4.0 McArthur River Diversion

4.1 Purpose

As discussed in earlier sections of this report, the design of the McArthur River diversion has been modified since the preparation of the Draft EIS (URS, 2005a) to reflect optimisations in the proposed Open Cut Project and to incorporate recommendations that were provided as part of the EIS review. The purpose of this section is to address the requirements of the PER guidelines with respect to the McArthur River diversion. Specifically it includes:

- An updated assessment of the geomorphology of the McArthur River following a recent site survey of critical reaches and the incorporation of the results of visual assessments of the channel geometry in the revised design of the diversion channel (Section 4.3)
- Characterisation of the existing aquatic habitats along the reach of the McArthur River that is to be diverted based on the results of a recent survey (Section 4.4)
- The results from a more detailed calibration of the hydraulic model of the existing river to the January 2003 flood event. (Sections 4.5.2 and 4.5.3)
- Review of roughness coefficients used in the hydraulic modelling. (Sections 4.5.4 and 4.5.5)
- A sensitivity analysis of the ground terrain survey accuracy on the results of the hydraulic modelling (Section 4.5.6)
- Re-modelling of the existing McArthur River. (4.5.7)
- Modifications to the design of the proposed diversion channel and the methodology used to refine the design with the hydraulic model. (Section 4.5.8)
- Hydraulic modelling of the modified diversion design in terms of the key hydraulic parameters of velocity, shear stress, and stream power (Section 4.5.9)
- Assessment of the stream power and erosion potential in the various reaches of the proposed diversion channel (Section 4.5.10)
- Development of a rehabilitation strategy for the diversion channel (Section 4.6)
- Assessment of the effects of the clearing of the riparian corridor on habitat fragmentation (Section 4.7)

4.2 Summary

Table 4.1 provides a summary of the geomorphological, hydraulic, and ecological assessment undertaken of the revised design of the proposed diversion channel.

Table 4.1
Summary of Methodologies, Results and Conclusions

Item	Methodology	Results	Conclusion
Geomorphology for McArthur River	Desk top analysis of aerial photographs, maps, orthophotos and HEC-RAS model outputs Ground surveys and aerial reconnaissance conducted during site visit in May 2006 Joint meetings and fieldwork with EPA and Professor Erskine in May 2006.	McArthur River comprises three reaches in the mine area: - Upstream anabranching reach with variable characteristics including significant rock bars and waterholes - Uniform mine reach consisting of a single straight alluvial channel with broad levees - Downstream bedrock confined and gorge reaches through the Bukalara Range Channel of the McArthur River is relatively simple steep sided 10 -15 m deep, adjusted to convey ~ 500 m^3/sec (5-yr ARI event) before flowing out onto its floodplain The channel is lined with dense riparian vegetation, and is stable Design of the diversion will seek to replicate the form and function of the present channel of the McArthur River Where required by subsurface conditions or revegetation needs, the design will differ from the natural channel, but will be consistent with conditions in the reaches of the McArthur River upstream and downstream of the mine reach.	Stable river morphology upstream and downstream of the realignment can be maintained during mine life and after mine closure. Stable diversion morphology can be achieved that will ensure the McArthur River continues to function as a straight river capable of transmitting bank-full flood flows up to the 5-year ARI event.
Revised Calibration of HEC-RAS model	The revised analysis utilised cross-section specific Manning's roughness coefficients based field inspection with EPA and Professor Erskine in May 2006.	Difference in measured and modelled water level at DIPE gauge = 100 mm Difference in measured and modelled water level at MIM gauge = 140 mm Manning's coefficients for the main McArthur River channel varied from 0.08 to 0.23 depending on flow rate	The calibration of the HEC-RAS model to the measured gauge water levels for the January 2003 flood event was considered acceptable The Manning's roughness coefficients are appropriate based on calibration results, desktop estimation using Cowan's Method, and recent site inspection.

Item	Methodology	Results	Conclusion
		Desktop estimation of Manning's coefficients using Cowan's Method resulted in similar roughness values (typically within 10%).	
Sensitivity Analysis of the ground terrain survey accuracy	Random cross-sections within the HEC-RAS model were varied between -0.2 m to +0.2 m for various flow rates.	Differences in water level were acceptable at <1% Differences in velocity, shear stress, and stream power vary from 0% to 20% and were not significant. Higher percentages were for low values and a 20% increase was still a low value.	The relatively small inaccuracies in the photogrammetric survey will not result in significantly different hydraulic results that could potentially impact the design and function of the McArthur River diversion.
Model hydraulic performance of diversion channel.	The calibrated HEC-RAS model was used to determine acceptable velocities, shear stress and stream powers as follows: - Use detailed hydraulic analysis of the existing river system to define 'natural' levels of velocity, shear stress and stream power for stable sections of the river where bed and bank materials are similar - Model velocity, shear stress and stream power of the diversion and compare to existing river values and guidelines for diversions through similar geology - Modify the design of the diversion by varying geometric parameters and the inclusion of rock riffles and large woody debris to achieve acceptable hydraulic parameters.	The model results for the revised diversion design were as follows: Upstream Alluvial Section - The velocity, shear stress and stream power are similar to that of the existing mine reach of the McArthur River - The velocity, shear stress and stream power values are within those recommended in the ACARP guidelines - The maximum stream power results are less than the calculated threshold erodibility values using the Annandale (1995) methodology. Downstream Rock Section - The maximum velocity, shear stress and stream power values are within those recommended in the ACARP guidelines - The maximum stream power results are less than the calculated threshold erodibility values using the Annandale (1995) methodology.	The model results for the revised diversion design indicate that: - The diversion channel will have a similar hydraulic performance to the existing river and will convey similarly sized bank-full flood flows - The diversion channel will be stable over the mine life and beyond and will not be subject to significant erosion or sediment deposition - The diversion channel will not result in detrimental impacts to the existing McArthur River upstream or downstream of the diversion.
Rehabilitation Strategy	Existing aquatic, riverine and riparian habitats were characterised following field surveys conducted in May 2006 Specialist advice was sought on technical aspects of species selection, seed collection and vegetation establishment.	A rehabilitation strategy was developed for the diversion which included the following: - The inclusion of large woody debris in along the channel bed to provide micro-habitats for fish - Revegetation of the channel banks including:	A functioning aquatic ecosystem will be able to be established along the diversion channel which will provide a suitable environment for fish passage Revegetation of the diversion channel banks will enable a functioning ecosystem to be established and sustained within a timeframe that would not cause fragmentation of fauna populations.

Item	Methodology	Results	Conclusion
		– Use of seeds and seedlings from local species already growing along the river bank – Planting in topsoil that has been placed within rough rocky banks along the diversion channel to prevent the topsoil being washed away – Provision of soil and fine sediment in the porous substrate on the channel banks will encourage root development and sustain moisture for plant establishment and survival. – For areas of the diversion channel through rock, crevices and rough rocky banks (scree) will be created to contain pockets of soil. – For areas of the diversion channel through alluvial materials, topsoil in the bank cover rock will provide a medium for root development and moisture retention. – Implementation of an effective maintenance program including fertilising, watering and weed control – Implementation of an effective monitoring and replacement program	

4.3 McArthur River Geomorphology

4.3.1 Introduction

The geomorphology of McArthur River upstream and downstream of the mine has been described in order to provide a basis for assessing the impact of the river diversion on channel and floodplain landforms, sediment transport and hydrological systems. In addition, this material is important in the context of ecological conditions both in the riparian vegetation corridor and in stream habitat environments.

The assessment has been carried out using the flowing resources:

- 1:50,000 scale Commonwealth Government topographic maps Series R733 (Carabirni 6156/3; Stretton Creek 6065/2; Bessie Spring 6064/1; Amelia Creek 6164/4)
- 1:250,000 scale Commonwealth Government geological map (Bauhinia Downs Sheet SE 53-2)
- 1: 50,000 scale aerial photographs dated 17/9/1995 (NTc 1301 Run 21 #s 167-169; Run 22 #s 127-130; Run 23 #s 73-77; Run 24E #s 51-54; Run 25E #s 35-37)
- Orthophoto coverage and associated digital terrain model from 2004
- Outputs from a HEC-RAS model of 48 km of the McArthur River channel.

The site was re-visited in May 2006, and ground-based field work carried out at various sites along the 10 km of McArthur River channel between the MRM and DIPE stream gauging sites. In addition, a helicopter survey was conducted of some 40 km of the channel between the Kilgour River confluence and western Bukalara Range.

Field examination of the McArthur River occurred some three weeks after a flood caused by Cyclone Monica that had affected northern Australia in late April 2006. The peak flow of 690 m^3/sec at the MRM gauge represents about a 3-year ARI event. This flood had resulted predominantly in deposition of sand along the channel banks, but also some small areas of erosion damage, and as a result, the ground observations reported from the survey reflect the recent passage of this event.

The field data have been used to inform the HEC-RAS modelling, engineering and biological design specifications for the proposed diversion channel so that morphological and sedimentological aspects of the environment can be incorporated into the design and management strategies.

4.3.2 McArthur River Catchment

Channel Network

The McArthur River catchment covers about 20,000 km^2, in the eastern part of the Northern Territory. It rises in tributaries along about 100 km of the northern slopes of the Barkly Tableland, which is about 215 km inland from the Gulf of Carpentaria. The mine is 90 km from the coast, and the catchment area above this covers 10,000 km^2. The McArthur River drains from the western part of the tableland, while a large tributary, the Kilgour River, drains from the eastern part of the upper catchment.

Much of the upper catchment is hilly, but downstream of the Kilgour River confluence (about 20 km south-west of the mine) it opens out onto broader plains particularly on the left side of the river. Downstream of the mine, the river course becomes constricted for some 20 km in a bedrock gorge where it passes through the Bukalara Range, before opening out onto the Borroloola plains of the Carpentaria Lowlands. The range is hydrologically significant as it obstructs flood flows causing a backwater effect that extends up-valley beyond the mine area.

The Kilgour River is the last major tributary to join the McArthur River upstream of the Bukalara Range. However, a number of small creeks do enter the river in this reach. Barney Creek joins from the left just down-valley of the mine, and has a total catchment area of 570 km^2 that includes Buffalo Creek (170 km^2) and Surprise Creek (100 km^2). On the right, an un-named stream with a 95 km^2 catchment joins at Eight Mile Waterhole (10 km south-west of the mine), and Bull Creek with a 75 km^2 catchment joins 3.5 km east of the mine. As the McArthur River enters the Bukalara Range proper it is joined by Emu Creek (catchment of 55 km^2) from the north and the Glyde River (catchment of 2500 km^2) which is a large tributary of similar catchment size to the Kilgour River.

Channel Planform

For most of its 25 km length upstream of the Bukalara Range, the McArthur River flows in a single main channel. Sinuosity in this section is low at 1.06, and much of this comes from a single large bend at chainage 27500. Thus for most of its length the river channel would be classed as straight (i.e. sinuosity <1.05) (Morisawa, 1985).

Along much of this part of the valley the river is flanked by 1 to 8 subsidiary channels that occur across a 2 to 4 km wide floodplain. The pattern is similar to the anabranching style that is common in semi-arid and arid parts of Australia that has been defined as “a system of multiple channels characterised by vegetated or otherwise stable alluvial islands that divide flows at discharges up to nearly bank-full.” (Nanson and Knighton, 1996).

As described below, many of the anabranch channels occur well above bank-full flow height, and only one or occasionally two channels close to the main river carry water at bank-full stage. The McArthur River upstream of the mine exhibits some of the main characteristics of an anabranching river including a low relief semi-arid environment with dense channel vegetation, and is superficially similar to Type 2 island anabranching rivers (Nanson and Knighton, 1996).

Rainfall and Hydrology

The McArthur River catchment is located in the part of northern Australia that may be identified as experiencing a true monsoonal climate regime. Rainfall is strongly seasonal with a marked wet season occurring within the period from October to April, and river flow follows this pattern. Rainfall can result from thunderstorms, tropical cyclones and depressions, and convergence in the southern monsoon shearline.

Peak river flow months are usually February and March, although floods have occurred earlier in the wet season between November and January. Flood magnitude and frequency characteristics have been determined from discharge records at the DIPE gauging station 2.5 km south/south-west of the mine (URS, 2005a). The 2 and 5-year ARI peak flows are 460 m^3/sec and 1,300 m^3/sec respectively. At most places along the river the 5-year ARI flow exceeds channel capacity, and water spreads out onto the surrounding floodplain. The 100-year ARI flood has peak flows of 9,300 m^3/sec. The McArthur River generally dries up for one to two months each dry season, although periods of up to six months of no flow have been recorded.

Vegetation

Vegetation in the catchment area around the mine comprises low open eucalypt woodland that is sparsely treed on the bedrock hills, but with slightly denser coverage on the plains. There is a riparian corridor of varying width and density along the river and some of its anabranches. Growth is particularly dense along the banks of the McArthur River channel where a semi-closed canopy occurs and there is a more diverse community including species with rainforest affinities. True vine-thicket vegetation was not observed.

4.3.3 Geomorphic Environments of McArthur River

Introduction

A river channel functions as a conduit for water and sediment being carried by the river. Channels are typically adjusted to convey relatively small magnitude floods that have return periods in the range of about two to seven years, known as bank-full floods. These bank-full events are believed to be responsible for most channel change as the bed and banks are fully covered by flowing water, and significant erosion and deposition can occur at these times. Larger events exceed the capacity of the channel, and water spreads out over the adjacent floodplain. These flood waters do not accomplish a great deal of geomorphic work as they generally consist of shallow, relatively slow moving water that does not persist for long periods of time.

In addition to these physical processes, the channel also serves an important ecological function, providing the boundary conditions for the development of the riparian vegetation corridor (in particular soil and slope conditions), flow conditions necessary for the local fauna, and the in-stream habitats within the channel itself.

Thus, it is important that the river diversion design achieves the following functions:

- Accommodation of the bank-full flow events in terms of hydraulic capacity, sediment transport capacity, and erosion/deposition potential
- Floodplain capacity is retained such that mine facilities are not adversely affected
- Riparian vegetation is re-established so that ecosystem function is not adversely affected in the medium to long term
- Fish passage and in-stream habitat are retained as they currently occur.

This sub-section describes the geomorphic environments occurring along the existing McArthur River channel in the reach that is proposed for diversion, and the reaches both upstream and downstream of the mine. It identifies the present function of the channel and floodplain system as a basis for the development of the design of the river diversion.

Some 32 km of the McArthur River have been examined, covering 20 km upstream and 12 km downstream of the mine area. The upstream limit of observations was at the McArthur River – Kilgour River confluence (chainage 41000, at map reference Sheet 6064/1: 047-644), and the downstream limit was in the Bukalara Range (chainage 10000, at map reference 6165/3: 232-878). Three broad reaches are recognised as follows:

- Anabranching reach (chainage 20900 – 42115): a variable reach more than 20 km long characterised by a single main channel with multiple long anabranches on a 2 to 3.5 km wide floodplain. Two sub-reaches are identified (upper and lower)
- Mine reach (chainage 16100 – 20900): a uniform reach of 4.8 km length with short flood channels adjacent to the main flow and no anabranches
- Bukalara Range reach (chainage 0 – 16050): a 20 km reach confined within the Bukalara Range.

Anabranching Reach

The anabranching reach occurs along a relatively broad flat section of the McArthur River valley. The plains here are more than 5 km across and are at 40 to 55 m above sea level. Frequent low hills of Late Proteroozic dolomite of the McArthur Group of rocks rise 10 to 50 m above the plain, and they outcrop at numerous points along the river channel. Prominent rock outcrops have resulted in the development of permanent waterholes at Eight Mile Waterhole (chainage 29450) and Djirrinmini Waterhole (chainage 20900).

The defining characteristic of this reach is the low sinuosity main channel flanked by a wide floodplain with numerous anabranches. The reach extends upstream for at least 20 km from the rock bar that dams Djirrinmini Waterhole to the Kilgour River confluence (chainage 42115), and it continues upstream well beyond this point. There is considerable variability of slope, bed materials and riparian vegetation, and there are several long pools. Two sub-reaches are identified; upper and lower.

The upper sub-reach is approximately 12 km long and extends to the downstream end of the Eight Mile Waterhole. From the digital terrain model (DTM) data, the overall slope is 1 in 1,580 (0.00063 $mm.m^{-1}$)[1]. Sinuosity is 1.05. A typical cross-section across the upper reach is shown in Chart 4.1, which shows the channel and floodplain at chainage 40319, approximately 2 km downstream of the Kilgour River confluence.

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[1] The DTM data show the upper 8 km of the reach slopes very gently at 1 in 3,900 (0.000257 $mm.m^{-1}$), while the lower section is more steeply sloping at 1 in 625 (0.0016 $mm.m^{-1}$). However, there is no evidence on the aerial photographs for such a prominent knick point at chainage 33078.

The main channel is 14 m deep below the levee banks, which in turn are about 2 m above the floodplain. Riparian vegetation corridor is confined to the inner channel banks of the main channel and the adjacent anabranch at -100 m. The anabranch at -600 m has much less dense tree cover, and all others are very sparsely treed. This is consistent with the -100 m anabranch carrying water in most years (2-year ARI), while the -600 m anabranch less frequently carries flow (5-year ARI), and all other anabranches are only active very infrequently.

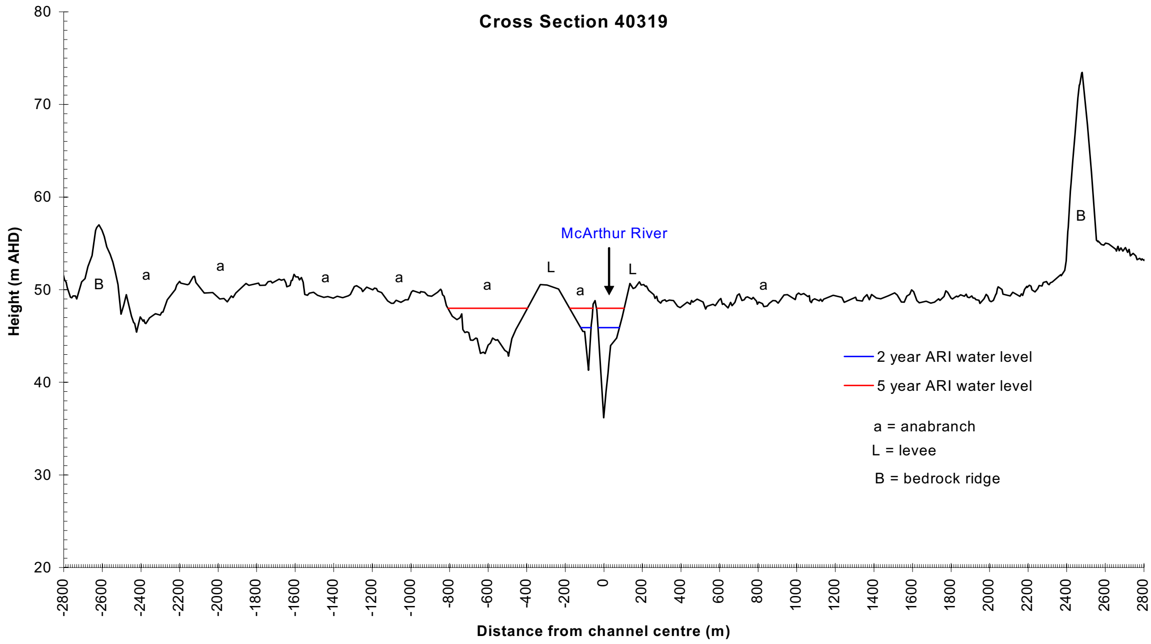


Chart 4.1

Cross-section Through the Upper Anabranching Reach at Chainage 40319

Pale coloured tones on the aerial photographs are interpreted as deposits of floodplain sediments. These extend 2.5 km away from the channel on the left side of the valley where the anabranches occur most commonly, and 1 km on the right side. The anabranches are shallow features, typically less than 2 m deep, and can run for up to 10 km before returning to the main river. There are many dry ponds in these anabranches shown on the topographic map, and these support a single tree-width riparian strip, otherwise the floodplain is very lightly treed.

A large in-channel bedrock outcrop marks the end of this sub-reach, as shown in Plate 4.1. This obstruction dams Eight Mile Waterhole, which early in the dry season extends upstream for nearly 6 km, although by August/September shrinks to about 2 km in length. The rock bar is about 250 m across and extends along 325 m of the channel. The waterhole is 60 m across, but narrows upstream to 25 m. It is 14 m below the true left floodplain, but only 6 m below the true right floodplain. Along the banks the riparian vegetation strip is very narrow, presumably due to the very steep side-slopes. The floodplain has narrowed to be 2 km wide, with bedrock outcrops occurring close along the true right side.

Plate 4.1

McArthur River Downstream at the Bedrock Outcrop Damming Eight Mile Waterhole and Floodplain Anabranches (May 2006)

The lower sub-reach is approximately 8 km long and extends to the rock-bar at the downstream end of the Djirrinmini Waterhole. The overall slope is steeper at 1 in 925 (0.0011mm.m^{-1}), although the downstream 3.5 km that includes the Djirrinmini Waterhole has a very gentle slope of 1 in 1,1500 (0.00009 mm.m^{-1}). Sinuosity is 1.04. One kilometre downstream of the Eight Mile Waterhole rock-bar the main channel passes through a 1.2 km long bend that is the only significant bend in the McArthur River upstream of the Bukalara Range. It appears to be bedrock controlled, and is cut off by a floodwater channel that follows a 0.8 km straight course directly to the downstream end of the bend (see upper right part of Plate 4.1).

A typical cross-section across the upper reach is shown in Chart 4.2, which shows the channel and floodplain at chainage 23891, approximately 4.5 km south-west of the mine. The narrow, steep sided channel is over 10 m deep, flanked by small levee banks, and a very irregular floodplain surface. This latter is probably closely underlain by bedrock. At 1000 m is the anabranch that heads off into Bull Creek, and at -820 m is the last returning anabranch on the left bank. This rejoins the McArthur River about 700 m downstream.

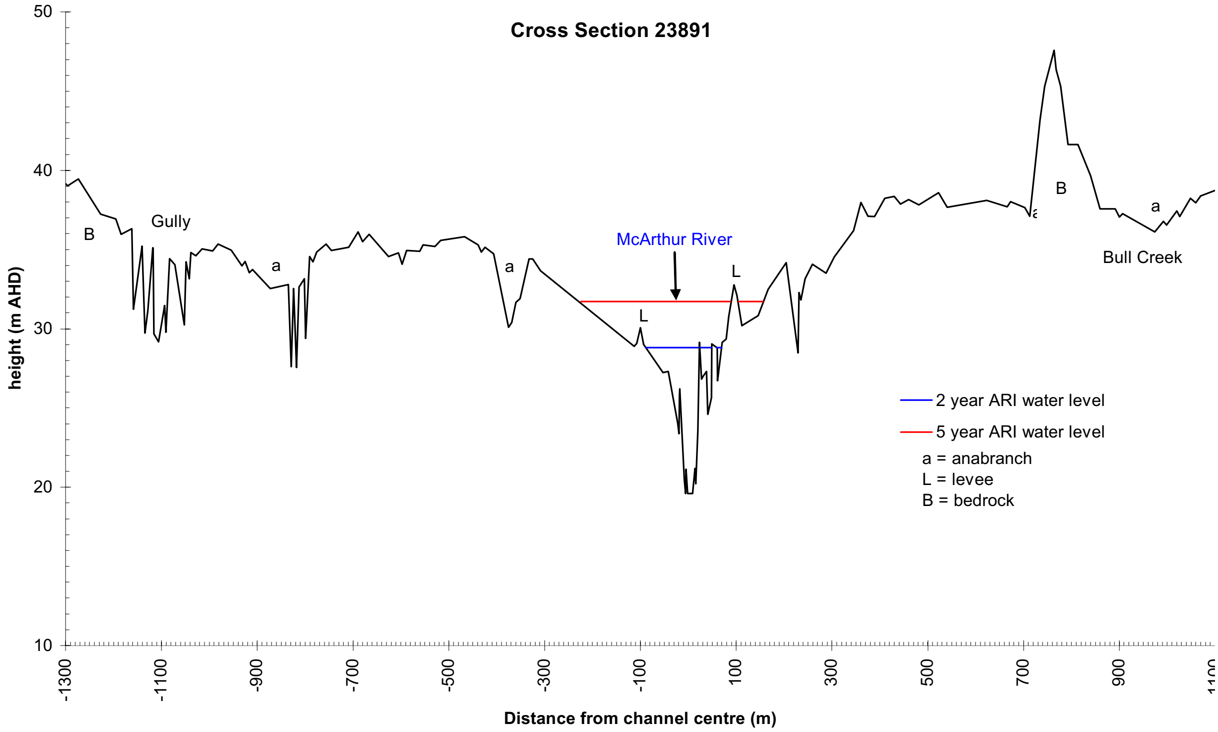


Chart 4.2

Cross-section of Anabranching Reach at Chainage 23891

The riparian vegetation corridor along this sub-reach is variable, being poorly developed in the upstream 5 km and very well developed in the downstream 4 km. Downstream of the Eight Mile rock-bar trees are sparse along the right bank and a little better developed on the left. This continues until about chainage 24000 and downstream from here the main channel is flanked by more dense riparian vegetation corridor that is up to 300 m wide on the north bank and 150 m wide on the south bank.

The floodplain beside this sub-reach is up to 2 km across, and contains only two to three anabranches, with fewer dry channel ponds. There are also fewer bedrock rises on the floodplain, although the more irregular surface topography suggests bedrock is not far below the surface. A small stream meets the McArthur River from the right at the Eight Mile rock-bar. In its lower course it picks up flow from an anabranch. It is the only tributary to join in the anabranching reach. About 1.5 km downstream from here another anabranch heads away from the river to the north-east. This would receive flow only during very large floods. It is the last significant anabranch to leave the McArthur River, and it eventually joins Bull Creek and rejoins the main river some 10 km downstream. The lower reaches of Bull Creek will be occupied by the main McArthur River diversion as described below.

The downstream part of the sub-reach contains the 700 m long by 25 to 30 m wide Djirrinmini Waterhole which is dammed by a 150 m long bedrock outcrop at chainage 21000, as shown in Plate 4.2. The DIPE gauging station cross-section is in the upper foreground between the small shed and the vehicle track.

Note wide riparian vegetation strip on the left bank, and rock bar damming the waterhole is in the middle ground.

Plate 4.2

McArthur River Downstream at Djirrinmini Waterhole (May 2006)

The last main north bank anabranch rejoins the main channel at about chainage 22000. As the floodplain anabranches become less numerous, they are replaced by a single anabranch that closely parallels the main river and is nowhere more than 300 m distant. These usually short (less than 1 km long) and shallow channels (less than 2 m deep) are occupied by floods of less than bank-full magnitude.

The anabranching style in this reach is most similar to the island anabranching river type of Nanson and Knighton (1996). The essentially straight laterally stable channel with levees and riparian forest contributing to cohesive bank conditions are characteristic of this river type as described by Erskine *et al* (2005). However, there are differences: discharge and stream power are higher and many of the anabranches do not carry flow at bank-full stage nor do they appear to be sand-floored. The floodplain style is also not typical of those identified by Nanson and Croke (1992). Their classification did not allow for anabranching rivers, although the special anastomosing type of anabranching river was included. In general, this reach of the McArthur River appears to comprise a new type of medium energy cohesive floodplain formed by regular flow events along a laterally stable single-thread river with floodplain anabranches. The frequent occurrence of bedrock both within the channel and on the floodplain may also be a significant factor in this channel and floodplain style. It contributes to the stability of the channel, the development of knick points and associated waterholes, and the ability of the channel to sustain high stream powers.

Mine Reach

The mine reach is about 5 km long from the Djirrinmini rock-bar to Barramundi Dreaming Ridge (chainages 21000 to 16000). It is the reach that will be substantially lost from the river system due to the proposed diversion. This is the most uniform of the three reaches identified here, comprising a single main channel with small side channels occupied during floods of less than bank-full magnitude. The slope of the reach is 1 in 1,250 (0.0008 $mm.m^{-1}$) and there are no knick points in the long profile. Sinuosity is low (1.05). The channel is formed in alluvium along its whole length, although there are a few small bedrock outcrops at the sides of the channel (see below). There are no waterholes, significant rock bars or pool and riffle sequences, and when flowing the channel has the form of a continuous run. In this reach, the McArthur River gains a tributary from the north-west from the Barney/Surprise Creek catchment.

There are three distinctive characteristics of this reach that are not seen along the other reaches: large levee-like features; tributary gullies; and discontinuous flood channels.

Along most of this reach the floodplain slopes up towards the main channel on both sides of the river, and this rising ground can be distinguished on the aerial photographs by its pale colour tones. The rise is usually 1 to 5 m, and occurs over distances of 150 to 400 m. These are interpreted as broad levees formed by over-bank deposition during floods. They appear to increase in height and width downstream, suggesting their formation may be related to backwater effects during floods when water is essentially ponded on the floodplain promoting more concentrated deposition close to the main channel.

Numerous small tributary gullies drain off the surrounding floodplain into the main river. These are short steep catchments up to 500 m long, with several tributaries, and they form 10 m deep by 50 m wide valleys cut into alluvium where they meet the river. Five join on the left bank, with eight joining on the right. In their upper reaches they cut through the above-described levee-like features. Their development is probably related to the levees, which will act to dam water on the floodplain as the flood water levels decline, and these gullies then carry the return flow of water to the main channel.

The main channel is flanked along the whole length of the reach by small, discontinuous side channels, typically occurring as a single channel on either side of the river. Usually only a few hundred metres long, they may be up to 3 m deep and have a top width of 250 m. They are essentially anabranches, although quite different in character to those in the previous reach as they tend to be shorter and carry water more frequently. However, these flood conduits are well grassed and contain numerous mature *Casuarina* and *Eucalyptus* trees.

Typical cross-sections of the mine reach channel are shown in Charts 4.3 and 4.4.

Cross-section 17094 (Chart 4.3) is in the downstream part of the reach, about 1 km downstream of the Barney Creek confluence. The section line runs up a tributary gully on the true right side and hence the topography from the river to approximately 600 m on the profile relates to this gully feature. The main channel is 14 m deep below the left bank levee, and has a top width of approximately 50 m before it expands laterally into the gully mouth. There is a small in-channel bench 8 m above the bed on the true left bank, but this part of the reach does not have a flood conduit channel. The levee features extend to about 400 m either side of the channel, and the gully at -400 m drains east into the un-named stream that will be occupied by the downstream end of the Barney Creek diversion.

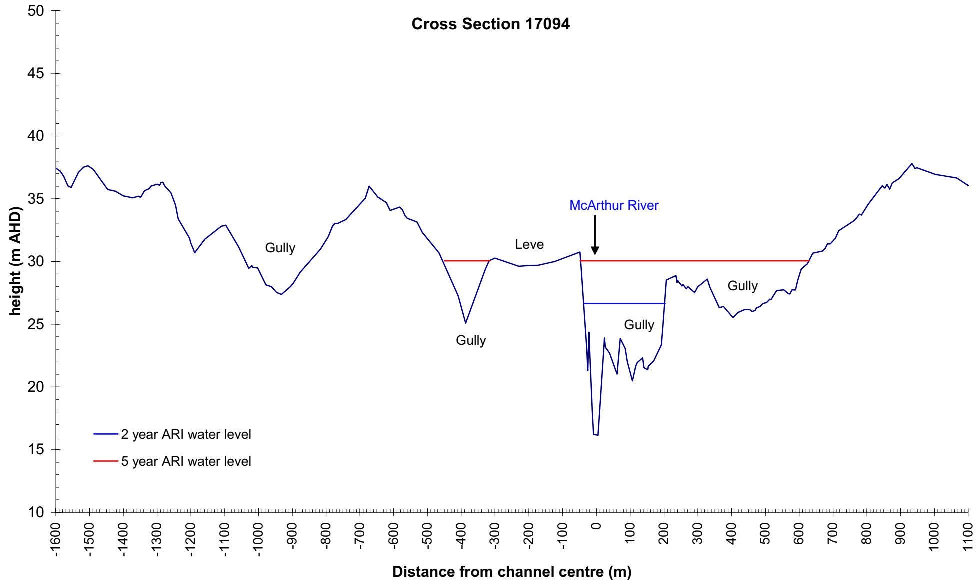


Chart 4.3

McArthur River Cross-section at Chainage 17094

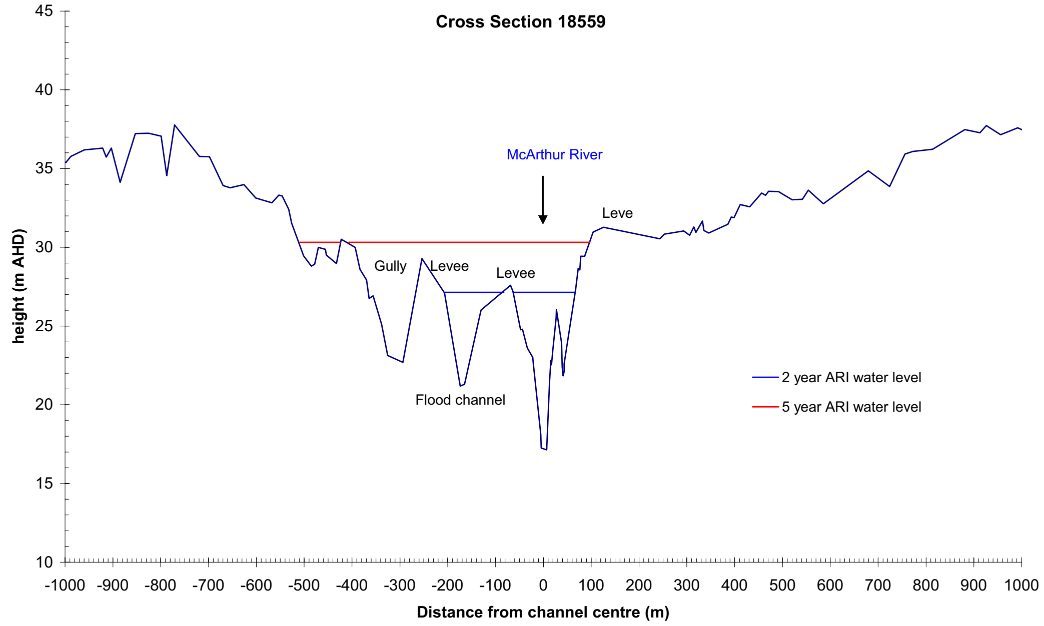


Chart 4.4

McArthur River Cross-section at Chainage 18559

Cross-section 18559 (Chart 4.4) is 1 km south-east of the mine. The channel in this location is shown in Plate 4.3. The main channel is approximately 14 m deep below the right bank levee, and is about 20 m wide at the base, with a small in-channel bench 9 m above the bed on the right bank. The channel has a top width of about 130 m at bank-full discharge when flow depths are 10 – 12 m. Discharge at this stage is about 500 m^3/sec. A 6 m deep flood channel is on the left 165 m from the main river. A levee-like feature extends 250 – 300 m either side of the channel, which is a little narrower than at the previous downstream site.

Plate 4.3

McArthur River Channel near Cross-section 18599 (May 2006)

The dense riparian vegetation corridor along the channel banks can be seen on Plate 4.3, and this contributes to the steep sides of the trapezoidal channel that slope at about 30°. At the top of the channel banks the riparian vegetation only extends 50 to 80 m across the levees. It is significantly less developed than the riparian vegetation at the lower end of the anabranching reach just upstream.

Alternating beds of sand and mud have accumulated in drapes over the channel bank. This is consistent with the oblique accretion process of floodplain formation described by Nanson and Croke (1992). Here and elsewhere in the reach, in-channel sediment is dominated by freshly deposited medium-fine sand. This appears to have been deposited in the recent Cyclone Monica flood event. The sand coated much of the channel bank to depths of 0.2 m, and in some locations banks up to 2 m deep have accumulated. Beneath this recent sediment the bank material was variable, being muddy in places and elsewhere had a more soil-like consistency.

Access to the channel was limited during the fieldwork due to in-channel flow and floodplain ground conditions. However, the channel was accessed at six locations and some general observations were possible.

At the rock-bar that dams Djirrinmini Waterhole, vegetation is sparse. Scattered small trees occur on the rock-bar, but these show damage consistent with the high flow velocities that occur though this section. Elsewhere the channel bed was generally clear of major accumulations of dead large woody debris, and from an aerial inspection only three locations were seen where trees had fallen right across the channel bed. However, there were some mature living trees well established in the channel bed. These indicate that for probably more than 10 years while these trees were becoming established, the McArthur River did not flood to the extent that significantly compromised the growth of these trees. Taken together, these observations have implications for the revegetation of the diversion channel. Where flow velocities are high, revegetation may require more management intervention. However, it is also possible that there could be periods of many years when significant floods do not occur and this would enhance vegetation re-establishment.

In-channel benches occur irregularly along the length of the reach, at various levels between 2 and 8 m above the channel bed, and they are up to 10 m wide. In general, the slopes of the channel banks along the mine reach are very steep for the size of sediment they are composed of. Although the mud sediments will contribute to bank cohesion, significant slope strength is probably provided by the extensive root mats of the trees that line the banks. These also provide roughness that reduces flow velocity adjacent to the banks. A few trees were observed to have been overturned in the recent flood, and their root mats were exposed. In addition, a small bank slump was observed during the aerial survey. However, these examples of erosion were isolated, and the dominant pattern through the mine reach was of a stable channel that has recently been mainly affected by small-scale deposition processes.

Classification of the reach using the scheme of Erskine *et. al.,* (2005) is difficult, as it has characteristics of both the island anabranching and straight river types. It has a nearly straight channel, sandy bed, is flanked by a broad floodplain and has large levee-like features. The channel bed does not contain pools and riffles. The floodwater conduits close to the main channel may represent anabranches, although they are not as distinctive as those developed in the anabranching reach upstream. In addition, stream power values derived from the HEC-RAS model suggest this is a higher energy channel than is typical of island anabranching rivers.

Bukalara Reach

The Bukalara Range is about 15 km across and rises to about 140 m above sea level, which is some 100 m above the McArthur River floodplain. The upper parts of the range are comprised of the early Palaeozoic Bukalara Sandstone that overlies the late Proterozoic Abner Sandstone. As the McArthur River passes through the range, it cuts through the softer Bukalara Sandstone for some 6 km before passing into the harder Abner Sandstone rocks. The course cuts through the Bukalara Range in a series of broad bends in a 22 km long reach with a sinuosity of 1.3. The overall slope is 1 in 3125 (0.00032 mm.m^{-1}), but the channel profile is irregular with several knick points and in the downstream parts of the reach there are many pools. There are no anabranches along the reach, although there are several high level cutoffs where floodwaters pass around low hills in bedrock channels up to 3 km long.

The start of the reach is at Barramundi Dreaming Ridge, 3 km east of the mine. Here the river is forced through a 150 m wide gap in the ridge, and the 1.5 km wide floodplain is confined between low bedrock hills. Emu Creek joins from the north 1.9 km downstream, and the Glyde River joins from the south a further 550 m downstream (chainage 13600). The McArthur River then enters the Bukalara Range proper, and becomes confined between higher sandstone ridges.

Although in a bedrock-confined zone, the channel and parts of the floodplain in the upstream part of the Bukalara Reach are formed in alluvium. A typical cross-section is shown in Chart 4.5, which is in the middle distance in Plate 4.4. The channel is nearly 11 m deep below the small left bank levee. The low ridge on the profile at -100 m in the centre of the valley is bedrock, while the lower parts of the floodplain that are inundated by the 5-year ARI flood are underlain by alluvium. Almost the full valley width is covered during the 5-year ARI event, and for larger floods the constriction caused through this part of the Bukalara Range causes a backwater effect that extends more than 10 km up the McArthur valley.

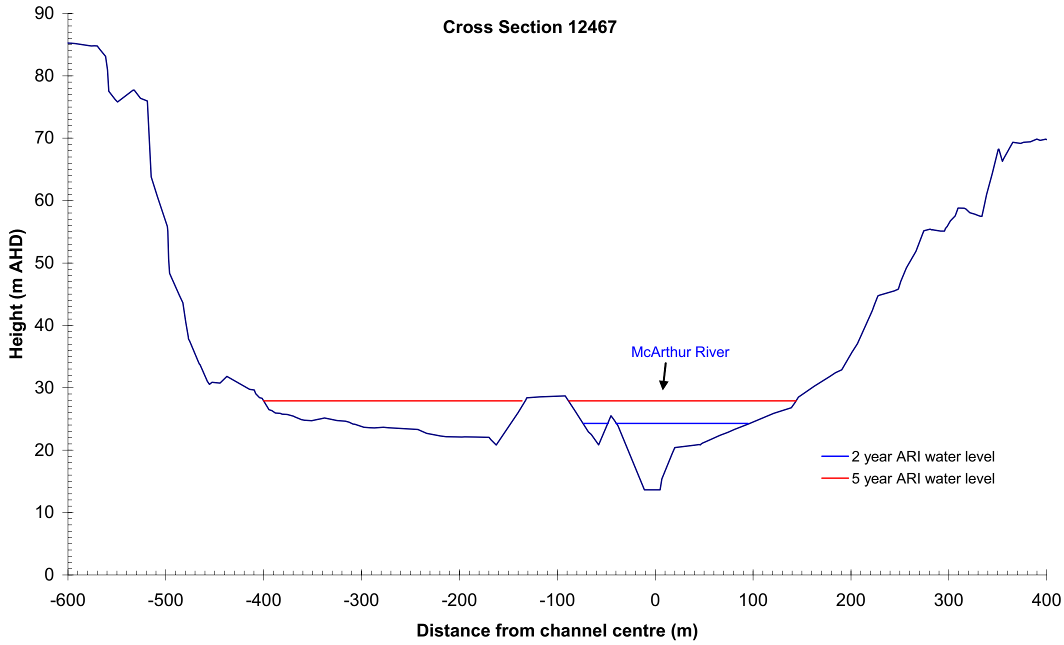


Chart 4.5

Cross-section of Bukalara Range Reach at Chainage 12467

Plate 4.4

McArthur River Looking Upstream from within the Bukalara Range (May 2006)

Riparian vegetation is very well developed particularly on the parts of the floodplain underlain by alluvium. This can be seen in Plate 4.4 where, on the true right side of the channel, the floodplain is clearly formed in bedrock, and there is very little vegetation away from the narrow belt of *Casuarinas* that have established on the narrow levee here. The line of the river is marked by the canopies of the pale coloured *Melaleuca argentea*. On the true left bank, a row of *Eucalyptus* trees occupies the levee bank, with the *Casuarinas* on the outer fringe.

In the downstream part of the reach, the alluvial channel and floodplain give way to bedrock where the Abner Sandstone outcrops across the whole valley. The river channel is wider and more irregular in cross profile here as it is probably largely formed in bedrock. Flows of more than the 5-year ARI remain confined within the channel banks. In this part of the reach, five permanent waterholes are shown on the topographic map (Carabirini 6165/3), and one is approximately 4 km long. They are presumably dammed behind bedrock outcrops in the bed. The river has also cut a floodplain in this bedrock some 20 m above the channel bed. From the HEC-RAS model it appears this is only inundated during floods greater than the 50-year ARI event.

From the stream types identified by Erskine *et. al.,* (2005), the Bukalara Reach can be classified as a bedrock-confined river in its upstream part, and a resistant-bedrock river gorge in the downstream part. This arrangement is the reverse of the typical pattern reported by Erskine *et. al.,* (2005) where the bedrock-confined reaches are usually found downstream of a gorge. This difference results from the pattern of bedrock resistance in the Bukalara Range where the weaker sandstone is in the upstream part of the reach, allowing the McArthur River to erode its valley more effectively.

The Bukalara Reach influences the McArthur River in the mine area in two ways: the constriction of the valley through the range creates a flood backwater effect that extends well up-valley beyond the mine site; and the bedrock outcrops in the channel restrict the free movement of fish upstream to periods of wet season flow.

4.3.4 Conclusions

This geomorphology assessment has described the environmental conditions in the McArthur River system upstream and downstream of the mine site in order to provide a context for development of the design of the river diversion. It can be seen that the mine reach is a stable alluvial channel which functions as a uniform run of even downstream slope, with a capacity that has adjusted to carry flows up to the magnitude of approximately the 5-year ARI event (approximately 500 m^3/sec). Over-bank flows onto the floodplain are affected by the backwater effect of the Bukalara Range resulting in the formation of a broad levee bank adjacent to the main channel. Ecologically, the dense riparian vegetation supports a number of rainforest-type trees and provides a riparian corridor for avifauna. The in-channel fish habitat is generally poor, although there are no major obstructions to fish passage.

The design of the diversion channel described below seeks to replicate these relatively simple environmental conditions where possible. The major differences will be as follows:

- The downstream part of the diversion will not be an alluvial channel as bedrock will be intersected in the excavation
- The upstream section will have two artificial rock riffle structures in the bed. These are required to reduce flow velocity so as to enhance the re-vegetation prospects on the channel banks. They are not expected to disrupt fish passage as is evidenced by the naturally-occurring rock-bars in the reaches upstream and downstream of the mine site. The placement of the artificial rock riffles in the diversion will not be inconsistent with this wider environmental pattern.

4.4 Aquatic Habitats of the Existing McArthur River Channel

4.4.1 Summary

This sub-section describes the aquatic, riverine and riparian habitats occurring along the existing McArthur River channel within the reach proposed for diversion. Data were obtained through field surveys conducted in May 2006 and illustrate the significant in-stream, bank-side and riverine habitats present. The data have been used to inform the engineering and biological design specifications for the proposed diversion channel so that key habitat types and management strategies can be included.

4.4.2 Survey Methods

Data on aquatic habitat characteristics were collected using the AUSRIVAS Physical Assessment Protocol (Parsons, Thoms and Norris, 2002). This system is used Australia-wide for characterisation of aquatic habitats and enables detailed assessments to be made of conditions at each sample site. While procedures within the protocol are comprehensive, they are designed for use over a range of conditions Australia-wide. Some variables were not relevant to the McArthur River sites and hence were either not recorded or noted only in a general context. Some additional parameters not included in the AUSRIVAS protocols were recorded because they were considered relevant to the project.

Sampling was conducted at 10 sites along the main McArthur River channel within the area to be diverted. Sites were chosen at relatively even spatial distribution (between 500 and 800 m apart) along the river to the extent allowed by access requirements. Two additional sites were also sampled in Barney Creek within the section of that stream to be diverted. The locations of the survey sites are shown on Figure 4.1.

At each site, a 100 m reach of the river was surveyed. The variables recorded were grouped into the following major categories:

- General site data
- Water quality
- Riparian zone vegetation
- Channel form
- Bed-form features
- Channel cross-section
- USEPA habitat assessment
- In-stream habitats.

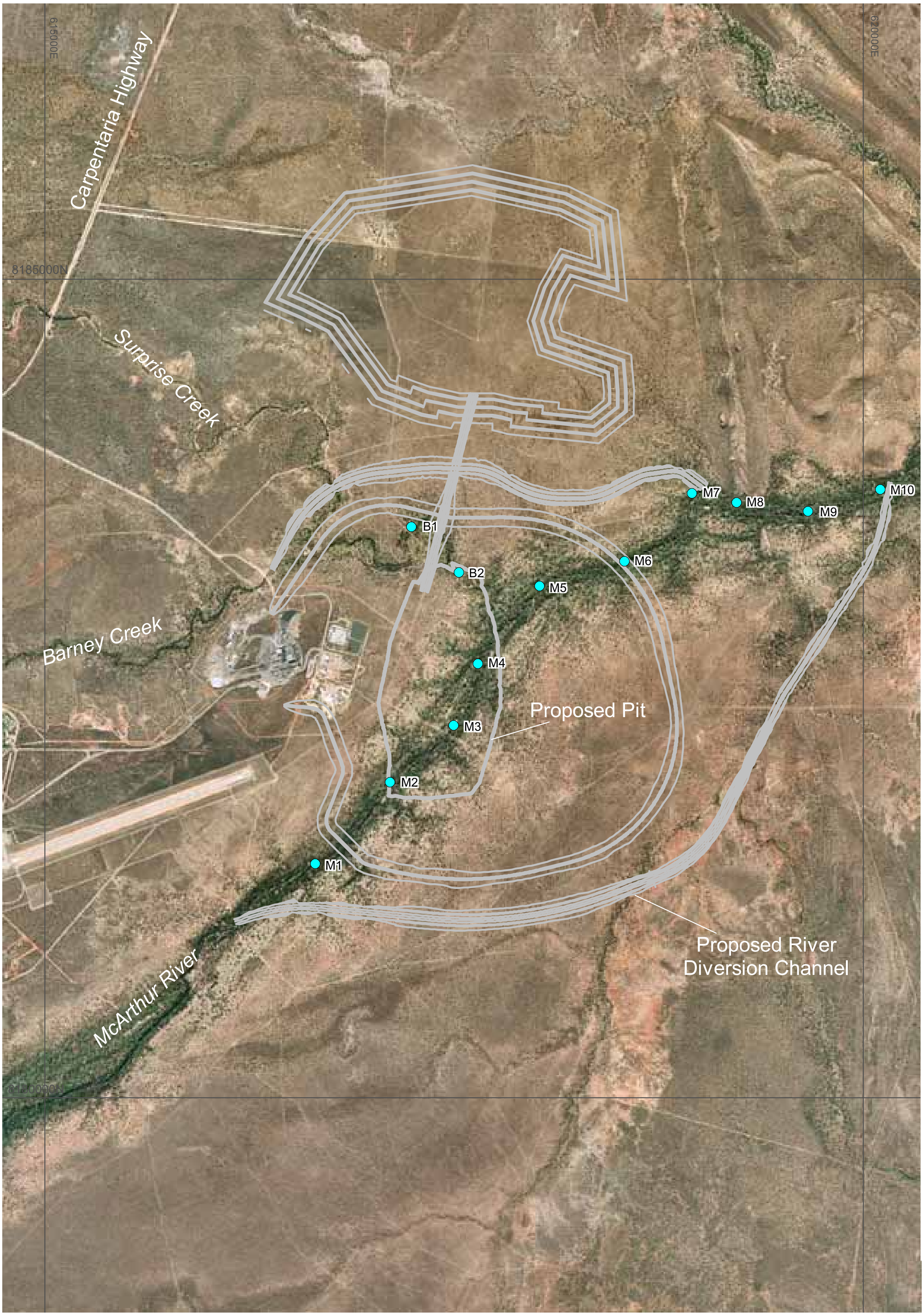
A planform sketch of each 100 m reach was made and site photographs were taken at each cross-section site. Copies are provided in Appendix E.

Following completion of the site-based surveys, a visual survey of the entire reach to be diverted was undertaken by boat.

4.4.3 General Site Conditions

At the time of the survey (6-9 May 2006), flows in the McArthur River were relatively high, due to the effects of recent rainfall from a late wet season tropical depression. Rainfall in the weeks prior to the survey had been fairly low, but 170 mm of rainfall were recorded at Borroloola between 26-29 April, a week prior to the surveys.

This rainfall had the effect of raising river levels. River flow and height records for the gauging station immediately downstream of McArthur River mine (MRM gauge) indicated that the river levels peaked on



0 500m 1000m
Scale 1: 35 000 (A4)

Horizontal Datum: AGD84, Zone 53
Date of Aerial Photography, 2001

● Aquatic Survey Site

xstrata

URS

McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

LOCATION OF AQUATIC HABITAT SURVEY SITES

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **4.1**	Rev: A
Job No: **42625552**	File No: 42625552-g-177.wor			**A4**

1 May with a maximum flow rate of 690 m^3/s and height of 10.3 m. River levels fell rapidly following this rain period. During the three-day survey period, flows declined from 47 m^3/s to 24 m^3/s and heights fell from 2.5 m to 1.8 m. These conditions inhibited measurement of some in-stream aquatic parameters, but did allow observation of the stream conditions at a period of relatively high flow. It is known that this reach of the river ceases to flow for significant periods towards the end of the dry season.

Data recorded in the survey are presented in Appendix E and are summarised in the following sections.

Water Quality

General water quality parameters were consistent over the survey. Water temperatures ranged between 20.9°C and 24.6°C. Conductivity ranged from 454 to 490 µS/cm and dissolved oxygen levels from 6.15 to 7.78 mg/L. pH ranged from 7.72 to 8.35. No sediment oils, water oils or odours were noted at any sites. Turbidity was estimated to be slight or turbid depending on the levels of suspended materials.

Riparian Zone Vegetation

The vegetation of the McArthur River corridor is mapped in the Draft EIS (URS, 2005a) as Map Unit No. 9 – Riverine Corridor. Two cross-sections presented in the Draft EIS Appendix H.4 (Figures 9 and 10) represent typical vegetation profiles along this reach of the McArthur River.

Vegetation along this reach of the river, especially in the riparian zone, is characterised by a low number of species which are able to tolerate the highly dynamic environment. The upper stratum trees are dominated by *Melaleuca argentea*, with sub-dominant species including *Casuarina cunninghamiana*, *Nauclea orientalis* and others. *C. cunninghamiana*, while often present in the river channel and edge habitat, is far more abundant on the upper banks, where it forms pure stands at some sites.

The mid-stratum is dominated by the freshwater mangrove (*Barringtonia acutangula*). This species is the primary tree species growing along the edge habitats of the mine reach of the McArthur River, frequently forming continuous or semi-continuous bands. Other species are *Syzygium eucalyptiodes* and *Pandanus aquaticus*, which constitute only occasional trees. There are no ground cover plants along the lower banks of the river, although some introduced and native grass and herb species are present on the upper banks.

Tall trees (mainly *M. argentea* and *C. cunninghamiana*) provide up to 50 to 60% shading of the McArthur River channel, while *B. acutangula* provides edge habitat shading of between 40% and 70%. Edge vegetation does not trail in the water in most areas of the McArthur River, due mainly to the nature of the plant species present. Overall, the vegetation of the river channel has low disturbance (apart from natural flooding disturbance) although the upper banks are disturbed by weed invasion and cattle activity.

Channel Form

There is an overall uniformity of channel form along the mine reach of the river.

The channel shape of the McArthur River ranges from a deepened U shape, through to two stage and multi-stage shapes, with no unnatural modifications except for cattle disturbance to the banks. The two stage bank profile is most prevalent. The bank shape is stepped or concave at all sites. This form generally provides a smooth sloping transition at the water's edge, with very little bank undercutting. The slope of the banks ranges from moderate (30-60°) to steep (60-80°).

The channel of the McArthur River through the proposed diversion area generally offers good or unrestricted passage for fish (at least while in flow), with no significant channel obstructions such as rock bars. Rock bars are present, however, upstream and downstream of the reach to be diverted. Minor side-point sand bars and rocky outcrops are present in some locations of the diverted reach, and these are generally vegetated.

Bed-form Features

All sites sampled along the McArthur River reach can be classified as having run bed-forms, while the two Barney Creek sites have a combination of riffles and glides. Bed compaction is low at all McArthur River sites, with a matrix-filled contact framework and gravel fractions not present. There is moderate sediment/sand deposition at all sites. The bed of Barney Creek is more stable, with sub-angular sediments and moderate to low compaction.

Channel Cross-section Features

Three cross-sections were documented at each site, one in the middle and one at each end of the 100 m transect. Results were averaged for analysis. Detailed cross-section profiles at 12 sites in the same general area are shown in Figure 12.5 of the Draft EIS (URS, 2005a). Stream width at the water surface recorded in May 2006 ranged from 16 m to 25 m. This is somewhat higher than the bed width of 10 to 20 m cited in Section 12 of the Draft EIS due to the elevated water levels at the time of sampling. Bank widths (to the first major step) at the time of sampling were generally 20 to 45 m either side of the channel, while bank heights were between 8 m and 18 m. The riparian zone generally extends for 50 to 60 m each side of the channel.

Bank materials are a combination of sands and fine materials, with sand dominating. Gravel was recorded at only one site. Substrates consist almost entirely of sands and fines.

At one site (M2), the main channel was divided into two, separated by a vegetated sand accretion in the centre of the channel. This mid-channel accretion was approximately 200 m long.

Due to safety considerations, it was not possible to accurately measure stream depths at the time of sampling, and due to the rapidly declining levels, measuring this parameter was of limited value. However, some spot depths recorded from a boat showed that generally, maximum depths within this reach at that time were between 1 and 2 m.

USEPA Habitat Assessment

The USEPA "HABSCORE" index is a rapid assessment protocol focussing on biological and physical stream parameters to indicate relative stream conditions. The physical parameters only are considered in the AUSRIVAS habitat protocol (Parsons, Thoms and Norris, 2000). Each parameter is scored separately and an overall comparative result is obtained by applying the total score as a percentage of the possible total.

For the McArthur River sites, highest scores were assigned for sediment deposition, lack of channel alteration, and condition of riparian zone and vegetative protection. The sites scored lowest for parameters such as epifaunal substrates/habitats, pool variability, channel sinuosity and bank stability. The percentage scores at each of the 10 McArthur River sites ranged from 38% to 46%, indicating that overall, the area has a below average rating for in-stream fauna colonisation. This is to be expected, given the highly dynamic nature of the reach and the lack of permanent pools.

In-stream Habitats

A series of additional recorded parameters were specifically designed to provide information on the key in-stream habitats along the McArthur River, especially those which might need to be established in the diversion channel.

The existing channel is a sandy, well-shaded run with high habitat consistency through its entire length. There is low sinuosity and bank edge habitats are rarely undercut or obstructed by rock bars. No aquatic macrophytes were recorded in this reach and it is considered unlikely that any macrophyte species could survive the high flows and substrate mobility in this area.

The most important in-stream habitats in this reach are those which provide eddies or other disruption to flow velocities, as they act as resting habitat for migrating aquatic fauna. They primarily include woody debris and log-jams, bank-side vegetation, in-stream or stream-edge trees and root masses. Large woody debris (LWD) is debris greater than 10 cm in diameter. Examples of LWD within the 100 m transect length and within 5 m of the water's edge were counted at each site. The lowest counts were 10 and 13 at the two lower sites, while other sites had between 10 and 38 pieces, for an overall average of 22 pieces per 100 m. It was also evident that the more substantial examples of LWD (i.e., pieces >30 cm diameter) play a more important role in creating log-jams and eddies than do smaller pieces. These larger pieces generally comprised about 35% of the overall total, or an average of 8 pieces per 100 m. Also notable is a habitat that might be termed small woody debris, comprising accumulations of twigs and branches embedded into the banks which protrude into the stream and create an edge microhabitat.

Several very large (>40 cm diameter breast height) trees are present in the bed of the McArthur River. These are chiefly *Melaleuca argentea* and *Casuarina cunninghamiana* with some larger *Barringtonia acutangula*. They provide stream obstructions, and when situated in proximity to one another, act as traps for passing LWD, thus creating log-jams which break up the stream flow and provide quiet water areas. The average number of these trees per 100 m along the river was about six. These trees (especially *Melaleuca argentea*) also create some root mass habitat although this is quite limited. Root masses from bank-side trees also invade the in-stream edges to provide another type of quiet water habitat although this too is limited in extent.

The role of the continuous or semi-continuous band (up to 70% in places) of *Barringtonia acutangula* along the banks and in the channel is considered possibly the most important for formation of in-stream habitat. Where this species forms clumps or stands, it provides dense shading, protection from predators and in-stream flow reduction. It also acts to stabilise the banks and trap passing woody debris.

Typical aquatic habitats occurring along the McArthur River within the existing diversion reach are illustrated in Plates 4.5 to 4.10.

Plate 4.5
Edge Habitat Dominated by *Barringtonia acutangula*

Plate 4.6
Minor Rock Bar With Tree Growth

Plate 4.7
Logjam Created By Presence of In-Stream *Melaleuca* Tree and Large Woody Debris

Plate 4.8
Small Woody Debris Embedded In Bank-Side Sediments Creating a Microhabitat

Plate 4.9
Debris Trapped by In-Stream Tree Growth Including *Melaleuca, Barringtonia* And *Casuarina*

Plate 4.10
Unstable Steep Sand Banks at the Mouth of Barney Creek

4.5 Revised Hydraulic Analyses of the McArthur River

4.5.1 Introduction

The hydraulic modelling (HEC-RAS) undertaken for the existing McArthur River system, as presented in the Draft EIS (URS, 2005a), has been updated and revised to address the specific issues listed in the PER guidelines. The additional work undertaken to do this includes the following:

- Re-calibration of the model for low river flows
- Re-calibration of the model to the January 2003 recorded flood levels
- Confirmation of the roughness coefficients using Cowan's method
- Sensitivity analysis of any inaccuracies in the survey data
- Re-modelling of existing river conditions
- Modification of the design of the river diversion
- Re-modelling of the modified diversion design.

A discussion of each of the above tasks is given below.

4.5.2 Re-calibration of the Hydraulic Model for Low Flows

A one-dimensional hydraulic model (HEC-RAS) was developed as part of the EIS investigations (URS, 2005a) to assess the hydraulic conditions of a 45 km reach of the McArthur River upstream and downstream of the mine. This included calibration of the model for flows of 20 m^3/s, 50 m^3/s and 100 m^3/s as well as the January 2003 flood event by iteratively changing the main channel and floodplain roughness coefficients until the calculated water surface elevation was similar to the observed water levels at the DIPE gauge (upstream of the mine) and the MRM gauge (downstream of the mine).

The low flow (20 m^3/s, 50 m^3/s, 100 m^3/s) calibration results were reported in Appendix K of the Draft EIS (URS, 2005a) and showed a difference between modelled water levels and the levels measured at the DIPE gauged of less than 0.05 m as shown in Table 4.2. These results were considered acceptable on the basis of the available data, and were therefore not modified as part of the additional work undertaken for the PER.

Table 4.2

Model Calibration Results for Low Flows

Flow (m^3/s)	DIPE Gauge Measured Level (m AHD)	Modelled Water Level (m AHD)	Difference (m)
20	23.40	23.38	0.02
50	23.88	23.93	0.05
100	24.77	24.72	0.05

As part of the PER investigations, an additional check of the calibration results was undertaken by comparing the modelled velocities for the low flow conditions to the measured velocities at DIPE gauge. The results of this comparison are shown in Chart 4.6 and show an acceptable level of calibration.

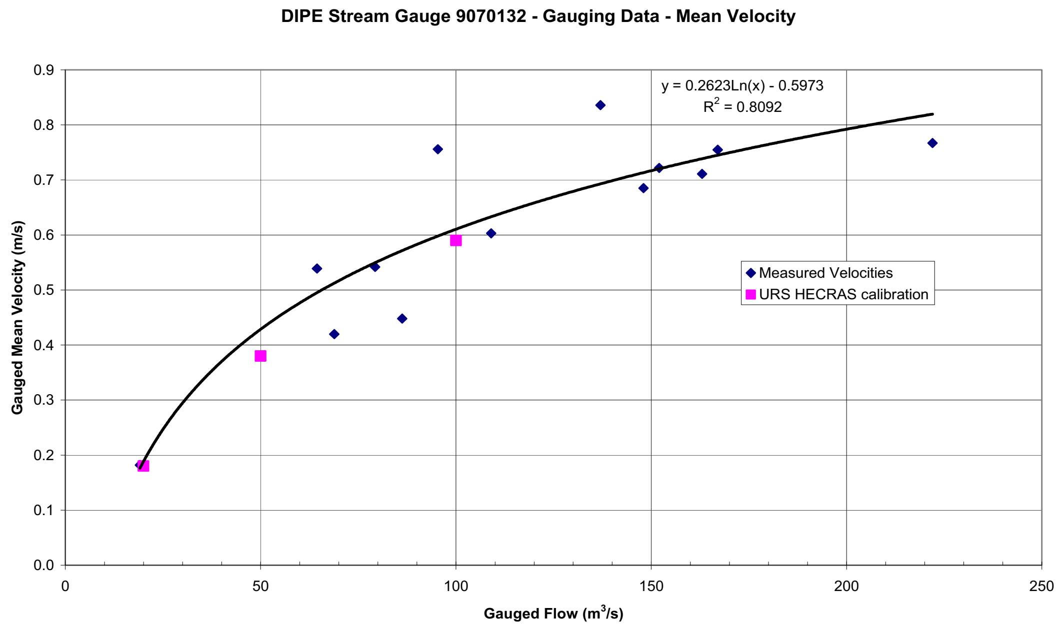


Chart 4.6
Comparison of Modelled and Measured Flow Velocities

4.5.3 Re-Calibration of Hydraulic Model to the January 2003 Flood Event

The calibration of the model to the January 2003 flood undertaken in the Draft EIS (URS, 2005a) assumed constant hydraulic roughness coefficients (Manning's) for the main channel and floodplain. These were 0.08 and 0.075 respectively. Comparison of modelled and measured water levels showed a difference of approximately 0.5 m higher at the MIM gauge and 0.5 m lower at the DIPE gauge.

Since the Draft EIS was prepared, additional field investigations of the McArthur River system have shown that variations in conditions along the river suggest that it would be more appropriate to include variable roughness coefficients in the model for different reach conditions. For example, there are some reaches of high density vegetation on the channel banks, some with high density large woody debris within the channel bottom, and some with lower density vegetation. A more detailed description of the different reach conditions is given in Section 4.4.

To better represent the complexity of the river channel system in the model, cross-section specific roughness coefficients were derived based on the findings of the recent field investigations. The areas of higher density channel and bank vegetation and high density large woody debris were assigned roughness coefficients which ranged from 0.085 to 0.1. The areas of lower density vegetation were assigned a roughness coefficient of 0.08.

Using the cross-section specific roughness coefficients, the model was re-calibrated against the January 2003 flood flows. The comparison of modelled and measured water levels is given in Table 4.3 which shows a difference of approximately 0.1 m at the DIPE gauge and 0.14 m at the MIM gauge.

Table 4.3
Model Recalibration Results for January 2003 Flows

Location	Peak Flow (m^3/s)	Measured Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)
DIPE Stream Gauge (upstream of mine)	4,700	36.21	36.11	0.1
MIM Gauge (downstream of mine)	5,600	33.70	33.56	0.14

These results are considerably better than those reported in the Draft EIS which used the constant roughness coefficients and are a good fit considering that the flood depth at the DIPE gauge was 15.3 m. Other variables that need to be taken into account in considering the accuracy of the calibration include possible errors in the measured flood levels, uncertainty in the high range of the DIPE gauge rating curve and localised hydraulic conditions such as temporary log jams during the flooding. Furthermore, there is some uncertainty associated with the flow estimate at the MIM gauge due to an unknown contribution of the Glyde River and other tributaries for the January 2003 flood event. This partially explains the greater difference between the modelled and measured levels at the MIM gauge.

4.5.4 Adopted Roughness Coefficients

The roughness coefficients that were used to achieve the model calibration described in Sections 4.5.2 and 4.5.3 have been used in the revised modelling of the diversion channel. Table 4.4 summarises the roughness coefficients adopted for the channel for the various flow scenarios.

Table 4.4
Adopted Roughness Coefficients

Flow (m^3/s)	Manning's Roughness Coefficient
20	0.23
50	0.12
100	0.08
4,720 (Jan 2003)	0.08 to 0.1 (typically 0.08 to 0.085)

4.5.5 Confirmation of Roughness Coefficients Using Cowan's Method

The hydraulic roughness coefficients given in Table 4.4 were determined from model calibration by assessing measured data for the specific site conditions. Alternatively, roughness coefficients can be established from reference guidelines. It is not unusual for hydraulic roughness values for Australian streams (particularly tropical streams with substantial riparian vegetation and debris) to be higher than roughness values documented in accepted international references (such as Barnes, 1967; Chow, 1959; and French, 1986). In order to verify the adopted roughness coefficients derived from model calibration, a desktop analysis has been undertaken that utilised the Cowan's method for estimating channel and flood plain roughness coefficients as described in Arcement and Schneider.

Cowan's method utilises the following equation and six factors in order estimate a composite channel roughness coefficient:

$$n_{total} = (n_b + n_1 + n_2 + n_3 + n_4)m$$

Where:

n_b = a base value of n for a straight, uniform, smooth channel in natural materials

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the channel cross-section

n_3 = a value for obstructions

n_4 = a value for vegetation and flow conditions

m = a correction factor for meandering of the channel.

Table 4.5 shows the range of base values for the factor n_b based on the type of material.

Table 4.5
Base Value of n_b for Cowan's Method

Bed Material	Median Size of Material (in millimetres)	Base n Value	
		Straight Uniform Channel	Smooth Channel
Sand Channels			
Sand	0.2	0.012	_ _
	.3	.017	_ _
	.4	.020	_ _
	.5	.022	_ _
	.6	.023	_ _
	.8	.025	_ _
	1.0	.026	_ _
Stable Channels and Flood Plains			
Concrete	_ _	0.012-0.018	0.011
Rock Cut	_ _	_ _	.025
Firm Soil	_ _	0.025-0.032	.020
Course Sand	1-2	0.026-0.035	_ _
Fine Gravel	_ _	_ _	.024
Gravel	2-64	0.028-0.035	_ _
Coarse Gravel	_ _	_ _	.026
Cobble	64-256	0.030-0.050	_ _
Boulder	>256	0.040-0.070	_ _

Plate 4.11
McArthur River Through Reach of Mine Site which Shows Channel Bed and Banks Composed of Sandy to Firm Soil Substrate

As shown in Plate 4.11, the McArthur River channel cross-section is relatively uniform, straight, and is typically composed of a sandy to firm soil substrate. On this basis a value of 0.030 was selected for factor n_b.

The McArthur River channel is generally stable, with some evidence of eroded and slightly scoured side slopes. On this basis, a value of 0.005 was adopted for n_1 from the range given in Table 4.6.

Table 4.6
Range of n_1 Values

Channel Conditions	*n* Value Adjustment	Example
Degree of Irregularity (*n_1*)		
Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
Minor	0.001-0.005	Compares to carefully degraded channels in good condition but having slightly eroded or scoured side slopes.
Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
Severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides or canals or drainage channels; unshaped, jagged, and irregular surfaces of channel.

Say 0.005

There are some reaches of the McArthur River, particularly for lower flows, where the channel cross-section shifts from side to side, as shown in Plate 4.12. On the basis of an alternating channel cross-section from large to small channels, a value of 0.005 was adopted for n_2 from the range given in Table 4.7.

Table 4.7
Range for n_2 Values

Channel Conditions	*n* Value Adjustment	Example
Gradual	0.000	Size and shape of channel cross sections change gradually.
Alternating occasionally	0.001-0.005	Large and small cross-sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
Alternating frequently	0.010-0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.

Say 0.005

Plate 4.12
McArthur River Showing Channel Changing from Large to Small Cross-Sectional Geometry

As shown in Table 4.8, the value of n_3 takes into account the obstructions to flow in the channel including woody debris and cumulative obstructions such as closely spaced trees in the channel. Examples of these are shown in Plate 4.13. The percent of obstruction in the channel will vary depending on the depth of the flow. In general, the lower flows will have a higher percent of the flow area obstructed, while the higher flows will encounter a greater amount of obstructions but the overall percentage of flow that is obstructed will decrease.

Table 4.8
Table of Criteria and Values for n_3

Channel Conditions	*n* Value Adjustment	Example
Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5% of the cross-sectional area.
Minor	0.005-0.015	Obstructions occupy less than 15% of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
Appreciable	0.020-0.030	Obstructions occupy from 15% to 50 % of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross-section.
Severe	0.040-0.050	Obstructions occupy more than 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross-section.

Say 0.005

Plate 4.13
McArthur River Showing Obstructions to Flow (Tree Growth on Channel Bed, Woody Debris)

On the basis of the above discussion, the values for n_3 will vary according to the depth of flow as the degree of obstruction as a percentage of the cross-sectional area varies. The adopted n_3 values are summarised in Table 4.9.

Table 4.9

Adopted Values of n_3

Flow (m^3/s)	Average Depth (m)	Range	Adopted n_3
20	4 – 4.5 m	0.025 – 0.04	0.035
50	4.5 – 5 m	0.015 – 0.025	0.02
100	5 – 6 m	0.01 – 0.02	0.015
4,720 (Jan 2003)	9 – 14 m	0.01 – 0.015 (Some obstructions and woody debris)	0.012
		0.015 – 0.025 (Large woody debris areas and closely spaced trees in channel bed)	0.02

As for n_3, the value of n_4 takes into account the relative density of vegetation grown in the channel including height and density of the vegetation with relation to the flow height. In general, the lower flows will flow around the tree trunks and will flow through the thick bushes and low lying vegetation growth. The higher flows will encounter a greater amount of vegetation but the overall height of flow, relative to the height of the vegetation, will increase. The range of n_4 values is shown in Table 4.10 and the adopted values are shown in Table 4.11.

Table 4.10
Table of Criteria and Values for n_4

Channel Conditions	*n* Value Adjustment	Example
Small	0.002-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation, supple tree seedlings such as willow, cottonwood, arrowhead, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation, brushy, moderately dense vegetation, similar to 1 to 2 year old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 0.61 meters.
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8 to 10 years old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.60m; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage), and no significant vegetation exists along channel bottoms where the hydraulic radius is greater than 0.61 meters.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes and all vegetation in full foliage), or desne cattails growing along channel bottom; trees intergrow with weeds and brush (all vegetation in full foliage).

Table 4.11

Adopted Values of n_4

Flow (m^3/s)	Average Depth (m)	Range	n_4
20	4 – 4.5 m	0.05 – 0.1	0.08
50	4.5 – 5 m	0.04 – 0.08	0.06
100	5 – 6 m	0.01 – 0.04	0.025
4,720 (Jan 2003)	9 – 14 m	0.01 – 0.03 (Typical vegetation density)	0.02
		0.02 – 0.04 (High vegetation density)	0.03

Lastly, Cowan's method incorporates the degree of meandering of the river channel, as shown in Table 4.12. The McArthur River is generally a straight river channel for the 40 km reach that has been modelled, therefore the degree of meandering (m) was set to 1.0.

Table 4.12

Table of Criteria and Values for m

Degree of Meandering (m)		
Channel Conditions	***m* Value Adjustment**	**Example**
Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2
Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5
Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

A summary of the values for the river channel's Manning's roughness coefficient (using Cowan's method together with the coefficients derived by the model calibration method) is provided in Table 4.13. In general, the Cowan's method predicts coefficients that are near to or slightly less than those generated by the model calibration. On this basis, the calibrated roughness values that have been adopted for the hydraulic modelling are considered reasonable.

Table 4.13
Summary of Cowan's Method and Calibrated Roughness Coefficients for the McArthur River Main Channel

Flow Rate (m^3/s)	n_b	n_1	n_2	n_3	n_4	m	Total n (Cowan's Method)	Calibrated n
20	0.03	0.005	0.005	0.035	0.08	1.0	0.20	0.23
50	0.03	0.005	0.005	0.02	0.06	1.0	0.12	0.12
100	0.03	0.005	0.005	0.015	0.025	1.0	0.08	0.08
4,720 (Jan. 2003)	0.03	0.005	0.005	0.012	0.02	1.0	0.072	0.08 (Some woody debris and light to medium vegetation)
				0.02	0.03		0.09	Varies from 0.085 to 0.1 (Large woody debris and/or high density vegetation)

Similarly, the Cowan's method was applied to the estimation of the Manning's roughness coefficient for the McArthur River floodplain. Table 4.14 shows that the Cowan's method predicts floodplain values that are similar to those derived by the model calibration method.

Table 4.14
Summary of Cowan's Method and Calibrated Roughness Coefficients for the McArthur River Floodplain

Flow Rate (m^3/s)	n_b	n_1	n_2*	n_3	n_4	m	Total n (Cowan's Method)	Calibrated n
4,720 (Jan 2003)	0.03	0.002	-	0.02	0.02	1.0	0.072	Varies from 0.07 to 0.085 (typically 0.079)

* Not applicable to floodplain estimation

4.5.6 Survey Accuracy and Significance

Topographic data used to define the existing river waterway geometry in the HEC-RAS model was based on an aerial photogrammetric survey undertaken in 2001 supplemented by detailed ground-based surveyed cross sections of the McArthur River in the vicinity of the mine. The accuracy of the base photogrammetric survey was in order of +/- 0.2 m accuracy in floodplain areas and the ground survey accuracy is approximately +/- 0.05 m.

A sensitivity analysis was undertaken to determine the potential effect that any inaccuracy in the survey data might have on the model results. The analysis was performed for modelled flows of 20 m^3/s, 50 m^3/s, and 100 m^3/s, as well as the 2-year and the 5-year ARI flood events by randomly varying the Reduced Level (RL) of the HEC-RAS cross-sections by either -0.2 to +0.2 m. The significance of any error in the model results was based on the predicted changes in water level and other hydraulic parameters caused by the imposed changes in cross-section RL. The higher flood events were not tested because any survey error that was present would be most significant for the low height flows.

The sensitivity analysis results, as presented in Appendix F.1, show that the difference in water level for the selected flow rates when the cross-section RL was randomly varied by +/- 0.2 m was less than 1%. On this basis it can be assumed that any differences in modelled water levels due to inaccuracies in the photogrammetric survey are not significant.

A sensitivity analysis was also undertaken to assess the effect that varying the cross-section RL by +/- 0.2 m would have on flow velocity, shear stress, and stream power. In general, the differences were in the order to 0% to 20%, where the larger percentage differences (greater than 5%) occurred at velocities less than 0.3 m/s, shear stresses less than 20 N/m^2, and stream power results less than 10 W/m^2. While a percentage change of greater than 5% may seem significant, because the base numbers for these parameters are so low, even increases of up to 20% will still result in low numbers which will have minimal impact of flow conditions.

Based on the results of the sensitivity analysis, any potential errors in the photogrammetric survey data used in the model are not significant for the purposes of impact assessment for the following reasons:

- The sensitivity analysis results, as discussed above, demonstrate that the potential differences in water level, velocity, shear stress and stream power as a result of any reasonable errors in the survey data will not significantly alter the design outcomes.

- The purpose of the hydraulic modelling was for impact assessment, specifically to compare existing river hydraulics with river hydraulics that would occur after the proposed diversion works. When relative comparisons are made between results from the same model, any survey error would be reflected in the same way in both the before and after scenarios and hence would not be relevant in assessing the degree of change.

4.5.7 Re-modelling of Existing River Conditions

The purpose of the hydraulic modelling (HEC-RAS) was to quantify key hydraulic parameters for a range of flood events and to compare the model results to the qualitative geomorphologic assessment. The existing river conditions that were modelled in the Draft EIS (URS, 2005a) were re-modelled using the modified roughness coefficients listed in Table 4.4.

Following the same methodology that was used in the Draft EIS, the hydraulic parameters used to characterise the river hydraulics were flow velocity, shear stress and stream power. These are described as follows:

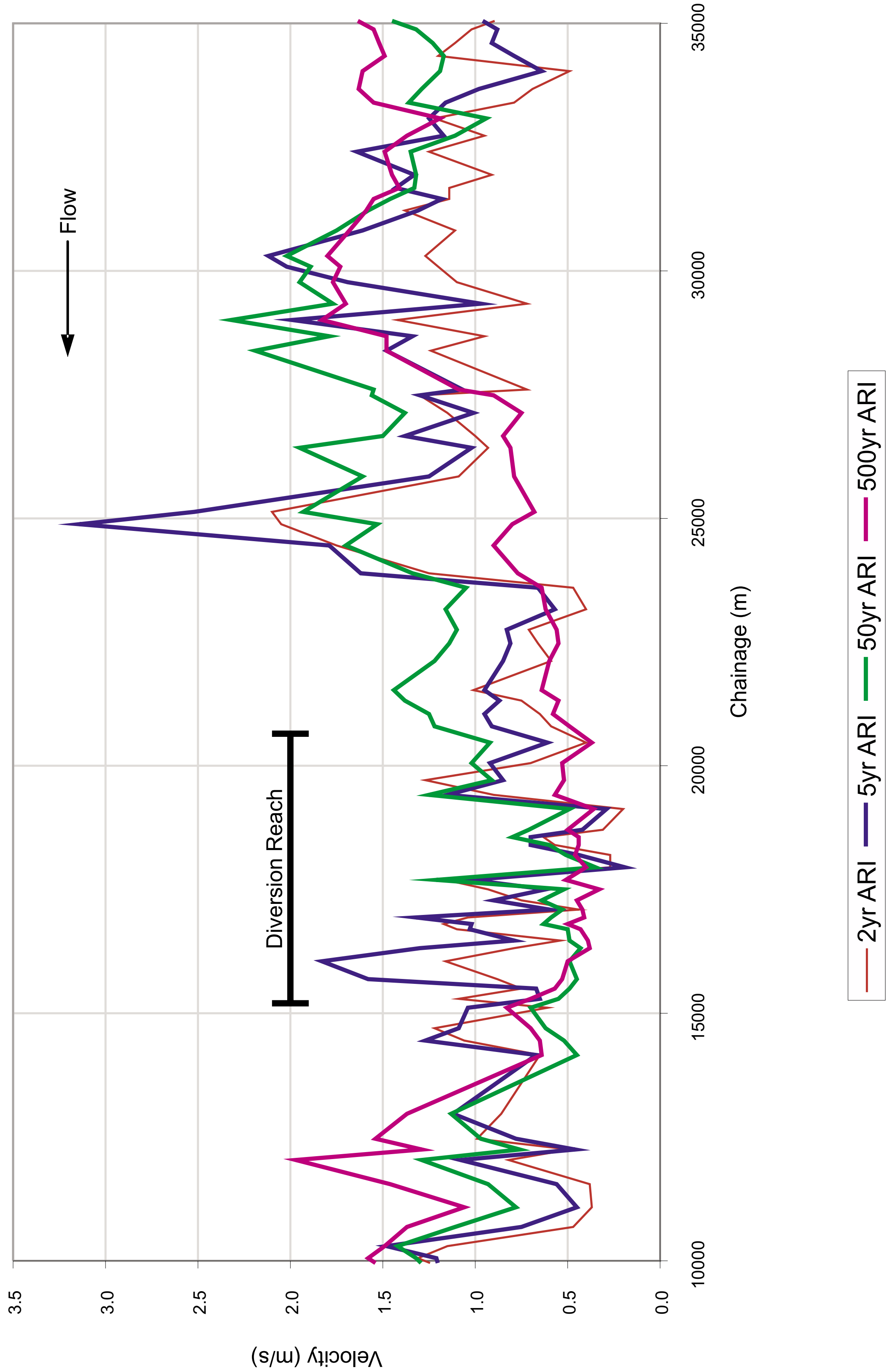
- Flow velocity (the speed of flow along the river) is commonly used for initial assessments of the potential for erosion
- The bed shear stress represents the force between the river flow and resistance to flow provided by the bed and banks of the river channel. Shear stress is commonly used to determine 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.

Longitudinal profiles of the existing river flow velocity and stream power for the 2, 5, 50 and 500-year ARI floods are presented in Figures 4.2 and 4.3 and are summarised in Table 4.16. The longitudinal profiles display the results for a reach that extends from approximately 10 km upstream of the proposed diversion to approximately 10 km downstream of the diversion. Additional hydraulic profile plots for the entire 45 km reach, all parameters and all analysed flow cases are presented in Appendix F.1.

Table 4.16

Summary of Key Hydraulic Parameters 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 - 1.3	0.4 - 1.6
	5-year	0.6 - 3.1	0.2 - 1.8	0.5 - 2.0
	50-year	0.9 - 2.3	0.4 - 1.4	0.8 - 3.3
	500-year	0.6 - 2.1	0.3 - 0.8	0.6 - 2.8
Shear Stress (N/m^2)	2-year	5 - 160	1 - 80	5 - 220
	5-year	11 - 330	1 - 160	10 - 270
	50-year	25 - 155	4 - 55	8 - 260
	500-year	8 - 115	4 - 25	15 - 170



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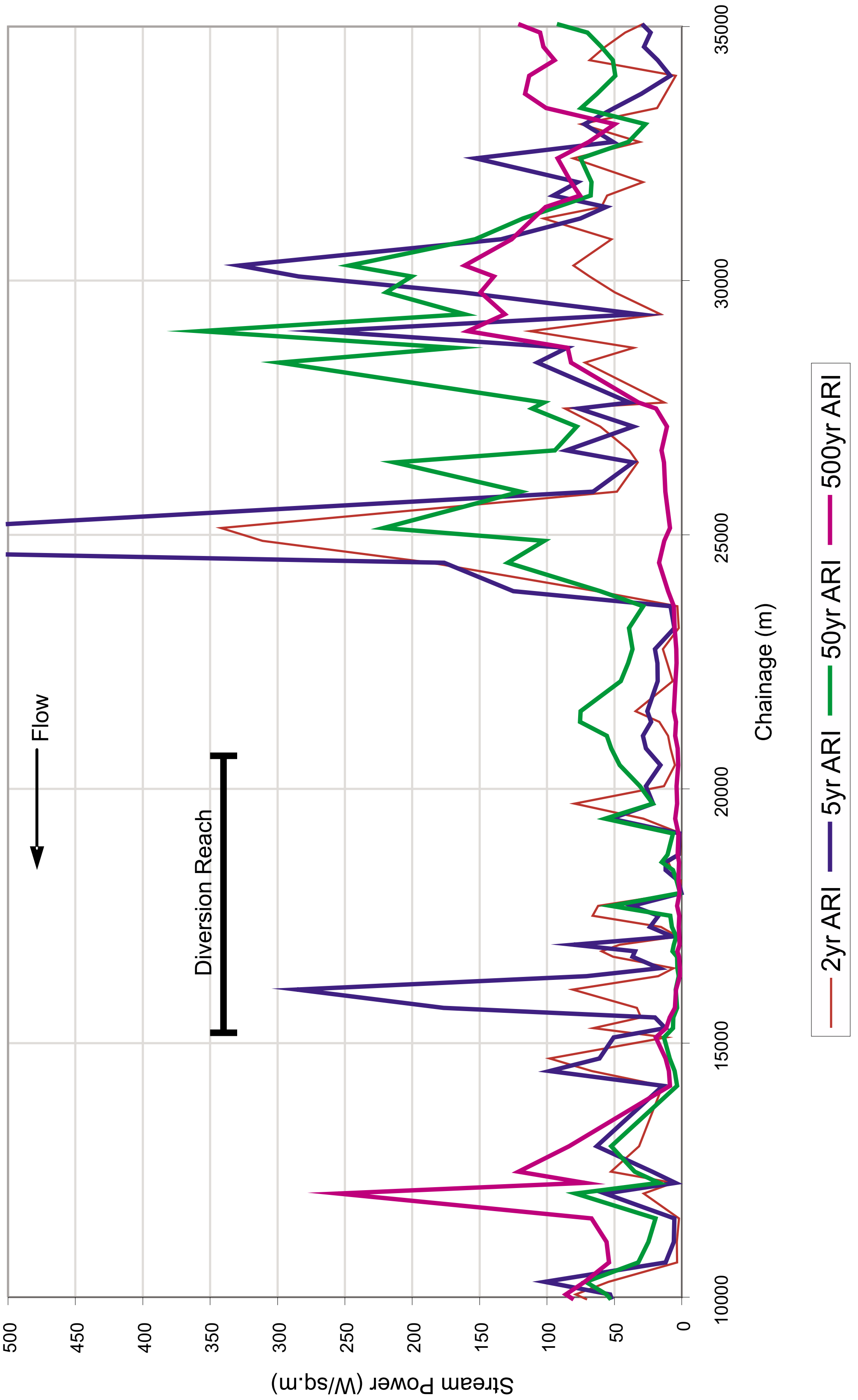
PROFILE OF VELOCITIES IN EXISTING McARTHUR RIVER

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **4.2**	Rev. A
Job No.: **42625552**	File No. 42625552-g-201.cdr			A4



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PROFILE OF STREAM POWER IN EXISTING McARTHUR RIVER

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **4.3**	Rev. A
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Hydraulic Parameter (Main Channel Flow)	Flood Event ARI	Upstream of Mine	Mine Reach	Downstream of Mine
Stream Power (W/m^2)	2-year	2 - 340	1 - 00	2 - 360
	5-year	9 - 1030	1 - 290	5 - 520
	50-year	30 - 360	1 - 70	3 - 860
	500-year	5 - 230	1 - 20	10 - 460

In general, the results show that the existing McArthur River currently exhibits higher localised velocities, shear stresses, and stream powers throughout the modelled reach.

The HEC-RAS model outputs for the existing river were checked for consistency where high values of any of the parameters (shear stress, velocity or stream power) occurred. These were checked in the field or on aerial photographs. In those situations, the high values generally occurred where bedrock was exposed in the channel or some other flow restriction was present. However, in all cases the river channel was stable.

4.5.8 Design Modification to Diversion Channel

Hydraulic Design Objective

The objective for the hydraulic design of the McArthur River diversion is to establish a hydraulic behaviour that is similar to that of the existing river, to ensure that the diverted channel is stable and supportive of revegetation and aquatic habitats, and to protect the upstream and downstream reaches from any detrimental changes in river hydraulics.

The diversion alignment as described in the Draft EIS was determined by the constraints provided by the local topography, the existing channel geometry, and the location of the flood protection bund. This alignment provides the best hydraulic result and has remains unchanged. However detailed consideration has been given to variations in channel geometry, bed and bank conditions, and flow parameters to ensure that the design objective can be achieved.

Design Criteria - Channel Geometry

Previous studies of creek and river diversions in the Bowen Basin in Queensland (ACARP, 2002) have shown that the more frequent flood events (e.g. the 2-year to 5-year ARI events) generally have the most geomorphologic influence on re-shaping channel cross-sections and alignments. These more frequently occurring events concentrate the stream flow within the channel banks, and have the potential to produce velocities high enough to induce erosion within the channel. The less frequent flood events, such as the 100-year ARI, tend to utilise the floodplain for floodwater attenuation, resulting in lower cross-sectional velocities and less potential for erosion (ACARP, 2002).

This situation also applies at McArthur River where flood flows in excess of the 5-year ARI generally break the river banks and spread out over the floodplain. Therefore, a key design condition for the diversion is for the channel flow capacity to replicate the natural river channel ‘bank-full’ flow capacity.

In this instance the 'bank-full' flow is approximately equivalent to the peak flows of a 5-year ARI flood event. For larger flood events, such as the 100-year ARI, floodplain interaction occurs as per the existing creek system.

Flow Velocity/Shear Stress as Indicators of Erosion Potential

Several methods have been developed to quantitatively compare the existing river hydraulics to those of the diversion channel for design purposes. The most common method uses channel velocity to estimate shear stress within the channel. The shear stress can then be related to the potential for erosion or sedimentation within the channel based on the characteristics of the channel bed and banks. Guidelines for maximum permissible velocities to minimise erosion can then be established based on the channel bed material.

It is important to recognise that velocity and shear stress provide an indication of local and immediate erosion potential only. Velocity and shear stress parameters generally indicate whether there is erosion potential to cause enlargement of the local channel cross section (depth and width). They generally do not indicate if there are other influences present which try to realign and reshape the channel alignment (e.g. meandering). The long-term stability of a channel's alignment is related to the morphological context of the reach. Stream power is a more useful indicator of hydraulic conditions reflecting the morphology of the channel, particularly for 'bank-full' flows that are commonly known to be 'channel forming' events.

Geomorphological Factors

All natural rivers constantly erode and deposit sediment relative to the magnitude, frequency and variability of flows. It is the interaction of flow hydraulics and bed/bank erosion/deposition which alters channel geometry and flow hydraulics. These factors vary over time and position in the catchment.

The spatial context of a river reach relative to the broader catchment and associated landforms is also important for the river's regime of erosion and/or sedimentation in a local reach. These factors relate to the supply of sediment from upstream, the flow parameters (velocity, shear stress and stream power), and the geometric influences (particularly gradient) for sediment transport within a stream reach.

Erosion is typical in the headwaters of catchments where gradients are steep, and the sediment supply from small upstream catchment area is limited. Deposition (accretion) is typical in lower reaches of catchments where there is substantial sediment supply from upstream and where gradients are flat allowing sediment to deposit and floodplain landforms to develop.

The middle reaches of catchments are typically in a 'net' balance (equilibrium) of erosion and sedimentation. However these reaches can be dynamic over short-term periods in response to variability in flow hydrology, sediment supply and hydraulics. The dynamics of these reaches means that erosion can occur for some flows (typically floods) and deposition can occur for other flows (receding flows after prolonged rainfall). The balance can also vary between erosion and deposition in individual flood events with erosion during the rising waters of a flood and deposition during the falling waters of a flood. Over the 'long-term' the cumulative hydrologic effect of frequent small flows and infrequent large flows results in a net balance of erosion and sedimentation.

It is not usually possible to evaluate and quantify the dynamics of short-term erosion and deposition cycles/variability (without extensive long-term data on stream geometry, sediment loads and flows over several decades). Hence, the stream power of river hydraulics for the 'bank-full' flood flow is a valuable indicator of the 'net average' effect of variability in hydrology on the overall morphological stability of a river system.

The reach of the McArthur River in the vicinity of the mine has generally firm sandy bed conditions in the existing channel and mature vegetation along the creek banks. Given these features and the location of the reach within the broader catchment (transition of middle reach to lower reach), the mine reach can be considered as having an equilibrium of erosion and sedimentation with a slight depositional trend.

The general implication for the stability of the proposed diversion is that some erosion and deposition within the diversion channel will occur and should be expected since the existing river exhibits this behaviour. A key issue in assessing the morphological stability of the diversion is the likely effect of erosion to adversely alter the diversion alignment and geometry by means of assessing the likely change to stream power for bank-full flows.

Stream Power

The assessment of stream power is considered to be a key parameter in evaluating the interaction of flow hydraulics and stream morphology. Stream power is the potential work that the flowing water performs to modify and reshape the river. In general, the stream power should be evaluated holistically by comparing the stream power over the entire river reach. Typical river channels show a sinusoidal stream power where it is greater in some areas and less in others.

The estimation of stream power is most valuable for flows in the channel at the bank-full level. This recognises that bank-full flows can occur for extended periods in major flood events, occur more frequently than large floods, and that bank-full flows are relatively confined (whereas larger floods tend to spread out onto adjoining floodplain areas which dissipates energy and power). Overall, the hydraulic conditions during bank-full flows have the greatest potential for stream erosion and re-shaping of the channel alignment.

Although stream power is a valuable and more direct indicator of hydraulic conditions relative to morphological stability (and more useful than velocity and shear stress), there are no firm scientific criteria to guide hydraulic design for stream diversions with respect to how much change in stream power is sustainable. The general approach for current best practice for river diversions is to design the diversion to avoid excessive increases in stream power and to monitor performance of the diversion during its operation.

Large increases in stream power can result in an excessive imbalance of stream power causing the river to reform itself (by meandering and changing the channel cross-section geometry) to reach an equilibrium regime. Large increases in stream power are typically the result of:

- Increasing channel slope, resulting from a shortening of the channel between two points (e.g. cutting off a meander to straighten a channel)

- Reducing the width and depth of the floodplain and the potential for flood attenuation in larger floods, thereby increasing flow depth and velocity (e.g. confining the floodwater to a smaller cross-section) and potentially increasing the duration of flow
- Decreasing the channel resistance (friction) by reducing or eliminating vegetation or other flow obstructions.

Channels will try to reach equilibrium in stream power by increasing overall stream length by forming meanders, and by widening the channel width and decreasing the channel slope by eroding and head cutting. To minimise the change in stream power, diversion channels need to have a similar cross-section (channel and floodplain), hydraulic roughness (bed conditions and vegetation) and channel slope as the existing river.

For these reasons, stream power has been used as a measure of the potential for long-term stability of the McArthur River.

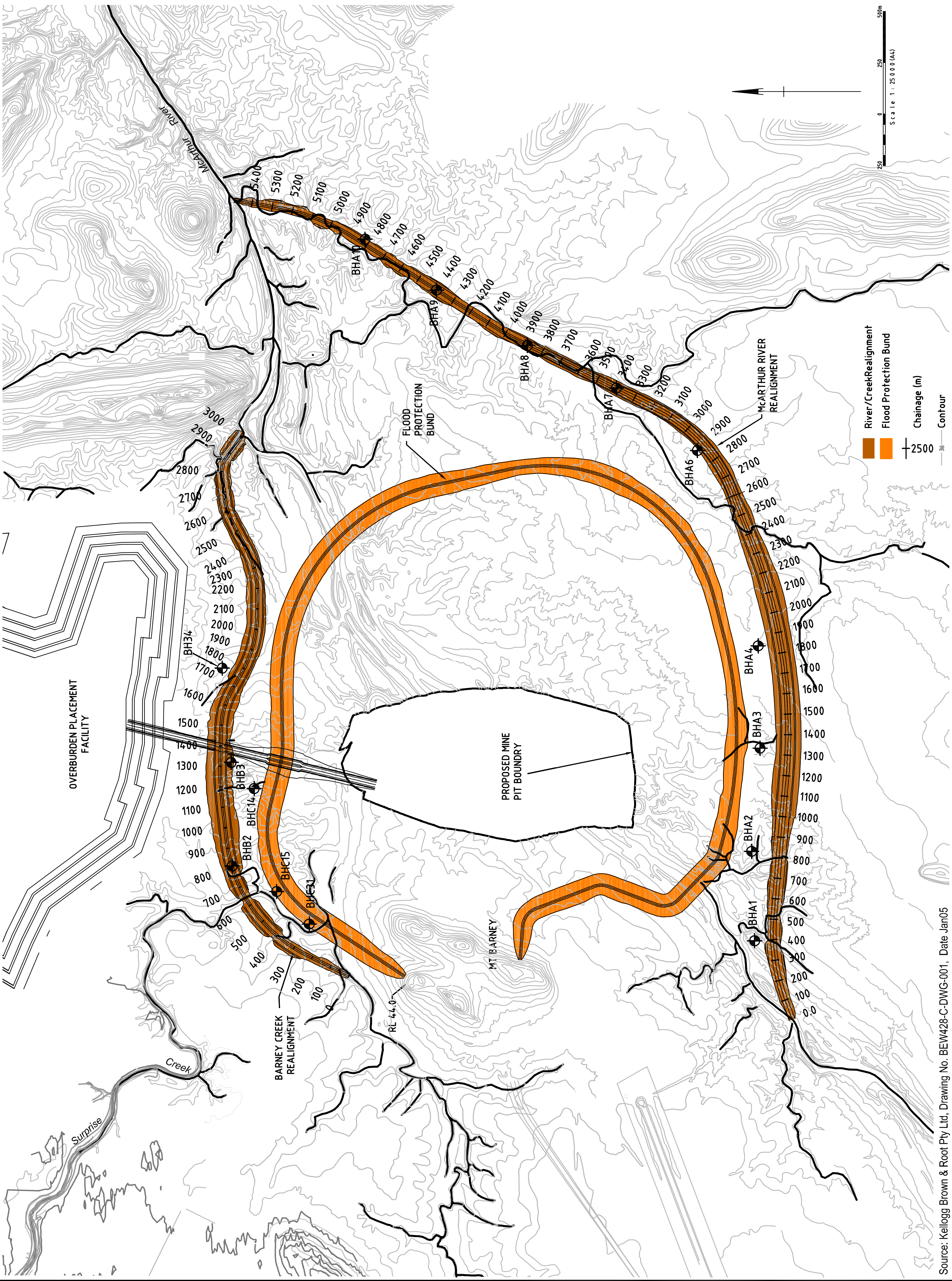
Modified Diversion Channel

Modifications have been made to the McArthur River diversion design to reduce the potential for impacts to the McArthur River system both upstream and downstream of the diversion channel, and for impacts to the diversion channel itself. While the diversion channel's cross-sectional geometry has not changed from that presented in the Draft EIS (URS, 2005a), changes that have been made include:

- Reducing the longitudinal grade of the upstream reach of the diversion channel through the alluvial section from 1 in 2,000 to 1 in 2,500
- Modifying the longitudinal grade of the diversion channel through the rock section from 1 in 900 to 1 in 750
- Incorporating six rock riffles (i.e. riffle-pool sequences) in the diversion channel at select chainages.
- Increasing the density of large woody debris in the diversion channel at irregularly space intervals
- Modifying the flood protection bund around the open cut to provide additional floodplain width for less frequent storm events
- Incorporating a stepped energy dissipation structure at the confluence of Bull Creek and the McArthur River diversion channel. While this will prevent the entry of fish into Bull Creek under most flow conditions, Bull Creek has minimal fish habitat value and this impact will not be significant.

Figure 4.4 shows the proposed alignment of the diversion channel and the flood protection bund. There has been no change to the alignment of the diversion from that shown in the Draft EIS. Thus the design modifications will not affect any known sacred sites in the area. Furthermore, the minor changes to the alignment of the flood protection bund will not affect any known sacred sites.

The longitudinal section of the river diversion is shown in Figure 4.5 while Figure 4.6 shows the typical cross sections.



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

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REVISED LAYOUT OF PROPOSED RIVER REALIGNMENT AND FLOOD PROTECTION BUND

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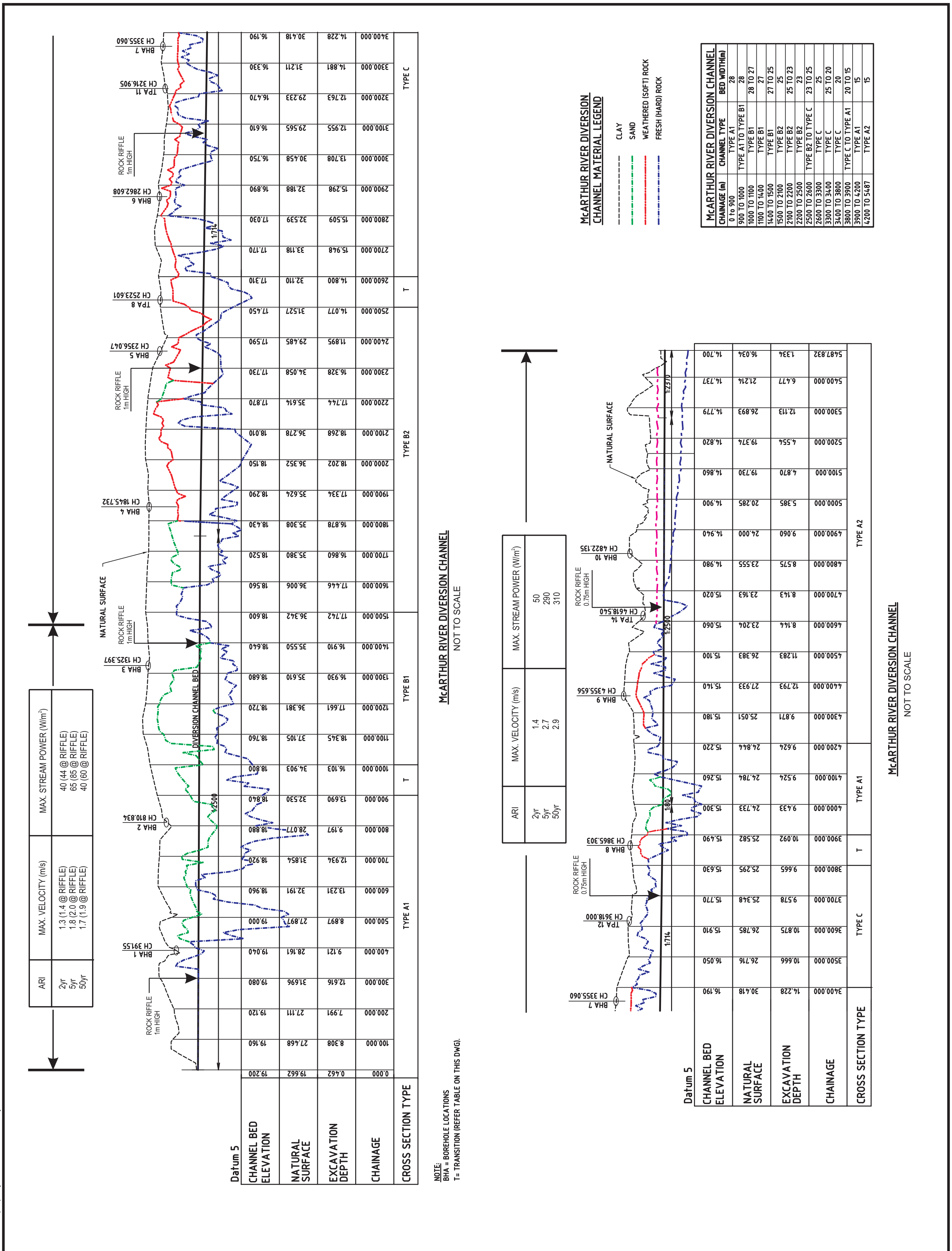
Job No.: 42625552	File No.: 42625552-g-191c.dwg		Rev. C / A4



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LONGITUDINAL PROFILE OF McARTHUR RIVER DIVERSION

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Figure: **4.5**

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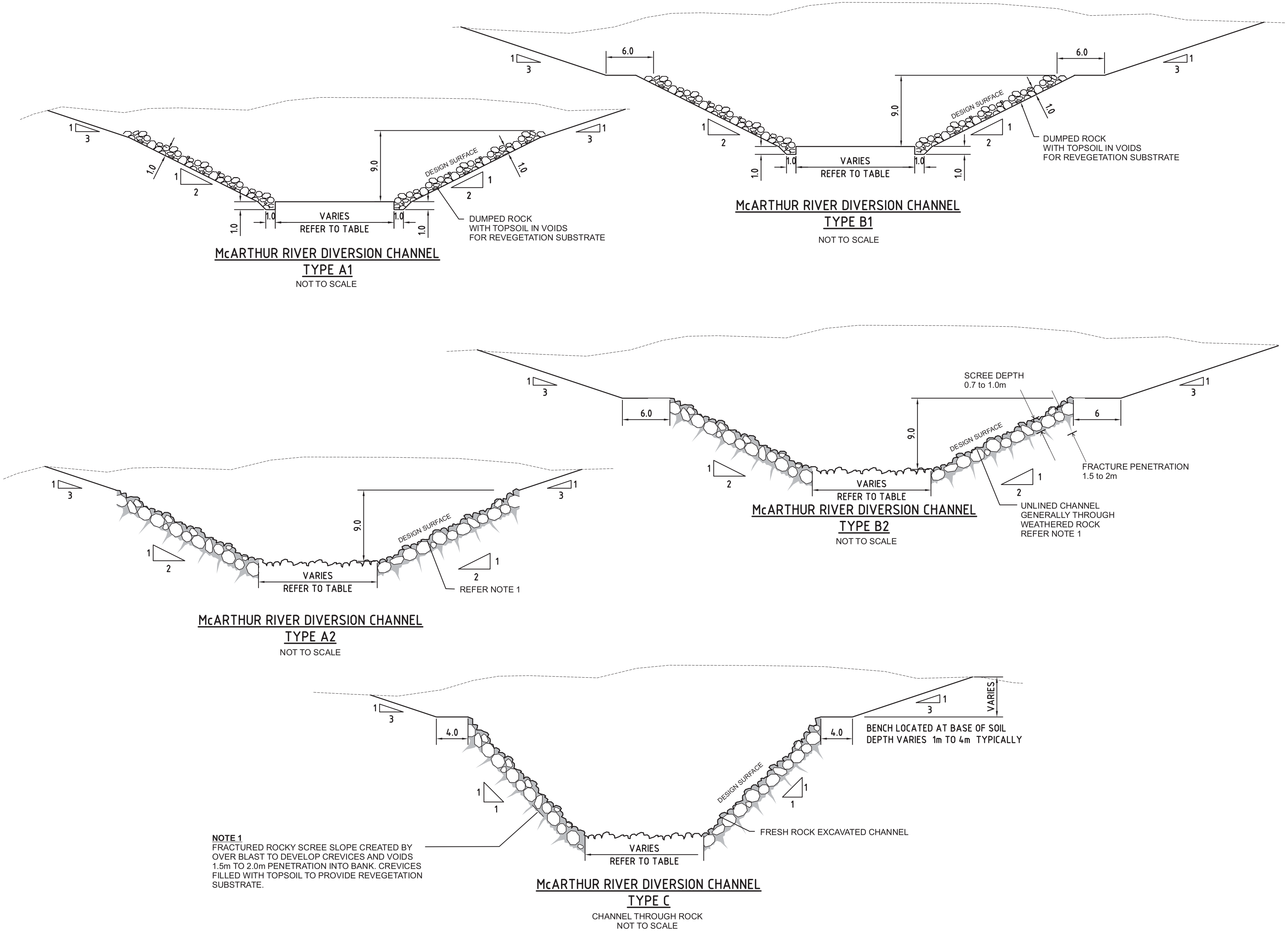

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TYPICAL CROSS SECTIONS OF McARTHUR RIVER DIVERSION

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Several variations of the diversion channel geometry were analysed in order to meet the design criteria. The cross-section of the diversion was developed to be similar to the existing channel dimensions and therefore replicate the existing bank-full flow capacity assuming similar slope and roughness conditions.

The diversion channel design includes the following geometry and parameters:

- From chainage 0 to 1500 m the channel bed will be in alluvium (silty sands and clays). To maintain acceptable hydraulics for fish passage and to minimise the risk of scour, peak flow velocities through this section will be limited by adopting a wider channel bed (25 to 28 m) with channel bank slopes of 2H:1V, similar to the existing channel banks. 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 9 m below the natural surface level.
- From chainage 1500 to the downstream end, the channel will be excavated through weathered and fresh rock (breccia and mudstone). Because rock has a much greater capacity than alluvium to resist erosion, the bed width is reduced to 20 m from chainage 3300 to 3800 and to 15 m width from chainage 3800 to the downstream end. However it will intercept a short length of alluvial material between chainage 3800 and 4200. Through this section the channel banks will be rock lined in the same manner as the channel in the upstream alluvial section. From chainage 4000 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.
- At both ends of the diversion channel protection strategies including rock armouring and timber groynes will be provided 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 diversion and the various tributary waterways that will flow into it.
- In sections where the channel banks are in alluvial materials, coarse rock armouring will be placed on the banks to a minimum thickness of 1 m. Voids in the coarse rock armouring will be filled with topsoil. The rock armouring is primarily intended to provide a stable growing substrate for the re-establishment of riverine vegetation. The rock armouring will retain the topsoil on the channel banks to enable the vegetation to establish. In addition, the rock armouring will provide erosion protection for the channel banks.
- In areas of dispersive soils, the banks will be lined with geofabric to protect the soils from erosion and the minimum rock thickness will be increased to 1.5 m.
- LWD will be placed in the bed of the channel to assist in rehabilitation, to provide localised habitat, and to encourage sediment trapping and meandering.
- Shallow pools (approximately 0.5 m in depth) will be incorporated in the base of the rock diversion section to provide variable fish habitat.

A summary of the realignment geometry and foundation conditions is presented in Table 4.17.

Table 4.17

Diversion 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 : 2,500	28	1:2	Sandstone and alluvial soils bed. Banks intercept silty clay and clayey sand.
600 to 950	1 : 2,500	28	1:2	Bed and banks intercept alluvial soils with layers of silty clay, clayey sand, and gravelly clayey sand.
950 to 1500	1 : 2,500	27	1:2	
1500 to 1750	1 : 2,500	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 9 m above the channel bed, both sides of channel from chainage 1000 to 1750, with bank slope above terraces at 1 in 3.
1750 to 2550	1 : 714	25 to 23	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 2400 and small gully intersected at chainage 3600. 6 m wide terraces 9 m above the channel both side of channel from chainage 1750 to 2600, with bank slopes above terraces at 1 in 3. 4 m wide terraces at interface level of weathered rock – alluvium, both sides of channel between chainage 2600 to 4000.
2550 to 3350	1 : 714	25	1:1	
3350 to 3850	1 : 714	20	1:1	
3850 to 4000	1 : 714	15	1:2	
4000 to 4200	1 : 2500	15	1:2	Bed and banks in sandy clay and silty clay. Zones of clayey sandy gravel.
4200 to 4900	1 : 2500	15	1:2	Bed and 5 to 10 m of lower bank in Dolomite. Upper banks in silty clay.
4900 to 5260	1 : 2500	15	1:2	Bed and banks in clay, and clayey sand. Downstream junction with McArthur River at chainage 5490.
5260 to 5490	1 : 2370	15	1:2	

[1] See Figure 4.4

Rock Riffles

Initial modeling of the diversion channel indicated that the stream power in the alluvial section could potentially exceed 65 W/m^2 which has been accepted as the criterion for vegetation establishment. Stream powers in excess of this amount will increase the risk that newly established vegetation will be damaged or removed by flood waters.

To reduce stream powers in the upstream alluvial section of the diversion to below the vegetation criterion, it is proposed to introduce two artificial rock riffles through this reach. Additionally, four artificial rock riffles will be constructed at select locations in the remainder of the diversion channel. The rock riffles will reduce flow velocity and stream power upstream of the riffle and also provide an upstream riffle pool of slower velocity areas for fish resting. The riffles have been designed in accordance with the criteria established by Newbury and Gaboury (1993). Key design features of the riffles are shown on Figure 4.7 and include the following:

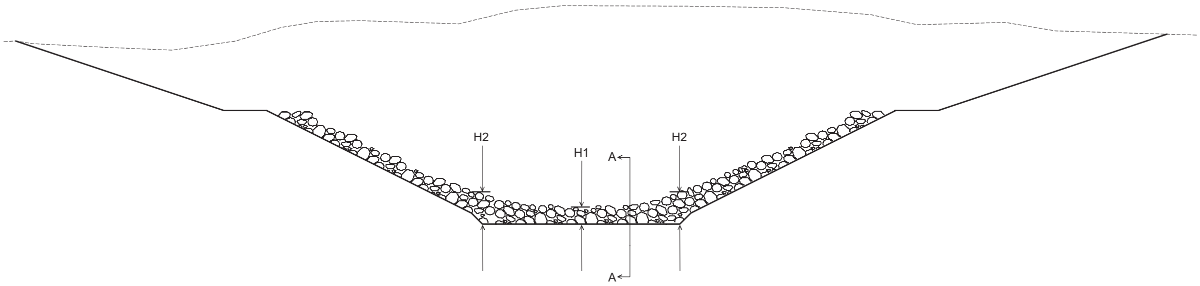
- The riffles will be placed across the full width of the channel bed. The four upstream riffles will be constructed with a maximum height of approximately 1.5 m at the edges and tapering to a U-shaped minimum height of approximately 1 m in the centre, and the two downstream rock riffles will have a maximum height of 1 m at the edges at tapering to 0.75 m in the centre. This design will allow for fish passage during normal and flood flows and create an upstream riffle pool as a slower-velocity resting area for fish.
- The downstream slope of each riffle will be approximately 1V:20H with the upstream slope approximately 1V:5H
- The riffles have been designed to be stable for the range of modelled floods. The guidelines recommend that the rock distribution not be uniform, and as such they have been designed with a D_{50} of approximately 250 mm (i.e. 50% of the rocks have a diameter greater than 250 mm). The rock will be sourced from the excavation of the downstream reach of the diversion channel through fresh rock strata. The rocks to be used will be angular in order to reduce the porosity of the riffle structure and to reduce the potential for uplift.
- Modelling has shown that rock riffles will be necessary in the alluvial section of the diversion to achieve the design stream power criterion. The riffles will be located at chainages 300, 1400, 2300, 3075, 3700, and 4650 as shown on Figure 4.5. The spacing of 600 m to 1,100 m between them ensures that the pool from the downstream riffle will not interfere with the hydraulics of the upstream riffle.

The existing river channel that is to be diverted does not contain any permanent riffles and is essentially a run within the context of riffle-pool-run sequences. The proposed diversion channel through the rock section will also exhibit features of a run between the naturally-occurring bedrock-controlled riffles that already exist in the reaches upstream and downstream of the mine site. The presence of the existing rock riffles in the river (e.g. the rock bar at the downstream end of Djirrinmini Waterhole) demonstrates that fish can readily traverse them. Thus, adding additional rock riffles to the diversion channel would not restrict the movement of fish.

4.5.9 Re-Modelling the Modified Diversion Channel

Modelling of the modified diversion channel design described in Section 4.5.8 was undertaken using the HEC-RAS model to assess the hydraulics of the existing river channel and to evaluate the hydraulic performance of the modified diversion channel. The model results for the existing river channel provided a baseline for comparison with the results for the diversion.

In order to assess the potential for erosion, the predicted flow velocities and shear stresses for diversion channel design were also compared to the Australian ACARP (2002) guidelines. These guidelines have been developed for the design of diversion channels within the Bowen Basin in central Queensland. They



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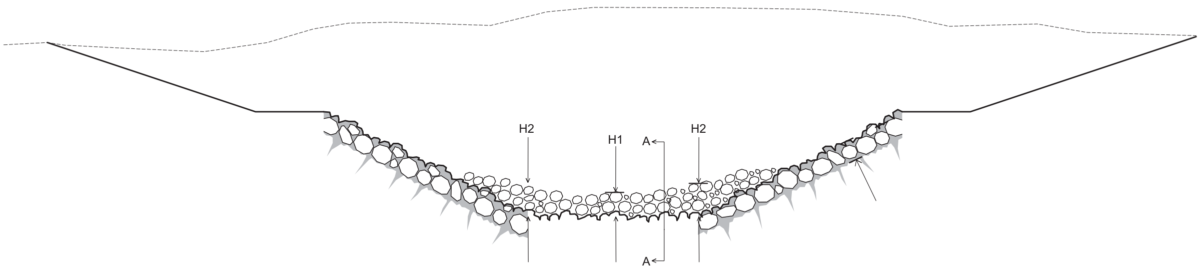

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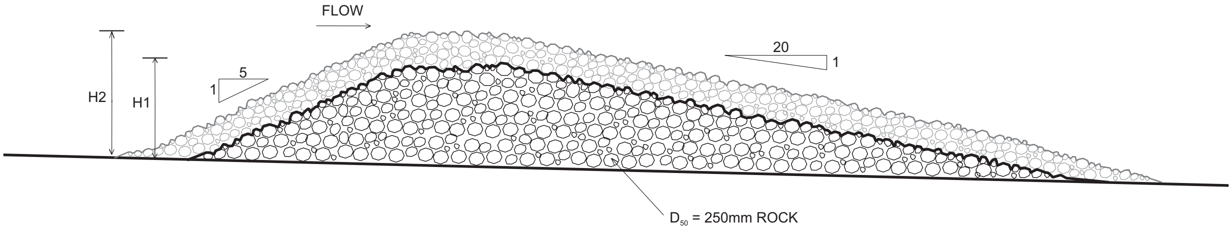


SECTION A

NOT TO SCALE

H1(m)	H2(m)
1.0 0.75	1.4 1.0

xstrata

URS

McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

TYPICAL SECTIONS FOR ROCK RIFFLES

Drawn: VH | Approved: CMP | Date: 29-06-2006
Job No.: **42625552** | File No. 42625552-g-214.cdr

Figure: **4.7** | Rev. A | A4

are relevant to the design of the McArthur River diversion design because rivers and creeks in the Bowen Basin are typically ephemeral with sandy bends, similar to the McArthur River. The guidelines suggest maximum stream powers for stable channels for a range of geological conditions and flow events.

Summaries of the velocity, shear stress and stream power results are presented in Table 4.18 to 4.20 and selected plots are presented in Figures 4.8 and 4.9. These plots show the results for the short-term situation before revegetation has established and the long term after vegetation is established. All plots for water level, velocity, shear stress and stream power are presented in Appendix F.1.

Table 4.18

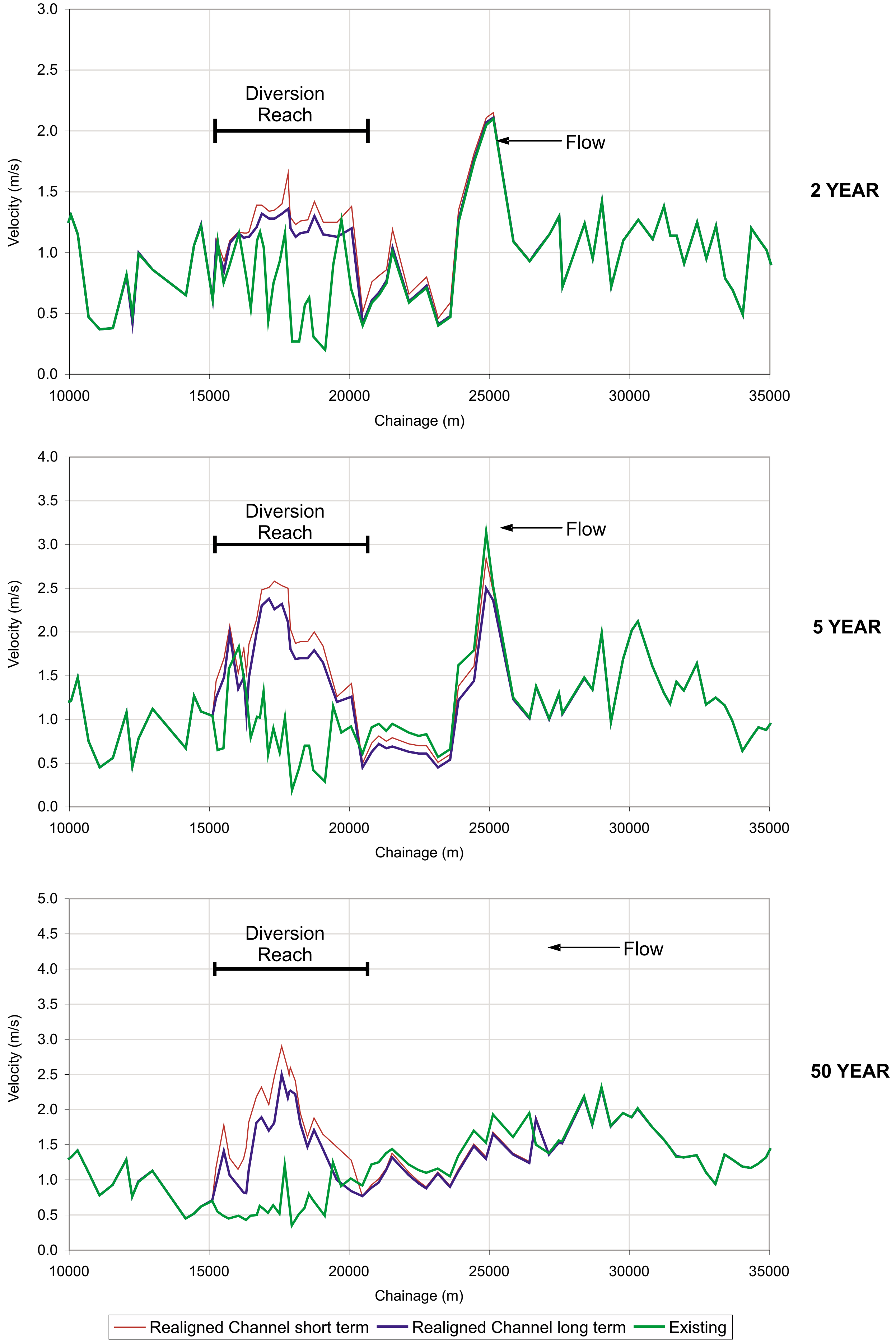
Summary of Predicted Flow Velocities (m/s)

ARI	Existing River	Alluvial Section of Diversion		Rock Section of Diversion	
		Model Result	ACARP Guideline	Model result	ACARP Guideline
2 year	0.3 – 1.0 Max 1.3	0.5 – 1.1 Max. 1.4	1 - 1.5	0.9 – 1.3 Max. 1.4	1.3 - 1.8
5-year	0.2 – 1.4 Max 1.8	0.6 – 1.5 Max. 1.8	Not defined	1.5 – 2.2 Max. 2.7	Not defined
50-year	0.4 – 1.2 Max 1.4	0.7 – 1.2 Max. 1.7	1.5 - 2.5	1.4 – 2.0 Max. 2.9	2.0 - 3.0
100-year	0.4 – 0.6 Max 0.7	0.8 – 1.2 Max 1.6	Not defined	1.6 – 2.0 Max. 2.4	Not defined
500-year	0.3 – 0.5 Max. 0.8	0.6 – 1.0 Max. 1.3	Not defined	1.0 – 1.5 Max. 1.8	Not defined

Table 4.19

Summary of Predicted Shear Stresses (N/m^2)

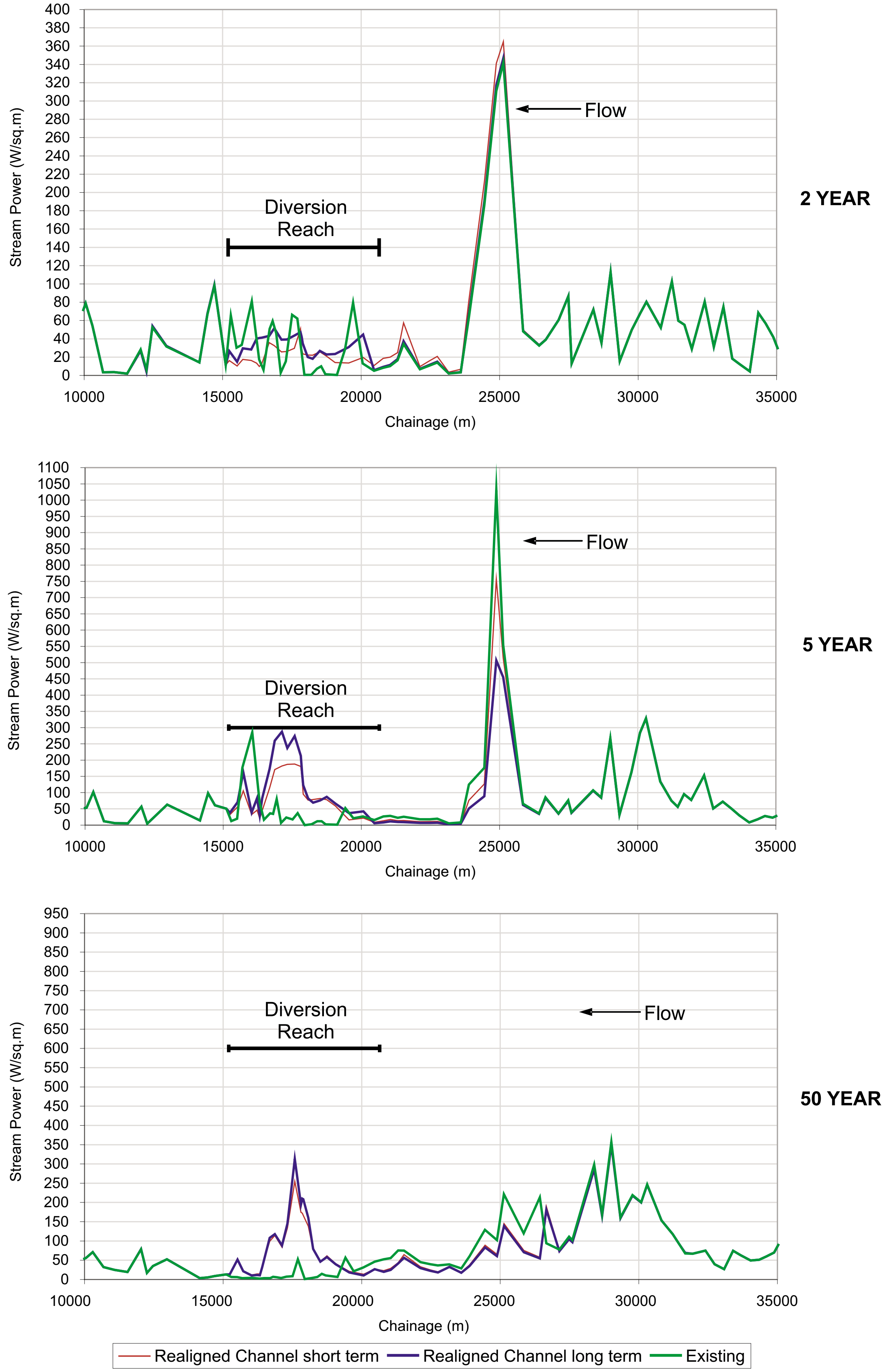
ARI	Existing River	Alluvial Section of Diversion		Rock Section of Diversion	
		Model Result	ACARP Guidelines	Model Result	ACARP Guidelines
2-year	5 – 60 Max 80	10 – 25 Max. 37	<40	10 – 30 Max. 40	<55
5-year	20 – 150 Max 160	20 – 40 Max. 45	Not defined	40 – 80 Max. 120	Not defined
50-year	10 – 30 Max 55	15 – 25 Max. 35	<80	30 – 70 Max. 125	<120
100-year	10 – 20 Max 25	10 – 15 Max. 20	Not defined	20 – 50 Max. 75	Not defined
500-year	5 – 15 Max. 25	5 – 10 Max. 14	Not defined	10 – 20 Max. 30	Not defined



McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

PROFILE OF VELOCITY IN DIVERTED McARTHUR RIVER

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **4.8**	Rev. A
Job No.: **42625552**	File No. 42625552-g-203.cdr			A4



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URS

McARTHUR RIVER MINE
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PROFILE OF STREAM POWER IN DIVERTED McARTHUR RIVER

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **4.9**	Rev. A
Job No.: **42625552**	File No. 42625552-g-204.cdr			A4

Table 4.20

Summary of Predicted Stream Powers (W/m^2)

ARI	Existing River	Alluvial Section of Diversion		Rock Section of Diversion	
		Model Result	ACARP Guidelines	Model Result	ACARP Guidelines
2-year	1 - 80 Max 100	10 – 25 Max. 40	20 - 60	10 – 35 Max. 50	50 - 110
5-year	1 – 250 Max 290	6 – 50 Max. 65	Not defined	60 – 150 Max. 290	Not defined
50-year	6 – 40 Max 70	10 – 30 Max. 40	100 - 150	50 – 150 Max. 310	100 - 350
100-year	5 – 15 Max. 20	10 – 30 Max. 40	Not defined	40 – 100 Max. 150	Not defined
500-year	3 – 5 Max. 20	3 – 10 Max. 15	Not defined	10 – 30 Max. 50	Not defined

The above model results show that:

- The predicted hydraulic parameters (velocity, shear stress and stream power) for the alluvial section of the diversion channel are similar to those for the existing McArthur River for the range of floods modelled. The long-term risk of instability for the diversion channel is therefore low.
- The predicted hydraulic parameters for the alluvial section of the diversion channel are generally within the ACARP guidelines for incised channels. The long-term risk of instability for the diversion channel is therefore low.
- Not withstanding the low risk of channel instability, large woody debris will be strategically placed in the base of the McArthur River diversion channel to artificially increase the roughness at these locations to lower channel velocities and stream power, to assist in sediment deposition and to provide micro habitat for fish.
- The reaches upstream and downstream of the diversion channel show similar velocities and stream powers for the scenarios with and without the diversion and no changes are expected to existing erosion or sedimentation patterns in these areas.

The model results confirm that the diversion as proposed will achieve the adopted design criteria and it is not expected to result in any significant detrimental hydraulic impacts to the McArthur River system.

The stream power results indicate that the long-term morphological stability of the McArthur River can be achieved and should be similar to that of the existing McArthur River channel. Notwithstanding the satisfactory model results, a more detailed assessment of the stream power and erosion potential through the diversion has been undertaken and is presented in the following section.

4.5.10 Stream Power and Erosion Potential of Diversion

Annandale Analysis

The Annandale (1995) method is considered best practice for estimating the erodibility of various geologic materials. The Annandale method utilises quantifiable geotechnical tests (from test pits and boreholes) to evaluate an Erodibility Index, K, that has been calibrated to extensive field observations and research of a wide range of materials from loose sand, cohesive clay, jointed weathered rock, to hard rock. This method has been applied to spillway flows with high energy impacting on rock or earth materials for major dams, where the consequences of failure would be catastrophic in environmental, social, and economic terms. The application and acceptance of the Annandale method for such high risk applications demonstrates assurance that the erodibility of the earth and rock materials relative to stream power can be assessed with confidence. The Erodibility Index, K, is calculated using the following equation:

$$K = Ms * Kb * Kd * Js$$

Where:

Ms = Mass Strength Number (correlated from Standard Penetration Test (SPT) blow count for granular material and Vane Shear Strength test for cohesive material)

Kb = The particle/block size number (relates the D_{50} particle size for granular material and Rock Quality Designation (RQD) and joint numbers/size for cohesive material).

Kd = Discontinuity or inter-particle bond shear strength number (relates the tangent of the minimum friction angle for granular material and relates joint roughness and clay layer gouging for cohesive material)

Js = Relative joint structure number (equal to 1 for granular material and relates joint spacing/number of joints and direction joints for cohesive material)

The estimated Erodibility Index results are then plotted on Chart 4.7 for cohesionless material, and Chart 4.8 for cohesive or rock materials and rock particle sizes greater than 100 mm in order to obtain an erodibility threshold stream power. The threshold stream power is then compared to the stream power results from the detailed hydraulic analyses to determine the material's erosion potential.

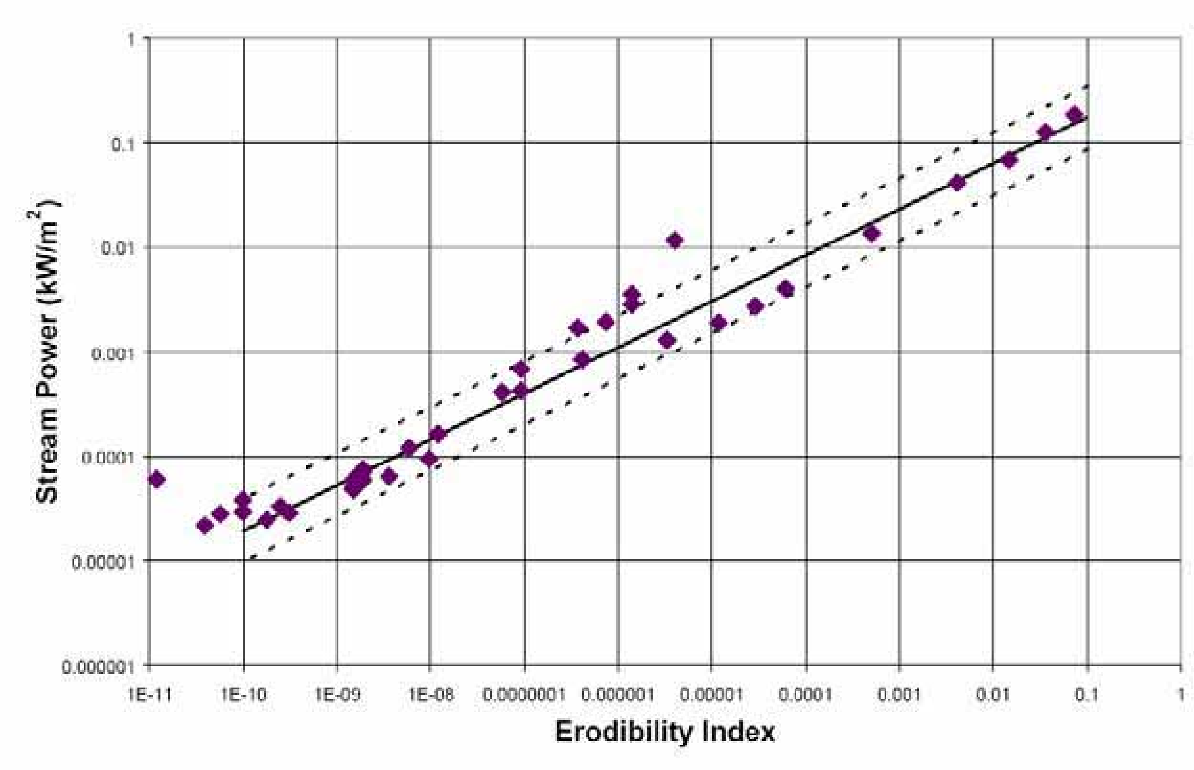


Chart 4.7
Erodibility Index versus Stream Power for Granular Material up to 100 mm

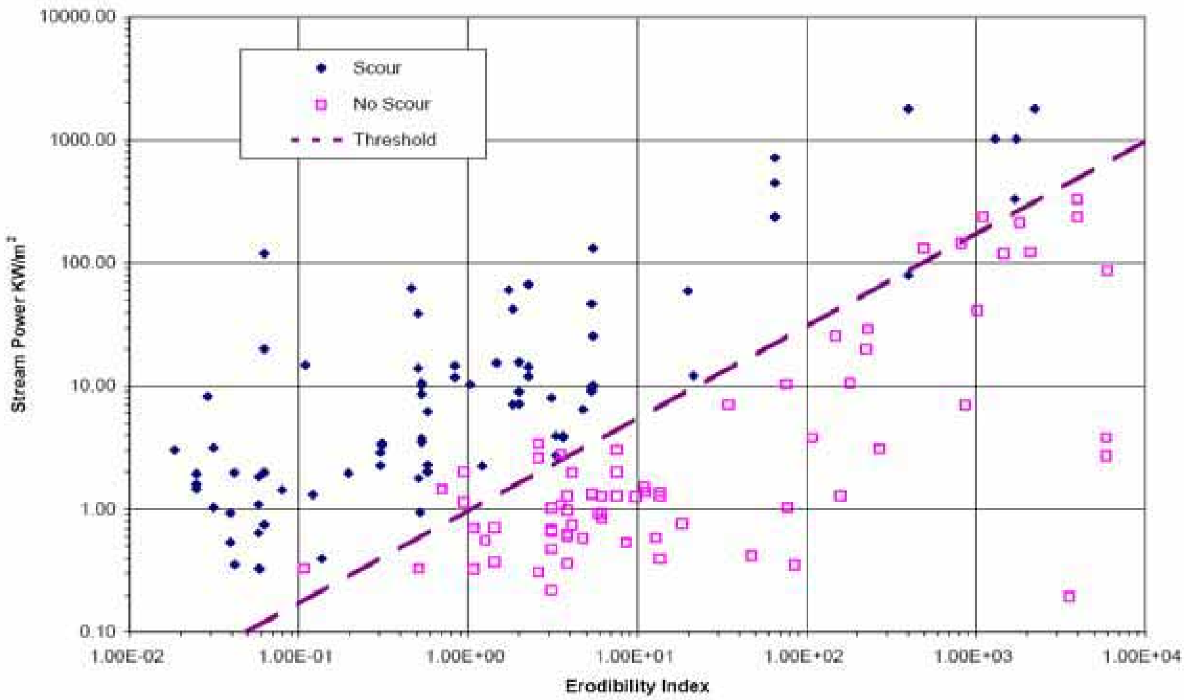


Chart 4.8
Erodibility Index versus Stream Power for Cohesive Material and Large Rock Particles

Alluvial Section of Diversion

An Annandale analysis was performed for the three boreholes (BHA01, BHA02, and BHA03) through the upstream alluvial section. The results of this analysis are shown in Table 4.21.

Table 4.21

Annandale Analysis Results for Alluvial Section of Diversion Channel

Borehole	Material description at base	RQD	SPT	D50 (mm)	Jn	Jr	Ja	Ms	Kb	Kd	Js	K	Max. Stream Power (W/m^2)
BA01	Sandstone	50	-	-	5	1	1	17.7	10.0	1	0.4	7.1E+01	24,400
BA02	Clayey sand	-	17	0.1	-	-	-	0.09	1	0.6	1	5.4E-02	115
BA03	Silty sand		10	0.1	-	-	-	0.07	1	0.6	1	4.2E-02	95

Table 4.21 shows that the silty-sand materials will resist erosion for stream powers up to approximately 95 W/m^2.

Table 4.22 compares the modelled stream powers for the alluvial section of the diversion with the results from the Annandale analysis as well as the ACARP guidelines.

Table 4.22

Comparison of Modelled and Guideline Stream Powers through Alluvial Section

ARI	Modelled Stream Power in Diversion	Modelled Stream Power in Existing River Channel	Annandale Analysis	ACARP Guidelines For Incised Channel
2-year	40	100	95	20 – 60
5-year	65	50		Not Defined
50-year	40	60		50 - 150
100-year	30	20		Not Defined
500-year	15	5		Not Defined

Table 4.22 shows that the diversion channel through the alluvial section would resist erosion for the following reasons:

- The stream powers in the diversion channel would be of the same order as those in the existing river channel
- The Annandale analysis results show that the alluvial material has a threshold stream power of approximately 95 W/m^2, which is greater than the maximum stream power in the diversion of 65 W/m^2
- The predicted stream powers in the diversion for both the 2-year and 50-year ARI events are within the range given in the ACARP guidelines

- The maximum stream powers in the alluvial section would occur at the rock riffles which will resist erosion for stream powers up to 500 W/m^2.

The above results show that the rock lining of the alluvial banks which will be used to retain topsoil for revegetation purposes is not necessary for erosion prevention.

The channel bed in these alluvial materials will be unlined because, due to the low stream powers, it would not be subject to significant erosion. Any erosion of the channel bed which did occur would be limited by the downstream, upstream and bank controls. The depth and downstream migration of any erosion of the channel bed would be limited by the presence of rock in the lower two-thirds of the diversion channel. Any lateral erosion would be limited by the erosion resistant rock lining of the channel banks. The potentially erodible, but erosion constrained, channel bed will allow the river to regenerate a natural meandering pattern for low flows in the channel without generating excessive sediment and without causing unsustainable or destructive erosion.

Based on the above results, the alluvial section of the proposed diversion channel would be stable in both the short term and long term.

Rock Section of the Diversion

An Annandale analysis was performed for the boreholes (BHA04 to BHA10) through the rock section of the diversion. The results of this analysis are shown in Table 4.23.

Table 4.21

Annandale Analysis Results for Alluvial Section of Diversion Channel

Bore hole	Material description at base	RQD	Jn	Jr	Ja	Ms	Kb	Kd	Js	K	Max. Stream Power (W/m^2)
BA04	Shale	31	5	1	1	17.7	6.2	1	0.4	4.4E+01	17,000
BA06	Mudstone	100	5	1	1	35	20.0	1	0.4	2.8E+02	68,000
BA07	Breccia	90	1	4	0.75	35	90.0	5.3	1	1.7E+04	1,400,000
BA08	Breccia	97	1	4	0.75	35	97.0	5.3	1	1.8E+04	1,500,000
BA09	Dolomitic/ sandstone/ siltstone	80	5	1	1	17.7	16.0	1	0.4	1.1E+02	35,000
BA10	Dolomite	100	5	1	3	35	20.0	0.3	0.4	9.3E+01	30,000

Table 4.23 shows that the weathered rock and fresh rock strata in the diversion will resist erosion for stream powers greater than 17,000 W/m^2.

Table 4.24 compares the modelled stream powers for the rock section of the diversion with the results from the Annandale analysis as well as the ACARP guidelines.

Table 4.22

Comparison of Modelled and Guideline Stream Powers through Rock Section

ARI	Modelled Stream Power in Diversion	Annandale Analysis	ACARP Guidelines For Bedrock Controlled
2-year	50	>17,000	50 – 110
5-year	290		Not Defined
50-year	310		100 - 350
100-year	150		Not Defined
500-year	50		Not Defined

The results show that the diversion channel through the rock section would resist erosion for the following reasons:

- The Annandale analysis results show that the rock strata has a threshold stream power greater than 17,000 W/m^2, which is significantly greater than the maximum predicted stream power of 290 W/m^2
- The predicted stream powers in the diversion for both the 2-year and 50-year ARI events are within the range given in the ACARP guidelines.

Based on the above results, the rock section of the proposed diversion channel would be stable in both the short term and long term.

4.6 Rehabilitation of the Proposed Diversion Channel

4.6.1 Introduction

This section outlines a rehabilitation plan for the proposed diversion channel. The plan is based on prior studies (e.g. URS 2005b, Appendix K) and has been developed in consultation with sub-consultants Marj King (Top End Seeds) and Dr. Mark Burns (Global Soils). It is based on development of suitable substrate conditions and use of key local species. An additional supporting document The ‘Keys to Sustainable Ecosystem Establishment on Mine Sites’ (Appendix I) provides further general information.

Realignment of the McArthur River will create an altered riverine and riparian environment which will require effective, long-term and sustainable revegetation, consistent with existing vegetation communities in the area. Revegetation of the proposed diversion channel is considered by MRM to be a high priority necessary for the early establishment of aquatic and riparian ecosystem function.

4.6.2 General Guidelines

High velocity flows during the wet season can dislodge young establishing plants with inadequate root systems. Similarly, if plants are unable to establish deep root systems that can access deep soil water during the dry season, they could die. Quickly establishing deep healthy root systems for both artificial and naturally established native plants will be critical to the ecological success of the project.

Approximately two-thirds of the diverted channel will be cut into hard rock and the balance will be cut into softer alluvial soils. Site preparation requirements, as a prerequisite for vegetation establishment, will be different for each substrate condition.

For the section of the channel excavated into rock, there is a risk that shallow rooted plants will be ripped out during high flows or die during the dry season, due to inadequate root depth which provides anchoring and/or access to soil moisture. Observations of sections of the existing river show that trees will grow and survive in fractured rock provided they can get their roots down into fine substrates. This observation provides a useful guide to future site preparation along the rocky sections of the channels. Provided there is a reasonable component of fines, rough rock sections are desirable because they slow flow velocities and protect the fine material from erosion. Consequently, the infilling of fractured rock voids with clean topsoil is a key requirement for rehabilitation success.

The remaining third of the diversion channel will be cut into softer alluvial material. This provides a different set of parameters for vegetation establishment. In particular, instability of topsoil placed on the channel banks can result in young plants being scoured out. Even though soft when wet, the banks can also be compacted during construction thus restricting initial root establishment. Rapid and deep root development must be encouraged. To overcome this problem, adequate soil depth will be created by adding rock cover to at least 1 m depth and infilling with weed free, non-dispersive soil. In addition, in sections of the alluvial channel where there are dispersive soils, geotextile will be placed on the bank before capping with fractured rock. In these sections, the depth of the rock/soil mix will be increased to 1.5 m to allow for restricted root growth through the underlying geotextile.

Other potential impediments to vegetation establishment are weeds. Weeds can quickly out-compete slower establishing native species. Diligent weed control, particularly in the stripping, stockpiling and re-spreading of topsoil will be a high priority. Basic machinery hygiene will also be maintained. Grazing animals may also damage newly revegetated areas and these would be excluded by fencing if necessary.

4.6.3 Proposed Rehabilitation Strategy

Site Clearing – Topsoil and Vegetation Recovery

Techniques to ensure the correct stripping, stockpiling and re-spreading of topsoil include: separation of dispersive and non-dispersive soil material; minimisation of handling and consequent soil structural degradation; and weed management. The latter is particularly important for revegetation success. As such, the weed content of soil along the channel alignment will be assessed and managed. Soil from areas with likely low weed content will be separated from highly weed-contaminated material. Only relatively weed-free material will be used when infilling amongst rocks on the channel banks. This may necessitate a number of activities such as scalping off the thin weed infested top layer of soil prior to stripping the underlying weed-free soils. At a later date, carefully scalping off of the weed infested top 5 to 10 cm of topsoil dumps prior to re-use may remove up to 95% of weed propagules. Immediate sowing of topsoil dumps after emplacement with a dense sterile cover crop such as millet, will help control initial weed competition and limit erosion of the topsoil dumps.

There are other day-to-day topsoil management practices which will be implemented (Appendix I) as necessary to address site-specific issues as they arise.

Site Preparation

In the rocky sections of the channel, over-excavation or over-blasting by 1.5 - 2 m beyond the design cross section width will be undertaken with the fractured rock and loose rock retained as a scree surface on the channel banks. The objective will be to create a fractured rocky slope with rocks ranging from 200 mm to 900 mm in diameter. In addition some fracturing of the channel floor to a shallower depth (0.5 m) will be undertaken for trapping sediment. Such fracturing of the floor will also create loose rock material which can be pushed up into velocity-reducing riffles and, in the process, create shallow ponds. Some initial experimentation with blasting size and patterns may be necessary to ensure the best possible outcome.

In the alluvial sections of the channel, rock of appropriate diameter (maximum diameter of 700 mm with less than 20% smaller than 200 mm in diameter) will be placed on the banks to at least 1 m depth along the sections with non-dispersive soils. Where the channel cuts through dispersive soils, geotextile will be placed under the rock layer which will be increased to a minimum depth of 1.5 m to allow for restricted root growth through the underlying geotextile.

Channel Bank Preparation to Enhance Vegetation Establishment

To encourage root development and sustain moisture for plant establishment and survival the channel banks will be covered with topsoil and fine sediment to form a porous substrate on the channel banks. The rough rocky banks along with crevices and voids in loose or fractured rock will contain the topsoil and sediment.

Following the creation of the rough rocky banks, suitable weed-free topsoil will be spread over the banks ensuring it is well worked into the voids, cracks and crevices as much as possible by sluicing. For this reason, topsoil stockpiles will be located close by, will be as weed free as possible, and will not contain dispersive material. The actual depth of topsoil to be spread will depend on how well it can be worked into the rocky matrix. However, the maximum amount of topsoil will be spread. Rapid settlement is likely to occur following the first rain. The created patches of soil will be of sufficient depth for tube stock to be planted into. The entire area will also be directly sown with native species immediately after soil emplacement.

Further silting of the rocky slopes (particularly lower down) is expected from natural sedimentation from river flows. The rough rocky banks will also assist in trapping and establishing a range of natural river borne seeds. It is expected that the natural return of native plant species will be greatly assisted by the coarse textured slopes.

Placement of Large Woody Debris

Following topsoil re-spreading, felled timber will be re-spread across the slope and anchored if necessary to act as LWD in the channel. This timber material will further assist sediment trapping and habitat creation, and provide shade for aquatic fauna. It will also restrict access by grazing animals which have the potential to damage young plants.

The correct placement and anchoring of this timber is important, otherwise it is at risk of washing away. Large diameter timber (greater than 30 cm diameter) can be placed in the channel bed or up the banks, while finer branches are best placed partially extending into the floor of the channel where they can trap sediment, reduce flow velocities and create micro-habitat. Hence, placing a component of the timber debris with the tree heads intruding into the channel will be undertaken.

Timber will also be placed to ensure the best possible chance of retention during high flow events. The placement of coarse rock on the banks will greatly assist the anchoring of timber. However, further artificial anchoring will also be used particularly on the channel bed. Placement of LWD will be at about one third to half the abundance of LWD naturally present in the existing river reach (Section 4.4.3). This is considered sufficient to create initial habitat diversity and to activate a natural debris and sediment trapping process.

LWD would be placed in general accordance with the following specification:

- LWD to be placed in the bed of the channel to assist in rehabilitation, to provide localised habitat, and to encourage sediment trapping and meandering. LWD to comprise dead trees with a minimum Diameter Breast Height (DBH) of 300 mm, but preferably greater than 450 mm.

- LWD to be located at irregular spacing, placement, and alignment to resemble a random distribution. In channel sections with a sand/clay bed, the maximum spacing of LWD to be approximately 100 m (minimum 30 m). In rock excavated sections, the maximum spacing of LWD to be approximately 200 m. LWD are to be placed irregularly on alternating sides of the bed, in a random fashion. Near tributary junctions, LWD to be placed on the bank opposite to the side where the tributary joins. About 20 to 40% of LWD to be in groups of two or three logs placed to resemble a log jam. Log jams to be placed closer to the banks and not obstruct more than 50% of the channel bed.

- Shallow loose sand (around 200 mm to 400 mm depth) to be placed on the upstream and downstream side of logs to resemble sand bars. At least two thirds of LWD to be anchored. Anchoring to be achieved by partial (>25%) burying of the log and root ball, chaining to a timber pile driven into the sand or clay bed, or chaining to a grouted steel bar in rock beds.

- Approximately 60 to 80% of LWD to be aligned angled from the bank (about 30 to 60 degrees) in the downstream direction. The remainder to be perpendicular to the bank and some pointing upstream.

- Shallow pools (approximately 0.5 m in depth) to be incorporated as over-excavated rock material in the base of the rock diversion section.

LWD in the existing channel will not be removed for relocation into the new channel except in areas scheduled for clearing. Strict requirements will be in place to maintain habitats in the existing channel and to prevent flow/fish obstructions during construction.

Revegetation Species

Local species suitable for use in the revegetation program have been identified in Appendix K of the EIS Supplement (URS, 2005b). These species can be divided into riverine/lower riparian species and higher bank species. Species and planting methods for the riverine and lower bank habitats are summarised in Table 4.23

Table 4.23

Riverine and Lower Bank Species and Planting Method

Species	Planting Method
Melaleuca argentea	Tube stock and direct seeded
Melaleuca leucadendra	Tube stock and direct seeded
Eucalyptus camaldulensis	Tube stock and direct seeded
Casuarina cunninghamiana	Tube stock and direct seeded
Acacia hemsleyi	Tube stock and direct seeded
Barringtonia acutangula	Tube stock
Nauclea orientalis	Tube stock
Ficus coronulata	Tube stock
Ficus hispida	Tube stock
Pandanus spiralis	Direct seeded
Chrysopogon elongatus	Tube stock
Cyperaceae sp	Tube stock

Although a number of these species are not present in the existing channel near the mine, they do grow along the river both upstream and downstream of the proposed diversion. Other locally occurring species may be used after further site investigation.

A key species for this area is *Barringtonia actangula* which is the most abundant edge habitat plant in the existing channel. Seeds from these trees will be collected early in the wet season so that they can germinate and be propagated. They will then be of sufficient size to plant late in the same wet season. *Casuarina cunninghamiana* will have to be planted/direct seeded in the wet season. By both planting seedlings and direct seeding at the same time, the likelihood of success can be improved. Generally, the more plants established the better, but if there is excessive regrowth then it may be necessary to thin out some of the plants.

Planting will be at a rate of one seedling per m^2. Usually on mine sites the direct seeding rate is 2.5 kg/ha but the proposed rate of one seedling per m^2 is approximately double that. Germination rates for direct seeding are about 10%.

Transplanting of mature trees has also been considered but it presents a number of logistical problems and this method is not considered suitable for this project. The best time to dig up and move trees is once the early rains have started, but this means access with heavy machinery which would not be possible given the nature of the soil. If trees are moved before the rains start, the transpiration rates are high and the trees would probably die even if they are provided with irrigation. There are also various issues associated with access to planting sites on the channel banks with the potential to damage progressing rehabilitation areas. In addition to these issues, it is considered doubtful that larger transplanted trees would be able to re-establish their root systems in time to withstand wet season flooding and hence could be pushed over by floodwaters. Seeding or direct planting is preferred way to establish vegetation in this dynamic environment.

It is expected that by the beginning of the wet season following planting and direct seeding, those trees that survive the wet will be about 1 m tall. Subsequent growth is expected to be about 1 m per year, although this figure cannot be confirmed and will vary between species and situations. The percentage of plants surviving to the first year cannot be estimated and is largely dependant on seasonal fluctuations. Growth rates and survival will be monitored and adjustments made to the program accordingly. The monitoring program will include replacement of dead plants in any areas of significant mortality.

For the upper bank zone, all the species listed below would be direct seeded. Two grass species, *Chionrachne* sp. and *Chrysopogon elongatus* would also be planted.

- *Corymbia bella*
- *Eucalyptus camaldulensis*
- *Lophostemon grandis*
- *Melaleuca leucadendra*
- *Acacia drepanocarpa*
- *Hibiscus spp.*
- *Terminalia spp.*
- *Acacia helnsleyi*
- *Acacia holosericea*
- *Acacia platycarpa*
- *Atalaya hemiglauca*
- *Eucalyptus microtheca*

It is proposed that there will be a blended interface and overlap of the two groups of plants. The extent of this overlap will be determined as the channel is constructed.

An important issue is the rapid collection of seed and propagation of tube stock to meet the proposed time frames. There is currently infrastructure for a small nursery at Borroloola in which plants are being grown for local use. This facility will be upgraded and resourced for the project. Seed collection for the project has already commenced and to date the following species and quantities have been collected and are stockpiled.

- *Lophostemon grandis* (4.5 kg)
- *Melaleuca leucadendra* (1 kg)
- *Melaleuca argentea* (14 kg)
- *Eucalyptus camaldulensis* (37 kg)
- *Corymbia bella* (9 kg)
- *Eucalyptus chlorophylla* (6 kg)

Fertiliser Use

It is proposed to place two 21 g slow release Agriform fertilizer pills under each planted tube stock. Similarly, it is proposed to apply a N,P,K fertiliser (e.g. Crop King 88) at a rate of 100 kg/ha in conjunction with applied seed. The fertiliser will provide the necessary bulking agent for the applied native seed. As fertiliser will rapidly stimulate any weeds present, the importance of using relatively weed-free topsoil is highlighted.

Bank Moisture for Vegetation Survival

The alluvial soils and exposed bedrock of the existing river banks generally have a low permeability. Moisture for riverine vegetation is generally obtained from the shallow sediment on the channel bed and in sediments deposited on the banks. Groundwater levels in the river banks influence the available moisture for bank vegetation and are primarily controlled by river water levels.

The proposed bank preparation and surface treatments of the diversion channel will provide porous media in the channel banks to sustain moisture for vegetation. The rough rocky bank finish, installation of riffles, and replacement of large woody debris will further enhance the restoration of bed and bank sediment deposits. Over time, establishing bank vegetation and further accumulation of large woody debris will further enhance sediment deposition on the channel bed and banks.

Similar to the existing river channel, moisture in the banks of the diversion channel will vary relative to river water levels and will develop a variable profile relative to height above the river bed. In time, as vegetation becomes established and self sustaining, the vegetation species will adapt to the seasonal moisture profile as they do at present. These conditions and controls should ensure that adequate moisture is available to sustain riparian vegetation.

To confirm that adequate moisture will be available for riparian vegetation, the vegetation will be monitored with annual surveys during the first five years of rehabilitation, and monitoring frequency will be reviewed thereafter in consultation with the Northern Territory Government. In the first two years after planting, the vegetation growth will be visually monitored monthly during the dry season.

In the event that vegetation stress or deficiency due to lack of moisture is identified from the monitoring program, one or more of the following contingency strategies will be employed:

- Supplementary irrigation of bank vegetation with clean groundwater sourced from the existing borefield could be undertaken until vegetation establishment adapts to the seasonal bank moisture profile
- Additional small riffles may be installed to locally increase river levels in strategic areas. These will prolong moisture recharge of the bank areas and raise the moisture profile relative to bank height above the river bed. Riffles may also be used to further enhance sediment trapping and formation moisture stored in sand, silt bars, and bank-drape sediments.
- Additional large woody debris may be installed to enhance sediment trapping and formation of sand and silt bars, and bank-drape sediments to increase moisture storage.

The most suitable contingency strategy or combination of strategies will be determined, implemented and monitored with information from the vegetation monitoring programme. Specialist rehabilitation professionals will be consulted to select, optimise, and oversee the implementation of the contingency measures.

Maintenance

Revegetated areas (particularly with tube stock) may require supplementary watering after establishment. A suitable tanker/watering arrangement will be dedicated to revegetated areas. The tanker will use the maintenance track along the edge of the channel. Correct watering to ensure saturation of the root system is important to ensure success. Maintenance weed control may also be necessary. Only non soil-residual herbicides such as Roundup will be used.

The need for careful maintenance fertiliser applications will be assessed as vegetation develops. There will be a need for day-to-day decisions by an experienced environmental scientist during and after channel construction to ensure the revegetation program is successful.

Vegetation Establishment Beyond Channel Banks

In addition to bank revegetation, it is proposed that where practical, vegetation will be established along a 20 m wide strip beyond the top of the channel banks (as an extension of the bank vegetation). This will assist the transition from channel vegetation into the surrounding undisturbed vegetation. This 20 m wide corridor will also include an access track at the top of the slope for watering and other maintenance access. The area will be ripped and sown/planted after one to two years when surrounding revegetation has been established.

Direct Seeding Versus Tube Stock Planting

Direct seeding of woody native trees and shrubs is widely practiced in tropical Australia. Assuming a total sowing rate (all species combined) of 5.5 kg/ha, more seed will need to be collected than is currently available. Consequently, seed collection efforts will be significantly intensified.

Tube stock planting is more maintenance intensive than direct seeding but is needed in conjunction with direct seeding to enhance species diversity across the site because some species don’t direct seed well.

An approximate planting density of 1,000 trees/ha is proposed but this will vary across the site with more dense plantings closer to the channel bed.

As a consequence of the rough rocky slope and channel floor, significant trapping of water-borne and air-borne seed is expected. This process should result in increased numbers of woody trees and other species establishing over time, particularly on the lower slopes. Assessment of natural recruitment will be included in the monitoring program.

Timing

Timing issues which will be considered in the program include:

- Collection of appropriate quantity and diversity of seed to meet anticipated needs
- Construction of a suitable nursery and the early production of at least 35,000 tube stock
- Direct seeding undertaken immediately after soil is spread (or ripped above channel) and before rain and surface crusting occurs
- Assessment of what areas will be available for topsoiling/seeding/planting and co-ordination of this with seed/tube stock supply
- Optimum scheduling of topsoil stripping and re-spreading on rocky slopes
- Co-ordination of all works with the wet season.

Monitoring

Regular monitoring and feedback will be important during the revegetation project. This will be informal in the initial stages as the program develops, but a formal data collection system to validate results will be set up once the program is established. Monitoring of rehabilitation efforts will include the following components:

- Quantitative assessments of erosion, deposition and woody debris at permanent sites along the channel
- Plot-based measurement of plant re-growth and re-colonisation, detailing plant species and sizes over time
- Regular surveys of the channel length to identify any areas requiring additional management or remedial measures.

4.7 Clearing and Riparian Habitat Fragmentation

4.7.1 Summary

The proposed realignment of the McArthur River and subsequent construction of the flood protection bund and open cut will necessarily result in the loss of riparian vegetation. The vegetation communities to be cleared are not listed as threatened, and are common and widespread throughout the region. However, the riparian vegetation along the McArthur River is an important dispersal corridor for fauna species, and loss or fragmentation of this habitat may impact species which are dependent on it.

4.7.2 Proposed Clearing Schedule

The proposed clearing schedule is illustrated in Figure 4.10. The loss of riparian vegetation as a result of the river realignments will be slow and gradual and much of the existing river channel will remain, particularly in the early years of open cut developed.

The initial clearing of the riparian corridor will be limited. In the first year (2006), only minor clearing will occur at the extreme downstream end of the McArthur River and Barney Creek diversion channels. In 2007, additional construction clearing will be required for the flood protection bund, haul roads, and the upstream connection of the diversion channel to the river.

During the first 3 years of the open cut project (2007-2009), the mine pit will require clearing of the northern edge of the riparian corridor for a length of approximately 1 km. While the water flow along the old river channel inside the bund will be cut off, most (75%) of the riparian vegetation will not be cleared and will continue to function as a movement corridor for birds and other fauna species. During this time, vegetation that will have been planted along the river realignment will be establishing.

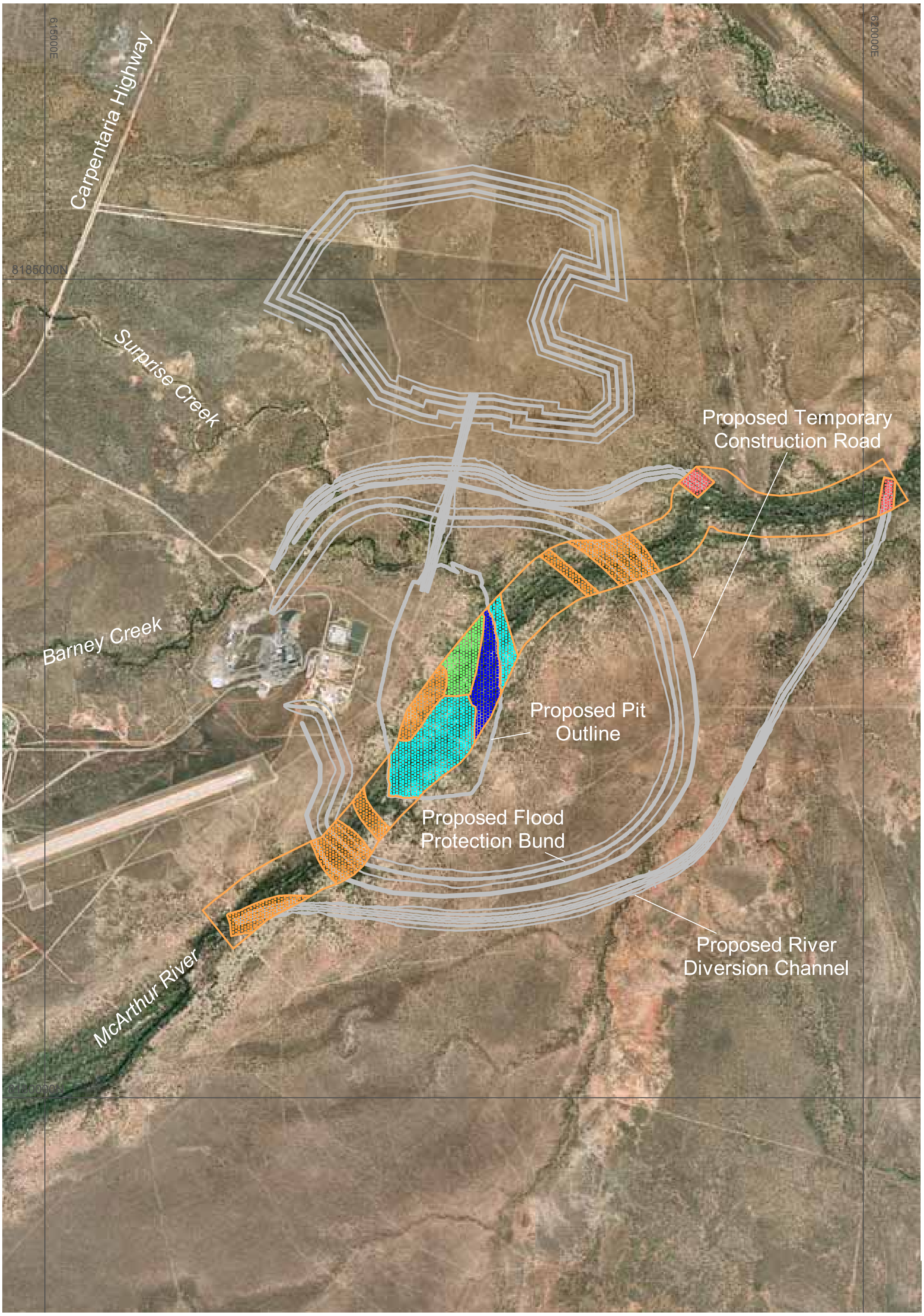
In 2010, a further 800 m section of the old river channel will be cleared as the mine pit expands. Disturbance of the old river channel will increase to 1,300 m in 2015.

The balance of the riparian vegetation inside the bund will remain. While its health may gradually decline due to the lack of water flows (surface water drainage will still accumulate in the old channel), this vegetation is still expected to provide some functionality as a movement corridor and as fragmented habitat. This functionality will be even greater along the old river bed outside of the flood protection bund, which at the downstream end will effectively become a lower section of Barney Creek. By this time the rehabilitation along the river diversion will have had time to become established and will be beginning to function as a movement corridor.

4.7.3 Potential Fauna Impacts

Fragmentation of fauna populations along the riparian corridor will not be as sudden or significant as if the entire existing channel was cleared at once. There will be a gradual transition over 10 years from the functionality of the existing river channel to that of the diversion.

The impacts of this process on fauna are also likely to be gradual. Larger mobile animals, such as wallabies will be capable of moving away from the disturbance, while micro habitat for smaller species such as reptiles and frogs will persist in patches for some time. Impacts will also be felt by birds, especially those which are specialist riparian species such as white-browed robin and purple-crowned fairy-wren.



0 500m 1000m
Scale 1: 35 000 (A4)

Horizontal Datum: AGD84, Zone 53
Date of Aerial Photography, 2001

Year 2006
Year 2007
Year 2008
Year 2010
Year 2015

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MCARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

CLEARING SCHEDULE FOR MCARTHUR RIVER RIPARIAN CORRIDOR

Drawn: VH	Approved: CMP	Date: 27-06-2006	Rev: A
Job No: **42625552**	File No: 42625552-g-173.wor	Figure: **4.10**	**A4**

Fauna surveys conducted in riparian habitats in the vicinity of the McArthur River mine indicate that this vegetation type is species rich when compared to the adjacent woodland habitats. The riparian habitat supports a suite of bird species including: generalists that occur across a range of habitats within the local area; species that are more likely to be associated with denser and more complex vegetation types; and a small number of riparian habitat specialists.

In the northern Australian wet/dry tropics, large rivers and streams support narrow bands of riparian vegetation that contrast strongly with adjacent open forests and savanna woodlands (Woinarski *et. al.,* 2000). Major features of these habitats are that they incorporate elements of monsoonal rainforests, they present a continuous linked habitat of dense vegetation which generally displays higher structural and floristic diversity than surrounding habitats, and they are generally more productive and wetter than surrounding habitats (Woinarski *et. al.,* 2000; Martin *et. al.,* 2006). Australian riparian habitats support a disproportionately large number of plant and animal species relative to their area when compared to drier open forest and savanna woodland habitats.

The high diversity of fauna species noted in riparian habitats in the northern wet/dry tropics extends to birds, with one study showing that riparian sites support approximately twice the number of bird species (and total individuals) as all other habitat types (Woinarski *et. al.,* 2000). Within continuous bushland, riparian areas support higher species richness and total bird abundances than dryland habitats. This is potentially related to higher moisture and nutrient levels producing a more diverse plant community with associated higher levels of structural complexity, with a corresponding greater number of resources and higher niche availability (Bently and Catterall, 1997).

Habitat connectivity is another significant factor that influences the suite of species present in riparian habitats. The provision of a long continuous link through the riparian habitats of major rivers is in contrast to the other main habitats for these species which are the more structurally diverse northern Australian wet/dry tropics - monsoonal vine forests. The latter habitats characteristically occur as a fragmented patchwork in the wider landscape (Price *et. al.*, 1995; Woinarski *et. al.,* 2000).

It has been identified that fragmentation of forested habitats has negative impacts on forest-dependent biota remaining in the fragments, and that these impacts can be particularly significant if riparian corridors are impacted (Catterall, 1993). While fragmentation of habitat can have biogeographic consequences and physical impacts on forest-dependent species, the size, shape, and position in the landscape can also influence how the changes impact biota utilising the fragments (Saunders *et. al.*, 1995; Jansen, 2005). The effects of fragmentation may be ameliorated by restoration of the habitat, such as in the case of the McArthur River project by re-establishing an alternative riparian corridor of sufficient width (e.g. >100 m) on the realigned river channel. This strategy can be expected to re-establish connectivity along the linear riparian corridor following successful rehabilitation.

Most studies focusing on the use of corridors by wildlife have examined corridors which have been left in a fragmented landscape, rather than restored corridors or projects that aim to re-establish riparian corridors (Jansen, 2005). Many of the studies associated with restoration of mined areas in northern Australia concentrate on the rehabilitation of areas of habitat within an undisturbed surrounding landscape, rather than the re-establishment of a narrow band of a specific habitat within a wider habitat matrix. However Jansen (2005) in a study of the restoration of riparian vegetation linking remnant rainforest patches in the wet tropics of Queensland, found that a riparian restoration project could re-establish connectivity for forest birds and provide habitat for closed forest specialists.

4.7.4 Proposed Monitoring Program

In order to assess the impacts of habitat fragmentation created by the river diversion, it is proposed to establish a monitoring program based on assessment of bird diversity which will particularly target riparian habitat specialists as indicator species. The long-term program will sample sites upstream and downstream of the planned diversion, in fragmented habitats along the old river channel (within the bund), and at sites along the diversion channel.

Monitoring of bird populations is relatively cost effective when compared to the effort required to monitor other vertebrate fauna groups, and monitoring of a population of birds provides researchers with feedback from a whole community of organisms rather than a single species (Burnett *et. al.,* 2005). Monitoring birds can therefore provide a useful measure of the relative success of a habitat restoration project (Burnett *et. al.*, 2005). Important aspects of bird monitoring programs designed to assess the success of habitat restoration include the provision of an assessment of the effectiveness of the restoration program, provision of feedback for adaptive management of restored riparian habitat, provision of a guide to riparian restoration design by providing information on the condition and habitat associations of the local bird populations, and provision of a relatively cost effective monitoring tool (Burnett *et. al.,* 2005).

Details of a proposed bird monitoring program are provided in Appendix J.