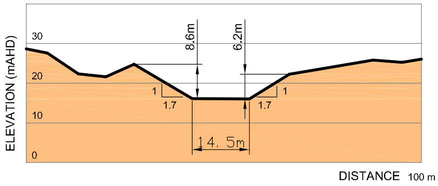

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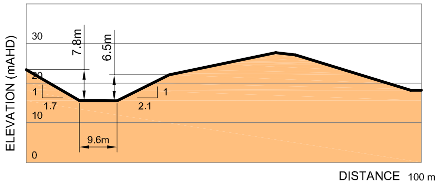

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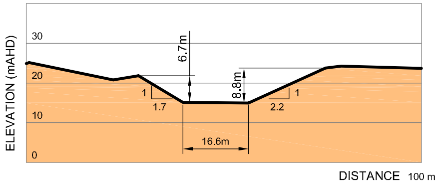

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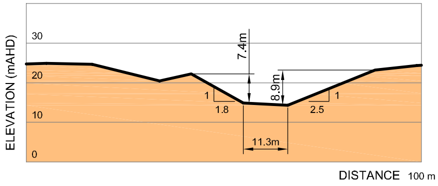
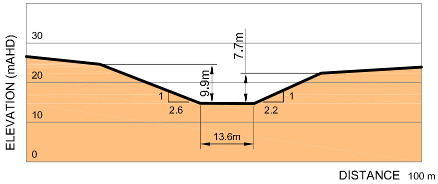


SECTION 12



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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

TYPICAL McARTHUR RIVER CROSS SECTIONS

Drawn: VH	Approved: CMP	Date: 25-07-2005	Figure: 12.5	Rev. B
Job No.: 42625552	File No.: 42625552-g-067b.dwg			A4

13.7) and adjacent/downstream of the mine (Sections 2, 7, 9 – Figure 12.5) the underlying bedrock is exposed at the bed and/or lower banks and forms localised riffles (hydraulic controls).

The banks of the existing river channel have moderate to dense vegetation which becomes sparser with increasing distance/height away from the river channel. The geomorphologic significance of the existing river bank vegetation includes, influences on flow hydraulics (particularly to reduce flow velocity and stream power), protection against erosion (roots act to 'reinforce' of soil structure), and enhancing the trapping of sediment from upstream sources.

Broader Floodplain Features

Throughout most of its course, the McArthur River main channel overflows during floods and spreads floodwaters laterally across the floodplain for several kilometres. In some areas the floodplain contains a series of flood runner channels on one or both sides of the main channel. The flood runner channels traverse the floodplain parallel to the main channel and provide additional flood conveyance when the main channel overflows. Flood runner channels have been identified in Reaches 1, 4 and 5, as shown on Figure 12.4. No major flood runner channels have been identified in the immediate vicinity of the mine (Reaches 2 and 3).

Bukalara Range immediately downstream of the mine is a major floodplain constriction.

Channel Anabranches

There are two locations in the upper reaches where there is evidence of the potential formation of anabranches. Anabranches are a channel feature that can split the main channel flow into a series of braided channels, and over time can preferentially direct more of the main channel flow into an overflow channel or flood runner channel causing these channels to become the new main channel. The formation of anabranches is a function of the frequency and magnitude of flooding, sedimentation rates, and the river's energy capacity to create a 'shortcut' through more hydraulically efficient sections of the floodplain channels or overflow channels.

One potential anabranch feature has been identified near the upstream end of the study reach (Reach 5) and a second anabranch feature is evident approximately 5 km upstream of the mine (Reach 3). Hydraulic modelling shows that the flood runners in the floodplain and the anabranches generally do not convey flow until streamflow in the main channel exceeds approximately 500 m^3/s which corresponds approximately to a 2-year ARI flood event.

Channel Meanders

The degree of meandering of the main channel can be described as the sinuosity of the river. The sinuosity is the length of the flow channel between two points divided by the straight-line length between the same two points. A sinuosity of 1.0 indicates that there is no meander in the channel.

An assessment of sinuosity (Table 12.5 and Figure 12.4) shows that the McArthur River through the 45 km study reach has low sinuosity that varies between 1.05 and 1.14, with an average sinuosity of 1.10.

Reach 2 (the location of the proposed channel realignment) has an existing sinuosity of 1.08 which is marginally lower than sinuosity of reaches upstream (1.10) and downstream (1.14). This observation is consistent within the broader context of this channel reach which is deeply incised upstream of its passage through Bukalara Range.

Table 12.5

Sinuosity as Measure of Meandering along the McArthur River - Existing Conditions

Reach No	Stream Length (km)	Straight Line Distance (km)	Sinuosity
1	10.3	9.0	1.14
2	9.1	8.4	1.08
3	9.2	8.4	1.10
4	8.0	7.6	1.05
5	8.8	8.0	1.10
Average	-	-	1.10

The proposed realignment of the McArthur River will add approximately 400 m to the river length. This will increase the sinuosity of Reach 2 from 1.08 to 1.13. This increase is minor and the sinuosity of the river will remain consistent with upstream and downstream reaches.

Assessment of Existing River Hydraulics

A one-dimensional hydraulic model (HEC-RAS) was developed to assess the hydraulic conditions of the 45 km reach of the McArthur River for existing conditions. The purpose of the hydraulic analysis was to quantify key hydraulic parameters for a range of flood events and compare the hydraulic results to the qualitative geomorphologic assessment. The model was calibrated for flood flow conditions to observed flood levels for the 2003 flood event, and for low flow conditions (of interest for fish passage) to the rating curve from the DIPE Stream Gauge located upstream of the mine. Description of the model development and calibration is presented in Appendix K.

Hydraulic parameters of interest to characterise the frequent river flood hydraulics and their river flow correlation with geomorphology are channel flood velocity, shear stress, stream power, and sediment transport capacity. These are described as follows:

- Flow velocity (the speed of flow along the river) is commonly used for initial assessments of the potential for erosion.
- The bed shear stress represents the force between the river flow and resistance to flow provided by the bed and banks of the river channel. Shear stress is commonly used to determine the potential for sediment movement.
- Stream power provides the most reliable indicator of the potential for the river channel to erode based on the energy dissipation rate of flow along the river. It is a measure of the rate of work done by the river flow and is calculated as the product of shear stress and velocity.

- Sediment transport capacity is a measure of the river channel's potential to carry sediment. It is important to note that sediment transport capacity is not a measure of the actual sediment transport for a specific flow. The actual sediment transport for a specific flow event is related to the rate of sediment supply from the upstream catchment, potential to obtain sediment by erosion of the river if sediment supply is deficient, and the sediment transport capacity of the river flow. These relationships can be highly dynamic and variable even for similar magnitude flood events. Erosion and sedimentation of the river is strongly influenced by the relationship between actual sediment transport/supply and the flow's sediment transport capacity such as:
    - When the actual sediment transport is less than sediment transport capacity, the river flow will attempt to source additional sediment by erosion of vulnerable areas (where flow stream power exceeds the erosion resistance of the bed/bank substrate). In river systems with substantial riparian vegetation, the actual sediment transport can often be less than the sediment transport capacity due to limited potential for the flow to obtain sediment to achieve its sediment transport capacity.
    - When the actual sediment transport is greater than the sediment transport capacity, the river flow will reduce it sediment load by deposition along the river bed.

Longitudinal profiles of the existing river flow velocity and stream power for the 2, 50 and 500-year ARI floods are presented in Figure 12.6 and are summarised in Table 12.6. Additional hydraulic profile plots for all parameters and all analysed flow cases are presented in Appendix K.

Table 12.6

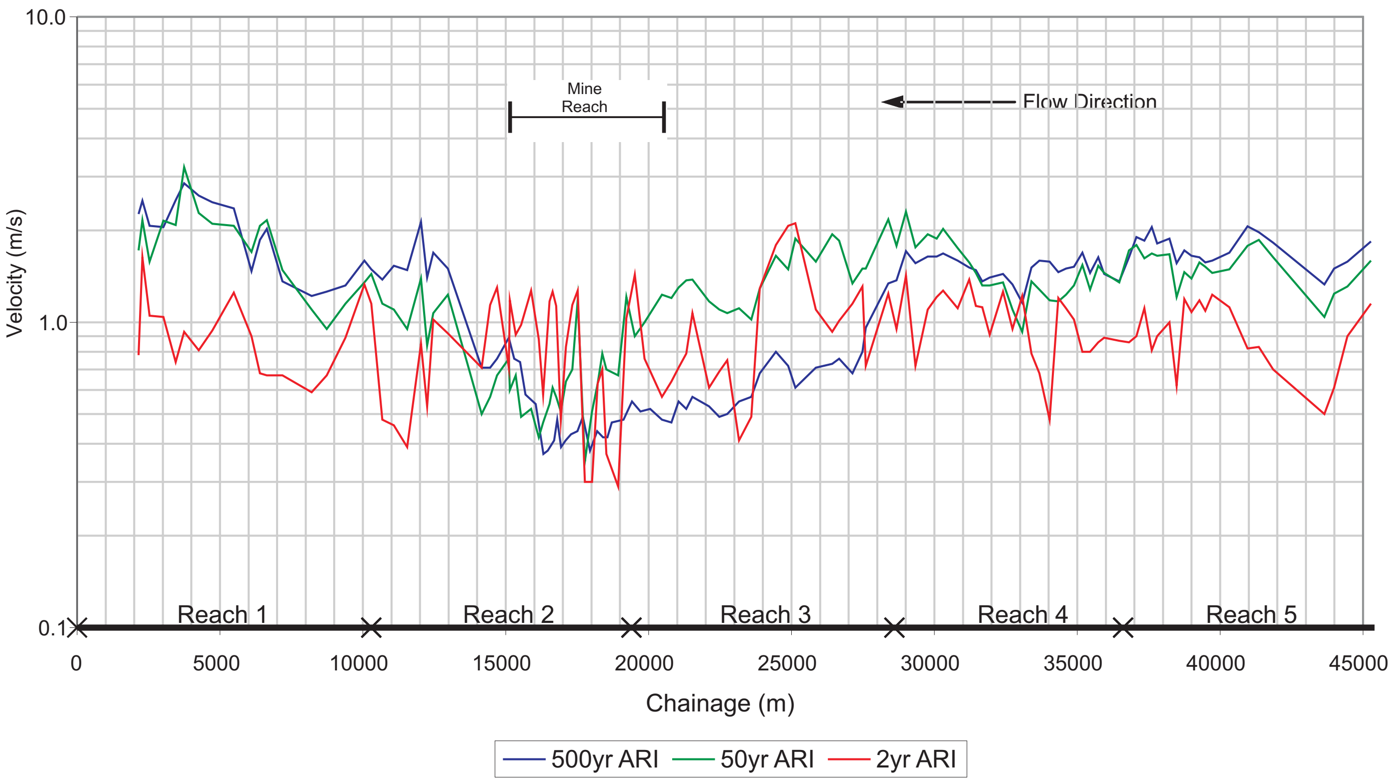
Summary Flood Hydraulics for Existing McArthur River

Hydraulic Parameter (Main Channel Flow)	Flood Event ARI	Upstream of Mine	Mine Reach	Downstream of Mine
Velocity (m/s)	2 year	0.5 – 2.1	0.3 – 1.4	0.4 – 1.6
	50 year	0.9 – 2.3	0.4 – 1.4	0.8 – 3.2
	500 year	0.7 – 1.7	0.4 – 0.9	0.7 – 2.9
Stream Power (W/m^2)	2 year	5 – 350	1 – 100	2 – 160
	50 year	25 – 350	1 – 70	3 – 800
	500 year	5 – 230	1 – 10	10 – 500
Maximum Sediment Transport Capacity (1) (t/day)	2 year	3,700,000	400,000	1,300,000
	50 year	5,500,000	300,000	26,000,000
	500 year	2,700,000	15,000	10,000,000

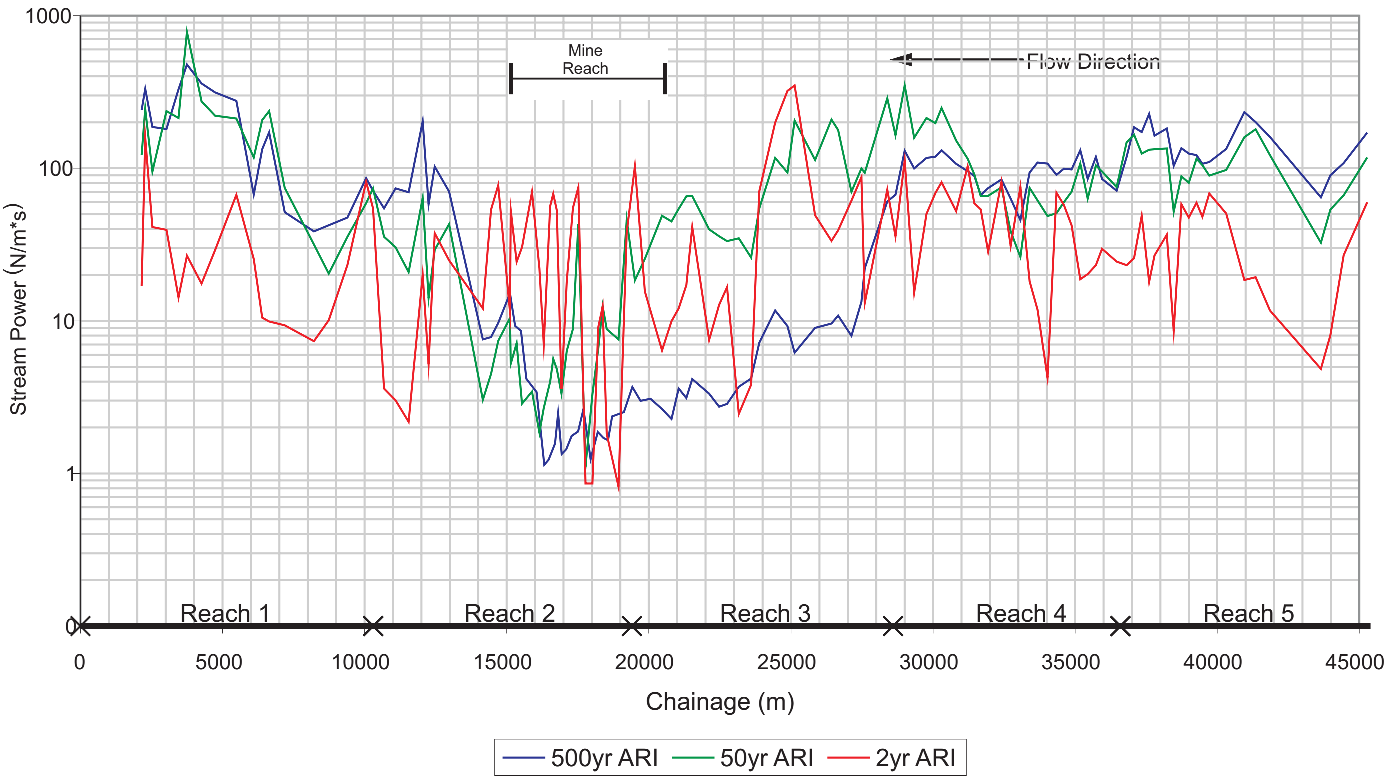
Note (1): Maximum Sediment Transport Capacity for Specified Sediment Particle Size Distribution – Refer Appendix K

Overall River Channel Stability

A summary of the hydraulic modelling results (Table 12.6, Figure 12.6) shows that Reach 2 (near the mine and proposed channel realignment) currently has a lower flow velocity and stream power than the reaches upstream and downstream for a range of flood events. The reach downstream of the mine



FLOW VELOCITY FOR EXISTING CONDITIONS



STREAM POWER FOR EXISTING CONDITIONS

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

EXISTING RIVER FLOW VELOCITY AND STREAM POWER PROFILES

Drawn: VH	Approved: CMP	Date: 25-07-05	Figure: **12.6**	Rev. B
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through the Bukalara Range has the highest stream power, which is consistent with the narrower floodplain, compared to the reaches upstream which have broad areas of floodplain inundation in large flood events.

The McArthur River reach near the mine currently has a lower hydraulic potential for erosion and a higher potential for sedimentation than the upstream and downstream reaches. Thus the mine reach is much less prone to erosion than other reaches upstream and downstream of the mine. This conclusion is also supported with historical cross-section surveys in 1975, 1986, and 1992 of the McArthur River channel at the DIPE Stream Gauge (MIM Pump Station) that show no change in the river cross-section in the last 30 years (cross-section plots are presented in Appendix K).

12.7 Existing Surface Water Quality

12.7.1 McArthur River Water Quality Monitoring Program

The declared beneficial uses for the McArthur River and its catchment are “Aquatic Ecosystem Protection” and “Recreational Water Quality and Aesthetics”. These environmental values are important to guide assessments of existing surface water quality. The current river system is considered to be “slightly to moderately disturbed” relative to ANZECC (2000a) water quality guidelines for fresh and marine waters, and the trigger levels for water quality (where ANZECC recommendations are appropriate) apply for 95% level of protection.

Investigations of river water quality prior to the existing mine development generally had limited data which were not sufficient to characterise the natural variability of water quality in the McArthur River. Since the development of the existing mine, a water quality monitoring program has been implemented to assess the water quality of the McArthur River in the vicinity of the mine. Two monitoring sites have been established. Site SW6 is located downstream of the mine and downstream of the Barney Creek junction, and Site SW7 is located upstream of the mine (Figure 12.7). Since 1995, water quality at these sites has been sampled at monthly intervals (when flowing) for the parameters listed in Table 12.7. Analysis of key water quality statistics and trends has been undertaken to determine:

- Median statistics of key parameters, and the 20th to 80th percentile range (Table 12.7);
- Correlation of water quality results with flow at the time of sampling (Figure 12.8); and
- Time series comparison between the upstream and downstream sites (Figure 12.9).

McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

SURFACE WATER MONITORING LOCATIONS

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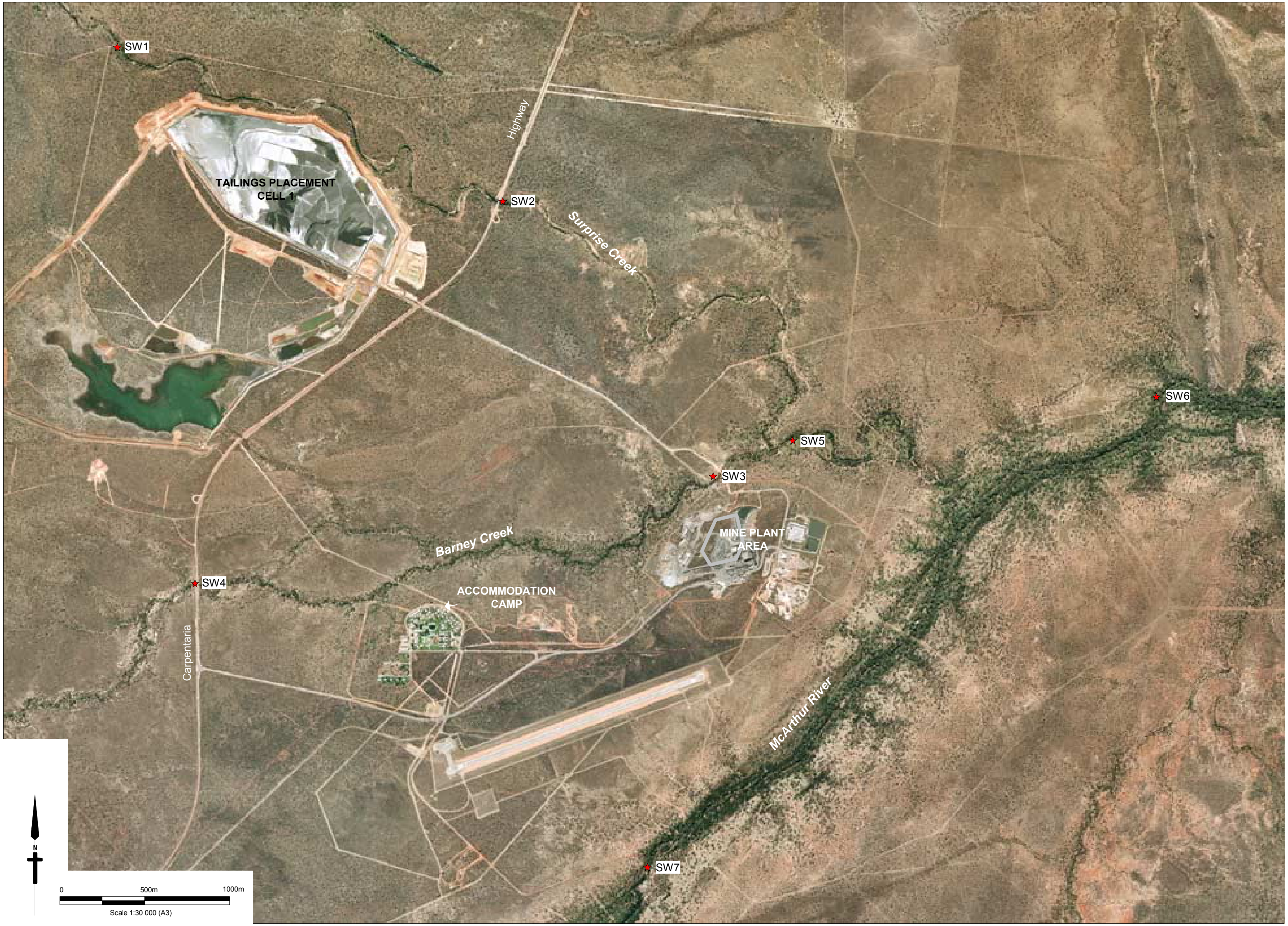
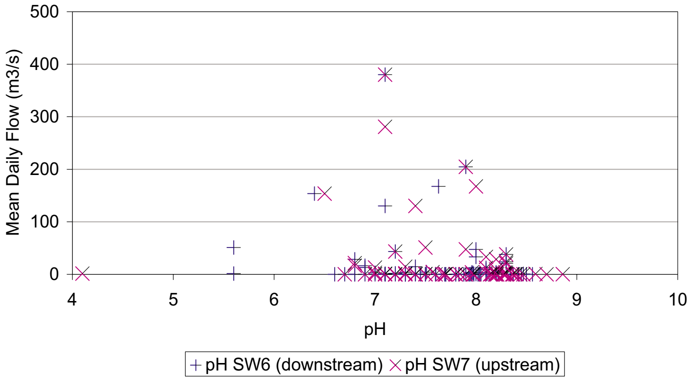


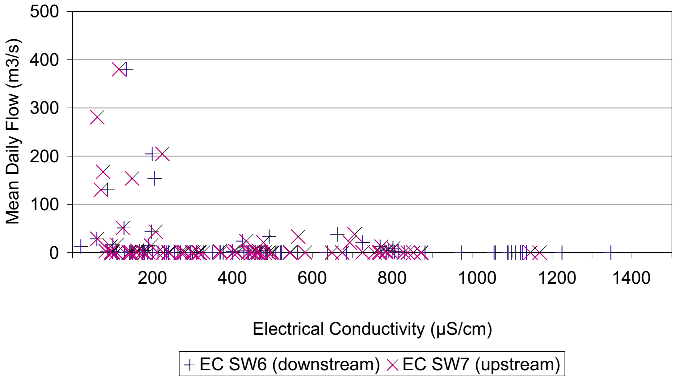
Date of Aerial Photography, 2001

★**SW1** Surface Water Monitoring Location

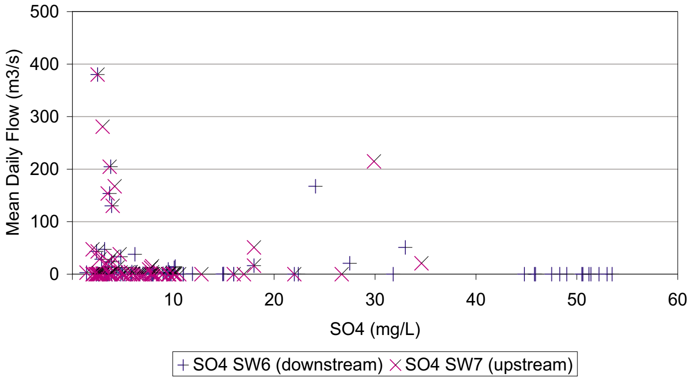
Correlation of pH and River Flow



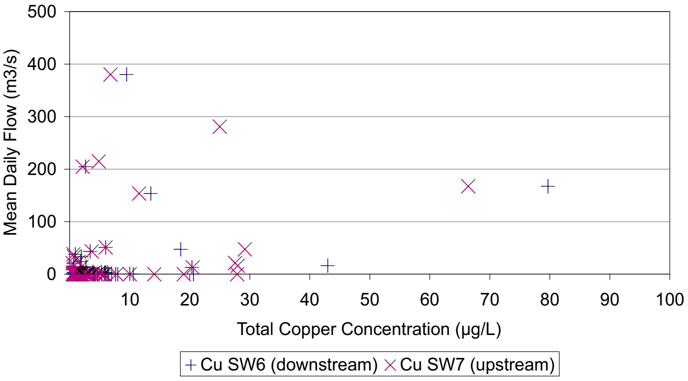
Correlation of Electrical Conductivity and River Flow



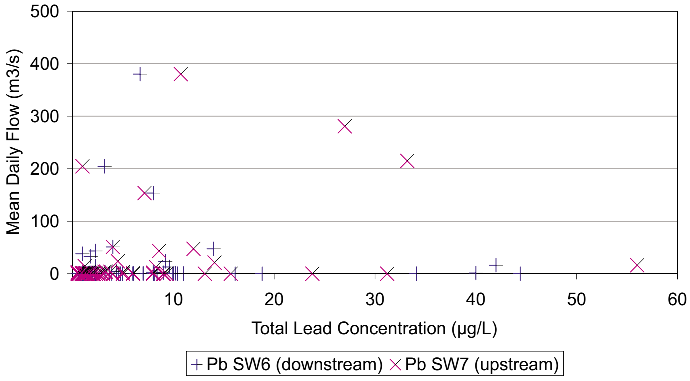
Correlation of SO4 concentrations and River Flow



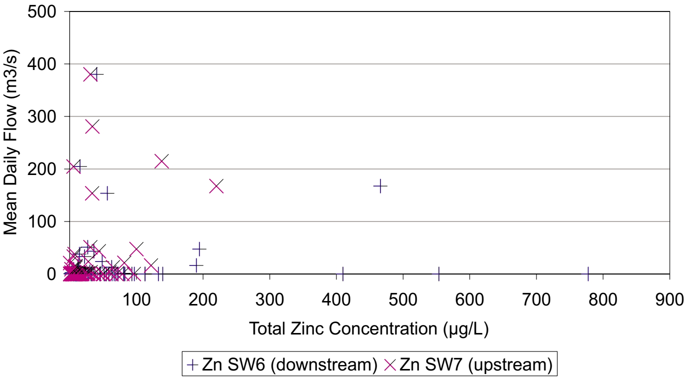
Correlation of Total Copper Concentrations and River Flow



Correlation of Total Lead Concentrations and River Flow



Correlation of Total Zinc Concentrations and River Flow



McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

CORRELATION OF WATER QUALITY WITH McARTHUR RIVER FLOW

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Figure: **12.8**

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

TIME SERIES PLOTS OF WATER QUALITY IN McARTHUR RIVER

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Job No.: **42625552**	File No. 42625552-g-057.cdr	

Figure: **12.9**

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Table 12.7

Statistics of Surface Water Quality in McArthur River (1995 to 2003)

Parameter	SW7 (Upstream)	SW6 (Downstream)
pH	**7.8**[1] (7.2 – 8.3)[2] 92 samples	**7.7** (7.1 – 7.7) 90 samples
Electrical Conductivity (µS/cm)	**350** (140 – 730) 90 samples	**400** (175 – 800) 88 samples
Sulfate (SO_4) (mg/L)	**5.1** (3.0 – 9.5) 86 samples	**8.0** (3.7 – 25.5) 84 samples
Total Copper (µg/L)	**2.2** (1.1 – 5.8) 77 samples	**2.3** (0.9 – 6.0) 83 samples
Total Lead (µg/L)	**3.2** (1.0 – 9.1) 65 samples	**3.9** (1.4 – 9.4) 69 samples
Total Zinc (µg/L)	**9.0** (5.3 – 34.4) 90 samples	**23.0** (8.8 – 71.5) 87 samples

[1] Median values shown in **bold**

[2] 20th to 80th percentile range shown in brackets

Surface water quality in the McArthur River near the mine site is strongly influenced by the seasonal streamflow and generally high ambient levels of metals as total suspended solids (TSS), particularly copper, lead and zinc, in the water and stream sediments. Ambient levels of metals in McArthur River (i.e. flow upstream of the mine not affected by mining activities) are naturally elevated due to the close proximity of mineralised zones to the surface. The metals are contained within or adsorbed onto sediments, so are readily entrained and transported in streamflow. The concentration of metals in streamflow increases in proportion to the sediment load. Sediment loads during floods in the middle reaches of the McArthur River near the mine site can be high with TSS up to 900 mg/L (Hollingsworth Dames & Moore 1992).

pH

Figure 12.9 illustrates seasonal variations in water quality in the McArthur River upstream of the mine site. pH shows an increasing trend during the wet season, typically ranging from 7.0 to 7.5 (neutral) in October to 8.0 to 8.5 (slightly alkaline) by March with a strong relationship to streamflow. pH tends to decrease during high flow periods then increase as streamflow recedes leading up to the dry season, stabilising at around 8.0 to 8.5 in ponds during the dry season. The onset of the subsequent wet season then leads to a reduction in pH. Median pH downstream of the mine site is slightly lower than pH upstream of the mine site. Both sites comply with ANZECC (2000a) guideline trigger levels for freshwater rivers in tropical Australia (guideline range of pH 6.0 to 8.0).

Salinity and Sulfate Concentrations

Salinity and sulfate concentrations are also strongly related to streamflow. Salts tend to accumulate during the dry season as a result of evaporation. Concentrations then decrease during the wet season with dilution and flushing from fresh runoff water. Salinity levels begin to rise again as stream flows decrease toward the end of the wet season due to evaporation and reduced flushing of base flows. Salinity, as measured by *in-situ* Electrical Conductivity normally remains less than 1,000 µS/cm, which is considered to be fresh. The ANZECC (2000a) guideline trigger levels for rivers in tropical Australia have a wide range of uncertainty (range 20 to 250 µS/cm) and are not appropriate for the McArthur River where natural flows upstream of the mine exceed guideline values. Median electrical conductivity measured downstream of the mine is approximately 15% higher than median values measured upstream of the mine.

Sulfate concentrations vary from a minimum of 1 to 5 mg/L during the peak of the wet season to 20 to 100 mg/L during the dry season. There are no recommendations for sulfate concentration trigger levels in the ANZECC (2000a) guidelines. The downstream monitoring site shows median sulfate concentrations approximately 60% higher than the median concentrations upstream of the mine. Natural sulfate sources derived from the geology of Barney and Surprise Creek catchments and minor historical seepage from the existing tailing storage facility into Barney Creek are possible causes of increased sulfate concentrations (and electrical conductivity) in the McArthur River downstream of the mine. The historical seepage problems associated with the proximity of the existing Tailings Storage Facility to Surprise Creek, is currently being addressed as discussed in Section 12.7.2.

Metals

The metals copper, lead and zinc show an opposite trend to salinity with respect to stream flows. Concentrations tend to increase during the peak flows when turbidity levels are highest, consistent with strong metal-sediment attachment. During the dry season, metals precipitate out of the water column and collect in the sediments as a result of the increasing water alkalinity. Copper, lead and zinc levels tend to vary from a low of 1 µg/L toward the end of the wet season to a peak of 20 to 100 µg/L early in the wet season.

Throughout the McArthur River system, concentrations of copper, lead and zinc frequently exceed ANZECC (2000a) trigger values (1.4, 3.4 and 8.0 µg/L respectively). The ANZECC (2000a) guidelines are based on limited data for rivers in the Northern Territory and are considered unsuitable for definitive water quality assessment. In instances (such as at MRM) where adequate local water quality data are available, the ANZECC (2000a) guidelines provide for establishing interim water quality trigger levels for median water quality at a test site (e.g. downstream of the mine) as the 80th percentile concentration at a reference site (e.g. upstream of the mine). Table 12.7 shows that median concentrations of metals at the downstream monitoring site are below the 80th percentile concentrations of metals at the upstream monitoring site. Consequently it is considered unlikely that adverse impacts on aquatic ecosystems have occurred to date from elevated metal concentrations.

MRM is currently working with DBIRD to agree on site-specific trigger values for water quality in the McArthur River (MRM, 2005).

12.7.2 Surprise and Barney Creeks

Water quality in Surprise and Barney Creeks shows signs of elevated lead and sulfate concentrations. Recent monitoring data have shown some elevated lead, zinc and sulfate levels in Barney Creek downstream of the operation, probably as a result of runoff from the processing area, from entrainment in local runoff water of dust accumulated during the dry season, or from historical tailings seepage. Surprise Creek has elevated levels of sulfates, probably sourced from leachate from the northern side of the tailings storage facility (TSF). There is no sign of acidification of waters in local streams as a result of acid drainage.

As discussed in Section 7.3.4, seepage was discovered in Surprise Creek adjacent to the TSF in 1997. Water in the creek was found to contain elevated sulfate concentrations (positive indication of tailings origin) but only background levels of lead and zinc. Regular monitoring of the water in Surprise Creek indicated no or minimal transport of lead and zinc in the water from the tailings. Remedial actions taken as a result of the seepage included pumping of water from the creek back into the TSF, installing a geopolymer barrier wall around the perimeter of Cell 1 fronting Surprise Creek, reducing tailings accumulation in the section of the TSF nearest the creek, and instigation of a groundwater monitoring program. Ongoing management strategies for this seepage are discussed in Section 7.3.4.

12.7.3 Water Quality Influences Downstream of the Mine

Downstream of the mine to Borroloola, the concentration of sediment and metals tends to decline as a result of dilution with cleaner water. Streamflow in the Glyde River generally has lower suspended solids than the McArthur River and lower seasonal variation because the catchment and stream bed has a rocky substrate and is less prone to erosion. In the estuarine reaches downstream of Borroloola, the concentration of suspended sediment decreases rapidly due to flocculation caused by increasing salinity and pH from tidal waters (seawater).

12.8 Existing Water Management Strategy

12.8.1 Existing Mine Site Water Management

Overview

Since the commencement of existing underground mining operations, water management at the mine has been subject to continuous improvement in terms of overall strategies, operation procedures, water management infrastructure upgrades, corrective actions and safeguards. A major aspect of the existing water management system is ensuring flexibility for extremes of drought and flood. It recognises that excessive accumulation of mine waters can have undesirable consequences in extreme storm and rainfall events, particularly in tropical climate areas (DME, 1995). The water management system also recognises that sequences of climate (e.g. prolonged or sporadic wet seasons and successive 'large' wet seasons) may be just as critical for water management as a single extreme rainfall event.

Water Management Model

In 2001, a comprehensive water audit of the existing operation was completed and used to develop an Operation Simulation (OPSIM) model for the site's integrated mine site water management system (Water Solutions Pty Ltd, 2001). The OPSIM model is used to maintain a database of the quantity of water stored in, and moved through, the site's water management system. The model can also be developed with enhanced capabilities to assess water quality from an associated dissolved salts mass balance. The dissolved salts mass balance capabilities of the model are yet to be developed for the MRM mine site, pending on-going water quality data collection and review.

The OPSIM model represents the site's entire water management system and is a superior method of assessing the risk of discharge of dirty mine water to receiving waters, compared to simplistic approaches that use a 'design rainfall event' to determine necessary storage capacities. Specific rainfall events are system inputs which may or may not produce an uncontrolled discharge depending on the preceding storage levels (which are related to preceding rainfall events and event sequences) and the capacity of the water management system. An event of uncontrolled discharge to receiving waters is a system response (the net outcome of the capacity and operation of the water management system). The use of such a model to guide water management is therefore best practice as the real environmental risk to receiving waters is an uncontrolled discharge (system response) rather than a specific rainfall event (system input).

The OPSIM model has been calibrated against available monitoring data representing a wet period (Oct 2000 - Mar 2001) and a dry period (Jan - Oct 2000) (Water Solutions Pty Ltd, 2001).

Water Management Principles

The philosophy and strategy utilised to develop and optimise the mine water management system is based on the following water management principles (MRM, 2005):

- Minimise raw water consumption;
- Maximise the re-use of process water;
- Provide adequate storage for water supply;
- Minimise the generation and release of contaminants, with an emphasis on source control;
- Minimise the retention of 'clean' water;
- Maximise the efficiency of the mine and process water use; and
- Maintain a non-release system for 'dirty' mine waters, except under extreme conditions, as approved.

Mine Water Management System

The current water management system infrastructure and operations are summarised in Table 12.8. A schematic diagram of the existing mine water management system is shown on Figure 12.10. The main components of the system are:

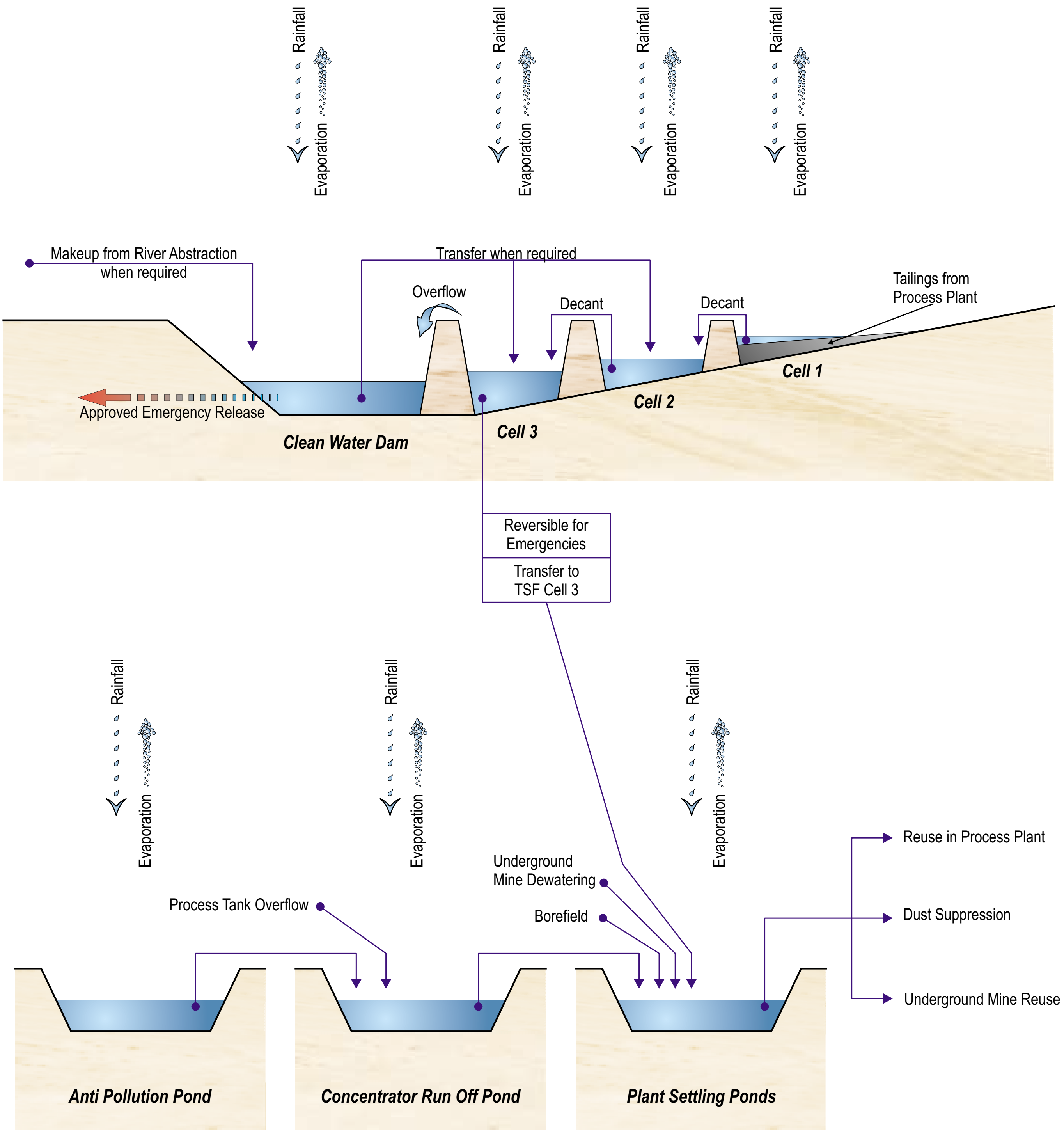
- Bore and potable water system;
- Use of 'natural' surface water;
- Process water and runoff containment system;
- Underground mine dewatering system; and
- Tailings return water system.

The process water component of the existing water management system is essentially a closed water circuit with approximately 80% of process water being recycled through the tailings water system and runoff containment systems. Water losses include moisture locked in tailings deposits, evaporation (as direct surface evaporation, enhanced evaporation by spray irrigation, and dust suppression) and seepage losses. For containment storages that have large catchment areas and hence are vulnerable to rainfall influences, overflows to the receiving environment only occur in very large and rare rainfall events or from rainfall event sequences.

The segregation of the water systems is based on water quality and water use. The catchment segregation at the mine aims to minimise the amount of contaminated water to be handled. Water is also 'harvested' from catchment surfaces for process reuse. Overall, the catchment dams are designed to capture dirty runoff from contaminated areas such as the concentrator, portal area, concentrate sheds and tailings storages. The catchment dams include the anti-pollution pond, concentrator runoff pond, Cell 2 and Cell 3 of the tailings storage facility (TSF), and the clean water dam. The settling ponds are the main storage used to source water for re-use in the process plant and for dust suppression.

With the current water management system, the clean water dam has the largest catchment and is also used to store water abstracted as required from Barney Creek, McArthur River and Little Barney Creek. The inflows to this storage are predominantly clean water. This storage has the greatest potential for overflow and requires an emergency release procedure for managing excessive rainfall inputs. A licensed emergency discharge procedure has been developed for the clean water dam in consultation with the DIPE (waste discharge licence No 103, issued November 2003). The procedure allows for variable flow discharges via pumps and siphons at a rate that must be limited to ensure that the zinc concentration monitored at the downstream McArthur River surface water monitoring site (SW6) does not exceed the concentration at the upstream monitoring site (SW7) by more than 50 µg/L (MRM, 2005). Specific monitoring and reporting procedures are invoked for the emergency discharge procedure. Discharge is not permitted when river flows at the existing DIPE stream gauge are below the 4 m gauge level (flow of approximately 100 m^3/s).

Modelling of the spill risk of Cells 2 and 3 of the existing tailings storage facility indicates an overtopping interval of approximately once in 20 years (MRM, 2005).



McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

SCHEMATIC DIAGRAM OF EXISTING MINE WATER MANAGEMENT SYSTEM

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The anti-pollution pond which collects runoff from around the underground portal has a small holding capacity and a large pumping capacity to transfer waters to the concentrator runoff pond. The operational procedures ensure priority of removing waters from this storage to maintain buffer storage capacity. The total storage capacity of the anti-pollution pond is sufficient to contain a 1 in 10-year – 1 hour rainfall event (80 mm), and the operating levels provide sufficient storm storage capacity to contain a 1 in 1-year – 30 minute storm (50 mm).

Table 12.8

Summary of Existing Mine Water Management System

Containment Storage	Location	Inflow Sources	Outflow Destinations
Anti-Pollution Pond (3 ML capacity)	At underground mine portal entrance	Rainfall	Evaporation Transfer to concentrator runoff pond
Concentrator Runoff Pond (63 ML capacity)	North of concentrator plant	Rainfall Process water tank (thickener) overflow Anti-pollution pond	Plant settling ponds for process reuse
Plant Settling Ponds (59 ML capacity)	East of concentrator plant	Rainfall Tailing return water Concentrator runoff pond Underground dewatering Borefields River surface water abstraction (as last resort for water shortages)	Reuse in concentrator process (primary makeup source) Evaporation Water cart (dust suppression) To underground mine for reuse Emergency transfer to TSF Cell 3 dirty water dam
Cell 1 – TSF	At TSF	Water in tailing slurry disposal Rainfall	Cell 2 decant Cell 3 decant Evaporation
Cell 2 – evaporation pond	At TSF	Decant from TSF cell 1 Transfer from clean water dam Overflow from TSF cell 3 Rainfall	Evaporation Transfer to TSF cell 3 Overflow to clean water dam
Cell 3 – dirty water dam	At TSF	Decant from TSF cells 1 and 2 Rainfall	Cell 2 for evaporation Transfer to plant settling ponds for reuse Overflow to clean water dam
Clean water dam	At TSF	Rainfall River surface water abstraction Overflows from TSF cells 2 and 3	Cells 2 and 3 evaporation disposal Transfer to plant settling ponds for reuse

12.8.2 Test Pit Project

Drainage Facilities

Prior to the development of the open cut project, a Test Pit operation has been developed within the footprint of the proposed open pit area to provide more detailed information on the possible future mining of the MRM deposit using open cut methods

The water management system implemented as part of the Test Pit operation includes the construction of a flood protection bund around the Test Pit to protect the working areas from inundation in flood events. The top of the bund will be at 39.5 m RL, which is the same flood protection level that has been adopted for the existing operations.

Within the flood protection bund, the water management system will consist of the following elements:

- A pit sump at the base of the Test Pit to collect groundwater seepage and surface water runoff.
- A bund runoff pond between the pit and the flood protection bund to collect runoff from within the bunded area.
- An OEF runoff pond to collect runoff from the Test Pit overburden emplacement facility (OEF).

All of the above ponds are connected by a pumping system which pumps collected water to the existing concentrator runoff pond. All potentially contaminated water is retained within the bunded and controlled water management system.

In addition, a series of sediment ponds has been constructed outside of the flood protection bund to collect runoff from the external surface of the bund wall and the service road around the toe of the bund wall. These ponds have been designed according to engineering guidelines for soil erosion and sediment control (Institution of Engineers Australia and the Australian Institute of Agricultural Scientists, 1996).

Impact on Existing Drainage System

The Test Pit project required a change to the existing site water management system to accommodate the runoff from the increased catchment area within the flood protection bund and the removal of the plant runoff ponds. This catchment will be potentially contaminated as it will contain the Test Pit, the OEF and a topsoil stockpile. The overall philosophy of the existing mine water management system will remain the same, that is, for site runoff to report to the concentrator runoff pond and be either reused as process water, dust suppression water or be pumped to the tailings storage facility.

The existing site water management system has been modified to take account of:

- Removal of the existing plant settlement ponds from available storage/capacity;
- Additional catchment runoff and collection;
- Test pit dewatering (including groundwater inflow and direct rainfall); and
- Pump and gravity transfers from within the bunded area.

Changes to the existing ponds include:

- Increased size of the existing anti-pollution pond by up to 50% to accommodate the additional runoff from the new ROM area.
- Modification of the existing concentrator runoff pond to accommodate the new haul road constructed across its southern end. This modification includes increasing the size of the pond to the

south of the haul road to enable it to act as a settlement pond. High-level culverts have been provided under the haul road to enable settled runoff to flow to the larger portion of the pond to the north of the haul road. The concentrator runoff pond also receives pumped runoff from within the flood protection bund area and the anti-pollution pond.

The impact of the loss of the plant settlement ponds and the increased runoff form within the bunded area has been modelled using the site's existing OPSIM water management model. The model was used to determine the effect of the Test Pit project on the overflow frequency of the site's storage ponds. The results of the modelling are summarised in Table 12.9.

Table 12.9

Impact of Test Pit Project on Frequency of Storage Overflows

Storage	Flows/Pumps to	Annual Exceedance Probability of Overflow		Maximum Overflow Duration (Days)
		Existing Situation	With Test Pit	
Anti-Pollution Pond	Concentrator Runoff Pond	1 in 5 years	1 in 5 years	2
Concentrator Runoff Pond	Tailings Evaporation Pond	-	1 in 3 years	5
Tailings Evaporation Pond	Dirty Water Cell 2	1 in 3 years	1 in 2 years	115
Dirty Water Cell 2	Clean Water Pond	1 in 115 years	1 in 50 years	29
Clean Water Pond	Surprise Creek	>1 in 115 years	>1 in 115 years	-

Note: The tailings evaporation pond and dirty water cell 2 are at the tailings storage facility and do not overflow externally

The modelling shows that, with the implementation of the Test Pit project, there is a risk of overflow from the concentrator storage pond of 1 in 3 years at the existing pumping rates between the mine site and the tailings evaporation pond. Should this overflow occur it would flow to Barney Creek. To ensure that such an overflow does not occur, MRM will manage the system so that in the event of a 1 in 3 year event occurring, water will be allowed to accumulate in the Test Pit rather than be pumped to the concentrator runoff pond. This will occur until such time as the pumping capacity of the concentrator runoff pond can pump sufficient water to the tailings evaporation pond to ensure that the concentrator runoff pond does not overflow. This is expected to be up to a maximum period of 5 days.

12.8.3 Existing Water Management at Bing Bong Port Facilities

The Bing Bong Port Facility has relatively little water use and the major focus of water management is the capture and containment of potentially contaminated stormwater runoff.

Raw water at Bing Bong is sourced from the Federation Bore (25 km distance from the site) and is used for camp facilities, machinery washing and drinking water. Wastewater is collected and treated in an on-site sewage treatment plant.

The stormwater runoff from the site drains to the site runoff pond (Figure 3.3). Additional runoff is collected at sumps on the wharf and adjacent to the wheel wash. Water collected from runoff and cleaning of the Aburri is also collected and pumped to the site runoff pond. Excessive rainfall is allowed to bypass the Aburri collection system and testing of this bypass water has determined that the water is sufficiently clean for disposal after ten minutes of heavy rainfall (MRM, 2005).

The site runoff pond was originally sized to retain a 100-year ARI – 72 hour storm event. However the operational 'buffer' storage capacity is actually highly dependant on the capacity for reuse, and evaporation disposal, of the captured waters. Water from the runoff pond is recycled for use as washdown water for the conveyor system and the Aburri. The evaporative potential of the pond has been increased by installing a pumping station and circuit of mist sprays around the perimeter and, more recently, an additional bank of mist sprays around the storage shed. These improvements have greatly reduced the probability of pond overflows. The current system (with evaporative sprays and recycling) is estimated to have an overflow probability of around 1 in 10 years.

12.9 Proposed Water Management Strategy

12.9.1 Mine Site

Overview

The open cut project will require a change to the existing mine site water management system to accommodate increased areas of runoff such as the overburden emplacement facility. The overall philosophy of mine water management will remain the same as the existing system (Section 12.8) and be updated over time in accordance with on-going industry improvements in best practice for mine water management.

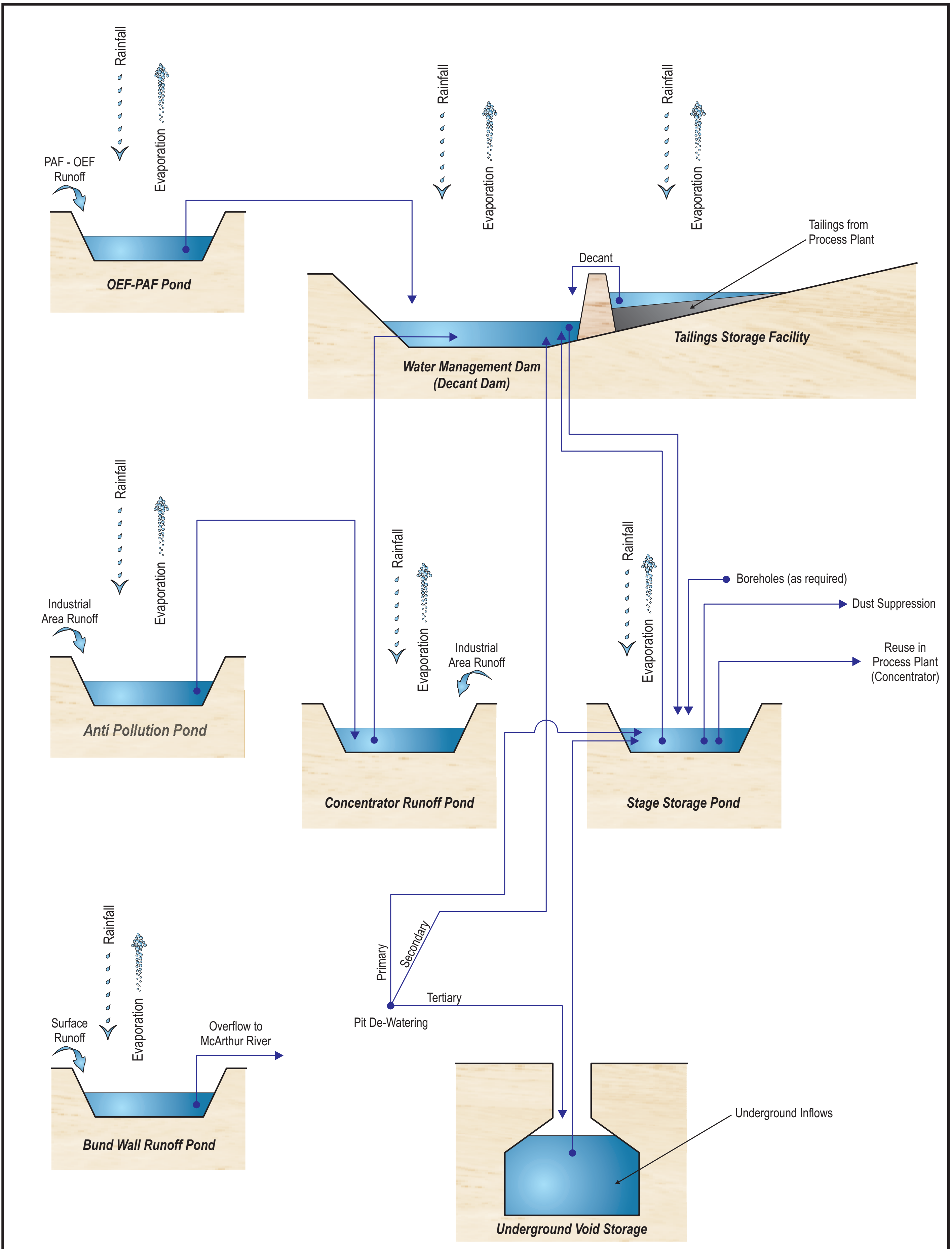
Mine Water Management Planning for the Open Cut Project

A preliminary evaluation of the mine water management system and associated water infrastructure required for the open cut operation has been prepared by Water Solutions Pty Ltd (2005) to support feasibility studies and open cut development plans. OPSIM modelling of the proposed water management system has been undertaken to confirm that the proposed system is viable for the open cut project.

Proposed Mine Water Management System

The proposed mine water management system is shown schematically on Figure 12.11 and summarised in Table 12.10. The OPSIM modelling utilised to develop the proposed water management system takes account of:

- Catchment runoff and collection;
- Open pit dewatering (including groundwater inflow and direct rainfall);
- Pump and gravity transfers;



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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

SCHEMATIC DIAGRAM OF
PROPOSED MINE
WATER MANAGEMENT SYSTEM

Drawn: LL	Approved: CMP	Date: 25-07-05	Figure: **12.11**	Rev. B
Job No.: **42625552**	File No. 42625552-g-066b.cdr			A4

- Borefield supply to the overall system;
- Groundwater inflows into the former underground mine workings;
- Water storage filling, spilling, evaporation, and seepage; and
- Climate variability (rainfall and evaporation).

The new storage facilities to be provided as part of the mine's water management system will include:

- Utilisation of the former underground mine voids as a major water storage facility. The OPSIM modelling has taken account of the reduction in the storage capacity of the underground mine working as the open pit develops during the mine life.
- Construction of a bund wall runoff pond, to collect surface water runoff between the flood protection bund and the edge of the open pit.
- Construction of a NAF sediment pond to remove sediment and reduce turbidity in runoff from the non-acid forming (NAF) zone of the overburden emplacement facility.
- Construction of a PAF containment pond to capture and contain runoff from the potentially acid forming (PAF) zone of the overburden emplacement facility.
- Construction of a water management dam at the tailings storage facility in place of the clean water and dirty water dams.
- Construction of ponds (to be known as stage storage ponds) to replace the plant settling ponds that will be removed as part of the Test Pit project. The stage storage ponds will have a similar function as the existing plant settling ponds, that is to be the primary source of water for the process plant and dust suppression, and to collect waters transferred from and between other dirty water storage dams.

The concentrator runoff pond and anti-pollution pond will remain as for the Test Pit project. Runoff from the area around the underground portal entrance will flow into the underground storage.

Dewatering of the open-cut pit will be directed to following available storages in priority order:

- Primary destination – Stage storage pond for reuse in process plant and for dust suppression;
- Secondary destination – TSF water management dam to maximise evaporative losses, and allow transfer back to the stage storage pond for reuse (when storage capacity is available); and
- Tertiary destination – Underground void storage.

All new containment ponds will be designed to minimise the potential for seepage losses and will include monitoring systems. Monitoring of seepage losses from existing ponds will continue, and corrective actions will be implemented to reduce and intercept seepage losses as required should seepage have potential adverse impacts on receiving waters.

Table 12.10

Summary of Proposed Mine Water Management System

Containment Storage	Location	Inflow Sources	Outflow Destinations
Concentrator Runoff Pond (upgraded capacity as necessary)	North of concentrator plant	Rainfall Process water tank (thickener) overflow Transfers from Anti Pollution Pond Runoff from industrial area	Evaporation Transfer to TSF Water Management Dam
Anti Pollution Pond	Between bund and open pit	Rainfall Runoff from underground portal area	Evaporation Pump to Concentrator Runoff Pond
Operating Cell – TSF	At TSF[3]	Rainfall Water in tailing slurry disposal	Evaporation Transfer (decant) to TSF Water Management Dam
Water Management Dam	At TSF	Rainfall Transfer from operating TSF cells OEF[1] – PAF[2] pond transfer Concentrator runoff pond transfer Stage Storage Pond transfer Underground Storage transfer	Evaporation Transfer to Stage Storage ponds for reuse
Underground Mine Void Storage	Adjacent/below open pit	Open pit dewatering Direct groundwater Inflows	Transfer to Stage Storage Pond for reuse
Stage Storage Pond	Between bund and open pit	Rainfall Borefields (makeup supply) Transfers from underground storage OEF[1] – PAF[2] pond transfer TSF Water Management Dam	Transfer to TSF Water Management Dam Reuse in concentrator process (primary makeup source) Water cart (dust suppression)
Bund Wall Runoff Pond	Between bund and open pit	Clean rainfall/runoff from areas between flood protection bund and edge of open pit.	Evaporation Overflows to McArthur River
OEF – PAF Pond	Edge of OEF – PAF zone	Rainfall/runoff from PAF portion of OEF	Evaporation Transfer to Concentrator Runoff Pond
OEF – NAF Pond	Edge of OEF – NAF[4] zone	Rainfall/runoff from NAF portion of OEF	Evaporation

[1] OEF = Overburden Emplacement Facility
[2] PAF = Potentially Acid Forming
[3] TSF = Tailings Storage Facility
[4] NAF = Non-Acid Forming

Overflow Risk Objectives for Containment Ponds

The containment ponds to be utilised for the proposed mine water management system will be sized to have sufficient storage capacity to minimise spill risk (i.e. overflow probability) based on the OPSIM modelling. The target spill risk objectives are commensurate with the principle of providing acceptable containment capacity for the majority of moderate and large rainfall events, while ensuring that extreme rainfall events or particular event sequences do not unnecessarily contribute to excessive accumulation of mine waters. This principle is particularly important for mines such as MRM operating in tropical climates where complete containment of every conceivable rainfall event is not practical, and could otherwise cause adverse environmental impact in the event of catastrophic release of excessive quantities of mine water.

The target spill risk objectives for each of the containment storages are presented in Table 12.11. The objectives vary according to the likely quality of waters contained in each storage and their potential risk to receiving waters in the event of overflow.

Table 12.11

Containment Storage Overflow Criteria

Containment Storage	Target Overflow Probability as Annual Exceedance Probability	Overflow Consequences
Concentrator runoff pond Anti pollution pond	1 in 5-years 1 in 6-years	Does not overflow to receiving waters, contained within flood protection bund. No impact on surface water environment. Impact on operations only.
TSF[3] – Water management dam	1 in 500-years	Overflows to receiving waters with potentially high concentrations of contaminants.
OEF[1] – PAF[2] Pond	1 in 100-years	Overflows to McArthur River via Surprise Creek and Barney Creek. While potential contaminants could include sediment and metals, minimal impact expected due to dilution of waters as overflow likely only when McArthur River flows are high.

[1] OEF = Overburden Emplacement Facility
[2] PAF = Potentially Acid Forming
[3] TSF = Tailings Storage Facility

Preliminary Water Management Performance Predictions

The proposed water management system has been assessed with the OPSIM model to predict the range of likely performance during the mine life (Water Solutions, 2005). The assessment has determined that:

- The open cut pit project is likely to be a net producer of mine water, primarily as a result of possible high groundwater inflow rates into the pit. With a conservative (high) estimate of the likely groundwater inflow rates into the pit, there is potential for the underground void storage to fill beyond its capacity.
- The time for the underground void storage to reach full capacity will depend upon rainfall conditions in the early years of mine operation and actual rates of groundwater inflow into the open cut pit.
- There is 10% chance that the underground void storage could fill within 8 to 9 years of commencement of open cut pit operations.
- There is 50% chance that the underground void storage would not completely fill over the first 17 years of operation with procedures to pump water to the TSF water management dam when the underground void storage exceeds 2,100 ML.

Based on the outcomes of the preliminary assessment, it has been concluded that there is sufficiently low risk and sufficient lead time to adapt the water management system in response to actual groundwater inflow rates that will be monitored from the commencement of open cut pit operations. It is proposed to adaptively manage and upgrade the water management system with a trigger level for the underground void storage (2,300 ML). When the underground void storage reaches this level there will be a 1 to 2 year lead time for construction of additional containment/evaporation storages and/or implementation of additional works/strategies to maximise evaporative losses from the system.

Operational Management and Mitigation Strategies

Implementation of the water management system for the open cut operations has been designed to ensure that there will be no adverse impacts on receiving waters by limiting the probability of uncontrolled discharges from key containment storages.

The OPSIM modelling will be used to determine, plan, and upgrade system performance on adaptive management basis. This provides maximum flexibility to accommodate actual groundwater inflow rates into the open cut, continually reassess the risk of discharge to the environment, and minimise reliance on external raw water supplies.

The following mitigation strategies will be implemented to ensure mine water management strategies, systems, works, and procedures are effective in avoiding potential adverse impacts on receiving surface waters:

- OPSIM modelling will be updated regularly to ensure reliable representation of:
    - the structure and operating rules of the water management system;
    - actual storage and transfer capacity of system components (confirmed by surveys);
    - mine production rates and associated concentrator process water balance;
    - rates of groundwater inflows into the open cut and total pit dewatering requirements (confirmed by flow monitoring);
    - varying catchment areas and ‘type’ over the mine life (e.g. staged construction of OEF and its runoff contribution to the OEF ponds);
    - varying water reuse demands and improved knowledge of demand influencing factors (e.g. seasonal variation, relationship to production rates, etc.)
    - improved knowledge of catchment runoff characteristics (confirmed by flow monitoring as required); and
    - variation of modelled climatic data with monitoring data (to confirm system performance in response to climate variation).
- Pumping water from the underground void storage to the TSF water management dam, when the underground void storage exceeds 2,100ML.

- Establishing a trigger level of 2,300 ML for the underground void storage, at which time the optimum upgrade for the water management system will be evaluated and implemented.
- On-going seepage management of new and existing storage ponds, review, assessment and implementation of interception strategies and mitigation works where necessary.
- Regular engineering safety/audit assessments of the integrity of water storages where there is potential for spill to receiving waters in the event of a storage breach.
- Review of the potential consequences from containment storage overflows as site water monitoring data are obtained, and where necessary, revise the target overflow probability used to size containment storages.
- Upgrading water management infrastructure (pond storage capacity, pumps and pipeline capacity) as required to maintain acceptable overflow criteria (spill risk) as determined from the OPSIM modelling.
- Updating OPSIM modelling/analysis technology, or upgrading modelling approach, as required to reflect on-going improvements in best practice water management for the mining industry.

Greenhouse Climate Change Influences on the Water Management System

Research literature reports that Greenhouse effects on climate change are generally expected to cause an increase in wet season rainfall in tropical Australia. It is not possible at this time to estimate the potential changes in the intensity of rainfall events, effects on rainfall event sequences (both inter-seasonal and inter-annual), typical wet season rainfall, evaporation, and the combined effects of these factors on runoff and floods. All of these factors (particularly rainfall event sequences), together with the capacities of the water management infrastructure are critical to the performance of the proposed MRM expansion water management system.

The proposed water management system has been developed on the basis of system modelling with a long period of historical rainfall record which accounts for a wide range of rainfall events and event sequences. This approach is consistent with international best practice as applied to diverse water management applications. In particular, the use of historical rainfall data ensures that the system is planned to handle a wide range of possible rainfall events and event sequences that are credibly known to be possible from past observations. The key strategy for water management at the MRM site is to continually update and re-assess the OPSIM model of the water management system, to guide the need to upgrade infrastructure (pipes, pumps, and storages) as required to maintain an acceptable low risk of overflow from containment storages to receiving waters. This adaptive management approach is consistent with a philosophy of continuous improvement. It will allow the water management system to be optimised with improving knowledge of water sources (particularly groundwater inflow into the open cut), and can include planning for Greenhouse climate change effects on rainfall when reliable predictions become available in the future.

12.9.2 Bing Bong Port Facilities

The open cut project will not result in any substantial changes at the Bing Bong Port Facility that would impact on existing surface water management systems/procedures and associated impacts on receiving surface waters to any significant degree.

Strategies to increase the reuse of water contained in the site runoff pond and to minimise the overflow risk of this pond will continue to be developed and implemented to improve overall water management at the site.

12.10 McArthur River and Barney Creek Realignments

12.10.1 Description of Works

Overview

Realignment of the McArthur River and Barney Creek around the proposed open pit is an integral part of the open cut project. In addition, the mine cannot utilise open cut mining methods without protection from flooding from McArthur River and Barney Creek. Hence a flood protection bund will be constructed around most of the perimeter of the mine pit (excluding the high ground around Mt Barney) to prevent flood waters from entering the pit. The locations of the realignments and the flood bund are shown on Figure 12.12.

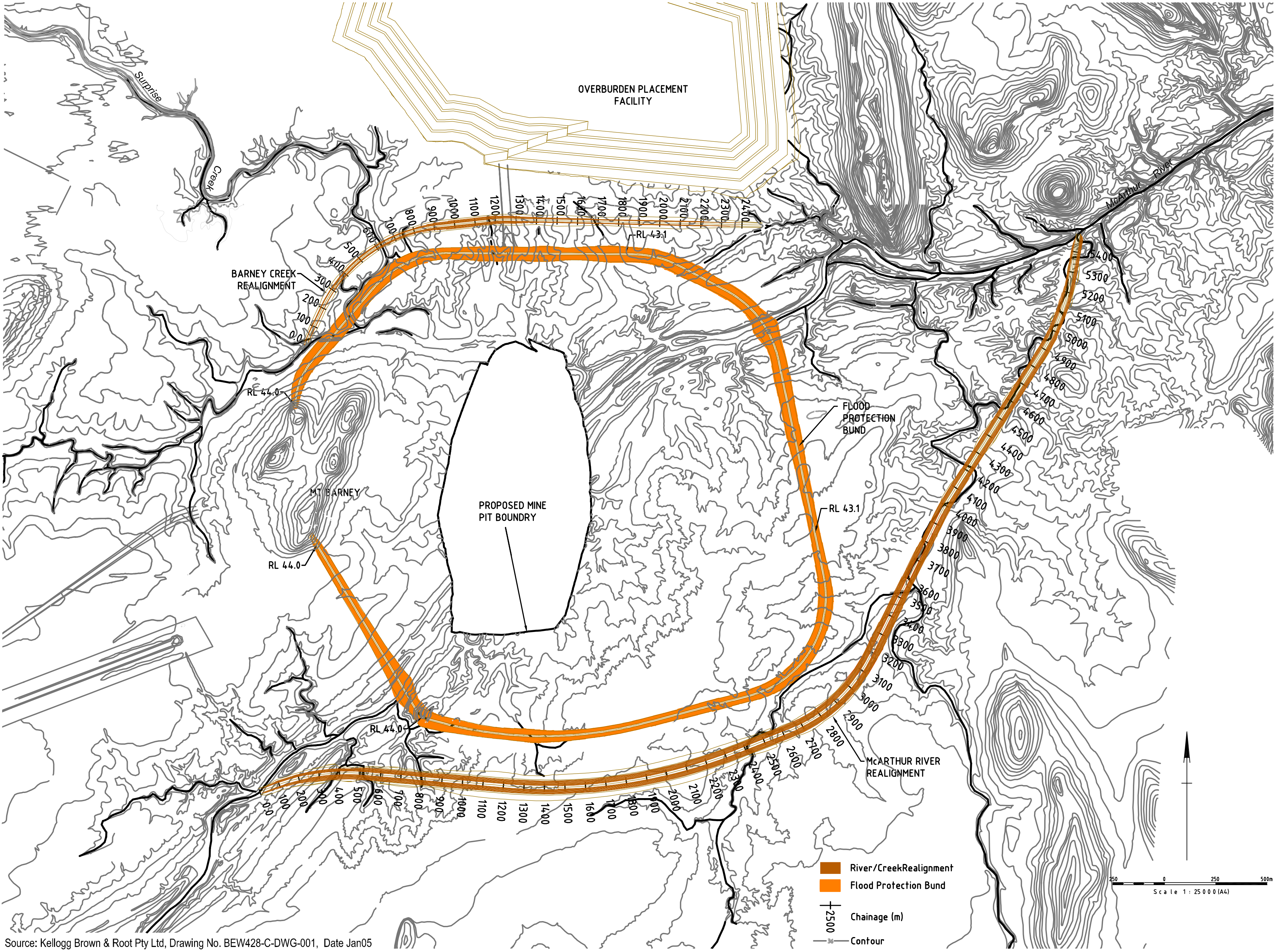
Hydraulic Model

Preliminary design for the proposed realigned river and creek channels and flood protection bund has been undertaken to feasibility stage by KBR (2003, 2005). The broad geometric design developed to date is sufficient for impact assessment purposes.

The hydraulic assessment undertaken for the preliminary channel design has utilised two-dimensional finite-difference hydraulic modelling. The model shows that for large flood events (typically in the order of 50-year ARI to 100-year ARI and larger), flood flows breakout of the McArthur River channel upstream of the mine, flow across the airstrip and can join the Barney Creek channel. The hydraulic analysis undertaken for the preliminary design of the Barney Creek realignment has considered flooding in Barney Creek occurring from Barney Creek catchment runoff as well as flood overflows from the McArthur River channel.

Design of Proposed Realigned Channels

The alignments of the new McArthur River and Barney Creek channels are shown on Figure 12.12, longitudinal and geological profiles are shown on Figure 12.13, and typical cross-sections and conceptual rehabilitation design are shown on Figure 12.14.



Source: Kellogg Brown & Root Pty Ltd, Drawing No. BEW428-C-DWG-001, Date Jan05

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

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File No.: 42625552-g-068c.dwg

LAYOUT OF PROPOSED RIVER REALIGNMENT AND FLOOD PROTECTION BUND

Figure: 12.12

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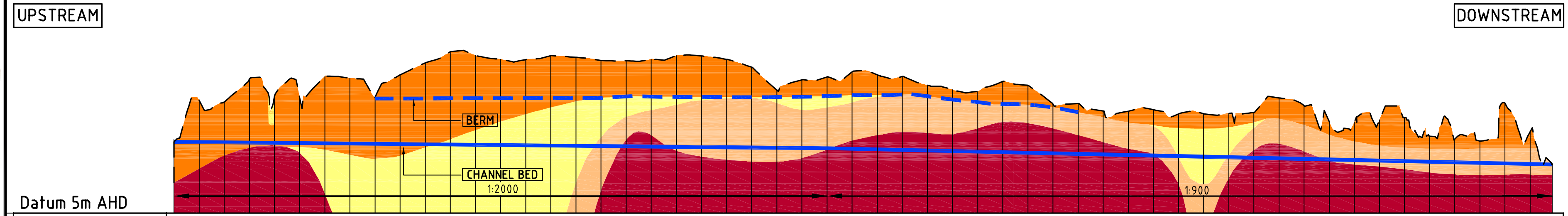


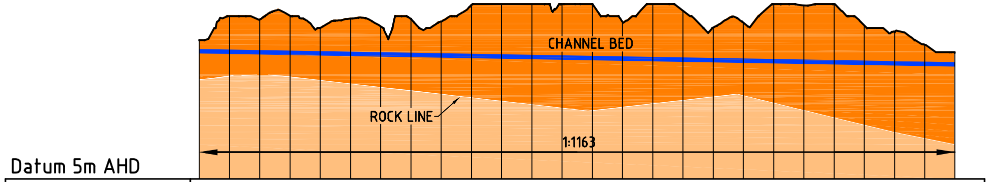
CHANNEL BED ELEVATION	19.200	19.100	19.000	18.900	18.800	18.700	18.600	18.500	18.400	18.300	18.200	18.100	18.000	17.900
NATURAL SURFACE	19.200	27.111	28.161	32.191	28.077	34.903	36.381	35.550	36.006	35.308	36.352	35.614	29.485	32.110
EXCAVATION DEPTH	0.000	8.011	9.161	13.291	9.277	16.203	17.781	17.050	17.606	17.008	18.152	17.514	11.485	14.210
CHAINAGE	0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600
CROSS SECTION TYPE*	TYPE A1					▷	TYPE B1	▷	TYPE B2			▷	TYPE B2	▷

CHANNEL BED ELEVATION	17.677	17.455	17.233	17.010	16.790	16.570	16.349	16.127	15.905	15.684	15.462	15.240	15.018	14.796	14.700
NATURAL SURFACE	32.539	30.458	29.233	30.418	26.785	25.295	24.733	24.844	27.933	23.204	23.555	20.285	19.374	21.214	14.700
EXCAVATION DEPTH	14.861	13.003	12.000	13.408	9.995	8.725	8.384	8.717	12.028	7.520	8.093	5.045	4.356	6.418	0.000
CHAINAGE	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000	5200	5400	5487
CROSS SECTION TYPE*	TYPE C			▷	TYPE C	▷	TYPE A1		TYPE A2						

*Refer Figure 12.14

TRANSITION

REALIGNED McARTHUR RIVER CHANNEL – GEOLOGICAL PROFILE



CHANNEL BED ELEVATION (mRL)	26.150			25.720			25.280			24.850			24.429		24.000
NATURAL SURFACE (mRL)	28.000	31.402	30.000		30.308	31.067	34.000	34	31.039		32.892	30.889	33.728	30.413	27.250	25.890
CHAINAGE (mRL)	0	200	400		600	800	1000	1200	1400		1600	1800	2000	2200	2400	2498
CHANNEL BED WIDTH	15.0m															

REALIGNED BARNEY CREEK CHANNEL – GEOLOGICAL PROFILE

- 🟧 CLAYEY SOILS – ALLUVIUM
- 🟨 SANDY AND GRAVELLY SOILS – ALLUVIUM
- ▨ WEATHERED ROCK
- 🟥 FRESH ROCK

Source: Adapted from Kellogg Brown & Root Pty Ltd, Drawing No. BEW428-C-DWG-002

McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

LONG-SECTIONS
OF PROPOSED
REALIGNED CHANNELS

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Date: 25-07-2005
Job No.: 42625552
File No.: 42625552-g-069b.dwg
Figure: 12.13
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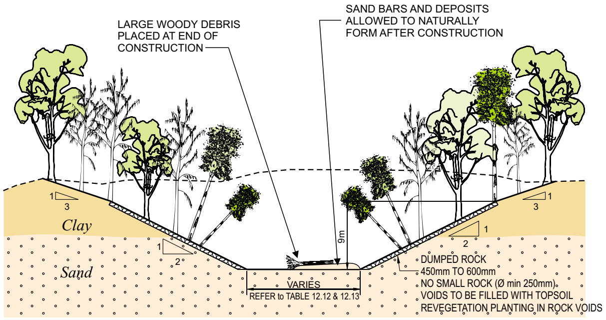
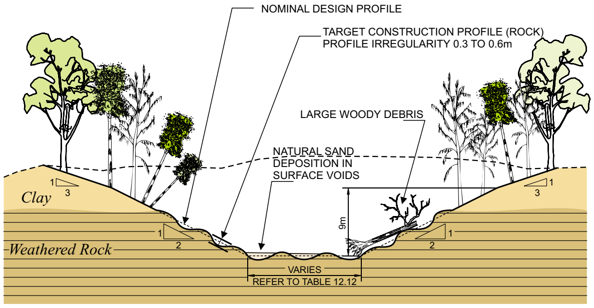
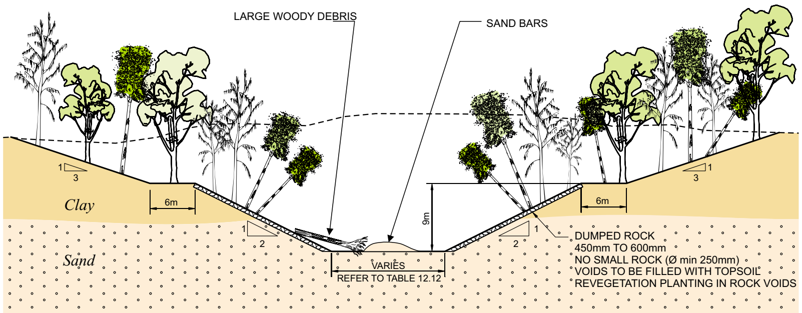
McARTHUR RIVER CHANNEL SECTION TYPE A1 AND BARNEY CREEK CHANNEL



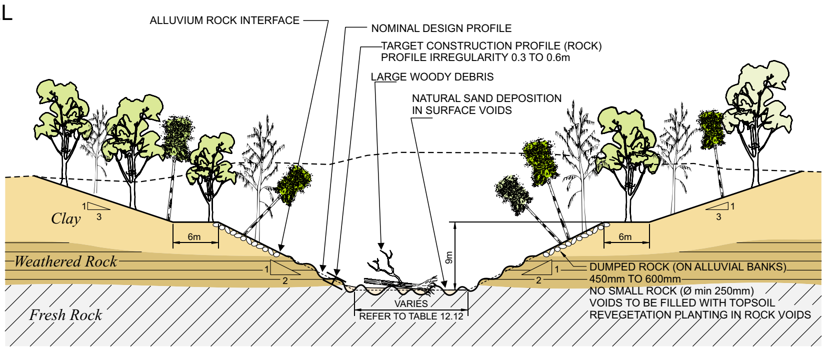
McARTHUR RIVER CHANNEL SECTION TYPE A2



McARTHUR RIVER CHANNEL SECTION TYPE B1

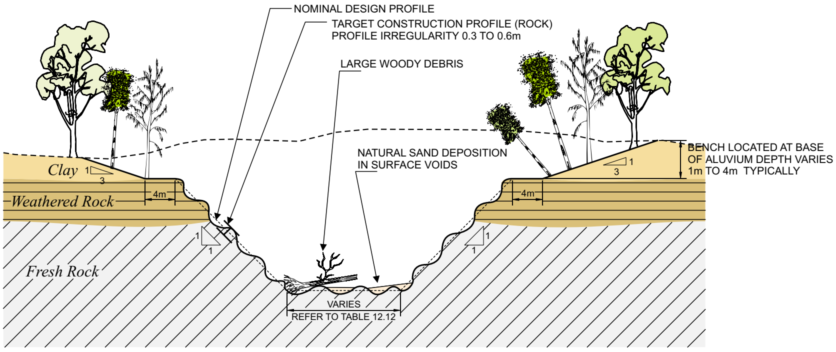


McARTHUR RIVER CHANNEL SECTION TYPE B2



McARTHUR RIVER CHANNEL SECTION TYPE C

CHANNEL THROUGH ROCK



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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

PROPOSED CHANNEL SECTIONS

Drawn: LL	Approved: CMP	Date: 25-07-2005	Figure: **12.14**	Rev. A
Job No.: **42625552**	File No. 42625552-g-149.cdr			A4

The new channel design has been developed to mimic the general geometry of the existing McArthur River low flow channel and the Barney Creek channel while also ensuring that the new channels will have acceptable hydraulic performance in terms of river stability (minimal erosion risk) and maintaining fish passage. The channel shape will be generally consistent with the existing river channel comprising a trapezoidal shape (flat bed), bank slopes at 1(V) in 2(H), and channel depth approximately 9m to the terrace (berm) levels.

The requirement to ensure acceptable hydraulic performance has recognised that revegetation of the channel bank will take some time to fully establish and replicate the hydraulic roughness of the existing river system. Accordingly, the hydraulic performance has been assessed for lower hydraulic roughness conditions than the existing river for the early years of the open cut pit project, and the design of the new channel has bed width larger than the existing river channel for these conditions.

The upstream and downstream bed levels of the new channels will match the bed levels at their junctions with the existing stream channels.

From an environmental perspective, the foundation conditions are important for the capacity of the new channels to resist the erosive force of stream flow and for the practicality of revegetating the channel banks. Revegetation and rehabilitation requirements for the new channels are discussed in more detail in Section 13.2.1.

McArthur River

The realignment of the McArthur River will isolate approximately 5,500 m of the existing river channel. The new channel will be approximately 400 m longer than the isolated channel. Approximately half of the isolated channel which traverses the proposed mine pit will be mined. A small portion of isolated channel (approximately 700 to 800 m length) will remain upstream of the mine pit and flood protection bund. The remaining portion of isolated channel downstream of the levee bank will be approximately 1,700 m long. Barney Creek joins this isolated channel approximately 600 m downstream of the flood protection bund. The isolated reaches of the McArthur River (immediately upstream and downstream of the bnd) will be retained in their natural state and are expected to provide some off-stream pool habitat for fish and aquatic fauna.

Geotechnical investigations have been undertaken on the channel realignment (Golder Associates, 2004). These investigations indicate that the realigned McArthur River channel will be located in a mixture of alluvial materials and rock.

From chainage 0 to 1,650 m the channel bed will be in alluvium (silty sands and clays). To maintain acceptable hydraulics for fish passage and minimise the risk of scour, peak flow velocities through this section will be limited by adopting a flatter bed slope (1:2,000) and a wider channel bed (25 to 28 m). The channel bed will be up to 18 m deep below the natural surface level, and 6 m wide terraces on both sides of the channel will be provided where the channel bed level is greater than 12 m below the natural surface level.

From chainage 1,650 m to the downstream end, the channel will be excavated through weathered and fresh rock (breccia and mudstone), and will intercept a short reach of alluvial material between chainage

4,000 m and 4,200 m. Because rock has a greater much capacity than alluvium to resist erosion, the bed slope will be increased to 1:900 downstream of chainage 2,600 m and the bed width reduced to 20 m at chainage 3,300 to 3,800, and 15 m bed width from chainage 3,800 m to the downstream end. From chainage 4,000 m to the downstream end the new channel will follow the alignment of a natural gully so the top flow width is greater as the flow spreads out to the natural terrain either side of the channel.

Special consideration will be given to the design of the channel at the start and end junctions with the river. At both ends protection strategies such as rock armouring will be considered for the bed and banks to ensure that the changes in flow direction do not create scour potential. In addition, localised protection works will be provided at the intersection points between the constructed channel and the tributary waterways that will flow into it.

In sections where the main channel banks are in alluvial materials, coarse rockfill armouring will be placed on the channel banks. Voids in the coarse rock armouring will be filled with topsoil. The rock armouring will provide additional erosion protection against flood velocities for the channel banks, but is primarily intended to provide a stable growing substrate for re-establishment of riparian bank vegetation until the vegetation is adequately established. The rock armouring in these sections is required to retain topsoil on the channel banks sufficient for revegetation to establish.

A summary of the realignment geometry and foundation design is presented in Table 12.12.

Table 12.12

Proposed McArthur River Channel Realignment

Design Chainage (m)[1]	Bed Slope	Channel Bed Width (m)	Channel Side Slopes (V:H)	Foundation Conditions and General Features
0 to 600	1 : 2,000	28	1:2	Sandstone and alluvial soils bed. Banks intercept silty clay and clayey sand.
600 to 1050	1 : 2,000	28	1:2	Bed and banks intercept alluvial soils with layers of silty clay, clayey sand, and gravelly clayey sand.
1050 to 1500	1 : 2,000	27	1:2	
1500 to 1750	1 : 2,000	25	1:2	Bed and lower banks (up to 5 m above bed) in shale, mudstone, and breccia. Upper banks intercept sand, gravelly sand, and silty clays. Channel transitions from 25 m to 15 m bed width at downstream end. 6m wide terraces 9m above the channel bed, both sides of channel from chainage 1000 to 1750, with bank slope above terraces at 1 in 3.
1750 to 2600	1 : 2,000	25	1:2	Bed and majority of bank height (up to 10 m above bed) predominantly in breccia with zones of shale, and mudstone. Upper level banks intercept silty clays, and sandy silty clay. Upper level bank slope at 1:3. Bull Creek intercepted at chainage 2,400 m, and small gully intersected at chainage 3,600 m. 6m wide terraces 9m above the channel both side of channel from chainage 1750 to 2600, with bank slopes above terraces at 1 in 3.
2600 to 3300	1 : 900	25	1:1	
3300 to 3800	1 : 900	20	1:1	
3800 to 4000	1 : 900	15	1:2	

Design Chainage (m)[1]	Bed Slope	Channel Bed Width (m)	Channel Side Slopes (V:H)	Foundation Conditions and General Features
				4m wide terraces at interface level of weathered rock – alluvium, both sides of channel between chainage 2600 to 4000.
4000 to 4200	1 : 900	15	1:2	Bed and banks in sandy clay and silty clay. Zones of clayey sandy gravel.
4300 to 4900	1 : 900	15	1:2	Bed and 5 to 10 m of lower bank in Dolomite. Upper banks in silty clay.
4900 to 5490	1 : 900	15	1:2	Bed and banks in clay, and clayey sand. Downstream junction with McArthur River at chainage 5,490 m.

[1] See Figures 12.12, 12.13, and 12.14.

Barney Creek

The geotechnical testing (Golder Associates, 2004) shows that the new Barney Creek channel will be located entirely within alluvium. On this basis the channel has been designed with a 15 m wide base, side slopes of 1V:2H and a bed slope of 1:1,160. As for the McArthur River, the start and end points of the Barney Creek realignment will be provided with scour protection to ensure that the changes in flow direction do not create erosion potential. Localised protection will be provided for the intersection of the new channel with Surprise Creek. The banks of the new Barney Creek channel will also be armoured with coarse rock and topsoil placed into voids, to provide a stable substrate for revegetation of the channel banks.

A summary of the realignment geometry and foundation design is presented in Table 12.13.

Table 12.13

Proposed Barney Creek Channel Realignment

Design Chainage (m)	Bed Slope	Channel Bed Width (m)	Channel Side Slopes (V:H)	Foundation Conditions and General Features
0 to 2,500	1:1,160	15	1V:2H	Bed and banks in silty clay and sandy silty clay. Surprise Creek intercepted at chainage 600 m. Proposed haul road crossing at approximate chainage 1,250 m to access overburden emplacement facility/waste rock dump. Downstream junction with Barney Creek at chainage 2,500 m.

Flood Protection Bund

If the mine pit is flooded, the impact on mine operations would be severe and hence a high level of flood immunity is essential. As discussed in Section 4.6.3, the proposed flood protection bund will be designed to protect the pit from all floods up to a 1 in 500-year ARI flood event. The probability of a 500-year ARI flood occurring within the planned 25 year period of open pit mining is 5%. The crest of the flood protection levee will be 1 m higher than the estimated 500-year ARI flood levels to provide sufficient freeboard for waves, allowing for some minor settlement of the levee bank, and recognising some inherent uncertainty in estimation methods for rare and extreme floods.

The design height of the levee at the upstream side of the mine is RL 44 m and RL 43.1 m on the downstream side. It will be constructed of compacted silty/sandy clay from the excavation of the McArthur River realignment channel with a cut-off trench at least 5 m deep where the bund intersects the McArthur River and 3 m deep along the remainder of its length. The batter slopes will vary from 1V:2H to 1V:4H with erosion protection provided as required. The external slopes exposed to high flood flow velocities or wave action with be armoured with rock fill protection.

12.10.2 Hydraulic Impacts on River Stability and Geomorphology

Hydraulic Roughness

A key assumption required to assess hydraulic impacts of the channel realignment is the hydraulic roughness factor for the new channel (known as Manning's 'n' values). Two key aspects that influence the hydraulic roughness values for the new channel are:

- Surface roughness which is related to the channel construction methods (specifically the practical tolerances of finished surface levels); and
- The influences of vegetation on flow resistance which is related to the likely vegetation conditions that can be achieved as part of rehabilitation works for the new channel.

It is expected that the earthworks operations to construct the realigned channel through the alluvial foundation materials can likely achieve a practical construction tolerance of finished levels of around 0.1 m. The construction of the channel through rocky foundations material will likely achieve a practical construction tolerance of around 0.3 m to 0.5 m or more depending on the degree of over-break of the rock which is related to the strength and fracture spacing in the rock. Hence, it is expected that bed and banks of the realigned channels will have considerable surface irregularity including some areas which may pool water when the river dries up or has very low flow.

It is expected that, over time, surface irregularity on the bed and banks of the channels will have environmental benefits as it will promote shallow sedimentation across the channel bed and the formation of sand bars, trapping of snags, etc. which will enhance the channel substrate habitat diversity for aquatic fauna. It will also be beneficial to intentionally produce high surface irregularity in some areas to promote variation in depth and flow velocity for fish passage. The construction of the new channel sections in rock will seek to achieve a deliberate surface irregularity of 0.3 to 0.6m (deviation from the nominal design channel section levels – refer Figure 12.14).

Furthermore, it is proposed to revegetate the banks of the realigned channel to mimic features of the natural McArthur River channel. Revegetation of the new channel banks will assist to minimise possible adverse ecological impacts such as avoiding discontinuity of the riparian vegetation along the river, providing shade cover on the banks of the realignment, providing a future source for river snags (when mature trees die and fall into the river), and minimising the potential for excessive predation of fish and other aquatic fauna in the new channel. It is also recognised that lower storey and ground-cover riparian bank vegetation is beneficial to attenuate flood velocities, and their roots systems can 'reinforce' alluvial soils to enhance resistance to erosion. To replicate the hydraulic roughness of the existing river, the long-term revegetation strategy will seek to achieve approximately the same density of mature trees as on the existing river banks. The proposed revegetation program is described in Section 13.2.1.

In the initial years of operation, the new channel will have young vegetation growth that will not provide substantial resistance to flow. Over time, vegetation growth and the resistance to flow will increase towards conditions expected to be similar to the original natural river channel. Calibration of the hydraulic model to the DIPE stream gauge rating curve for the existing river channel determined that existing channel roughness values are high for small flows and decrease with increasing flow (and depth). The calibrated roughness values for the existing river channel were 0.23 (20 m^3/s flow), 0.12 (50 m^3/s flow), and 0.08 (100 m^3/s flow and larger flood flows).

The overall implication of the above factors is that expected hydraulic roughness values for the realigned channels will change over time. Hence, the hydraulic impact assessment of the proposed realignment has considered two cases of hydraulic roughness reflecting the likely short-term conditions (young, newly planted revegetation provides minimal resistance to flow) and long-term conditions (established vegetation with upper storey stem density and lower-storey/ground-cover foliage densities similar to those of the existing river channel). These cases are:

- **Short-term** (minimal vegetation resistance) – hydraulic roughness would be attributed to surface irregularities only. For low flow conditions (fish passage flows < 100 m^3/s), Manning's 'n' values in the alluvial channel bed sections would be 0.040, rock armoured banks in alluvial sections would be 0.055, and targeted high surface irregularity in weathered rock and fresh rock sections would in the range of 0.07 (20 m^3/s flow) to 0.055 (100 m^3/s flow). For flood flow conditions (2 year ARI floods and greater), Manning's 'n' values would be 0.030 in alluvial bed sections, and 0.055 for rock armoured banks and targeted high surface irregularity in weathered rock and fresh rock sections of the channel. The Manning's 'n' values attributed to surface irregularity and rock armouring take account of the dimension of surface irregularity and depth of flow, based on the Limerinos (1970) equation.
- **Long-term** (fully established bank revegetation) – hydraulic roughness would be attributed to surface irregularities and vegetation resistance to flow. The calibrated roughness values for the existing river channel were used a guide to establish likely roughness values for this case. For low flow conditions (fish passage flows < 100 m^3/s), Manning's 'n' values in the alluvial channel bed sections would be 0.050 (allowing for some influence of likely natural accumulation of large woody debris on the bed), revegetation across rock armoured banks in alluvial sections would be in the range of 0.080, and targeted high surface irregularity in weathered rock and fresh rock sections would in the range of 0.07 (20 m^3/s flow) to 0.055 (100 m^3/s flow – similar to the short term case). For flood flow conditions (2 year ARI floods and greater), Manning's 'n' values would be 0.050 in alluvial bed sections, 0.08 for revegetation on rock armoured banks, and 0.045 for targeted high surface irregularity in weathered rock and fresh rock sections of the channel.

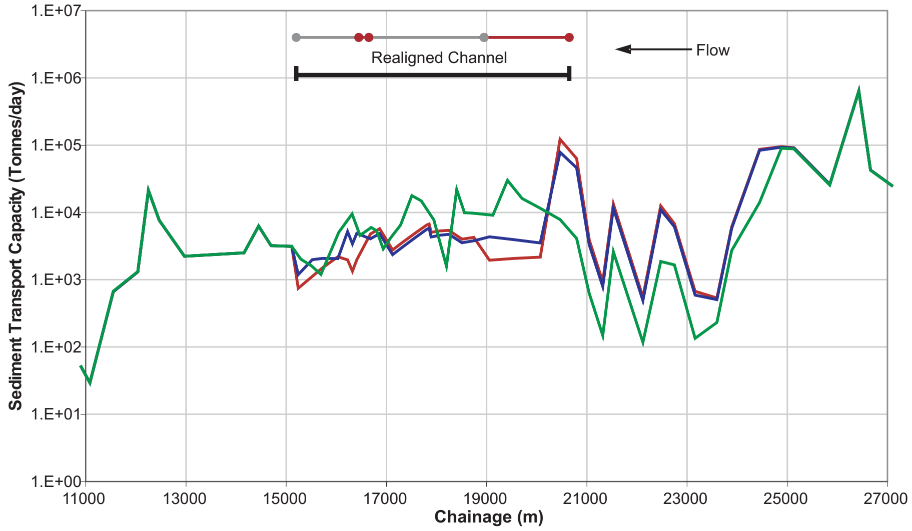
It is expected that the hydraulic roughness for the bed of the realigned channels will continue to increase after the bank revegetation matures as on-going accumulation of large woody debris would continue to provide increasing resistance to flow, and sedimentation of the channel bed would eventually provide a substrate to allow minor stands of vegetation to colonise on the channel bed. The adopted roughness values for the long-term case are therefore considered to be conservatively low, and it is expected that over a very long-term horizon (say 50 years or greater), the channel hydraulic roughness would eventually become similar to the existing river channel roughness values.

Erosion and Sedimentation Impacts and Mitigation Strategies

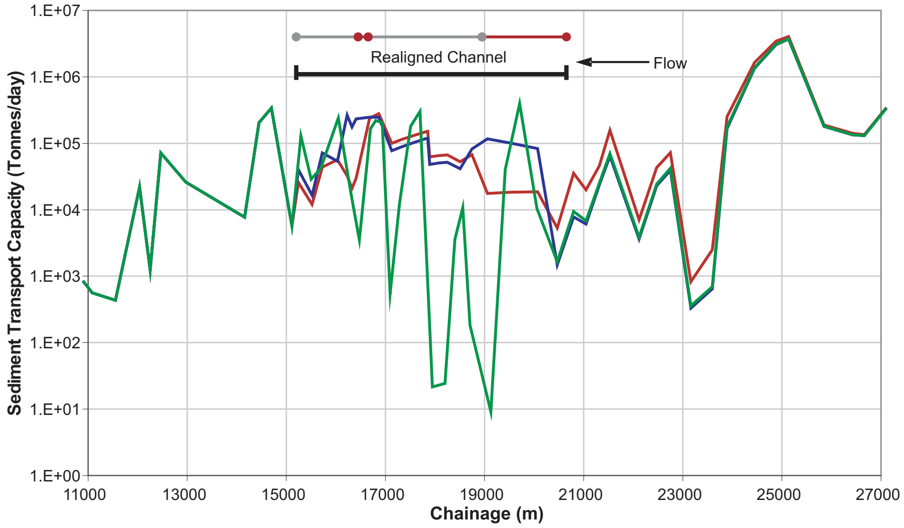
The hydraulic model was used to assess the effects of the 500, 100, 50, 5 and 2-year ARI flood flows. Changes in channel flow velocities, stream power and sediment transport capacity were calculated for the short-term and long-term cases, and compared with existing channel hydraulic parameters. Profile plots of hydraulic results for all cases are presented in Appendix K. Impacts on flood velocity and stream power are summarised in Table 12.14. Profile plots of sediment transport capacity are presented on Figure 12.15 and the impacts of changes in sediment transport capacity are summarised in Table 12.15.

From the assessment of channel velocity and channel stream power, the following erosion and sedimentation impacts and recommendations for mitigation strategies have been determined:

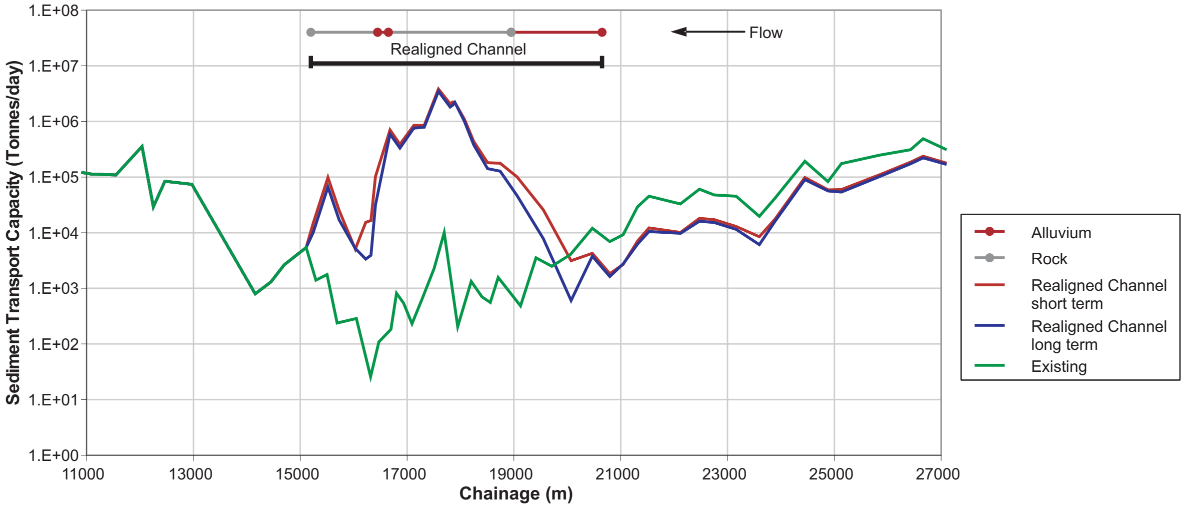
- There is unlikely to be wide-scale erosion of the new channel or upstream reaches sufficient to alter river form (shape and plan alignment) in the alluvial sections. The 5-year ARI flood is the most critical flood event for erosion of the alluvial sections of the new channel.
- Stream power and channel velocities in the new channel will be higher in the short-term until revegetation is sufficiently established to influence the flow resistance (hydraulic roughness of the new channel). This finding emphasises the need to revegetate the alluvial banks of the new channel and to provide surface irregularities along the channel bed to maximise the hydraulic roughness and minimise the risk of erosion. The revegetation planning will be undertaken prior to channel construction and sufficient flexibility will be provided for an adaptive management approach to adjust the implemented revegetation works to suit the actual foundation conditions encountered during/following construction.
- High to very high channel stream power will likely occur in some of the rocky bed sections of the new channel for the 50 and 100-year ARI floods. The rock will be able to resist the erosive forces, however it is likely that the sediment deposits that have naturally formed on the rock sections will be mobilised.
- In the short term, a slight increase (10 to 20%) in flow velocities and stream power is likely to occur upstream of the new channel for small flood events (2 year ARI) only. This suggests a minor potential for erosion, although velocities and stream power will remain sufficiently below levels likely to cause erosion. The estimated degree of short term erosion risk to the reach upstream of the new channel is not conclusive but is expected to be minor. The recommended mitigation strategy for this risk is to monitor erosion at fixed control locations with periodic (e.g. bi-annual) photographic surveys. Evidence of impacts on the morphology of the river will trigger further investigations of the cause and identification of remedial strategies and/or works.



PROFILE 100m³/s FLOW



PROFILE 2 YEAR ARI FLOOD



PROFILE 100 YEAR ARI FLOOD

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

COMPARISION OF EXISTING AND REALIGNED CHANNEL SEDIMENT TRANSPORT CAPACITY

Drawn: VH
Approved: CMP
Date: 25-07-05
Job No.: **42625552**
File No. 42625552-g-150.cdr
Figure: **12.15**
Rev. A
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Table 12.14

Flow Velocity and Stream Power Effects

Flood Event	Comparison of New Channel with Existing Channel		Comparison of New Channel with Upstream and Downstream Reaches	
	Flood Velocities	**Stream Power**	**Flood Velocities**	**Stream Power**
2-year ARI	New channel velocity higher than existing channel, but less than 1.3 m/s in alluvial sections. Maximum velocity 1.6 m/s in rock (not expected to erode).	New channel stream power in alluvial sections similar to existing channel.	Maximum velocity in new channel will be less than maximum existing velocity in reaches upstream and downstream. Velocities immediately upstream (up to 4 km) will increase by approximately 10% in the short-term, and return to existing channel velocities in the long-term.	Maximum channel stream power in new channel will be less than maximum existing channel stream power in reaches upstream and downstream. Channel stream power immediately upstream (up to 3 km) will increase by approximately 20% in the short-term and return to existing channel stream power in long-term.
5-year ARI	New channel velocity in alluvial sections similar to existing channel, and less than 1.7 m/s in alluvial sections. Maximum velocity 2.6 m/s in rock (not expected to erode).	New channel stream power in alluvial sections up to 40 % higher than existing channel.	Maximum velocity in new channel approximately 80% of maximum upstream existing channel velocities. Velocities immediately upstream (up to 4 km) will decrease by approximately 25%.	Maximum stream power in new channel will be less than maximum existing channel stream power in reaches upstream and downstream. Channel stream power immediately upstream (up to 4 km) will decrease by approximately 30%.
50-year ARI	New channel velocity higher than existing channel, but less than 1.3 m/s in alluvial sections. Maximum velocity 3.4 m/s in rock (not expected to erode).	New channel stream power in alluvial sections approximately 40 to 60% of existing channel stream power. Channel stream power in rock sections approximately 10 times greater than existing channel stream power, but not expected to cause erosion.	Maximum velocity in rocky sections of the new channel will be substantially higher than upstream and downstream reaches, but not expected to cause erosion of the rock base. Maximum velocities in alluvial sections of the new channel are consistent with upstream and downstream. Velocities immediately upstream (up to 4 km) will decrease by approximately 30%.	Maximum stream power in alluvial sections of the new channel will be substantially less than maximum existing channel stream power in reaches upstream and downstream. Rocky sections of the new channel will be subject to high stream power. Channel stream power immediately upstream (up to 4 km) will decrease by approximately 50%.
100-year ARI	New channel velocity higher than existing channel at downstream end of alluvial	New channel stream power in alluvial sections similar to existing channel and up to	Maximum velocities in alluvial sections of the new channel are consistent with upstream and downstream. Maximum	Maximum stream power in alluvial sections of the new channel will be substantially less than maximum

Flood Event	Comparison of New Channel with Existing Channel		Comparison of New Channel with Upstream and Downstream Reaches	
	Flood Velocities	**Stream Power**	**Flood Velocities**	**Stream Power**
	section, lower than existing at upstream end of alluvial section, but less than 1.0 m/s in alluvial sections for long-term conditions. Channel velocity for short term conditions up to 1.5m/s in alluvial sections. Maximum velocity 2.5 m/s in rock (not expected to erode).	50% lower than existing channel near upstream end of new channel. Maximum channel stream power in rock sections up to 10 times higher than existing channel, but not expected to erode hard rock base of the channel.	velocities in rock sections similar to maximum velocities in upstream and downstream reaches. Velocities immediately upstream (up to 4km) will decrease by approximately 20%.	existing channel stream power in reaches upstream and downstream. Rocky sections of the new channel will have high stream power, but well below maximum stream power upstream and downstream. Channel stream power immediately upstream (up to 4 km) will decrease by approximately 50%.
500-year ARI	New channel velocity in alluvial sections higher than existing channel, but less than 1.0 m/s for long-term conditions and less than 1.5m/s for short term conditions. Maximum velocity 1.8 m/s in rock (not expected to erode).	New channel stream power in alluvial sections similar to existing channel. Maximum channel stream power in rock sections up to 20 times higher than existing channel, but not expected to erode hard rock base of the channel.	Maximum velocities in alluvial sections of the new channel are consistent with upstream and downstream. Maximum velocities in rock sections less than maximum velocities in upstream and downstream reaches. Velocities upstream will be same as existing.	Maximum stream power in alluvial sections of the new channel will be substantially less than maximum existing channel stream power in reaches upstream and downstream. Rocky sections of the new channel will have high stream power, but well below maximum stream power upstream and downstream. Channel stream power immediately upstream (up to 12 km) will decrease by approximately 10%.

Table 12.15

Sediment Transport Capacity

Flow Condition	Comparison of New Channel with Existing Channel		Comparison of New Channel with Upstream and Downstream Reaches	
	Sediment Transport Capacity	**Implications**	**Sediment Transport Capacity**	**Implications**
Low Flows 20 - 100 m^3/s	New channel transport capacity 10 to 100 times lower than existing channel, particularly in downstream rock sections. Localised increase up to 100 times more than existing channel, at upstream end of new channel.	Low flow periods occur more frequently and for longer periods than flood events, and will dominate general sedimentation and erosion patterns over time. Sediment deposition will occur over the base of the rocky sections of the new channel. Increase in transport capacity at upstream end unlikely to cause erosion because flow velocities and stream power are low.	New channel transport capacity less than upstream and downstream reach transport capacity. New channel remains as least capacity to transport sediment past Bukalara Range.	Higher sediment capacity in upstream reaches suggests supply of sediment to new channel will likely be higher than the channel's capacity to transport sediment. Deposition on the channel bed will be the likely regime, and deposition could extend beyond the downstream end of the new channel, but not beyond Bukalara Range.
2-year ARI Flood	New channel transport capacity same as existing channel transport capacity.	No change in sediment transport regime for this level of flooding.	New channel transport capacity approximately 10 times less than upstream 'average' capacity. Transport capacity of new channel similar to capacity to transport sediment through Bukalara Range, however a reach of lower transport capacity (approx. 100 times less) exists between the new channel and Bukalara Range.	Neutral situation, no significant change in sediment regime. Some minor deposition between new channel and Bukalara Range is possible.

Flow Condition	**Comparison of New Channel with Existing Channel**		**Comparison of New Channel with Upstream and Downstream Reaches**	
	Sediment Transport Capacity	**Implications**	**Sediment Transport Capacity**	**Implications**
5-year ARI Flood	New channel transport capacity in rock sections up to 100 times higher than existing channel. New channel transport capacity in alluvial section similar and less than existing channel.	Deposition of sediment in upstream alluvial portion of new channel is likely. Potential to erode deposits of sediment from rocky sections and transport downstream.	New channel transport capacity less than upstream reaches and similar to downstream reaches. A reach of lower transport capacity (approx. 100 to 100 times less than new channel) exists between the new channel and Bukalara Range.	Deposition in upstream alluvial section of new channel, and possible remobilisation of sediment from this portion, as erosion occurs in downstream rock section of new channel. Any sediment mobilised from new channel is unlikely to travel past Bukalara Range.
50 and 100-year ARI Floods	New channel transport capacity in rock section up to 1000 times higher than existing channel. New channel transport capacity in alluvial sections generally similar or less than existing channel.	Deposition of sediment in upstream alluvial portion of new channel is likely. Potential to erode deposits of sediment from rocky sections and transport downstream, but sediment supply from rocky sections will be limited to thin deposits above the rock base.	New channel transport capacity in rock sections higher than upstream and downstream reaches. New channel transport capacity in alluvial section up to 1000 times lower than upstream existing channel transport capacity. A reach of lower transport capacity (approx. 10000 times less than new channel) exists between the new channel and Bukalara Range.	Deposition in upstream alluvial section of new channel, and possible remobilisation of sediment from this portion, as erosion occurs in downstream rock section of new channel. Sediment supply from rock sections will be limited, and flood sediment loads downstream of new channel unlikely to change significantly. Any sediment mobilised from new channel is highly unlikely to travel past Bukalara Range.
500-year ARI Flood	New channel transport capacity in rock section up to 1000 times higher than existing channel. New channel transport capacity in alluvial sections up to 100 times higher than existing channel.	Potential to erode deposits of sediment from rocky sections and portions of alluvial sections of new channel. Vertical erosion of the upstream alluvial section likely to be limited as downstream rock section of new channel will act as a control to limit the depth erosion. Erosion of banks of alluvial section will be limited by rock armouring and revegetation.	New channel transport capacity 10 times less than upstream and downstream transport capacity of existing channel. A reach of lower transport capacity (approx. 100 times less than new channel) exists between the new channel and Bukalara Range.	Localised potential for increased transport capacity in new channel to source sediment by erosion of new channel. Sediment source from new channel will be limited. Eroded sediment from the new channel unlikely to travel past Bukalara Range. Deposition will occur between the new channel and Bukalara Range.

In qualitative terms it would be expected that minor erosion and sedimentation will occur along the new channel and upstream and downstream reaches which would be consistent with natural cycles of erosion and sedimentation along the river. These natural cycles of erosion and sedimentation provide the sandy and silty substrate conditions found in several locations along the existing natural river channel, and also contribute to the long-term formation of alluvial landforms in the lower reaches of the McArthur River catchment.

The quantitative hydraulic assessment of sediment transport capacity confirms the qualitative expectations of natural cycles of erosion and deposition along the river. The sediment transport capacity results do not represent actual sediment transport for specific flow events, but rather the river's capacity to transport sediment. The actual sediment transport of the river for specific flow events will also be related to sediment supply from upstream reaches and capacity to source additional sediment to reach "full transport capacity" by erosion of the river channel. Upstream sediment supply is not readily quantifiable, and capacity to source sediment by river bed/bank erosion in a river system with substantial riparian vegetation and large woody debris is also not readily quantifiable. Nevertheless, the relative magnitudes of estimated sediment transport capacity (between the existing and new channels, and new channel and upstream/downstream reaches) provides a valuable indicator of likely key sedimentation and erosion impacts.

For low flow conditions which occur most frequently and for longer periods during the wet season, the general sediment regime will be deposition of sediment on the channel bed, particularly over rocky bed section in the downstream portion of the new channel. Maximising the surface irregularities of the rocky bed in the new channel and strategic placement of large woody debris (old tree logs – preferably with intact root ball) will further enhance trapping of sediment in these rocky sections. The deposition of sediment along the rocky bed sections of the new channel will be a beneficial impact as it will assist in the development of substrate diversity for aquatic fauna habitat and encourage natural colonisation of groundcover vegetation on the rocky bed sections of the new channel.

For low flow conditions, there will also be a localised increase in potential to carry sediment from the upstream end of the alluvial section of the new channel. The potential to carry sediment from this localised area may not be realised as sediment supply from the upstream will likely fulfil the transport capacity in this area. If minor erosion does occur from the upstream end of the new channel, it will be deposited a short distance downstream in the alluvial and/or rocky sections of the new channel.

For small flood flows that occur frequently (2-year ARI flood) the net impact on erosion and sedimentation is likely to be neutral. For slightly large floods (5-year ARI flood), the regime of erosion and deposition is likely to trend towards deposition in the upstream alluvial section of the new channel, and possible erosion of / sediment transport from the rock bed sections of the new channel. This regime will occur in the peak of a flood event and will likely remove previously deposited sediment from the base of the rock sections of the new channel. The quantity of sediment removed from the rocky sections of the new channel in peak flood conditions will be limited as erosion can only occur down to the rock level. In such floods, the sediment removed from the rocky sections of the new channel will be replaced by new sediment from upstream supply as flood waters recede through the low flow range in which deposition occurs. Hence, it is highly unlikely that a flood event would wash away naturally deposited sediment from the rocky sections leaving a bare rock channel bed (i.e. sediment deposits on the rock sections of the new channel will be replaced at the end of each flood event). Nevertheless, it can be expected that sediment bars and deposits in the rock section of the new channel will be highly dynamic in response to erosion during flood peaks, and deposition in low flow periods. Similarly a converse trend will occur for the upstream alluvial section of the new channel with deposition likely during flood peaks and erosion possible during low flow periods. The trend of regime change from deposition to erosion in the rock sections during flood peaks increases with increasing flood magnitude and will be more pronounced for larger 50 and 100 year ARI floods.

The potential for significant sedimentation well downstream of the mine, either from quantities of sediment mobilised from the new channel, or by changed river hydraulics as a result of the new channel, is extremely unlikely. Three key factors that limit the potential are:

- The main increase in sediment transport capacity in the new channel will occur in the rock sections where there will be limited sediment that can be mobilised in peak flood conditions.
- The potential depth of erosion from the upstream alluvial section of the new channel will be limited by the downstream rock section which will act as a hydraulic control.
- A reach of very low sediment transport capacity (10 to 100 times less than the new channel transport capacity) exists between the downstream end of new channel and Bukalara Range. This reach will deposit any excess sediment that is mobilised from the new channel.

Sedimentation Monitoring and Management Strategy

As discussed above, the new channel hydraulics indicate that significant sedimentation well downstream of the mine is highly unlikely, and the main area potentially prone to some sedimentation impacts is in the area from immediately downstream of the new channel to the Bukalara Range (approximately 2 to 3 km). It is also important to note that this reach is naturally in a sedimentation zone, and sedimentation in this area may not necessarily be attributed to the new channel works. For example, impacts from grazing land use in the upper McArthur River catchment, and other factors could also increase the sediment supply from the upper McArthur River leading to increased sedimentation in this area.

A sedimentation monitoring and management strategy will be implemented to monitor the degree of sedimentation upstream of the Bukalara Range, determine if any increased sedimentation is attributable to the new river channel, evaluate the significance of sedimentation on the riverine environment, and trigger the need for corrective action if required. The sedimentation monitoring strategy will include:

1. Topographic cross-section and photographic survey of the new channel and existing reach downstream to the Bukalara Range at 200 m intervals after the completion of construction to provide a primary benchmark for future reference.

2. Repeat survey (as above) after three flood events have passed through the new channel (at which time a reasonably balanced regime of erosion and deposition cycles along the new channel should be achieved) to provide a secondary benchmark for future reference.

3. Undertake bi-annual cross-section and photographic surveys of the existing McArthur River channel downstream of the new channel to the Bukalara Range for comparison to the benchmark surveys to identify excessive rates of sedimentation in this reach.

4. High resolution aerial photograph or equivalent satellite photo surveys at 5-yearly intervals. The aerial photograph survey will extend:

   – 25 km upstream of the mine to identify the possible changes in river features (e.g. anabranches meanders, flood runner channels) that may account for increased sedimentation as a result of increased sediment supply from upstream of the mine;

   – 25 km downstream of the mine to identify if any major sediment deposition or changes to river form are occurring downstream of the Bukalara Range;

5. The downstream bi-annual river cross-section surveys (item 3 above) will be the primary data source to identify excessive sedimentation rates in this reach. If excessive sedimentation is identified from these surveys, additional investigations will be undertaken to identify if the cause of the sedimentation is attributable to the realigned channel, or other factors such as increased sediment supply from upstream reaches. The additional investigations may include:

   – Expert analysis of the aerial/satellite photo data to identify if upstream changes to the river morphology and/or land use have potentially impacted on sediment supply to the realigned channel.

   – Resurvey of the new channel (topographic cross-sections and photographs) for comparison to the benchmark surveys (items 1 and 2 above) to identify and quantify erosion loss from the realigned channel works (i.e. if erosion from the realigned channel is the major cause of excessive downstream sediment deposition, a large change between the re-survey and benchmark surveys should be evident). In the event that this analysis identifies a likely cause of excessive sedimentation attributable to erosion of the realigned channel, additional detailed hydraulic investigations will be undertaken for forensic analysis of the hydraulic performance of the realigned channel. The hydraulic assessment will then be used to develop, plan, and implement appropriate corrective actions which could include refinement/modification of the realigned channel geometry or intensification/remediation of the revegetation of the new channel (where completed revegetation is shown to be deficient).

The presence of minor erosion and sedimentation along the new channel should generally be allowed to occur as it will assist in providing substrate diversity to enhance habitat for aquatic fauna. Remedial measures for minor erosion will be limited to areas that may be problematic for water quality (turbidity).

12.10.3 Impacts on Flood Levels

The combined effects of the realignment of McArthur River and Barney Creek, and the construction of the flood protection bund around the open cut mine will influence flood levels in the McArthur River in the vicinity of the mine.

The modelling used to evaluate hydraulics of the proposed new channel and flood protection bund provides an assessment of the impacts on flood levels. The modelling results demonstrate that the realigned river channel has sufficient capacity to convey the 2-year and 5-year ARI flood event within the top of the bank. Upstream of the realignment, the floodplain adjacent to the river is inundated in a 2-year ARI event resulting in a river width that is hundreds of metres wide. During larger flood events, the significance of the realigned channel in conveying flood flows is diminished as a more expansive floodplain up to several kilometres wide is used.

The flood modelling shows the following effects on flood levels:

- During small floods, water levels upstream of the mine will decrease slightly by around 0.7 m in a 2-year ARI event in the short-term, and increase to the same level as existing flooding in the long-term when revegetation becomes established.
- For a 5-year ARI flood, water levels upstream of the mine will increase by around 1.5 m in the short-term and 2.3 m in the long-term.
- Water levels upstream of the mine will increase in larger floods ranging by 1.3 m in a 50-year ARI event, 1.4 m in a 100-year ARI event, and less than 0.5 m in a 500-year ARI event. For these larger floods there will be minimal difference between short-term and long-term flood levels because the new main channel conveys a relatively small portion of the overall flood flow.
- The flood protection bund is the main feature of the proposed works that causes flood levels to increase for the larger flood events (i.e. events 50-year ARI and greater).
- The increase in flood levels reduces with increasing distance upstream of the mine. Approximately 6 km upstream, the increase in the 100-year ARI flood level reduces to 0.6 m.

The impact on flood levels for the 100-year ARI event is shown graphically on Figure 12.17.

The impacts of increased water levels during flood events will not produce adverse environmental impacts on the existing vegetation and ecology along the river. The impacts of increased flood levels will not adversely affect the proposed mining operations. All key mine infrastructure (open cut, concentrator plant and industrial area) will be located within the flood protection bund which will be designed to protect against floods up to the 500-year ARI event.

The impacts of increased flood levels could produce additional minor flooding impacts on the Carpentaria Highway and existing airstrip, although both of these facilities are subject to flooding under existing conditions. The flooding impacts on the airstrip will not generally affect the broader community as this airstrip is predominantly used for MRM personnel. MRM acknowledges the flood immunity limitations of the airstrip in large flood events (i.e. the airstrip would be closed for floods equal to or greater than the 50-year ARI event). The increased flood height caused by the project will result in a slightly longer period during which the airstrip would be closed.

The Carpentaria Highway is currently closed due to flooding for floods greater than the 5-year ARI event. The modelling indicates that the open cut operation is unlikely to significantly change the frequency at

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McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

Drawn: VH
Approved: CMP
Date: 25-07-05
Job No.: **42625552**
File No. 42625552-g-071b.cdr

IMPACT OF REALIGNED RIVER CHANNEL AND FLOOD PROTECTION LEVEE ON 100 YEAR ARI FLOOD LEVELS

Figure: **12.17**

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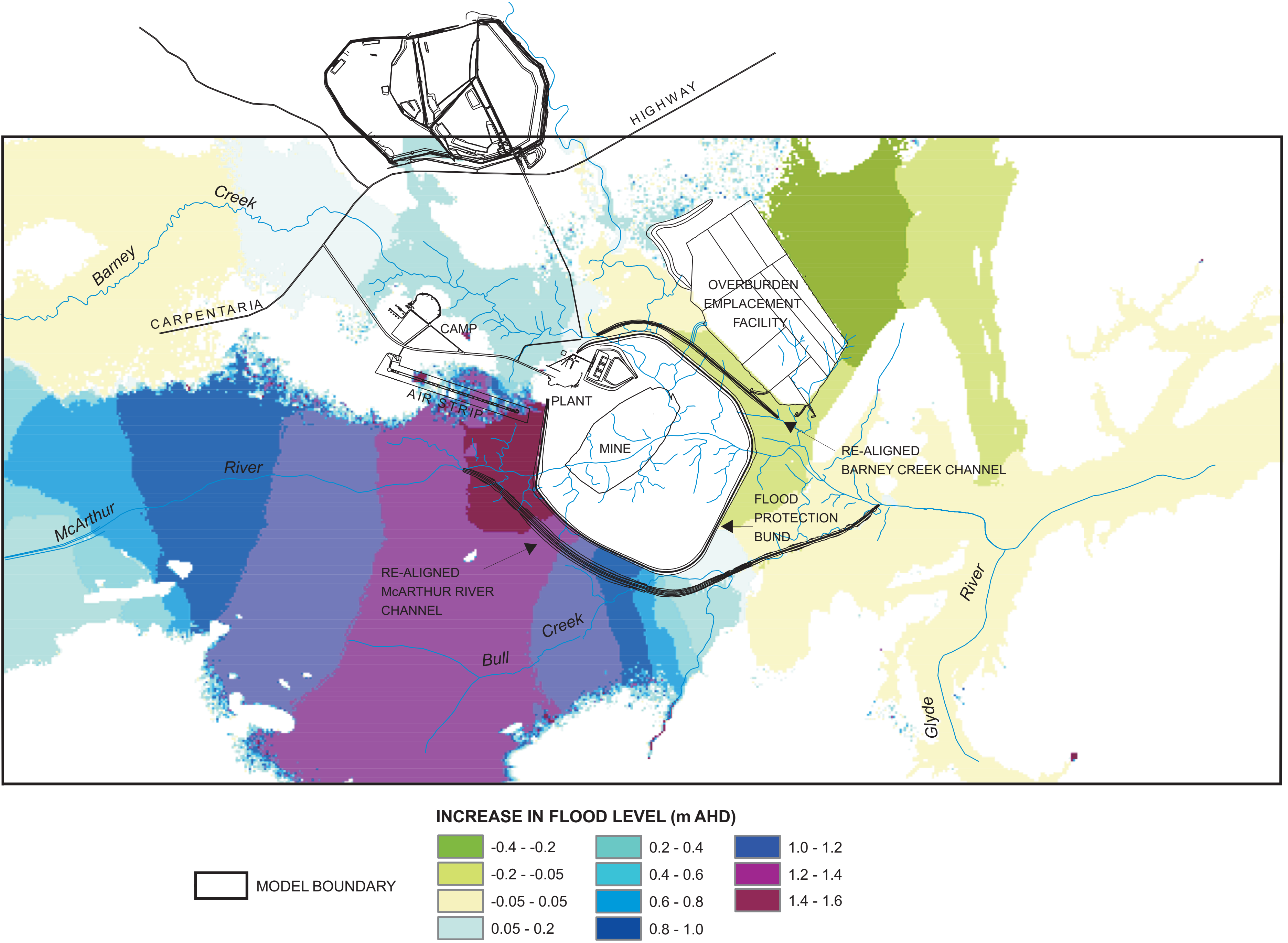

Source: KBR Report, July 2005

which the highway is closed due to flooding, but it could increase the average time-of-closure due to flooding. Discussions will be held with NT Government regarding the need for any mitigation measures.

12.10.4 Impacts on Fish Passage

Overview of Potential Impacts

The McArthur River is used for fish migration (Section 12.3.3). In general, the channel realignment will not be a major physical barrier to fish movement. The main potential impact would likely be limited to hindrance of fish passage by adverse changes to the river flow hydraulics in periods when fish migration occurs.

Extensive research and design guidelines are available for fish passage issues associated with large hydraulic structures such as dam and weirs, but little guidance is available for works such as stream realignments. Nevertheless, the broad factors and general principles for fishway design applied to large structures can be used to guide the fishway passage requirements for the realigned channel, with due recognition of local factors such as the tropical climate and characteristics of low flow hydraulics in the river.

It is considered that potential impacts on fish movements can be avoided with adequate mitigation strategies incorporated into the design of the new channel, post-construction assessment, and on-going monitoring. An initial assessment of the preliminary design of the new channel is presented herein to identify specific mitigation strategies.

Managing the Risk of Physical Barriers

The construction of the new channel has only minor potential to create a physical barrier to fish movement. The upstream and downstream bed levels of the channel will be designed to match the existing river bed levels at the junction with the existing river channel, and hence a physical barrier at these locations is unlikely. As discussed in Section 12.10.1, consideration has been given in the preliminary design of the new channel to the provision of erosion protection measures such as armouring at the upstream and downstream junctions with the existing river channel. The design of such measures will ensure that it does not form a physical barrier to fish movement.

A physical barrier may occur if very hard rock foundations are encountered in localised areas along the new channel. If left unchecked, substantial over-break of very hard rock may create a significant vertical drop in the channel bed level (of greater than 0.6 m) and this could form a physical barrier if the drop extends across the entire width of the channel. This risk can be easily mitigated by construction monitoring and post-construction assessment by an experienced fish biologist to identify such barriers, and implementation of additional remedial construction works if necessary.

It is proposed to construct a haul road across the Barney Creek realignment to provide access between the mine pit and overburden emplacement facility. To ensure that this crossing does not create a physical barrier for fish movement, it will be designed in accordance with the requirements of Cotterell (1998) and NSW Fisheries (1999). No road crossings will be constructed over the McArthur River realignment.

Hydraulic Impediment to Fish Movement

The realigned river channel has the potential to form a hydraulic obstruction to fish passage should flow velocities exceed the swimming ability of fish. As discussed in Section 13.5.4, a number of species of diadromous fish (fish that migrate between freshwater and estuarine areas, mainly for breeding purposes) inhabit the McArthur River.

Critical aspects of fish swimming ability as currently understood by fish biologists (Cotterell, 1998) are:

- **Burst Speed**. The ability for fish to swim at high speed for a short time (seconds) after which they tire rapidly. Fish use their burst speed to swim through localised high water velocity areas or to escape prey, and subsequently need to rest in water with low velocity.
- **Sustained Speed.** The ability for fish to swim at moderately high speed for longer periods (minutes). Fish can swim though channel reaches with moderate flow velocity providing the length of the reach is not too long.
- **Cruising Speed**. The ability for fish to swim at a speed continuously with little effort and stress.

There are no quantified data on these critical swimming velocities for fish species known to inhabit the McArthur River. Hence, to assess the potential significance of flow velocity on fish movement, a comparison has been made between the predicted flow velocities in the realigned channel and the flow velocities occurring in the existing river channel. The hydraulic modeling results to determine existing flow velocities have been verified with stream gauging data at the DIPE Stream Gauge immediate upstream of the mine (refer Appendix K).

Critical Flow Conditions

Recommendations reported by Harris (1997) suggest that fish passage through bypass channels should desirably be designed for flows up to the 80th percentile. Table 12.4 shows that the 80th percentile of the average daily streamflow peaks at 78 m^3/s during February. On this basis, with the expectation that McArthur River fish migration predominately occurs in the early wet season and late wet season, river flows up to 100 m^3/s are considered appropriate to assess fish passage hydraulics. With the adoption of this flow criterion, fish movement through the realigned channel should be possible for substantial periods during the critical migration times. Table 12.16 presents the likely minimum periods (as percentage of total time) that would be available for fish migration on this basis. It is important to recognise that this criterion does not mean that fish will not be able to pass through the realigned channel for flows in excess of 100 m^3/s. Rather, the criterion is adopted to provide guidance to hydraulic designers for design and post-construction mitigation strategies.

Table 12.16

Likely Minimum Periods of Fish Passage For Flows up to 100 m^3/s

Month	Percentage (%) of Time Flows Less than 100 m^3/s
November	99.6
December	97
January	90
February	82
March	86
April	99.7

The HEC-RAS hydraulic model was used to assess the likely flow velocities through the realigned channel for 50 m^3/s and 100 m^3/s flows and to compare them with velocities in the existing river channel and reaches upstream and downstream of the realignment. To account for the varying effective hydraulic roughness values as revegetation becomes more established and has a higher influence on flow resistance over time, cases were analyses for short-term and long-term roughness cases (as described in Section 12.10.2). The results of the assessment are summarised in Table 12.17. A longitudinal profile of flow velocity through the realigned channel is given on Figure 12.16.

Table 12.17

Assessment of Realigned Channel Velocities for Fish Passage Flows

Flow Case and Channel Case	Flow Velocities (m/s)	
	100 m^3/s Flow Rate	50 m^3/s Flow Rate
Reach-average **existing** channel velocities[1]	0.3 to 1.3	0.2 to 1.0
Reach-average **realigned** channel velocities (long-term)	0.8 to 1.1	0.3 to 1.0
Reach-average **realigned** channel velocities (short-term)	0.8 to 1.1	0.3 to 1.0
Maximum local reach velocities in **existing** channel	0.9	0.6
Maximum local velocity in **realigned** channel (long-term)	0.8	0.6
Maximum local velocity in **realigned** channel (short-term)	0.8	0.6

[1] Based on velocities in the reach of the existing McArthur River channel that will be isolated, and in reaches up to 10 km upstream and downstream.

The results show that as whole, the maximum and average flow velocities in the realigned channel will be comparable to the natural river channel flow velocities for flow conditions when fish are likely to be migrating. Hence a hydraulic barrier to fish movement resulting from high flow velocities that exceed the burst speed and sustained speed swimming ability of fish is considered unlikely.

One notable difference between the flow velocity profiles for the existing and realigned channels is the variation of flow velocity along the channel. The velocity profiles for the existing river show that low velocity zones (less than 0.3 m/s) occur at regular intervals along the river (typically around 1 to 2 km intervals). Velocity profiles for the realigned channel show that consistent velocities in excess of 0.3 m/s

McARTHUR RIVER MINE
OPEN CUT PROJECT
ENVIRONMENTAL IMPACT STATEMENT

Drawn: VH
Approved: CMP
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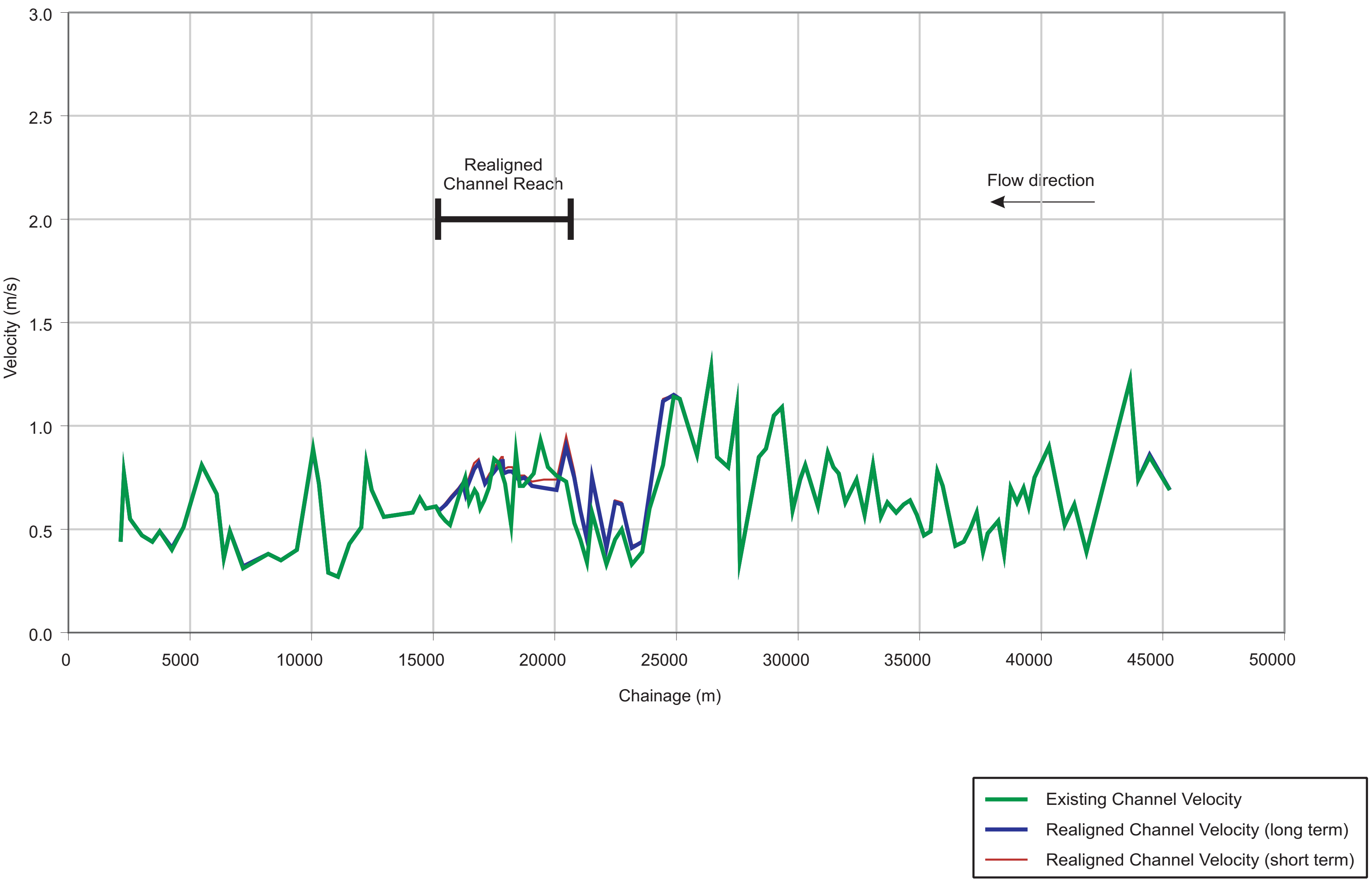
REALIGNED CHANNEL FLOW VELOCITY PROFILE FOR FISH PASSAGE FLOW

Figure: **12.16**
Rev. B
A4



could occur along its entire 5 km length. This result occurs because the hydraulic model assumes an even bed gradient along the realigned channel. In reality, rock over-break and practical construction tolerances will produce a realigned bed that has uneven gradient and should produce low velocity zones suitable for resting areas for fish.

Furthermore, off-stream pools will provide an opportunity for fish resting areas. Large pools will be available at the upstream and downstream ends of the realigned channel in the isolated sections of the original McArthur River channel that are retained immediately upstream and downstream of the mine pit. Additional off-stream pools along the realigned channels will be created at the locations where the realigned channels intersect tributary streams (e.g. chainage 2,400, 3,300 and 4,200 m on the McArthur River realignment, and chainage 600 and 1,600 m on the Barney Creek realignment (Figure 12.12)). Additional ecological mitigation strategies may be included around these constructed resting pools such as enhancing substrate/habitat diversity (e.g. placement of snags, creation of deep zones, and silt bars), and ensuring adequate riparian vegetation coverage around the perimeter of the pool.

Remedial Mitigation Strategies

With the implementation of design mitigation strategies outlined above, it is considered that the realigned channels can be constructed to operate without adverse impacts on fish passage. Nevertheless, two post-construction surveys will be undertaken to confirm that there will be minimal impact on fish passage and to identify if any refinements to the realigned channel is necessary. This strategy is consistent with best environmental practice where an adaptive management philosophy is implemented when uncertainties exist in predictive assessment methods.

The first survey will be undertaken towards the end of the construction period before river flows are allowed to pass through the new channel. This survey will seek to identify possible physical obstructions to fish passage, primarily vertical drops in the bed profile or at the Barney Creek haul road crossing. This will be a visual survey by an experienced environmental officer. The location and form of any potential physical barriers will be recorded and remedial works implemented to remove the obstruction prior to commissioning the channel.

A second survey will be undertaken after commissioning by an experienced fish biologist and river engineer to identify any hydraulic barriers to fish movement (localised high velocity zones) or long reaches of moderate velocity where there are insufficient resting pools or zones of low velocity flow. The survey will be undertaken when flows are between 50 m^3/s and 100 m^3/s and in the months when fish are likely to be migrating. The survey will include measurement of flow velocities at approximately 200 m intervals along the river and wherever high flow velocity areas are visually evident. The survey will also include assessment of the general flow conditions, areas with high velocity, and areas considered suitable as resting pools. The need for, and type of, remedial works will be developed specific to the identified problems and could include works such as:

- Strategic placement of boulders across the channel bed to provide variation of flow velocity across the stream and to facilitate small resting areas in downstream eddies. Large woody debris (tree 'snags') could also be used but may need to be artificially anchored to prevent being washed away in floods.

- Placement of sand or gravel deposits across part of the bed of the realignment to slow flow velocities and provide still zones. Artificial sand, gravel, or silt bars may be suitable where they can be placed such that they will not be washed away in floods.
- Creation or enhancement of deeper zones to facilitate low flow velocity areas to provide resting areas for fish.
- If necessary, the undertaking of additional excavation or removal of rock to remove specific features/bars/surface irregularities causing localised high flow velocity where the above alternative methods are not suitable.

12.10.5 Impacts on River Hydrology

Due to the large magnitude and variability of streamflow in the McArthur River from the large upstream catchment, the proposed river realignment will have no observable impact on general river hydrology.

It is possible that a very minor quantity of streamflow will seep through the bed and banks of the upstream alluvial reach of the realignment (design chainage 0 to 1,700 m) which intersect permeable alluvial geology that links to the mine pit.

The groundwater model can calculate such flow loss from the channel to the groundwater system. Based on the modelling results (Section 11.10.4), the initial loss in the first year of dewatering to the alluvium underlying the channel will be 60 kL/day. By the end of mining, the drawdown in the bedrock in the same area will have caused an increase of vertical leakage to 170 kL/day.

The increase in leakage (170 kL/day) to aquifers underlying the river is insignificant during the wet season when flows in the McArthur River at the mine site average 4,750,000 kL/day. Even at the end of the dry season (September) when average flows have declined to about 24,000 kL/day the increase in vertical leakage is still less than 1% of river flows. During dry years when river flows cease, the predicted vertical leakage will not significantly extend the no-flow period.

12.10.6 Impacts on Water Quality

Erosion and Turbidity

On-going minor erosion and sedimentation along the realigned channels is expected to occur throughout the mine life and be consistent with natural cycles of erosion and sedimentation along upstream and downstream reaches of the river. These processes are natural and are not considered to be adverse environmental impacts. Erosion of the realigned channel is likely to generate mainly relatively coarse sediment (sand and silt) and should not cause excessive turbidity. Natural turbidity in the upstream river is generally from runoff from the catchment into the river rather than erosion of the river channel itself.

One risk to potential impacts on turbidity is the presence of dispersive clay soils along parts of the realigned channel (Golder Associates, 2004). These finer grained soils are in various horizons within the alluvial sections.

Mitigation measures will be introduced to reduce the generation of turbid waters from the exposed dispersive clay soils. These will include identifying their locations during construction and assessing the most appropriate localised protection measures to minimise their potential to erode. These are likely to include covering areas of dispersive soils with a protective cover (e.g. the coarse rock armouring with topsoil filled into the voids) and may also require a local 'laying back' of the realignment channel batters (i.e. reducing the bank slope from 1V:2H to around 1V:3H as has been proposed for the higher banks levels – refer Figure 12.14) or increasing the density of revegetation particularly with respect to ground cover species.

The current surface water monitoring program implemented at the mine does not sample and test for total suspended solids or turbidity. It is proposed that the surface water monitoring program be expanded to include these parameters. Additionally a more intensive monitoring frequency will be implemented during and after the construction of the river realignment.

Flushing and Risk of Stagnation

The original reaches of the McArthur River channel outside of the flood protection bund that will be isolated by construction of the realigned channel will effectively become off-stream pools with reduced natural flushing from the river flows.

The isolated reach upstream of the mine will be relatively short, and stagnation of the waters in these pools during low flow periods is generally not expected to occur.

The isolated reach downstream of the mine will continue to receive flushing from Barney Creek inflows. While it is recognised that these flows will likely be less frequent, of less magnitude, and over shorter durations than the original McArthur River flow regime, they are likely to be sufficient to maintain flushing of this isolated reach at least on an annual basis.

It is proposed that the mine surface water monitoring program be expanded to include monitoring of water quality in both the isolated upstream and downstream reaches for the following parameters:

- Dissolved oxygen (DO, best overall indicator of river health);
- pH (particularly to identify impact if any from acid mine drainage);
- Electrical conductivity (EC);
- Turbidity;
- Total nitrogen, and total phosphorus (as indicator of potential causes of eutrophication);
- Chlorophyll 'a' (as an indicator of actual eutrophication symptoms in combination with DO results); and
- Total and filtered metals concentrations (copper, lead, zinc).

Geochemistry

The geochemical nature of the rock materials to be excavated from the proposed realigned channels has been assessed to determine if they are benign and suitable for use in construction of the flood protection bund and do not present an unacceptable risk to the immediate and downstream environment. The assessment was based on samples collected during an investigation undertaken in November 2004. The results of the investigations are more fully described in URS (2005a).

Acid-base test results showed that all samples had a neutral to alkaline pH (7.3 to 9.3; median 8.7) and low to moderate salinity (EC of 17 to 3,240 µS/cm; median 369 µS/cm) which indicated that initial runoff and seepage from these materials is likely to be pH neutral, slightly alkaline and fresh to slightly brackish. The total sulfur content is low and hence the maximum potential acidity would be low. In addition, eight of the 23 samples had a significant acid neutralising capacity and are likely to be acid buffering. The net acid producing potential was negative for all samples. On the basis of these results, all materials tested are classified as non-acid forming.

In addition to the acid-base testing, multi-element analysis was undertaken to determine the elemental makeup of each sample, specifically metal concentrations. The results indicate that arsenic, cadmium, copper, manganese and zinc can be present in some of the materials to be excavated from the realigned channels at concentrations greater than the recommended Environmental Investigation Level for these metals (ANZECC, 1992a). However, all metal concentrations (apart from lead in the Breccia samples) were less than the recommended Health Based Investigation Level for “parks, recreational open spaces and playing fields” established in the NEPM (1999). The occurrence of elevated metal concentrations in mineralised areas such as McArthur River is common and results from natural geology of the area.

Runoff and seepage from the excavated material will be neutral to slightly alkaline, therefore the risk of metal solubility and mobility is low. This was confirmed by the test data which showed that metals identified as slightly enriched in some rock materials are present in water extracts at concentrations within those recommended in surface water (ANZECC, 2000a) and groundwater (NEPM, 1999) guidelines. Hence, leaching of environmentally significant metals from the proposed levee bank materials is unlikely to present any impacts on local or downstream water quality.

12.10.7 Impacts on DIPE Stream Gauge

The Department of Infrastructure, Planning and Environment (DIPE) operates a stream gauging station upstream of the proposed realignment of the McArthur River. This gauge has provided stream flow data for the MRM project and the broader community since 1967. Stream gauging stations do not measure flow directly, but rather measure water level and utilise a rating curve to convert the water level measurements to estimates of river flow.

Realignment of the McArthur River will alter water levels upstream of the site which will affect the DIPE gauging station rating curve. It is not possible to reliably predict the impact on the rating curve due to the expectation that establishing vegetation in the realigned channel will result in a varying rating curve over time.

Appropriate measures to mitigate impacts on the gauging station will be developed interactively between MRM and DIPE. One strategy may be to utilise the MIM stream gauge downstream of the mine as the primary site for future stream flow monitoring. The downstream gauge will not be affected by the proposed river realignment.

12.11 Construction Impacts and Mitigation

Mine site preparation, bulk earthworks, topsoil storage areas, and construction of the overburden emplacement facility are all, to varying degrees, expected to increase the rate of both soil erosion and sediment production. Exposed areas and disturbed and/or displaced soils will be particularly prone to erosion by high intensity and short-duration rainfall events, which represent periods of high erosion risk. Erosion potential increases with the slope and extent of the area disturbed.

Disturbed areas exposed to rainfall-based erosion and scour can contribute significant quantities of sediments to the natural drainage. The degree of sediment production from individual disturbed areas will vary with sub-catchment geology, vegetation cover, soil stability, and topography.

The principal streams potentially affected by construction phase sediment loading and consequential in-stream sedimentation are:

- Barney Creek;
- Surprise Creek; and
- McArthur River.

In recognition of the erosion hazards associated with mine construction, MRM has formulated guidelines for erosion control. The underlying principles are based on the application of best management practices for controlling and minimizing the amount of erosion and, consequently, sediment production and delivery to the natural drainage. Details of the proposed erosion management strategies are given in Section 10.5.2.

12.12 Environmental Management

Environmental management plans for surface water during both the construction and operational phases are given in Sections 22.3 and 22.4 respectively.