9.0 Surface Water - Flood Protection Bund

9.1 Summary

This section provides the results of an analysis of the stability and integrity of the flood protection bund.

The bund has been designed as water storage dam in accordance with the Australian Committee on Large Dams (ANCOLD, 1999) requirements and has been based on extensive geotechnical site investigations and recent site experience with the Test Pit bund. The external and internal faces of the bund will be rock-filled with NAF rock to protect its internal clay core against erosion, and to provide geotechnical stability. The bund will be high enough to protect the mine pit from a 1 in 500-year ARI flood event.

The design has considered all relevant aspects that could affect the bund's stability including erosion, seepage, internal failure, and liquefaction. Stability analysis has shown that the bund will have a factor of safety that complies with best practice engineering design, and demonstrates that it will be stable in the short term and long term during flood events in both the McArthur River and Barney Creek.

The risk that the flood protection bund will be overtopped by a flood event larger than the 1 in 500-year ARI design event has been calculated as 0.2% during the first two years of operation and 1.2% during the subsequent 23 years of operation. Although this risk is extremely low and is acceptable to MRM, the likely impact of embankment overtopping has been considered.

The bund has been designed to include an emergency overflow section which, if overtopping occurs, would erode in a small area in a controlled manner and at a pre-determined rate. The eroded material would flow into the mine pit. In this way the vast majority of the bund would remain intact, and there would be minimal discharge of eroded material downstream in the McArthur River.

9.2 Flood Bund Integrity

9.2.1 Introduction

The flood protection bund will be constructed around the open cut to protect the working areas and associated infrastructure from inundation during flood events. The alignment of the flood protection bund has been selected to provide maximum opportunity for the future development of the McArthur River deposit as well as taking greatest advantage of the natural topography to minimise earthworks.

In addition, the alignment has been selected to provide adequate separation between the proposed diversion channels and the bund, and to maintain regulatory separation between the bund crest and the flight path for the McArthur River airstrip as defined by the Civil Aviation Safety Authority.

Although the flood protection bund will be required to prevent flooding of the open cut for only a short period of time each year, the standards adopted for its design are those which would normally be adopted for the design of a water retaining structure that would be required to permanently contain water. These standards are provided in guidelines published by ANCOLD (1999).

Engineering design of the flood protection bund has been undertaken on behalf of MRM by Brisbane based consultants Kellog Brown & Root Pty Ltd (KBR) and geotechnical consultants Golder Associates. KBR has undertaken the necessary design and have prepared drawings and technical specifications for construction. The Design Basis Report and Technical Specification for the McArthur River Mine Expansion civil works, including the flood protection bund, are included in Appendix B.

9.2.2 Design Basis

The design of the flood protection bund has been based on:

- Foundation investigations undertaken for the flood protection bund and diversions
- Experience with the construction of the Test Pit bund
- ANCOLD guidelines on the design and construction of water storage dams.

A comprehensive geotechnical investigation of the flood protection bund footprint, and the proposed construction materials to be sourced from the excavations for the McArthur River and Barney Creek diversions, was undertaken by independent specialist geotechnical consultants Golder Associates.

The investigations were undertaken in accordance with Australian Standard AS1726-1993 (Geotechnical Site Investigations) and consisted of the following:

- 31 drill holes at approximately 250 m centres along the bund centreline, supplemented by a number of groundwater monitoring bores and probe holes;
- Seismic refraction traverses (total 2,790 m length) along selected areas of the bund centreline
- 10 drill holes, 16 test pits and 4,330 m of seismic refraction traverses along the McArthur River realignment
- 6 drill holes, 10 test pits and 2,330 m of seismic refraction traverses along the Barney Creek realignment.

The investigations provided information on the strength and permeability of the foundations for the flood protection bund and the quantity and quality (strength and permeability) of materials for the bund construction. The results of this investigation are provided in Golder Associates (2004).

The Test Pit flood protection bund was constructed in August and September 2005 to provide flood immunity for the 6 ha test pit at McArthur River Mine. The bund was constructed with earth-fill sourced from overburden from the Test Pit.

The bund was built to a crest level of RL38 (6 m below the top of the proposed flood protection bund for the Open Cut Project) and with a maximum height of 15 m. The outer face (McArthur River side) of the bund was protected by a layer of rock sourced from the Test Pit.

The construction of the Test Pit bund confirmed the practicality of providing a key trench beneath the bund, together with moisture conditioning and compacting the natural clayey materials to the specified density.

During the 2005/2006 wet season, the McArthur River rose to within approximately 5 m of the crest of the Test Pit bund (Plate 9.1). No erosion was observed on the outer slopes of the bund, nor was there any under-seepage beneath the bund into the pit.

Only minor rill erosion of the unprotected inside earth-fill batter occurred as a result of runoff and incident rainfall (Plate 9.2) during the wet season. This type of erosion can be readily repaired as necessary. However, for the Open Cut Project bund, it is proposed that both the inner and outer walls would be protected by rock armour. This is discussed further in Section 9.2.4.

Plate 9.1

Outer Face of Test Pit During 2005/2006 Wet Season

Plate 9.2

Minor Rilling of Inner Face of Test Pit Bund at End of 2005/2006 Wet Season

9.2.3 Construction Program

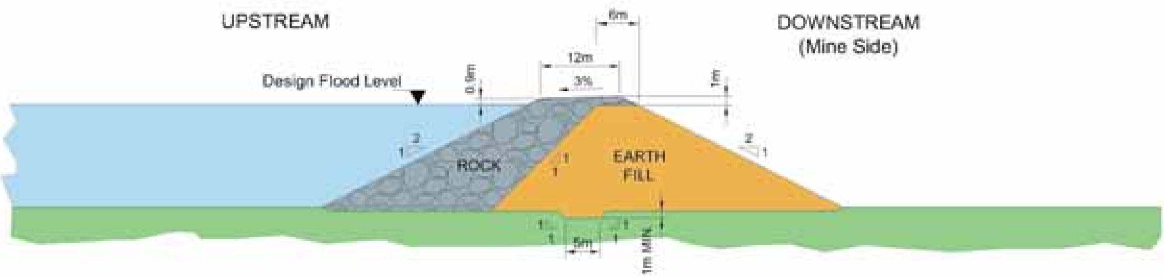
Subject to project approval, construction of the flood protection bund is proposed to commence in the second half of 2006 and continue through to 2009.

It is proposed to construct a zoned-fill water-retaining bund during the 2006 and 2007 dry seasons. The bund, designed to ANCOLD standards, would comprise an inner clay earth-fill zone to provide a low permeability barrier to seepage, and an outer rock-fill zone to provide protection against erosion and scouring of floodwaters and stability as the floodwater recedes. A typical cross section of the bund is shown in Figure 9.1 (Initial Construction).

Clay earth-fill and rock-fill used for this part of the bund construction would be sourced from the McArthur River and Barney Creek diversions. The materials zoning proposed for the bund maximises the use of the materials that will be extracted from the diversions of Barney Creek and the McArthur River. Sandy alluvium from the diversions that is not suitable for use in the flood protection bund will be placed as a weighting zone (for added stability) on the downstream side of the river sections of the bund.

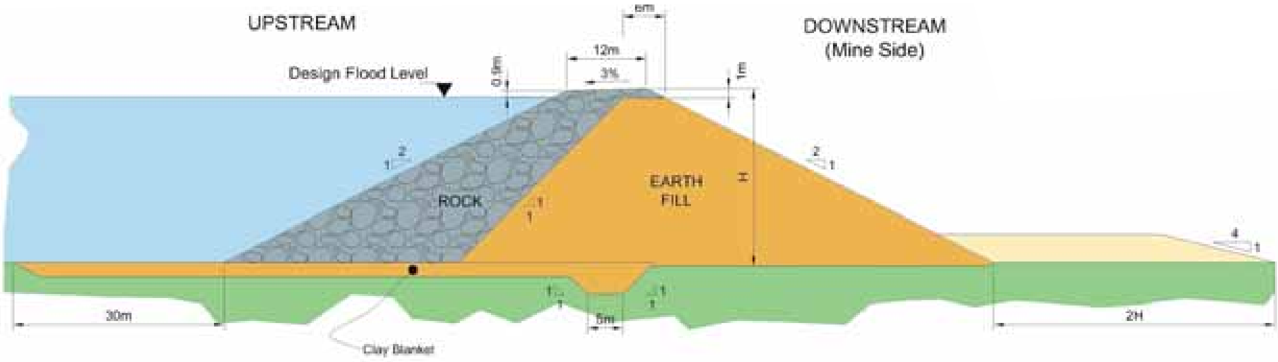
Construction of the flood protection bund has been staged to allow the following goals to be met:

- Continued mining of the Test Pit Southern Extension and operation of the processing plant
- Efficient use of materials from the diversion channels and the Test Pit Southern Extension



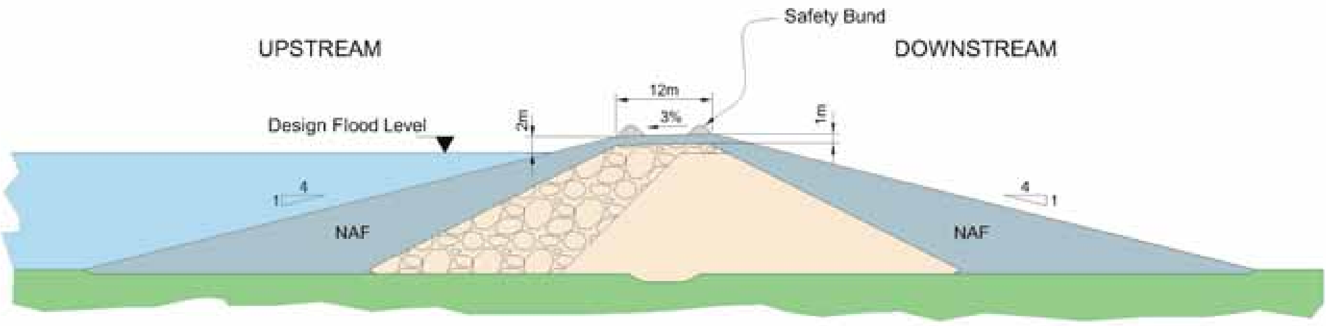
TYPICAL SECTION

Earth Fill
Rock Fill
Track Rolled Sandy Spoil



RIVER SECTION

INITIAL CONSTRUCTION



TYPICAL SECTION

Stage 1 Construction
Non Acid Forming (NAF) Mine Spoil

FINAL ARRANGEMENT

Source: Connell HATCH, May 2006

NOT TO SCALE

xstrata / URS	McARTHUR RIVER MINE OPEN CUT PROJECT PUBLIC ENVIRONMENTAL REPORT		FLOOD PROTECTION BUND
Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: 9.1 — Rev. A
Job No.: 42625552	File No. 42625552-g-178.cdr		A4

- Optimisation of haul distances and construction equipment usage
- Passage of normal flood flows without erosion of the partially completed bunds and diversions.

The extent of construction proposed during the 2006 and 2007 dry seasons is shown on Drawing BEE508-C-DWG-005 in Appendix B. During the 2006 dry season, it is proposed to construct the flood protection bund to its full height between chainages 0-1800, 3200-6000 and 6800-7450. During the 2007 dry season, the remainder of the bund will be constructed using earth-fill and rock-fill sourced from the remainder of the McArthur River diversion.

Commencing during the 2007 dry season and continuing through to 2009, NAF materials from the Test Pit Southern Extension and then from the open cut, will be placed against the inner and outer slopes of the initial flood protection bund to flatten the overall batter slopes from 50% (1V:2H) to 25% (1V:4H).

The flatter outer slopes of the bund will increase the long-term stability of the embankment, and will allow immediate and progressive rehabilitation by topsoil and seeding. In addition to flattening the batters, the NAF will also be used to raise the crest of the flood protection bund by 1 m thereby providing greater protection against flooding. The final arrangement of the flood protection bund is shown on Figure 9.1.

During 2006, the flood protection bund between chainage 0-1800 may be constructed to the final arrangement (1V:4H batters) to maximise material won from the Barney Creek diversion. If this is the case, the bund will be constructed with compacted earth-fill and a protective layer of rock armour will be placed over the outer wall of the bund.

9.2.4 Design Considerations

To ensure both the long-term and short-term integrity of the flood protection bund, the following aspects of the bund design were considered:

- Crest level
- Stability
- Liquefaction of sand layers in the bund foundations (from seismic or blasting activity)
- Seepage beneath the bund
- Internal erosion
- Erosion of the outer batters
- Erosion of the inner batters
- Inspection and monitoring during operation.

A detailed discussion of each of these issues is provided in Golder Associates (2006) which is included in Appendix B. A summary of the above design issues is provided in the following sections.

Crest Level

The magnitude and frequency of flooding in the McArthur River was determined using flood frequency procedures detailed in IE Aust (1987) and based on actual flood data for the McArthur River for the period 1969 to 2003. Inflow from tributary catchments was scaled from the McArthur River data based on catchment area.

Hydraulic modelling using 'state of the art' two-dimensional (2D) hydraulic modelling software, developed by WL/Delft Hydraulics of the Netherlands, was undertaken by KBR to determine the water levels for floods in the McArthur River with various return intervals. MRM adopted a flood with a return interval of 1 in 500-year as the design event for the flood protection bund, as this was considered to provide an acceptable level of risk for the project.

The crest level of the bund has been set at 0.9 m above the 1 in 500-year ARI flood event for the initial construction, and 2 m above the design flood event for the final arrangement. Assuming flood level and wind speed are independent of each other, the probability that the flood protection bund will be overtopped is 0.2% in the first 2 years of the project and 1.2% over the 25 year life of the project.

Hydraulic modelling using the one-dimensional (1D) hydraulic modelling software HEC-RAS, as described in Section 5 of this PER, was also undertaken to estimate water levels for flood flows in the Barney Creek diversion channel, assuming no concurrent flooding in the McArthur River. The HEC-RAS results, as presented in Appendix F.2, show that a flood in Barney Creek with a return interval of 1 in 500 years would not overtop the flood protection bund.

Stability

The stability of the flood protection bund was determined for critical loading conditions using the slope stability software program Slope/W. Unlike water storage dams, where water is permanently stored against the face of the dam, the face of the flood protection bund will be intermittently subject to inundation during each year as flood waters rise and fall. Seepage forces resulting from this periodic inundation were determined using the seepage analysis program Seep/W.

The factors of safety (FoS) determined from the analyses, together with the minimum FoS recommended in ANCOLD guidelines and current best practice, are presented in Table 9.1.

Table 9.1

Summary of Stability Analyses

Loading Condition	Calculated FoS	Minimum Required FoS
End of Construction – Initial Construction	1.73	1.30[1]
Inner (downstream) face of Initial Construction and design flood event (500-year ARI).	1.39	1.30
Inner (downstream) face of Final Arrangement and design flood event (500-year ARI).	2.04	1.50[1]
Outer (upstream) face of Initial Construction under receding 500-year ARI design flood event (Rapid Drawdown Condition)	1.91	1.25[1]
Inner (downstream) face of Initial Construction, design flood event (500-year ARI) and earthquake loading.	1.70	1.10[2]

Notes:
1) ANCOLD (2003)
2) US Corps of Engineers

The analyses indicate that with respect to embankment stability, the proposed design meets the current 'best practice' for the stability of water storage reservoirs.

Liquefaction

Liquefaction is the process whereby saturated sandy soils can lose strength when subjected to vibrations resulting from earthquakes or blasting. Factors affecting the liquefaction potential of sandy materials include grain size, density, and magnitude and period of vibrations. If liquefaction occurs within embankment foundations, either excessive settlement or slope instability may result.

In the case of the flood protection bund, geotechnical analysis has shown that earthquake-induced vibrations will be too small to induce liquefaction of foundation sands, and that blast-induced vibrations be of such short period and duration that the risk is considered negligible.

Seepage

It is proposed that seepage beneath the bund will be minimised by the construction of a key trench under the full length of the embankment. The key trench will be excavated to a minimum depth of 1 m, with a base width of 5 m, and will be backfilled with compacted low permeability clayey earth-fill, which will connect with the low permeability sections of the flood protection bund.

Where permeable sandy soils are intersected in the base of the trench, the trench will be deepened until clayey materials are intersected. Although the key trench may not be needed in some areas (where clay occurs at the surface), it will provide additional seepage protection and will allow the identification of sandy layers at depth.

A key trench similar to that proposed for the flood protection bund was also constructed for the Test Pit bund. During the 2005/2006 wet season, no seepage into the Test Pit was observed from flood events.

Internal Erosion

Internal erosion (referred to as piping) of earth-fill in the flood protection bund could occur if soils used for the construction of the bund are dispersive, or if there is a defect in the construction that would allow a concentrated leak to form.

Although the potential for piping of the earth-fill will be minimised by the use of clay materials with a low potential for dispersion (Emerson Class > 2), and because compaction of the earth-fill at a high moisture content and high density will mitigate against dispersion, the development of a concentrated leak through either a naturally occurring shrinkage crack or a defect in the embankment construction cannot be ignored. As a consequence an event tree analysis was used to assess the risk of piping.

Event tree analysis undertaken by Golder Associates (2006) estimated that the annual risk of piping through the bund is 1 in 2,200 for the initial construction arrangement, and 1 in 3,400 for the final arrangement as shown in Figure 9.1.

The use of a filter fabric on the downstream face of the initial construction arrangement (between the earth-fill and NAF) was evaluated, and was shown to significantly reduce the risk of piping (to the order of 1 in 100,000). However, this additional measure was considered unwarranted, as the risk of piping (without geotextile) is of the same order of magnitude as the risk of the embankment being overtopped.

Erosion of Outer Batters

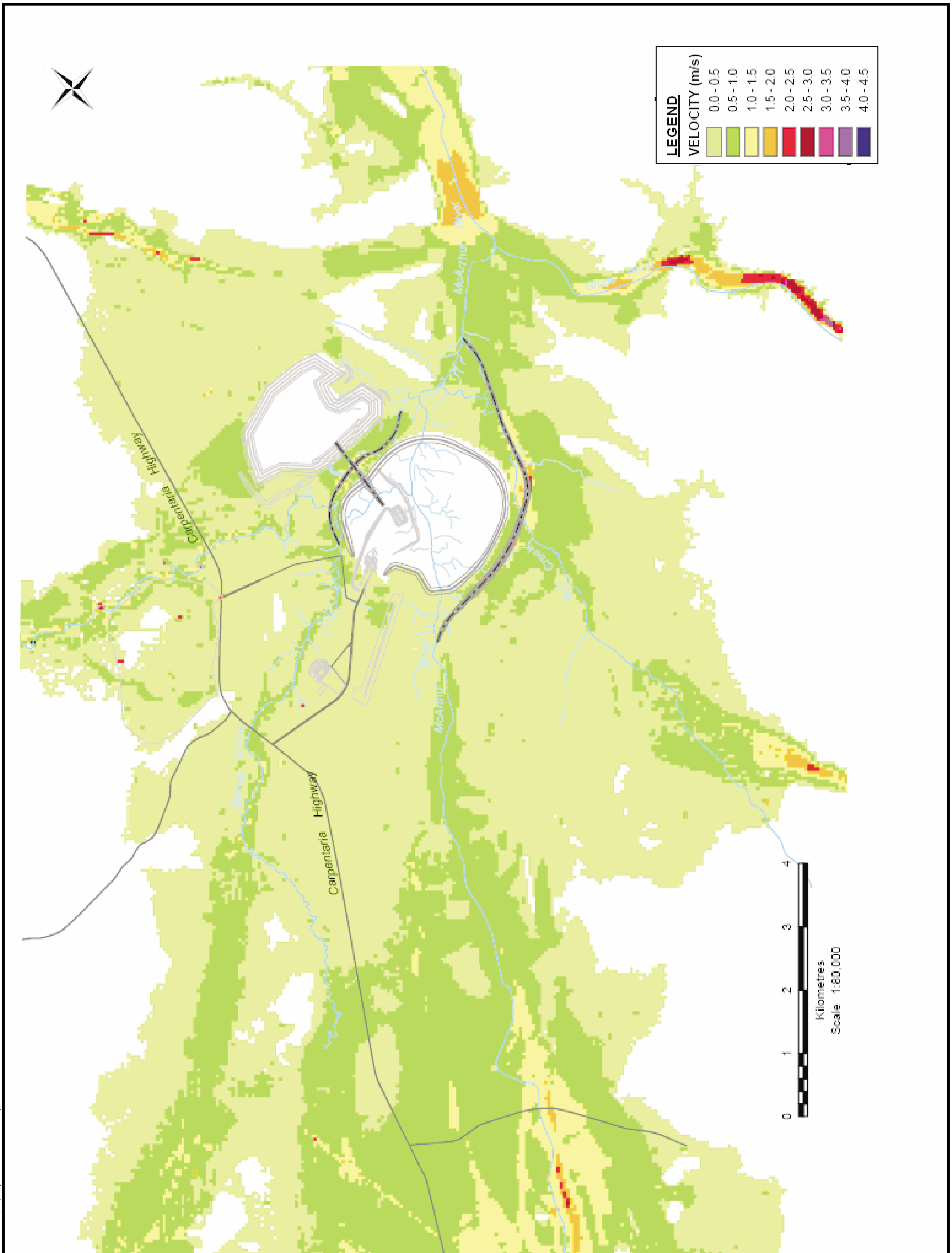
Two-dimensional hydraulic modelling of the design flood event undertaken by KBR (Figure 9.2), shows that the maximum flood velocity at the outer face of the flood protection bund during a 1 in 500–year ARI event will be of the order of 1.5 m/sec.

The risk of scouring of the outer face of the flood protection bund by floodwater would minimised by the use of rock-fill. The rock-fill used on the outer face (maximum particle size 400 mm) will be capable of withstanding a scour velocity of up to 2.6 m/sec (Austroads – Waterway Design Manual). In addition, the rock-fill will provide long-term protection against scouring resulting from incident rainfall during the wet season.

Erosion of Inner Batters

Earth-fill batters will be exposed on the inner slopes of the flood protection bund for a maximum of 2 years. The batters will then be covered with NAF rock generated as part of the mining operations (maximum particle size 400 mm). Topsoil will be spread over the rock-fill materials to promote rehabilitation.

Experience gained with the existing Test Pit bund indicates that minor rilling of the exposed earth-fill face may be expected during the first two years of operation, until the face is flattened and covered with NAF rock. Any rilling would be repaired as necessary. Subsequently, the rocky NAF material and established vegetation would provide long-term protection against any scouring resulting from incident rainfall during the wet season.



Source: Connell HATCH, May 2006

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McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

500 YEAR ARI FLOOD VELOCITIES

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: 9.2	Rev. A
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Monitoring and Surveillance

In the context of embankment dam engineering, monitoring refers to measurements taken by survey or instrumentation, while surveillance refers to observations made as part of a documented inspection program. Monitoring and surveillance guidelines for embankment dams are described in ANCOLD guidelines (2003). On the basis of these guidelines, the following monitoring and surveillance program is proposed for the flood protection bund.

The foundation and embankment pore water pressure will be monitored to check actual values against design expectations. Three embankment sections comprising a total of 25 piezometers tips will be data-logged at six-hourly intervals. Telemetric transmission of upper-catchment rainfall and flood water levels (for advanced warning) and flood levels adjacent to the flood protection bund will also be implemented to allow immediate action to be undertaken when predetermined trigger levels are exceeded.

The proposed surveillance plan will include the following:

- An annual professional dam engineering inspection and review of monitoring data prior to the onset of each wet season
- Documented weekly inspection of the full length of the crest and downstream (mine side) toe by experienced mine engineering personnel through the wet season
- Documented daily inspection of the full length of the crest and downstream (mine side) toe by experienced mine engineering personnel during actual flood events that exceed a pre-determined trigger level.

9.3 Overtopping Risk

The risk that the flood protection bund will be overtopped by a flood event larger than the 1 in 500–year ARI design event has been calculated as 0.2% during the first two years of operation, and 1.2% during the subsequent 23 years of operation. Although this risk is extremely low, the likely impact of embankment overtopping is catered for in the design.

A key feature of any embankment overtopping is to ensure that the overtopping occurs at a pre-determined location, where the impacts can be managed and not randomly along the whole length of the embankment. To facilitate any overtopping of the flood protection bund, it is proposed that an emergency overflow section 0.5 m lower than the adjacent bund crest is constructed. The proposed emergency overflow section would be constructed on the southern side of the flood protection bund between chainage 6750 and 7000 (Drawing BEE508-C-DWG-302 in Appendix B).

To minimise the potential for damage to the other areas of the flood protection bund, it is important that the water level on either side of the bund is balanced in as short a time as possible. In order to achieve this, a ‘fuse plug spillway’ approach will be adopted, whereby the embankment will be designed to breach and erode in a controlled manner to allow maximum discharge through the breach. This approach is commonly used in major water storage dams and has, for example, recently been constructed at Wivenhoe Dam, Queensland.

Analysis indicates that, at final pit depth, the water level on either side of the bund would balance in 6.5 hours if a 250 m wide, 6 m deep, breach was allowed to form. As the peak flow capacity of such a breach is in the order of 6,000 m^3/sec, and the 500-year ARI catchment discharge is in the order of 19,000 m^3/sec, the breach would have a significant effect on reducing the flood level prior to the water levels balancing.

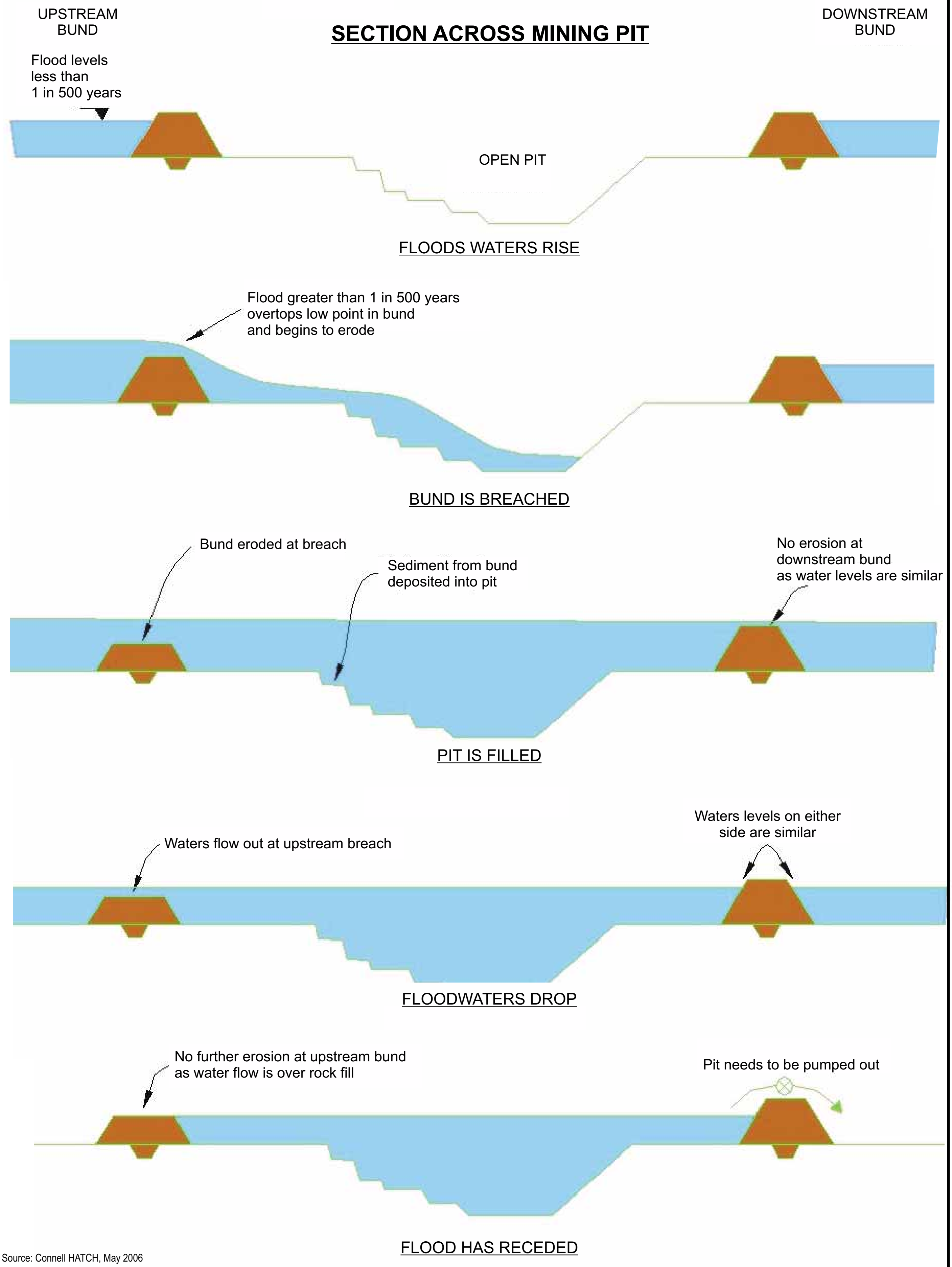
To ensure that the emergency overflow section erodes in a controlled manner and at the pre-determined rate, special design features will be incorporated into the upper 6 m of the embankment in this section. Such features may include a narrower crest, a thin upstream sloping clay core, sand fill shoulders, and minimal use of rock-fill and rock protection, while a conventional section incorporating a thick clay core and standard rock-fill will be used below 6 m depth to minimise erosion to ground level.

The likely sequence of events in the case of the bund being overtopped by floodwaters is shown in Figure 9.3.

In the highly unlikely event that the flood protection bund is overtopped, the design strategy anticipates that materials from the breached embankment will be swept into the open cut, as this will be the lowest point in the interior of the bund. The open cut will then become filled with floodwater. As the floodwaters recede, the outflow through the breach will be at a much slower rate than the inflow, and the resistant base and sides to the breach will minimise further erosion. Water levels in the open cut will drop until the top of the eroded breach is reached.

Should erosion of breach materials occur during the outflow, it is anticipated that they will be deposited near the outside of the breach, as the breach is located in a relatively quiet backwater of the bund, away from the main flow paths. It is not anticipated that this relatively small volume of material would cause any more contamination of the aquatic environment of the McArthur River than would normally be expected in a flood event with a recurrence interval in excess of 500 years.

It is proposed that an early warning system would be implemented to ensure that the open cut can be evacuated, and all personnel and equipment moved to high ground, before the flood protection bund is breached. The early warning system will incorporate telemetric transmission of upper catchment rainfall and flood water levels (for advanced warning), together with a flood level trigger and a rate of rise trigger levels. These trigger levels would be incorporated into the operation and monitoring plan of the flood protection bund.



Source: Connell HATCH, May 2006

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Drawn: VH · Approved: CMP · Date: 27-06-2006	Job No.: **42625552** · File No. 42625552-g-179.cdr	Figure: **9.3** · Rev. A · A4