HALPERN GLICK MAUNSELL PTY LTD

FORTESCUE IRON ORE PROJECTS

ASSESSMENT OF MINESITE SURFACE WATER AND GROUNDWATER ISSUES

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1. Introduction

1.1 Background

Austeel Pty Ltd propose to develop an iron ore mining and processing operation located some 70km southwest of Karratha on the Northwest Pilbara coast. The project, referred to as the Fortescue Iron Ore Projects, is based on three major magnetite orebodies, known as the Central, Southern and Northern Blocks. Initial project development will involve the mining of the Central Block only.

The orebodies are contained within the Brockman Iron Formation that outcrops as a series of basement ridges flanking the Fortescue River floodplain, extending from Balmoral north-northeastwards to Point James on the coast. The open pits are planned to go some 250 to 300m below ground level. This will put the pits some 220 to 270m below the local and regional water table.

It is proposed that the main project water demands will be met by desalinated seawater, although this would be supplemented by any water of suitable quality for a range of purposes that may be derived from pit dewatering.

The project also includes a transport corridor to a port facility to be constructed at Cape Preston.

As part of the overall project approvals, Austeel are required to produce a Public Environmental Report (PER). Halpern Glick Maunsell Pty Ltd (HGM) were commissioned by Austeel to complete the PER on their behalf. HGM engaged Aquaterra Consulting Pty Ltd to assist them with the minesite surface water and groundwater components of the PER.

This report presents the results of investigations and assessment completed to date.

1.2 Approach to Investigation

Preliminary review of the project proposal and background hydrological and hydrogeological conditions at site suggested that surface water and groundwater impacts would not be significant issues. As such, the approach to the investigation was structured to include a desktop assessment of the issues with limited fieldwork to provide some recent and site specific data, with provision for additional investigations if significant impacts were indicated.

The scope of works for the initial investigation programme included the following:

- Initial site visit with HGM project manager to inspect the mine site and surrounding areas, collate available background information and mapping, and brief site project personnel on surveying requirements;
- Follow-up site visit to conduct a field survey of groundwater levels and water quality, and undertake simple permeability testing in selected exploration boreholes;
- Descriptions of the existing hydrological and hydrogeological regimes;
- Flood analyses to assess the potential impacts of floods on project infrastructure and the potential impacts of the project on the Fortescue Floodplain;

- Assessment of the effects of tidal/storm surge on the above analyses;
- Determine the need for water treatment (eg. settling basins) to ensure that site discharges meet expected licence conditions;
- Assessment of general dewatering requirements, including estimated total dewatering volumes and likely changes in water quality, and the need for management of disposal of water in excess of water supply demands;
- Prediction of the scale of impact of pit dewatering on the local/regional hydrogeological system(s) during operations and development of impact management strategies;
- Description (semi-qualitative) of the long term impacts of decommissioned pits (below water table) and tailings storages on the local regional hydrogeological system(s), with particular emphasis on potential salinity increases;
- Provision of an overview of monitoring needed to quantify predicted impacts.

The results of the above did not point to the need for additional investigations at this time.

2. Surface Water

2.1 Investigations

Background surface water information for the project area comprises streamflow gauging data for the Fortescue River, aerial photography and published 1:50,000 topographical mapping. To supplement this data, a one-day site visit to the project development area and lower Fortescue River area was conducted in February 2000. Access to the Fortescue River and adjacent flow channels was restricted, due to the wet site conditions (from recent flooding) and lack of access tracks. However, from the topographical mapping and the limited observations obtained, sufficient information has been obtained to describe the general surface water conditions in the project area.

To provide a reliable assessment of the Fortescue River flood levels, detailed survey cross-sections of the river channel and floodplains are required, however, these could not be obtained due to the wet site conditions. Instead, the 10m contours taken from 1:50,000 topographical mapping were used to develop approximate flow cross-sections and profiles for the site. A survey cross-section of the river and adjacent floodplains, covering the gas pipeline route that crosses the Fortescue River over 15km upstream from the main project development area, was obtained from Epic Energy. This data was used as a reality check on the approximate cross-sections estimated from the topographical mapping.

Streamflow data for the lower Fortescue River was obtained from the Water and Rivers Commission, Jimbegnyinoo Pool gauging station (site 708003), which has been operational since 1969. This gauging station is located just upstream from the North West Coastal Highway Bridge. The Water and Rivers Commission (Joanne Gregory, fax dated 24/11/99) provide flood flow estimates for the lower Fortescue River of 3080m^3/s and 5320m^3/s for the 10 year and 100 year annual recurrence interval (ARI) flood events respectively, based on data from this gauging station.

2.2 Existing Hydrological Regime

The project area is located adjacent to the lower Fortescue River, which has an effective catchment area of approximately 20,000km^2. The total Fortescue River Basin has a catchment area of around 50,000km^2, however, the upper portion of this basin drains only as far as the Fortescue Marsh Area, approximately 350km from the coast, and does not drain into the lower Fortescue River (WRC, 2000).

Upstream from the North West Coastal Highway, the Fortescue River is generally contained between high ridges. However, downstream from the Highway, the topography becomes less pronounced and the river flowpath less constrained. During large flood events, river flows will break away from the main flow channel and extend over the adjacent floodplains. Through the floodplains, numerous smaller flow channels have developed discharging in the same general direction as the main channel.

The Fortescue River adjacent to the project area has a well defined main flow channel, typically 4 to 6m deep and around 100m wide. The main channel has a gravelly bed and typically has gum trees along both banks, except near the tidal river mouth where mangroves grow along the banks. Vegetation over the floodplains varies. Some sections contain wide open grass areas with scattered trees, while other sections comprise dense scrub. The Edward and Du Boulay Creeks flow in a northwesterly direction through the general project development area and discharge into the Fortescue River. These creeks, which drain ridges located to the east and southeast from the project area, have catchment areas of approximately 30km^2 and 210km^2, respectively. Near the project areas, both creeks typically have main flow channels with 5 to 10m width gravel beds and trees along the banks. Floodplains adjacent to the creeks typically comprise open grassed areas with scattered trees.

Rainfall runoff from the steep ridges located within the general project area would tend to be rapid and short lived. These steep and incised drainage lines typically link into lower energy flow channels located around the perimeter of the ridges and then drain to the main Fortescue, Du Boulay or Edward systems, or directly to the coast. Tidal levels at the Fortescue River mouth vary between a mean high water spring of approximately 1.8m AHD and a mean low water spring of approximately –1.9m AHD. These levels cause inundation over the coastal tidal marshes.

2.3 Potential Flood Heights

2.3.1 Fortescue River

Flood levels in the Fortescue River adjacent to the general project development area have been estimated using the HEC-RAS computer program. The HEC-RAS program provides a back-water analysis model for open channel flow with input data including flow cross-sections, waterway roughnesses, discharge and starting water level. The flow cross-sections for the model were estimated from 10m contours on the 1:50,000 topographical mapping, hence they are very approximate. Waterway roughnesses were estimated from limited site observations and aerial photography. Peak flood discharges of 5320m^3/s and 3080m^3/s representing the 100 year ARI and 10 year ARI events respectively, were used for the analyses. The model results were not sensitive to realistic variations in the downstream starting water level.

Indicative 100 year ARI flood levels obtained from the model for the lower Fortescue River, and the approximate area of inundation are shown in Figure 2. The 10 year ARI flood levels are estimated to be around 0.5 to 1.0m lower than the 100 year ARI levels. Due to the approximate nature of the flow cross-section and roughness data used in the model, these flood levels can only be considered as indicative. However, they are likely to be accurate to within +/-2m and provide a good indication of the Fortescue River flooding regime through the project area.

The estimated 100 year ARI flood levels show that flood flows break away from the main river channel and adjacent floodplains, for these extreme flood events. A main breakaway zone exists around 3 to 4km upstream from Balmoral Homestead where peak flood levels would tend to overspill to the northwest. Adjacent to the project area, several flood flow channels have developed. During peak flood events, flow widths of several kilometres are likely to develop.

Peak flows in the main river channel during the 100 year ARI flood event are estimated to be between 6 to 8m depth adjacent to the project area. Peak main channel average flow velocities are estimated to vary between around 2.5m/s in the downstream areas containing wide floodplains and around 5.0m/s in the more confined upstream areas. Corresponding 100 year ARI average flood depths and velocities over the floodplains are around 1 to 2m depth and 0.4 to 0.8m/s respectively. Where defined flow channels have developed over the floodplains, flow depths and velocities will likely be significantly higher.

2.3.2 Edward and Du Boulay Creeks

The runoff response of the Edward and Du Boulay Creeks would be significantly faster than the main Fortescue River, due to their smaller catchments. Consequently, flood flows on the Edward and Du Boulay Creek systems would typically peak and then be in recession before the main Fortescue River reaches its peak.

Peak discharges and flood levels in Edward Creek have been estimated based on catchment characteristics and field observations of the creek hydraulic parameters. However, detailed ground survey data of the creek is not available and any flood level estimate can only be approximate. Where Edward Creek enters the project area (plant site), preliminary estimates of the peak 10 year and 100 year ARI discharges are around 55m^3/s and 185m^3/s respectively. Along the main flow channel, these discharges are estimated to produce flood depths of typically 2 to 3m with average velocities of around 2 to 2.5m/s for the 10 year ARI flood event. For the 100 year ARI flood event, main channel flow depths are estimated to typically be 3 to 4m and average flow velocities around 2.5 to 3m/s. Flow depths and velocities will vary along the creek line depending on the actual channel and floodplain cross-section. Over the creek floodplains, flow depths and velocities will be lower than in the main channel. Average floodplain flow velocities are estimated to be around 0.5 to 1m/s for the 10 year ARI event and 1 to 1.5m/s for the 100 year ARI event.

In a similar manner, peak flood flow depths and velocities have been estimated for Du Boulay Creek, again based on very limited data. These flow depths and velocities are typically less than those for the Edward Creek, due to the less steep mainstream gradient and less incised channel. Where Du Boulay Creek enters the project area (Tailings Dam), the preliminary estimate of peak 10 year and 100 year ARI discharges are around 140m^3/s and 750m^3/s respectively. For the 10 year ARI event, this discharge is estimated to produce a peak flow depth of approximately 2m in the main flow channel, with an average velocity around 1.5 to 2m/s. For the 100 year ARI event, the main channel peak flow depth is estimated to increase to approximately 3m, with an average flow velocity around 2 to 2.5m/s. Over the creek floodplains, corresponding peak flow depths and flow velocities would be lower than in the main channel, with average velocities estimated to be around 0.3m/s and 0.6m/s for the 10 year and 100 year ARI event respectively.

2.4 Potential Tidal/Storm Surges

Normal tidal variations cause inundation over the saline coastal flats and coastal intertidal flats. Mean spring tide levels vary by approximately +/-1.8m, and mean neap tide levels vary by approximately +/-0.5m, from mean sea level. The highest and lowest astronomical tides, which are the highest and lowest tidal levels which can be predicted to occur under average meteorological conditions, vary by approximately +/-2.5m from mean sea level. Under abnormal meteorological conditions, greater variations in the tidal range are possible.

During severe storm conditions, storm surges and breaking waves can cause an additional increase in coastal sea levels. Storm surges are predominantly generated by wind stresses. These wind stresses induce ocean currents which, if blocked, cause water build up and elevated ocean levels. Low atmospheric pressures also cause ocean water levels to rise. Actual sea levels are produced by the interaction of astronomical tides, storm surges and wave set-up. These interact non-linearly to produce total sea levels that are lower than the sum of the individual components.

The project development area is prone to tropical cyclones and associated storm surge flooding. A direct hit from a cyclone such as Vance (1999), which passed over Exmouth, would cause considerable flooding in low lying areas from storm surge. It is reported that a storm surge of around 6m was experienced in the Exmouth area from Cyclone Vance.

A preliminary investigation on the potential impact of tropical cyclone storm surge on coastal flooding for the project development area has been undertaken by Global Environmental Modelling Systems (GEMS). For this investigation, GEMS used inhouse computer modelling to simulate the effect of Cyclone Vance crossing the coast, at mid-tide (0.0m AHD), at the mouth of the Fortescue River. The modelling results, which are given in Appendix A, suggest a worse case outcome of storm surge flood levels at 6.5m AHD. From discussions with GEMS, this would likely translate to an inland flood level around 7.0m AHD. If the cyclone coincided with a high tide, the storm surge flood level could increase to around 8m AHD.

GEMS are not able to assign a probability to this type of event occurring at this location, without undertaking considerably more detailed studies. Cyclones with an equal magnitude to Vance are not uncommon (eg. John – 1999, Olivia –1996), however, when they cross the coast the extreme surge effect is only likely to spread over a 20 to 40km strip. Based on their experience, GEMS feel that a storm surge of 6.5m would likely be more extreme than a 100 year ARI event, for the project development area.

The preliminary investigation undertaken by GEMS predicts that flooding from an extreme cyclonic storm surge event combined with a high tide, could extend to around 8m AHD, inland from the coast. Topography plans (1:50,000) for the project development area show that all proposed facilities for the Austeel project are located above the 10m AHD contour. Based on this preliminary assessment, the proposed project development is not likely to be subjected to impact from cyclonic storm surge events. Peak discharges from the main river systems, due to their catchment response times, are unlikely to coincide with the peak storm surge arising from a cyclonic event. Hence it is not reasonable to combine the influences of these two events.

2.5 Site Runoff

Local runoff from the project infrastructure areas will be collected and treated to remove sediments to acceptable levels prior to release to the natural environment. Alternatively, some runoff will be used for site process water. 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.

2.6 Impact Management Strategies

2.6.1 Potential Impacts

The waste dumps for the project are proposed to be located to the west of the main pit area, completely blocking the Du Boulay Creek and partially blocking the Fortescue River eastern floodplain (Figure 2). The Du Boulay Creek and associated tributaries are also completed blocked by the proposed tailings dam. Du Boulay Creek potentially carries a large flood discharge and major creek diversion works will be required to enable drainage of the catchment. Flood diversion works will also be required around the 20 year and 40 year waste dumps to protect against flood flows in the Fortescue River system. The partial blockage of the Fortescue River eastern floodplain, although creating some local flood level increases, is predicted not to cause a measurable increase in flood levels along the main river system.

The proposed plant site is located across Edward Creek completely blocking the catchment outlet (Figure 2). Although smaller than Du Boulay Creek, Edward Creek still carries a potentially large flood discharge that will need diverting around the development area.

The proposed pit development area is located on the western flank of a ridge which drains to Du Boulay Creek and the Fortescue River system (Figure 2). The proposed pit intercepts numerous small incised drainage lines which drain runoff from the ridge. Upslope from the pit boundary, these drainage lines typically have very small catchments, which will need to be intercepted and diverted to prevent external runoff entering the pit.

The future waste dump area, sited east from the proposed plant site, is partially located on a ridge area and is mostly away from the main drainage pathways (Figure 2). Numerous small incised drainage lines which originate from within the dump footprint area (and drain the ridge), will be buried under the dump. Drainage from areas external to the waste dump which will be intercepted by the development, will need to be diverted around the dump footprint.

2.6.2 Drainage Management Strategies

Du Boulay Creek, upstream from the proposed tailings dam, needs to be diverted to enable drainage of the catchment. Two diversion options have been considered. The first option is to divert catchment runoff around the eastern side of the tailings dam and then around the northern side to rejoin the existing creek channel downstream from the tailings dam. The second option is to intercept Du Boulay Creek just upstream from the tailings dam and divert all runoff to the southwest to flow around the southern side of the main ridge (near to Balmoral Homestead) and into the Fortescue River.

The preferred diversion is the second option because it would likely require less engineering works to develop and because it significantly reduces the flow in the lower Du Boulay Creek making diversion works around the proposed waste dumps less extensive. The effect of the diversion on flow redistribution in the main Fortescue River would be insignificant. However, the additional discharge in the existing drainage pathways south from Balmoral Homestead would likely result in some readjustment of the natural drainage channels. Diversion works although less extensive, would still be required around the eastern and northern sides of the tailings dam to drain runoff from the local catchments.

Fortescue River eastern floodplain (and floodplain channel) flows will be diverted around the western side of the 20 year and 40 year waste dumps. These diversion works will likely comprise an excavated channel to link the existing upstream and downstream natural channels, plus bunds with rock armouring around the dump perimeter. Du Boulay Creek flows (probably significantly reduced due to upstream diversion works) will be diverted around the south of the waste dumps and link into the Fortescue River diversion works. These diversions will also likely comprise an excavated channel with bunding.

Edward Creek will be either diverted around the eastern and northern sides of the plant site, or accommodated within the development by appropriate hydraulic engineering design. These diversion works will also intercept discharges from local catchment to the plant site. Natural peak flood flow velocities in the main creek channel are estimated to be relatively high (2.5 to 3.0 m/s for 100 year ARI event), hence all diversion works would likely need to be rock armoured.

The numerous small incised drainage lines upslope from the Austeel pit eastern boundary, will be intercepted and drained to the south around the pit boundary. An excavated channel will direct these discharges in to the Du Boulay Creek diversion works.

Drainage external to the future waste dump footprint will be diverted around the dump boundary to join into existing natural pathways.

Drainage from disturbed zones within the project infrastructure areas which potentially contains sediments, will be collected and treated to remove sediments prior to release to the natural environment. Where practical, site drainage will be used for process water.

3. Groundwater

3.1 Investigations

The following assessment of groundwater issues is based on a review of site/area specific background reports, Aquaterra's experience in the Pilbara region in general, and on the results of limited recent site investigations.

3.1.1 Background Review

Information reviewed included:

- Reports on the groundwater resources of the area by Bradberry Associates (1965) and GSWA (1989, 1993).
- Report by Ypma (1992) on the geology of the Central Block, including water quality data.
- Published geological and topographical maps.
- Site maps (by Thiess, 1996) showing minesite geology.

3.1.2 Site Investigations

During the initial (one-day) site visit in February 2000, drill core/cuttings were inspected and discussions held with the project geologist who was supervising a resource evaluation infill-drilling programme at the time. Groundwater levels were measured in mineral exploration boreholes and water samples were bailed from several boreholes and electrical conductivity (EC) measured. The EC of pumped water samples from several station wells was also measured during a general inspection of the project area. Results are included in Appendix B.

Following this initial site visit, airlift yields were recorded and water samples collected from the remaining RC boreholes in the programme by the project geologist. The EC of these samples was later measured in the Austeel project office in Karratha.

A second four-day site visit was undertaken in April 2000, during which time the following were undertaken:

- Survey of groundwater levels in mineral exploration boreholes over the Central Block area and in accessible station wells and monitor bores from previous investigations in the area. Results are included in Appendix B. Note that due to flooding of the Fortescue River floodplain, it was not possible to access old GSWA monitor bores on the floodplain.
- Rising head tests on selected mineral exploration boreholes in the Central Block area to provide direct estimates of insitu permeability of the orebody and footwall/hanging wall rocks. Test procedures, data and analysis results are included in Appendix C.
- Collection of water samples from selected mineral exploration boreholes and other bores with field measurements of EC. Selected samples were also submitted for laboratory analysis. Results are included in Appendix B. Laboratory reports are included in Appendix D.

3.2 Existing Hydrogeological Regime

3.2.1 Geology

Figure 3 shows the surface geology in the general project area. The eastern part of the area is characterised by two series of north-northeasterly trending ridges of outcropping Lower Proterozoic aged rocks of the Mount Bruce Supergroup, which are part of the Hamersley Basin. These rocks dip steeply to the west-northwest and become generally younger from east to west, although there are numerous minor faults in the area that have resulted in some repeats of stratigraphic horizons. There is also one major fault parallel to the regional strike, and located between the two series of ridges, that has resulted in the absence of several major stratigraphic units.

The eastern, and highest series of ridges are formed by the Kylena and Maddina Volcanics which comprise basalts and tuffs. The western series of ridges are made up of banded iron formation (BIF), cherts, shales and breccias of the Brockman Iron Formation (and to a lesser extent the underlying Mount MaCrae Shale-Mount Sylvia Formation). Three main orebodies have been identified; the Central, Northern and Southern Blocks. These are high-grade magnetites that have developed within the Joffre Member of the Brockman Iron Formation. A thin veneer of Quaternary aged alluvial, colluvial and residual soils overlies the basement rocks in low lying areas, with some creek bed alluvium along drainage courses.

Figure 4 shows the surface geology in the area of the Central Block. This shows the mapped distribution of the main units in the Brockman Iron Formation and the underlying Mount McRae Shale-Mount Sylvia Formation. In the project area, the mapped sequence, from youngest to oldest is:

- Breccia- which appears to be the local equivalent of the Yandicoogina Shale
- Joffre Member- in which the magnetite orebodies have developed
- Whaleback Shale
- Dales Gorge Member- BIF, chert and shales
- Shales- shales, breccia and BIF which appear to be a local equivalent to lower units of the Dales Gorge Member
- Mount McRae Shale-Mount Sylvia Formation- shales and BIF

As outlined above, there are numerous faults (both strike-slip and dip-slip faults) and significant strike slip has resulted in the several repeats of the Joffre Member across the mine site area. Many of the fault planes have been intruded with dolerites.

The western part of the project area lies on part of the Fortescue River floodplain. This is underlain by a sequence of sediments. The lower most unit is the Cretaceous aged Yarraloola Conglomerate, which comprises rounded gravels with minor sands and clays. This unit forms part of the Carnarvon Basin and unconformably overlies units of the Mount Bruce Supergroup that are stratigraphically higher (younger) than the Brockman Iron Formation (Weeli Wolli Formation and possibly others). The Yarraloola Conglomerate is unconformably overlain by the Tertiary aged Trealla Limestone, which comprises clays, marls and crystalline limestone. This is unconformably overlain by the Quaternary aged Fortescue River alluvium, which forms an alluvial fan extending from basement outcrops, that border the coastal plain, to the coast. The alluvium includes gravel bed-load deposits in the present and past riverbeds and overbank deposits of silty clays with some sands and gravels. There are also calcrete deposits over the zone of water table fluctuation and some colluvial deposits on the flanks of the major ridges.

Figure 5 shows a section through the project area.

3.2.2 Aquifer Characteristics

A summary of the hydrogeological properties of the various geological units outlined above is presented in the table below.

Age	Unit	Comments
Quaternary	Fortescue River Alluvium	-Gravels form major aquifer with high permeability. -Aquifer covers extensive area beneath floodplain. -Groundwater is fresh in most of floodplain area. -Groundwater is marginal to brackish on edge of floodplain. -Groundwater is brackish to saline at depth near coast.
	Eluvium-Residual Soils	-Mostly above the water table. -Forms local aquifer where saturated, connected to alluvium.
Tertiary	Trealla Limestone	-Aquitard. -Forms confining layer to Yarraloola Conglomerate. -Forms base of overlying alluvial aquifer.
Cretaceous	Yarraloola Conglomerate	-Confined aquifer with moderate to low permeability. -Forms narrow channel aquifer in old river course. -Intersected in three GSWA bores. -Groundwater is fresh in these bores.
Proterozoic	Weeli Wolli Formation	-Indurated rocks with no primary porosity or permeability. -Some minor fracture induced secondary aquifer properties. -Not aquifers in project area. -Groundwater is marginal to brackish in mine area.
	Brockman Iron Formation	
	Mt McRae-Mt Sylvia Formation	
	Maddina Volcanics	

The major aquifers in the project area are the gravels of the Fortescue River alluvium and to a lesser extent the Yaraloola Conglomerate. Previous investigations (Commander, 1993 and Bradberry Associates, 1965) indicate that the alluvium is potentially a major source of fresh water and could support substantial pumping. Aquifer permeabilities in excess of 50m/d and bore yields of up to 900kL/d each have been demonstrated. Sustainable abstraction of around 10,000ML per year has been estimated. Numerous station wells and bores in the area tap this aquifer.

The Yarraloola Conglomerate is much less extensive than the shallower alluvium in the project area and appears to be limited to a narrow channel. Permeabilities of less than 2m/d have been indicated, although the water quality, where tested, appears to be as good, if not better than in the alluvium.

As outlined in the above table, there are only minor secondary aquifer properties in the Proterozoic basement rocks, associated with fracturing. There are some station wells and bores in areas of subcropping basement, although much of the water yielded by theses is likely derived from the overlying eluvium (residual soils).

From discussions with project geologists, none of the mineral exploration drill-holes in the Central and Northern Blocks made significant water (in the case of RC holes) or lost significant water (in the case of diamond drill holes). In fact most of the holes drilled “dry” with only a few holes making any measurable water. The maximum flow recorded was around 2L/s (or 170kL/d) in drill-hole A7 in February 2000. It has also been reported that water levels measured in many RC mineral exploration holes, drilled in the Central and Northern Blocks in 1992, remained below sea level some weeks after drilling. This indicates a very slow recovery rate for groundwater levels, which further indicates low bulk aquifer permeability.

The results of recent rising head permeability tests (refer Appendix C) provide some quantitative estimates of bulk permeability and transmissivity. Test results indicate permeability in the order of 10^{-2} m/d (full units are $m^3/d/m^2$) for the holes tested. Given the depths of the holes tested (all around 100m or so), these data indicate a very low transmissivity of around $1m^2/d$ (full units are $m^3/d/m$). However, the drill-holes tested showed much quicker recoveries than was indicated in earlier investigations, and the recent test results are considered likely to represent upper limits to the range of permeability and transmissivity across the site.

The tightness of jointing and fracturing apparent in drill-core inspected on site and as reported (and as confirmed by the low groundwater yields and permeabilities) suggest that the Basement Rocks in the pit area are not suitable for stygofauna habitat, although no specific testing has been carried out to date.

3.2.3 Groundwater Flow

Figures 6 and 7 show water table contours based on recent field survey data and historical records. Groundwater flow in the region is generally from southeast to northwest towards the ocean, with local groundwater flows being influenced by topography, recharge and discharge zones.

Proterozoic basement rocks- These aquifers are recharged by the infiltration of rainfall and local runoff in areas of outcrop and via leakage from overlying residual soils and sediments in areas of subcrop. These aquifers discharge by baseflow to local drainages and by throughflow to the Fortescue River alluvium and coastal sediments. As such groundwater flow in the basement rock aquifers is generally from topographic highs towards the Fortescue River and the coast, with some local convergence about creeks during non-flood periods. Based on hydraulic gradients indicated by groundwater level contours on Figure 7, and the transmissivity indicated by rising head testing (refer Appendix C), the groundwater throughflow in the basement rock aquifers in the minesite area is around 5kL/d per km (width of flow section).

Fortescue River alluvium- This aquifer, and deeper sediments on the main floodplain, are mostly recharged by the infiltration of river flow, although there is some minor direct infiltration of rainfall and some throughflow from flanking basement rock aquifers. These aquifers discharge by baseflow to the Fortescue River during periods when the water table is above the riverbed and above river water levels, and by evapotranspiration. The latter occurs via vegetation on the floodplain and also as direct evaporation from the near shore tidal flats where the fresh groundwater flows up to the surface above a saline water interface (refer next section). As such, groundwater level contours tend to be parallel to the coast with flow in a northwesterly direction, although there is local divergence of groundwater flow away from the main River channels at times of river flow and local convergence of groundwater flow about the River channels in periods of little to no flow. The groundwater throughflow in the main aquifer (gravels) in the alluvium has been estimated (Commander, 1993) at up to 9.2GL/yr (an average of around 25ML/d).

3.2.4 Groundwater Quality

Appendix D presents the laboratory reports for water samples collected from Central Block drill-holes and some nearby station wells) in April 2000, and from Central Block drill-holes in September 1993. Appendix D also includes tabulated results of analyses of water samples collected from drill-holes in the Central and Northern Blocks in 1992. The results of analyses of water samples from bores in the Fortescue River alluvium (Commander, 1993) were also reviewed.

The distribution of groundwater quality is best illustrated by salinity. Figure 8 shows groundwater salinity contours based on the April 2000 field survey results and earlier (pre-1993) results for the Fortescue River alluvium bores. There are basically three groundwater quality types in the region:

- Fresh groundwater (<1,000mg/L TDS) in the central part of the Fortescue River alluvium. This fresh water forms a “lobe” elongated along the main channels of the River as a result of recharge.
- Marginal to brackish groundwater (1,000 to around 2,000mg/L TDS) in the basement rock aquifers and on the flanks of the Fortescue River alluvium where throughflow from the basement rocks mixes with the fresh water in the alluvium.
- Brackish to saline groundwater (greater than 5,000mg/L TDS) adjacent to the coast, where there is a saline water interface between the fresh groundwater flowing northwards and seawater. This interface dips to the south (ie inland) forming a “salt water wedge” and groundwater salinity would increase with depth in the near coastal and tidal flats areas.

Groundwater quality data from the Basement Rock aquifers (from 1993 and 2000) is graphically plotted (Expanded Durov Plots) on Figures 9 and 10. These plots indicate the groundwater to be a predominantly sodium chloride type water which has evolved by simple dissolution or mixing since recharge of rainfall. Analysis of the data also shows no relationship between reported salinity and depth of drill-hole.

Comparison of the reported laboratory data with the Western Australian Water Quality Guidelines for Fresh and Marine Waters in relation to drinking water and livestock water guidelines indicates the following:

Fortescue River alluvium- Apart from at the flanks of the floodplain and in the near coastal zone, the groundwater quality conforms to the drinking water guidelines.

Basement Rocks- Apart from one drill-hole in the Central Block area (A11), the groundwater sampled from the basement rock bores and wells exceeds drinking water guidelines, mostly in relation to salinity (TDS) and chloride. However some of the samples collected in 1993 and 1992 also reported elevated (with respect to the guidelines) values for sulphate (M7, CB1, CB2, NB2, NB2A, NB3 and NB4), manganese (M7, M15, M16, M23, CB1, CB2, PHD10, NB2, NB2A, NB4 and BAL17), barium (M9), nickel (M11), boron (M11) and cadmium (M7).

However, apart from several exceptions, all the groundwaters sampled are within the guidelines for stock water usage. The exceptions are some of the GSWA monitor bores located on or adjacent to the tidal flats, and basement rock bores M7 (salinity, magnesium and calcium), M9 (cadmium), M23 (salinity) and NB4 (magnesium). However, we believe that the water quality results for Central Block drill-holes M7 and M23 are likely to be a reflection of contamination by drilling fluids rather than in-situ groundwater quality, especially given that nearby drill-holes report much lower salinities.

It should also be noted that the NB prefix drill-holes are in the Northern Block area and, while we do not have precise locations, reports (Ypma, 1992, 1993) indicate that these drill-holes are very close to the coast and tidal flats.

3.2.5 Beneficial Use

Based on the groundwater quality data discussed above, the highest beneficial use of the existing local and regional groundwaters is:

- Fortescue River alluvium (central parts)- potable usage.
- Basement Rock aquifers (including mine site areas)- stock usage.

However, these beneficial uses do not preclude other uses for the groundwater.

3.3 Water Supply

Estimated total project water demand is around 34GL/yr, of which 18GL/yr would be used in mining, initial beneficiation (concentrator) and the HBI plant. At this stage, it is proposed that the bulk of the raw water supplies for mining and processing would be sourced from the ocean via a desalination plant, although this would be supplemented by any water of suitable quality derived from pit dewatering. The only impact of water supply pumping on the mine site area, then, would be dewatering pumping. This is discussed in Section 3.4.

The potential impacts of the importation of desalinated water and disposal of process water in tailings is covered in Section 3.6.

However, given the indicated supply potential of the Fortescue River alluvium aquifers, this source could supply up to one third of the raw water demand. The potential for using the local groundwater resources would be investigated in more detail during the detailed project design stage.

3.4 Pit Dewatering

As outlined in Sections 3.2.2 and 3.2.3, the basement rocks which make up the ore host sequence, the footwall and hanging wall are indurated and have little to no primary porosity and permeability. There are some minor secondary aquifer properties associated with faults and fractures, however, mineral exploration drilling in the area has not intersected significant water. Most holes were reported to be “dry”, with very slow recovery of water levels at the completion of drilling and limited hydraulic testing indicated low aquifer permeability and transmissivity.

The pit will be fully developed within the basement rocks (ie no pit walls will be open to the flanking alluvium) and, as such, it is the hydraulic characteristics of the basement rocks that will largely control pit inflows.

However, the proposed open pit could be developed down to around 300m depth below surface, which is around 270m below the current water table. As such, even with low aquifer permeability and transmissivity in the pit walls, there is the potential for measurable pit inflows.

3.4.1 Estimated Pit Inflows

Potential pit inflows were estimated using two analytical modelling methods:

- Equivalent Well model
- WinFlow model

The models assumed the instantaneous development of the pit to full depth and predict steady state (ie long-term) inflows to the full pit. The Equivalent Well model also predicts transient inflows at various times after full pit development.

Base case predictions assumed a transmissivity of 1m^2/d. This is based on the results of the hydraulic testing and assumes that the deepest parts of the sequence intersected by the pit (ie below the depths of the drill-holes tested) contribute little additional permeability. Note, however, that it is considered that this estimate of transmissivity reflects the higher end of the range of transmissivities at site and therefore the base case predictions should be considered conservative (ie they overpredict inflows).

For transient model predictions, a base case specific yield of 0.5% was adopted.

Sensitivity analyses were also undertaken to assess the impact in changes to critical model parameters.

Equivalent Well Model- This method involves the Dupuit-Forchheimer and Thiem equations describing flow to a well. The pit is represented by a large diameter well with equivalent area and volume, and the model approximates the discharge from the pit (via sumps etc) required to maintain water levels at the base of the pit at various times. If it is assumed that the seepage face (of inflows) will be maintained at the pit base, the model can be used to approximate pit inflows. In low permeability aquifers, the seepage face will rarely be at the pit base but rather at some height above the pit floor. As such this method tends to over-approximate inflows.

The model was initially run for steady state conditions assuming that the Fortescue River alluvium would provide a constant source of recharge to the basement rock aquifers at a distance of 1km from the mine. That is, the radius of influence of the pumping out of pit inflows (ie the radius outside which groundwater level drawdowns would not occur) would not expand beyond 1km from the pit.

For base case conditions, the model predicts steady state inflows of 2.1ML/d.

The predicted inflows are linearly related to, and thus sensitive to, assumed transmissivity, so if the transmissivity is half or double that of the base case, the predicted inflows are 1.1ML/d and 4.2ML/d respectively. If the recharge boundaries (and maximum radius of influence) are moved further away from the pit to, say, 2.5km, the predicted inflows are 0.7ML/d.

The model was then run for transient state conditions, assuming that there were no recharge boundaries and that the radius of influence could expand infinitely. For base case conditions, the model predicts inflows of around 1.3ML/d after 10 years and 0.9ML/d after 20 years. The transient model is less sensitive to variations in transmissivity with values of half and double the base case resulting in predicted inflows of 1.2ML/d and 1.7ML/d respectively. However, the transient model is sensitive to specific yield with assumed values 1% and 0.1% resulting in predicted inflows of 2.5ML/d and 0.6ML/d respectively.

WinFlow- WinFlow (Rumbaugh, 1996) is a Windows based two dimensional analytical groundwater flow model based on the Strack function for steady state flow and the Theis and Hantush & Jacob equations for transient flow conditions.

The model was run to predict steady state groundwater flow into the base of the pit, using the line sink package. Head dependent line sinks, with a constant head set at the pit base, were used to simulated flow into pit sumps around the perimeter of the pit base. This package can only predict steady state, and not transient flow conditions, and the results are independent of storativity.

For base case conditions (which include a fixed reference head 1km radius from the pit) the model predicts long term inflows of around 1.3ML/d. As with the Equivalent Well model, the predictions are linearly related to transmissivity.

However, if the fixed reference head (or maximum radius of influence) is moved out to 2.5km radius, the inflow prediction drops to around 0.5ML/d.

Summary- It should be noted that the analytical models make a number of simplifying assumptions and cannot take into account spatial and temporal variations in aquifer parameters or pit conditions. In particular, the steady state model is more conservative in that it assumes symmetrical boundary conditions and the transient model less conservative in that it assumes no boundary conditions. In practice, the radius influence will likely be restricted to within around 1km to the west (as a result of recharge from the Fortescue River alluvium), around 5km to the north (ie. the coastal tidal flats) but be able to expand much further to the south and east. That is, groundwater level drawdowns would not be expected to extend beyond the margins of the Fortescue River alluvium or the coastal tidal flats, but could be expected to expand to the south and east. The models used are not suitable for predicting actual drawdowns at different radii from the pit, however, the indicated aquifer transmissivities are low and very steep "cones of depression" in the water table would be expected around the pit. That is, drawdowns immediately around the pit would be close to the pit depth but groundwater levels would rise sharply with distance from the pit. The water table would also be recharged regularly by surface water flows in the local drainages and measureable drawdowns would not be expected beyond several kilometres from the pit.

The models are, however, considered appropriate to provide order of magnitude predictions of potential inflows.

3.4.2 Dewatering

Given the nature of the basement rocks, advanced dewatering of the pit will not be practical. Rather, the inflows will need to be directed towards pit sumps that can then be pumped to the surface.

Should geotechnical (pit wall stability) conditions require depressurisation of the pit walls, this would most probably be best achieved by lateral drain holes drilled from the base of the pit. These would then drain into the pit and the water collected and removed via the in-pit sump pumping system.

3.4.3 Impact on Groundwater Flows

Overall, the results suggest that inflows in the order of 1 to 2ML/d could be expected from a fully developed mine. In practice, inflows (and groundwater level drawdowns) will commence once the pit progresses below the water table and gradually increase as the pit deepens. This will cause a convergence of groundwater flow lines about the pit and could result in the interception of most of the groundwater throughflow in the Basement Rocks aquifer in the pit area. Some of the groundwater throughflow in the Fortescue River alluvium will also be diverted towards the pit. Assuming (conservatively) that around half the water pumped from the pit derives from the alluvium, this would represent only 4 to 8% of estimated groundwater throughflow in the alluvium.

3.4.4 Impact on Groundwater Quality

Based on the available data, it is not expected that the quality of groundwater inflow to the pit will deteriorate (ie increase in salinity). In fact, the inflow quality could well improve depending on the actual contribution to total pit inflows from diversion of groundwater throughflow from the Fortescue River alluvium.

3.5 Final Voids

For the purposes of this assessment, it has been assumed that the open pit will be left largely as is at the completion of mining. That is, the pit will not have been backfilled or infilled with waste rock from Central Block mining operations, nor will it be infilled with waste rock from future mining operations (ie Northern or Southern Blocks).

3.5.1 Pit Water Level

At the completion of mining and the cessation of sump pumping, the pit will gradually fill with water to a level defined by the long-term balance between inflows and outflows. The inflows will be groundwater flow and incident rainfall recharge. The principal outflow mechanism will be evaporation losses from the free water surface in the pit and from seepage faces on the pit walls. Outflow to groundwater can also occur when if the pit water level recovers sufficiently to be higher than the water table on the down-gradient side of the pit.

However, given the climatic conditions (high evaporation compared to rainfall) and the groundwater flow in the Basement Rocks aquifer (natural flows and predicted pit inflows), losses from the pit will greatly exceed inflows and the pit will become a groundwater sink. Based on published figures for Onslow and Port Hedland, average pan evaporation for the area is around 2200mm/yr, while average rainfall is around 260mm/yr. Allowing for a pan factor of 0.6, this results in a potential deficit (or net loss) of around 1060mm/yr. If this is applied to the pit area (ie assuming the pit is full of water) average net losses would be around 1400ML/yr or around 3.8ML/d. This significantly exceeds the estimated natural (pre-mining) groundwater throughflow in the mine site area and is also some two to four times the estimated maximum pit inflows when the pit is fully developed.

In practice, however, the pit will never fill under natural conditions. At the cessation of sump pumping, the pit will gradually fill as a result of groundwater inflow (which will initially be at rates estimated to be between 1 to 2ML/d), incident rainfall over the pit and runoff from the pit catchment. Initially, the area of the pit water surface will be small and evaporative losses will be lower than inflows, and the pit water level will continue to rise. However, as the pit water level rises the following will act to slow the rate of rise:

- The hydraulic gradients towards the pit will decline, and inflow rates will decline.
- The surface area of the pit water will increase, and evaporative losses will increase.

At some point the evaporative losses will balance total inflows and the pit water levels will stabilise. Given the relative magnitudes of potential evaporation and inflows, the steady state pit water level will be well below the pre-mining water table. Comparison of estimates of potential evaporation losses at various pit water levels using a simple pit depth vs area model, with predicted steady state inflows at various water levels using the Equivalent Well model (and base case conditions), suggests that the pit water level may only recover by about 100m. That is, the pit water level may remain some 170m below the pre-mining water table.

3.5.2 Impact on Groundwater Flows

At the estimated pit water recovery level referred to in Section 3.5.1, evaporative losses are estimated to be around 1.8ML/d. That is, of the same order of magnitude as the requirement for the removal of pit inflows at the end of mining. The impact on groundwater flows, then, will also be similar. That is, the expected impacts would be interception of most of the groundwater throughflow in the Basement Rocks aquifer in the pit area together with interception of up to around 8% of the estimated throughflow in the Fortescue River alluvium.

3.5.3 Impact on Groundwater Quality

As a result of evaporative losses from the pit water surface, the salinity of the water in the pit will increase with time. Using a simple mass balance model, and assuming a final pit water level of 100m above the pit base (or 170m below the pre-mining water table) it is estimated that pit water salinity will increase by around 30mg/L per year. That is, assuming a starting concentration of around 2,000mg/L, the pit water salinity could increase to the following levels with time:

- 10 years: to around 2,300mg/L
- 100 years: to around 5,000mg/L
- 1000 years: to around 32,000mg/L

However, as outlined in Section 3.5.2, the pit will become a groundwater sink. That is, under most conditions, water will flow into the pit, but not out of the pit and so regardless of the salinity of the pit water, there will be little to no impact on groundwater quality outside the pit.

There is, however, the potential for saline water to flow out of the bottom of the pit in the very long term when pit water salinity is sufficiently high that density differences (between pit water and groundwater) are sufficient to overcome normal hydraulic gradients. That is, saline water could “sink” out of the pit and into the Basement Rock aquifer. The saline plume could then migrate away from the pit under the influences of gravity and hydraulic gradients. However, as the pit is a groundwater sink, the hydraulic gradients over a large area will be towards the pit. As such, it is expected that the plume will tend to remain beneath the pit.

Thus, the development of a saline pit lake should not have any impact on groundwater quality, other than in the immediate vicinity of the pit.

3.6 Tailings Dam

Ore processing will include a concentrator process (basically a wash plant), which will produce large volumes of tailings. The tailings slurry will essentially contain fine sand to silt sized particles of the host rock and water. The tailings are to be disposed of into a conventional paddock type tailings dam located to the southeast of the Central Block mining area within the De Boulay Creek valley.

Much of the water discharge to the tailings dam will be recovered (by decant pumping and underdrainage and seepage collection systems) and recycled back to the plant. However, there will be some water that remains entrained in the tailings and there will be some water that may bypass the underdrainage and seepage collection systems. Any water that does bypass these systems will enter the local aquifers (alluvium-eluvium and underlying Basement Rocks) and move down hydraulic gradient. Seepage losses would result in a water table mound beneath the tailings dam and initial flow would be away from the tailings dam in an almost radial pattern. However, the overall hydraulic in the area gradient will be towards the northwest and any seepage will ultimately be towards the Fortescue River alluvium, roughly following the course of De Boulay Creek.

Initially, the seepage water will be fresh (note that process water will be desalinated seawater) and would result in a fresh water plume within the marginal to brackish Basement Rock and local alluvial-eluvial aquifers.

There will be some evaporative concentration of salts in open water areas on the tailings dam and where the phreatic surface within the tailings is close to the surface. However, it is expected that the areas of open water and the phreatic surface will be controlled to minimise water losses (and thus reduce make-up water requirements). Incident rainfall over the tailings dam will also act to partially dilute any salinity build-up within the tailings dam.

It is not expected that seepage from the tailings dam will result in any reduction in the beneficial use of local groundwaters. In fact, seepage may well result in an improvement in groundwater quality in the Basement Rock and overlying alluvial-eluvial aquifers in the vicinity of the tailings dam.

3.7 Impact Management Strategies

3.7.1 Pit Dewatering

As outlined in Section 3.4, sump pumping to maintain dry mining conditions will intercept most groundwater throughflow in the Basement Rocks in the vicinity of the pit and could intercept up to 8% of the groundwater throughflow in the Fortescue River alluvium.

In terms of the Basement Rocks, the nearest station wells are located some 5 to 6km up-hydraulic gradient or across-hydraulic gradient from the pit, and it is considered unlikely that the interception of groundwater throughflow will significantly impact on these wells. However, should regional drawdowns (as a result of pit dewatering) impact on the yield of these wells, fresh water make-up could be supplied to the well troughs via narrow diameter off-take pipes from the main plant water supply.

In terms of the Fortescue River alluvium, there are no existing station wells down-hydraulic gradient of the pit that might be impacted. In fact, it is considered unlikely that the impact of the diversion (towards the pit) of such a small proportion of the total groundwater throughflow could be measured. The range of natural variations in groundwater throughflow, as a result in variations in river flow (and recharge) will greatly exceed the minor proportion of average flow that could be diverted towards the pit.

Monitoring to confirm and quantify any impacts, and to provide data for refinement of predicted future impacts, is recommended in Section 4.

It is proposed, at this time, that all dewatering discharge will be used around the mine site or in the plant process water circuit. As such, there should be no excess dewatering discharge. However, if there becomes a requirement to discharge excess dewatering water, it is proposed that this would be discharged to a point in the Fortescue River within the tidal fluctuation zone.

3.7.2 Pit Void

As outlined in Section 3.5, the pit void will act as a groundwater sink in the long term. Evaporative losses are estimated to be almost as high as final pit dewatering rates and the pit water will eventually become saline over many years. However, as also outlined in Section 3.5, the saline water will largely remain confined within the pit, apart from some possible very long-term density flow of hypersaline water at very low rates downwards out of the bottom of the pit.

Groundwater quality monitoring to confirm and quantify any impacts, and to provide data for refinement of predicted future impacts, is recommended in Section 4.

3.7.3 Tailings Dam

As outlined in Section 3.6, it is not expected that the tailings dam will have any adverse impact on local or regional groundwaters. In fact seepage from the tailings dam will likely result in:

- the development of a local groundwater mound which would have the effect of reducing the potential drawdown impacts of pit dewatering on the two nearby station wells;
- increased groundwater throughflow beneath Du Boulay Creek towards the Fortescue River, which would partially reduce the impact of diversion of groundwater throughflow in the alluvium towards the pit; and
- possible improvement in groundwater quality around the tailings dam.

However, if free water is allowed to remain on the tailings dam for extended periods, the salinity of the water within the tailings could increase due to evaporative concentration. Seepage quality may then be poorer than the surrounding groundwater and a more brackish plume might develop. To reduce the risk of this, it is proposed that the use of tailings return water be prioritised over the use of raw desalinated water. This will also help in achieving maximum possible settled tailings density and tailings dam disposal life.

Monitoring to confirm and quantify any impacts, and to provide data for refinement of predicted future impacts, is recommended in Section 4.

4. Project Monitoring

General surface water and groundwater monitoring programmes are outlined below. These should be initiated before mining commences to provide additional baseline data and continued throughout mining in the area. The precise scope and frequency of monitoring should be confirmed once detailed design of the mine and infrastructure have been completed.

4.1 Surface Water

The Austeel mining activities could potentially increase the surface water runoff sediment loads. Although runoff from all development areas will be collected and passed through a sediment basin, prior to release to the environment, some increase in runoff sediment load could potentially still occur. We recommend that the sediment load in the existing surface water runoff be monitored to provide background data.

The recommended surface water sediment monitoring sites are located on tributary creeks to the Fortescue River, prior to entry to the Fortescue River. These sites are:

- Edward Creek
- Du Boulay Creek
- The creek channel in front of Balmoral Homestead

4.2 Groundwater

It is proposed to install groundwater monitor bores in the following general locations around the pit:

- around the margin of the pit (up to four bores);
- between the pit and potentially affected station wells (three bores); and
- between the pit and the Fortescue River (four bores- one bore each in the Basement Rocks and in the alluvium at the edge of the floodplain, on two transects).

These bores would be monitored to confirm regional drawdown and groundwater quality impacts of dewatering and the final void, and to provide data for refinement of predicted future impacts (ie by trend analysis or groundwater modelling).

Pit water quality would also be measured after the completion of mining of the Central Block pit (while other pits are mined) to provide data on salinity increases with time.

It is also proposed to install groundwater monitor bores at the following general locations in the area of the tailings dam:

- between the tailings dam and the two nearby station wells (two bores);
- upstream of the tailings dam in (or adjacent to) the Du Boulay Creek drainage (one bore) to provide background water quality; and
- downstream of the tailings dam in (or adjacent to) the Du Boulay Creek drainage (two bores).

These bores would be monitored for groundwater levels and quality to confirm local mounding and groundwater quality impacts of tailings disposal, and to provide data for refinement of predicted future impacts (ie by trend analysis or groundwater modelling).

SECTION 5 - REFERENCES

- Bradberry Associates, 1965. *Water Resources of the Lower Fortescue River Area*. Unpublished report to Raymond International and Cliffs International.
- Commander, D.P, 1989. *Fortescue River Coastal Plain Bore Completion Reports*. Unpublished GSWA Hydrogeology Report No. 1989/13.
- Commander, D.P, 1993. *Hydrogeology of the Fortescue River Alluvium*. Unpublished GSWA Hydrogeology Report No. 1993/14.
- Commonwealth of Australia, 1992. *Bilano, Balmoral and Preston Topographical Maps*. Sheets 2155-3, 2155-4 and 2156-3 of the 1:50,000 series.
- Commonwealth of Australia, 1992. *Balmoral Topographical Map*. Sheet 2155-4 of the 1:100,000 series maps.
- Environmental Protection Authority, 1993. *Western Australian Water Quality Guidelines for Fresh and Marine Waters.* EPA Bulletin 711, October 1993.
- GSWA, 1972. *Yarraloola Geological Map.* Sheet SF50-6 of the 1:250,000 series maps.
- Thiess Contractors, 1996. *Interpreted Site Maps showing Geology of Central, Northern and Southern Blocks.* Unpublished maps prepared for Mineralogy Pty Ltd.
- Water and Rivers Commission, 2000. *Surface Hydrology of the Pilbara Region.* Unpublished Report SWH32/2000.
- Ypma, P.J, 1992. *Mineable Ore Reserves of the Central Block of the Balmoral Mining Lease.* Unpublished report to Mineralogy Pty Ltd by YRS Offshore Research Services B.V.

APPENDIX A

Report on Cyclone Storm Surge Investigation

APPENDIX B

Summary of Field Survey Results

APPENDIX C

Rising Head Permeability Test Results

APPENDIX D

Laboratory Analysis Results