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## MARILLANA IRON ORE PROJECT

## HYDROGEOLOGICAL INVESTIGATIONS

**Prepared for:** Brockman Resources

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# MARILLANA IRON ORE PROJECT

# HYDROGEOLOGICAL INVESTIGATIONS

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# EXECUTIVE SUMMARY

Exploration activities undertaken by Brockman Resources Ltd (Brockman) on tenement E47/1408 have identified a commercially viable iron ore resource, for which Brockman are now submitting a mining proposal.

To support this mining submission to the Department of Industry and Resources, Brockman have engaged Aquaterra Ltd (Aquaterra) to submit a hydrogeological report identifying and assessing the impacts of abstracting a groundwater supply for mine and camp purposes at a rate of up to 30L/s.

To enable this hydrogeological assessment, Aquaterra undertook a staged programme of works as follows:

- Stage 1 comprised a review of existing data and this was used to make an initial assessment of all water supply targets and supply options across the lease.
- Stage 2 included observations and analysis of geological samples from a selection Reverse Circulation (RC) and diamond holes on site and the reaction of static groundwater levels in falling head tests.
- Stage 3 comprised a review from the finding of Stage 2 and the subsequent drilling and aquifer testing of 6 piezometers and 2 test production bores, from which details on the water quality and hydraulic characteristics of the aquifer could be assessed.
- Stage 4 comprised the development of a groundwater model to simulate groundwater abstraction drawdown impacts over a 5 year period from bores located on the Brockman tenement.

**Aquifer Description**

From the desk top review undertaken in Stage 1 and the investigation undertaken in Stage 2, the Tertiary Hematite Detrital (THD) aquifer was identified as the target aquifer for the water supply. The aquifer, where found within the tenement, is approximately 1m to 40m in thickness and is broadly characterised by red brown gravel to silty gravel detritals, comprising sub angular to sub rounded hematite, maghemite, with some pisolites and occasional goethite.

**Aquifer Testing**

To ascertain the impact of abstracting a groundwater supply at a rate of up to 30L/s, a programme of bore performance and aquifer testing was undertaken. The programme comprised multi-rate step and constant rate tests on the two test production bores.

The bore and aquifer testing for the Potable Bore was undertaken between 6th and 8th April 2008. The step test results indicated that the bore had poor efficiencies of between 2% and 10% but that these inefficiencies could be attributed to turbulent flow and hence well loss as opposed to flow inefficiencies within the aquifer. The one day constant rate test, indicated that the transmissivity of the aquifer was between 110m$^2$/day and 450m$^2$/day. However, it was considered likely that the rate of 110m$^2$/day was more typical of the aquifer over long term pumping. Since the drawdown response indicating this transmissivity rate reflected more of a confined response, which is likely to occur within the aquifer when groundwater drainage from lithologies above the THD have been depleted.

Aquifer testing on the PS1PB commenced on the 17th June with a step test and concluded with a seven day constant rate test commencing on the 18th June. The step test results indicated efficiencies between 44% and 66%, representing a more laminar flow component to the bore compared to the Potable Bore. The constant rate test analysis was interpreted utilising the Neuman Methodology (for a delayed yield from storage response). Transmissivity results of between $269m^2$/day and $468m^2$/day were calculated with recovery results after the seven day test yielding transmissivity results of between $2130m^2$/day to $522m^2$/day.

Source Reliable Output calculations were undertaken utilising the transmissivity parameters from the above tests. These SRO calculations were undertaken to ascertain the response or water levels measured in the bore and the radius of impact (cone of depression) to long term pumping activities. The calculations were undertaken over a pumping period of 1825 days (5 years) and the assumed period between effective recharge events to allow for the long term pumping levels to be evaluated at a conservative level was also 1825 days. Given the diameters of the constructed bores, it was considered that for the Potable Bore a pump achieving up to 8L/sec could fit down the bore so this was used as the proposed abstraction rate for which the long term pumping effects would be assessed.

The SRO calculations indicated that when the Potable Bore was pumped in isolation at a rate 8L/sec (Transmissivity = $110m^2$/day) for 1825 days the drawdown of the water table in the immediate vicinity of the bore was 6.7m which represents a 28% reduction in the saturated thickness of the aquifer.

The diameter of the bore casing PS1PB indicated that a pump achieving approximately 80L/sec could fit down the bore. The SRO calculations however indicated that a rate of 30L/sec the expected pumping rate required on the site (Transmissivity = $270m^2$/day), the drawdown of the water table in the immediate vicinity of the bore was 11.2m which represented a 46% reduction in the saturated thickness of the aquifer.

Both these calculations indicated the sustainability of the aquifer to these abstractions when pumped in isolation.

To establish the drawdown impacts of both bores operating in tandem further SRO calculations were undertaken.

Iterations on the combination effects were analysed and the results indicated that when the PS1PB is pumped up to 30L/sec and the Potable Bore is pumped at rates from between 2.5L/sec and 8L/sec there is a minimal (between 0.14m and 0.44m) additional drawdown impact on the aquifer over 1825 days of pumping with a recharge event after this 5 year (1825 days) pumping period..

**Groundwater Modelling**

The modelling assessment undertaken to substantiate groundwater impacts indicated that when operating the PS1PB at 30L/sec and the Potable Bore at 2.5L/sec over a 5 year period with no recharge the expected maximum drawdown in the vicinity of PS1PB is 14.75m and at the Potable Bore it is 1.4m. These drawdowns represented a 61% reduction in the saturated thickness of the aquifer in the immediate vicinity of the PS1PB and 6% reduction in the saturated thickness of the aquifer in the immediate vicinity of the Potable

bore.  The modelling also assessed that the cone of depression would extend out to 4600m in the vicinity of PS1PB and 1400m from the Potable Bore

**Groundwater Potential Impacts**

The static groundwater level at the test bore these locations lies at approximately 34mbgl to 38mbgl, and it is considered highly unlikely that there will be any groundwater dependent flora adversely affected by the groundwater abstraction.

These SRO and modelling calculations (pumping at 30L/sec from the PS1PB and 2.5L/sec from the Potable Bore) also indicates that should stygofauna be present within the aquifer it is considered unlikely that the stygofauna will be adversely affected by abstractions, as less than 61% of the saturated thickness of the aquifer in the vicinity of PS1PB is impacted.  The results also indicate that the cone of depression from operating at these pumping rates is negligible at a radial distance of 4000m from the pumping bores.  Hence, not only are flora, and stygofauna which may be present within the aquifer not adversely affected, but the data suggests that neither will the Fortescue Marsh, which lies some 20km to the north (down gradient from the pumping

**Groundwater Chemistry**

Groundwater samples from the Potable Bore and the PS1PB were taken at the end of the constant rate test and analysed. The chemical data indicates neutral to very slightly alkaline groundwater (pH 7.7 to pH 8) with conductivity values around 1400$\mu$s/cm for the potable bore and 2300$\mu$s/cm for PS1PB.  Utilising a groundwater chemical analysis tool, (the expanded Durov Plot) the groundwaters from these bores fell within the sodium chloride sub field, typically indicating mature groundwater.

Groundwater samples from both the piezometers and the bores were also collected and analysed both prior to the PS1PB Constant Rate Test (CRT) and immediately after the seven day CRT.  The groundwater showed no significant changes in groundwater chemistry prior to or after the test suggesting that the groundwaters from the bores and piezometers were not adversely affected by any upcoming/mixing from the underlying hypersaline Wittenoon Dolomites during pumping operations.

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# SECTION 1 - INTRODUCTION

## 1.1 BACKGROUND

The Marillana hematite detrital iron ore prospect is located on the northern flanks of the Hamersley Ranges in the Fortescue River Valley approximately 100km northwest of Newman. Brockman Iron Pty Limited, a wholly owned subsidiary of Brockman Resources Limited (Brockman) has an exploration tenement (Licence No E47/1408) located within this area (Figure 1). Exploratory drilling by Brockman Resources within this tenement has identified a commercially viable iron ore resource.

Before mining operations can commence on site, a Mining Proposal needs to be submitted and approved by the Department of Industry and Resources (DoIR). DoIR assesses the submission from the initial planning stage of the mining operations, through to the operation phase, decommissioning phase and closure. DoIR assesses the proposal in terms of the management of the potential significant environmental impacts that result as a consequence of the mining operations.

Hence, to support this mining proposal, Brockman have engaged Aquaterra to submit a hydrogeological report identifying and assessing the impacts of abstracting a groundwater supply for construction, dust suppression, ore handling and processing and camp purposes at a rate of up to 30L/s.

In order to carry out a comprehensive study Aquaterra undertook a staged approach of work where by the findings of the preceding stage fed into and were the foundations for the subsequent stages. These key Stages were:

Stage 1    Desk Study

Stage 2    Preliminary Hydrogeological Investigation

Stage 3    Detailed Hydrogeological Investigation

Stage 4    Groundwater Modelling

***Stage 1*** - comprised a review of existing data and this was used to make an initial assessment of all water supply targets and supply options across the lease. The data sources reviewed included published data, information from previous work conducted in the area, data from the DoW and data provided by Engenium (Brockman's Project Managers). These data streams along with geological maps, topographic maps and satellite images were used to assess the geology and catchment areas and to infer any groundwater supply targets.

***Stage 2*** - involved a review of the initial groundwater chemistry results provided by the client for RC holes MRC46, MRC49 and MRD 53; and observations and analysis of geological samples from a selection Reverse Circulation (RC) and diamond holes on site. A number of falling head tests were also conducted, the falling head tests were carried out on existing RC holes which had been retrospectively constructed as piezometers[1]. The piezometers were constructed by onsite RC drillers in the absence of a qualified Hydrogeologist and as such the construction details are absent.

***Stage 3*** - comprised a review of the findings of Stage 2 and the subsequent drilling of 2 test production bores and 6 piezometers, from which details on the water quality and hydraulic characteristics of the aquifer could

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[1] Piezometer – non pumping small diameter bore that is used to measure the elevation of the water table or petentiometric surface.

be assessed. For the purposes of the project, the bores were described as Potable Bore and Piezo Site 1 in Pit Production Bore (PS1PB) the piezometers were described a Piezo Site 1 Shallow, Piezo Site 1 Deep, Piezo, Piezo Site 2 Shallow, Piezo Site 2 Deep, Piezo Site 3 Shallow and Piezo Site 4 Deep. The test production bores and piezometers were drilled to a depth of between 60mbgl and 114mbgl. All were drilled into the THD with the exception of Piezo Site 4 Deep, which extend below THD into the underlying crystalline dolomite of the Wittenoom Formation.

*Stage 4* - involved the construction of a numerical groundwater model for the Marillana Iron Ore Project. The model was constructed in order to establish if there would be any potential groundwater impacts and surface water interactions between the basement and superficial aquifers on the environmentally sensitive Fortescue Marsh from groundwater abstractions within the Brockman tenement.

# SECTION 2 - PRELIMINARY HYDROGEOLOGICAL ASSESSMENT

## 2.1 GEOLOGICAL / HYDROGEOLOGICAL SETTING

The area subject to this investigation is centred on the exploration lease (E47/1408). The lease is located on the north east facing slopes of a 19km section of the Hamersley ranges. The regional geology is characterised by south west dipping basement of Lower Proterozoic lithologies (Hamersley Group) sitting unconformably beneath Tertiary detritus material. The Fortescue Marsh runs through a broad valley probably formed by the preferential erosion of the Mt McRae, Mount Sylvia and Wittenoom Formations. The Marsh is bounded by the Hamersley Ranges (Brockman Iron Formation) to the south and the Chichester Ranges (Marra Mamba Iron Formation) to the north.

The main aquifers in the area and those which are of primary concern to this project are the Paraburdoo Member Dolomite and the superficial Tertiary Hematite Detritals (THD). The THD comprises a combination of unconsolidated hematite and pisolitic gravels and iron cemented, pisolitic Channel Iron Deposits (CID).

## 2.2 PRELIMINARY HYDROGEOLOGICAL ASSESSMENT

### *Groundwater Levels*

Groundwater levels through the lease were found to vary from 3mbgl to 40mbgl. With groundwater levels between 30mbgl and 40mbgl, occurring along the slopes of the Hamersley ranges, and the shallow groundwater levels being present towards the northern boundary of the lease. These field investigations were consistent with the expected groundwater flow direction which is in a north easterly direction from the Hamersley Ranges to the Fortescue Marsh.

### *Water Quality*

The results of groundwater chemistry analyses provided by the client from RC holes MRC46, MRC 49 and MRC 53 indicated that the local groundwater is dominated by sodium and chloride ions. Typical of groundwater with long residence times and limited interaction with recently recharged groundwater. Groundwater was found to be neutral, with pH in the range of 7.4 to 7.8, and fresh with salinity (as electrical conductivity) between 1300μs/cm and 1500μs/cm. The locations of the mineral exploration holes from which these groundwater samples were obtained are shown on Figure A1, Appendix A. The main groundwater chemical analysis for these three RC groundwater samples is presented in Table A1, Appendix A; and the Durov plot displaying the major cations and anions is presented in Figure A2, Appendix A.

### *Site Visit*

A short site visit was undertaken on 27th and 28th November 2007. The purpose of the site visit was to cover the following:

- General site overview including; geographical relief, access tracks, etc.

- Brief Geological and hydrogeological investigations and water level survey of reverse circulation (RC) and diamond drill holes on site.

- Brief hydrogeological investigations relating to older (Water and Rivers Commission) WRC production bores on and around the Lease. These are pre-existing bores drilled by third parties in the past.

The main outcomes from the field trip were:

- The water table across the ore body is contained within or above THD deposits.

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- The geological samples from the diamond drill holes indicate high permeabilities across the orebody.

- The old WRC bores (that were found) have either been completely removed or are collapsed and unusable.

- The local groundwater gradient (where measured) is relatively flat at approximately 5x10-4 flowing in a northerly direction.

A further site visit was completed on the 11th to 13th of December 2007 in order to undertake a number of falling head tests on RC holes that had been retrospectively constructed as piezometers. These falling head tests were undertaken to estimate hydraulic conductivity (the rate at which water can move through a permeable medium) of the test area. The falling head results are presented in Table 2, Appendix A.

The conclusions from the observation and field activities for those bores tested, suggested that the hydraulic conductivity values range from $5x10^{-1}$ to $6x10^{-3}$m/day. These range in values indicated that there was a high degree of heterogeneity at the local scale.

The results were used in conjunction with our experience in similar geological environments elsewhere in the Pilbara to provide an indicative assessment of aquifer characteristics and potential bore yields. This is summarised in Table 2.1.

The indications from these aquifer Units were that, for the purposes of achieving the 30L/sec water supply for dust suppression and mine camp supply purposes the THD ore body aquifer should be further investigated by means of the drilling and construction of bores/piezometers and their subsequent testing. This would enable a detailed assessment of the hydraulic parameters of the aquifer.

**Table 2.1**
**Summary of Hydrogeological Characteristics**

| Aquifer Unit | Groundwater Source Potential | Description | Indicative Production Bore Yield (kL/day) |
|---|---|---|---|
| Ore body Tertiary Detritus (Mineralised CID and Pisolite) | High | Mineralised detrital hematite-goethite material (arranged in pod structures in the drainage channels feeding from the Hamersley Range) is thought to be high yielding. Typically across the lease this unit is 10 to 15m thick. The overburden is composed of clay rich alluvium and other detrital material and is thought to be in the region of 40m thick. It is likely that the waters within these units are fresh to slightly brackish. | 1,000-2,000 |
| Tertiary Detritus (non mineralised clays and detritus) | Low - Moderate | The Tertiary material that is not thought to be significantly mineralised will have a lower permeability. Conceptually this material is contained between the highly mineralised pods of the Ore bodies. It is likely that the waters within these units are fresh to slightly brackish. | <100 |
| Paraburdoo Member – Wittenoom Formation | Moderate | This member of the Wittenoom Formation can be a significant aquifer when associated with karstic development. From previous work it is believed the karstic zones occur in narrow and discontinuous zones possibly associated with the contact with the underlying West Angelas Member. It may sometimes, therefore be hard to locate a transmissive zone within the dolomite. Yields depend on the extent of karst development. It is likely that the water contained within this unit is saline to hypersaline. | 500-1,000 |

To enable this third phase of work Brockman applied to the Department of Water (DoW) for a licence under Section 26D of the Rights in Water and Irrigation (RIWI) Act to construct or alter a well (26D CAW license). Brockman obtained a license to construct up to 17 non artesian bores on 25th January 2008, a copy of which is provided in Appendix A.

# SECTION 3 - DETAILED HYDROGEOLOGICAL ASSESSMENT

## 3.1 BORE CONSTRUCTION

DGS Drilling Ltd undertook the exploration drilling and bore construction under direct contract to Brockman. DGS Drilling mobilised to site on 27th February 2008. All drilling and bore construction was carried out between 1st March 2008 and 20th April 2008. Due to the unconsolidated nature of the formations all drilling was undertaken utilising mud-rotary drilling methods.

A total of six piezometers and two test production bores were drilled and constructed. Bore locations are presented in Figure 2. The constructions details of the test production bores and piezometers are presented in Table 3.1.

### 3.1.1 Test Production Bores

Two test production bores were constructed. The Potable Bore was drilled between the 1st to the 9th March and the Piezo Site 1 in Pit Production Bore (PS1PB) was drilled between the 4th and the 14th April 2008. Composite bore logs for these and the piezometers are presented in Appendix B.

The Potable Bore was constructed using 155mm ND Class 12 uPVC casing fitted with an end cap. Slotted casing (1mm slots) was placed over the main aquifer interval from 35 to 53mbgl adjacent to the THD deposit. A 3m blank PVC sump was installed beneath the screened section. All casing joints were connected using both PVC solvent cement and screws. The annulus between the bore wall and the casing was packed with washed and graded gravel and the completed bore was developed by airlifting until the discharge was clear and free of suspended sediment. The bore was finished with a steel lockable security cap fitted to the surface casing.

The PS1PB was constructed using 250mm ND Class 12uPVC casing and 250mm ND wire wound well screens (1mm aperture). The stainless steel well screens were placed over the main aquifer interval between 21.85 and 58.27mbgl with a 3m stainless steel sump from 58.27mbgl to 61.27mbgl. PVC casing joints were connected using PVC solvent cement and screws while stainless steel screens and sumps were welded. The annulus between the bore wall and the casing was packed with washed and graded gravel and the completed bore was developed by airlifting until the discharge was clear and free of suspended sediment. The bore was finished with a steel lockable security cap fitted to the surface casing.

On completion bore PS1PB and the Potable Bore yielded 18 L/s and 2.5L/s respectively during airlift development.

### 3.1.2 Piezometer Installation

The six piezometers were installed between the 16th March 2008 and 20th April 2008. The piezometers were constructed using 52mm ND Class 12 uPVC fitted with an end cap. Slotted casing (1mm slots) was placed adjacent to the main aquifer interval (THD) at Piezo Site 1 Shallow, Piezo 2 Shallow, and Piezo Site 3 Shallow. At Piezo Site 1 Deep and Piezo Site 2 Deep. The slotted casing (1mm slots) was placed adjacent to the altered Mt McRea/Mt Sylvia  At Piezo Site 4 Deep the slotted casing (1mm slots) was placed adjacent to the underlying crystalline sheared dolomite of the Wittenoom Formation. Composite bore logs are presented in Appendix B

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**Table 3.1**
**Marillana Iron Ore – Bore and Piezometer Construction Details**

| Piezometer/Bore ID | Location coordinates | Drill Dates | Drilling Method | Drilled Depth mbgl | Drilled Diameter mm | Construction Material | Slotted Interval m | Casing Interval | Casing ID mm | SWL 20/04/08 mbtosc | Bore Elevation mbtosc | Airlift yield L/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Potable Bore | 730060mE 7498100mN | 01/03/08 to 09/03/08 | Mud Rotary | 65 | 0-3m = 311 3-65m=250 | C12 uPVC | 33-53m | 0-35m 53-56m | 250 | 37.93 | 449.68 | 2.5 |
| Piezo Site 1 Shallow | 726938.4mE 7500765.4mN | 01/04/08 to 02/04/08 | Mud Rotary | 62 | 0-3m = 250 3-65m=150 | C12 uPVC | 24-59.7m | 0-24m | 50 | 33.92 | 449.61 | 1-2 |
| Piezo Site 1 Deep | 726938.7mE 7500763.3mN | 27/03/08 to 01/04/05 | Mud Rotary | 84 | 0-3m = 250 3-65m=150 | C12 uPVC | 69.1-75.1m | 0-69m | 50 | 33.98 | 449.60 | 3-4 |
| In Pit Production Test Bore | 726937.4mE 7500772.4mN | 04/04/08 to 14/04/08 | Mud Rotary | 65 | 0-3m = 311 3-65m=250 | C12 uPVC Stainless steel Johnson Well Screen 1mm slot Stainless Steel sump | 21.8-58.3m | 0-21m 58-62.m | 250mm | | 444.38 | 18 |
| Piezo Site 2 Shallow | 727777.6mE 7500899.9mN | 16/03/08 to 18/03/08 | Mud Rotary | 60 | 0-3m = 250 3-60m=150 | C12 uPVC | 21.4-57.4m | 0-21.4m | 50 | 26.91 | 437.31 | 1 |
| Piezo Site 2 Deep | 727777.8mE 7500902.3mN | 10/03/08 to 18/03/08 | Mud Rotary | 76 | 0-4m = 250 4-65m=150 | C12 uPVC | 66.5 72.5m | 0-66.5m | 50 | 26.95 | 437.30 | 1 |
| Piezo Site 3 Shallow | 728189.9mE 7502288.7mN | 20/04/08 to 22/04/08 | Mud Rotary | 72 | 0-3m = 250 4-72m=150 | C12 uPVC | 21.5-36.5 | 0-21.5m 36.5-42.5m | 50 | 14.80* | 424.62 | n/a |
| Piezo Site 4 Deep | 7503163.5mE 728806.3mN | 15/04/08 to 20/04/08 | Mud Rotary | 114 | 0-4m = 250 4-114m=150 | C12 uPVC | 72-114 | 0-72m | 50 | 3.31** | 418.54 | n/a |

*Water level recorded on 22/04/08
**Water level recorded on 21/04/08
mbgl = meters below ground level
mbtosc = meters below top of security casing

## 3.2    AQUIFER TESTING

As part of the Stage 3 investigations both the Potable Bore and PS1PB were hydraulically tested.  The tests comprised a multi-rate step test (where by the bore is pumped at increasing abstraction rates each of equal duration (100 min) during which the pumping water level in the bore is measured and recorded) and a constant rate test where by the bore is pumped at a fixed abstraction rate followed by a recovery period and groundwater level response to abstraction is recorded in the pumped bore and nearby observation bores/piezometers.

### 3.2.1    Potable Bore

Test pumping on the Potable Bore was undertaken between 6th and 8th April 2008 by Boretec.).  The test pumping was undertaken using an electric submersible pump.  The step test comprised pumping at five increasing abstraction rates, each of 100 minutes duration, during which the pumping water level in the bore was measured and recorded.  The CRT comprised a 24 hour test followed by a recovery period.  As there were no monitoring bores available, only the pumping water level in the production bore was measured.

A summary of the test pumping is presented in Table 3.2

**Table 3.2**
**Summary of test Pumping Results for the Potable Bore**

| Pumping Test Type | Duration | Pumping Rate (L/sec) | Pumping Bore Drawdown (m) | Analysis | Apparent Bore Efficiency (%) | Transmissivity m²/day | Hydraulic Conductivity |
|---|---|---|---|---|---|---|---|
| Step Test | 5 x 100 min steps | 1 | 0.31 | Biershenk and Wilson | 10.3 | | |
| | | 2.5 | 1.89 | | 4.4 | | |
| | | 3.5 | 3.54 | | 3.2 | | |
| | | 4.5 | 5.85 | | 2.5 | | |
| | | 6 | 12.61 | | 1.9 | | |
| Constant Rate Test | 24 hours | 5.5 | 9.01 | Cooper Jacob | | 110 (3 to 12 minutes) 453 (12 to 1440 minutes) | 7.0 29.0 |

*Step Test*

The step test was conducted with abstraction rates ranging from 1 to 6L/s.  Using the Biershenk Wilson analysis method, coefficients of aquifer loss (B) and apparent well loss (C) were found to be $3.77 \times 10^{-4}$ and $3.379 \times 10^{-5}$ respectively.  The apparent efficiency of the bore operating at these flow rates ranged from 10% at 1L/sec to 2% at 6L/sec (Figure 3).  The apparent efficiency means that much of the head loss caused by inefficiency is attributed to turbulent flow which may be attributed to focussed inflows from discrete aquifer horizons combined with the limited open area of the slotted PVC casing.  Once the pump in the bore was switched off at the end of the last pumping step there was a rapid rise of groundwater within the bore column and the static water level was attained within 5 minutes.  This rapid rise on the cessation of pumping confirms that the low efficiencies of the bore reflect the well loss component and not the aquifer loss component.

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### 3.2.2 Constant Rate Test and Recovery

The constant rate test was conducted at a rate of 5.5L/s for a period of 24 hours.  Following the CRT a period of water level recovery was also monitored in the bore.  The shape of the drawdown plot (Figure 4) suggests semi-confined (leaky) aquifer response in the pumping bore.  The water level during the 24 hour pumping test did not reach steady state conditions with groundwater levels continuing to fall at approximately 2 to 3cm during the last 120 minutes of the test.

Using the Cooper-Jacob straight line method for analysis, transmissivity values of between 110m$^2$/day and 453m$^2$/day were calculated.  The transmissivity rate of 110m$^2$/day was derived from early time data, (3 minutes to 12 minutes) (Figure 4). The value of 453m$^2$/day was derived from the aquifer drawdown response between 12 and 1000 minutes and probably reflects the effects of gravity drainage (leakage) offsetting the rate of drawdown.  Towards the end of the test drawdown starts to increase again and it is likely the slope of the drawdown curve will return to the initial transmissivity observation.  Hence a transmissivity of 110m$^2$/day may be a more representative of long term pumping.

On cessation of pumping the water level rebounded to its non pumping static water level within 2 minutes indicating that most of the drawdown was well loss rather than formation loss.  The expression of this response can be seen in Figure 5.  The rapid response of the groundwater level within the bore did not allow a comprehensive analysis of the data but with the data available a Transmissivity value of 220m$^2$/day was calculated.

### 3.2.3 PS1PB

Testing of PS1PB was conducted by Boretec, under sub-contract to Test Pump Australia (TPA) between 17th June and 26th June 2008.  The test pumping was undertaken using a vertical turbine pump, powered at surface by a diesel engine.  A diesel booster pump was also used to aid disposal of discharge water and reduce pumping duty of the turbine pump (and therefore increase pumping capacity).  Discharge of pumping water was via a 150mm light duty lay flat hose to a creek bed located approximately 700m to the northwest of the pumping bore.

***Step Rate Test***

The Step Test comprised 5 steps of increasing discharge rates each of 100 minutes duration. The pumping rates, drawdown and estimated bore efficiencies in the bore during this step test are presented in Table 3.3.

The step test results using the Biershenk & Wilson analysis are presented in Appendix B.  Coefficients of aquifer loss (B) and apparent well loss (C) were 7.0x10$^{-4}$ and 2.0x10$^{-7}$ respectively, translating to apparent well efficiencies of between 44% and 66% for the rates tested (Figure 6).

These efficiencies are higher than those reported in the Potable Bore reflecting the increased efficiency and greater open area of the stainless steel well screens.

**Table 3.3**
**Summary of PS1PB Step Test Pumping Results**

| Pumping Test Type | Duration | Pumping Rate (L/sec) | Pumping Bore Drawdown (m) | Analysis | Apparent Bore Efficiency (%) | Transmissivity m²/day | Hydraulic Conductivity |
|---|---|---|---|---|---|---|---|
| Step Test | 5 x 100 min steps | 15 | 1.28 | Biershenk and Wilson | 66 | | |
| | | 20 | 1.90 | | 59 | | |
| | | 25 | 2.62 | | 54 | | |
| | | 30 | 3.43 | | 49 | | |
| | | 36.5 | 4.63 | | 44 | | |

*Constant Rate Test*

An extended constant rate test was conducted for a period of 7 days to better assess leakage and boundary conditions of the aquifer. Discharge rates over the duration of the constant rate test were kept as close as possible to 33L/s however, some variations occurred particularly when the booster pump was being fuelled/serviced. Accumulated flow over the duration of the test was used to determine the average discharge rate of 32.5L/s. Groundwater levels were observed and recorded at the pumping bore and surrounding piezometers. Following the completion of the constant rate test, an hour of water level recovery was also monitored. (The distance from the production bore to Piezometer 1 shallow and Piezometer 1 deep are 7.1m and 9.3m respectively).

The drawdown curves derived from the pumping tests were analysed using the Neuman method. The Neuman analysis takes into account the delayed yield that usually occurs in pumping tests completed in unconfined aquifers. Estimates of hydraulic conductivity (permeability) and transmissivity were calculated, the results of which are presented in Table 3.4 and the drawdown profile of PS1PB and Piezo Site 1 Shallow and Piezo Site 1 Deep are presented in Figure 7.

**Table 3.4**
**Summary of the PS1PB Constant Rate Test Pumping Results - Neuman Analysis**

| Bore ID | Duration | Pumping rate (l/s) | Drawdown (m) | Transmissivity (m²/day) | Hydraulic conductivity (m/day) |
|---|---|---|---|---|---|
| Pumping production bore | 10080 minutes | 32.5 | 4.23 | 269 | 8.97 |
| Observation Piezo 1 shallow | 10080 minutes | 0 | 0.74 | 468 | 15.6 |
| Observation Piezo 1 deep | 10080 minutes | 0 | 0.40 | 339 | 11.3 |

Following the cessation of pumping rapid recovery of water levels in the bore were observed, with 96% of water level recovered in 60minutes. Water level recovery data was analysed utilising the Theis Recovery method. Estimated parameters of transmissivity and hydraulic conductivity were calculated and are presented in Table 3.5.

**Table 3.5**
**Summary of the PS1PB Recovery Results - Theis Recovery Analysis**

| Bore id | Recovery time after pumping | Drawdown (m) | Recovery (m) | Percentage recovery of total drawdown | Transmissivity (m$^2$/day) | Hydraulic conductivity (m/day) |
|---|---|---|---|---|---|---|
| Pumping Production Bore | 60 minutes | 4.23 | 4.06 | 96 | 213 | 7.1 |
| Observation Piezo 1 Shallow | 60 minutes | 0.74 | 0.55 | 74 | 522 | 17 |
| Observation Piezo 1 Deep | 60 minutes | 0.40 | 0.24 | 60 | 522 | 17 |

## 3.3    SUSTAINABLE ABSTRACTION

### 3.3.1    Source Reliable Output Calculations

A source reliable output (SRO) calculation was performed using the results of the step and constant rate test. The SRO analysis uses the bore performance characteristics from the step test and the aquifer parameters determined from the CRT to predict the long-term pumping water levels in the bore.

***Potable Bore***

The SRO calculations for the Potable bore assume transient radial flow conditions into the bore for homogenous and isotropic aquifer of infinite extent to estimate the long term drawdown of a pumping bore. Such conditions are unlikely in a real setting; however, the SRO calculation does allow an indication of likely pumping water levels and therefore sustainable bore yields.  The component of drawdown attributed to well loss determined from a step rate test is incorporated with the hydraulic parameters determined from a constant rate test to give a total estimate of the long term pumping water levels at different pumping rates.

Analyses was undertaken using the more conservative and representative transmissivity value of 110m$^2$/day. A storativity value of 8 x 10$^{-3}$ has been included as this is a typical value for many semi-confined aquifers. The maximum allowable pumping water level is an arbitrary level assigned to protect the aquifer from over abstraction; in this case a level of 45mbgl has been selected, which is approximately half of the saturated thickness of the aquifer.  It should be noted however, that the pumping water level will be greater than actual aquifer water levels as the component of well loss is also incorporated into the calculation.

Using a range of abstraction rates over a period of pumping of 5 years (it is assumed that that the aquifer will receive a recharge event most years however, to represent a 'stress' condition on the aquifer a period of five years without recharge was simulated).  The analysis of the data using SRO calculations indicates that the bore could sustain a pumping rate of 8.25L/s with a maximum pumping water level of 45mbgl.  For short term use, sustainable abstraction rates may be even higher.  The SRO calculation is presented in Figure 8.

Given the diameter of the bore and thus the size of the pump which could be installed, it appears that the bore may only be suitable for a pump rated up to approximately 8 to 9L/s assuming discharge at close proximity to the bore.  If water is required to be pumped some distance from the bore then actual pumping rates are likely to be lower.

Using an abstraction rate of 8L/s and a transmissivity value of 110m$^2$/day the drawdown over 1825 days of pumping in the immediate vicinity of the bore was assessed to be approximately 7m, which represents a 30% reduction in the saturated thickness of the aquifer.

### *PS1PB*

SRO analysis was undertaken using the conservative representative transmissivity values of 270m$^2$/day. A storativity value of 8 x 10$^{-3}$ was included as this is a typical value for this type of aquifer. The discharged rates assessed were the same as those used within the step test (15, 20, 25 and 30L/sec). The maximum allowable pumping water level of half of he saturated thickness of the aquifer (45mbgl) has been selected to limit aquifer dewatering. Applying the SRO analysis over a period of 5 years without recharge indicates that that the bore could sustain a pumping rate of 30L/sec with a maximum pumping water level of 45mbgl (Figure 9). The estimated drawdown of approximately 11m at the bore equates to a reduction in the saturated thickness of the aquifer in the immediate vicinity of the bore of approximately 46%.

Initial assessment of pumping capacity indicates that 30L/s against the predicted pumping water level of 45mbgl is readily achievable. Furthermore, dependent on the pump selected pump sizing water should be able to be reticulated by the bore pump at the nominated 30L/s for considerable distance without reducing abstraction rates.

### 3.3.2   Pumping Interference

The SRO calculations undertaken on both bores suggest the sustainable pumping from each bore to be of the order of 8L/sec from the Potable Bore and 30L/sec from the PS1PB (constrained by 50% aquifer depletion) when pumped in isolation.

To establish the drawdown impacts of both bores operating in tandem further SRO calculations were undertaken.

Iterations on the combination effects were analysed and the results indicated that when the PS1PB is pumped up to 30L/sec and the Potable Bore is pumped at rates from between 2.5L/sec and 8L/sec there is only a minimal additional impact on the aquifer. The calculations are presented in Table 3.6 and Appendix C.

**Table 3.6**
**(PS1PB and Potable Bore – Drawdown Interference)**

| Production Bore (transmissivity 270m$^2$/day) | Potable Bore | | | | | |
|---|---|---|---|---|---|---|
| | Abstraction Rate 2.5L/sec | | Abstraction Rate 5L/sec | | Abstraction Rate 8L/sec | |
| **Abstraction rate 30L/sec** | (Additional Drawdown (m) on Production Bore) | (mbgl) | (Additional Drawdown (m) on Production Bore) | (mbgl) | (Additional Drawdown (m) on Production Bore) | (mbgl) |
| | 0.14 | 45.03 | 0.27 | 45.17 | 0.44 | 45.34 |

# SECTION 4 - GROUNDWATER MODELLING

## 4.1 MODEL OBJECTIVES

The objectives of the current Marillana groundwater modelling are to:

- Assess the water supply potential of the sediments around a number of proposed pits;

- Assess potential drawdown impacts of the water supply.

## 4.2 MODEL SET-UP

### 4.2.1 Background

The model developed for the Marillana system includes features to simulate:

- The hydrogeological features of the aquifer system over the area of current investigation;

- Rainfall recharge to the aquifer system;

- Groundwater inflows from upstream of the northern and southern model boundaries ;

- Groundwater discharge via evaporation from the Fortescue Marsh and phreatophytic vegetation; and

- Groundwater pumping.

The model was developed using the USGS modular three-dimensional finite-difference program MODFLOW (McDonald and Harbaugh, 1988), one of the leading industry codes for groundwater flow modelling using the PMWin Pro interface.

### 4.2.2 Model Extent and Grid

The model extends from the Hamersley Range to the Chichester Range north and south of the Fortescue Marsh respectively. The model covers a maximum distance of 42.2km north south and 30.6 km east west. To align the model with the inferred principal flow directions, the model domain has been rotated 65° from its northwest corner. The model and all associated data have been plotted using the GDA 94 Zone 50 coordinate system. Coordinates for the four corners of the rectangular model domain are detailed in Table 4.1. The model uses a uniform grid size of 200m square cells distributed over 150 rows and 206 columns. The extent and boundary conditions of the groundwater model are shown in Figure 10.

**Table 4.1**
**Model Domain**

|  | Easting* (m) | Northing* (m) |
|---|---|---|
| Top right | 755645 | 7523451 |
| Top left | 727909 | 7536380 |
| Bottom left | 710078 | 7498137 |
| Bottom right | 737809 | 7485205 |

*GDA 94 Zone 50

### 4.2.3 Data Summary

A summary of the key data used to set up the numerical model is provided in Table 4.2.

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**Table 4.2**
**Data Summary**

| Parameter | Data source |
|---|---|
| Topographic levels | SRTM digital elevation model and Brockman resources collar survey |
| Potential aquifer horizons | Exploration bore logs |
| Water levels | Measurements from Aquaterra and data from Brockman Resources (June, 2008) |
| Evaporation | Monthly data for Wittenoom station |
| Rainfall | Climatic data for Newman |

### 4.2.4   Model Geometry

Based on the conceptual model outlined in previous sections, the numerical groundwater model has three layers (Table 4.3).

**Table 4.3**
**Model Layers**

| Layer | Description | Thickness |
|---|---|---|
| Layer 1 (L1) | Overburden, Tertiary Clay, Valley Fill Sediments, THD/TPS | 60m |
| Layer 2 (L2) | Brockman Iron Formation, Mc Rae Shale and Mt Silvya formations | 30 – 50m |
| Layer 3 (L3) | Wittenoom Formation | 35 – 50m |

The elevation of the top of layer 1 (ground level) was interpolated from a SRTM digital elevation model and from the Brockman Resources exploration bore hole collar survey.  The bottom of the model (bottom of Layer 3) was set uniformly at 280mRL. The elevations for the bottoms of Layer 1 and 2 were based on bore-log information.

## 4.3   GROUNDWATER INFLOW AND OUTFLOW

### 4.3.1   Boundaries

Fixed head inflow boundaries were assigned on the south, north and east of the model domain. A fixed head groundwater outflow boundary was assigned to the most downstream end of the Fortescue Marsh within the model domain.  The elevations of fixed head boundary conditions are assigned consistent with available data.  The elevations of the fixed head boundary conditions are shown in Figure 10 and are summarised as follows:

- 416m on the southern inflow boundary

- 410mRL on the northern inflow boundary, and

- Between 396.5 and 400mRL along the downstream Fortescue Marsh boundary.

All other model boundaries are the no flow type.

### 4.3.2   Rainfall Recharge

Apart from the groundwater inflow boundaries assigned on the north and south of the model domain, all inflow to the groundwater model results from direct infiltration of incident rainfall.  The rainfall recharge

distribution for the model is shown in Figure 11. Three different recharge regimes were defined considering that 10% of the average annual rainfall recorded for Newman infiltrates into groundwater

- 17mm of rainfall (1.9 x10$^{-4}$ m/d) enters the marsh during the wet season between January and March;

- 10.1mm (5.5 x10-5 m/d) infiltrates between April and September; and

- 4.1mm of precipitation (4.4 x10$^{-5}$ m/d) infiltrates between October and December.

Recharge in the creeks would occur mainly during the wet season, when runoff volumes increase due to higher precipitation in the hills. Percolation along streambeds (occurring mostly in the foothills) is expected to be about 1.4mm/yr.

### 4.3.3 Evapotranspiration

Evaporation was assigned to the Fortescue Marsh and the Coolibah stand just south of the marsh (Figure 12) using the Evapotranspiration Package in Modflow. Assigned evaporation values range from 907.7mm during the period January to March 1134.1mm during the period April to September and 1102mm between October and December. The extinction surface was set consistent with available topographic data with the extinction depth assigned to 5m to represent evaporation from the shallow water table beneath the marsh and evapotranspiraiton from vegetation.

### 4.4 MODEL CALIBRATION

### 4.4.1 Introduction

Model calibration is the process by which the independent variables of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data (usually obtained from groundwater level monitoring). This process typically involves refining the aquifer properties, in this case the hydraulic conductivity and specific yield of the sediments, to achieve the desired degree of correspondence between the observed and modelled data.

Long term monitoring data for the catchment are not available to allow long term or transient calibration. Groundwater monitoring from nearby catchments, where water tables are shallow and highly seasonal surface water flows are observed, the resulting groundwater level variation is such that an average or steady state condition cannot be easily defined. Instead a dynamic calibration process was undertaken such that the model was used to simulate seasonal variation in water levels due to the distinct wet/dry season groundwater patterns observed in the Pilbara.

### 4.4.2 Calibration

Specified horizontal and vertical hydraulic conductivity in the base-case model were modified by trial and error to find a reasonable match between water levels measured on 165 piezometers distributed all over the region (combined database from Aquaterra, Brockman Resources and DoW) and those values predicted by the model. A scatter plot of observations for data predicted for the end of the wet season are displayed in Figure 13.

Comparing the measured and predicted water levels for the alluvial aquifer, the Root Mean Squared (RMS) error as a proportion of measured range of heads is 18%. This value is higher than the generally accepted

scaled RMS of 10 %; however there remains uncertainty in the available groundwater monitoring data. Collar elevations of monitoring and test bores are derived from GPS data rather than survey data. Additionally hydrogeological features were not included in the model to improve calibration that could not be justified on the basis of the current hydrogeological understanding.

Predicted groundwater level contours for the upper aquifer (Layer 1) after calibration presented in Figure 14. The groundwater flow direction is from the north and south toward the Fortescue Marsh. South of the marsh, the groundwater flow direction is from the south west to the north east and north west around the Coolibah stand.

Hydraulic conductivities adopted for model calibration are summarised in Table 4.4 and illustrated in Figure 15. Hydraulic conductivity within the ore body was assigned a maximum of 10m/d. The valley crossing the tenement in SE-NW direction is rich in alluvial materials and was assigned a value of 1.5m/d. A lower hydraulic conductivity of 0.9m/d was assigned to the marsh, as it is mainly composed of silts and clays. A hydraulic conductivity of 1m/d was assigned to the low hydraulic conductivity sediments just upstream of the marsh. Adopted specific yield values and confined storage values are also summarised in Table 1.5 and are assigned consistent with similar hydrogeological environments (Figure 16).

**Table 4.4**
**Aquifer Parameters after Calibration**

| Model Layer | Horizontal Hydraulic Conductivity ($K_h$) | Vertical Hydraulic Conductivity ($K_v$) | Confined Storage ($S_s$) | Specific yield (Sy) |
|---|---|---|---|---|
| | m/d | m/d | | |
| **1,** THD/TPS; Valley Sediments; Tertiary Clays | 1 to 10.0 | 0.1 to 1.0 | | 0.01 to 0.15 |
| **2,** Mt McRae and Mt Sylvia Formations | 0.05 | 0.005 | 0.00005 | |
| **3,** Wittenoom Formation | 0.05 | 0.005 | 0.00005 | |

As outlined above, the model currently does not make any allowance for groundwater recharge from large flood events. Such recharge events, occurring every few years would serve to refill the upper aquifer and minimise any drawdown impacts. The absence of such recharge will add further conservatism to model predictions.

### 4.4.3 Water Balance

The annual predcited water balance is presented in Table 4.5. The main inflow to the system is due to recharge, with a significant change in storage predicted due to the distinct wet/dry season pattern. Evapotranspiration from the marsh and the Coolibah trees make up the greatest discharge from the model domain.

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**Table 4.5**
**Calibrated Steady State Water Balance**

| Parameter | Predicted Volume (kL) | |
|---|---|---|
| | In | Out |
| Recharge | $2.49 \times 10^8$ | |
| Evapotranspiration | | $2..35 \times 10^8$ |
| Groundwater Inflows | $7.97 \times 10^6$ | |
| Groundwater Outflows | | $2.23 \times 10^7$ |
| Storage | $4.70 \times 10^7$ | $4.68 \times 10^7$ |
| Total | $3.05 \times 10^8$ | $3.05 \times 10^8$ |
| Discrepancy (%) | 0.01 | |

## 4.5    MODEL PREDICTION SCENARIOS

### CASE A:

The calibrated model was used to predict the impact of water supply pumping for a period of 5 years. The prediction assumed the proposed water supply will be derived from 2 bores in the THD aquifer close to the proposed mining development. Abstraction is assigned continuous over a period of 5 years, at a rate of 216kL/d (2.5L/s) from the existing potable Bore and 2592kL/d (30L/s) from the Test Bore.

### CASE B:

Case B was set up identical to Case A assuming there was no rainfall recharge for entire projected demand period (5 years)

## 4.6    RESULTS

### CASE A

Predicted drawdown after 5 years of water supply pumping is shown in Figure 17.  A maximum drawdown of 14.75m (equivalent to a 61% reduction in the saturated thickness of the aquifer) is predicted at the test bore at the end of the simulation.  Maximum drawdown at the potable bore is 1.4m (equivalent to a 6% reduction in the saturated thickness).  Drawdown is predicted a distance of 1400m away from the potable bore and 3600m from the test bore. The cone of depression thus covers, a total area of approximately 7.5km by 5km. The predicted average water balance over the 5 year prediction period is shown in Table 4.6 and presented graphically in Figure 18. While Recharge and evapotranspiration account for more than 75% of the total predicted flows to and from the system, groundwater pumping makes up approximately 6%. The pumping volume is comparable to the volume predicted to flow out of the Fortescue Marsh outflow boundary.

### CASE B

At the end of the simulation the cone of depression is similar to that calculated in the previous scenario (Case A.).  Within this scenario a maximum drawdown of 14.77m is predicted at the test bore with the cone of depression (radius of impact) calculated to extend a distance similar to the Case A.

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The similarities of the two scenarios indicate that rainfall recharge is not a significant factor in the water balance of THD aquifer.  This is to be expected as most of the recharge is applied to the marsh area, introducing an element of conservatism to the modelling.

The predicted average water balance over the 5 year prediction period is shown in Figure 18.  Assuming no recharge, evapotranspiration accounts for more than 75% of the total predicted outflow from the system. Groundwater pumping makes up less than 10% (around 6%). The pumping volume is comparable to the volume predicted to flow out of the Fortescue Marsh outflow boundary.

# SECTION 5 - GROUNDWATER QUALITY

Groundwater quality analyses were carried out on samples from both the Potable Bore and PS1PB. Samples were collected at the end of the constant rate pumping tests. Groundwater samples were also collected from the surrounding piezometers both before and after the long term pumping test undertaken on PS1PB.

The groundwater samples were collected following the Aquaterra sampling protocol where a minimum of four wetted casing volumes were removed from the bore/piezometer and there was a stabilisation of EC (conductivity) and pH prior to sample collection.

The collected water samples were dispatched from the site immediately after collection to allow samples to reach the laboratory within a 24 hour period. Major ions and trace metals analysis were conducted by the NATA accredited laboratories of SGS Australia Pty Ltd.

Results are summarised in Tables 4.1 to 4.3 and compared with the Australian Drinking Water Guidelines for reference. Analytes that exceed ADWG for health and aesthetic guidelines values are highlighted in the tables. The relative concentrations of the major ions are presented on an expanded "Durov" plots in Figures D1 to D3, Appendix D.

Both shallow and deep groundwater samples can be classified as sodium-chloride type groundwater, indicative of mature groundwater with long residence times. The groundwater typing shows no indication of mixing with recently recharged groundwater. However, the deep ground water samples tend to be more mature (closer to the sodium-chloride end-point) than the shallow groundwater sample.

The water chemistry results indicate no significant change in water quality resulting from the 7 day test pumping trial at a discharge rate of 32.5L/sec.

**Table 4.1**
**Water Chemistry Results from the Marillana Potable Bore**

| | Units | Marillana Potable Bore 08/04/08 | Marillana Potable Bore 29/6/08 | ADWG | |
|---|---|---|---|---|---|
| | | | | Health | Aesthetic |
| pH | pH Units | 7.7 | 8.1 | a | 6.5-8.5 |
| Conductivity @25°C | μS/cm | 1400 | 1100 | | |
| Total Dissolved Solids (calc as NaCl) | mg/L | 830 | 660 | b | 500 |
| Sodium, Na | mg/L | 170 | 200 | b | 180 |
| Potassium, K | mg/L | 21 | 22 | | |
| Calcium, Ca | mg/L | 24 | 30 | | |
| Magnesium, Mg | mg/L | 36 | 39 | | |
| Hardness (as $CaCO_3$) | mg/L | 210 | 230 | b | 200 |
| Iron, Fe | mg/L | <0.02 | <0.02 | a | 0.3 |
| Chloride, Cl | mg/L | 280 | 260 | b | 250 |
| Bicarbonate, HCO3 | mg/L | 210 | 210 | | |
| Carbonate CO3 | mg/L | <1 | <1 | | |
| Sulphate, SO4 | mg/L | 88 | 80 | 500 | 250 |
| Nitrate, NO3 | mg/L | 2.5 | 3.5 | 50 | |
| Fluoride, F | mg/L | 0.2 | <0.1 | 1.5 | |
| Free Cyanide, Cn | mg/L | <0.01 | n/a | 0.08 | |
| Soluble Aluminium, Al | mg/L | <0.02 | n/a | a | 0.2 |
| Arsenic, As | mg/L | <0.002 | n/a | 0.007 | |
| Soluble Manganese, Mn | mg/L | <0.005 | n/a | 0.5 | 0.1 |
| Soluble Lead, Pb | mg/L | <0.005 | n/a | 0.01 | |
| Soluble Cadmium, Cd | mg/L | <0.001 | n/a | 0.002 | |
| Nitrite-Nitrogen, $NO_2$-N | mg/L | <0.005 | 3.5 | 3 | |
| Soluble Silver, Ag | mg/L | <0.005 | n/a | 0.1 | |
| Soluble Barium, Ba | mg/L | <0.01 | n/a | 0.7 | |
| Soluble Selenium, Se | mg/L | 0.003 | <0.003 | 0.01 | |
| Soluble Mercury, Hg | mg/L | <0.0005 | n/a | 0.001 | |
| Soluble Boron, B | mg/L | <0.2 | n/a | 4 | |
| Soluble Molybdenum, Mo | mg/L | <0.01 | n/a | 0.05 | |
| Soluble Nickel, Ni | mg/L | <0.005 | n/a | 0.02 | |
| Soluble Copper, Cu | mg/L | <0.005 | n/a | 2 | 1 |
| Soluble Zinc, Zn | mg/L | <0.005 | n/a | a | 3 |
| Hexavalent Chromium # | mg/L | <0.01 | n/a | 0.05 | |
| Ammonia Nitrogen $NH_3$-N | mg/L | <0.1 | <0.1 | a | 0.5 |
| Antimony, Sb # | mg/L | <0.002 | n/a | 0.003 | |
| Bromide, Br | mg/L | 0.4 | 0.4 | | |
| Hydrogen Sulphide,$H_2S$# | mg/L | <0.1 | n/a | a | 0.05 |
| Total Coliforms | CFU/100mL | >300 | 0 | 1 | |
| Turbidity | n/a | None | n/a | b | 5 NTU |

'a – Insufficient data to set guidelines based in health considerations
'b – no health based guideline is considered necessary
HPC – Heterotrophic Plate Count

**Table 4.2**
**Water Chemistry Results Before and After Aquifer Test**

| | Units | PS1PB | | Piezo 1 Shallow | | Piezo 1 Deep | | Piezo 2 Shallow | | Piezo 2 Deep | | Piezo 3 Shallow | | Piezo 4 Deep | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | 15/6/08 | 26/6/08 | 18/6/08 | 26/6/08 | 16/6/08 | 26/6/08 | 16/6/08 | 27/6/08 | 16/6/08 | 27/6/08 | 16/6/08 | 27/6/08 | 20/6/08 | 28/6/08 |
| pH | pH Units | 8 | 8.1 | 7.4 | 8 | 7.5 | 8.1 | 7.6 | 8.1 | 7.7 | 8.3 | 7.8 | 8.2 | 8 | 8 |
| Conductivity @25$^o$C | µS/cm | 2300 | 2300 | 2200 | 1800 | 6000 | 6200 | 1800 | 1600 | 3500 | 4900 | 3000 | 2900 | 64000 | 43000 |
| Total Dissolved Solids @ 180$^o$C | mg/L | 1200 | 1200 | 1100 | 920 | 3200 | 3800 | 880 | 820 | 1700 | 3100 | 1500 | 1500 | 66000 | 44000 |
| Soluble Iron, Fe | mg/L | 0.21 | 0.03 | 0.03 | 0.02 | 0.07 | 0.03 | 0.04 | 0.02 | 0.09 | 0.04 | 0.06 | 0.09 | 0.52 | 0.64 |
| Sodium, Na | mg/L | 360 | 420 | 310 | 320 | 1000 | 1200 | 240 | 270 | 530 | 900 | 460 | 520 | | 13000 |
| Potassium, K | mg/L | 34 | 39 | 30 | 31 | 130 | 92 | 39 | 45 | 130 | 170 | 46 | 48 | | 1000 |
| Calcium, Ca | mg/L | 34 | 36 | 32 | 34 | 49 | 56 | 30 | 33 | 41 | 35 | 38 | 39 | 300 | 230 |
| Magnesium, Mg | mg/L | 48 | 53 | 43 | 46 | 80 | 94 | 35 | 38 | 54 | 61 | 45 | 54 | 1200 | 800 |
| Chloride, Cl | mg/L | 490 | 580 | 470 | 420 | 1600 | 1700 | 350 | 340 | 830 | 1400 | 690 | 680 | 30000 | 20000 |
| Carbonate, $CO_3$ | mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Bicarbonate, $HCO_3$ | mg/L | 200 | 200 | 210 | 200 | 320 | 270 | 230 | 230 | 250 | 260 | 320 | 260 | 270 | 340 |
| Sulphate, $SO_4$ | mg/L | 150 | 180 | 150 | 140 | 470 | 480 | 120 | 120 | 220 | 370 | 210 | 200 | 8100 | 5200 |
| Nitrate, $NO_3$ | mg/L | 3.4 | 3.4 | 3.3 | 3.4 | <0.2 | <0.2 | 4.3 | 3.2 | <0.2 | 1.5 | <0.2 | 3.1 | 0.3 | <0.2 |
| Fluoride, F | mg/L | 0.4 | 0.4 | 0.1 | 0.4 | <0.1 | 0.4 | 0.1 | 0.4 | <0.1 | 0.5 | 0.1 | 0.4 | 1.1 | 2.1 |
| Hardness (as $CaCO_3$) | mg/L | 280 | 310 | 260 | 270 | 450 | 530 | 220 | 240 | 330 | 340 | 280 | 320 | 5800 | 3900 |
| Cation/Anion balance | % | 4.5 | 4.5 | -1.2 | 5.7 | -2.4 | 1.6 | -1.9 | 4.5 | 1.3 | -0.1 | -3.8 | 4.7 | n/a | -0.1 |
| Sum of Ions (calc.) | mg/L | 1311 | 1510 | 1249 | 1197 | 3620 | 3870 | 1048 | 1078 | 2063 | 3160 | 1814 | 1804 | n/a | 40796 |
| Soluble Selenium, Se | mg/L | <0.002 | <0.003 | <0.002 | <0.003 | 0.002 | <0.006 | 0.002 | <0.003 | 0.02 | <0.006 | 0.003 | <0.003 | n/a | <0.03 |
| Soluble Boron, B | mg/L | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 0.2 | <0.2 | <0.2 | <0.2 | 0.2 | <0.2 | <0.2 | n/a | <2 |
| Bromide, Br | mg/L | 0.3 | 0.4 | 0.6 | 0.3 | 1.2 | 0.94 | 0.5 | 0.3 | 0.3 | 0.8 | 0.9 | 0.5 | 15 | 9.5 |

# SECTION 6 - IMPACTS

## 6.1    GROUNDWATER POTENTIAL IMPACTS

The static groundwater level at the production bore locations lies at approximately 34mbgl to 38mbgl, and it is considered highly unlikely that there will be any groundwater dependent flora adversely affected by the groundwater abstraction.

SRO analysis and groundwater modelling results indicate that should stygofauna be present within the aquifer it is considered unlikely that the stygofauna will be adversely affected by abstractions, (over 5 years with no recharge within this period) as less than 61% of the saturated thickness of the aquifer is impacted in the immediate vicinity of the PS1PB and 6% of the saturated thickness of the aquifer is impacted in the immediate vicinity of the Potable Bore  The results also indicate that the cone of depression (drawdown) from operating the PS1PB at 30L/sec extends to 4000m, and from operating the Potable Bore at 2.5L/sec extends to 1400m.  Hence, not only are flora and stygofauna, which may be present within the aquifer, highly unlikely to be adversely affected, the Fortescue Marsh which lies some 20km down gradient to the north is also well outside the likely area of impact.

## 6.2    IMPACTS ON OTHER USERS

Old WRC bores and one active pastoralist bore, identified as the Weeli Bore have been identified in the surrounding area.  The location of the Weeli Bore is approximately 600m down the groundwater gradient from the Potable Bore.

It is understood that the Weeli Bore is operated periodically to supply water to a small number of cattle troughs and it is considered likely that this bore abstracts water from the THD formation.

The Weeli Bore is the only known groundwater abstraction in the area and when the Potable is pumped constantly at 8L/sec over 365 days with a recharge event after 365 days it is estimated (from Theis calculations) that the drawdown at the Weeli Bore will be in the region of 0.61m and when the Potable Bore is pumped for 1825 days with a recharge event after 1825 days (5 years) the drawdown in the Weeli Bore is estimated to be 2.46m.

Calculations from the modelling indicating that when the PS1PB is pumped at 30L/sec and the Potable Bore 2.5L/sec the drawdown at the Weeli Bore is likely to be in the region of between 0.1m and 0.2m.  Hence, the Weeli Bore is unlikely to be adversely affected from the operations of the Potable and PS1PBs over the model 5 years to recharge period.

However, if abstraction from Weeli Bore is adversely affected then it may be necessary for Brockman to make good the water supply with a small diameter off take from the nearby production bore.

# SECTION 7 - CONCLUSIONS

## 5.1 OPERATING PARAMETERS

Brockman resources have requested Aquaterra investigate the potential for groundwater abstraction and associated impacts for a groundwater production supply up to 30L/sec and a potable bore supply up to 2.5L/sec from bores located within the Brockman tenement at Marillana.

Analysis of hydraulic testing data obtained from two bores constructed within the THD aquifer (the Potable Bore and PS1PB) indicate that the Potable Bore can sustain (constrained by a maximum allowable drawdown of 50% of the saturated thickness of the aquifer at each location) abstractions of up to 8L/s and PS1PB up to 30L/s over a 5 year period without recharge. In addition, these two bores are located approximately 4km from one another and are not adversely impacted by the operation of the other bore and interference drawdown between the two bores is minimal.

## 5.2 POTENTIAL GROUNDWATER IMPACTS

The static groundwater level in the vicinity of the Potable Bore and PS1PB lies at approximately 34mbgl to 38mbgl, and it is considered highly unlikely that there will be any groundwater dependent flora adversely affected by the groundwater abstraction.

These SRO and groundwater modelling calculations also indicate that should stygofauna be present within the aquifer it is considered unlikely that stygofauna habitat will be adversely affected by abstractions as less than 61% of the saturated thickness of the aquifer in the immediate vicinity of the PS1PB and 6% of the saturated thickness of the aquifer in the immediate vicinity of the Potable Bore is impacted, when these bores are operated in tandem at rates of 30L/sec and 2.5L/sec respectively. The results also indicate that the impact from operating at these pumping rates extends to 3600m from PS1PB and 1400m from the Potable Bore. Hence, not only are flora and stygofauna, which may be present within the aquifer, highly unlikely to be adversely affected, the Fortescue Marsh which lies some 20km down gradient to the north is also well outside the likely area of impact.

### 5.2.1 Groundwater Chemistry

Groundwater samples from the Potable Bore and the PS1PB were taken at the end of the constant rate test and analysed. The chemical data indicates groundwater to be generally neutral (pH 7.7 to pH 8) with conductivity values around 1100μs/cm (600mg/L TDS) for the potable bore and 2300μs/cm (1200mg/L TDS) for PS1PB. Utilising the expanded Durov Plot the groundwater from these bores are classified as sodium chloride dominated end point waters.

Groundwater samples from both the piezometers and the bores were also collected and analysed both prior to and immediately after, the long-term testing at PS1PB. The samples showed no significant changes in groundwater chemistry prior to or after the test indicating that these bores were not affected by mixing of the underlying hypersaline Wittenoom Dolomites.

# SECTION 8 - REFERENCES

Chiang, W.-H. and Kinzelbach, W. (2000) 3D-Groundwater Modeling with PMWIN – A Simulation System for Modeling Groundwater Flow and Pollution. Springer-Verlag Berlin Heidelberg New York, S.346.

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