# OPEN CUT MINING ADJACENT TO EPHEMERAL CREEK AND SRING SYSTEMS – PILBARA, WESTERN AUSTRALIA.

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***ABSTRACT:*** The Pilbara region, located in the north-west of Western Australia, is significant as the second-largest source of iron ore on the planet. Iron ore mines owned and operated by Pilbara Iron are located within the Hamersley Basin. This paper refers to the Greater Paraburdoo mines, the 4WEST and 4EAST pits, located on the southern margin of the Hamersley basin. The groundwater model refers to ephemeral watercourses: Seven Mile and Pirraburdoo creeks, which are adjacent to the two pits, and Ratty Springs, located upstream from 4WEST and within Pirraburdoo creek.

The spring and creeks hold cultural heritage significance for local Aboriginal communities. Two of these, the Gobawarrah Minduarra Yinhawanga (GMY) and Innawonga native title claim groups, initiated hydrological work on the two creeks and Ratty Springs, with the aim of determining the effects of dewatering on the natural water flows of these systems.

The numerical model used to simulate drawdown in the Pirraburdoo and Seven Mile Creeks was derived from MODFLOW96 with the MT3D96 interface code, using the PMWIN Pro software interface and the PCG2 solver package. The model covered an area of 77 $km^2$, the calibration period was from May 1997 to December 2004, and the prediction period was from January 2005 until December 2015. The model has four layers and incorporated effects caused by mining voids, 4WEST and 4EAST ore bodies, creek bed material, weathered bedrock below creeks and surrounding banded iron formations (BIF). The model has been calibrated using the trail-and-error method set down by (Middlemis et al, 2001). The current dewatering schedule (12 ML/day) in the 4WEST and 4EAST mining areas does not affect the water table levels in the adjacent creeks significantly or for any considerable periods of time.

However, changes to mine plans may occur - for example, in response to changed commodity prices - and may lead to significant increase in rates of vertical advancement. This, in turn, affects dewatering schedules, as greater the vertical advancement requires increased dewatering effort. When an accelerated mine plan is applied to the model and dewatering rates are increased to 18 ML/day, draw-downs in the creeks are more noticeable. The model has therefore helped to indicate the extent to which increased dewatering rates may be acceptable, especially in terms of immediate and longer-term damage to riparian species i.e. Melaleuca and Eucalypt. Predictions from the model may also allow mine planners to schedule decreased rates of vertical advancement, where this is required to meet environmental constraints.

**KEY WORDS**

Groundwater models, dewatering, mining, creeks and springs.

## INTRODUCTION

The Central Pilbara region of Western Australia is located approximately 1,000 kilometres south of Broome and 1,500 kilometres north of Perth. The project area is part of the Greater Paraburdoo mining operations, owned and managed by Pilbara Iron (formally Hamersley Iron), a member of the Rio Tinto group, and covers an area of 77 $km^2$. Pirraburdoo and Seven Mile Creeks and Ratty Springs (located within the Pirraburdoo Creek) are found within the project area (Figure 2).

Both creeks are within the Turee Creek system and are major tributaries to the Ashburton River. The regional stream flow direction is east to west. However, the creeks associated with this project flow north to south.

The Pilbara's rainfall is dominated by cyclonic events and convective isolated thunderstorms in summer (Nov – Mar), while mid-year (May – July) is dominated by scattered rainfall from low-pressure fronts. The majority of rainfall occurs in the summer cyclonic events. The region receives on average between 300 – 500 mm/year, while evaporation is 3,000 – 5,000 mm/year (Figure 1). This determines the region's climate characterisation as hot, semi-arid to arid. Evaporation is highest throughout the summer months. The closest weather station providing evaporation records is Wittenoom, 100 kilometres north of Paraburdoo. Since 1968 the average annual evaporation rate has been 3,102 mm. The greatest deficit between rainfall and evaporation occurs between the months of July and November. Seasonal temperature variation throughout the Pilbara is extreme with winter daily minimums of 0 – 5 and summer maximums 45 – 50 degrees Celsius.

The winter period, characterised by of low rainfall and relatively high evaporation, plus any additional stress from dewatering, presents the greatest risk of stress to the trees within the creeks or at Ratty Springs. At the same time, the water table is at its lowest natural level.

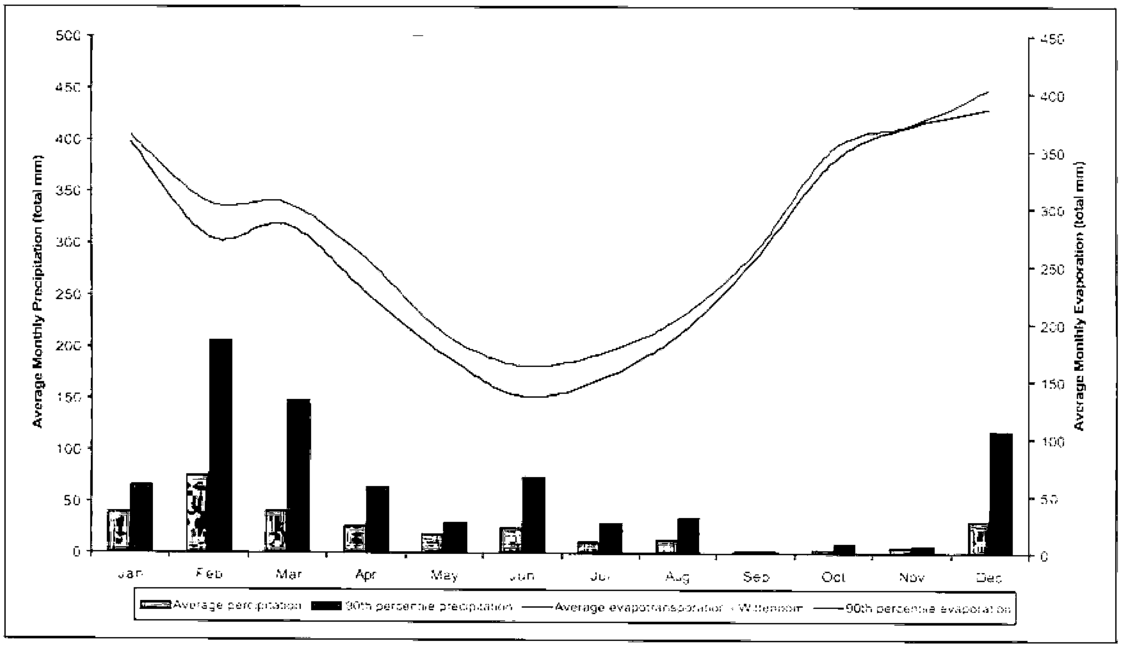



Figure 1. Average and 90th percentile values for rainfall (Paraburdoo BOM weather station) and evaporation (Wittenoom BOM weather station). The average and 90th percentile for evaporation are very similar, while there are extensive differences for rainfall.

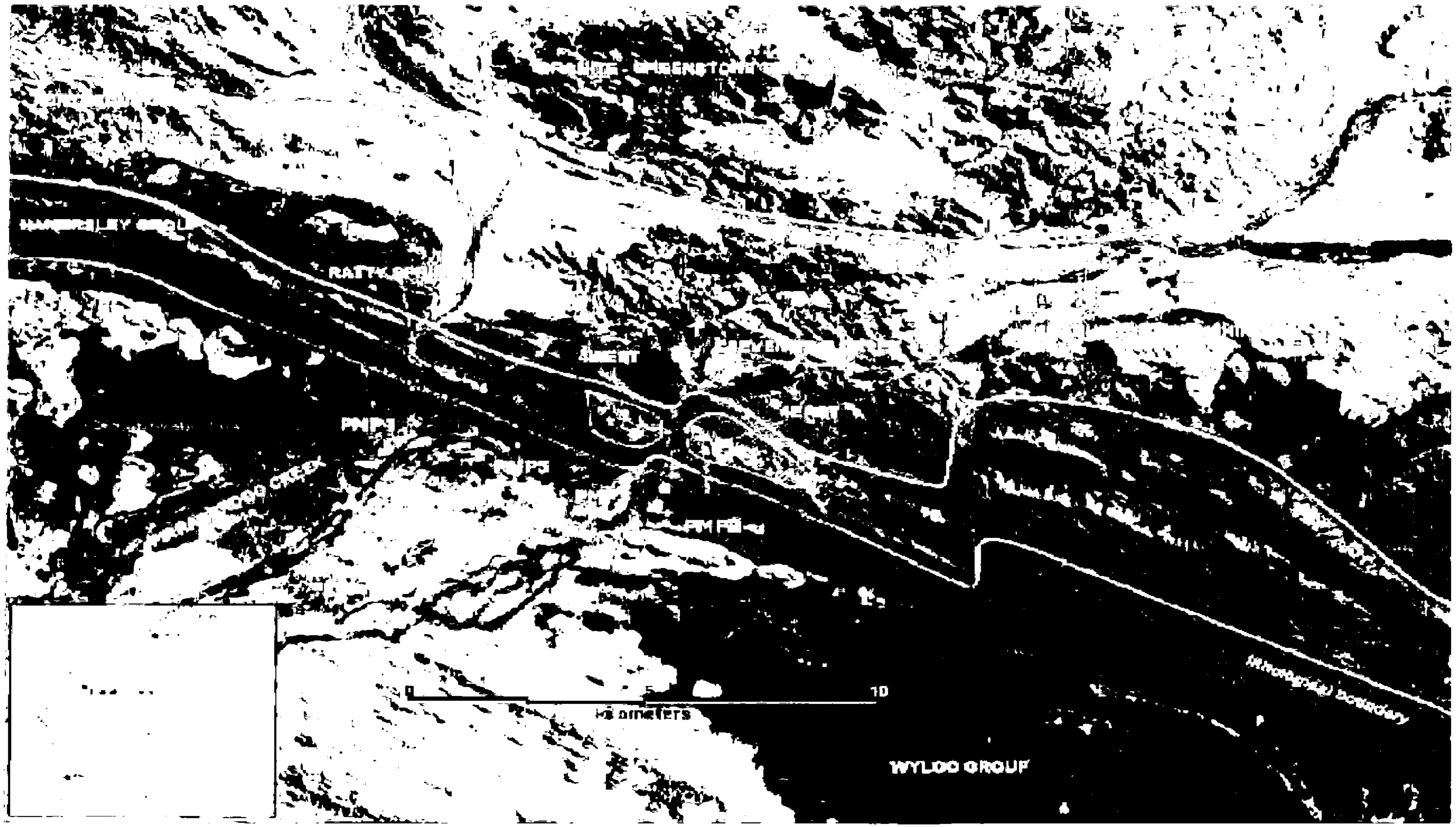



Figure 2. Satellite imagery of the project area, illustrating the 4WEST and 4EAST pits, Southern Well Field, creeks, groundwater flow directions and overall geomorphology.

## DEWATERING AND MINING HISTORY

Groundwater extracted from the well fields of the Paraburdoo mine site is sourced from a number of aquifers, with groundwater age and yield dependent on aquifer characteristics. The Mine well field, commissioned in 1971, was the earliest and had eight operating wells; it has since been re-named the Southern Wellfield. The other two well fields found on site are the in-pit well fields of 4WEST and 4EAST, both commissioned in the late 1990s.

Only two of the original eight wells are currently operating in the Southern well field. This is due to the age of the well field (30 years old) and the current reliance on water from in-pit dewatering for mineral processing and mining applications (mainly dust suppression on haul roads). The Southern well field is located in the Wyloo Group of rocks, which are significantly different to the Hamersley Supergroup rocks. The Wyloo Group are found in a shallow marine sedimentary environment, Protozoic in age, dominated by quartzite, iron stones and carbonates. By contrast, the Hamersley Supergroup is Archaean to Proterozoic in age and dominated by banded iron formations (BIFs), shales and chemically deposited carbonates.

The 4WEST well field has five wells, drawing water predominately from the Brockman Iron Formation. However, 4W4 well draws from both the Pirraburdoo Creek colluvium and the Brockman Iron Formation. This is significant for the development of the groundwater model, as the effects of dewatering on the creek colluvium were not fully understood at the time of implementation. Past modelling of water flows in these creeks included the 1998 Aquaterra groundwater model and report.

The 4EAST well field was commissioned in October 2001. Originally five bores were developed and initial pumping rates ranged between 12 – 36 l/sec. Wells 4ED1 and 4ED2 pumping performance quickly declined, possibly due to these bores being screened in lower porosity material of the Weeli Wooli formation. This well filed has the dual purpose of dewatering the 4EAST pit and supplying water for the process plant, and specifically the plants thickner process (tank used to separate mud and clay materials using flocculants, leaving fresh water).

Dewatering rates from January 1998 to December 2004 are illustrated in (Figure 3). The increase that can be seen in late 2001 is the result of the commissioning of the 4WEST and 4EAST in-pit dewatering. The groundwater table levels shown are from piezometers; 99RS04 located at Ratty Springs, while Ratty#1, Ratty#4 and 98PZ1 are piezometers located downstream towards the 4WEST pit, respectively. This illustrates that the closer to the 4WEST pit the greater the decrease in groundwater levels, as expected.

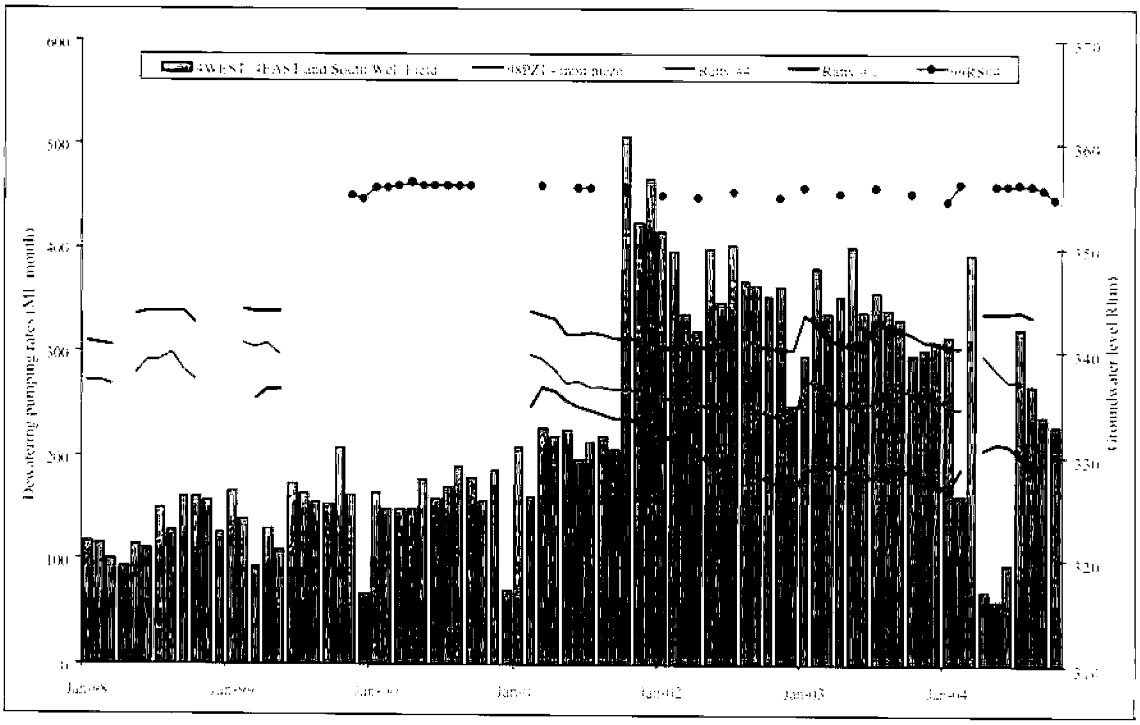


Figure 3. Well field pumping rates and the groundwater monitoring illustrating the effects that dewatering is having on groundwater levels from Ratty Spring (99RS04) moving progressively closer towards the 4WEST mining area, culminating at the in-pit piezometer (98PZ1).

## GEOLOGICAL SETTING

The Hamersley Basin occupies an area of 100 000 $km^2$ and is the depositional basin for the Mount Bruce Super Group. This supergroup is comprised of three groups, which in order of depositional age are: Fortescue Group, Hamersley Group, and Turee Creek Group (Figure 4). The project area has the Fortescue through to Wyloo Groups outcropping within it, and is orientated approximately parallel with the outcrops. The Wyloo group is located within the Ashburton Basin adjacent to the Hamersley Basin.

Underlying this super group is the Granite-Greenstone Terrane. Granite-greenstones outcrop as structural features such as the Rocklea, Milli Milli, Wyloo Domes, Mount Sylvia inlier and the North Pilbara Granite-Greenstone Terrane. The Granite-greenstone and Fortescue contact is unconformable and the original greenstone palaeotopography would seem to be generally gently undulating with an overall southerly dip. However on the localised scale, it exhibits steeply dipping ridge topography, with relief varying from a few hundred to thousands of metres (Trendall, 1990). The subsequent deformation events that have occurred throughout the basin and the final pattern seen today may be a product of the interference that the Granite-greenstone Terrane palaeotopography exhibited, rather than just a product of basin sedimentary deformation.

The Fortescue Group, which is predominantly a flood basalt/ dolerite series and grades into a marine sedimentary unit of the Jeerinah Formation, indicates stable depositional conditions. This stable period remained throughout deposition of the Hamersley Group Banded Iron Formation (BIF), shale and carbonate sediments. There is a conformable contact between the Fortescue and the Marra Mamba Formation at the Nammuldi member.

The Hamersley Group is significant for its abundance of BIF – the source of some of the largest and richest iron-ore bodies worldwide – and for the small amount of stratigraphic variation throughout the basin, especially with respect to bed thickness; it is also known for the shale and BIF chemistry. This and other factors have led many workers to speculate on the genesis of the basin; for example, the basin's shales are not considered to be true basin-derived sedimentary rock; instead, they are more likely to be ash-fall related deposits or tuffs, from volcanic activity that could not have been adjacent to the basin. If they are in fact of volcanic origin, ash-fall would have disrupted the uniformity recorded through the basin. In addition, drop-bomb features are not common throughout the basin, suggesting that these sediments floated in from an external source. The BIF itself is also likely to be a chemical precipitate and not iron-rich, silica-rich injections from nearby volcanic activity. The nature of this depositional basin would be one of little volcanic activity, deep enough to produce the bed-chemical and thickness uniformity with periodic injection of ash from some external volcanic source. The Hamersley group constitutes the bulk of the remaining 60% of the Mount Bruce Supergroup, with a general thickness of about 2.5 km, about a kilometre of which consists of intrusive igneous rocks.

The Turee Creek Group sits conformably above the Boolgeeda iron formation of the Hamersley Group. The Turee Group is defined by greywacke, sandstone and siltstone formations. The Turee is the third and final group of the Mount Bruce Super Group, and has a local thickness of about 5 km.

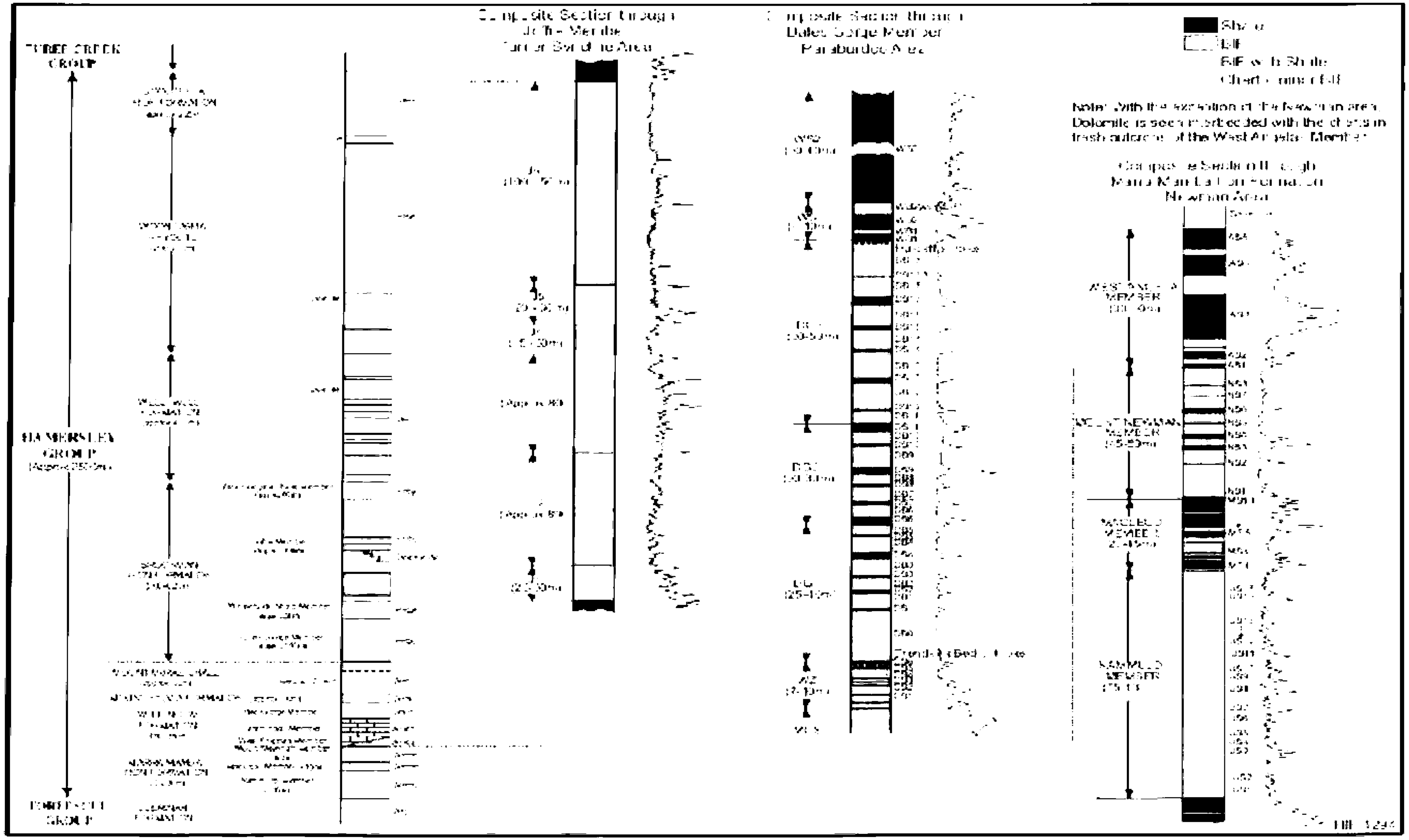


Figure 4. Stratigraphic column of the Hamersley Group.

## CONCEPTUAL HYDROGEOLOGICAL MODEL

The mineralised portions of the Brockman and Marra Mamba Iron Formations, the Wittenoom formation, colluvium/alluvium creeks, the Fortescue (Northern Well Field – Pilbara Iron) and Wyloo Groups (especially the Duck Creek Dolomites – Southern Well Field – Pilbara Iron) are all recognised aquifers within the Hamersley Basin. These aquifers depend mainly on secondary sedimentary porosity. The relationships between geological structure and groundwater flow, as well as the relationship between the creek beds of the Pilbara and their role in recharge to groundwater, are not well understood. The conceptualisation phase for the Ratty Springs project first examined previous models completed in the 4EAST and 4WEST mining area – including (Aquaterra 2003). Further geological mapping, combined with existing geological models, formed the basis for determining the major hydrogeological boundaries and properties of this conceptual model. A 1:5,000 scale mapping project was undertaken over the area; this mapping helped to define the timing and characteristics of the faults and general lithology.

Groundwater flow direction is dominated by geomorphology, colluvium/alluvium and local as well as regional structure. A majority of rainfall either flows as surface water within creeks or as base flow to these creeks, some groundwater sinks exist due to localised structures and some water is lost to evaporanspiration. Creek colluvium material which is poorly sorted, well rounded with grain sizes varying from sands to boulders, and have been drilled at thickness of between 3 – 15 meters (2001 drilling in Pirraburdoo and Seven Mile Creeks). These creek beds have conductivities of between 5 and 10 m/day and possibly higher. The connectivity of these creek beds to bedrock will be via a combination of structural conduits or conductivity.

### i. Hydrogeological units

***Aquifers for the Hamersley Basin.***

- Wittenoom Formation - Dolomite

This chemically precipitated carbonate sediment is found in either a crystalline - massive form or in a weathered almost karst-like form (as found at Millstream, near Karratha, WA). The crystalline dolomite is hydraulically tight and will have hydraulic conductivities of between 0.1 – 0.01 m/day, while weathered dolomite is typically greater then 10 m/day. This unit was drilled in the 2001 drilling campaign at Ratty Springs and in both the Seven Mile and Pirraburdoo Creeks.

- Mineralised Brockman

The mineralised Brockman Formation in Paraburdoo differs in texture and overall rock mass strength when compared to Mount Tom Price and Newman mineralisation. This is due to the lack of intensive structural deformation and the lack of supergene enrichment, which re-crystallises the hematite. The texture at the Paraburdoo mine is soft and powdery, and typically is weakly cemented. This texture, coupled with definite joint sets and semi-regional structure in-filled by dolerite intrusions, makes for a favourable groundwater flow and storage. The hydraulic conductivities for this material varied between 5 – 10 m/day.

- Alluvial sediments

Riverbed material, found in the ephemeral streams is generally poorly sorted and well rounded. Sediments vary in size from millimetres in diameter to boulders. This suggests fast, high-energy flood events. The riverbed sediments in the project area are generally 10-15 metres in vertical thickness. Calcrete lenses are found sub-surface and at the edges of creeks, which form as carbonate precipitates from groundwater. Subsequent flood events erode the last lens formed and eventually new lenses form, creating thin fingers of calcrete. These lenses are thicker near the creek edges and thinner towards the centre of the creek. In the 2001 Ratty Spring investigations, one to two metre thick calcretes were intersected during drilling.

***Low hydraulic units of the Hamersley Basin.***

Within the Pilbara there are many lithological units act as aquicludes and or aquitards.

- Shale

Shale of the Mount Bruce Super Group is derived from terrestrial volcanic eruptions in the form of ash deposits. They are typically well sorted and similar grain sizes, this leads to the units having relatively higher porosity yet very low primary permeability. This leads to a unit which over time can hold a significant amount of water yet have a very low hydraulic conductivities in the order of $1 \times 10^{-4}$ m/day.

- Intrusions

Dolerites intrusive within the Hamersley Basin are generally of three orientations, NNE, NW and E to W, and ages. They have generally intruded along planes of weakness, such as faults and lithological contacts. There will exist a weathering profile for a majority of these intrusive bodies, water flow along and across them will be minimal, where as fresher bodies will have a fractures contact surface as well as an internal fracture network which will allow some through flow, however the preferential flow direction will be parallel to the intrusions contact surface. At the Tom Price and Paraburdoo Mines, there are clear examples of aquifer compartmentalisation due to fault derived dolerites. Hydraulic conductivities associated with weathered dolerites would be in the order of $1 \times 10^{-5}$ m/day, while for fresh dolerite Hydraulic conductivities would be $1 \times 10^{-3-4}$ m/day, through these features and 0.5 – 1 m/day along these contacts. These structures have created compartmentalisation of aquifers, and are evident in the North Deposit pit in Tom Price and Channar East Three pit at the Greater Paraburdoo Operations.

- BIF

Banded Iron Formation, from a hydrogeological point of view will come in two basic conductive types, one being massive, silicious and very hard, exhibiting low Hydraulic conductivities in the order of $1 \times 10^{-5}$ m/d. The other type is generally located between this fresh and the mineralised iron formation, this type has been described as "biscuity" friable and soft, this having Hydraulic conductivities in the 1 - 5 m/day range. There are structural and mineralisation mechanisms which aid in the formation of this more friable version.

### ii. Geological structure and groundwater flow

Field mapping at a scale of 1:5 000 was conducted in December 2004, to better define the structures that potentially link the 4WEST and 4EAST pits with the bedrock material associated with the creeks and Ratty Springs. It indicated several features that may aid or impede groundwater flow. These faults and intrusions have not been included in the model, and further work is required to determine their hydraulic conductivities, both along and across these structures. Consultants, geotechnical engineers and mine geologists have mapped other features and structures within the mapping area, especially in the pits. These structures, as discussed in the introduction, are described as listric down to the south features reactivated as further rifting and tectonic forces continued, generating the associated slumping of BIF sediments. Back release down to the north faults also occurred between the major slipping planes of these listric faults.

The down to the south listric faults also had a lateral release plane, in the form of a north-south, near-vertical fault. These occur along the boundary of the 4WEST and 4EAST mining pits and along the western margin of the 4WEST pit. Along these NNE orientated faults displacement is generated by a rotational component not dip-slip. These north-south orientated faults, like many faults in the Hamersley Basin, are associated with dolerite intrusions. These intrusions are recognised for having high hydraulic conductivities along their margins, but low conductivities across them. This has been quantified by piezometer and bore drilling programmes in the 4WEST pit (Blanks, 2002).

Jointing sets created by subsequent deformation events exert another structural control for groundwater flow. While this structural aspect is not incorporated in the project model, these structures can be observed at a meso-scale and to some extent have been recorded by the Geotechnical Department. The Geotechnical mapping takes into account the defects size, frequency, and opening size, and records the amount of iron-staining as an indication of previous groundwater flow. These joint sets, which are preferential to deformation strengths, propagate throughout all geological units and would aid in the overall regional flow of groundwater in the Hamersley Basin.

Within the ore bodies of Pilbara Iron, there exists a weak, remanent sedimentary texture. It can grade to a sugar texture, and indicates that the ore can be very porous. This texture, coupled with the localised jointing texture and semi regional/regional structures, all combine to act as conduits for groundwater flow.

### iii. Stream flow and groundwater recharge

Work conducted in 2001 within the Pirraburdoo and Seven Mile Creeks, focused on defining the aquifer systems along these creeks and establishing wether a second aquifer existed between he alluvium and bedrock materials. Five holes were drilled into the creek bed and into the underlaying bedrock. holes were then developed and nested piezometers were installed. The holes for this study were 99RSO1-2. 3-4. PMO01, R96PA020 and PM07 (Figure 6).

The creeks located within the project area are underlain by weathered Mount Sylvia Dolomites, mineralised Brockman Formation, Ashburton or Fortescue bedrock materials. It is considered that connectivity between the river colluvium and the Mt Sylvia and Brockman Formations would be high. However flow rates into the Fortescue basalts and dolerites as well as the Wyloo Groups are less. There possibly exists a direct connectivity between the colluvium and the weathered bedrock. and also connectivity between colluvium material and other units, by way of structural conduits.

The creeks are either discharging water (periods of low rainfall and base flow) or gaining water (base flow). It is assumed that at the time of flooding the amount of water recharging the creek alluviums and bedrock would be minimal. the majority of recharge would occur once the flooding has decreased and base flow is at its maximum. Further work is required on the recharge mechanism of the alluvium - bedrock and the role the unsaturated zone has on this recharge, and at times discharge.

A cumulative residual rainfall graph was produced using rainfall data from the Paraburdoo Bureau of Meteorology weather station (Figure 5). This was for the same period of the project January 1998 – December 2004. It illustrates that water table increases are not always associated with just a rainfall recharge. It should be stressed that piezometer Ratty # 1 is located within the Pirraburdoo Creek and will monitor rainfall and river recharge, as well as the effects of dewatering. The cumulative residual rainfall graph also illustrates the following:

- Small variation in the water table i.e. +/– 1.8 meters.
- There is no overall increasing or decreasing trend in water table levels.
- Cumulative residual rainfall indicates periods of wet and dry periods, yet the hydrographs either do or do not respond to this rainfall recharge or the rainfall did not fall near piezometer Ratty # 1.
- Another source of water related to groundwater recharge, this would most likely be via river recharge.

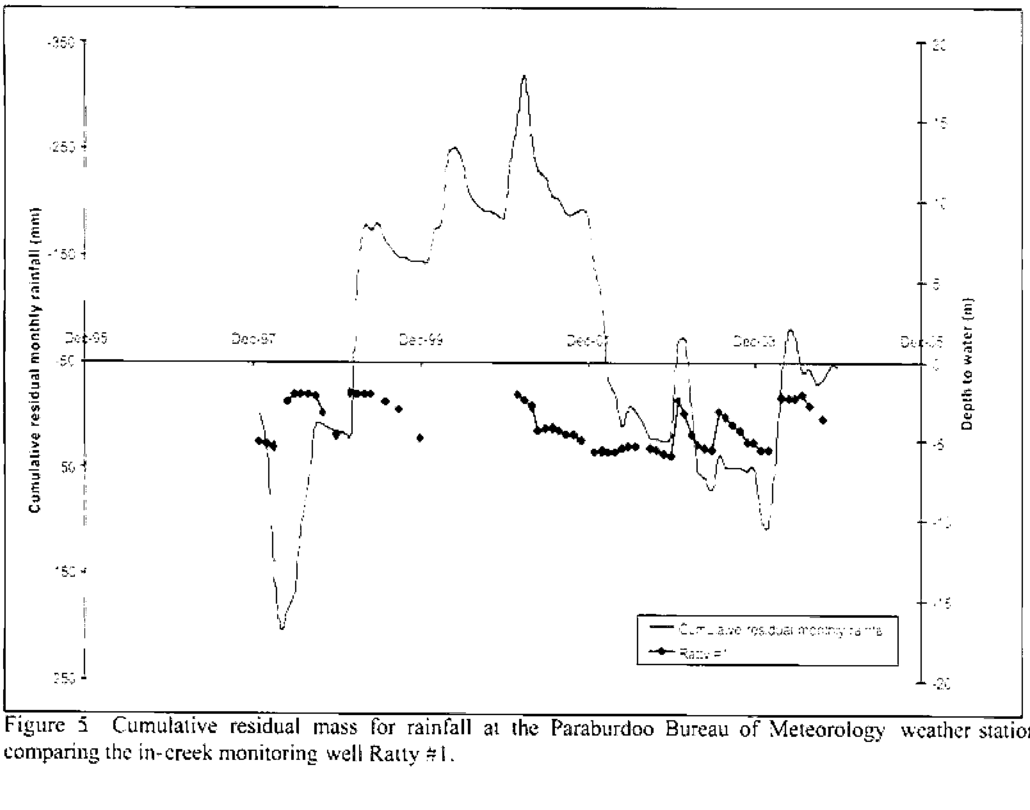



Figure 5 Cumulative residual mass for rainfall at the Paraburdoo Bureau of Meteorology weather station, comparing the in-creek monitoring well Ratty #1.

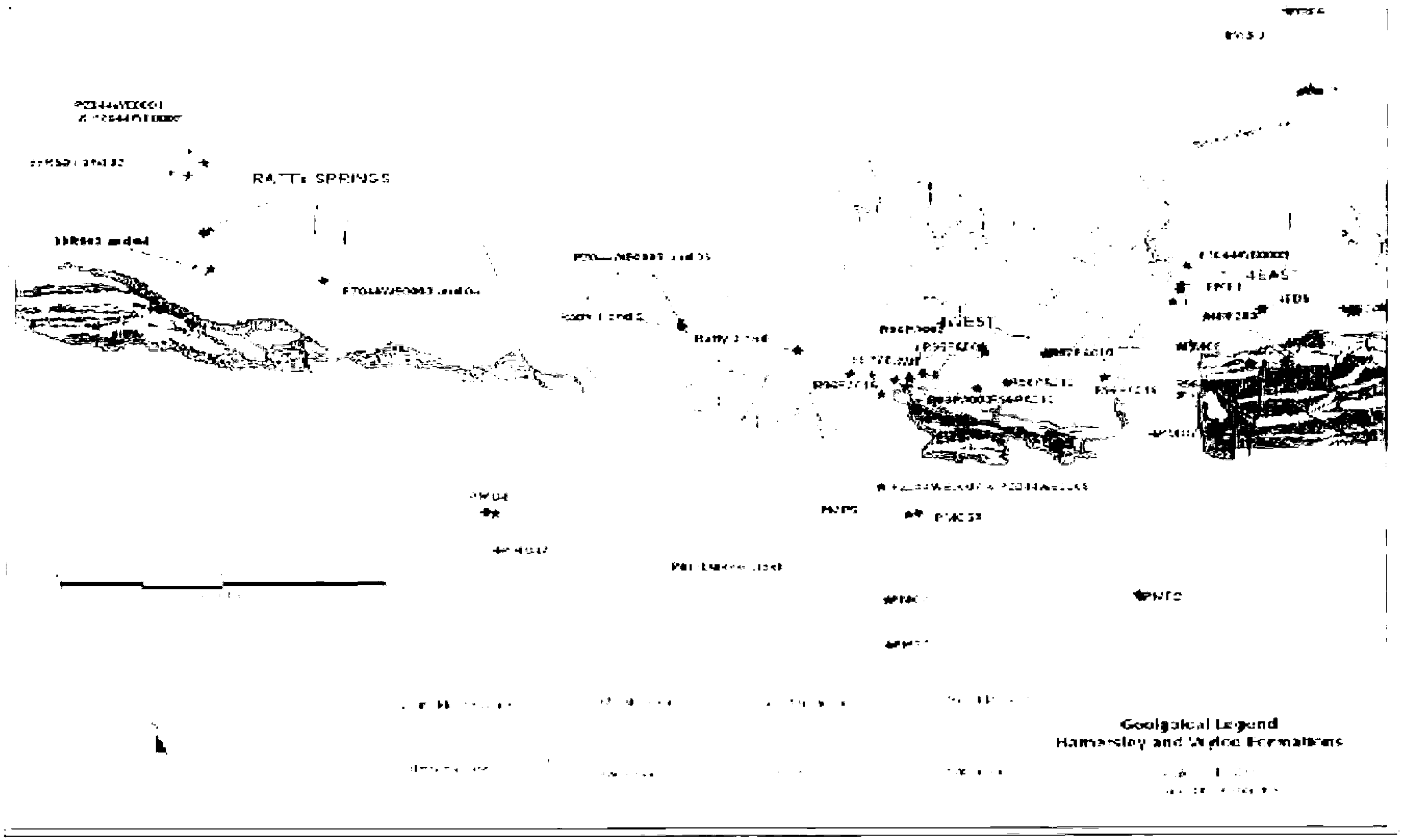



Figure 6. Bore and monitoring well locations and lithological units of the Paraburdoo area.

### iv. Groundwater discharge

Groundwater discharge occurs at Ratty Springs in the form of a surface water expression, else where water is lost as evapotranspiration and dewatering.

Dewatering occurs predominately from the Joffre Member ore as well as the bores in the Southern well field. Dewatering rates have varied over time. The most noticeable between January 1998 and mid 2001, when rates increasing from 2,000 to 6,000 $m^3$/day, with the inclusion of the 4EAST dewatering infrastructure that rate then jumped to 16,000, where it then declined back to a rate of 12,000 $m^3$/day in late 2004.

Evapotranspiration (ET) was assumed to be greatest in the riverine creek areas due to the high density of Eucalypt and Melaleuca, while the cliffs and flood plains where given lower ET rates. The ET rate was calculated using Bureau of Meteorology's evaporation data from Wittenoom (the closest evaporation data available), and then applying a 50% factor to this evaporation rate to approximate the ET component. Research by the University of Western Australia (Landman, 1997) has shown that Eucalypts in the Pilbara transpire approximately 100 l/day.

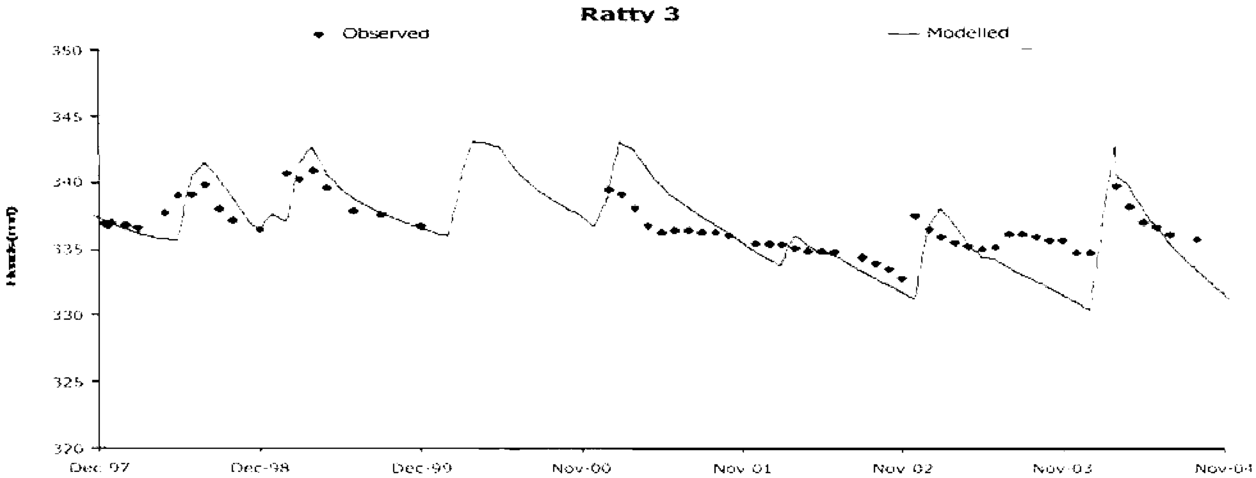
Outflow at the fixed head I-Boundary – through the upstream catchments varies between 1000 to 1500 $m^3$/day and at the down stream catchments boundary between 4000 to 6000 $m^3$/day.

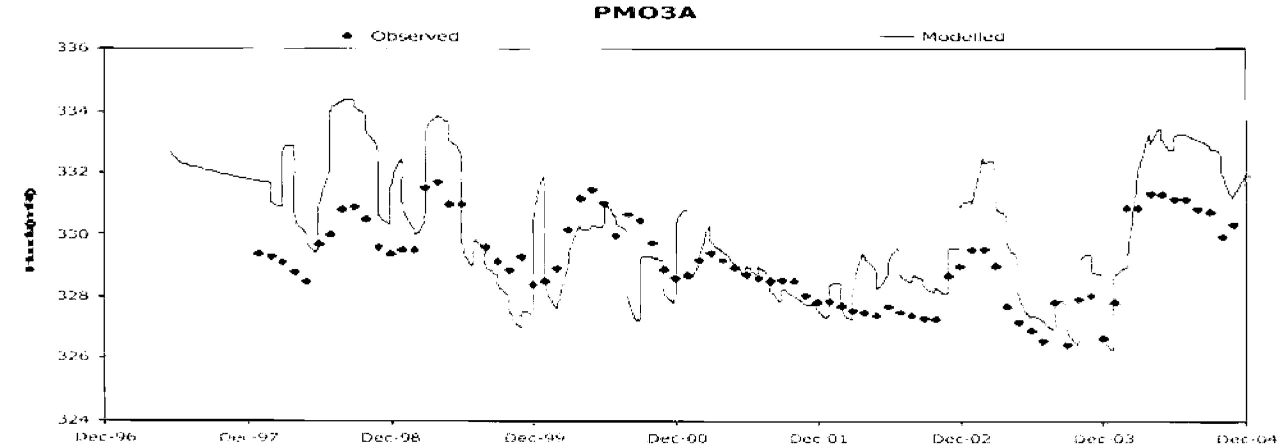
## MODEL INTRODUCTION

The numerical model used is a four layered system, the top layer being confined and representing the river colluvium material, the second layer which was confined/unconfined (transmissivity varying), with other model parameters summarised in (Table 1). Layer two represented the ore body within the pits and the weathered bedrock under the creeks, the third layer was a massive semi conductive layer and the fourth layer massive impermeable bedrock. The cell sizes are regulised at 50x50 meters, with 220 cells wide by 140 cells wide. The calibration period was 84 stress periods long and represented data starting from the 20th of May 1997 through to 31st December 2004. The prediction period was from stress period 85 through to 216, 1st January 2005 through to 31st December 2015. With the exception of stress period 1 all stress represented month periods, the basic units for this model where days and meters.

The model simulation period was for 6794 days, 216 stress periods and 2250 time steps. A steady state was run to create pre mining initial heads, the majority of the calibration runs (87 in total) used transient state, with time steps equalling ten and multiplier of 1, with the exception of stress period one. The initial pre mining heads were calculated using historical pre-mining water monitoring data and making some assumptions based on topography to water depth, while horizontal and vertical conductivity – as no definite anisotropic trend occurs in layers one and two – the ratio between horizontal and vertical conductivity remained at 1.

Model calibration was achieved by a combination of trial and error and examining previous modelling conducted in the area, especially the Woodward Clyde, 4WEST Groundwater Model report, and the Aquaterra 4WEST 2001 report. Both these groundwater models did not incorporate river recharge using the river package instead recharge was used to simulate rainfall as well as the river recharge component. The results from calibration run number 87 are illustrated in (figure 7).



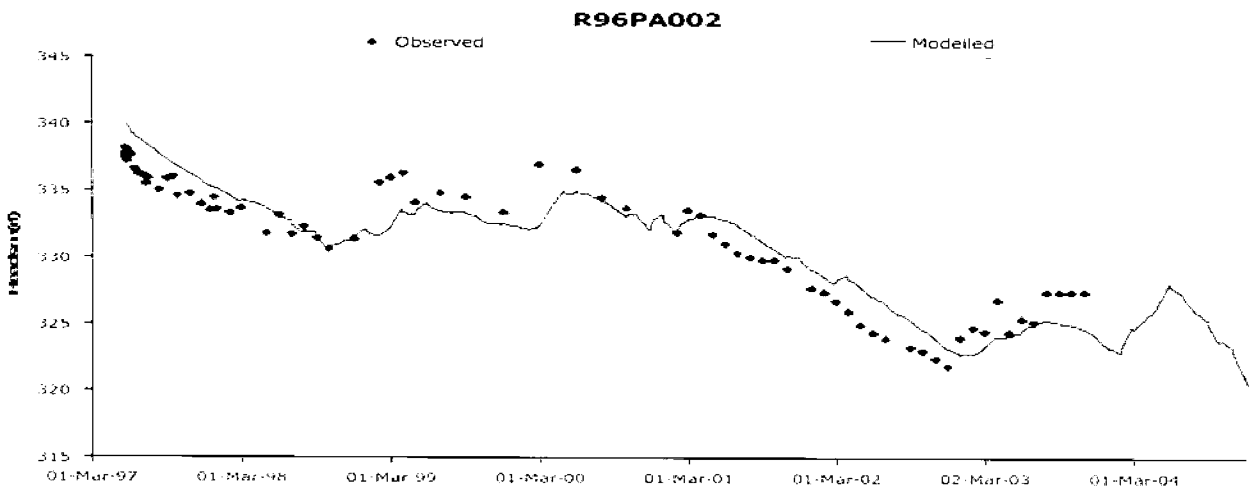




Figure 7. Calibration results from the Ratty 3 and PM03A monitoring wells. note that Ratty 3 is a monitoring well located in the Pirraburdoo Creek and PM03A is located in the 4WEST mining area.

**MODEL PARAMETERS**

| | Layer Property | Transmissitivity | Leakance | Storage Coefficient | Horizontal Hydraulic Conductivity (m/d) | Vertical Hydraulic Conductivity (m/d) | Storage Coefficient | Specific Yield |
|---|---|---|---|---|---|---|---|---|
| Layer 1 | Unconfined | Calculated | Calculated | User Specified | Colluvium = 5, Ore = 1.2 | Colluvium = 2, Ore = 1 | 1 x 10-4 | Colluvium = 0.1, Ore = 0.52 |
| Layer 2 | Confined/Unconfined (Transmissitivity varies) | Calculated | Calculated | User Specified | Bedrock below creeks = 0.52, Ore = 4 - 6 | Bedrock below creeks = 5, Ore = 6 | 1 x 10-4 | Bedrock below creeks = 0.075, Ore = 0.02 - 0.045 |
| Layer 3 | Confined/Unconfined (Transmissitivity varies) | Calculated | Calculated | User Specified | Bedrock = 0.001 | Bedrock = 0.001 | 1 x 10-4 | Bedrock = 0.005 |
| Layer 4 | Confined/Unconfined (Transmissitivity varies) | Calculated | Calculated | User Specified | Bedrock = 0.001 | Bedrock = 0.001 | 1 x 10-4 | Bedrock = 0.001 |

**TRANSIENT TIME DATA**

| | Evapotranspiration | Recharge | River | Well | Wetting Capacity |
|---|---|---|---|---|---|
| Layer 1 | winter = 2 - 4 x $10^{-3}$, summer 6 - 8 x $10^{-4}$ m/d | 10% hard rock = 4 - 5 x $10^{-5}$ 20% soils = 3 - 5 x $10^{-4}$ m/d | River conductance = 600$m^2$/d, stagiing varied from 0.25 - 1.5 m | | Iteration interval = 6, wetting factor = 0.9, h = Bot + WETFCT*[THRESH], WETFCT = -2 |
| Layer 2 | | | | 100 - 3000 $m^3$/d | |

Table 1. Summary of model parameters and transient time based attributes.

## MODELLED PREDICTIONS AND RESULTS

Three major factors control the way projections are formulated and are used to set limits on what is potentially achievable, given historical climatic and pumping data. These factors are:

1. The life of mine
2. Future dewatering requirements
3. CSIRO's global warming weather predictions and historical rainfall, river-flow and ET trends.

All of these have individual ranges; some are natural and others are man-made. For example, mine planning, global recessions affecting iron ore markets, and the strategy of using existing dewatering infrastructure are human interventions, while natural rainfall or ET cycles are natural events that may or may not be modified by man-made factors such as greenhouse gases and global warming.

However, there are some facts and assumptions that can be included to make judgments regarding what are appropriate ranges for ET, rainfall, river recharge and pumping schedules.

Predictions about life of mine vary greatly. The current Pilbara Iron five-year mine plan for 4WEST has minimal tonnes planned, while the medium-term plan which has now been advanced to a three-year outlook, has potential to advance-mine this pit using contractors, and turn the 5.8 ML/day dewatering into a 14.6 ML/day rate, as seen in (figure 8). The likely prediction is that the 5.8 ML/day rate may increase to ~10 ML/day with two additional bores (4W7 and 4W8) being equipped and utilised. There is a need to make some adjustments for both aquifer and bore productivity losses over time. There are some examples in both the 4EAST and 4WEST pits with 4EAST being a combination of aquifer performance and bore efficiency – while 4WEST is predominantly bore efficiency. The pumping predictions may not take into account downtime, bore development and pump/motor upgrades, which could make significant improvements to efficiencies and extraction rates.

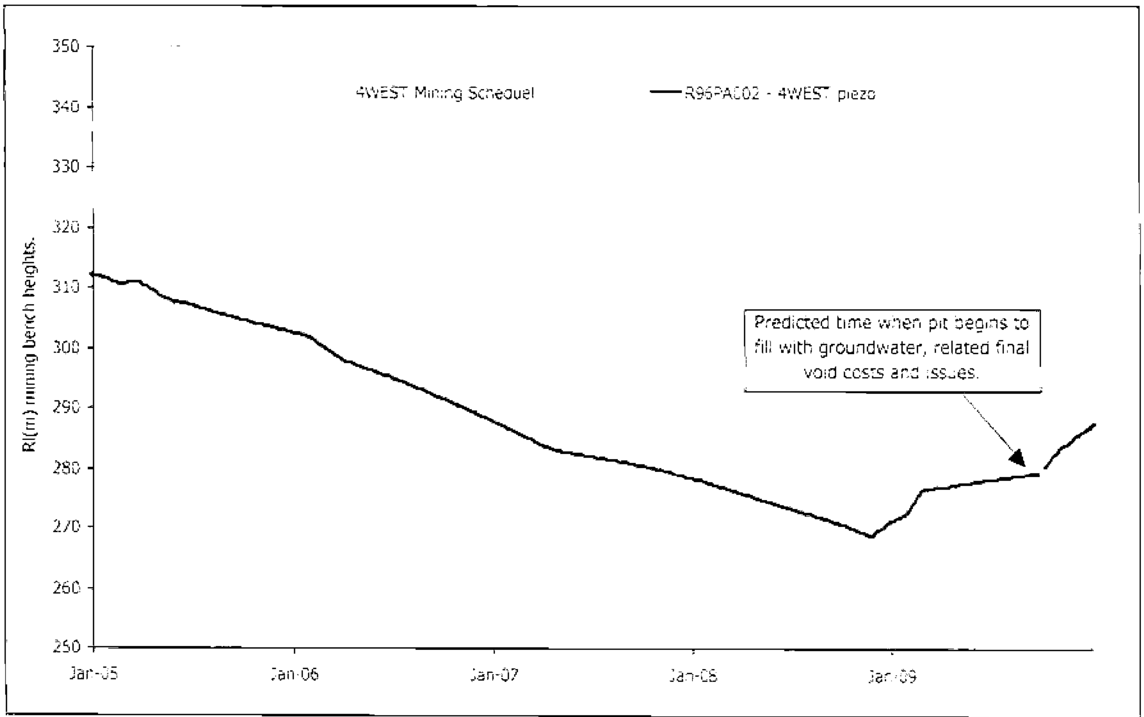



Figure 8. 4WEST actual and theoretical pit progressions with the associated dewatering regimes.

Global warming and weather predictions from the CSIRO indicate that, between 1990 and 2030, the Pilbara region will have a 20% chance of being either wetter or drier. Evaporation is predicted to increase. These assumptions are based on many meteorological models, combined to make some predictions about future climatic conditions (CSIRO 2004). The approach will be to have the 20% wetter and drier as the upper and lower cases for rainfall. However the mid-range is harder to predict, because even weather stations like Mount Florence, which is considered to have a high level of accuracy and has the longest continuous period of recording, show no long-term trend towards change in rainfall. The data has been examined using residual mass and rolling averages. No method shows a pattern occurring, and it would be difficult to give only the best and worst-case scenarios. One approach would be to take the last 10 years of rainfall and interpolate this for future rainfall and ET. The river recharge component would be assumed, using the same method in the transient model case for these future scenarios.

Predictions for average rainfall, evaporation and river recharge are based on monthly averages used to compile a yearly average trend. However, using averages alone would exclude some of the climatic characteristics of the Pilbara, particularly the rainfall extremes or cyclonic events. These cyclonic events were included in the prediction by identifying the months, from the Paraburdoo weather station, in which rainfall exceeded 100mm. A pattern emerged which indicated that, on average, in the month of February, a cyclone affected the region every two years. The average for the events greater than 100mm was 120mm and this was used for February cyclone events, every two years. Anecdotal evidence shows that the creeks flow every third year and not necessarily from cyclone events; therefore, to represent this recharge, these events were represented by increased rainfall recharge, while maintaining the creek normal average river head flow. It was shown in calibration that additional rainfall recharge and increased overall head in river components produced excessive throughput for the river cells, when compared to manual calculations, so combinations involving high rainfall and higher heads in the creeks were avoided. The average prediction was then used to produce a 20% less or drier climate scenario, and a wetter or 20% greater scenario, based on CSIRO's climate predictions for Australia.

## CONCLUSION

The modelling work conducted for this project and subsequent masters studies has indicated that historically there is no evidence of groundwater level decrease near or at Ratty Springs due to mine dewatering. This model and its calibration results enable Pilbara Iron to better manage the adjacent riverine groundwater table fluctuations and importantly to determine which ones are natural versus dewatering induced. It will also enabled further studies related to saturated – unsaturated groundwater flow in the form of tracer studies and aid in the closure management of the 4WEST and 4EAST mines.

However while this work has answered some questions it has also raised many more and further studies, like the ones mentioned above, are still required.

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