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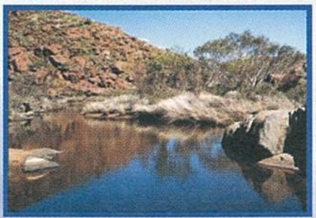
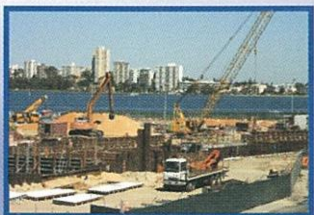
SPINIFEX RIDGE

SURFACE WATER MANAGEMENT





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SECTION 1 - INTRODUCTION

1.1 BACKGROUND

Moly Mines propose to develop a molybdenum resource in the Spinifex Ridge area, located 50km north east of Marble Bar.

The proposed mine development will be centred around Spinifex Ridge with the open pit and waste dumps south of the ridge and the Tailings Storage Facility (TSF) and plant to the north. A tunnel is to be constructed through the ridge to enable vehicle access between each side of the ridge. The open pit footprint intersects the main creek just upstream of Coppin Gap (known as Coppin Creek), and hence diversion of this creek is required to permit mining. All other mine infrastructure is to be located outside of the main creek flow paths.

A preliminary hydrological assessment and conceptual designs for Coppin Creek Diversion Channel have been completed during a pre-feasibility study (refer Report 058b *Spinifex Ridge Project Surface Water Assessment*, Aquaterra, October 2006). The route for the diversion channel was selected to best fit into the natural topography. This diversion channel route and design from the pre-feasibility study will be reviewed as part of this study.

The diversion channel isolates the proposed pit area from the Coppin Creek flows, however it does not account for surface water management issues that arise from the waste landforms constructed to accommodate waste rock from the mining process. Further engineering works (bunds, drainage channels and dam walls) are required to re-align hydrological pathways in the relevant catchments such that local run-off that comes into contact with the waste landforms are managed and kept isolated from the creek flow.

1.2 SURFACE WATER MANAGEMENT BEST PRACTICE STRATEGY

Approximately 120 Mbcm (million bank cubic metres) of waste will be generated from a 10 year pit. Waste landforms are engineered structures that need to be designed for long term stability. Key features of the design include concave slopes on the high walls of the landforms, and dumping in 10m high benches (*Waste Rock Characterisation and Landform Optimisation for the Spinifex Ridge Molybdenum Project*", Landform Solutions, April 2007). With regard to surface hydrology, issues of erosion, sedimentation, seepage contamination and containment of flows need to be accounted for in landform design.

The proposed mine development contains two PAF landforms (Landform 1 and 2). Thus surface water management includes the minimisation of seepage through PAF Landform 1 and Landform 2, and containing base seepage and surface run-off. To ensure that there is no uncontrolled release of run-off from these waste landforms to the environment, all run-off that comes into contact with these landforms should be directed into the cut-off section of Coppin Creek. This will be achieved by a system of engineered diversion bunds, impermeable dam walls and flow through rock drains.

These measures are not considered necessary for Landform 3, because it is built to contain only NAF material. For this landform the management philosophy is to control sediment loading before run-off and through-flow connects into Coppin Creek.

1.3 SCOPE OF WORK

Surface water management is required for the proposed development areas, in particular, the proposed 3 waste landforms. The scope of work includes:

- Based on the proposed waste landform outlines, calculation of waste landform internal catchments and the catchment areas cut off by the waste landforms
- Calculation of flood peaks and flood volumes at the waste landform perimeter.
- Calculation of available storage volumes at the proposed u/s edge of waste landforms.
- Assessment of the impact of retained flood events.
- Consideration of bunding and diversion works, and indicative sizing of erosion and sediment control works. Generation of longitudinal surface sections along the proposed u/s edge of waste landforms, as a guide to the feasibility of diversions.
- Rock drains along original creek lines to drain intercepted external catchments.
- Analysis of the proposed Coppin Creek cut-off storage.

1.4 DEFINITIONS

- *100 year ARI flood* - The flood having an average recurrence interval (ARI) of 100 years. It has a 1% chance of occurring or being exceeded in any one year, and at least a 50% chance of being experienced at least once in any average life span of a person. The 100 year ARI flood has been generally adopted in Australia and overseas as the basis for floodplain management planning.
- *Floodplain* - The portion of a river valley adjacent to the river channel which is covered with water when the river overflows its banks during floods. The term also applies to land adjacent to estuaries which is subject to inundation during floods.
- *Flood prone area* - The land which would be inundated as a result of the 100 year ARI flood.
- *Floodway* - The river channel and portion of the floodplain which forms the main flow path for floodwaters once the main channel has overflowed. If floodways are even partially blocked, upstream flood levels may be raised thereby affecting areas which may not have been affected previously.
- *Flood fringe* - The area of the floodplain, outside the floodway, which is affected by flooding but where development could be permitted providing appropriate measures are taken. These areas are generally covered by still or very slow moving waters during the 100 year ARI flood.
- *PAF (*Potentially Acid Forming Material) – Waste rock that has the potential to acidify water it comes into contact with, due to it's geochemistry.
- *NAF (*Non Acid Forming Material) – Waste rock that does not have the potential to acidify water it comes into contact with, due to it's geochemistry.

2.1 REGIONAL CLIMATE

WA has three broad climate divisions. The south-west corner has a Mediterranean climate, with long hot summers and wet winters. The northern part is dry tropical, receiving summer rainfall in a wet season lasting from December to March. Cyclones occur during this period, bringing heavy rain and potentially causing destruction to coastal towns. The remainder is mostly arid land or desert climates.

The Spinifex Ridge deposit is located in the north east Pilbara region of Western Australia, as shown on Figure 1. In general, the Pilbara's regional climate may be described as arid with wet summers, and waterways are typically ephemeral, generally flowing only a few times a year. Winter occurs between the months of June and August, and summer between the months of December and February. In the general Spinifex Ridge area, daily maximum winter temperatures average 27°C during the day and daily minimums average 13°C at night. Daily maximum summer temperatures average 41°C during the day and daily minimums average 26°C at night.

The average annual rainfall in the area is 360mm, and this falls mostly in the summer months due to cyclone activity and localised thunderstorms. The average annual evaporation is 3,285mm, with average monthly evaporation far exceeding the average monthly rainfall.

2.2 REGIONAL HYDROLOGY

Proposed development at the site comprises an open pit and waste landforms located on the south side of Spinifex Ridge, and a TSF and plant on the north side. Supporting infrastructure in the area includes nearby sealed roads, the Telfer gas pipeline within 50km to the north, railway facilities and deepwater port facilities to the west at Port Hedland and Dampier.

The De Grey River catchment is the main drainage system in the north east Pilbara area, as shown on Figure 1. It is one of the largest river systems in the Pilbara, with a total catchment area of around 50,000km^2, and extends as far eastwards as the Great Sandy Desert. The Oakover and Nullagine Rivers (large rivers themselves) combine about 50km north east of Spinifex Ridge to form the De Grey River. Further downstream, near the mouth of the De Grey River (located about 70km north east from Port Hedland), numerous major rivers join the river including; the Coongan, Shaw, East Strelley and West Strelley.

The Spinifex Ridge catchment drains northwards into Kookenyia Creek which discharges into the De Grey River.

Flood discharge, flow and water level data are not recorded on the waterways in the general Spinifex Ridge area, so accurate relationships between rainfall, runoff and flood level have not previously been derived. Therefore, regional techniques are typically relied upon to produce flow estimates in this area.

2.3 LOCAL HYDROLOGY

The general Spinifex Ridge Project area is set in a rugged landscape, with steep and in places, severe slopes above a generally subdued plain. In the study area, a ridge 100m to 150m high, known as Spinifex Ridge, is the dominant feature in the landscape, running east to west (Figure 2). Two breaks in Spinifex

Ridge, known as Coppin Gap and Kittys Gap, direct flow from the upstream catchments through these narrow gaps in the ridge. This “venturi” effect increases flow velocities through the gap such that a scour depression has formed. In large flood events, these gaps become the defining hydrological feature, causing upstream waterways to flood and spread because of the reduction in flow-through cross-sectional area.

Floodwaters combine downstream from these two gaps, then flow about 25km northwards before discharging via Kookenyia Creek into the De Grey River.

The drainage catchment is 2.9km^2 upstream of Kitty’s Gap and 79km^2 upstream of Coppin Gap. The waterways near the ridge typically meander between rocky outcrops near Spinifex Ridge, and elsewhere are less clearly defined. The vegetation is typically low scrub and trees scattered across the terrain with the dominant vegetation type being Spinifex.

2.4 PEAK DISCHARGE ESTIMATES

No streamflow gauging data exists on the waterways in the study area. The document *Australian Rainfall and Runoff* (ARR, revised 1998) is produced by the National Committee on Hydrology and Water Resources, and provides the best available information on design flood estimation. ARR recommends the use of the Rational Method and Index Flood Method, as most appropriate for the area.

The Rational Method calculates the 10 year ARI flood discharge, which can then be factored for larger or smaller flood events by “frequency factors”. The Index Flood Method calculates the 5 year ARI flood discharge which can similarly be factored. Within the Pilbara Region, the accuracy of any flood estimate is low, and the SEE (standard estimate of error) for the methods is high. In this case, the actual flow off a catchment may reasonably be considered to lie within the wide range of 70-150% of the calculated estimate.

The results from the Rational Method were the more conservative estimates (Aquaterra, 2006), and better reflected other unpublished peak discharge estimates in the Pilbara. Consequently, the Rational Method results were adopted. The calculated 100 year ARI peak discharge for Coppin Creek and the proposed diversion channel is 921m^3/s.

As part of the previous study, the Rational Method discharges were calculated for a number of different catchment sizes. To enable the results to be applied across a range of different catchment sizes, a curve was fitted to the calculated discharges and catchment areas. On this basis, the 100 year ARI peak discharge for typical rural catchments in the project area may generally be estimated as $4.3A^{0.63}$, where A is the catchment area in hectares. Around the mine site itself, flows from waste landforms may be greater due to steeper grades, or possibly less if stormwater is trapped on the landforms. It may be noted that in general that ARR methods are considered to over estimate flows, and the above estimates may be considered an upper bound for estimates.

2.5 PROBABLE MAXIMUM PRECIPITATION

The probable maximum precipitation (PMP) for minor catchments was also calculated. The PMP magnitude (together with its spatial and temporal distributions) may be used in turn to calculate the probable maximum flood (PMF). The PMF is one of a range of conceptual flood events used in the design of hydrological structures. The main use of the PMF is for spillway design of dams that will minimise the risk of overtopping of the dam crest. In this case, the PMF was required to assist in assessing the damming effects of water ponded behind waste landforms and water stored in the Coppin Cut-off.

The document *Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method (GSDM)*, Bureau of Meteorology was used. Probable Maximum Precipitation (PMP) is defined by the World Meteorological Organization (1986) as *'the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year'*. Notional ARI's for various PMP estimates as a means of indicating the security levels may be considered as 10 million years for areas of 100km^2 and below, rising to 1 million years for an area of 1000 km^2. PMP estimates are statistical values, and accuracy can vary depending on the level of confidence. The confidence interval for recommended ARI values may be plus or minus two orders of magnitude.

Table 1
Probable Maximum Precipitation at Spinifex Ridges

Duration (Hours)	PMP (mm)
0.25	244
0.5	353
0.75	446
1	518
1.5	668
2	781
2.5	862
3	946
4	1082
5	1192
6	1260

3.1 GENERAL PRINCIPLES

The general objectives with regards to erosion management of surface water are to:

- Maintain the integrity, functions and environmental values of watercourses and sheet flow; and
- Maintain or improve the quality of surface water to ensure that existing and potential uses, including ecosystem maintenance are protected.

3.2 GENERAL SURFACE WATER IMPACTS

The Pilbara landscape is subject to extreme climatic events such as high rainfall intensities and storms associated with cyclonic activity. The risk of erosion and sedimentation can therefore be high, particularly on disturbed or degraded lands. As such the engineering design of the project will incorporate site-specific surface water controls including diversion and dispersion mechanisms, and erosion and sedimentation controls. No areas of major erosion hazard have been identified, however specific management measures will be implemented if such areas are located.

Potential surface water impacts include:

- Interruption to the existing surface water flow patterns.
- Reduction of surface water runoff volume and quality in the downstream environment.
- Impact on downstream vegetation communities that may be dependent on this drainage.
- Discharge of various chemicals, including hydrocarbons from the construction camp and accommodation village, sewage treatment plant, mine workshop, Tailings Storage Facility (TSF), etc.
- Impacts from haul roads and other infrastructure.

The following general strategies will be noted and implemented to minimise surface water impacts from the Project:

- Where feasible, upstream surface water flows will be diverted around potentially sediment producing structures with appropriate grades into adjacent or downstream defined surface water flow pathways.
- Construction on or near natural flow paths will be planned for the dry season where practicable. Temporary stabilisation measures will be used if high erosion risk zones are identified.
- Where required, diverted surface water will be discharged over spreader mechanisms / riprap pads, etc to encourage the flows to slow and disperse.
- Surface water runoff from disturbed areas, waste landforms and stockpiles will typically contain sediment and require treatment in sediment basins, prior to discharging to the downstream environment. Disturbance will be kept to the minimum to achieve the design function and necessary for safe working conditions. Vehicle movements will be kept to the minimum necessary and existing tracks used where possible.
- Sediment or silt traps to control erosion and the deposition of sediment downstream, are generally more effective when they are located close to the source of sediment and “dirty” water is not allowed to mix with the “clean water”, so as to reduce the volume of water to be treated. The sedimentation basins will be sized appropriately for the rainfall events.

- Haul roads and other infrastructure will be located to be reduce interference to surface water flows. Culverts will be installed on tracks and roads at creek crossings.

3.3 SURFACE WATER IMPACTS – DURING CONSTRUCTION

The risk of erosion and sedimentation due to surface runoff is higher during the construction phase. There is potential for the water quality of watercourses downstream of the proposed infrastructure to deteriorate, if safeguard measures are not put in place. These sediments can reduce the capacity of water courses and impact water course ecology. The construction phase will be planned for the dry season where practicable, and temporary stabilisation measures will be used in high erosion risk zones.

Soil erosion and sedimentation control measures will be applied where practical during construction activities such as clearing, drainage works, and removal and storage of topsoil and earthworks. Disturbance will be kept to the minimum necessary to achieve the design function and necessary safe working conditions.

The techniques and criteria which would be applied during construction operations will include:

- Clearing: Vegetation is the most effective method of minimising erosion and sedimentation. Initial clearing will be limited to areas of workable size actively being used for construction.
- Buffer Zones: Buffer zones will be provided between the areas of disturbance and natural drainage lines. These buffer zones will place a high priority on the protection of natural drainage lines from impacts resulting from construction activities.
- Drainage and Flooding: Flows from undisturbed areas will be separated from disturbed areas.
- Erosion and Sediment Controls: Use temporary erosion and sediment control structures such as diversion banks, drains, and sediment basins.
- Topsoil Stockpiles: Topsoil will be stripped and stored away from drainage lines and located upstream of sediment basins. Revegetation will be encouraged. Diversion banks / catch drains will protect the stockpiles from external surface flows.

3.4 SURFACE WATER IMPACTS – DURING OPERATIONS

Surface runoff downstream of mine operations typically contains sediment. The runoff may contain other pollutants such as oil and grease from workshop and truck parking areas.

Waste landforms have the potential to discharge sediment water to the environment and erosion protection is an important aspect of the final rehabilitation of the waste landforms. The wall slopes of the landforms will be sculpted to form concave slopes with an increasing angle of inclination from the bottom up. Design specifications state that the first 10m will be inclined an angle of 8deg, increasing to 16deg up to 20m and 26deg for up to 30m above the base (Landform Solutions, April 2007).. This gives an overall angle of inclination of 13.3degrees.

Surface water from waste landforms and stockpiles will be directed to sedimentation basins prior to; discharge to the environment; the Coppin Creek cut-off; or for dust suppression and the water circuit. Surface runoff from haul roads will be kept local to minimise downstream impact, and larger access tracks / roads may require culverts for the creek crossings.

Away from the main creek channels, mine infrastructure may interrupt sheet flow runoff, concentrating it in diversion channels, or alongside flood bunds or raised pads and locally increase flow velocities.

4.1 LANDFORM 1

Landforms 1 and 2 are joined and form one landform, however, they are treated separately because they have separate surface water management issues.

Based on the Landform 1 outline shown in Figure 2, the landform will occupy approx 70ha and will contain encapsulated PAF rock, surrounded by NAF material. A ROM pad will be constructed at the eastern end of the landform, effectively being part of the landform.

The landform commands a surface water catchment of 220 ha. The landform is a valley fill with a portion of the catchment located upstream of the western edge of the landform (Figure 2). As such, there is potential for a lake to form upstream in large storm events, which requires drainage through or past the landform. Such situations may require construction of culverts, flow-through rock drains or diversions, depending on the size and characteristics of the upstream catchment.

The top of the valley / catchment divide between Kittys Creek and Coppin Creek (500m from the western end of the landform) lies at RL196m. The toe of the landform lies at RL184m, a difference of 12m. Note that topographic levels are to AHD (Australian Height Datum), and has been used hereafter (mine levels may be AHD + 1000m).

4.2 LANDFORM 2

Landform 2 will lie to the south of the ridge line dividing Landforms 1 and 2, and to the west of Coppin Creek. The landform will be about 1000m long and 900m wide (~90ha), and will also contain encapsulated PAF rock, surrounded by NAF material. The landform will be a side hill structure constructed on sloping terrain, with the north and west sides of the landform against higher ground, and the south and east faces formed on lower terrain closer to the Coppin Creek flood plain.

There are small catchments to the south of the ridge line which will pond up along the western face of Landform 2 (Figure 2), comprising a total area of less than 20ha.

4.3 LANDFORM 3

Landform 3 will lie to the east of Coppin Creek and abuts the proposed diversion channel that runs on the north-west side. The landform will be about 1100m wide and 1900m long, and occupy an area of ~170ha. The landform will contain only NAF material.

4.4 LANDFORMS - GENERAL

As part of good environmental strategy, PAF material needs to be isolated from the surrounding environment and measures taken to minimise and control water that comes into contact with it. It was estimated that a total of 37 Mdcm (million dump cubic metres) of PAF waste would require encapsulation. Encapsulation of (in Landform 1 and 2) will be achieved by placing NAF waste as a base below the PAF, and also placing it to either side (walls) and above (capping). The base material will cover drainage channels in the landform footprints to a depth of 15m, to provide a vertical barrier to wetting of encapsulated waste. To ensure that runoff water onto the landform surface (direct and from adjacent ridges) does not encounter material requiring encapsulation, a minimum lateral wall thickness of 10m was adopted. A capping of 10m of benign waste was used over the entire dump area. Approximately one third of the total landform volume is available for material requiring encapsulation (Landform Solutions, April 2007).

The top surface of the landform will need to be shaped to ensure that it can adequately handle runoff from rainfall falling directly onto the surface, and from surrounding topography. It is important that concentrations of surface water flow and localised ponding are minimised, through a network of bunding across the landform surface. Rehabilitation of horizontal surfaces of waste landforms will incorporate soils that can best support vegetated soil cover to minimise through-drainage. The underlying NAF waste rock would also be compacted to restrict the rate of infiltration into the landform (Landform Solutions, April 2007).

This top cover strategy is not critical for Landform 3, and there will be no concerted effort to provide a low permeability cover or top layer to prevent vertical seepage into the landform. The focus for Landform 3 is to minimise and contain sediment transport so that is does not enter Coppin Creek.

With respect to sloping surfaces on waste landforms, appropriate slope angle, bunding, and engineering design is required to limit concentrated flow and minimise erosion on the outer faces of the waste landform. The nature of the soil material at the surface is also important e.g. to ensure sufficient coarse material in the surface soils on sloping areas, such as rocky mine waste immediately below a final layer of topsoil, and ripping this final profile to mix these layers. Surface materials which contain both coarse fragments and fine soil materials will allow creation of an erosion-resistant surface that also has some capacity to store soil moisture and thus support plant growth (Landform Solutions, April 2007). Appropriate contour drains to provide effective water management will benefit vegetative growth. Berms should be installed (between changes of slope) to minimise sheet water flows. Larger flows will overtop and carry on down the slope (Figure 3).

The landforms will be placed outside the (Coppin Creek) 100 year ARI flood limit / floodplain, except for the western toe of Landform 3 (Figure 2). The western toe of this waste dump, is located in a flood fringe area (not the flood way) and hence would not be expected to experience highly erosive flood waters.

4.5 WATER PONDING AT THE REAR OF LANDFORMS

Where waste landforms or tailings storage facilities are placed over drainage/creek lines, then commonly water is allowed to pond behind the structure, infiltrate, evaporate (when the catchment is minor), or find its own way around the landform either naturally or in constructed diversion channels. Where terrain is steep and rugged, these latter options become less viable. The landform itself then tends to require engineering as a dam-like structure, with outlet structures and spillways. There is a thus a greater need to consider both the structural integrity of the landform, and the hydraulic performance of the landform in extreme storm events.

Water ponding at the rear of the landforms therefore needs to be managed. Management options include:

- *Option 1*: Filling of upstream catchments with waste (to remove the catchment, whereby rainfall would fall directly onto the landform surface, where it would be managed in surface flow, or allowed to pond on and seep into the landform (avoiding PAF material).
- *Option 2:* Diversion of the creek lines around the landform

- *Option 3:* Rock drains under the landforms, using permeable, robust, competent and geochemically clean waste to line old stream lines, and thus allow upstream water to flow under the structure.
- *Option 4:* Culverts under the landforms, to drain upstream catchments
- *Option 5:* Retaining water upstream, and allowing it to infiltrate or evaporate. This may be an option for minor ponding, but is not preferred for major catchments.

4.5.1 Option 1: Filling / Removing the Ponding Area

Option 1 obviates the direct problem of ponding behind a landform. However this method does not remove the contributing catchment and the water must be directed through a drainage system to the sides of the landform, after which it must be collected, or allowed to pond on top of the landform. Thus large volumes of water may potentially collect on the landform, and seep into the surface; or the larger top surface area may exacerbate erosion and sediment issues as grading of the surface directs run-off to a storage/pond area.

Given the engineering efforts required to shape, grade and make impermeable waste landforms, increasing the top surface area can complicate construction and management issues with only limited hydrological benefit.

4.5.2 Option 2: Diversion of Creek Lines

Diversion of creek lines reduces the quantity of surface water that comes into contact with the waste landform and can reduce the scale of management measures for affected surface waters.

The landforms will remain in their proposed form in the long-term, and as such this option represents the most effective, safest long-term solution. The main disadvantage of diversion channels, is the cost, or in some cases, the impractability of constructing the diversion channel, particularly in complex topography where drainage directions can vary greatly over short distances.

4.5.3 Option 3: Rock Drains / Underflow

Option 3 requires use of a permeable rock matrix. In a landform containing rock materials ranging from sand size to boulders, end-dumping in thick layers can result in the coarsest fraction / large boulders ending up at the bottom of the deposit. The material would be placed by dropping it from a high platform, and allowing it to rill down the sides, with the larger material aggregating at the base. Moly Mines indicated the material would be in the order of 200mm to 1000mm in diameter, equivalent to boulder size. This then would create a french drain effect, or 'rock drain' in the lower portions of the landform. Experience with these drains at other mine sites suggests that the effectiveness is highly dependent on the construction techniques utilized.

These 'flow-through' rock drains can be placed over the top of natural creek lines, and be high and long. Flow through the rock drain is a function of the effective porosity of the material. Because the wetting area in rock fill is lower than in an open free-flowing creek, the capacity is much reduced. If the creek that supplies the rock drain floods, the ability of the drain to convey water may exceed the peak flood flow and a large but temporary pool may develop at the upstream end of the landform. The free surface within the rock drain then becomes elevated, as does the point of exit at the downstream face of the landform (Figure 3).

4.5.4 Option 4: Culvert

Option 4 replaces the rock drain with a pipe culvert. A culvert would lower the possibility of blockage, but the major problem with culverts relates to their life span and longevity, and the structural ability of the culvert to withstand the pressure from overlying high fills.

4.5.5 Option 5: Damming Water Upstream

Option 5 is considered suitable for minor ponding. However, the larger the potential lake that may form, the longer it will take to dissipate (via infiltration and evaporation), and the more likely it is to be aggravated by another following storm. If the capacity of the pond is exceeded, then uncontrolled flow may cause washouts, while high phreatic seepage lines through the landforms may similarly cause erosion problems.

It is considered appropriate to establish arbitrary limits upon the sizes of the potential lakes. Ideally, such limits may be a maximum depth of 3-4m at the damming wall, and lake dissipation within one month (100 year ARI storm). Practical limitations at some sites may dictate that the arbitrary limits will be exceeded. At such sites, the risk implications should be assessed

4.5.6 Summary

Options 1 and Option 2 will utilised as required. Where these options are impractical, it is proposed to adopt Option 3 (rock drains / underflow) (refer Figure 3) by placing readily available large, clean, blocky fill under the landforms, along the existing creek lines, in particular. The material will be used to generally populate the bottom of Landforms 1 and 2 with coarse material, as a drainage blanket. This will ensure that encapsulated PAF material above the drainage blanket remains as dry as possible and the potential for acid generation is minimised. It is understood that no particular effort will be made to provide Landform 3 with such a drainage blanket, however particular drainage lines will need to be treated in such a way where there are specific significant creek lines trapped behind the rear of Landform 3.

4.6 DESIGN OF ROCK DRAINS

The construction of rock drains by such methods as end tipping waste material, comes with the uncertainty of exact permeabilities that will result in the field situation. Thus designs need to be based on a conservatively large permeable zone, with particular detailing at the inlet and outlet ends.

Design of flow-through spillways in Tasmania was first considered by Tasmanian Hydro Electric Commission engineer, the late John Wilkins. Wilkins used the concept successfully at Laughing Jack Dam, and later at the North Slot Dam at Savage River. A particular contemporary case at Australian Bulk Mineral’s (ABM) Savage River iron ore mine, located in rugged topography in Tasmania, has been well documented.

The Savage River mine has operated since 1967. Operations ceased briefly in 1995 before being re-opened by ABM. Over its 40 years of operation to date, large volumes of waste rock have been generated. Due to the extremely rugged topography, the siting of waste rock landforms is difficult, and a section of Broderick Creek proved to be an appropriate site for a waste landform, if the storm water flow could be properly managed.

Broderick Creek has a large catchment (2,150ha) and is perennial (average annual rainfall 2,000mm). By comparison, the creek under Landform 1 has a smaller catchment (220ha) and is ephemeral (average annual rainfall 360mm). Due to potential cyclonic activity, however, it is anticipated that flood flow peaks in the two catchments would be somewhat similar.

Erosion of early dumps placed in Broderick Creek was recognised as an environmental issue, and led to a review of spillway options for the landform which was effectively damming the valley (i.e. options to allow creek flow past the landform). An environmentally acceptable spillway to allow long term, maintenance free, operation was required as part of mine abandonment policy in the early 1990's. The spillway was constructed over the top of the waste landform, ensuring that the level in the upstream dam was capped at a manageable maximum level.

The review of options led to adoption of a flow-through rock drain, which utilised hard coarse waste rock as a drainage zone. Construction was successful, and has since led to extension of this concept for further major development of waste landforms at the site. The upstream creek/pond level falls in the summer/fall period, and then rises about 10-12 m in the winter/spring during the main rainy season. The hydraulics of the flow-through however, keeps the flow fairly consistent at approximately $1m^3/s$.

The engineering details of the rock drain in Broderick Creek were described in a Technical Paper *Design and Performance of A "Flow – Through" Spillway at Broderick Creek Waste Rock Dump – Savage River Mine* by D Brett and B Hutchison (2003). Results of site flow monitoring were used to demonstrate the effectiveness of the design, and the actual permeability values achieved.

Clogging of the rock drain can result from sediment build-up or from geochemical properties of the waste rock. At Broderick Creek, the fear was not sedimentation, but clogging due to coatings on alkaline materials (mainly magnesite and dolomites) from oxidation. ABM selected the rock-fill material (calcite chlorite schist) such that oxidation was minimized.

4.7 ROCK DRAIN – KEY CONCEPTS

Key design concepts for the design of rock drains may be summarised below:

Rock-fill properties

- Free draining, open graded, hard rock rock-fill construction material (at Savage River this comprised both selected rock-fill, and rock-fill produced by segregation during placement, that resulted in a maximum size 500mm grading with minimal fines).
- Rock-fill with a low reactivity to potentially acidic environments.

Wetted area dimensions

- Internal central section of the rock-drain: cross section matching design flow
- Downstream outlet of the rock drain: Larger cross section area, with selected large diameter rocks, to prevent development of a high phreatic line on the downstream face, which has potential for erosion, instability and contact with PAF within the landform.

- Upstream inlet of the rock drain: Larger cross section area with selected larger diameter rocks to allow for long term reduction in permeability of the upstream outer face by vegetation or silting. Larger rock may also discourage vegetation growth on the face.

PMF & long term planning

- Ponding will develop upstream. Rare storm events need to be considered (500 year and PMF) in the design of the landform structure (using conservative phreatic surfaces within the structure), and the hydraulics of the rock drain.
- In the event of long term blockage of the rock drain (after centuries?) then the landform will revert to a more conventional dam (i.e. pond water behind it) with the need for an "auxiliary" spillway. This allows for the regulation of water levels in the dam at appropriate levels. The "dam" structure should be conservatively designed for this contingency. At Savage River the spillway was over the top of the dump, for example the Landform 1 spillway would be provided by the natural ridge into Kitty's Creek.

Construction techniques

- Successful construction of the rock drain requires good control of the materials used and landform techniques within the critical areas, and a high level of commitment and field control by construction personnel.

4.8 PERMEABILITY OF ROCK DRAIN

Permeability is a measure of a material's ability to transmit fluids. Together with the level of saturation, permeability determines the quantity of flow through a unit cross-sectional area under a unit gradient of hydraulic head. Based on published information, the permeability of clean sand may range from 1-100 m/d (effective size 0.06mm – 2mm), and gravel from 100-1000 m/d (2-60mm).

Empirical equations have been developed to estimate the hydraulic conductivity of granular materials. Two such equations are known as Kenney's formula (developed for compacted sands used in dams); and Hazen's formula (developed for sand filters, which typically are looser and thus have a higher hydraulic conductivity). For sand with effective size 0.06mm – 2mm, the equations predicts k value of about 1-100m/d (clean Perth sand may range from 5-20m/d).

It is understood that most of the rock material proposed for the landforms is boulder size. As both formulae were developed for clean sands, it is problematic to extend the equation to particles orders of magnitude larger. However, based on the equations, the permeabilities of granular media of cobbles and boulders may be extrapolated as per Table 2.

Table 2
Extrapolation of Permeabilities for Granular Media, Based on Empirical Relationships

Material	Particle Size (mm)	Permeability, *k* (m/d)
Clean Gravel	2 - 60	100 - 100,000
Cobbles	60 - 200	100,000 – 1,000,000
Boulders	> 200	> 5,000,000

Thus a "boulder size" rock drain can be very porous and permeable, but permeability can be easily affected by the amount of fines trapped in the pore space. Even a small percentage of fines, such as 5-10%, will decrease permeability dramatically. During the waste landform construction, as the coarse rock rills down to its lowest point, large boulders will accumulate at the base, but will also carry finer material down with them. Over the long term, and within the waste landform, water will seep down through the landform and carry finer material into the coarse material. Water ponding on the upstream face of the landform will also carry finer material onto the face and clog the pores.

The aim at Broderick Creek was to produce a segregated coarse rock drain (max 500mm with minimal fines), with overall bulk permeability k of 0.2-0.4m/s (17,000 - 34,000m/d) and void ratio of 0.85. Field measurements suggested an actual permeability of 0.5-1.0m/s (43,000 - 86,000m/d), equivalent to a D_{10} (10th percentile particle size) of about 15-25mm (coarse gravel size particles), which indicates that the pore spaces within the larger cobbles and boulders, were indeed filled with much finer material.

4.9 CAPACITY OF ROCK DRAINS

Based on the length of Landform 1 (1300m), the maximum hydraulic gradient (with ponding) is approximately 2% (i.e. (196m-170m)/1300m). The normal hydraulic gradient (i.e. ground surface slope in the old creek line) is ~1% (i.e. (184m-170m)/1300m). An hydraulic grade line of 0.01 has been assumed for design purposes.

Two design approaches were considered to determine required cross-sectional area.

Based on a HGL of 0.01, and measured permeability of 0.5-1.0m/s, the Darcy relationship provides a flow capacity of 0.5-1.0m³/s (for each 100m² of cross sectional area).

Wilkins formula is based on void velocity (Vv) and porosity (n) (refer *Flow of Water Through Rock-fill and its Application to the Design of Dams*; Wilkins JK; Proceedings 2nd Australia – New Zealand Conference on Soil Mechanics and Foundation Engineering, Canterbury, New Zealand, 1956).

Assuming a D_{10} effective size of 15-25mm and a (conservative) porosity of 0.25, the Wilkins formula provides an overall velocity of ~0.013-0.017m/s or 1.3-1.7m³/s (for each 100m² of cross sectional area).

A capacity of 1.0m³/s per 100m² of cross sectional area has been adopted. As a general rule, the preference is for a lower height and wider cross-section, so that more of the rock drain area is engaged at lower flood levels, but this is not critical.

4.10 OTHER ASPECTS

The rock drains installed need to be free draining, open graded rock-fill of appropriate rock type/quality for long-term effective operation. The size of rock drains required needs to match the minimum design capacities discussed above, but also depends upon the availability of suitable rock in the desired quantities and qualities, and the high level of commitment and field control required to achieve success. Thus effective rock drains may be installed in critical targeted areas only, or may be more widely spread over the bottom layers of the landforms. Temporary ponding will develop upstream of the rock drains, and in the event of blockage of the rock drain, the landforms would retain water and therefore needs to be designed as a "dam".

The upstream inlet needs to be at least five times the capacity of the central section of the drain. This larger cross-section may be achieved by extending selected rock-fill in front of the landform, allowing water to enter the rock fill via a wider cross-section and through the top of the rock-fill. The downstream outlet also needs to be a larger cross-section / larger selected rocks, to protect the downstream face and ensure the stability of the rocks.

In large storms, the phreatic line / flow level through the creek lines will be higher than in other parts of the landform dump (assuming that the rock drains have been specifically constructed along the creek line). As such, it may be desirable to raise the PAF material near the creek lines.

5.1 LANDFORM 1 ROCK DRAIN DESIGN

Based on the Landform 1 outline shown in Figure 2, the contributing catchment to the rock drain (including a proportion of the landform top surface, as well as the catchment to the west of the landform) is ~130ha (depending partially on the way the top surface of the landform is graded) (refer Figure 4). The 100 year ARI flood would generate approximately 300,000m³ of water, while the probable maximum flood would generate >2.0 million m³ of water.

The maximum storage capacity behind Landform 1 is dictated by the shallow divide within the valley at RL196m, between Coppin Creek and Kitty's Creek. At a top water level of RL196 m, approximately 1.0 million m³ of water could be stored, with a depth of water at the landform of approximately 12m (for comparison purposes, the proposed landform crest is approximately RL230-240m). Thus a portion of the PMF flood volume would spill westward into Kitty's Creek catchment, leaving the valley "full".

For the 100 year ARI flood event, the capacity of the drain may be chosen based on level pool routing concepts:

Table 3
Landform 1 Catchment Area ~130 ha: Storage - Outflow Calculations (100yr ARI)

Average Outflow (m^3/s)	Design Outflow (m^3/s)	Peak Volume Stored Behind landform ('000m^3)	T (hrs) to Drain at Average Outflow
0	0	300	-
1	2	175	48
2	4	136	19
3	6	117	11
4	8	103	7
5	10	93	5

Assuming a design outflow capacity of say 2m³/s, then a minimum 200m² of rock drain flow area is required (e.g. 5m x 40m, or other suitable combinations). The temporary volume stored (~175,000m³) would occupy 15%-20% of the available storage (~1.0 million m³) behind the landform and pond to several metres deep against the landform.

Reduced Storage Area (Landform Solutions Figure 2)

Landform Solutions show a Landform 1 design (Landform Solutions, Figure 2, April 2007) with the landform filling the valley to the shallow divide between the Coppin Creek catchment and the Kittys Creek catchment. This reduces the available storage area to the west of the landform, however, the notional contributing catchment to the rock drain (including a proportion of the landform top surface, as well as the catchment to the west of the landform) remains at about ~130ha (again, depending partially on the way the top surface of the landform is graded). The 100 year ARI flood would generate approximately 300,000m³ of water. If there was sufficient storage left available behind the landform (without overtopping into Kitty Creek, then the design requirements as described in Table 3 above apply and a design outflow capacity of say 2m³/s and a minimum 200m² rock drain apply.

The amount of water (and sediment) permitted to flow back into Kitty Gap needs to be limited. Sediment basins are commonly designed for the 10 year ARI 6hr design rainfall event, and larger events pass through the basin, there is also a larger volume of water so the dilution of the sediment is greater. The 10 year ARI flood would generate approximately 100,000m³ of water.

As a minimum, a temporary storage volume of ~70,000m³ (100m² rock drain) or ~60,000m³ (200m² rock drain) should be retained to prevent flow over the divide back into Kitty Creek, up to the 10yr ARI event.

The alternative management solution is to control flood volumes by decreasing the contributing catchment area. This can be done by altering the grading and slopes on the top surface of Landform 1, such that all surface water run-off is directed to the east and directly into the Coppin Creek Cut-off. In this scenario, the contributing catchment becomes the small area between the landform and Kittys Gap, and the western wall slope of Landform 1.

In this scenario top surface flows will run along the entire top surface of Landform 1 and measures are required to reduce velocities and erosion.

5.2 LANDFORM 2 ROCK DRAIN DESIGN

The contributing catchment to the rock drain (including a proportion of the landform top surface, as well as the catchment to the west of the landform) is ~45ha (depending partially on the way the top surface of the landform is graded) (refer Figure 4). The 100 year ARI flood would generate ~100,000m³ of water, while the probable maximum flood would generate ~800,000m³ of water.

Landform 2 is in rugged terrain and the maximum storage capacity behind the landform is dictated by a catchment divide RL196m from the valley to the south. At a top water level of RL196 m, approximately 500,000m³ of water could be stored, with a depth of water at the landform of approximately 14m (for comparison purposes, the proposed landform crest is approximately RL230-240m). Thus a portion of the PMF flood volume would spill south, leaving the valley “full” (Figure 3).

For the 100 year ARI flood event, the drain capacity may be chosen based on level pool routing concepts:

Table 4
Landform 2 Catchment Area ~45ha: Storage - Outflow Calculations (100yr ARI)

Average Outflow (m³/s)	Design Outflow (m³/s)	Volume Stored Behind landform (‘000m³)	T (hrs) to Drain at Average Outflow
0	0	100	-
0.5	1	54	30
0.75	1.5	46	17
1	2	41	11
2	4	30	4
3	6	24	2

Assuming a design outflow capacity of 1.5m³/s, then a minimum 150m² of rock drain flow area is required (e.g. 5m x 30m, or other suitable combinations). The temporary volume stored (~46,000m³) would occupy 10% of the available storage (~500,000m³) behind the landform and pond to several metres deep against the landform.

The inlet to the rock drain would be at the southern end of the pond. The rock drain would meander, beneath the landform, following existing flow paths to the north east as shown in Figure 4.

5.3 LANDFORM 3 ROCK DRAIN DESIGN

There are several minor catchments behind Landform 3 (Figure 4), and because of the rugged terrain, it is not feasible to cut a drainage channel and divert these catchments. Consequently these catchments will remain hydrologically separate from each other and are considered separately.

The largest contributing catchment (which includes a proportion of the landform top surface, as well as the catchment to the east of the landform) is ~30ha (depending partially on the way the top surface of the landform is graded) (refer Figure 4). The maximum storage capacity behind the landform is dictated by a catchment divide RL205m in the valley to the east. At a top water level of RL205m, approximately 700,000m³ of water could be stored, with a depth of water at the landform face of approximately 19m.

The 100 year ARI flood will generate ~67,000m³ of water, while the probable maximum flood would generate ~550,000m³ of water (the PMF would thus be retained within the valley). For the 100 year ARI flood event, the capacity of the drain may be chosen based on level pool routing concepts:

Table 5
Landform 3 Catchment Area ~30 ha: Storage - Outflow Calculations (100yr ARI)

Average Outflow (m³/s)	Design Outflow (m³/s)	Volume Stored Behind landform (‘000m³)	T (hrs) to Drain at Average Outflow
0	0	67	-
0.5	1	31	17
1	2	23	6
1.5	3	19	3.5

Assuming a design outflow capacity of 1.0m³/s, then a minimum 100m² of rock drain flow area is required (e.g. 4m x 25m, or other suitable combinations). The temporary volume stored (~31,000m³) would occupy 5% of the available storage (~700,000m³) behind the landform and pond to several metres deep against the landform.

The second largest contributing catchment (northern), including a proportion of the landform, is approximately 15ha (refer Figure 4). This catchment would overtop to the north should the water level reach approximately 3m deep at the landform, and hence a rock drain is not considered necessary.

A minor catchment exists between the two larger catchments, and will only produce relatively small volumes of runoff, and does not require a rock drain.

The third largest contributing catchment (southern) would pond to a depth of 2m before overtopping to the south. The overflow would then enter into the drainage channel/bund system to the south of Landform 3 and be directed to the sedimentation basin.

6.1 GENERAL

Coppin Creek will be diverted around the pit, in a major diversion channel located to the south and east of the pit. A section of Coppin Creek between the diversion point and the pit will therefore be cut-off. To protect the main pit from floodwaters, substantial diversion bunds are required on the main creek upstream and downstream from the pit. Upstream of the pit, a bund adjacent to the pit (Upstream Diversion Bund) and a bund at the creek diversion (Upstream Diversion Bund) will form a contained cut-off area of the creek approximately 700m long, that will be used to store all seepage and surface water flows emanating from Landform 1 and Landform 2.

The total contributing catchment area to the cut-off section is ~350ha, comprising Landform 1, Landform 2, and a small area of natural catchment near the ROM pad. The total runoff in a 100 year ARI storm event is estimated as ~785,000m^3.

The design criteria for selection of the bund crest levels, are the flood levels in diverted from Coppin Creek. An appropriate safety factor on the crest level of the bunds may be gained by determining flood levels if Coppin Creek flood discharges are increased by 50%. In this case, the estimated flood levels upstream and downstream upstream and downstream from the pit become RL175m (cf RL174m) and RL169m (cf RL166m at Coppin Gap) respectively. This disproportionate water level change for a 50% discharge increase (i.e. 1m u/s and 3m d/s) arises from the constricting Coppin Gap.

6.2 FREEBOARDS

Typically for pit flood bunds, a minimum freeboard of 2m above the design 100yr ARI flood is allowed. For the Spinifex Ridge flood bunds, we recommend that the bunds be designed with:

- 2m freeboard above the design 100yr ARI level near Coppin Gap
- 3m freeboard above the design 100yr ARI level near in Coppin Creek (u/s of the pit)
- 2m-3m freeboard (prorata) for bunds in between

Note that these are the recommended minimum levels and, given the consequences of a bund failure, these levels should ideally be increased to improve the safety factor.

6.3 BUND 1 - UPSTREAM PIT BUND

The northern bund or Upstream Pit Bund will be the last line of defence between Coppin Creek and the open pit. Allowing a 2m freeboard above the 100 year flood level in Coppin Creek (at the upstream diversion point), the crest level should be RL176m. The bund is required to be an engineered water retaining structure with an impervious clay core. Depending on the final placement of the Upstream Pit Bund, it is expected to be between 430–600m long.

The haul road will cross Coppin Creek along this bund as access to Landform 3.

6.4.1 BUND 2 - UPSTREAM DIVERSION BUND

The Upstream Diversion Bund will be located just downstream from the entrance to the proposed Coppin Creek diversion channel. It will ensure that water within the Coppin Creek cut-off section (which has come into contact with Landform 1/Landform 2), and the flows in Coppin Creek diversion channel remain separate. Allowing a 2m freeboard above the 100 year flood level, the crest level should (also) be RL176m. The bund is required to be an engineered water retaining structure with an impervious clay core. At the location described in Figure 4 the Upstream Diversion Bund is approximately 390m long.

6.4.2 BUND 2 - UPSTREAM DIVERSION BUND SPILLWAY

A spillway through the Upstream Diversion Bund, set at RL174m, is proposed as a link between the cut-off section to Coppin Creek and its diversion channel. A spillway is required to allow excess water flowing into the cut-off storage resulting from extreme flood events, a means of escape back into the creek. The proposed spillway level matches the external 100 year ARI flood level in Coppin Creek at the diversion point, and provides a total flood storage of approximately 750,000m^3. Thus most of the estimated 100 year ARI runoff volume can be stored at RL174m, with the remainder escaping via the spillway into the Coppin Creek diversion. Given the volumes present during the 100 year ARI flood, such volumes would be subject to massive dilution.

The main spillway should preferably be located on higher ground at the eastern abutment side of the Upstream Diversion Bund, to minimise erosion protection works on the higher embankment itself (in terms of Reno mattresses and rock riprap, etc). The size of the spillway should be limited, to lower the potential inflow rate from Coppin Creek when external flood levels exceed the spillway level. Assuming the cut-off storage is already full (at TWL RL174m, e.g. from a previous cyclonic event), then the spillway size may be calculated using level pool routing. The cut-off storage surface area is ~30ha so an allowable temporary 0.5m rise in level during a flood event would provide temporary storage of 150,000m^3 (i.e. 0.5m x 300,000m^2). This large storage volume mitigates the peak 100 year ARI flow into the cut-off storage (~100m3/s) to an average outflow of ~10m^3/s. The spillway required for a design 20m^3/s flow (at a depth of 0.5m, ensuring water level does not exceed RL174.5m) is a broad crested weir ~20m wide.

7.1 GENERAL

Surface water diversion results from interruption to existing surface water flow patterns. Diversion requires a combination of bunding and excavated channels to carry flood waters via a flow path different from the natural water course. A combination diversion channel and bund system is suggested as it is efficient to use the cut from channel excavation as fill for bund construction. The diverted water is directed into a defined water course which joins the original water course at a point downstream.

Major water retaining diversion bunds (Bund 1 and Bund 2) are located at either end of the Coppin Creek cut off, as described previously. In addition to these, further bunding is required to contain water that has been in contact with the waste landforms, and to ensure that the downstream side of the pit is not flooded during a 100yr flood event.

7.2 BUND 3 – DOWNSTREAM PIT BUND

Bund 3 is located across Coppin Creek on the north-eastern side of the pit, and prevents Coppin Creek flood levels from the Coppin Gap backing up into the pit (Figure 4). This bund does not need to retain water for any length of time (only hours). It effectively forms part of the normal pit surrounding bund, albeit more substantial. As such it should be adjacent to the pit (i.e. as far upstream as practical, to prevent additional catchment feeding into cut-off section between the bund and the north-eastern edge of the pit). There does not appear to be any earthworks savings (i.e. less bund length) by moving the bund downstream towards Coppin Gap.

The 100 year ARI flood level at Coppin Gap is RL166m at Coppin Gap, and slightly higher near the pit (~ RL166.4m) in the backwater upstream of Coppin Gap (refer Report 058b *Spinifex Ridge Project Surface Water Assessment*, Aquaterra, May, 2007). The proposed minimum bund crest level must therefore be RL166.4m plus a 3m freeboard ~ RL169.4m. The ground level is about RL160m or RL161m, so the bund would be maximum 8-9m high. At the pit edge, the Downstream Pit Bund would be approximately 300m long.

As flood events become more extreme (than the 100 year ARI event), the flood situation becomes less controlled. Flood levels rise (by many metres) disproportionately due to the restriction of the Coppin Creek Gap. There is virtually no way of preventing total flooding of the pit in extreme flood situations, however the risk of this eventuality is correspondingly lower.

7.3 BUND 4 - CREEK DIVERSION BUND

The proposed Coppin Creek diversion channel cuts across a creek line on its north west side, which requires blocking off to prevent flow directly accessing the pit (refer Report 058b, X-section RS110, and Appendix A).

The ground level at RS110 is ~169m (the channel base is somewhat lower) while the 100 year ARI event flood level at RS110 is ~171.4m (cf RL166m at Coppin Gap). The proposed minimum bund crest must therefore be set at RL171.4m plus a 2.5m freeboard = RL173.9m.

7.4 LANDFORM 1 AND LANDFORM 2

The Landform 1 valley landform, and Landform 2 immediately to the south, will contain encapsulated PAF material, and as such, all water seeping from the landforms, and shedding from the top surface, will be directed to the Coppin Creek cut-off. The top cover will comprise a mixture of rock and vegetation cover, to minimise erosion. The top surface of final landform will be domed to shed water in various directions, subject to final design. From a hydraulic point of view, the preference is to shed water directly towards the east, to minimise water that collects in trapped valleys at the rear of the landforms.

Flow off the top surface towards the east will enter directly into the Coppin Creek cut-off, and flow to the west will mix with water within the valley catchments upstream of the landforms, and pass through rock drains into the Coppin Creek cut-off.

To ensure all seepage and runoff from the landform will be directed to the Coppin Creek cut-off, a bund / channel system is required to be constructed from the higher ground to the south of Landform 2, around the toe of the landform to the proposed Coppin Creek cut-off (Figure 4). The channel component will be set on a continuous downgrade towards the cut-off, while the bund will contribute to hydraulic capacity, and allow more balanced earthworks. The proposed arrangement is shown in Figure 5.

To ensure all seepage and surface run-off is captured and directed to the cut-off, the hydraulic capacity of the bund / channel system is to match the 100yr ARI flood event, with a freeboard of 0.5m. The channel will enter Coppin Creek at RL174m (see Figure 4 for location).

Catchments contributing to flow in the collection channels/bunds are marked on Figure 4 in blue. Catchments contributing to seepage through-flow marked on Figure 4 in red.

7.5 LANDFORM 3

The Landform 3 landform, located on the east side of Coppin Creek, will contain only NAF material, and as such, is considered chemically clean. All water seeping from the landform, and shedding from the top surface, will be captured and directed to sedimentation basins, before entering Coppin Creek.

Again, the top cover will be a mixture of rock and vegetation cover, to minimize erosion. It is less critical that the top of the landform be shaped to shed water, since the waste material is considered clean and seepage is less of an issue.

The trapped valleys will pond water behind the landform from the natural catchments to the east, and together any water shed from the top surface, will then flow under the landform in rock drains. Flows exiting the landforms (along old creek lines) will pass through sedimentation basins before flowing into the proposed Coppin Creek diversion channel.

On the north west side of the landform, run-off from the landform will also be directed into sedimentation basins constructed in old creek lines. Elsewhere on the southern, south-eastern and western sides of the landform, two bund & channel systems will collect run-off and direct it towards sedimentation basins.

The hydraulic capacity of the bund / channel system for Landform 3 is to be the 10yr ARI flood event, and no freeboard is required.

Catchments contributing to seepage flow through rock drains are marked in red. Those contributing to run-off are marked in blue.

7.6 DIVERSION CHANNELS AND BUNDS

The construction of diversion channels is partially determined by the terrain (longitudinal profile) and practical construction considerations, and the design flow chosen. Diversion channels need not necessarily have sufficient capacity to carry the full 100 year ARI flood event. Rather, the design capacity depends on the impacts of flooding. If flood flow in areas normally free of flooding may have potentially adverse impacts on other mine infrastructure or the environment, then diverted water needs to remain confined within its diversion channel (capacity 100 year ARI capacity).

The nominal channel design flow would be generally smaller (e.g. 2 or 5 year ARI capacity) to minimise earthworks and cost; and as such, lower probability / higher flow events would be partly carried in the excavated channel and partly as surface flow outside the channel. It is generally proposed that the bund and channel system provide a balanced cut and fill to minimise earthworks and provide the overall design dimensions (Figure 4). In undulating terrain the depth of the channel and the height of the bund will vary along the profile.

Protection and armouring may be required if the diversion channel runs alongside other mine infrastructure (e.g. a landform face), and at outlets (e.g. into Coppin Cut-off).

Earth bunding would typically consist of a minimum 3m wide crest with side batters of 1:2.5, and be built to an engineering specification using competent materials. When bunds are required to retain water for long periods of time (e.g. Bund 1, Bund 2) then materials of an impervious nature, are also required to minimise seepage.

Excavated open diversion channels would typically have side batters of 1:2. A bottom width of 4m is suggested because it is easily constructed with earth moving equipment. Flow paths formed by the construction of an earth bund will take on the cross section of the existing ground.

SECTION 8 - SEDIMENTATION BASINS

8.1 GENERAL

Key issues associated with the surface water runoff are erosion and sediment control, particularly during initial pre-stripping and clearing for the landforms and pits. Sediment basins and erosion control structures will be constructed down slope of all waste landform and pits (as appropriate) to manage these issues.

Local runoff will be collected and treated to remove sediments to acceptable levels prior to release to the natural environment. Bunds and drainage diversion works will be constructed around the perimeter of all infrastructure areas. These will be designed to effectively divert and prevent natural runoff waters originating outside the development sites from mixing with internal site runoff.

Concerns relating to the mine water management system focus on containment of runoff from the mining and waste landform areas and the potential effects on external surface water environment.

8.2 DESIGN CRITERIA

Sediment basins would be located at low points and be constructed by forming earth bunds. Storage volume consists of the permanent pool settling zone and sediment storage zone. The internal size of the basins varies depending upon the design inflow. Commonly, design criteria are based on *Soil Erosion and Sediment Control Engineering Guidelines for Queensland Construction Sites* (Institution of Engineers Australia, 1996). The size is calculated to match the settling velocity of the target sediment size with the design flow. For design of the sediment basins, a target size of particle is chosen, for which there is an associated settling velocity. Coarser particles settle faster than smaller particles, and settling of fine silt and clay within sediment basins is generally not as effective. Flocculants can be added to reduce the Total Suspended Solids (TSS) if required to settle fine silt and clay.

For design of the sediment basins, a target of medium sized silt particles > 0.02mm (20µm, with settling velocity Vs 0.00029m/s), will be adopted for the 10 year ARI 6hr design rainfall event (rainfall intensity 17.2mm/hr). Hence, for the design event, the sediment basin is expected to be effective in removing sand and medium to coarse silt.

Based on the criteria described above, it can be shown that:

- V_{runoff} (volume of runoff in m^3) from Ac = 685*Ac (where Ac is the catchment area in ha)
- Q (average 10 year ARI 6hr design flow in m^3/s) = 0.032*Ac or 114*Ac m^3/hr
- As (basin surface area in m^2) = 131*Ac
- The depth of water in the "permanent settling zone" (i.e. the free water body above any settled out silt), should be sufficient for one to two hours storage at the design flow (minimum of 0.6 m deep).
- The sediment storage zone lies beneath the permanent settling pool and is sized to store reasonable amounts of sediment (commonly, sufficient capacity to ensure that desilting is not required more frequently than once every 5 years. A sedimentation deposition rate of 100m3/ha/year is a reasonable starting point, from which to calculate the required depth of the sediment storage.

8.3 DESIGN FEATURES

For mine sites, the outlet structure generally consists of a spillway only (no 'control' outlet such as an overflow pit / pipe system is generally provided). Thus smaller flow events are fully contained within the basin, such that no sediment is released downstream. Larger events up to the design storm pass through the basin and over a spillway. Theses events larger than the design event are still treated by the basin prior to discharging downstream. The trapping efficiency is less, but there is also a larger volume of water so the dilution of the sediment is greater.

After a storm event, the water in the basin would slowly infiltrate and evaporate until the basin was empty. Alternatively, water could be pumped out following significant storm events. Prior to the commencement of the wet season, the sediment basins should be cleaned out. A ramp into the basin is constructed so that sediment removal could be by front end loader (or similar). The sediments removed from the basin would be contained in an area where they would not be transported by the next storm event back into the sediment basin, or to the downstream environment.

The length to width of the basin should be at least 3:1, and ideally more elongated, where the length is the distance from the inlet to the outlet. Where this is not possible on the site, baffles should be incorporated to increase the effective ratio and prevent short circuiting.

8.4 LANDFORM 1 AND LANDFORM 2

The Coppin Creek cut-off will form the sedimentation basin for Landform 1 and Landform 2. As described previously, the total contributing catchment area to the cut-off section is ~350ha, comprising Landform 1, Landform 2, and a small area of natural catchment near the ROM pad.

The volume of runoff is estimated at 240,000m^3 (10 year ARI event), and the average runoff rate over 6 hours is therefore 40,000m^3/hr or 11m^3/s. The required basin surface area is 45,500m^2 or 4.5ha.

As described previously, the Coppin Creek cut-off storage surface area is ~30ha, which greatly exceeds the design requirement of 4.5ha. It is therefore considered that the cut-off would be an effective sedimentation basin.

The outlet structure to the cut-off only consists of the spillway through Bund 1 (Pit Bund). It is unlikely that the spillway would ever operate, and as such flow events would normally be fully contained within the cut-off storage, and no sediment released downstream. The water in the cut-off would slowly infiltrate, evaporate, and be utilised by mining operations, until the cut-off was empty.

In addition to this major storage, it may be desirable to place smaller sedimentation basins at the upstream end of each of the rock drains, formed by damming the valley line just upstream from the rock drain entrance:

- Landform 1 rock drain (Ac ~130ha) requires a basin surface area of 1.7ha
- Landform 2 rock drain (Ac ~45ha) requires a basin surface area of 0.6ha

8.5 LANDFORM 3

A number of sedimentation basins will be required for Landform 3. These will be formed by damming the valley line just downstream from creek lines exiting from beneath Landform 3:

- total top surface catchment area (Ac ~38ha) requires a total basin surface area of 0.5ha

It may be desirable to place smaller sedimentation basins at the upstream end of the rock drain, formed by damming the valley line just upstream from the rock drain entrance:

- Landform 3 rock drain (Ac ~27ha) requires a basin surface area of 1.9ha

The two diversion bund/channel systems to the south and west of Landform 3 also require sedimentation basins:

- southern bund (Figure 4) (Ac ~72ha) requires a basin surface area of 1.0ha
- western bund (Figure 4) adjacent to Coppin Creek (Ac ~45ha) requires a basin surface area of 0.6ha

SECTION 9 - CONCLUSIONS AND RECOMMENDATIONS

Moly Mines propose to develop a molybdenum resource in the Spinifex Ridge area, located 50km north east of Marble Bar. The scope of work cover the proposed development areas, in particular, the proposed 3 waste landforms.

The general objectives with regards to surface water, erosion and runoff include the maintenance of the integrity, functions and environmental values of watercourses and sheet flow, and to maintain or improve the quality of surface water to ensure that existing and potential uses, including ecosystem maintenance are protected. As such the engineering design of the Spinifex Ridge project will incorporate site-specific surface water controls including diversion and dispersion mechanisms, and erosion and sedimentation controls.

The landforms will generally be placed outside the (Coppin Creek) 100 year ARI flood limit / floodplain. Top surfaces will be shaped to maximise water run-off and minimise (vertical) seepage into the landforms, which might come into contact with PAF rock.

Where waste landforms or tailings storage facilities are placed over drainage/creek lines, then water ponding at the rear of the landforms therefore needs to be managed. It is proposed to drain larger catchments by constructing rock drains beneath the landforms, by placing readily available large, clean, blocky fill along the existing creek lines (in particular).

Rock drains requiring free draining, open graded, hard rock rock-fill construction material, good control of the materials used within the critical areas, and a high level of commitment and field control by construction personnel. A capacity of $1.0m^3/s$ per $100m^2$ of cross sectional area has been adopted (assuming a hydraulic grade line of 0.01).

Based on level pool routing concepts, the required capacity of the rock drains may be selected from a range of stored water (pond volume trapped behind the landform in the 100 year ARI flood event) versus the flow capacity of the rock drain.

There are a number of major bunds required. To protect the main pit from floodwaters, substantial diversion bunds are required on Coppin Creek upstream and downstream from the pit. Upstream of the pit, a bund adjacent to the pit, and a bund at the creek diversion will form a contained cut-off area of the creek, that will be used to store seepage and surface water flows from Landform 1 and Landform 2.

Another bund is required where the proposed Coppin Creek diversion channel cuts across a creek line on its north west side.

Collection systems (bund / channel systems and rock drains) are required to collect water passing beneath the waste landforms, water seeping through the landform and water running off the top surfaces, and direct them to the Coppin Creek cut-off and sedimentations, as required.

FIGURES

APPENDIX A

REPORT 058A (AQUATERRA, OCTOBER 2006): RELEVANT FIGURES RELATING TO COPPIN CREEK DIVERSION

NOTE: Pit outlines in Appendix A are superseded/subject to change.