RECOMMENDED IMPROVEMENTS IN DESIGN OF THE McARTHUR RIVER AND BARNEY CREEK DIVERSION CHANNELS FOR THE McARTHUR RIVER MINE OPEN CUT PROJECT

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EXECUTIVE SUMMARY

The shortcomings in the information contained in the EIS for the McArthur River Mine Open Cut Project EIS (URS, 2005) include:

- No hydrological information for Barney and Surprise creeks is provided.
- No errors are cited for the ground elevations for the photogrammetrically determined cross sections nor how these are translated into uncertainty in the calculated water surface levels in HEC-RAS hydrodynamic model.
- The adopted roughness coefficients are high but the HEC-RAS model calibration resulted in a poor fit to a known flood profile. The roughness coefficients may be incorrect.
- The adopted grain size for McArthur River sediment is very fine and seems inappropriate.
- There is a marked drawdown in the water surface profile immediately upstream of the diversion channel during the 1:2 and 1:5 year ARI events which produces very high shear stresses and specific stream powers that will cause erosion. This drawdown requires further investigation.
- Additional geomorphological work is required to determine whether the McArthur River and Barney and Surprise creeks are currently stable. No work has been undertaken to date on Barney and Surprise creeks.
- Meaningful river reach analysis needs to completed for the McArthur River and started for Barney and Surprise creeks to assist in the design of the two diversion channels. In particular, the types of channel units or aquatic habitats present must be documented.

Recommended improvements in the design of the diversion channels include:

- Supplying appropriate information for the Barney and Surprise creeks diversion channel.
- Following the methods outlined in the Rehabilitation Manual (Rutherfurd *et al.*, 2000a; 2000b) for the design of the diversion channels.
- Outlining the method used to derive the channel geometry for the McArthur River diversion channel.
- Incorporating the same aquatic habitats as exist in the current channel in the diversion channel design.
- Incorporating large wood loadings, spacing, orientation and accumulations in the diversion channel design that mimick the current channel. Large wood must be appropriately sourced.
- Providing meaningful information on the revegetation proposal, including species, seed source, planting densities, vertical zonation of species, etc.
- Meaningful discussion of sediment erodibility for the material used to form the banks of the diversion channel and what measures will be taken to decrease erodibility.
- Details of the proposed channel monitoring program.
- Offsets for the destruction of 8 km of river channel by the two channel diversions.

The predicted impacts of the diversion channels on up- and downstream channel morphology include:

- No information has been provided in the EIS to make any meaningful predictions of the potential impacts of the Barney and Surprise creeks diversion channel.
- Upstream progressing degradation will occur due to the drawdown immediately upstream of the diversion channel and the consequent very high shear stresses. No information is presented in the EIS to enable an assessment of the likelihood that armouring will reduce the magnitude of bed degradation.
- Downstream deposition will occur, converting the channel into a sand slug.
- The banks of the diversion channel will erode until dense riparian vegetation is re-established which will take more than 10 years.

INTRODUCTION

This report was commissioned by Ms Juanita Croft and Mr Rod Johnson of Environmental Assessment, Northern Territory Environment Protection Agency, Department of Natural Resources, Environment and the Arts to:

1. critically evaluate the adequacy of information included in the Draft Environmental Impact Statement for the McArthur River Mine Open Cut Project (URS, 2005) for the proposed realignments of the McArthur River and Barney Creek for diversion around the open cut pit.
2. recommend, if necessary, improvements in design for the two diversion channels.
3. predict potential impacts on channel morphology up- and downstream of the two diversion channels.

The alignment of the two proposed diversion channels is shown in Figure 12.12 of URS (2005). The materials through which the two diversion channels will be constructed are shown in Figure 12.13. Selected aspects of the channel designs are outlined in Tables 12.12 and 12.13. Results of selected hydrologic, hydraulic and geomorphic investigations are included in Appendix K of Volume 2 as well as in Section 12 of Volume 1 of URS (2005).

The basis of this assessment is all of the following:

- URS' Environmental Impact Statement for the proposal (URS, 2005).
- Field inspections of the McArthur River catchment in 2002.
- Over 10 years lecturing on river restoration and river engineering.
- Previous and current research on channel diversions around open cut mines (for example, Hardie *et al.*, 1994).
- Continuing research on tropical river geomorphology, including rivers draining to the Gulf of Carpentaria (for example, Erskine *et al.*, 2005).
- Continuing research on river rehabilitation (for example, Erskine, 2001; Erskine and Webb, 2003).
- Continuing research on the role of riparian vegetation and large wood in influencing channel morphology (for example, Webb and Erskine, 2003a; 2003b).
- Use of HEC-RAS for the prediction of fish passage (Erskine, 2005a).
- River classification and reach analysis (for example, Erskine, 2005b; Erskine *et al.*, 2001).
- Experience as a member of many expert panels relating to rivers.

EVALUATION OF ADEQUACY OF SUPPLIED INFORMATION

Hydrology

Flood frequency analysis of the annual maximum series at gauging station 9070132 on the McArthur River was used to derive flood peak discharges for a range of average recurrence intervals. These discharges were then scaled to downstream relevant locations in the mine lease by use of the equations outlined in Appendix K. A constant exponent of 0.6 was used in all equations. If the scaling equations adopt reliable constants and exponents, then this approach is appropriate.

There appears to be an error in Figure 12.3. The median flow should have a flow duration of 50% and hence is greater than the 80% and 90% flow, which it currently is not. The figure needs revising so that it is correct.

No hydrological information is presented for Barney and Surprise creeks in the EIS (URS, 2005). The realigned channel cannot be designed without such information.

Hydraulics

The HEC-RAS one-dimensional, standard step, backwater model for steady, gradually varied flow (US Army Corps of Engineers Hydrologic Engineering Centre 1998a; 1998b; 1998c) was used to characterise hydrodynamic conditions on the McArthur River in the vicinity of the proposed open cut mine for a range of flows up to the 1:500 year flood. The standard step method is an iterative procedure where successive attempts are made at determining an energy-balanced water surface elevation at a section of unknown flow depth given the cross-sectional geometry and knowledge of the flow conditions at an adjacent cross section (US Army Corps of Engineers Hydrologic Engineering Centre 1998c). The final estimated water surface elevation at the unknown section must have an associated energy that equals the total energy of the cross section of known flow conditions, less any calculated head losses between them. The newly predicted water surface elevation is then taken as known for the next incremental step along the reach. In this manner a water surface profile can be calculated for an indefinite length of channel, provided stage and discharge conditions are given at an initial cross section and the assumptions of gradually varied flow are satisfied (O'Connor and Webb 1988). HEC-RAS is reliable when used with appropriate assumptions and has been widely applied in many flood studies.

The use of photogrammetrically-derived cross sections introduces an error in the computed water surface levels for all discharges because the ground levels are usually accurate to only ± 0.1 m or worse. No error term for the heights for such cross sections is mentioned in Appendix K or how this translates into uncertainty in the calculated water surface levels. The number and location of cross sections seems appropriate. The length of the McArthur River covered by the hydraulic model is also appropriate. However, no analyses were conducted for Barney and Surprise creeks.

The adopted roughness coefficients from the model calibration are high. Supporting photographs to justify such high values would be helpful, given the relatively poor model calibration. For such straight channels, there must be a lot of tall trees that do not completely drown out during floods. Is this the case? The equation and r^2 for the relationship shown in Figure K.4 should be added.

The adopted grain size data for McArthur River sediment (TPA09 in Figure K.5) contains about 65% finer than about 0.075 mm. I find this hard to believe. It would seem that soil data was unquestioningly applied to the channel bed material. Bed sediment should have been appropriately sampled and analysed. If not, the sediment transport capacity calculations are meaningless and should be deleted.

There is a significant drawdown immediately upstream of the proposed diversion channel on the McArthur River for a 1:2 and 1:5 yr ARI flood. Is this section of channel cut into bedrock? If not, it should be actively eroding. If it is not eroding, then the hydraulic model is wrong because no alluvial or bedrock channel can withstand a specific stream power of

greater than 200 W/m^2 or a shear stress greater than 160 N/m^2. I am very concerned about the magnitude of the specific stream power/shear stress on the McArthur River. In my experience, when specific stream power exceeds 35 W/m^2 sand-bed channels usually erode (Erskine, 1999). On the McArthur River, specific stream power often exceeds 80 W/m^2 and hence the channel should be a very active sand-bed stream with many pockets of rapid bank erosion. If not, I find it hard to believe the veracity of the hydraulic model outputs. Furthermore, there are profound implications for the diversion channel. I have no doubt that, if the diversion channel is subjected to specific stream powers of 80 W/m^2 within the first 5 years after construction, then it will be completely destroyed by extensive bed and bank erosion.

Figure 1 shows the results of Brookes' (1990) research on European rivers. At low bankfull specific stream power, channels experience deposition. Stable channels are usually subjected to moderate bankfull specific stream power and neither deposit nor erode sediment. Erskine *et al.* (2005) found that the meandering forested (*Allosyncarpia ternata*) sand-bed streams at Jabiluka, NT, conformed to this pattern. When bankfull specific stream power exceeds 35 W/m^2 channels often erode. As stream power progressively increases above 35 W/m^2 the probability of erosion increases. Erskine (1999) documents the case of the Cann River in East Gippsland, Victoria, eroding when a number of interacting causes increased bankfull specific power above this threshold (Figure 2).

The units for stream power in Figure 12.6 have been changed to N/m.s which is inconsistent with the units (W/m^2) in Appendix K.

Appendix K contains no data on the Barney Creek diversion channel. As it is 2.5 km long, it requires similar treatment to the McArthur River.

Geomorphology

The data for one cross section at the gauging station must be supplemented by additional data to justify calling the existing channel near the mine as stable (see Appendix K, p. K-24). At the very least a specific gauge plot should have been constructed for the gauging station and air photograph interpretation of all available photographs should have been conducted. The air photographs should cover at least the whole length of channel for which hydraulic modelling was completed. The representativeness of a single piece of site specific data is always a concern. By itself, it is not helpful.

Section 12.6 is poor and needs to present more meaningful, correct, geomorphological information. Furthermore, Surprise and Barney creeks must be included in such work. River reaches are homogeneous lengths of stream within which hydrological, geological, and adjacent catchment surface conditions are sufficiently constant so that a uniform river morphology or a consistent pattern of alternating river morphologies is produced (Erskine, 2005b). Channel reaches consist of relatively homogeneous associations of landforms and habitat types, which distinguish them from adjoining reaches and are typically 10 km to greater than 100 km in length (Erskine, 2005b). Channel reaches are the appropriate spatial scale to define specific reach or river types, such as those defined by Rosgen (1994; 1996), Brierley and Fryirs (2000) and Erskine *et al.* (2005). This was not done in the EIS and should be (see Section 12.6). The five reaches listed in the EIS do not seem to conform to reaches as defined above and no river type for each has been identified but

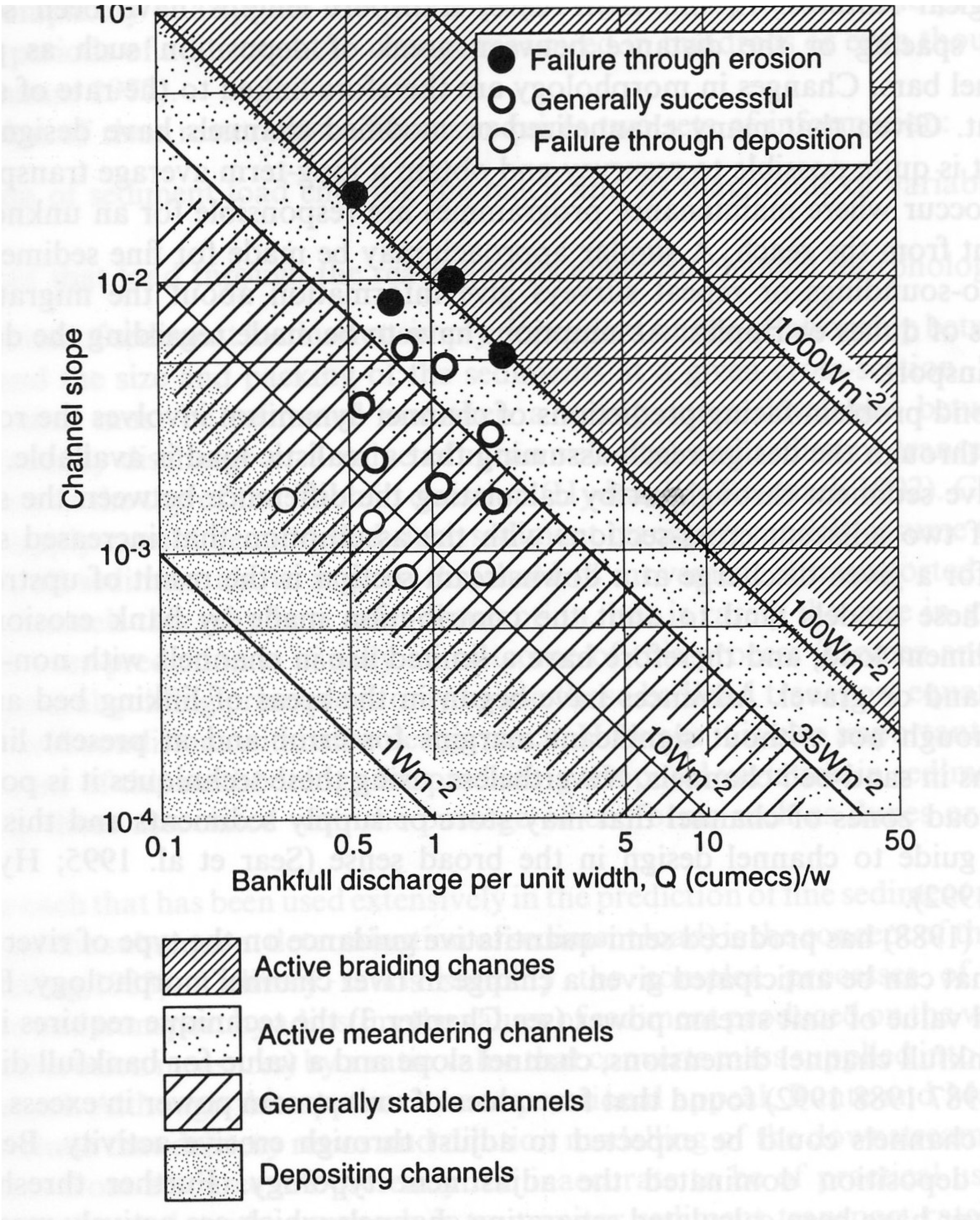

Figure 1. Bivariate plot of bankfull discharge per unit channel width versus channel slope showing that deposition occurs at low powers (<7 W/m^2), channels are stable at moderate powers (5-35 W/m^2) and that channels erode at high powers (>25-100 W/m^2). From: Brookes (1990).

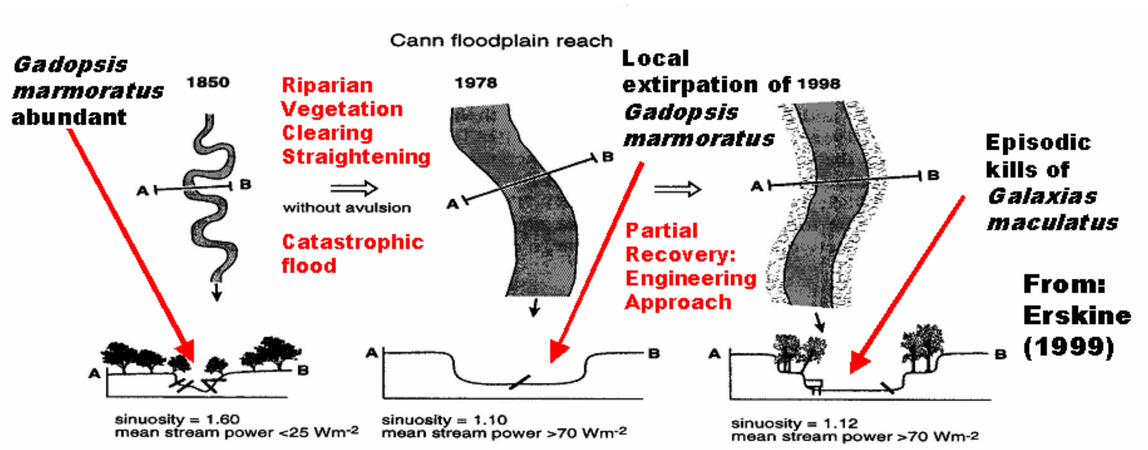

Figure 2. Metamorphosis of the Cann River, Victoria due to the increase in bankfull specific stream power from <25 W/m^2 to >70 W/m^2 caused by channel straightening, desnagging and reduced form roughness. From: Erskine (1999).

must be. It is wrong to call a river meandering when its sinuosity ranges up to 1.14 (page 12-9). These are low sinuosity or straight channels (Erskine *et al.*, 2005).

Hawkins *et al.* (1993) defined channel units (or aquatic habitats) as quasi-discrete areas of relatively homogeneous depth and flow that are bounded by sharp physical gradients. Each channel unit exhibits different physical characteristics and can also be associated with habitat-specific fish species assemblages (Petersen and Rabeni, 2001a; 2001b). It is essential to know what aquatic habitats or channel units are present on the channels that will be diverted so that they can be incorporated into the design for the diversion channels. The proposed constant slope for the constructed bed profile of the diversion channels is totally inappropriate, as discussed in the next section.

Anabranching rivers consist of multiple channels separated by vegetated islands that divide streamflows up to nearly bankfull stage (Nanson and Knighton, 1996). The islands have relatively stable banks and separate individual channels (Nanson and Knighton, 1996). Six types of anabranching rivers have been defined by Nanson and Knighton (1996) on the basis of specific stream power, boundary sediment size and channel morphology. These channels are erroneously called braided in the EIS, a mistake that is made repeatedly for Australia's tropical rivers.

River terraces are abandoned floodplains (Leopold *et al.*, 1964). Floodplain abandonment occurs by channel incision and hence stranding high above the contemporary floodplain or by deposition and burial. The so-called 'river terraces' in the EIS are 'in-channel benches' and are discussed in detail by Erskine and Livingstone (1999), among others. All reference to terraces in the EIS should be replaced by benches.

RECOMMENDED IMPROVEMENTS IN DIVERSION CHANNEL DESIGN

While I support the concept of designing realigned channels so that they mimick the general geometry of the existing channel, this approach has not been adopted, despite comments to the contrary in the EIS.

Newbury and Gaboury (1993) popularised the approach to river rehabilitation that mimicks natural materials and geometry of streams. The premise is that if natural

hydrology and morphology are recreated with careful consideration of hydraulics, then it is highly likely that natural ecological recovery will occur. Abiotic factors such as channel morphology and water quality are considered key targets of restoration rather biotic factors because they are easier to measure and evaluate. Regional channel geometry relationships can serve as templates for river rehabilitation. The source of the channel dimensions for the diversion channels are not outlined in the EIS and must be. Aquatic habitats, such as pools and riffles, must be included in the design. They involve morphological complexity in the bed profile that creates diverse hydraulic conditions. A constant slope bed profile is totally inappropriate. Natural pool-riffle spacing is about 4-8 channel widths. It is also important to recreate the natural planform, which, in this case, is straight or low sinuosity. Therefore, the suite of issues involved in designing a meandering channel does not apply to the McArthur River. However, it remains to be determined whether channel planform is relevant to the Barney and Surprise creeks diversion.

There are no data on large wood loadings, spacing, orientation and accumulations in the EIS. Large wood must be incorporated into the design of the two diversion channels, based on the characteristics of large wood in the current channels, if the design is to mimick natural channels (Erskine and Webb, 2003). Furthermore, appropriate sources of large wood must be identified which do not remove existing trees from river channels. Large wood often induces scour that forms a range of pool types that are important aquatic habitat (Webb and Erskine, 2005).

While I strongly support the revegetation proposal, there are no details of the program contained in the EIS. It is essential that species, planting densities, vertical zonation of species, seed sources, maintenance of genetic integrity, etc are adequately covered in the EIS. A greenhouse and nursery will be essential, as will the employment of a plant ecologist to collect local seed stocks to be germinated. After germination, plants will need to be grown to a size that can be planted. Tube stock sourced from another area is not as successful as local sources and effectively dilutes local genetics (Webb *et al.*, 1999). It is difficult to ensure that appropriate riparian revegetation is achieved when no details are provided.

'A Rehabilitation Manual for Australian Streams' (Rutherfurd *et al.*, 2000a; 2000b) has been adopted as the standard code of practice for the design and construction of river diversions in other Australian states (for example, NSW). It is important that consistent requirements for river diversions are adopted throughout Australia and this manual should be followed for the McArthur River Mine Open Cut Project. Natural Channel Design is outlined in Part 2 of Volume 2 (Rutherfurd *et al.*, 2000b) and should be followed.

The erodibility of the material to be exposed/filled on the banks of both diversion channels must be discussed. Similar soil units elsewhere on the mine site exhibit dispersion. Gypsum or lime should be used to stabilise the sediment so that flutes, tunnels/pipes, rills and gullies do not develop before vegetation is established. Major bank erosion in similar material has occurred on other river diversions (for example, Isaac River in central Queensland).

Details of the proposed channel monitoring program should also be outlined in the EIS.

The biodiversity offsets discussed in the EIS do not consider offsets for the realigned diversion channels but should. Rehabilitation of at least an equivalent length of channel to that destroyed by the two diversions (8 km) should be requested. In NSW, some Councils (for example, Lake Macquarie Council) recommend that the offset should be seven times greater (56 km) than that destroyed. There needs to be an economic incentive for mining companies to reduce the length of channel diversions to the shortest possible. The proposed McArthur River diversion could be shorter and still permit open cut mining.

PREDICTED IMPACTS OF THE DIVERSION CHANNELS ON UP- AND DOWNSTREAM CHANNEL MORPHOLOGY

The lack of information on the Barney and Surprise creeks diversion in the EIS precludes any meaningful assessment at this stage. Additional work is still required.

Upstream

The HEC-RAS results in Appendix K show that there is a substantial, localised increase in flow velocity, shear stress and specific stream power during the 1:2 year and 1:5 year ARI events upstream of the diversion channel on the McArthur River. This zone is located further downstream in the diversion channel during the 1:50 year ARI event. The HEC-RAS results should be checked to make sure that they are correct because the shear stress and specific stream power are extraordinarily large. The EIS does not discuss this zone and whether bedrock is exposed in the channel boundary. Given the high predicted shear stress and specific stream power, bedrock erosion would be expected, even if bedrock is exposed. If the material in the channel boundary at this zone is alluvium, upstream progressing degradation will occur. Such erosion will propagate upstream over time, generating large amounts of sediment (depends on depth of degradation) and draining upstream waterholes. Degradation of 10 m can be expected if the channel-fill sediment is that thick. Armouring is a natural self-stabilising tendency of rivers which selectively erodes the finer sediment in the bed material and concentrates the coarser sediment on the bed surface. Gravel armour layers produced by bed degradation are monolayers that coat and hence protect the finer underlying sediment from erosion (Figure 3). The channel boundary sediment sampling for the EIS was insufficient to

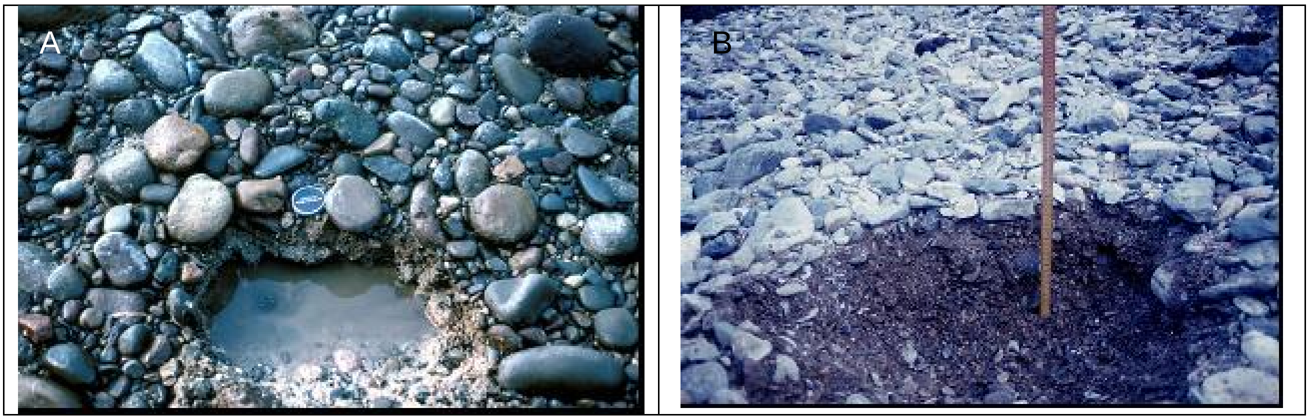

Figure 3. Gravel armour monolayers overlying sandy gravel produced by bed degradation on (A) Snowy River in Victoria and (B) Hunter River below Glenbawn Dam, NSW (Erskine, 1985; Erskine *et al.*, 1985).

enable an assessment of whether armouring will occur or not. However, given the extremely high shear stress and specific stream power, armouring is unlikely to occur at the zone of highest shear stress because all gravel would be transported during floods. The diversion channel should be redesigned so that the drawdown to the diversion channel does not occur.

Downstream
Deposition downstream of the diversion channel on the McArthur River will occur because there is an extended zone of low flow velocity, shear stress and specific stream power. Such deposition will be chronic if upstream sediment supply is high. It is predicted that sediment supply will be high because of the high probability of upstream bed degradation (see above) and erosion of the banks of the diversion channel (see below). Such deposition is predicted to bury aquatic habitats (pools, runs, riffles) and form in-channel benches at locally wider cross sections. Riparian plants will be buried and those species and specimens that cannot tolerate such deposition will die.

It is predicted that a sand slug or long section of sand aggradation will form downstream of the diversion channel. Sand slugs exhibit poor quality aquatic habitats and restrict fish passage due to lack of resting areas and large areas of open water. It is essential that such a sand slug should not form because they are difficult and expensive to rehabilitate. Therefore, the flow velocities, shear stresses and specific stream powers in the diversion channel should be reduced so that they are consistent with the downstream channel.

Diversion Channel
The banks of the diversion channel will exhibit accelerated erosion immediately after construction and for a substantial time thereafter because:

- At least some of the bank materials are dispersible and no treatments are proposed.
- The proposed bank batters are very steep. While tree root mats, tree roots and bank-attached trees are all important for forming a boundary layer of low flow velocity along the bank and for reinforcing bank sediments, as noted in the EIS, these trees will not exist for over a decade. Mass failure of the non-tree reinforced banks is highly probable on the proposed steep bank angles.
- Fill is proposed to be placed among any rockfill which will be leached straight into the channel. Rockfill must be minimised so that appropriate media for plant establishment exist along the diversion channel.
- The time needed for plant establishment will be relatively long in this strongly seasonal climate. As a result, rainwash (combined raindrop splash and overland flow) will erode the banks as will channel flows.
- No plans to provide a temporary surface mulch over the river banks have been proposed. Furthermore, shear stresses in the diversion channel are so high that they will remove any organic mulches, except in local backwater areas.

The sediment generated by bank erosion of the diversion channel will be substantial and will also be deposited further downstream.

CONCLUSIONS

The shortcomings in the information contained in the EIS for the McArthur River Mine Open Cut Project EIS (URS, 2005) include:

- No hydrological information is presented for Barney and Surprise creeks.
- No errors are cited for the ground elevations for the photogrammetrically determined cross sections nor how these are translated into uncertainty in the calculated water surface levels in HEC-RAS.
- The adopted roughness coefficients are high but the HEC-RAS model calibration resulted in a poor fit to a known flood profile. This is not surprising given that no discharge information had been collected at the Mine Site gauge. The roughness coefficients may be incorrect.
- The adopted grain size for McArthur River sediment is very fine and seems inappropriate.
- There is a marked drawdown in the water surface profile immediately upstream of the diversion channel during the 1:2 and 1:5 year ARI events which produces very high shear stresses and specific stream powers that will cause erosion. This drawdown requires further investigation.
- Additional geomorphological work is required to determine whether the McArthur River and Barney and Surprise creeks are currently stable. No work has been undertaken to date on Barney and Surprise creeks.
- Meaningful river reach analysis needs to completed for the McArthur River and started for Barney and Surprise creeks to assist in the design of the two diversion channels. In particular, the types of channel units or aquatic habitats present must be documented.

Recommended improvements in the design of the diversion channels include:

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- Meaningful discussion of sediment erodibility for the material used to form the banks of the diversion channel and what measures will be taken to decrease erodibility.
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