Water and Environment

MARILLANA PROJECT GROUNDWATER STUDY & MANAGEMENT PLAN

Prepared For	Brockman Resources
Date of Issue	26 March 2010
Our Reference	832G/G7/145f

As part of Aquaterra's commitment to the environment this PDF has been designed for double sided printing and includes blank pages as part of the document.

MARILLANA PROJECT GROUNDWATER STUDY & MANAGEMENT PLAN

Prepared For	Brockman Resources
Date of Issue	26 March 2010
Our Reference	832G/G7/145f

MARILLANA PROJECT GROUNDWATER STUDY AND MANAGEMENT PLAN

	Date	Revision Description
Revision A	05/10/2009	For Brockman Review
Revision B	12/10/2009	Figures complete, GWMP re-structure
Revision C	27/10/2009	Final mark-up
Revision D	06/11/2009	Final
Revision E	15/02/2010	Final, with requested alterations
Revision F	26/03/2010	Final, with further contingencies outlined

	Name	Position	Signature	Date
Originator	Damien Janssen	Senior Hydrogeologist		26/03/2010
Reviewer	Duncan Storey	Senior Principal Hydrogeologist		26/03/2010

	Location	Address
Issuing Office	Perth	Suite 4, 125 Melville Parade, Como WA 6152 Tel: 08 9368 4044 Fax: 08 9368 4055

EXECUTIVE SUMMARY

BACKGROUND

The Marillana Iron Ore Project is located within the Hamersley Province on the southern Pilbara Craton in the Pilbara region of Western Australia approximately 100km northwest of the township of Newman (Figure 1.1). The project is located within Exploration Licence E47/1408 and is subject to Mining Lease applications M47/1414 and M47/1419. All tenements are held by Brockman Iron Pty Ltd (Brockman), a wholly owned subsidiary of ASX listed company Brockman Resources Limited.

Brockman is investigating the feasibility of mining the Marillana iron ore deposit. The tenement covers 95km^2 of the Fortescue Valley and borders the Hamersley Range. Extensive areas of supergene iron ore mineralisation are developed within the dissected Brockman Iron Formation, which caps the range. This is the likely source material for the Tertiary Hematite Detritals and Channel Iron Deposits that comprise the target iron ore within the tenement. A significant proportion of the deposit lies below the water table and dewatering will be a component of the mining operation. A water supply will also be required for the processing plant and dust suppression throughout the operation.

Aquaterra were engaged by Brockman for the hydrogeological investigations to assess groundwater issues related to the project, namely:

- Mine Dewatering.
- Water supplies for the process plant and village.
- Determining a hydrogeological baseline and assessing potential impacts on the groundwater system related to the project development.
- Identifying areas of key uncertainty and the recommendation of additional studies.

In addition, a groundwater management plan, developed in conjunction with Brockman, is presented that minimises/mitigates potential impacts on the project area from dewatering activities.

FIELD INVESTIGATIONS

Aquaterra has undertaken a hydrogeological drilling programme earlier this year. This included 17 exploration holes (completed as piezometers) and two production bores. These were subjected to pumping tests, along with a number of airlift tests and falling head tests. The outcomes of previous investigations in 2008 were also assessed, and all available information has been considered in this study. A summary of the drilling completed at the project is summarised in Table ES-1, and hydraulic test results summarised in Table ES2.

CONCEPTUAL GEOLOGY & HYDROGEOLOGY

On the basis of the recent field campaign (cf. Sections 2 & 3) and desktop study to incorporate all available data, the following conceptual geological understanding has been developed:

- A CID palaeochannel incised into weathered basement (BIF/shale/dolomitic shale). The CID subsequently underwent significant weathering, likely being dissected by palaeo-drainages off the Hamersley Range. The remnant CID therefore formed a series of discontinuous mesas.
- A period of calcrete precipitation followed, which is interpreted (on the basis of the data currently available) to be regionally extensive and laterally continuous.
- A period of scree deposition followed, burying the CID and calcrete beneath a sequence of pisolite gravels and hematite detritals.
- This was then buried beneath non-mineralised transported overburden, which is modern-day ground surface.

The hydrogeological aspects relating to the project are:

- Groundwater level of 20-30mbgl in the vicinity of the proposed orebody, shallowing to 10mbgl in the northern reaches of the tenement.
- Groundwater quality in the Tertiary sequence less than 2,500mg/L TDS on tenement, and generally <1,000mg/L in the orebody.
- The CID, calcrete, pisolite gravels (TPS) and hematite detritals (THD) units have varying aquifer properties that have been incorporated into subsequent numerical modelling.
- The estimated groundwater throughflow is quite low (~1,000kL/d), and most of the groundwater volumes are coming from storage.
- Seasonal recharge is a significant factor that has been represented through transient modelling, and will be verified as long-term water level data becomes available.

GROUNDWATER MODELLING

Groundwater modelling was conducted to assess the potential for dewatering of the CID/detrital orebody to supply the project water demand. Model predictions suggest that the proposed borefield, with one bore located in each mining panel, operated consistent with the proposed mining sequence will be sufficient to satisfy water supply requirements until Year 9 of the project.

The MAR modelling results for preferred re-injection option indicates that peak groundwater mounding (which occurs at ~2 years operation) will be 11m above the pre-mining water level (12mbgl at the Abalone East site). Recirculation effects increase dewatering requirements by less than 3%.

As no long term monitoring data and hydraulic testing are available, there remains uncertainty in the aquifer parameters used to construct the model. Sensitivity analysis suggests that the model is most sensitive to changes in the adopted hydraulic conductivity of the orebody and the adjacent calcrete. Despite this, overall borefield yields are predicted to decrease by less than 10% when aquifer hydraulic conductivity values for these two units are halved.

The proposed closure strategy, which includes backfilling on the mine path with waste rock and fines rejects to above the pre-mining watertable has also been modelled. Model results suggest that water levels within the mine path are not significantly impacted by this closure strategy with little to no impact to the groundwater system predicted outside of the mine path.

- Salinity modelling was conducted to assess the potential water quality fluctuations that might be encountered during dewatering operations. The predicted salinity of dewatering volumes after six years of continuous groundwater pumping that maintains water levels at the base of the projected pit is up to 4,000mg/L TDS, with some associated increases in salinity with the rock formations below the base of mining.

Table ES1: Summary of Hydrogeological Drilling at the Marillana Project

Bore ID	Location Details		Drilling Information				Construction Information							Geology
	Easting (MGA94)	Northing (MGA94)	Date Drilled		Depth (m)	Diam. (mm)	Cased Depth (mbgl)	Casing	Diam. (mm)	Slotted Interval (mbgl)	Water Table		Airlift Yield (L/s)	
			Start	Finish							SWL (mbgl)	Date		
2009 Hydrogeological Drilling Programme														
PB1	730770.73	7497751.53	17/05/09	18/05/09	63	400	63	Steel & s/steel screens	254	50-62	31.96	11/06/09	8-10	0-21 TOB, 21-45 THD, 45-58 TPS, 58-61 CID, 61-63 TD1
PB2	734322	7495004	12/05/09	13/05/09	53	400	53	Steel & s/steel screens	254	38-50	24.8	11/06/09	15-20	0-15 TOB, 15-33 THD, 33-45 TPS, 45-51 CID, 51-53 TD1
Obs1	727623.23	7501474.39	22/04/09	22/04/09	46	150	44	Class 12 uPVC	50	21-44	22.86	11/06/09	0.5	0-19 TOB, 19-46 THD
Obs2	727111.93	7500620.07	20/04/09	21/04/09	76	150	76	Class 12 uPVC	50	28-76	33.74	11/06/09	~5	0-20 TOB, 20-46 THD, 46-70 CID, 70-76 TD1
Obs3	728087.16	7499727.17	3/06/09	5/06/09	75	150	75	Class 12 uPVC	50	33-75	40.75	11/06/09	~6	0-33 TOB, 33-59 THD, 59-75 CID
Obs4	731878.66	7496654.33	30/05/09	31/05/09	70	150	70	Class 12 uPVC	50	30-68	29.07	11/06/09	~2	0-22 TOB, 22-38 THD, 38-68 TPS, 68-70 CID
Obs5	734293	7495041	27/05/09	28/05/09	58	150	58	Class 12 uPVC	50	22-58	22.1	11/06/09	~2	0-14 TOB, 14-36 THD, 36-42 TPS, 42-52 CID, 52-58 TD1
Obs6	730745.49	7497771.48	3/05/09	4/05/09	64	150	64	Class 12 uPVC	50	34-64	32.55	11/06/09	1-2	0-24 TOB, 24-42 THD, 42-54 TPS, 54-60 CID, 60-64 TD1
Obs7	730758.63	7497786.91	23/04/09	30/04/09	148	150	148	Class 12 uPVC	50	100-148	33.59	11/06/09	~1	0-24 TOB, 24-42 THD, 42-51 TPS, 51-60 CID, 60-80 TD1 80-148 Mt Sylvia Formation
Obs8	731349.16	7498264.88	1/06/09	3/06/09	53	150	53	Class 12 uPVC	50	22-53	20.65	11/06/09	~0.5	0-20 TOB, 20-53 THD
Obs9	730560.62	7500151.45	7/06/09	7/06/09	41	150	41	Class 12 uPVC	50	23-41	13.15	11/06/09	~0.5	0-24 TOB, 24-41 THD
Obs10	730750.63	7497779.80	30/04/09	2/05/09	78.5	150	77	Class 12 uPVC	50	65-77	32.47	11/06/09	2-3	0-24 TOB, 24-44 THD, 44-56 TPS, 56-60 CID, 60-77 TD1
Obs11	737306	7500645	8/06/09	9/06/09	30	150	29	Class 12 uPVC	50	4-28	13.96	11/06/09	~1	0-20 TOB, 20-29 XCC
Obs12	734758.87	7495192.14	27/05/09	28/05/09	40	150	39	Class 12 uPVC	50	22-39	17.65	11/06/09	<2	0-10 TOB, 10-34 THD, 34-40 TPS
Obs13	734285	7495051	20/05/09	25/05/09	148	150	147.5	Class 12 uPVC	50	110-146	22.1	11/06/09	7-8	0-18 TOB, 18-38 THD, 38-44 TPS, 44-80 CID, 80-100 TD1, 100-147.5 Wittenoom Formation
Obs14	734781.09	7499348.39	9/06/09	10/06/09	28	150	28	Class 12 uPVC	50	4-28	14.77	11/06/09	~1	0-22 TOB, 22-29 XCC
Obs15	726291.50	7504601.43	10/06/09	11/06/09	36	150	34	Class 12 uPVC	50	7-31	9.58	11/06/09	~1	0-36 TOB
Obs16	727138.43	7501008.75	18/04/09	19/04/09	62	150	62	Class 12 uPVC	50	32-62	30.05	11/06/09	0.5	0-22 TOB, 22-48 THD, 48-61 TPS, 61-62 TD1
Obs17	736728.04	7493174.87	29/05/09	30/05/09	46	150	46	Class 12 uPVC	50	22-46	21.4	11/06/09	<2	0-14 TOB, 14-34 THD, 34-46 TPS
2008 Hydrogeological Drilling Programme														
Pz1 (s)	726938	7500765	1/04/08	2/04/08	62	150	60	Class 12 uPVC	50	24-60	33.80	13/06/09	2	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID
Pz1 (d)	726939	7500764	27/03/08	1/04/08	84	150	75	Class 12 uPVC	50	69-75	33.72	13/06/09	3	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID, 62-75 BCG
Pz2 (s)	727777	7500900	16/03/08	18/03/08	60	150	57	Class 12 uPVC	50	21-57	26.73	13/06/09	1	0-20 TOB, 20-60 THD
Pz2 (d)	727777	7500902	10/03/08	16/03/08	76	150	72	Class 12 uPVC	50	66-72	26.76	13/06/09	1	0-20 TOB, 20-60 THD, 60-73 NSR

Bore ID	Location Details		Drilling Information				Construction Information							Geology
	Easting (MGA94)	Northing (MGA94)	Date Drilled		Depth (m)	Diam. (mm)	Cased Depth (mbgl)	Casing	Diam. (mm)	Slotted Interval (mbgl)	Water Table		Airlift Yield (L/s)	
			Start	Finish							SWL (mbgl)	Date		
Pz3 (s)	728190	7502288	20/04/08	22/04/08	72	150	42	Class 12 uPVC	50	21-36	14.35	13/06/09	1	0-18 TOB, 18-28 THD, 28-43 CID
Pz4 (d)	728806	7503163	15/04/08	20/04/08	114	150	114	Class 12 uPVC	50	72-114	9.74	13/06/09	-	0-40 TOB, 40-43 THD, 43-58 CC, 58-62 CLAY, 62-73 WF (weathered), 73-114 WF
Potable	730060	7498103	1/03/08	9/03/08	65	250	56	Class 12 uPVC	155	35-53	37.92	9/03/08	2.5	0-33 TOB, 33-50 THD, 50-53 CC
PS1PB	726937	7500772	4/04/08	14/04/08	65	400	62	Class 12 uPVC & s/steel screen	254	22-58	33.80	13/06/09	18	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID

Table ES2: Summary of Pump Test Interpretation and Aquifer Parameters

Geology	Bores	Aquifer Test Type	T Range (m^2/d)	K Range (m/d)	Remarks
Alluvium / THD (northern pit wall)	Obs1 Obs8 Obs12	Rising Head	-	0.13	-
Orebody (TD2, TD3)	PB1 PB2 PS1PB Obs2 Obs5 Obs6 Obs16	Pumping Test	100 - 770	3 - 25	Piezometers in the orebody displayed typical leakage response during pumping tests
	Obs6	Rising Head	-	-	Recovered too quickly to measure early data, implies moderate to high K
	Obs5 Obs6	Falling Head	-	0.1 – 0.4	-
Basal Conglomerate (TD1)	Pz1 deep Obs10	Falling Head	-	0.2 – 0.3	-
	Obs10	Pumping Test	-	-	Response during pumping infers a degree of hydraulic connection with overlying ore
Basement (Hamersley Group)	Obs7 Obs13	Rising Head	-	0.001 - 0.04	Low permeability in basement units
	Obs7 Obs13	Falling Head	-	0.007 - 0.1	Low permeability in basement units
	Obs7 Obs13	Pumping Test	-	-	Lack of response during pumping infers no hydraulic connection with overlying aquifer

Table ES3: Local Geology and Hydrogeology

Age	Lithology	Description	Groundwater Potential
Quaternary	Transported overburden	Poorly consolidated silty sandy colluvial gravel, with angular to sub-rounded clasts of BIF, cherts and shales, and occasional clay bands	Generally of low permeability, but will be a source of storage where located below the water table, due to its hydraulic connection with the underlying THD
TD3	Tertiary Hematite Detritals	Transported mineralised detrital unit, comprising of poorly consolidated hematite-rich BIF clasts, angular to sub-rounded, with varying pisolith and clay content	This unit is generally of moderate permeability where present below water table. The Potable bore drilled in 2008 is constructed in this aquifer, and testing results suggested a transmissivity of 110m^2/d, and a hydraulic conductivity of 7m/d (Aquaterra, 2008a)
TD3	Tertiary Pisolite Gravel	Similar to the Tertiary Hematite detritals, but with the well-rounded pisolith component increasingly dominant. This formation has variable clay content and is poorly to very poorly consolidated	During recent drilling, much air was lost to the formation, suggesting that where the clay content is low, that this formation has high permeability and is high-yielding.
TD3	Calcrete	Buff/pink/white in colour, with calcareous and siliceous zones. It is generally 10-20m thick, although reached ~50m thickness is some areas	It is thought to be of moderate permeability, although this is likely to vary to the degree that the calcrete has been reworked and weathered. Bore installed, and test-pumping to be undertaken to confirm permeability.
TD2	Channel Iron Deposit	Cemented pisolite gravel which has developed vuggy porosity. There is variable clay content, and the unit is poorly to moderately consolidated. CID forms from palaeo creek beds	With its high permeability it forms a preferred pathway for groundwater flow. As both the Hematite Detritals and Pisolite Gravel that surround CID are permeable, the discontinuous nature of the CID is not expected to significantly affect the continuity of groundwater flow through the system.
TD1	Basal Conglomerate	Below the CID at several locations an unmineralised transported chert-dominated detrital material was encountered. The extent of this basal conglomerate is unknown, but it is suspected to be limited to the bounds of the palaeochannel	This unit is of low permeability, while being is hydraulic connection with the overlying ore zone
Proterozoic	Hamersley Group	The Wittenoom Formation is made up of three members, two of which are likely to be present beneath the Project tenement. These are the Bee Gorge Member (calcareous shale and dolomite) and Paraburdoo Member (dolomite).	Permeability of this unit was low where encountered in recent drilling. There is no evidence of this unit being in hydraulic connection with the overlying Tertiary units.

WATER SUPPLY & DEWATERING

To achieve the initial mine schedule dewatering targets, the pumping drawdown may generate more water than required for project activities. Surplus water is predicted for the first three years of mining. This water will not be discharged to the environment, but rather, will be re-injected back into the orebody aquifer. This strategy puts the surplus water back into storage in the orebody aquifer, making it available for later utilisation, and minimising the impacts of dewatering where possible. In the long-term as dewatering continues, it is projected that further supplementary water supply (above what is produced through dewatering) will be required for the operations beyond year 9.

Brockman's preferred option (in alignment with DoW hierarchy of water management options) is to source water via a pipeline from a neighbouring operation that is discharging significant surplus water. Water supply solutions are also available through water supply borefields on-tenement, or in the vicinity of the Brockman tenement, should an off-take arrangement not eventuate.

Table ES4: Preliminary Site Water Balance - Life of Mine

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Water Demand (L/s)	220	280	280	280	230	230	230	230	230	230
Dewatering (L/s)	320	360	330	280	230	230	230	230	230	210
Surplus / Shortfall (L/s)	100	80	50	0	0	0	0	0	0	-20
Year (continued)	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Water Demand (L/s)	230	230	230	230	230	230	230	230	230	230
Dewatering (L/s)	190	180	160	120	120	100	100	100	60	50
Surplus / Shortfall (L/s)	-40	-50	-70	-110	-110	-130	-130	-130	-170	-180

IMPACTS

The main impact on the groundwater system from the Marillana project will be a decline in groundwater levels in the area around the dewatering borefield and a reduction in groundwater outflow to adjacent areas. However, it is anticipated that these impacts will be minimal for the following reasons:

- Groundwater levels beneath the orebody at the base of the Hamersley Ranges are naturally deep, and generally do not support phreatophytic vegetation.
- The exception to this is the phreatophytic vegetation localised in the vicinity of the Weeli Wolli Creek channel. The drawdown effects in this area are expected to be mitigated by channel flow events numerous times per year that will recharge the creek channel groundwater level.
- Elsewhere over the project area, while there is reduction in overall potentiometric levels, no geological units will be dewatered.
- The only existing groundwater user in the area is the Marillana Station bores utilised for cattle watering points. Any potential shortfall would be supplemented from Brockman water supply.
- The area is characterised by low rates of groundwater recharge and throughflow. As such a reduction in outflow from the Marillana area to adjacent areas affects relatively small volumes of water.
- Groundwater modelling shows that watertable levels and water quality beneath the Fortescue Marsh will not be affected.

It should be noted that the extent of the drawdown cone is anticipated to be a worst-case. In particular, it has been assumed that the calcrete is laterally extensive and continuous. If the calcretes are truncated by basement topography or dissected by lower permeability palaeo-drainage lines, then the drawdown zone of influence will be considerably more constrained.

Re-injection of surplus water will, for a few years, lead to elevated groundwater levels in the vicinity of the MAR operations. Modelling indicates that ongoing dewatering operations will quickly mitigate any impact associated with MAR.

It is considered likely that there will be minimal detrimental impact caused by MAR-related groundwater mounding for the following reasons:

- ▼ Groundwater levels are predicted to remain greater than 10m below ground level during re-injection operations.
- ▼ The groundwater mounding feature is predicted to be short-lived, being completely gone only two years after MAR operations cease.
- ▼ Groundwater mounding will be localised to a few square kilometres directly surrounding the MAR operations.

There is also potential for groundwater quality to deteriorate at the Marillana project over time. However, it is anticipated that these impacts will be minimal for the following reasons:

- ▼ Groundwater quality abstracted during dewatering/water supply will generally remain in the range of fresh to brackish, and will be utilised in the beneficiation process.
- ▼ The beneficial use of this water resource will not be affected. The only groundwater users in the area relate to Marillana Station stock water points. Water quality in the fresh to brackish range is currently found in most bores to the north of the project area.

Again, it should be noted that the salinity modelling has been approached conservatively. The selected section is across the deepest part of the pit, so the greatest depth of dewatering is modelled. Also, there is generally a thicker sequence of Tertiary detritus below the base of mining; and the active life of mining panels is generally shorter than what is represented in the modelling. Also, episodic inundation events (that would add fresh water to the system) are not incorporated into the salinity modelling.

GROUNDWATER MANAGEMENT PLAN

As has been demonstrated through Brockman's proposed approach to groundwater management of dewatering operations onsite (cf. Section 4), the value of water to the project has been recognised, and water management strategies developed that best utilise the available orebody water resource throughout the life of operations.

To achieve the initial mine schedule dewatering targets, the pumping drawdown may generate more water than required for project activities. Surplus water is predicted for the first three years of mining. This water will not be discharged to the environment, but rather, will be re-injected back into the orebody aquifer. This strategy puts the surplus water back into storage in the orebody aquifer, making it available for later utilisation, and minimising the impacts of dewatering where possible. In the long-term, it is projected that further supplementary water supply (above what is produced through dewatering) will be required for the operations beyond year 9.

The preferred option for Managed Aquifer Recharge (MAR) is via re-injection. A re-injection borefield of four bores would be installed at a location distant from dewatering operations and within the defined orebody. The location has been selected on the basis of the current mine plan; currently Abalone East, the southeastern end of the orebody, is the site for the MAR operations. A conceptual system arrangement of four bores spaced 500m apart has been adopted, with each bore re-injecting ~25L/s. This means that in year 1, four bores will be operational; in year 2, three bores will be operational; and in year 3, two bores will be operational.

It is projected that further supplementary water supply (above what is produced through dewatering) will be required for the operations beyond year 9. It is the preference of Brockman, in alignment with the philosophy of the DoW hierarchy of water management options, to source this supplementary supply from nearby operations that are discharging significant surplus water (DoW 2007). To this end, discussions have progressed on the following option:

- To develop an off-take agreement with a neighbouring operation that is discharging surplus water, and delivers this as a water supply supplement to dewatering at Brockman Marillana.

There are a number of mining operations in the vicinity of the Marillana project that are currently discharging significant surplus water via direct discharge to the creeks, or via re-injection into a down gradient palaeochannel aquifer. As part of the Department of Water (DoW) Water in Mining Guidelines (DoW 2009), a hierarchy of disposal options has been developed. In terms of the options being discussed, direct off-take (relocation for nearby use) is the preferred option, and is to be justified as being unsuitable for the project prior to implementing a scheme further down the hierarchy.

This option would require a pipeline corridor from the discharge point to the Marillana operations. Any pipeline corridor would require a vegetation survey to be carried out, and it is likely to be the preferred option that the pipeline be buried.

There is also multiple potential on-tenement and off-tenement borefield solutions in the vicinity of the project that have been identified for water supply development should it be required.

Following cessation of dewatering, natural recharge and inflow processes will result in water levels recovering to pre-mining levels. All areas mined below the water table will be infilled to at least two metres above original water table level. There will therefore be no long-term pit-lake or void in the water table. Consequently, there will be no significant long-term impacts on water quality or groundwater flow.

The monitoring strategy will be implemented in two phases:

- Phase 1: monitoring water levels in both regional and orebody bores until implementation of the project. The objective of this phase is to establish a time series of background data, and confirm the environmental baseline. It will also monitor the water usage as it relates to the pre-mining operations construction demand.
- Phase 2: monitoring of water levels, groundwater abstraction and water quality during mine operations. The details of this second stage of monitoring should be confirmed during the detailed design work and will take account of the final borefield designs, mine plans and dewatering and any conditions or constraints resulting from the environmental review process. The Phase 2 monitoring programme would be outlined in the “Operating Strategy” that will be submitted to Department of Water as part of the groundwater licencing process for mining operations requirements.

CONTENTS

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

1.1 BACKGROUND

The Marillana Iron Ore Project is located within the Hamersley Province on the southern Pilbara Craton in the Pilbara region of Western Australia approximately 100km northwest of the township of Newman (Figure 1.1). The project is located within Exploration Licence E47/1408 and is subject to Mining Lease applications M47/1414 and M47/1419. All tenements are held by Brockman Iron Pty Ltd (Brockman), a wholly owned subsidiary of ASX listed company Brockman Resources Limited.

Brockman is investigating the feasibility of mining the Marillana iron ore deposit. The tenement covers 95km^2 of the Fortescue Valley and borders the Hamersley Range. Extensive areas of supergene iron ore mineralisation are developed within the dissected Brockman Iron Formation, which caps the range. This is the likely source material for the Tertiary Hematite Detritals and Channel Iron Deposits that comprise the target iron ore within the tenement. A significant proportion of the deposit lies below the water table and dewatering will be a component of the mining operation. A water supply will also be required for the processing plant and dust suppression throughout the operation.

Aquaterra were engaged by Brockman for the hydrogeological investigations to assess groundwater issues related to the project, namely:

- Mine Dewatering.
- Water supplies for the process plant and village.
- Determining a hydrogeological baseline and assessing potential impacts on the groundwater system related to the project development.
- Identifying areas of key uncertainty and the recommendation of additional studies.

In addition, a groundwater management plan, developed in conjunction with Brockman, is presented that minimises/mitigates potential impacts on the project area from dewatering activities.

1.2 KEY ASSUMPTIONS IN RELATION TO THE PROJECT DEVELOPMENT

1.2.1 WATER DEMANDS

The Marillana project will incorporate a beneficiation-processing plant. In addition to the process water supply, construction and dust suppression requirements have been estimated. Also the mine-village will have a population of around 550 people (1100 during construction phase), and potable water demand has been based on levels of supply of around 310L/capita/day.

Total water demand for the project has been estimated at ~220L/s in year 1, rising to ~280L/s in year 3, and decreasing to ~230L/s at year 5 onwards.

1.2.2 MINE PLANNING

Dewatering targets are based on the mine plans provided by Brockman.

1.3 GROUNDWATER STUDY AREA

The groundwater study area is centred on the valley just to the north of the Hamersley Ranges, to the west of where Weeli Wolli Creek exits the ranges. The area is centred on the base of the ranges, where the Marillana detrital orebody is located. Much of the wider area is not covered by Brockman tenements. A hydrogeological drilling programme has been undertaken in the area recently and no long-term monitoring data are available. Some information has been gleaned from the drill-hole database from Brockman and previous explorers' work in the general area.

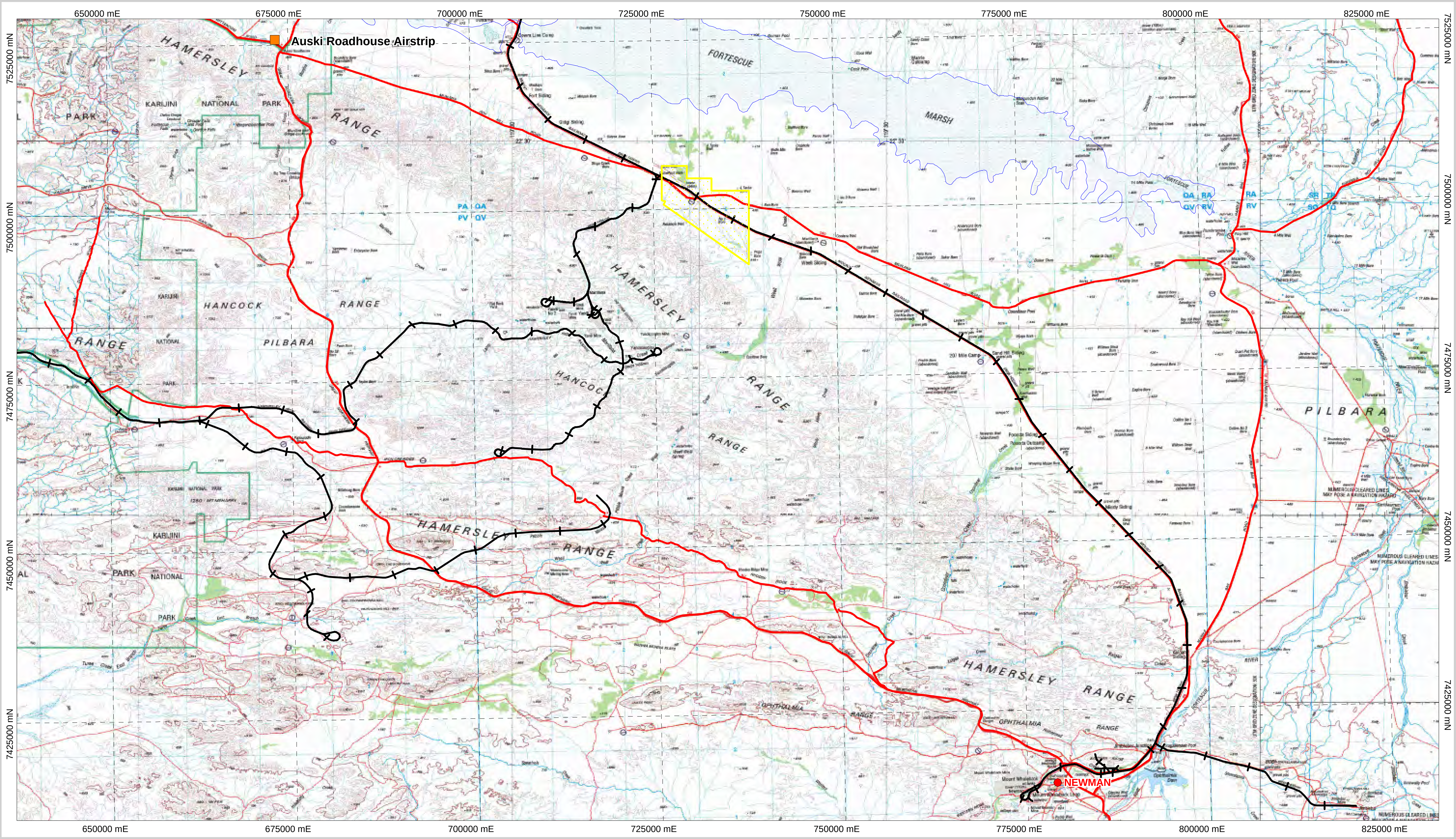
Based on our extensive experience in similar detrital orebodies within the Pilbara and multiple hydrogeological investigations in the Fortescue Valley area, along with recent reviews of the available data from Brockman Resources and Department of Water (DoW); and the field programme results as recorded in this report; we have updated our conceptual hydrogeological model of the region and the Marillana project site. Of particular focus has been:

- Distribution of Channel Iron Deposit (CID) and its connection with overlying pisolitic (TPS) and finer detrital (THD) material.
- Connection between the mineralised material and the adjacent Tertiary sediments, including calcretes.
- The presence of a Basal Conglomerate within the palaeo-channel beneath the CID.
- Significance of the hydraulic characteristics of the basement material and potential hydraulic connection with the orebody, as it has the potential to influence the water quality during dewatering of the orebody.

1.4 SCOPE OF THIS REPORT

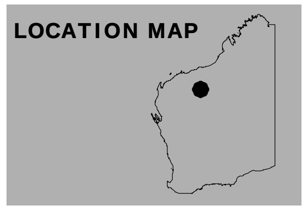
This report presents the results of the recent field investigation programme; along with numerical simulation modelling of the regional groundwater system; and presents recommendations for a groundwater development strategy to meet projected dewatering and water supply requirements for the Marillana Project. Groundwater study recommendations are also made for future work.

A Groundwater Management Plan (GWMP) for the Brockman Marillana project is presented in Appendix A, directly following the Groundwater Study report.



aquaterra

LOCATION MAP



AUTHOR:	DJ
DRAWN:	MS
DATE:	20/05/09
JOB NO:	832G
REPORT NO:	145
REVISION:	...
PROJECTION:	GDA94 Z50
SCALE:	1:500,000

0 10 20 km

LEGEND

▨	Tenement
—	Roads
┼	Railway

FIGURE 1.1

MARILLANA IRON ORE PROJECT
LOCATION MAP

Loction: F:\Jobs\832G\MapInfo\145a_Fig1.1_Location_Map.wor

2 FIELD INVESTIGATIONS

2.1 SITE RECONNAISSANCE & PREVIOUS WORK

Site reconnaissance and data review were undertaken over the period February 2009 to April 2009, with two broad objectives:

- Targets for dewatering investigations were identified from previous mineral drilling.
- Targets and requirements for investigation of the regional groundwater system were identified during data review and site reconnaissance.

Generally, drill sites were aligned where possible to areas of previous ground disturbance to expedite site access.

A short hydrogeological drilling and testing programme was undertaken by Aquaterra in 2008 (Aquaterra 2008a), which aimed to assess the water supply potential for an above-watertable mining operation. Two production bores and several shallow and deep piezometers were installed, and two pumping tests were undertaken.

2.2 DRILLING

2.2.1 DRILLING CONTRACT

The drilling work was undertaken by Barber Drilling (Barber) under direct contract to Brockman Resources. Barber mobilised a Foremost DR24 Drill Rig (Rig 2), support vehicles and crew to Marillana on 17th April 2009 and the work was completed by 14th June 2009. Work undertaken by Barber comprised:

- Groundwater exploration and piezometer construction.
- Production bore drilling and construction (test dewatering bores).
- Infiltration testing.

All of the drilling is summarised in Table 2.1 and detailed logs are presented in Appendix B. Drilling locations are also illustrated in Figure 2.1.

For all exploration drilling, 2m samples were collected and logged onsite, for all production bore drilling 6m samples were collected and logged onsite, all by a hydrogeologist.

All works were completed under a section 26D licence to construct or alter wells (licence No. CAW 168340 and CAW 168341). These licences are presented in Appendix C

2.2.2 EXPLORATION DRILLING

In total 1095m of exploration drilling were completed, comprising 17 exploration bores of depths varying from 28m to 148.5m. Bore were drilled at 6” diameter by dual rotary (rotary percussion) drilling. Bio-degradable drilling foam was commonly used as a fluid additive to aid with the clearing of drill cuttings, particularly on the deeper “open” holes, when temporary casing was not required to be installed to full depth.

Bores were generally completed with 50mm ID Class 12 PVC casing (1mm slot size), and slotted below the water table. Where possible the annulus of each bore was backfilled to the surface with 3.2-6.4mm graded gravel pack. Where the permeability of a stratigraphically significant lower unit was being investigated, a bentonite plug was used to seal the annulus below the contact between the upper and lower units.

Bores located in regional monitoring locations used a 3mm slot size, so that they could be better utilised as stygofauna monitoring locations.

All monitoring bores were completed with a lockable steel cap and a concrete pad. The drill pads were all cleared of any rubbish on completion.

2.2.3 PRODUCTION BORE DRILLING

In total 180m of production bore drilling was completed, comprising two production bores to depths of 63m and 53m, and 64m of drilling associated with an abandoned hole.

The bores were drilled using the dual rotary drilling technique at 16” diameter. Bio-degradable drilling foam was commonly used as a fluid additive to aid with the clearing of drill cuttings.

The drilling difficulties experienced were related to the pisolite gravel. The gravels were highly unconsolidated resulting in collapse during drilling. To compound this, much of the compressed air being used down-the-hole was escaping into the gravelly formation, rather than clearing the gravel from the drillhole to the surface. This meant that the casing was unable to advance to total depth, and the temporary steel casing was bogged to the point where retrieving it became too difficult to complete. A re-drilled bore was successfully completed nearby.

Test production bores were completed with 254mm ID steel blank and slotted casing and stainless steel-wired screens. The annulus of each bore was gravel packed with 3.2-6.4mm graded gravel pack. Each bore was developed for between 6 and 8 hours by airlifting and surging until the discharge was free of sediments.

Bores were completed with a steel cap and concrete pad, and the drill pad was cleared of any rubbish.

Table 2.1: Summary of Hydrogeological Drilling at the Marillana Project

Bore ID	Location Details		Drilling Information				Construction Information							Geology
	Easting (MGA94)	Northing (MGA94)	Date Drilled		Depth (m)	Diam. (mm)	Cased Depth (mbgl)	Casing	Diam. (mm)	Slotted Interval (mbgl)	Water Table		Airlift Yield (L/s)	
			Start	Finish							SWL (mbgl)	Date		
2009 Hydrogeological Drilling Programme														
PB1	730770.73	7497751.53	17/05/09	18/05/09	63	400	63	Steel & s/steel screens	254	50-62	31.96	11/06/09	8-10	0-21 TOB, 21-45 THD, 45-58 TPS, 58-61 CID, 61-63 TD1
PB2	734322	7495004	12/05/09	13/05/09	53	400	53	Steel & s/steel screens	254	38-50	24.8	11/06/09	15-20	0-15 TOB, 15-33 THD, 33-45 TPS, 45-51 CID, 51-53 TD1
Obs1	727623.23	7501474.39	22/04/09	22/04/09	46	150	44	Class 12 uPVC	50	21-44	22.86	11/06/09	0.5	0-19 TOB, 19-46 THD
Obs2	727111.93	7500620.07	20/04/09	21/04/09	76	150	76	Class 12 uPVC	50	28-76	33.74	11/06/09	~5	0-20 TOB, 20-46 THD, 46-70 CID, 70-76 TD1
Obs3	728087.16	7499727.17	3/06/09	5/06/09	75	150	75	Class 12 uPVC	50	33-75	40.75	11/06/09	~6	0-33 TOB, 33-59 THD, 59-75 CID
Obs4	731878.66	7496654.33	30/05/09	31/05/09	70	150	70	Class 12 uPVC	50	30-68	29.07	11/06/09	~2	0-22 TOB, 22-38 THD, 38-68 TPS, 68-70 CID
Obs5	734293	7495041	27/05/09	28/05/09	58	150	58	Class 12 uPVC	50	22-58	22.1	11/06/09	~2	0-14 TOB, 14-36 THD, 36-42 TPS, 42-52 CID, 52-58 TD1
Obs6	730745.49	7497771.48	3/05/09	4/05/09	64	150	64	Class 12 uPVC	50	34-64	32.55	11/06/09	1-2	0-24 TOB, 24-42 THD, 42-54 TPS, 54-60 CID, 60-64 TD1
Obs7	730758.63	7497786.91	23/04/09	30/04/09	148	150	148	Class 12 uPVC	50	100-148	33.59	11/06/09	~1	0-24 TOB, 24-42 THD, 42-51 TPS, 51-60 CID, 60-80 TD1 80-148 Mt Sylvia Formation
Obs8	731349.16	7498264.88	1/06/09	3/06/09	53	150	53	Class 12 uPVC	50	22-53	20.65	11/06/09	~0.5	0-20 TOB, 20-53 THD
Obs9	730560.62	7500151.45	7/06/09	7/06/09	41	150	41	Class 12 uPVC	50	23-41	13.15	11/06/09	~0.5	0-24 TOB, 24-41 THD
Obs10	730750.63	7497779.80	30/04/09	2/05/09	78.5	150	77	Class 12 uPVC	50	65-77	32.47	11/06/09	2-3	0-24 TOB, 24-44 THD, 44-56 TPS, 56-60 CID, 60-77 TD1
Obs11	737306	7500645	8/06/09	9/06/09	30	150	29	Class 12 uPVC	50	4-28	13.96	11/06/09	~1	0-20 TOB, 20-29 XCC
Obs12	734758.87	7495192.14	27/05/09	28/05/09	40	150	39	Class 12 uPVC	50	22-39	17.65	11/06/09	<2	0-10 TOB, 10-34 THD, 34-40 TPS
Obs13	734285	7495051	20/05/09	25/05/09	148	150	147.5	Class 12 uPVC	50	110-146	22.1	11/06/09	7-8	0-18 TOB, 18-38 THD, 38-44 TPS, 44-80 CID, 80-100 TD1, 100-147.5 Wittenoom Formation
Obs14	734781.09	7499348.39	9/06/09	10/06/09	28	150	28	Class 12 uPVC	50	4-28	14.77	11/06/09	~1	0-22 TOB, 22-29 XCC
Obs15	726291.50	7504601.43	10/06/09	11/06/09	36	150	34	Class 12 uPVC	50	7-31	9.58	11/06/09	~1	0-36 TOB
Obs16	727138.43	7501008.75	18/04/09	19/04/09	62	150	62	Class 12 uPVC	50	32-62	30.05	11/06/09	0.5	0-22 TOB, 22-48 THD, 48-61 TPS, 61-62 TD1
Obs17	736728.04	7493174.87	29/05/09	30/05/09	46	150	46	Class 12 uPVC	50	22-46	21.4	11/06/09	<2	0-14 TOB, 14-34 THD, 34-46 TPS
2008 Hydrogeological Drilling Programme														
Pz1 (s)	726938	7500765	1/04/08	2/04/08	62	150	60	Class 12 uPVC	50	24-60	33.80	13/06/09	2	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID
Pz1 (d)	726939	7500764	27/03/08	1/04/08	84	150	75	Class 12 uPVC	50	69-75	33.72	13/06/09	3	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID, 62-75 BCG
Pz2 (s)	727777	7500900	16/03/08	18/03/08	60	150	57	Class 12 uPVC	50	21-57	26.73	13/06/09	1	0-20 TOB, 20-60 THD

Bore ID	Location Details		Drilling Information				Construction Information							Geology
	Easting (MGA94)	Northing (MGA94)	Date Drilled		Depth (m)	Diam. (mm)	Cased Depth (mbgl)	Casing	Diam. (mm)	Slotted Interval (mbgl)	Water Table		Airlift Yield (L/s)	
			Start	Finish							SWL (mbgl)	Date		
Pz2 (d)	727777	7500902	10/03/08	16/03/08	76	150	72	Class 12 uPVC	50	66-72	26.76	13/06/09	1	0-20 TOB, 20-60 THD, 60-73 NSR
Pz3 (s)	728190	7502288	20/04/08	22/04/08	72	150	42	Class 12 uPVC	50	21-36	14.35	13/06/09	1	0-18 TOB, 18-28 THD, 28-43 CID
Pz4 (d)	728806	7503163	15/04/08	20/04/08	114	150	114	Class 12 uPVC	50	72-114	9.74	13/06/09	-	0-40 TOB, 40-43 THD, 43-58 CC, 58-62 CLAY, 62-73 WF (weathered), 73-114 WF
Potable	730060	7498103	1/03/08	9/03/08	65	250	56	Class 12 uPVC	155	35-53	37.92	9/03/08	2.5	0-33 TOB, 33-50 THD, 50-53 CC
PS1PB	726937	7500772	4/04/08	14/04/08	65	400	62	Class 12 uPVC & s/steel screens	254	22-58	33.80	13/06/09	18	0-23 TOB, 23-43 THD, 43-45 TPS, 45-62 CID

2.2.4 HYDRAULIC TESTING

The hydraulic testing is summarised in Table 2.2. Details of individual tests are provided in Appendix D and the interpretations are summarised in Section 3.2.5.

Rising Head Tests (RHT) and Falling Head Tests (FHT) were carried out in selected monitoring bores. Rising head tests were carried out using a 32mm airline inside the 50mm casing to airlift the bore for a period of time (generally between 30 and 45 minutes). Discharge rates were in the range 0.3 to 2L/s. Recovering water levels were then measured and the data used to estimate aquifer transmissivity.

Falling head tests were carried out. The water level in the bore was raised as quickly as possible using the rig water-truck and the subsequent water level decline was measured, and the data used to estimate aquifer transmissivity.

Table 2.2: Summary of Hydraulic Testing

Test	**Bore**	**Date**	**Test Interval (mbgl)**	**Geology**
Rising Head Tests (Test Pump Australia)				
RHT	Obs1	6/06/2009	21 – 44	THD
RHT	Obs6	7/06/2009	34 – 64	THD/TPS/CID
RHT	Obs7	7/06/2009	100 - 148	Basement
RHT	Obs8	7/06/2009	23 – 53	THD
RHT	Obs10	7/06/2009	65 – 77	Basal Conglomerate
RHT	Obs12	6/06/2009	22 – 39	THD/TPS
RHT	Obs13	6/06/2009	114 – 148	Basement
Falling Head Tests (Barber Drilling)				
FHT	Pz1 - deep	6/06/2009	69 – 75	Basal Conglomerate
FHT	Obs5	6/06/2009	22 – 58	THD/TPS/CID
FHT	Obs6	6/06/2009	34 – 64	THD/TPS/CID
FHT	Obs7	6/06/2009	100 - 148	Basement
FHT	Obs10	6/06/2009	65 – 77	Basal Conglomerate
FHT	Obs13	6/06/2009	114 – 148	Basement

2.3 PUMPING TESTS

2.3.1 PUMPING TEST CONTRACT

Pumping tests undertaken during the field programme comprised step discharge pumping tests and constant rate pumping tests. Testing was carried out by Test Pumping Australia (TPA), directly contracted to Brockman. TPA mobilised to site on 23rd May 2009, with all pump testing completed by 5th June 2009.

Testing was carried out using a vertical turbine pump and direct-drive diesel motor.

2.3.2 TESTS

Pumping tests are summarised in Table 2.3 and details are presented in Appendix D. The interpretation is summarised in Section 3.2.5.

Step tests were carried out on two production bores (PB1 and PB2); they comprised four (PB1) and five (PB2) steps each of 100 minutes duration. The data from these tests was used to evaluate the hydraulic efficiency of each bore, to estimate aquifer parameters and to allow selection of a test rate for the constant rate test.

A constant rate test was carried out on production bores PB1 and PB2; and on production bore PS1PB, present from a previous drilling programme. The test duration was 48 hours for PB1 and PB2, and 60 hours for PS1PB. Throughout each test, water levels were measured in both the pumping bore and adjacent monitoring bores.

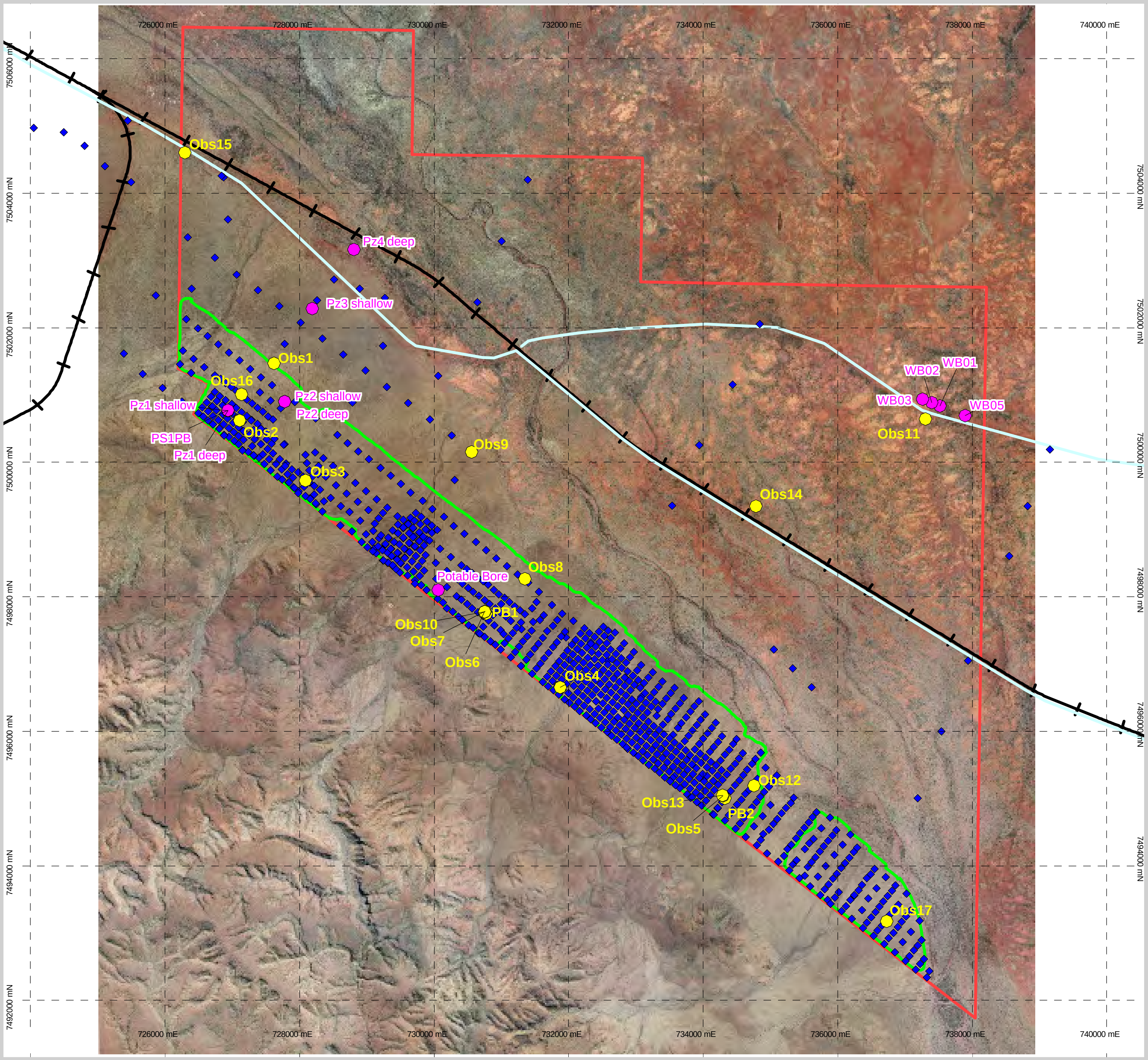
Recovering water levels were measured in the pumping bore for one hour after cessation of pumping.

2.3.3 SURVEY

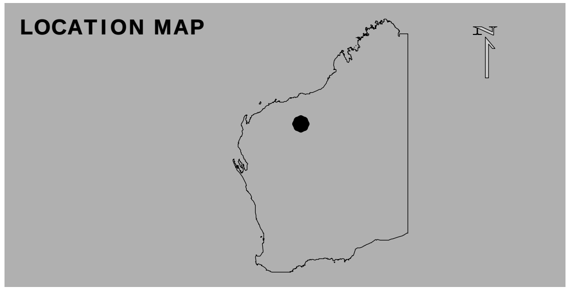
The coordinates and collar RLs for the bores completed in this drilling programme were collected by a Brockman-contracted survey team (cf. Table 2.1).

Table 2.3: Summary of Pumping Tests

Bores		**Step Test**			**Constant Rate Test**						**Lithology Screened**
Pumping	**Observation**	**Date**	**Steps**	**Discharge Rate (L/s)**	**Dates**			**Discharge (L/s)**	**Water Levels (mbgl)**		
					Start	**Finish**	**Duration**		**Start**	**End**	
PB1	-	24/05/2009	4x100 minutes	15-31	25/05/2009	27/05/2009	48 hours	25	31.94	43.21	THD/TPS/CID/TD1
	Obs6	-	n/a	n/a					32.815	33.34	THD/TPS/CID/TD1
	Obs7	-	n/a	n/a					32.63	32.8	Basement
	Obs10	-	n/a	n/a					32.395	32.83	TD1
PB2	-	2/06/2009	5x100 minutes	18-47	3/06/2009	5/06/2009	48 hours	43	30.38	35.025	THD/CID/TPS
	Obs5	-	n/a	n/a					21.875	23.55	THD/TPS/CID/TD1
	Obs13	-	n/a	n/a					21.23	22.345	Basement
	Obs12	-	n/a	n/a					17.675	17.73	THD/TPS
	MRC776	-	n/a	n/a					20.57	20.727	THD/TPS/CID
PS1PB	-	n/a	n/a	n/a	29/05/2009	31/05/2009	60 hours	42	36.09	38.58	THD/TPS/CID
	Obs2	-	n/a	n/a					33.645	33.84	THD/CID/TD1
	Obs16	-	n/a	n/a					30.71	30.76	THD/TPS
	Obs1	-	n/a	n/a					22.745	22.74	THD



LOCATION MAP



LEGEND

● Bore Locations 2009
● Bore Locations 2008
◆ Drill Holes
— Roads
┼ Railway
🟩 Pit Outline
🟥 Tenement

aquaterra

FIGURE 2.1
HYDROGEOLOGICAL DRILLING LOCATIONS

AUTHOR:	DJ	REPORT NO:	145
DRAWN:	MS	REVISION:	...
DATE:	08/09/09	PROJECTION:	MGA94 Z50
JOB NO:	832G	SCALE:	1:85,000 (A4)

Location: F:\Jobs\832G\MapInfo\145a_Figure2.1.wor

3 GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY

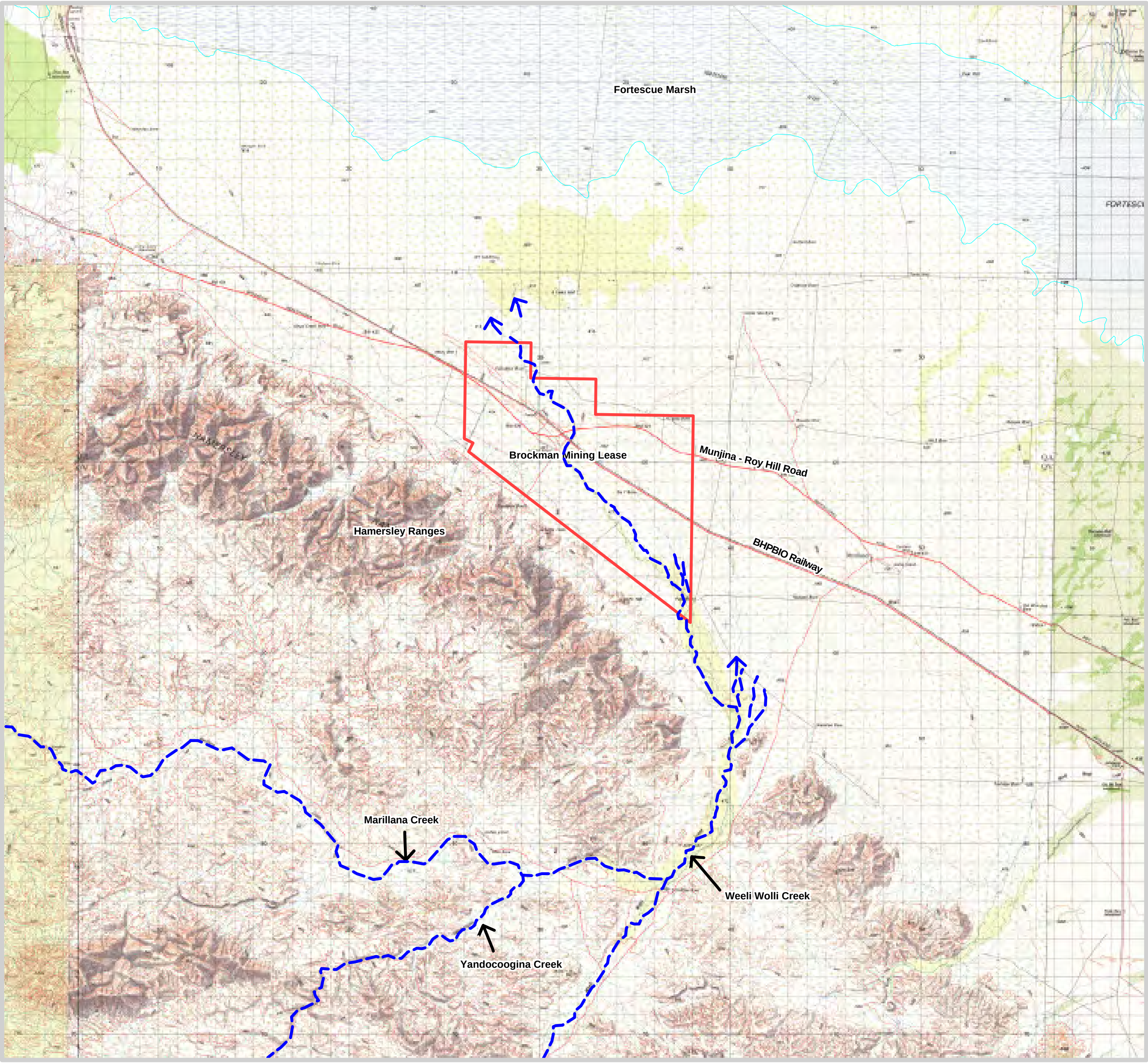
3.1.1 SETTING

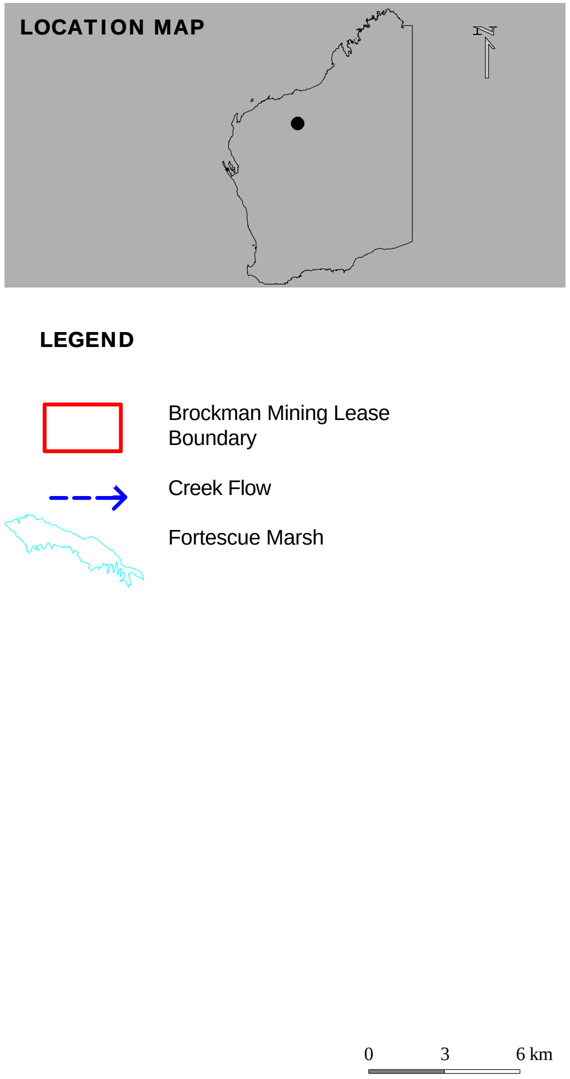
The Project area lies on the Fortescue Valley floor to the northeast of the Hamersley Range (Figure 3.1). The area is flat-lying and consists of mainly transported colluvium and alluvium deposits (the erosional detritals of the adjacent Hamersley Range) with minor outcrops of canga and Wittenoom Dolomite. The combined thickness of the transported cover is up to 120m, and it hosts the targeted detrital deposits.

Transported cover can be divided into four units, including: colluvium (and alluvium/calcrete), hematite detritals, Pisoliths and cemented Pisoliths. The colluvium and alluvium are interbedded and vary in thickness from 10 to 57m in the areas drilled; the material becomes progressively fine-grained and clay rich distal to the Hamersley Range. The alluvium also contains an extensive calcrete layer. Below the colluvium/alluvium at the base of the range are hematite detrital accumulations, interbedded with lenses of pisolite-rich material. In places, the base of the profile is cemented goethitic pisolite, interpreted to represent a buried and partially re-cemented channel iron deposit (CID), resulting from an ancient drainage course associated with the ancestral Weeli Wolli Creek. The hematite detritals and pisolite-rich material likely represent scree-fans and reworked CID proximal to the Hamersley Range. The regional outcrop geology of the Project area is presented in Figure 3.2.

3.1.2 STRUCTURE

The region is dominated by the presence of the Fortescue Valley, an east-north-east to west-south-west trending feature that is defined by the Hamersley Ranges to the south and the Chichester Ranges to the north. As is typical of these ranges in the Pilbara, they develop as strike-ridges of iron-rich, erosion-resistant material. To the south of the tenement, the Hamersley Ranges correlate with the outcrop of Brockman Iron Formation, while to the north, the Chichester Ranges are defined by the outcrop of Marra Mamba Iron Formation. The significant width of the Fortescue Valley in this area is likely a function of the low dips (almost horizontal) of the basement stratigraphy, and the preferential erosion of the Wittenoom Formation in the valley floor.



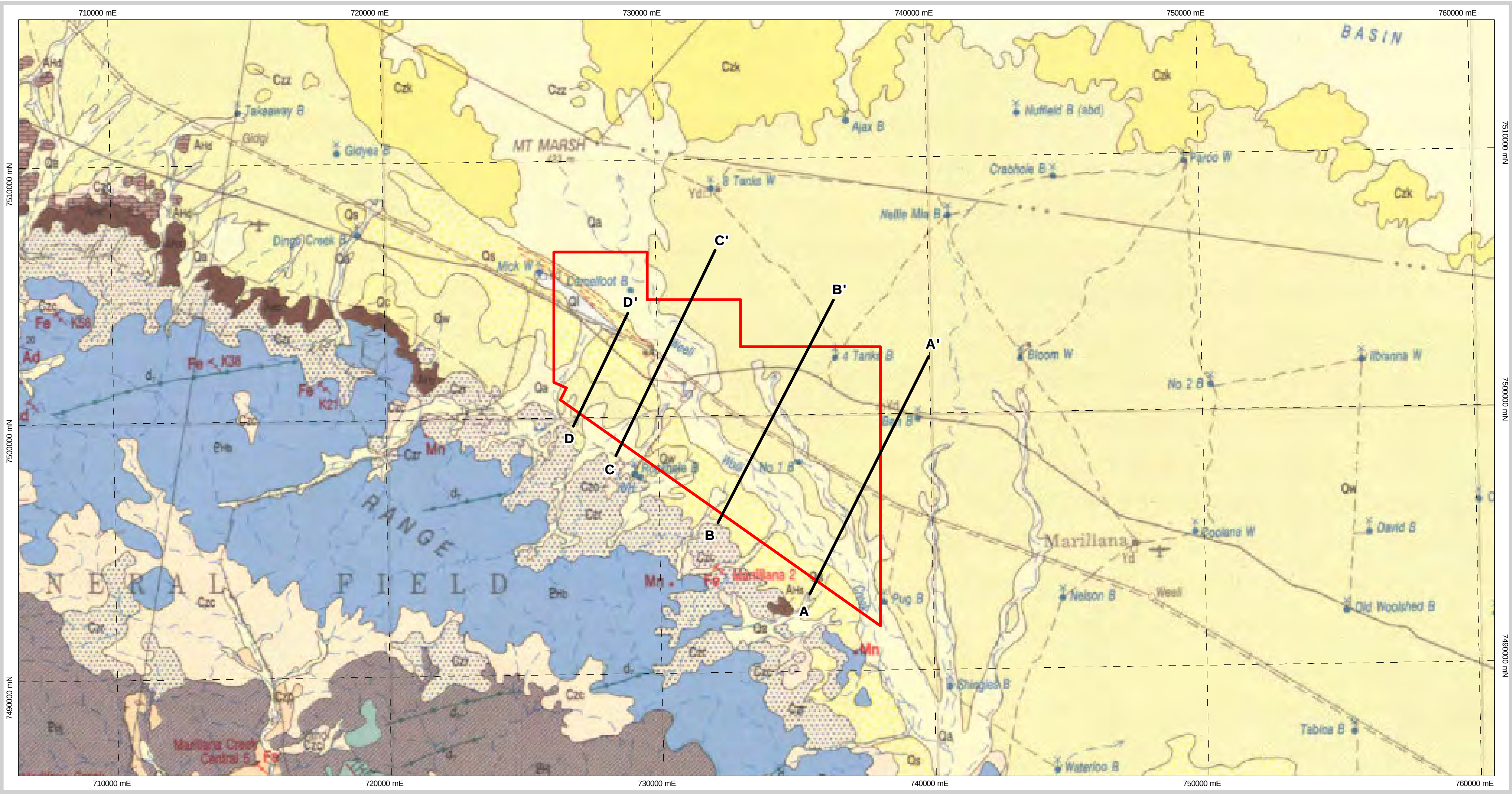


aquaterra

FIGURE 3.1
REGIONAL TOPOGRAPHY & DRAINAGE

AUTHOR:	DJ	REPORT NO:	145
DRAWN:	MS	REVISION:	...
DATE:	08/09/09	PROJECTION:	MGA94 Z50
JOB NO:	832G	SCALE:	1:300,000

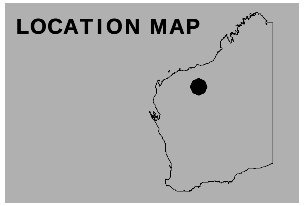
Location: F:\Jobs\832G\MapInfo\145a_Figure2.1.wor



Loction: F:\Jobs\832G\MapInfo\145a_Figure3.2.wor

aquaterra

LOCATION MAP



AUTHOR: DJ
DRAWN: MS
DATE: 20/09/09
JOB NO: 832G
REPORT NO: 145
REVISION: ...
PROJECTION: GDA94 Z50
SCALE: 1:200,000

LEGEND

🟥 Tenement

C ―― C' Location of Hydrogeological Sections (Figures 3.8 & 3.9)

Qa - Alluvium
Ql - Lacustrine deposits
Qc - Colluvium
Qs - Eolian deposits
Qw - Alluvium & Colluvium

Czc - Colluvium
Czz - Brecciated siliceous caprock
Czk - Calcrete
Czr - Hematite, geothite deposits

PHj - Weeli Wolli Fm
PHb - Brockman Iron Fm
AHs - Mt McRae/Mt Sylvia Fm
AHd - Wittenoom Fm

FIGURE 3.2

REGIONAL OUTCROP GEOLOGY

3.1.3 REGIONAL GEOLOGY

The Hamersley Group is an approximately 2,500m thick sequence of BIF, shale, dolomite, mafic volcanics and dolerite sills, and is Archaean to Palaeoproterozoic in age. A notable feature of this group is the presence of five major BIF units that are laterally continuous throughout the province with no apparent facies change. Two of these units, the Marra Mamba Iron Formation and the Brockman Iron Formation, host all of the major deposits in the Pilbara, and are the source of most detrital iron deposits. Table 3.1 provides a summary the major stratigraphy in the Pilbara.

Table 3.1: Stratigraphy of the Regional Geology of the Study Area

Age	Group	Formation / Member	Description
Cainozoic		Tertiary Detritals	
		▼ TD3	High matrix zone (silty gravel), Oakover Formation, Calcrete
		▼ TD2	Channel Iron deposit (CID) / vitreous goethite, Goethitic clay
		▼ TD1	Clay, Pisoliths and silty clay
Lower Proterozoic	**Hamersley Group**	Boolgeeda Iron Formation	Jaspilite, siltstone, shale and BIF
		Woongarra Volcanics	Lavas, pyroclastic rocks and BIF
		Weeli Wolli Formation	Jaspilite and shale
		Brockman Iron Formation	
		▼ Yandicoogina Shale Member	Shale and BIF
		▼ Joffre Member	BIF with minor shale bands
		▼ Whaleback Shale Member	Interbedded shale, chert and BIF
		▼ Dales Gorge Member	Interbedded BIF and shale
		Mt McRae Shale	Graphitic and chloritic shales interbedded with BIF
		Mt Sylvia Formation	Shale, dolomite and BIF bands
		Wittenoom Formation	
		▼ Bee Gorge Member	Calcareous shale and dolomite
		▼ Paraburdoo Member	Dolomite - some karstic
		▼ West Angela Member	Manganese-rich shale with minor BIF and chert bands
		Marra Mamba Iron Formation	
		▼ Mount Newman Member	BIF with thin shale bands
		▼ MacLeod Member	BIF with extensive interbedded shales and "podded" BIF horizons
		▼ Nammuldi Member	Cherty BIF with occasional shale bands

3.1.4 PROJECT GEOLOGY

The general conceptual geology (shown in Figure 3.3) suggests that in the early Tertiary, a palaeochannel was incised into the Proterozoic basement along the base of the Hamersley Ranges.

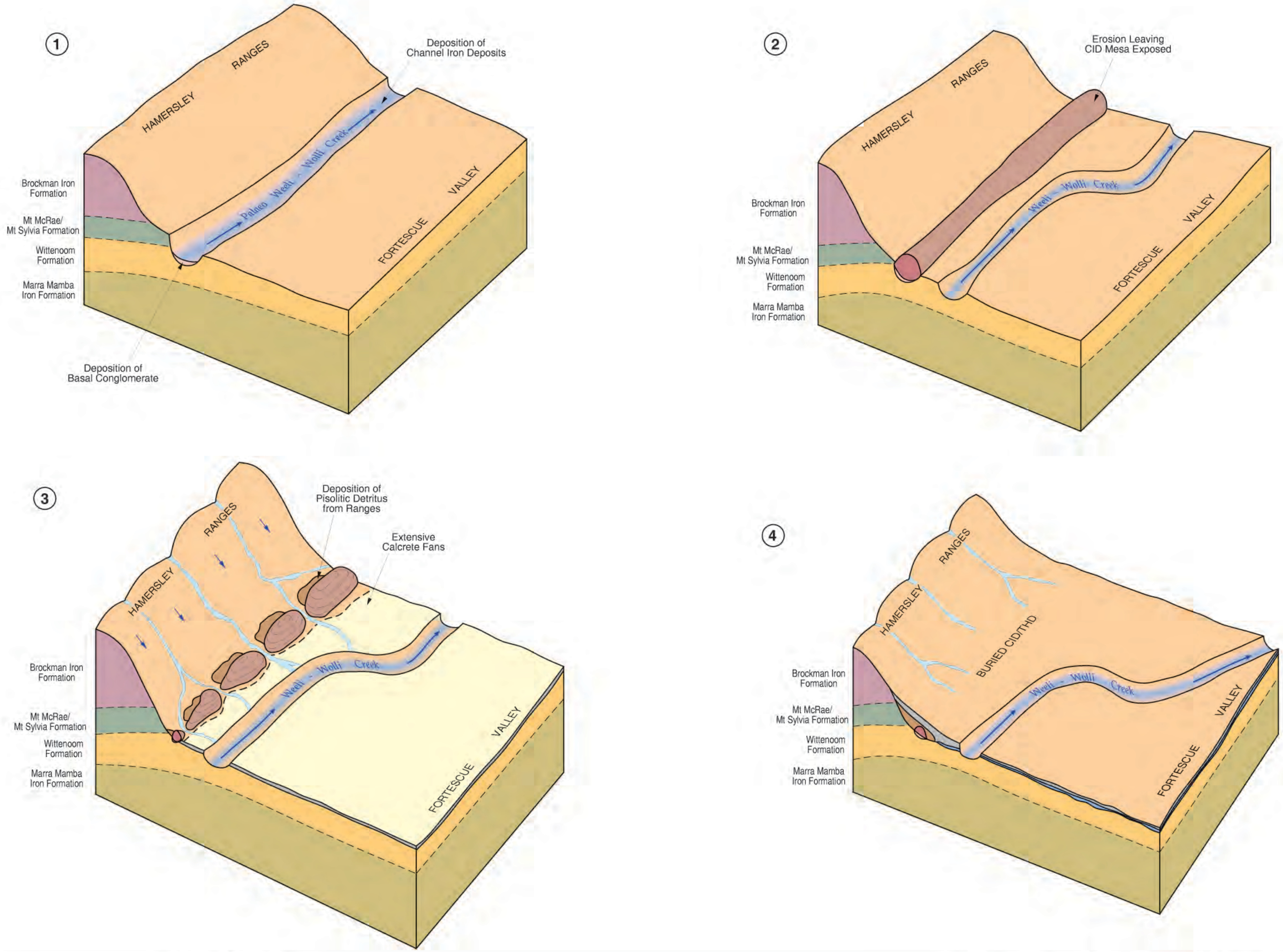
A channel iron deposit was formed, and subsequent erosion of the surrounding bedrock exposed the CID mesa. Continuing erosion meant that a sizeable portion of the mesa was also eroded away, and subsequently had a series of calcrete, pisolite gravel, hematite detritals and alluvium deposited over it (cf Section 3.3)

The key revisions to our conceptual geological understanding compared to our prior understanding (Aquaterra 2009a) are:

- A more extensive calcrete formation within the valley alluvial sequence. There is interpreted to be significant hydraulic connection between the orebody aquifers and the calcrete to the north of the orebody 9although it is unclear how far this extends off-tenement).
- A deeper Tertiary sequence, with further CID located beneath the calcrete at various locations along the length of the resource.
- The presence of a basal conglomerate unit beneath the CID. This early Tertiary deposit is thought to be present within the limits of the palaeochannel associated with the CID on tenement. Ongoing stratigraphic control drilling is being undertaken by Brockman to confirm the thickness and lateral extent of this unit.

Table 3.2: Local Geology and Hydrogeology

Age	Lithology	Description	Groundwater Potential
Quaternary	Transported overburden	Poorly consolidated silty sandy colluvial gravel, with angular to sub-rounded clasts of BIF, cherts and shales, and occasional clay bands	Generally of low permeability, but will be a source of storage where located below the water table, due to its hydraulic connection with the underlying THD
TD3	Tertiary Hematite Detritals	Transported mineralised detrital unit, comprising of poorly consolidated hematite-rich BIF clasts, angular to sub-rounded, with varying pisolith and clay content	This unit is generally of moderate permeability where present below water table. The Potable bore drilled in 2008 is constructed in this aquifer, and testing results suggested a transmissivity of 110m^2/d, and a hydraulic conductivity of 7m/d (Aquaterra, 2008a)
TD3	Tertiary Pisolite Gravel	Similar to the Tertiary Hematite detritals, but with the well-rounded pisolith component increasingly dominant. This formation has variable clay content and is poorly to very poorly consolidated	During recent drilling, much air was lost to the formation, suggesting that where the clay content is low, that this formation has high permeability and is high-yielding.
TD3	Calcrete	Buff/pink/white in colour, with calcareous and siliceous zones. It is generally 10-20m thick, although reached ~50m thickness is some areas	It is thought to be of moderate permeability, although this is likely to vary to the degree that the calcrete has been reworked and weathered. Bore installed, and test-pumping to be undertaken to confirm permeability.
TD2	Channel Iron Deposit	Cemented pisolite gravel which has developed vuggy porosity. There is variable clay content, and the unit is poorly to moderately consolidated. CID forms from palaeo creek beds	With its high permeability it forms a preferred pathway for groundwater flow. As both the Hematite Detritals and Pisolite Gravel that surround CID are permeable, the discontinuous nature of the CID is not expected to significantly affect the continuity of groundwater flow through the system.
TD1	Basal Conglomerate	Below the CID at several locations an unmineralised transported chert-dominated detrital material was encountered. The extent of this basal conglomerate is unknown, but it is suspected to be limited to the bounds of the palaeochannel	This unit is of low permeability, while being is hydraulic connection with the overlying ore zone
Proterozoic	Hamersley Group	The Wittenoom Formation is made up of three members, two of which are likely to be present beneath the Project tenement. These are the Bee Gorge Member (calcareous shale and dolomite) and Paraburdoo Member (dolomite).	Permeability of this unit was low where encountered in recent drilling. There is no evidence of this unit being in hydraulic connection with the overlying Tertiary units.



A	30-07-09	DRAFT	CR	DJ
REVN	DATE	AMENDMENT	DRN	APPROVED

NOTES:

FIGURE 3.3

DESIGNED: D. JANSSEN
DRAWN: ENVIRONMENTAL DRAFTING
CHECKED: D. JANSSEN
APPROVED: —
CAD FILE: 832G-Drawing01.dgn
SCALE: SCHEMATIC ONLY

aquaterra
water resource and environmental solutions
Suite 4, 125 Melville Parade
Como, Western Australia 6152
Telephone (08) 9368 4044
Facsimile (08) 9368 4055

Brockman Resources

MARILLANA IRON ORE PROJECT
CONCEPTUAL HYDROGEOLOGICAL
EVOLUTION

ORIG SIZE A3
PROJECT No 832G
DRAWING No 832G-Drawing01
REVN A

3.1.5 TERTIARY LANDSCAPE AND THE GROUNDWATER SYSTEM

Weeli Wolli Creek is well established adjacent to the Marillana deposit, with the headwaters in the Hamersley Ranges to the south. It seems likely that the ancestral Weeli Wolli drainage course correlates with the buried pisolite mesa running parallel to the Hamersley Ranges on the valley floor. Based on the trend of these pisolites (as intersected by mineral drilling on tenement), one of the (potentially multiple) palaeo-flow directions was to the west-north-west upon exiting the Hamersley Ranges, aligned with the modern Weeli Wolli Creek. However, there is potentially another palaeochannel, observed in the regional aeromagnetic data, which continues to the northeast upon exiting the Hamersley Ranges, and it is likely that a significant proportion of the groundwater flow from the Weeli Wolli system may still flow in this direction.

Groundwater levels (cf Section 3.2.3) suggest that a proportion of the current groundwater flow system still exploits the Tertiary flow path across the Marillana tenement, with groundwater flowing northwest through the palaeochannel system upon exiting the Hamersley Ranges beneath the Weeli Wolli Creek drainage line, although a large proportion is likely to flow in a north-easterly direction.

3.2 HYDROGEOLOGY

3.2.1 REGIONAL HYDROGEOLOGY

The Weeli Wolli Creek catchment area is 4769km^2, and this upstream catchment includes three major mining areas: Hope Downs, Area C, and Marillana Creek. The Weeli Wolli Creek system has a combination of groundwater and surface water flow, which represents the upstream recharge. The Weeli Wolli Creek sediments comprise alluvials and CID, and are hydraulically continuous with the Tertiary sequence in the Fortescue Valley. Since the commencement of mining operations upstream, the natural groundwater throughflow has been intercepted, and dewatering from Hope Downs and Yandi is affecting the quantity and distribution of recharge in the upstream area, and it is likely that additional groundwater to the project may result. During high rainfall events, there is significant surface water flow into the project area – some of this run-off reached the Fortescue Marsh, while some infiltrates in the groundwater system.

The most extensive aquifer in the area is associated with an alluvial sequence that extends northeast from the lower slopes of the Hamersley Ranges across to the Fortescue Marsh. The alluvial deposits consist of clays, silts, sands, gravels and calcretes, and extend to depths of 100m. Over most of the area, low permeability clays with occasional sand and gravel lenses dominate the alluvial sequence. In these areas, the permeability is typically low (0.1 to 1m/d).

Closer to the base of the ranges, a channel iron deposit (CID) lies within a palaeo-valley. The CID is up to 40m thick, is typically goethitic, and is pisolitic in parts. The CID is typically highly porous and vuggy with significant secondary porosity from joints and solution cavities. It is assumed that the palaeochannel continues downstream beyond the Project's tenement (perhaps aligning to the north towards the Fortescue Marsh west of the Project tenement), while upstream, it is anticipated that the palaeochannel aligns with the modern drainage line of Weeli Wolli Creek where it extends up into the Hamersley Ranges.

Basement rocks in the area comprise the Mt McRae, Mt Sylvia (both predominately shale) and Wittenoom Formations of the Hamersley Group. The shales form the basement beneath the western end of the palaeochannel ore deposit, while Wittenoom Formation underlies the majority of the region.

3.2.2 DRILLING RESULTS

Orebody Drilling

Drilling in the orebody was aimed at determining the hydrogeological characteristics of the ore and adjacent unmineralised material that will form the pit walls.

Based on experience on other detrital orebodies and drilling and testing during this programme, the ore itself is permeable. Complete or partial loss of circulation during drilling occurred occasionally due to the vuggy nature of the CID, and the unconsolidated nature of the overlying pisolite gravels, and as such, measured airlift yields cannot be considered indicative, and would generally represent an underestimate of true yield.

Airlift yields ranged between 1L/s (6” exploration bore) and 10L/s (16” production bore), while pump-testing these bores yielded up to 46L/s.

Pumping test analyses indicate hydraulic conductivity of the orebody ranging between 5-15m/d (Section 3.2.5 and Appendix D). This estimate is typical for conductivities encountered in other detrital ore deposits in the Pilbara.

Permeability of underlying basal conglomerate and unmineralised basement units was lower, reflected by lower airlift yields and estimates of hydraulic conductivity (derived from rising head and falling head tests) ranging from 0.001 to 0.1m/d.

Regional Drilling

Drilling to the north of the orebody within the tenement was aimed at providing information on the hydrogeological characteristics of the alluvials, and installing long-term baseline monitoring locations.

Bores were drilled through up to 40m of Quaternary and Tertiary valley fill comprising alluvium and colluvium. Calcretes were encountered 25-30mbgl, particularly in the northeast of the tenement. It is difficult to estimate the regional extent of the calcretes on the basis of the holes drilled to date, although from a geomorphological perspective, it is likely to be extensive.

3.2.3 WATER LEVELS

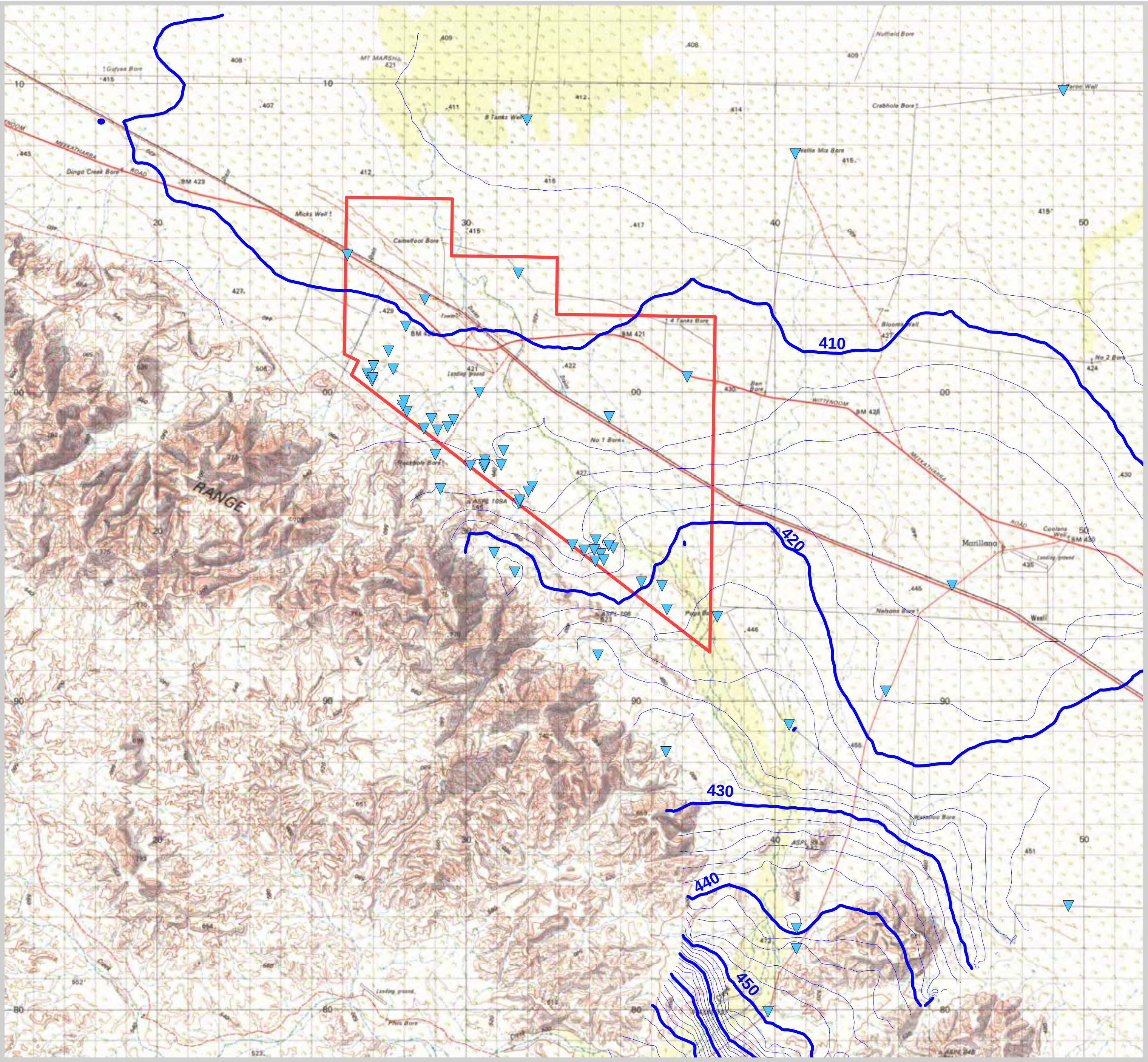
Regional Water Levels

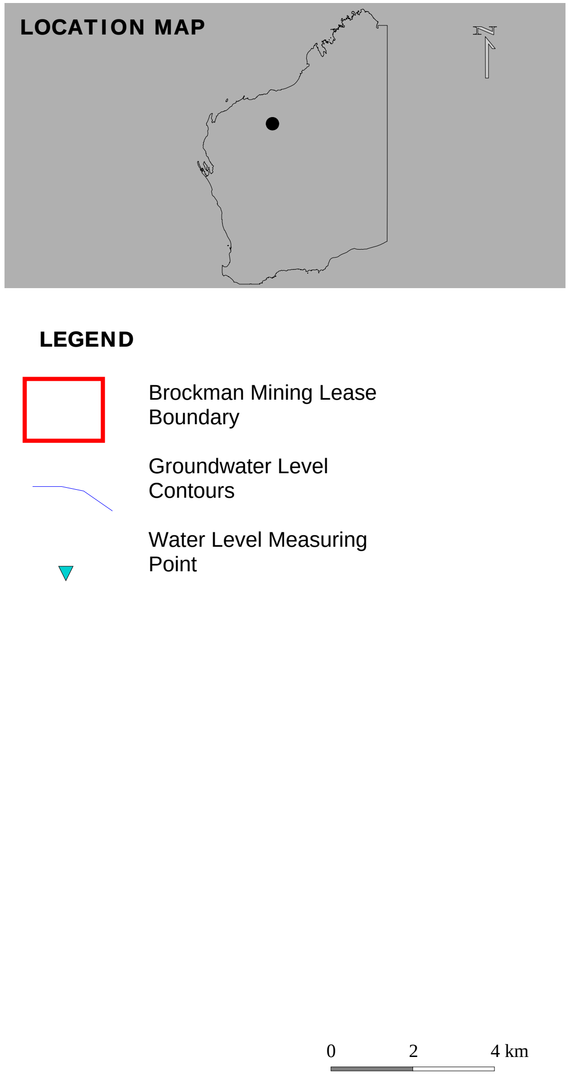
In general, the water table throughout the region is a subdued reflection of the topography, so that groundwater levels are generally highest along topographic high points and lowest in valley locations. However, because groundwater gradients are generally shallower than topography, the depth to water table is generally least in low-lying areas and greatest along ridge lines. From the groundwater level contours (Figure 3.4), it appears likely that the main groundwater flow from the Weeli Wolli Creek system continues north-easterly through the Weeli Wolli alluvial fan, while a proportion flows through the project tenement.

Tenement Water Levels

Groundwater levels across the Marillana site have been measured from existing regional water bores, along with recently installed stygofauna monitoring holes and piezometers. The data shows that groundwater levels on tenement vary from approximately 424mRL, where Weeli Wolli Creek exits the Hamersley Ranges to the east of the Marillana tenement; down to 410mRL several kilometres into the valley towards the Fortescue Marsh, and also west along strike of the orebody near the base of the Hamersley Ranges.

Contours of the groundwater levels shows that the water table generally has a low gradient to the north (towards the centre of the valley); while locally within the palaeochannel, the flow is in a north-westerly direction along the base of the Hamersley Ranges, likely an artefact of preferential groundwater flow through the more permeable palaeochannel (Figure 3.4).





aquaterra

FIGURE 3.4

REGIONAL GROUNDWATER LEVEL CONTOUR MAP

AUTHOR:	DJ	REPORT NO:	145
DRAWN:	MS	REVISION:	...
DATE:	08/09/09	PROJECTION:	MGA94 Z50
JOB NO:	832G	SCALE:	1:185,000

Location: F:\Jobs\832G\MapInfo\145a_Figure2.1.wor

3.2.4 WATER QUALITY

Regional

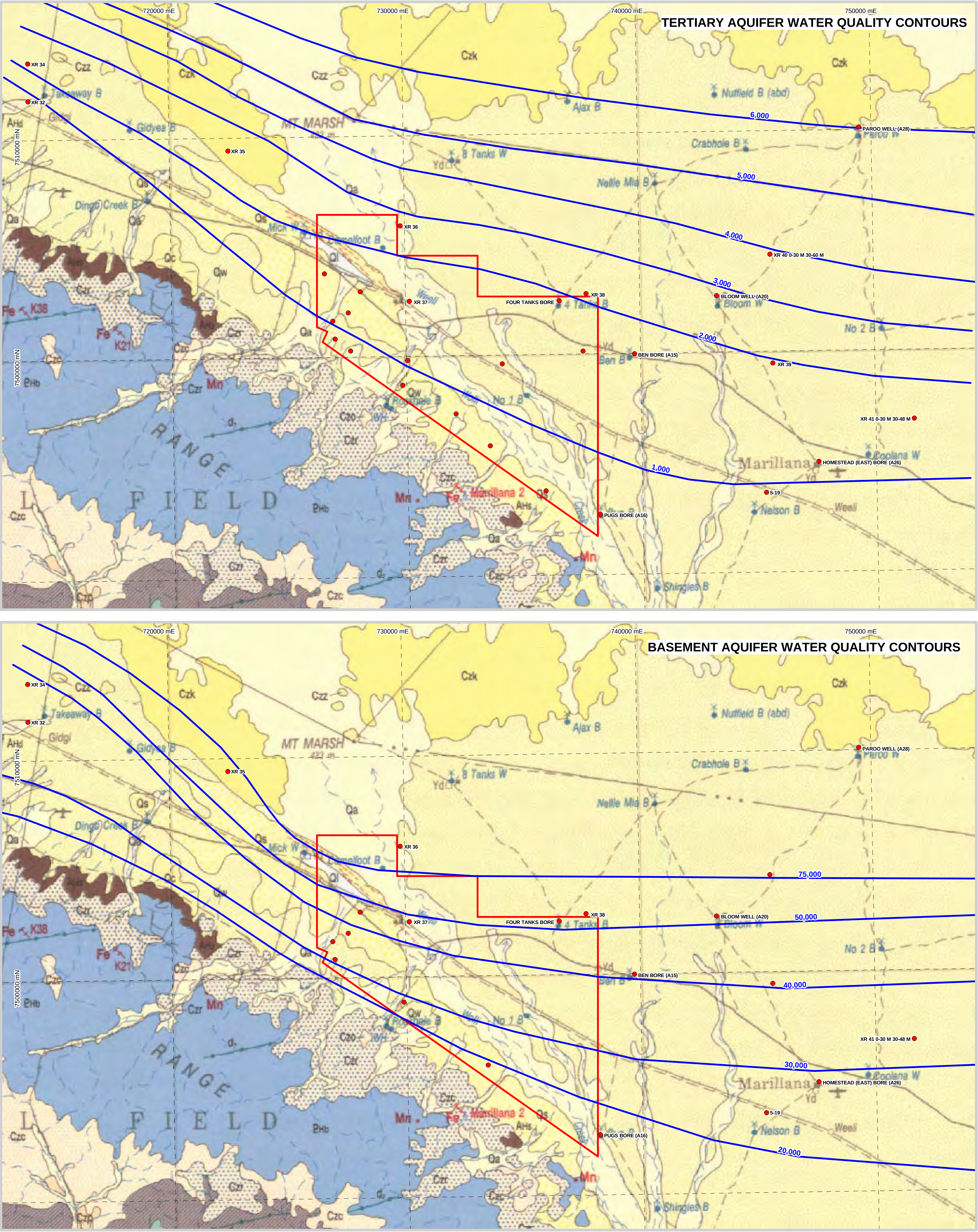
Data regarding the salinity of groundwater within the area was gathered from the Department of Water's AQWABASE system, along with hydrogeological drilling programmes completed by Aquaterra in 2008 and 2009. There are two distinct aquifers which show different salinity profiles. Within the shallow alluvial aquifer, groundwater is freshest (<1,000mg/L TDS) close to the Hamersley Ranges, as this is the recharge zone for the alluvial aquifer, where groundwater flows in from the Weeli Wolli groundwater system. The salinity of the groundwater in the alluvial aquifer increases to approximately 6,000mg/L TDS over a distance of 15km northwards in the valley (Figure 3.5). Due to a lack of time series water quality data, it is not clear whether there is a fluctuation in water quality related to seasonal variations. The salt distribution is likely related to the Fortescue Marsh surface water body recharging relatively fresh water immediately following an inundation event, and becoming progressively more saline as evapo-concentration takes place (cf. Section 3.3.3).

Within the Wittenoom Formation dominated basement, groundwater is approximately 20,000mg/L TDS in the basement beneath the orebody. The groundwater salinity increases rapidly within the basement further north into the valley, with a salinity of 75,000mg/L TDS 10km into the valley (Figure 3.5). This is attributed to the longer residence times of groundwater within the basement aquifer; the limited affects of freshwater recharge to the system; and the limited mixing between the shallow and deep aquifers, which means salt content concentrates over longer time periods without dilution.

On Tenement

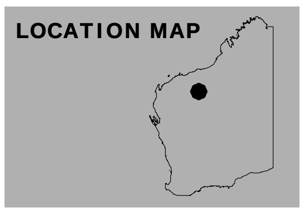
Water samples were collected from most bores drilled during the 2009 hydrogeological drilling programme, and were analysed for major ions. The results are plotted on an expanded Durov diagram (Figure 3.6) and summarised in Table 3.3. Detailed analyses are also presented in Appendix E. Several trends can be inferred from the data:

- All of the waters were Cl- and Na+ dominant, indentifying them as "mature" waters, with the chemical composition likely associated with extended aquifer residence times along the groundwater flow path. This suggests that a large proportion of recharge enters the groundwater system further up-gradient, rather than locally, or that mixing of local recharge with mature waters is taking place.
- The orebody and basal conglomerate waters appear less mature than the regional alluvial samples and basement samples. This is likely related to Weeli Wolli palaeochannel being the path of groundwater flow into the system. The regional alluvial waters require slightly longer residence times for water to reach the more distal locations.
- The basement waters are distinctly more mature when compared with the orebody, basal conglomerate and regional alluvial waters. The basement waters also displayed significantly elevated salinity. We can infer from this that these waters are related to a groundwater of significantly longer residence time, and have not undergone mixing with the alluvial waters above. This also suggests that there is little to no connectivity between the alluvial and basement aquifer systems.



aquaterra

LOCATION MAP



AUTHOR: DJ
DRAWN: MS
DATE: 20/09/09
JOB NO: 832G
REPORT NO: 145
REVISION: ...
PROJECTION: GDA94 Z50
SCALE: 1:150,000

0 2 4 km

LEGEND

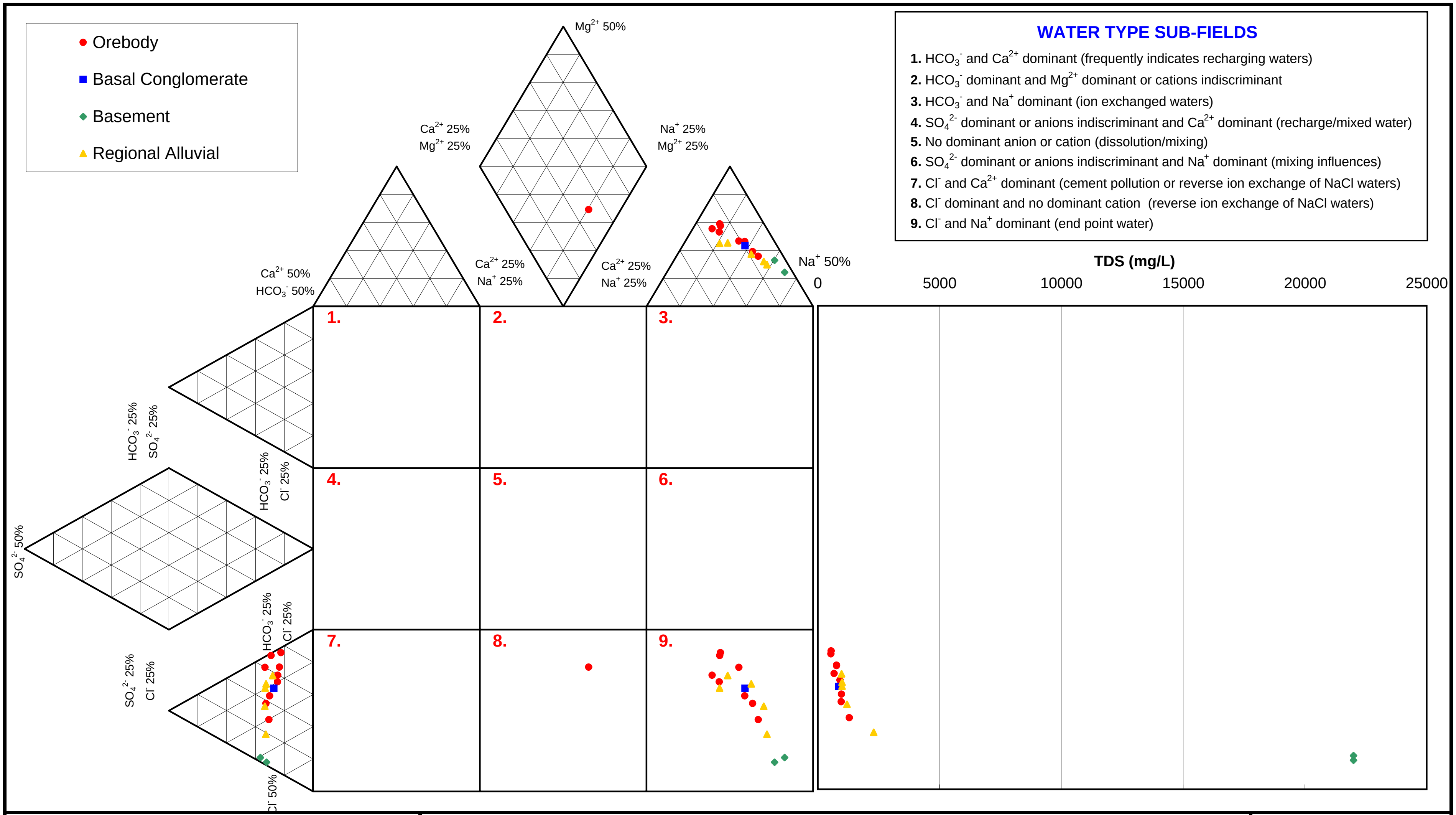
- ● Bores with salinity data
- Salinity contours (mg/L)
- ▭ Tenement

FIGURE 3.5
WATER QUALITY CONTOUR MAPS
TERTIARY & BASEMENT AQUIFERS

Loction: F:\Jobs\832G\MapInfo\145a_Fig3.5.wor

Table 3.3: Groundwater Quality Analyses

Bore	Cations					Anions				WQ Data		
	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Fe mg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	pH pH units	EC mS/cm	TDS mg/L
PB1	120	15	26	35	0.03	1	210	70	180	7.1	890	540
PB2	150	17	41	42	0	1	210	69	240	7.5	1100	680
PS1PB	380	37	35	51	0	1	190	160	540	7.6	2200	1300
OBS1	370	38	30	43	0	1	230	170	490	8.3	2100	1200
OBS2	270	28	29	41	0	1	190	130	380	7.3	1600	970
OBS4	250	37	31	49	0.05	1	220	120	370	7.2	1600	980
OBS5	200	22	47	51	0	1	260	92	330	8.1	1500	920
OBS6	120	16	26	34	0	1	210	50	170	8.3	920	550
OBS7	8900	600	230	700	1.7	1	360	4000	13000	7.3	37000	22000
OBS8	200	25	30	40	0	1	250	110	260	7.5	1300	780
OBS9	290	28	34	42	0	1	270	140	370	7.8	1700	1000
OBS10	230	28	30	41	0	1	230	99	330	8.3	1500	870
OBS11	240	30	51	49	0.02	1	310	120	360	8	1600	980
OBS12	130	12	74	62	0	1	290	82	290	8.1	1300	780
OBS13	8300	590	310	940	1.2	1	270	3700	14000	8	36000	22000
OBS14	240	43	64	52	0.03	1	250	140	370	7.3	1700	1000
OBS15	720	66	54	76	0.03	1	240	330	1100	7.9	3900	2300



WATER TYPE SUB-FIELDS

1. HCO_3^- and Ca^{2+} dominant (frequently indicates recharging waters)
2. HCO_3^- dominant and Mg^{2+} dominant or cations indiscriminant
3. HCO_3^- and Na^+ dominant (ion exchanged waters)
4. SO_4^{2-} dominant or anions indiscriminant and Ca^{2+} dominant (recharge/mixed water)
5. No dominant anion or cation (dissolution/mixing)
6. SO_4^{2-} dominant or anions indiscriminant and Na^+ dominant (mixing influences)
7. Cl^- and Ca^{2+} dominant (cement pollution or reverse ion exchange of NaCl waters)
8. Cl^- dominant and no dominant cation (reverse ion exchange of NaCl waters)
9. Cl^- and Na^+ dominant (end point water)

aquaterra

Expanded Durov Diagram

Figure 3.6

Date: 05/10/09

F:\Jobs\832G\G7 - DFS Reporting\145a_Figures\[145a_Figure3.6.xls]EXPANDED DUROV (1)

Project: Marillana Stage 2
Project No: 832G
Description:
Client: Brockman Resources

HydroCHEM 2.0

3.2.5 AQUIFER PARAMETERS AND HYDRAULIC RESPONSE TO PUMPING

Hydraulic parameters of various hydrogeological units in the study area have been estimated from rising head and falling head tests and also from pumping tests. Data were analysed using standard graphical methods of analysis and the results are summarised in Table 3.4. Full results are presented in Appendix D.

Salient points in relation to aquifer parameters and hydraulic response are:

- The orebody aquifer is of high permeability. Estimates of aquifer transmissivity range between 100 and 770m2/d. Based on this range, an hydraulic conductivity of 5 to 15m/d has been adopted for the orebody.
- The basement is of low permeability. The potentiometric surface associated with the basement is approximately 1 to 1.5m lower than the water table associated with the orebody (where measured). This suggests distinct groundwater systems, and a naturally downward hydraulic gradient between the shallow and deep aquifers.

Key features of the hydraulic response of the orebody aquifer during pumping include:

- Drawdown trends and rates in the pumping bore and adjacent observation bores within the orebody are consistent for each test, suggesting hydraulic consistency across the ore zone.
- No drawdown response is observed in observation bores drilled into underlying basement units (obs7 during the test on PB1, and obs13 during the test on PB2).
- Decreases in the rate of drawdown are observed in test and observation bores during all of the pumping tests, which is indicative of a leakage response from surrounding units.
- In relation to mine dewatering, the low permeability material surrounding the orebody may result in hydrostatic heads within the surrounding low permeability units being in excess of heads in the dewatered orebody; horizontal drain holes may be required to depressurise pit walls for geotechnical stability.

Table 3.4: Summary of Pump Test Interpretation and Aquifer Parameters

Geology	Bores	Aquifer Test Type	T Range (m^2/d)	K Range (m/d)	Remarks
Alluvium / THD (northern pit wall)	Obs1 Obs8 Obs12	Rising Head	-	0.13	-
Orebody (TD2, TD3)	PB1 PB2 PS1PB Obs2 Obs5 Obs6 Obs16	Pumping Test	100 - 770	3 - 25	Piezometers in the orebody displayed leakage response during pumping tests
	Obs6	Rising Head	-	-	Recovered too quickly to measure early data, implies moderate to high K
	Obs5 Obs6	Falling Head	-	0.1 – 0.4	-
Basal Conglomerate (TD1)	Pz1 deep Obs10	Falling Head	-	0.2 – 0.3	-
	Obs10	Pumping Test	-	-	Response during pumping infers a degree of hydraulic connection with overlying ore

Geology	**Bores**	**Aquifer Test Type**	**T Range (m^2/d)**	**K Range (m/d)**	**Remarks**
Basement (Hamersley Group)	Obs7 Obs13	Rising Head	-	0.001 - 0.04	Low permeability in basement units
	Obs7 Obs13	Falling Head	-	0.007 - 0.1	Low permeability in basement units
	Obs7 Obs13	Pumping Test	-	-	Lack of response during pumping infers no hydraulic connection with overlying aquifer

Figure 3.7 illustrates the general results of the field drilling and testing programme.

3.2.6 GROUNDWATER RECHARGE AND DISCHARGE

Aquifers are recharged directly from rainfall events. Direct recharge of rainfall in arid environments is minimal. However, indirect recharge may be locally significant with infiltration of runoff (streamflow) along drainage courses and the marsh. Recharge occurs preferentially along creeks and from the Fortescue Marsh, where evapotranspiration from the Marsh is periodically supported by recharge when the Marsh is inundated with surface water. This understanding of the recharge fits with the observed water quality gradients within the alluvial and basement aquifers on the Project tenement.

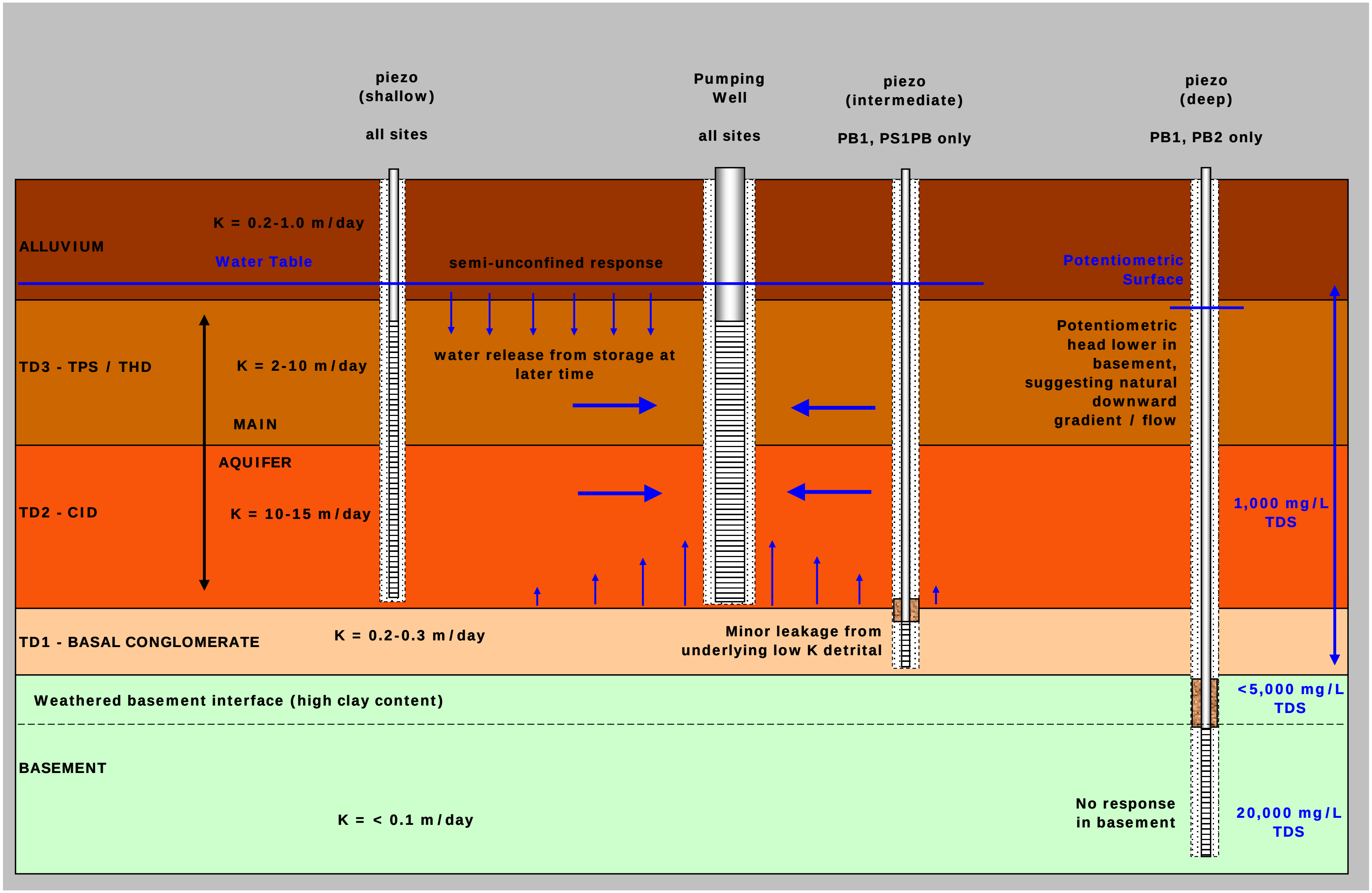
Groundwater Recharge

No long term groundwater level or creek flow monitoring is available for the Marillana area. Consequently, direct observations about the timing and magnitude of groundwater recharge events cannot be made. However, several inferences can tentatively be made from the available data:

- While all groundwater in the Tertiary aquifer on the tenement is relatively fresh, the majority of water samples from the area indicate it is an end-point type (i.e. Cl- and Na+ dominant). This suggests that much of the recharge is entering the groundwater system further up the catchment rather than locally, or that the younger waters are mixing with the more mature signature waters.
- Hydraulic gradients are moderate to low across the Fortescue Valley, and aquifer transmissivity is generally low (with the exception of the orebody aquifer, and potentially the calcrete aquifer).

Groundwater Discharge

- Within the study area, there is not believed to be any extensive zones of phreatophytic vegetation, and evapotranspiration from groundwater-dependent vegetation is likely to be low. Localised zones of phreatophytic vegetation (eucalypts) are present along the Weeli Wolli Creek drainage line.
- There are no existing users in the area with significant abstractions. There are a number of stock bores and these will contribute only a small component of groundwater discharge.
- The majority of groundwater discharge therefore occurs as throughflow, predominantly to the north toward the Fortescue Marsh.
- Not withstanding, previous studies have shown the Weeli Wolli Creek surface and groundwater system represent less than 10% of the total inputs to the Fortescue Marsh.



MARILLANA HYDROGEOLOGY - SUMMARY CONCEPTUAL LONG-SECTION FIGURE 3.7

3.3 CONCEPTUAL HYDROGOELOGY

3.3.1 UPSTREAM SYSTEM AND RECHARGE

Pre-mining groundwater conditions within the Weeli Wolli system are estimated at 8 to 10ML/d of baseline throughflow. Operations further up the catchment are now intercepting this throughflow, and also removing large volumes of groundwater from storage within the orebodies. However, due to the magnitude of the discharges associated with these operations back to Weeli Wolli Creek, it is estimated that more water is actually reaching the down-gradient groundwater system now than was originally interrupted by mining operations.

A key revision to our conceptual hydrogeological understanding compared to our prior desktop and analytical work (Aquaterra 2009a) is:

- In our early conceptual understanding, it was interpreted that all of the groundwater flow from the Weeli Wolli groundwater system flowed through the palaeochannel orebody on the Marillana tenement. Our revised understanding, on the basis of numerical modelling and more comprehensive regional water level mapping, suggests that only a proportion of this groundwater flow (perhaps only 10%) passes through the tenement, with much of the groundwater flowing northeast upon exiting the Hamersley Ranges, via another suspected palaeochannel.

3.3.2 MARILLANA AREA

The sedimentary rocks of the Hamersley Group outcrop along the southwest boundary of the Project area, where they form part of the Hamersley Range. These rocks typically have a low permeability, which can be locally enhanced where mineralised, fractured or weathered.

Incised within these rocks is the Fortescue Valley, infilled with a sequence of Tertiary and Quaternary deposits, up to 120m thick. Along the base of the Hamersley Ranges is a discrete and deeply incised palaeo-drainage which hosts a basal conglomerate (10-15m thick). The lateral extent and continuity of this unit is the subject on ongoing investigation by Brockman Resources. This basal conglomerate is overlain by a channel iron deposit that is podded and discontinuous in nature due to weathering subsequent to deposition. The CID unit has a high permeability.

During the subsequent erosion of the CID mesa, the northern ‘valley-facing’ side of the mesa was eroded back to palaeo-ground level in some locations. There was then a period of calcrete precipitation across the valley of significant thickness. It is not yet understood how extensive this calcrete formation is, or whether it is interrupted by basement highs or dissected by lower permeability channel and alluvial sediments, which will have implications on the lateral extent of hydraulic connection within the calcrete formation.

A pisolite gravel (TPS) was then deposited over this weathered and dissected CID, likely as a scree deposit from the neighbouring Hamersley Ranges (the TPS is observed as thickening towards the base of the range). The TPS is a moderate to highly permeable aquifer where present below the water table, which is likely dependent upon variable clay content. The CID and TPS are in hydraulic connection.

At a later stage, mineralised hematite detrital material (THD) was shed from the Hamersley Ranges, burying the CID and pisolite horizons with up to 20-30m of THD. The THD has moderate permeability. Again, due to the nature of the deposition, the THD is in hydraulic connection with the underlying TPS and CID.

Overlying all of these formations is a Quaternary sequence of colluvium and alluvium, which is generally fine-grained, with moderate clay content. It is deemed that this lithology would be of low permeability where present below the water table; however, where connected to the other sub-water table Tertiary deposits, it is likely to be a source of storage via leakage in the long-term.

Groundwater contours across the region are a subdued reflection of topography, ranging from more than 428mRL along the Hamersley Ranges, to less than 410mRL along the floor of the valley (Figure 3.4).

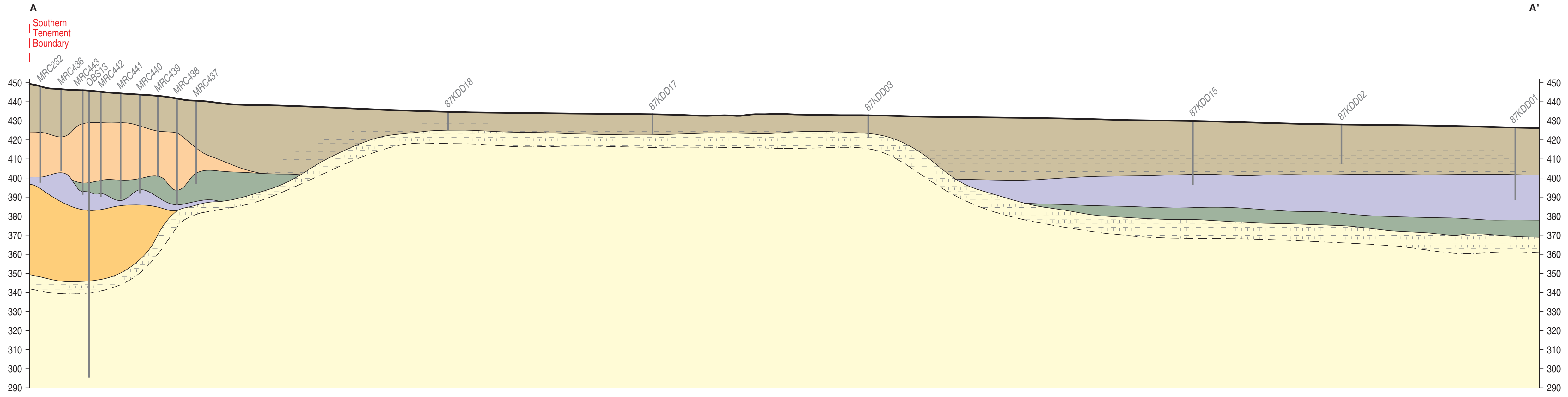
Regional groundwater flow is in a general northerly direction, flowing from the ranges to the Fortescue Valley with a relatively low hydraulic gradient. Locally, the preferential groundwater flow path of the CID means that groundwater flows in a north-westerly direction in the vicinity of the palaeo-channel.

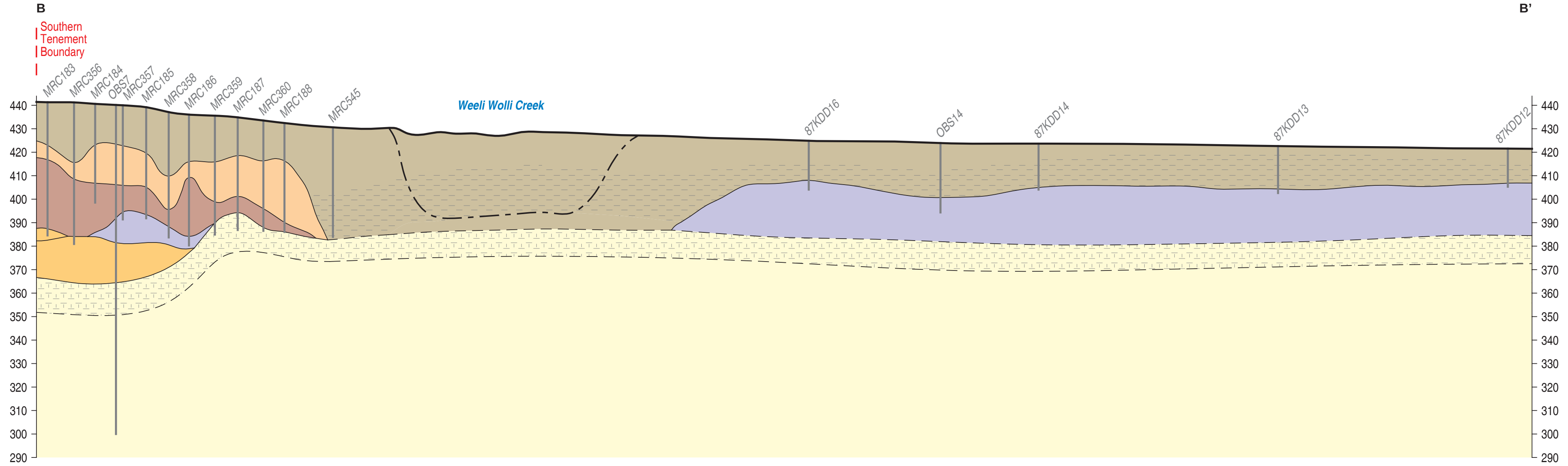
Aquifers are generally recharged from rainfall events. Direct recharge of rainfall in arid environments is minimal. However, indirect recharge may be locally significant with infiltration of runoff (streamflow) along drainage courses and the marsh. Recharge occurs preferentially along creeks and from the Fortescue Marsh, and it is likely that much of the recharge to the aquifers at the project are derived from further up the Weeli Wolli catchment (as suggested by the geochemical signatures of the water samples obtained at site). This understanding of the recharge also fits with the observed water quality gradients within the alluvial and basement aquifers in the area (Figure 3.5).

Significant rainfall events can potentially induce a groundwater level increase of several metres, and it is likely that sizeable background seasonal fluctuations occur in the region, and are likely to be magnified the vicinity of Weeli Wolli Creek, which sustains numerous channel flow events every year.

Water quality distributions are distinct in the alluvial and basement sequences. The basement has 20,000mg/L TDS below the mine area, increasing to an estimated 150,000mg/L TDS beneath the southern margin of the Fortescue Marsh. Within the alluvial sequence, water is fresh <1,000mg/L TDS near the base of the Hamersley Ranges, increasing to an estimated 7,000mg/L TDS near the southern margin of the Fortescue Marsh.

Figures 3.8 to 3.9 illustrate the current conceptual hydrogeological understanding of the project area (the locations of these sections are shown in Figure 3.2), which has informed the subsequent numerical modelling undertaken for this work.





Legend

|	Drillhole/Bore Location
▨	Tertiary Alluvium (Alluvium/Colluvium)
▨	Tertiary Alluvium (Clay-rich Alluvium)
▨	Hematite Detritals
▨	Pisolite Gravel
▨	Calcrete
▨	Clay
▨	Channel Iron Deposit
▨	Basal Conglomerate
▨	Weathered Basement (Wittenoom Formation)
▨	Basement (Wittenoom Formation)

0 200 400 600 800 1000

HORIZONTAL SCALE - METRES
10x VERTICAL EXAGGERATION

G:\work\aquaterra\832G\832G-Drawing02.dgn

NOT FOR CONSTRUCTION

PRELIMINARY

aquaterra
water resource and environmental solutions

Suite 4, 125 Melville Parade
Como, Western Australia 6152

Telephone: (08) 9368 4044
Facsimile: (08) 9368 4055

REFERENCES

REVISIONS

No	DATE	DESCRIPTION	DRN	CHK	APP	No	DATE	DESCRIPTION	DRN	CHK	APP

		DATE
DESIGNED	D. JANSSEN	03-07-09
DRAWN	C. REEVES	06-07-09
CHECKED	D. JANSSEN	06-07-09
APPROVED		

CLIENT: **BROCKMAN RESOURCES**

DRAWING TITLE:

MARILLANA IRON ORE PROJECT
HYDROGEOLOGICAL CROSS SECTIONS

PROJECT NUMBER: 832G

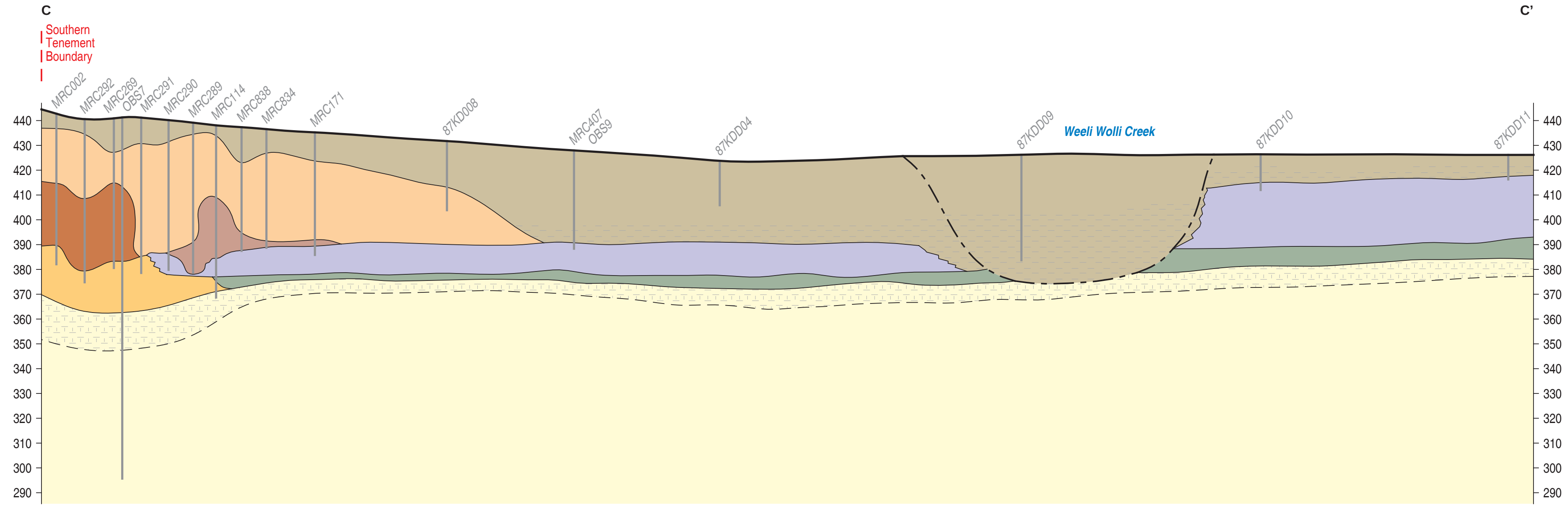
DRAWING NUMBER:

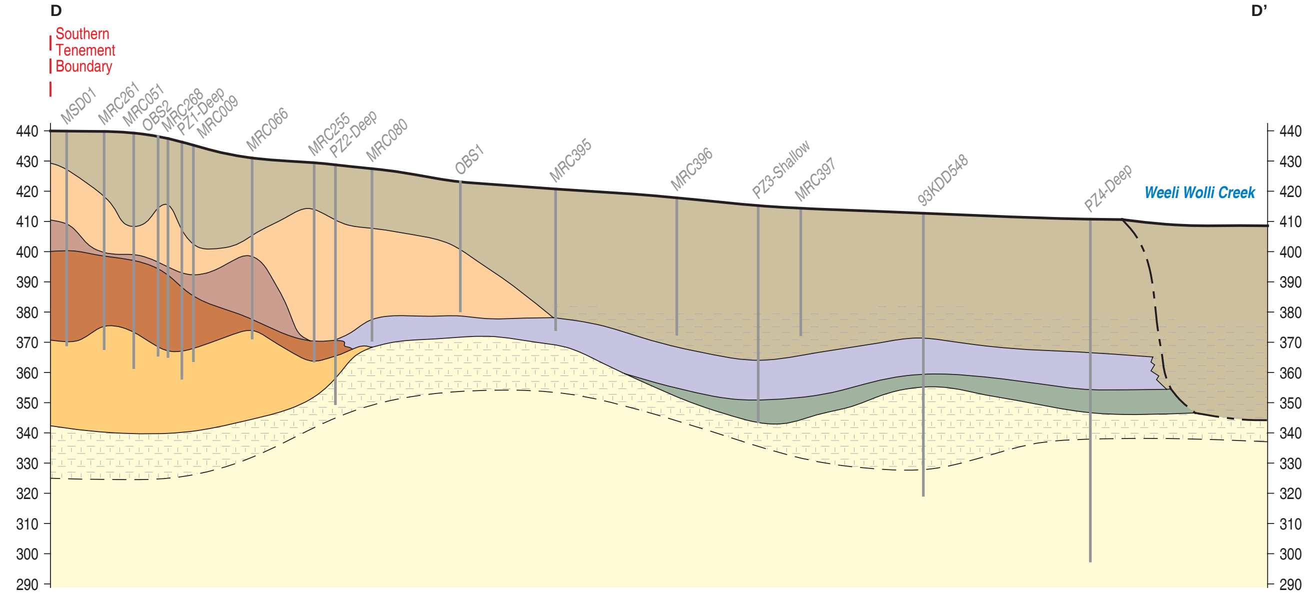
832G-Drawing02

SCALE: 1 : 25 000 at A3

REV
A

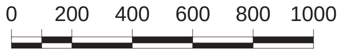
CAUTION
PROJECT DRAWING ONLY





Legend

│	Drillhole/Bore Location
▨	Tertiary Alluvium (Alluvium/Colluvium)
▨	Tertiary Alluvium (Clay-rich Alluvium)
▨	Hematite Detritals
▨	Pisolite Gravel
▨	Calcrete
▨	Clay
▨	Channel Iron Deposit
▨	Basal Conglomerate
▨	Weathered Basement (Wittenoom Formation)
▨	Basement (Wittenoom Formation)



HORIZONTAL SCALE - METRES
10x VERTICAL EXAGGERATION

G:\work\aquaterra\832G\832G-Drawing03.dgn

NOT FOR CONSTRUCTION

PRELIMINARY

aquaterra
water resource and environmental solutions

Suite 4, 125 Melville Parade
Como, Western Australia 6152

Telephone: (08) 9368 4044
Facsimile: (08) 9368 4055

REFERENCES

REVISIONS

No	DATE	DESCRIPTION	DRN	CHK	APP	No	DATE	DESCRIPTION	DRN	CHK	APP

		DATE
DESIGNED	D. JANSSEN	03-07-09
DRAWN	C. REEVES	06-07-09
CHECKED	D. JANSSEN	06-07-09
APPROVED		

CLIENT: **BROCKMAN RESOURCES**

DRAWING TITLE:

MARILLANA IRON ORE PROJECT
HYDROGEOLOGICAL CROSS SECTIONS

PROJECT NUMBER: 832G

DRAWING NUMBER:

832G-Drawing03

SCALE: 1 : 25 000 at A3

REV
A

CAUTION
PROJECT DRAWING ONLY

3.3.3 DOWNSTREAM SYSTEM & DISCHARGE

Current hydrogeological data indicates that water levels in the alluvium on the plain are below the bed of the marsh, thus suggesting that the Marshes are a predominantly surface water feature as opposed to a groundwater discharge area. During flood events salts deposited during previous drying episodes are redissolved, and the freshwater entering the Marshes becomes moderately saline.

Following a flood event, a portion of the ponded surface water infiltrates causing water levels to rise beneath the marsh, ultimately to ground level (the marsh bed). Continual evaporation removes ponded surface water, after which the groundwater table in the marsh bed sediments will decline to its former position under the combined processes of direct evaporation and radial groundwater flow. Under this concept, any change in groundwater level beneath the marsh will have no impact on the occurrence of surface water ponding, or on the rate of seepage from the marsh bed into the water table. It is conceivable however, that where the groundwater level is lowered significantly, an increased amount of water would be required to fully saturate the profile, which would reduce the duration of surface water ponding. However, there is no significant effect on groundwater levels below the Fortescue Marsh anticipated, even in the worst case model predictions undertaken.

The alluvium and orebody aquifers on the flanks of the valley are recharged with fresh water during rainfall events. Given there is a hydraulic gradient towards the Marshes, this water will drain towards it. As a result of recharge from the ponding on the Marshes, groundwater both below and close to the Marshes is saline, whilst that further away and up gradient is fresh.

3.4 GROUNDWATER DEVELOPMENT POTENTIAL WITHIN THE MARILLANA AREA

The main aquifer system identified in the Marillana area is the orebody aquifer. However, it is noted that the Tertiary aquifer sequence extends significantly deeper (20-60m) below the currently proposed base of mining in many areas. Groundwater abstraction from the orebody aquifer will be necessary for mine dewatering, and will be utilised as the primary mine water supply.

Issues that will affect the long term supply potential from this aquifer include:

- Areal extent and thickness of the aquifer will affect both the volume in storage and number of bores that can be installed without running dry. For the orebody aquifer, this is generally defined through orebody geological modelling, although some more recent drilling has also been taken into consideration.
- Rates of groundwater recharge and throughflow in the orebody are not well understood on a seasonal variation level, and it is likely that a substantial part of groundwater abstracted from this aquifer will be drawn from storage. Groundwater modelling has been carried out to assess the long term sustainability of abstraction from this aquifer (cf. Section 4).
- Water quality over the life of mining. Processing demands can utilise water up to 7,000mg/L TDS. Salinity modelling has been carried out to assess the long-term water quality considerations (cf. Section 5).

Smaller capacity supplies to meet camp water supply requirements can be obtained from a combination of local calcrete aquifers and overlying alluvium. Indeed, some water supply exploration has been undertaken near the site of the proposed Marillana camp in the northeast of the tenement (Aquaterra 2008b). A preliminary evaluation of other water supply options over a wider area has also been undertaken to provide some targets for future work should additional water be required.

4 GROUNDWATER FLOW MODELLING

4.1 MODELLING OBJECTIVES

The aim of the groundwater flow modelling was to assess dewatering requirements for the Marillana iron ore deposit. A numerical model had previously been established as part of the 2008 study; this was updated with new data and the revised conceptual hydrogeology developed during the current study. The calibrated groundwater model was used to determine dewatering requirements for the deposit for the projected mine schedule and the potential for this dewatering to supply the projected water supply.

The key features of the regional groundwater model are discussed in the following sections and may be summarised as follows:

- Groundwater inflow from the upper Weeli Wolli catchment and the Chichester and Hamersley Ranges.
- Groundwater recharge to the Fortescue Marsh and from surface water flows affecting the modelled area.
- Groundwater discharge (via evapotranspiration) from the Fortescue Marsh.
- Groundwater pumping from the proposed dewatering borefield.

4.2 GROUNDWATER FLOW MODEL SETUP

The numerical modelling package Modflow 2000 was used to develop the groundwater model operating under the Groundwater Vistas graphical user interface (Version 5, Rumbaugh and Rumbaugh, 1996 to 2009). Modflow is one of the industry leading groundwater flow modelling packages.

The model grid and extent is shown in Figure 4.1. The corner coordinates of the model are shown in Table 4.1. The model grid was rotated 65 degrees from the MGA grid such that the model grid was aligned with the predominant flow direction toward the Fortescue Marsh.

Table 4.1: Model Domain Coordinates

Corner	Easting*(m)	Northing*(m)
North West	727883	7536403
North East	755688	7523438
South West	710054	7498169
South East	737810	7485185

*MGA94 zone 50

Model cell size ranges from 50m in the immediate Marillana orebody area to 400m at the model boundaries. The refined grid area was used to provide adequate resolution in defining the geometry of the target orebody and the curvature of the water table in areas of expected maximum water table drawdown in the mining area. The model consists of 5 layers, 231 rows and 303 columns resulting in approximately 349,965 cells.

Model layer elevations were set consistent with available geological information within the model boundary as detailed in Table 4.2.

Table 4.2: Model Layer Details

Layer	Hydrogeological Units
1	Basement (Shale and BIF), TPS, THD, Alluvium
2	Basement, TPS, THD
3	Basement, TPS, THD, Calcrete, Wittenoom
4	Basement, TPS, THD, CID, Alluvium, Wittenoom
5	Basement and Wittenoom

The hydrogeological units represented in each layer are illustrated in Figure 4.2 to 4.6. A representative cross section view of the hydrogeological units is shown in Figure 4.7. The base of layers 1 and 4 was set consistent with available geological information while the base of layer 2, 3 and 5 were set at a uniform level of 390mRL, 372mRL and 280mRL respectively. Contours of the base of model layers 1 and 4 are presented in Appendix F.

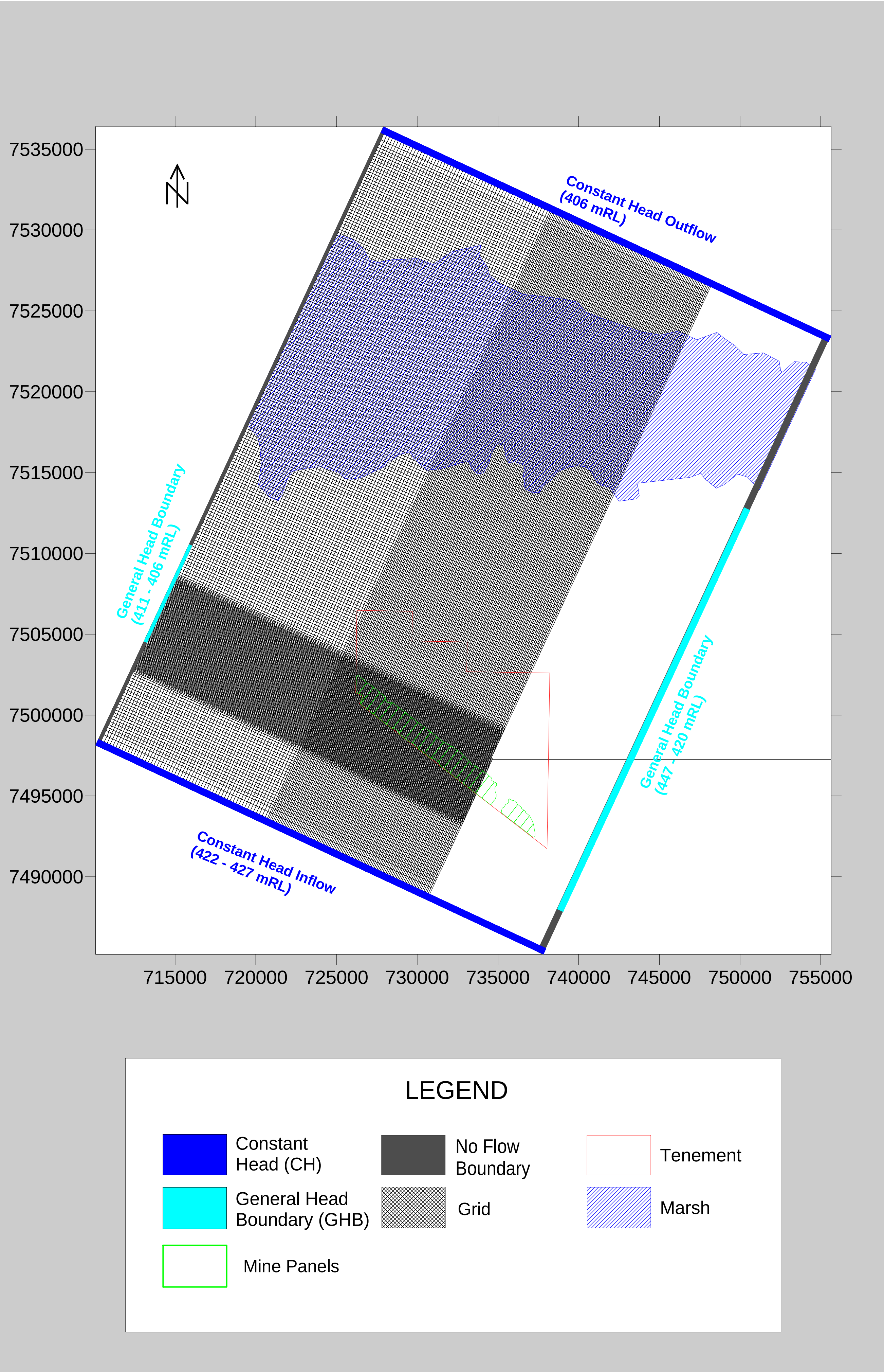
4.3 GROUNDWATER INFLOW AND OUTFLOW

4.3.1 GROUNDWATER THROUGHFLOW

The general direction of groundwater flow within the model boundary is:

- From the Chichester and Hamersley Ranges toward the Fortescue Marsh (ie. north to south and south to north respectively).
- Westerly from upper parts of the Weeli Wolli catchment with some minor inflow from the east.

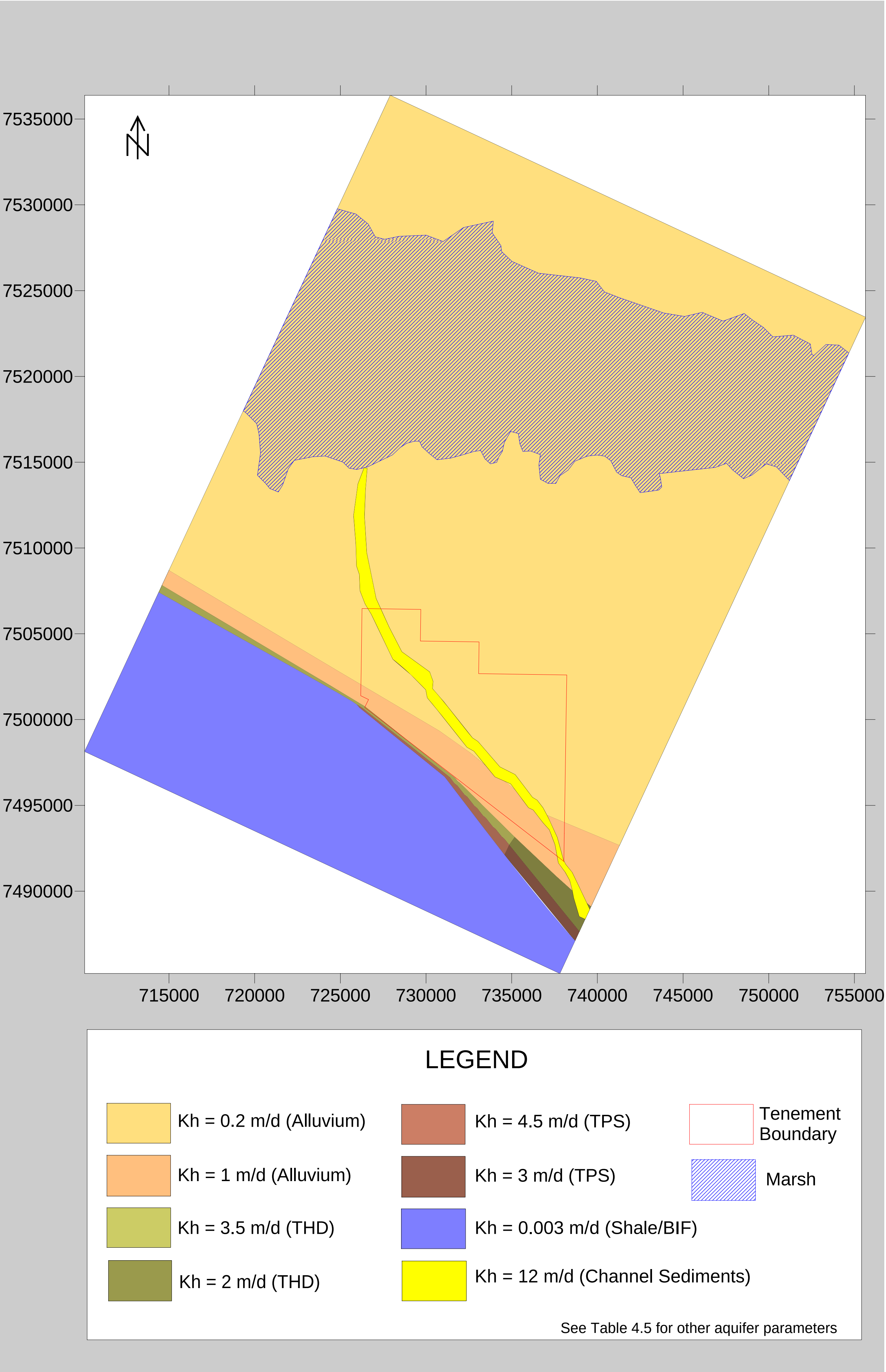
Two fixed head boundaries simulate inflow from the Chichester and Hamersley Ranges as shown in Figure 4.1. The northern boundary is set at 406mRL, while the southern boundary varies from 422 to 472mRL. These elevations are based on interpretation of available regional water level data. General Head Boundaries simulate inflow to the CID aquifer on the eastern and western model boundaries south of the Fortescue Marsh (refer Figure 4.1). The eastern boundary is set at 420 to 447mRL with a conductance of 2.0e-2m^2/d while the western boundary is set between 406 and 411mRL with a conductance of 2.0e-2m^2/d. These values are also set consistent with interpretation of regional water level data. The location and extent of model boundaries is shown in Figure 4.1.



MODEL GRID AND BOUNDARY CONDITIONS

FIGURE 4.1

F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/grid_BC.srf

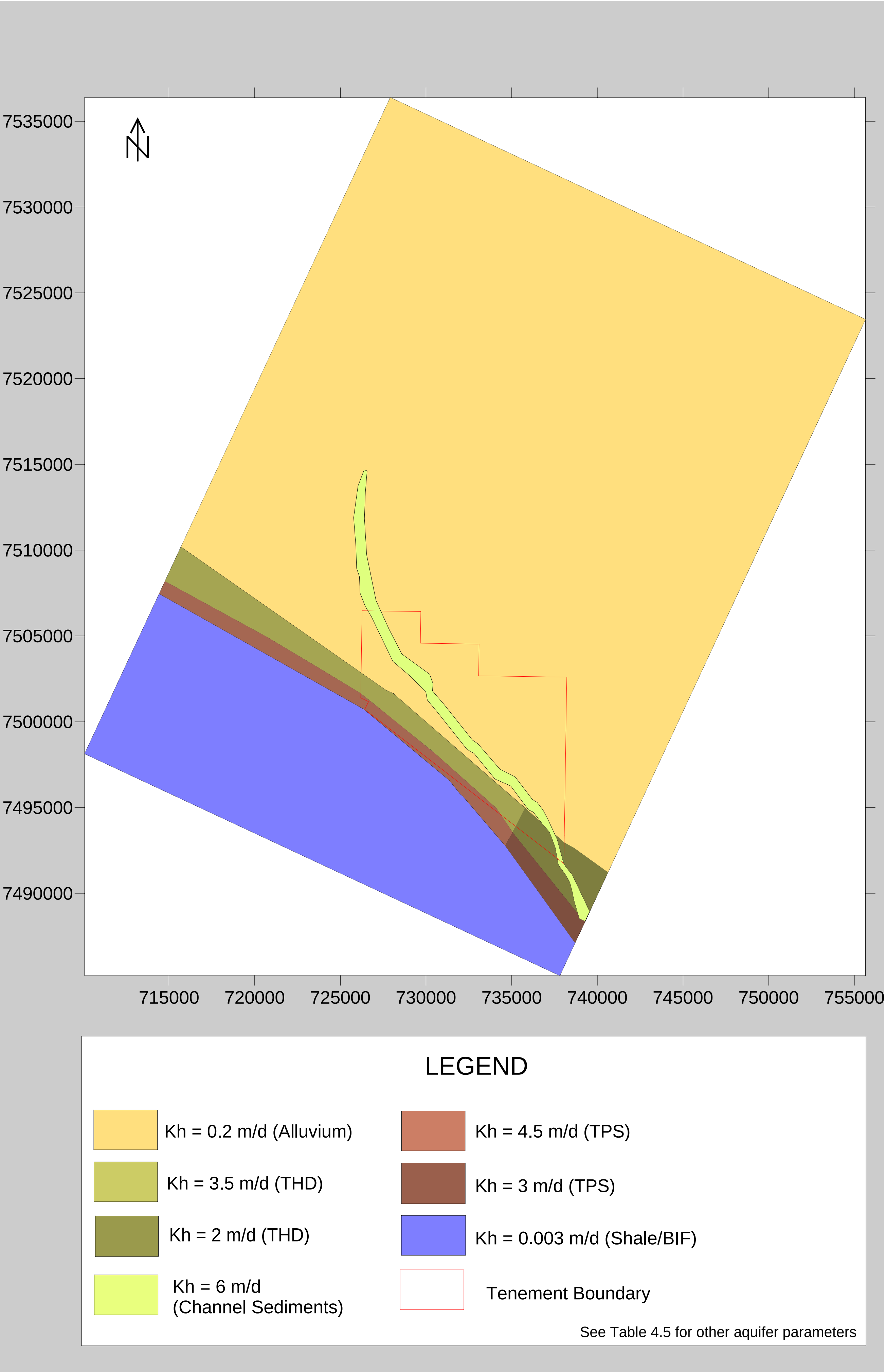


See Table 4.5 for other aquifer parameters

aquaterra

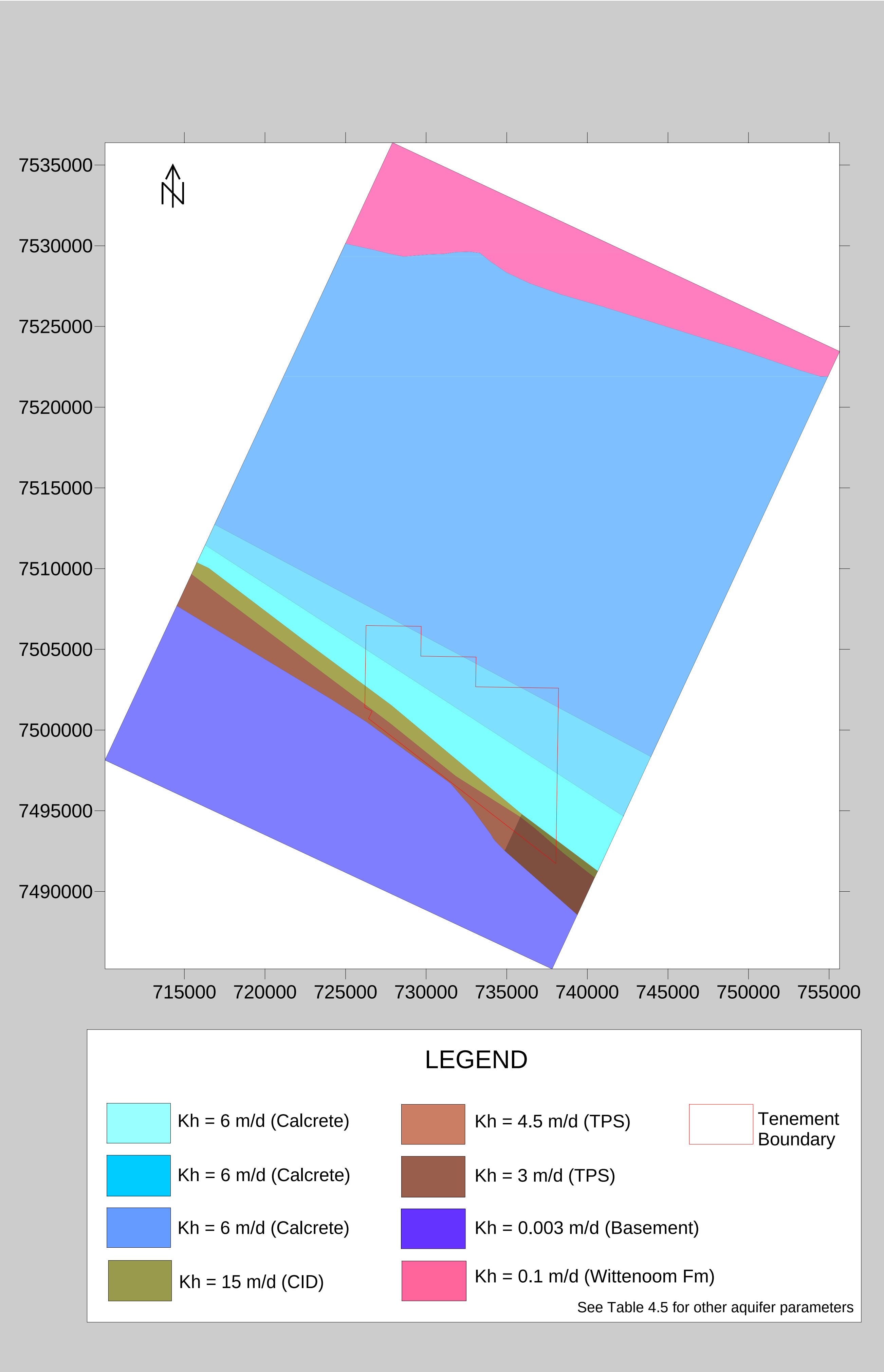
PARAMETER DISTRIBUTION: LAYER 1 FIGURE 4.2

F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/K_layer1.srf



PARAMETER DISTRIBUTION: LAYER 2 FIGURE 4.3

F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/K_layer2.srf

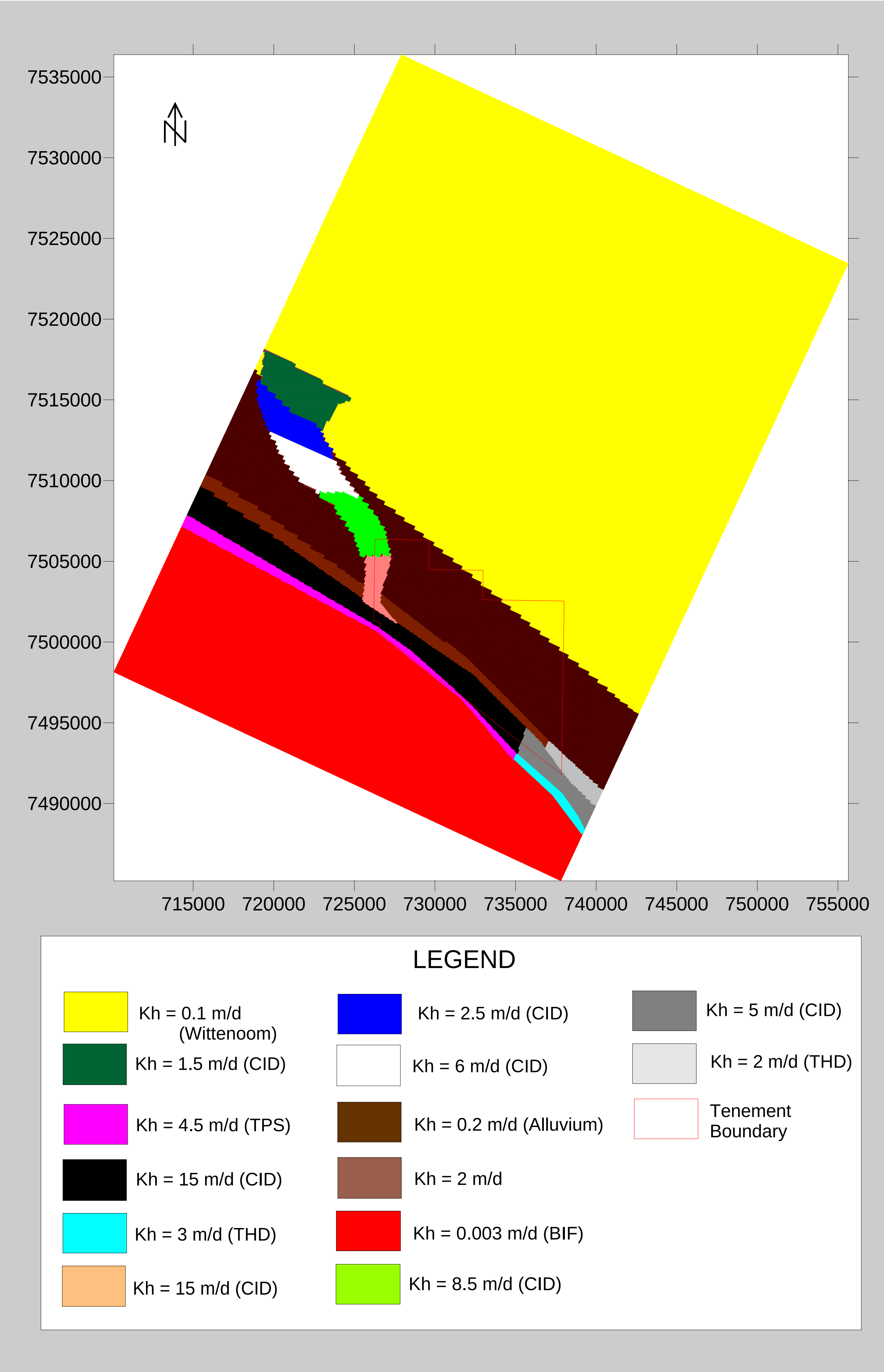


See Table 4.5 for other aquifer parameters

aquaterra

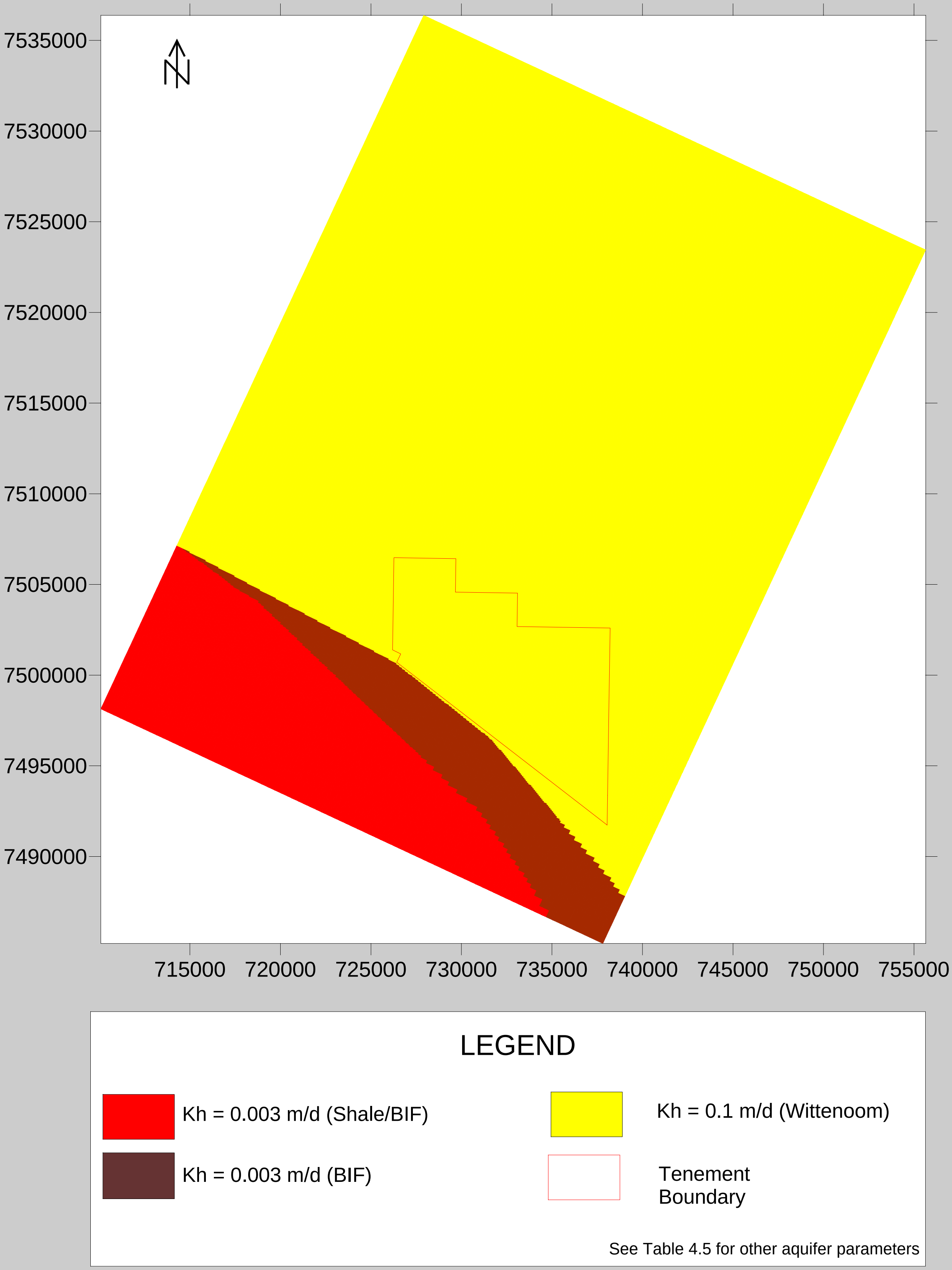
PARAMETER DISTRIBUTION: LAYER 3 FIGURE 4.4

F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/K_layer1.srf



PARAMETER DISTRIBUTION: LAYER 4 FIGURE 4.5

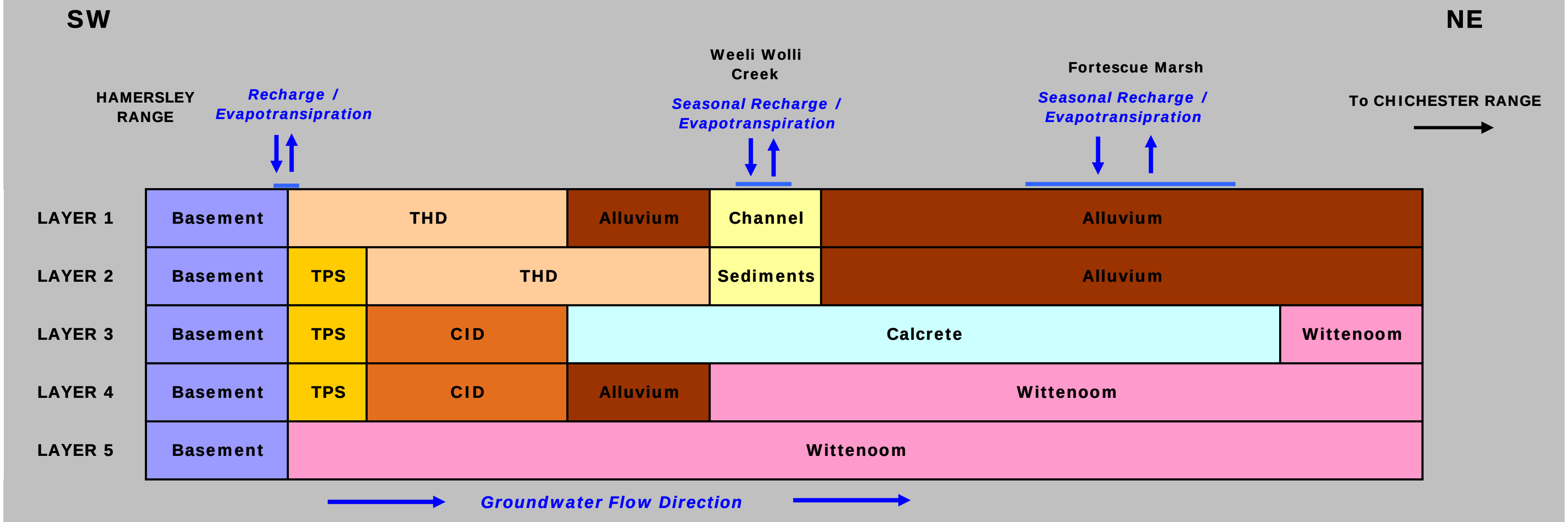
F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/K_layer4.srf



See Table 4.5 for other aquifer parameters

PARAMETER DISTRIBUTION: LAYER 5 FIGURE 4.6

F:/Jobs/832G/G6 - GW Modeling/Results/Calibration/run70/K_layer5.srf



Notes:

This section is not to scale

Layers are depicted as horizontal to show connections.

Layers specified in the model are consistent with available information (depth and extent)

GROUNDWATER MODEL: SCHEMATIC CONCEPTUAL CROSS-SECTION FIGURE 4.7

F:\Jobs\832G\G7 - DFS Reporting\145a_Figures\[145a_Figure4.7.xls]Section

4.3.2 RAINFALL RECHARGE

Inflow to the groundwater system is provided via rainfall recharge to the Fortescue Marsh and an area immediately south of the proposed mining area corresponding to the basement/alluvial contact on the flanks of the Hamersley Range. This recharge is assigned as a proportion of recorded rainfall. The average annual rainfall recorded for the region is around 310mm per year. The model is set up to reflect the distinct wet and dry seasons that occur in the Pilbara with the percentage of rainfall assigned adjusted during calibration. The distribution of rainfall recharge is shown in Figure 4.8 and discussed in further detail in Section 4.4.2 (Table 4.3).

The lower reach of Weeli Wolli Creek before it discharges to the Fortescue Marsh falls within the model boundary. Flows in the creek are generated primarily by rainfall runoff from the creek catchment. Over the modelled area these flows recharge the alluvial aquifer and provide a significant proportion of recharge. Flows in Weeli Wolli Creek are seasonal with the highest flows occurring in the wet season between December and March. Recharge from creek flows is assumed to occur every two years. Based on analytical calculations using monitoring data from further upstream in the catchment, it is assumed that a total volume of 600L/s recharges the extent of Weeli Wolli Creek shown in Figure 4.8 for a period of a month. This equates to an infiltration rate of 1,700kL/d per km of inundated creek channel.

4.3.3 EVAPOTRANSPIRATION

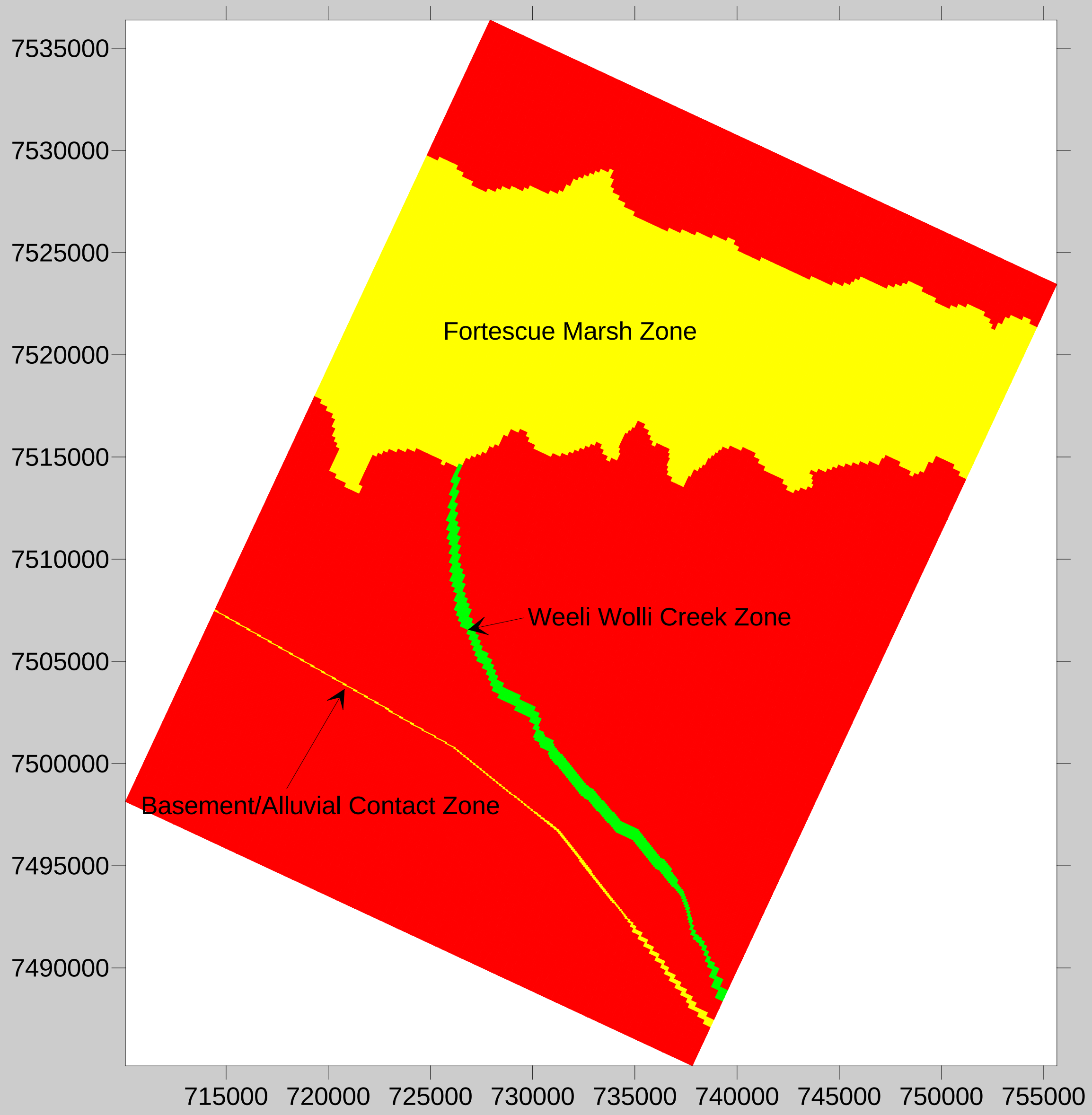
Evaporation from the shallow water table underlying the Fortescue Marsh is modelled using the Evapotranspiration (ET) package in Modflow such that if aquifer water levels are at or above a specified evaporation surface ET occurs at the maximum specified rate. If the aquifer water levels decrease below the specified ET surface, the ET rate decreases linearly to zero as the predicted water level reaches an elevation equal to the ET surface minus the extinction depth. The ET rate is also set to zero wherever the aquifer water level is below the elevation equal to the ET surface minus the extinction depth. This is illustrated schematically in Figure 4.9.

The average annual evaporation in the area is approximately 3.1 metres per year. The seasonal variation in evaporation is captured using an averaged rate for each season as summarised in Table 4.3.

The evapotranspiration surface is set consistent with available topographic data for the marsh area with an extinction depth of 5 metres. The distribution of modelled ET is shown in Figure 4.8.

4.4 MODEL CALIBRATION

Model calibration is a process of demonstrating that a groundwater model can replicate historical monitoring data. During model calibration, aquifer parameters, the proportion of rainfall assigned as recharge and the values assigned to fixed head and general head boundaries were adjusted within realistic limits until a reasonable match between measured and predicted groundwater levels was produced.



Recharge Distribution (m/d)

	Fortescue	Weeli Wolli	Contact Zone
January	0.00019	0.003685	0.0000428
February to March	0.00019	0	0.0000428
April to September	0.000055	0	0.0000428
October to December	0.0000405	0	0.0000428

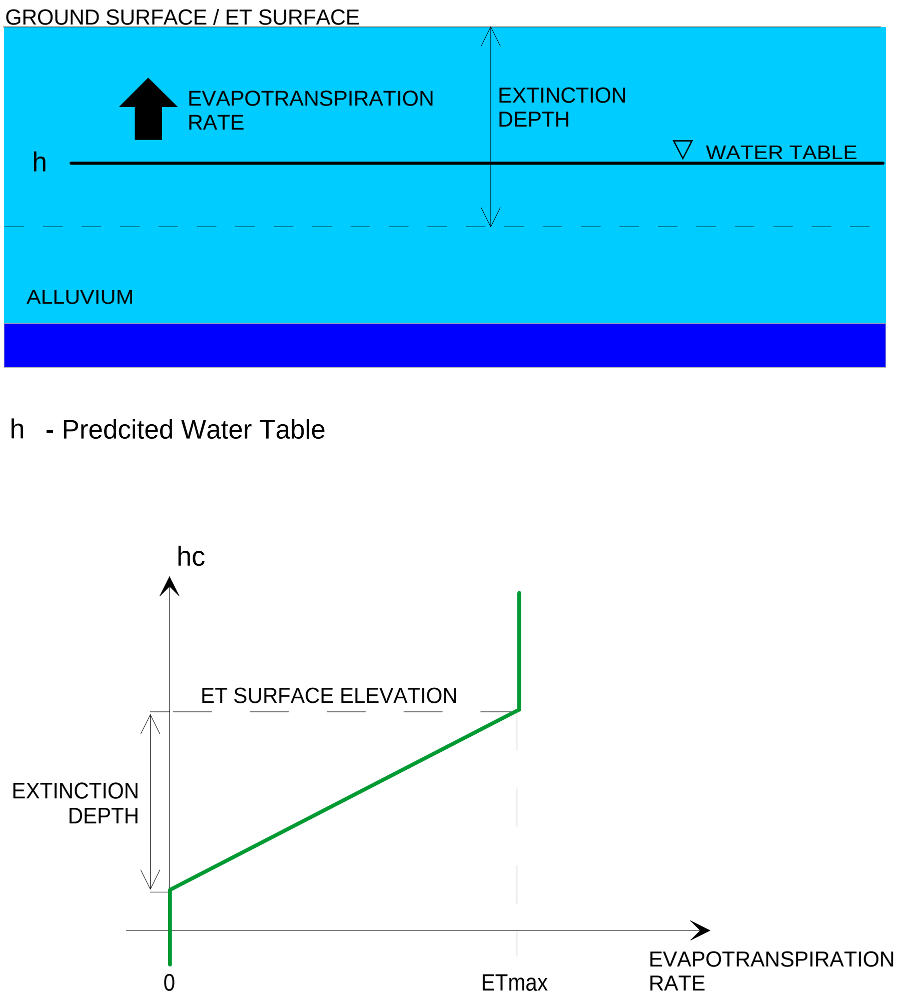
Evapotranspiration Distribution (m/d)

	Fortescue	Weeli Wolli	Contact Zone
January	0.0010086	0.005043	0.010086
February to March	0.0010086	0.005043	0.010086
April to September	0.006197	0.003099	0.006197
October to December	0.011978	0.005989	0.011978

aquaterra

MODELLED RECHARGE & EVAPOTRANSPIRATION DISTRIBUTION FIGURE 4.8

f"/jobs/832G/G7/145a figures/145a fig4.8.srf



SCHEMATIC EVAPOTRANSPIRATION SET UP FIGURE 4.9

4.4.1 INITIAL CONDITIONS

Groundwater monitoring data for the study area are available from June 2009. Conceptual understanding suggests that a seasonal trend in groundwater levels would be observed along Weeli Wolli Creek and to a lesser extent across the Marillana orebody aquifer. At this time however, groundwater monitoring data are not available to confirm this. Monitoring from further upstream in the Weeli Wolli catchment suggests that aquifers that underlie or are very close to Weeli Wolli Creek show water level increases of up to 5 metres as a result of wet season creek flows. As a result, groundwater conditions within the modelled area are not readily described by an average or steady state set of water levels conditions. To accommodate this, a set of initial conditions was generated using a dynamic calibration process. This involved running the model in transient mode (as outlined in Section 4.4.2), including all relevant aquifer stresses, until a set of water levels were identified that represented groundwater conditions that could be expected one month into the wet season (i. e. the beginning of January). Once these predicted water levels were identified, these conditions were used as initial conditions for the transient calibration. This was an iterative process repeated as required as aquifer parameters were adjusted during the transient calibration.

4.4.2 TRANSIENT CALIBRATION

As outlined above, strong seasonality in rainfall recharge will result in differences in groundwater levels from season to season and year to year depending on the amount of rainfall. Additionally, cyclonic events, or a sequence of events may further increase groundwater levels as underlying aquifers are recharged by flows in Weeli Wolli Creek. At present no data for the modelled area are available to confirm this but as conceptual understanding suggests this is the case, the model was run to replicate a typical seasonal response that could be expected for the catchment. This involved running the model for a period of twenty years with each year consisting of the wet and dry seasons, with the recharge and evaporation as outlined in Table 4.3. This time set up was chosen to allow creek recharge to occur biennially in January, and a distinction between the wet and dry seasons to be included.

Table 4.3: Annual Setup of Recharge and Evaporation

Season	Length (days)	Assigned Recharge	Assigned Evaporation
January	31	3.685e-3m/d along Weeli Wolli Creek, 1.9e-4m/d to the Fortescue Marsh, 4.28e-5m/d along the alluvium basement contact	5.043e-3m/d along Weeli Wolli Creek, 1.0086e-2m/d from the Fortescue Marsh, 1.0086e-2m/d along the alluvium basement contact
February to March	59	No recharge to Weeli Wolli Creek, 1.9e-4m/d to the Fortescue Marsh, 4.28e-5m/d along the alluvium basement contact	5.043e-3m/d along Weeli Wolli Creek, 1.0086e-2m/d from the Fortescue Marsh, 1.0086e-2m/d along the alluvium basement contact
April to September	183	No recharge to Weeli Wolli Creek, 5.50e-5m/d to the Fortescue Marsh, 4.28e-5m/d along the alluvium basement contact	3.099e-3m/d along Weeli Wolli Creek, 6.197e-3m/d from the Fortescue Marsh, 6.197e-3m/d along the alluvium basement contact
October to December	92	No recharge to Weeli Wolli Creek, 4.05e-5m/d to the Fortescue Marsh, 4.28e-5m/d along the alluvium basement contact	5.989e-3m/d along Weeli Wolli Creek, 1.1978e-2m/d from the Fortescue Marsh, 1.1978e-2m/d along the alluvium basement contact

The model was run over a period of twenty years, similar to the projected mine life to allow comparison between the mining and non-mining cases, and to also check that the assigned recharge rate did not result in any significant long term increase in predicted water levels.

Predicted and modelled water levels from June 2009 and the mid-point of the modelled dry season are presented in Figure 4.10. The scaled root mean square (SRMS) error for this time is 9.9%. This is consistent with the best practice for a catchment with limited data that suggests that the SRMS error should be less than 10%. There is the potential that some improvements to the model calibration could be achieved by further zonation of aquifers and aquitards. Such hydrogeological features which cannot be justified on the basis of current hydrogeological understanding have not been included to date, but could be in the future if data became available to support such changes.

Measured water levels for June 2009 and modelled water level contours for the mid-point of the dry season are shown in Figure 4.11 and show the general groundwater flow direction toward the Fortescue Marsh from the Hamersley Ranges and the upper part of the Weeli Wolli catchment and in the southern part of the model domain and from the Chichester Ranges towards the Fortescue Marsh on the northern side.

Predicted water levels for the twenty year period are shown in Figure 4.12 for observation points throughout the model domain. The locations of the observation points are shown in Figure 4.11. Observation points in the Fortescue Marsh show a response to creek flow recharge of more than 10 metres, while the location along the CID, and between the CID and creek show a recharge response of less than 1 metre. In the marsh area however, no response is predicted as the model does not allow for seasonal inundation.

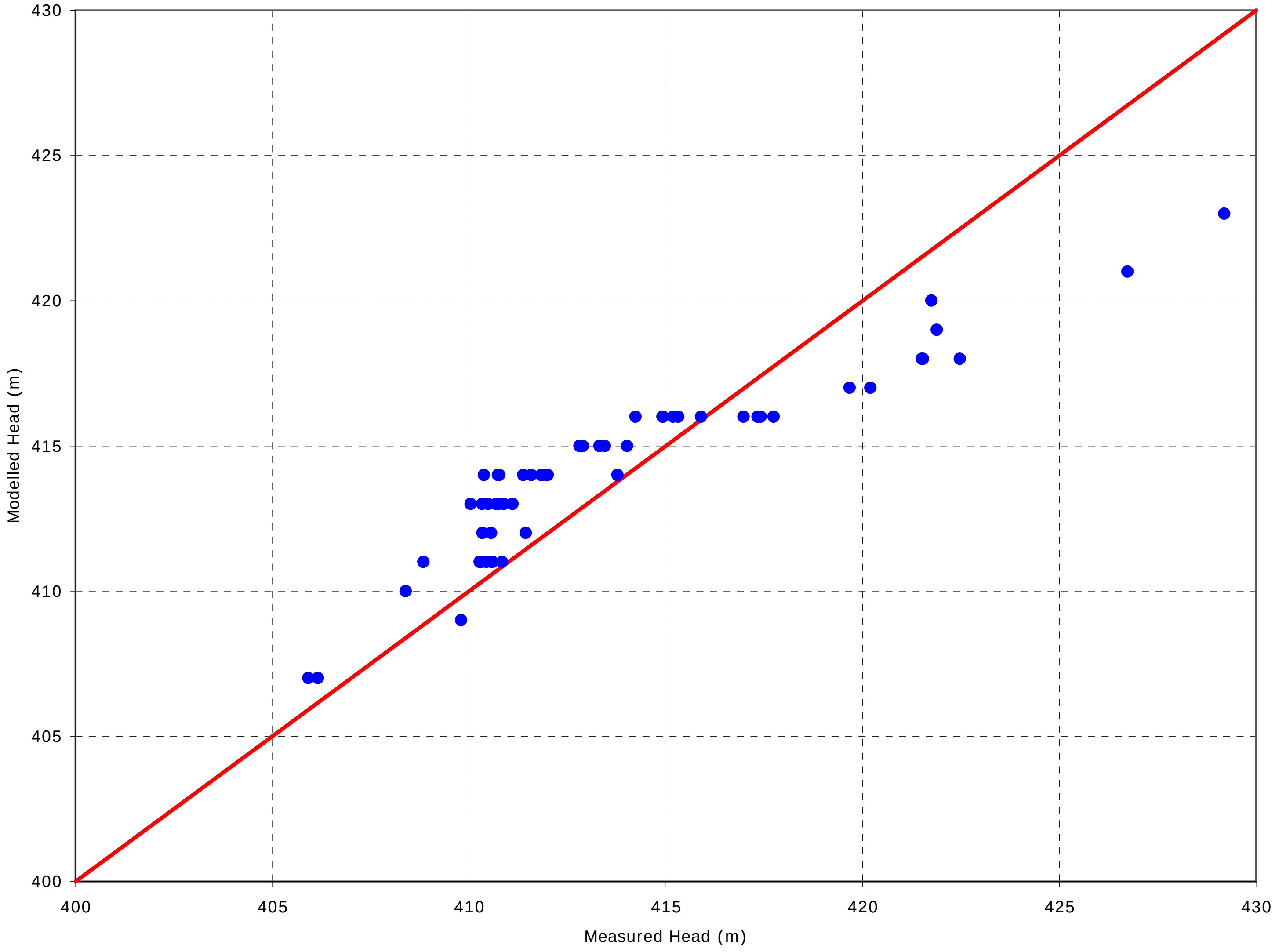
4.4.3 WATER BALANCE

Modelled water balance for the end of the assumed wet season (end of January) and the end of the dry season (end of December) are presented in Table 4.4.

Table 4.4: Model Predicted Water Balances for Dry and Wet Seasons

		In(kL/d)	Out (kL/d)
Dry Season	Storage	2930	20
	Constant/General Head Boundaries	1620	0
	Recharge	14500	0
	Evaporation	0	19030
	TOTAL	19050	19050
Wet Season	Storage	260	53670
	Constant/General Head Boundaries	1620	0
	Recharge	119075	0
	Evaporation	0	67285
	TOTAL	120955	120955

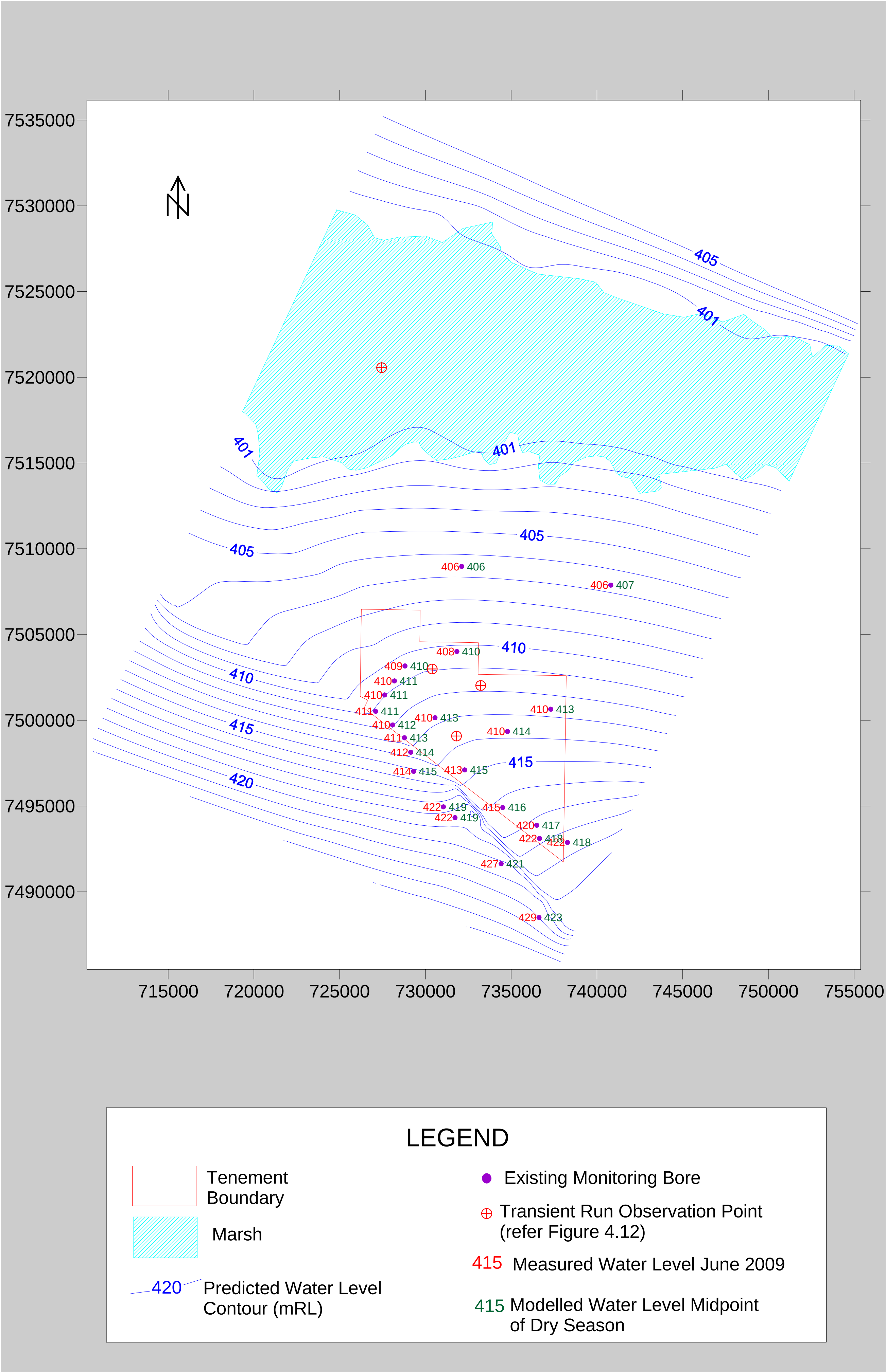
The predicted water balances suggests, as expected, that the major water balance components in the water balance corresponding to fluxes in and out of the model domain are associated with rainfall recharge and evaporation and that these are significantly greater at the end of the wet season.



aquaterra

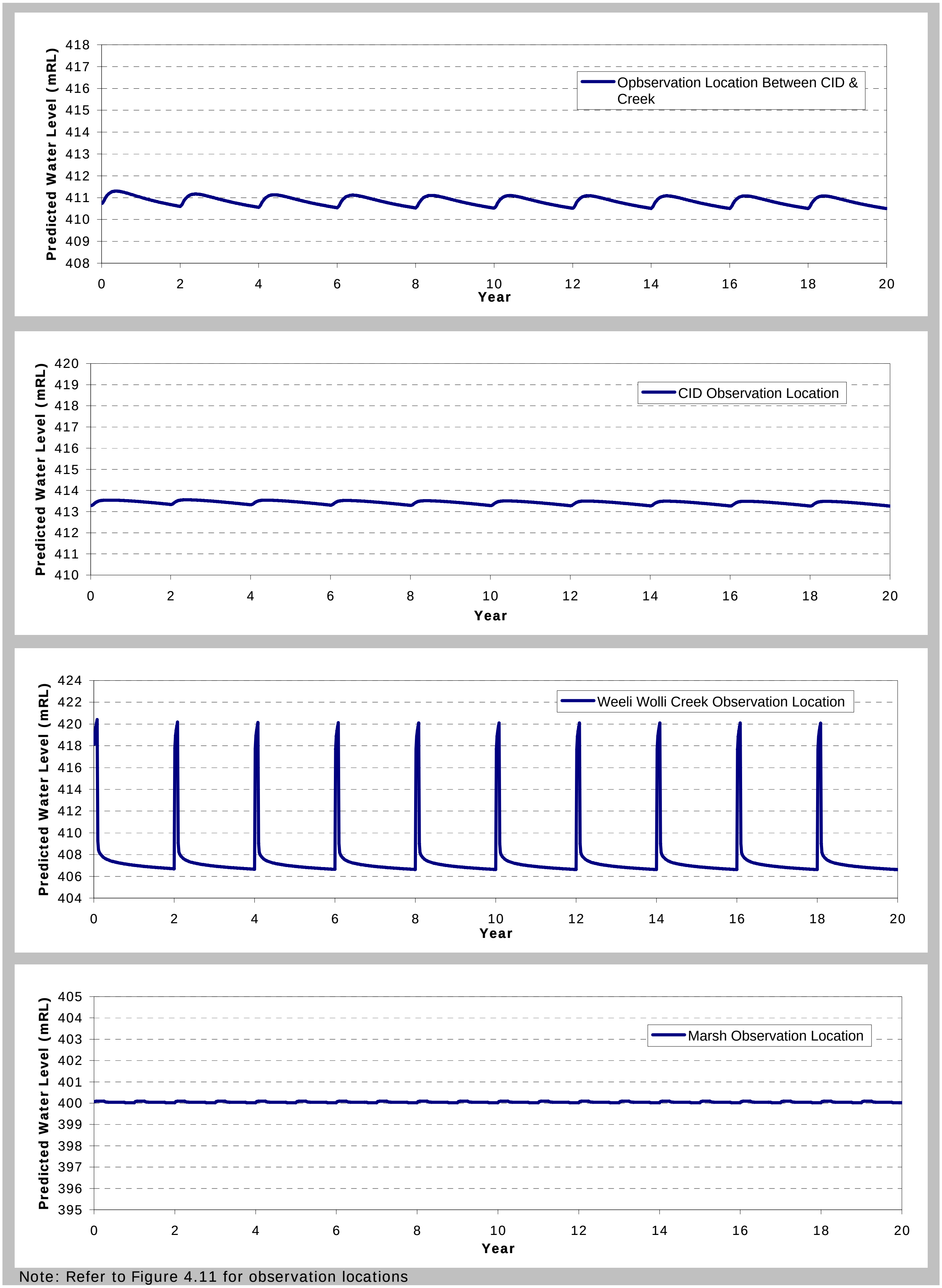
MEASURED VERSUS MODELLED WATER LEVELS FIGURE 4.10

F:\Jobs\832G\G7 - DFS Reporting\145a_Figures\[145a Figure4.10.xls]Figure 4.10



PREDICTED GROUNDWATER LEVELS FIGURE 4.11

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a fig4.11.srf



Note: Refer to Figure 4.11 for observation locations

aquaterra

PREDICTED TRANSIENT WATER LEVELS FIGURE 4.12

4.4.4 AQUIFER PARAMETERS

Figures 4.2 to 4.6 show the distribution of hydrogeological formations for the transient model. Calibrated aquifer parameters assigned to each formation are summarised in Table 4.5. Assigned aquifer parameters are consistent with available hydraulic testing data and similar hydrogeological environments.

A key assumption of the model set up, as shown in Figure 4.4 is that the calcrete observed in the vicinity of the orebody and in the northeast of the tenement are completely continuous and laterally extensive across the region (even extending beneath the Fortescue Marsh).

Aquifer storage parameters (both unconfined and confined) were assigned consistent with available information and similar hydrogeological environments. The model however, is not calibrated to these parameters as sufficient recorded aquifer stresses (such as recharge from streamflow or groundwater pumping) were not available to allow calibration of these aquifer parameters.

Table 4.5: Calibrated Aquifer Parameters

Model Layers		Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Unconfined Storage (%)*	Confined Storage*
1,2 and 4	THD	2.0-3.5	0.2-0.35	5.0	0.00001
1,2,3 and 4	TPS	3.0-4.5	0.3-0.45	5.0	0.00001
1, 2 and 4	Alluvium	0.2	0.02	1.0	0.00001
3	Calcrete	6.0	0.6	5.0	0.00001
3 and 4	CID	6.0-15.0	0.6-1.5	3.0	0.00001
1,2,3,4 and 5	Basement (BIF and Shale)	0.003	0.0003	0.1	0.00001
5	Wittenoom	0.1	0.01	0.1	0.00001

* Model not calibrated to these parameters. Values assigned consistent with similar hydrological environments for transient and prediction runs.

4.5 WATER SUPPLY AND DEWATERING PREDICTIONS

4.5.1 SET UP

The orebody is the main aquifer in the Marillana area and it will be an important component of mine water management to integrate dewatering with water supply requirements. Predictive modelling to assess dewatering requirements; to draw water levels to below the projected base of mining; and the potential for this water to supply the projected water demand was completed. Optimisation of dewatering and water supply requirements was focussed on achieving water supply requirements ahead of dewatering requirements as while extra dewatering can be achieved with additional pumping from bores and or sumps, the requirement for additional water supply would be far more difficult to address.

Model predictions assumed pumping from a proposed borefield drawing from the orebody aquifer for the twenty year life of the Marillana Iron Ore Project. The simulated borefield is located along the mine path with one bore assigned to each mining panel. Details of the setup of the twenty year prediction are summarised as follows:

- Rainfall and river recharge and evaporation are assigned consistent with the transient model.
- The mining schedule used for the dewatering predictions comprises a series of panels which are mined to total depth over time. Groundwater levels are to be drawn to or just below the projected base of mining by at least a year into mining of that panel.
- The proposed borefield is modelled using the Multi Node Well (MNW) package in Modflow 2000. The MNW package was chosen to simulate pumping bores because it is capable of

simulating groundwater pumping until a minimum specified water level is attained in the specified pumping location. The simulated bore or pumping location will draw water from the aquifer it is screened in, in this case the entire alluvial/CID sequence, at a specified initial pumping rate until it reaches a specified or minimum pumping level water level. If the water level in the specified pumping cell is drawn to or below the specified minimum level, the MNW package reduces the simulated pumping rate or ceases pumping if required such as to not fall below the minimum specified water level in that cell. For the prediction, the minimum pumping water levels were set consistent with the projected base of mining As a result, the deeper parts of the CID that are not planned to be mined are not dewatered to satisfy water supply requirements.

- The initial pumping rate for each bore was set to 2000kL/d at each of the 27 proposed pumping locations with one bore assigned to each panel. Two different pumping configurations were adopted. Case 1 assumed that bores pumped for the entire mine life of 20 years once they were commissioned; while Case 2 assumed that bores only operated during mining of the respective panel. As a result, Case 2 is a better representation of the groundwater pumping conditions than can be expected given anticipated mining and backfill strategies.

4.5.2 RESULTS

Water Supply

Total predicted pumping rates for Case 1 and 2 along with the project water demand are presented in Figure 4.13. For Case 1, pumping bores are assumed to continue operation after mining at a particular location is complete. The results suggest that water supply requirements can be met with the adopted configuration until Year 9 of the project with dewatering exceeding the projected water demand over this period. By Year 20 of mining total borefield yields decrease to less than 150L/s. For Case 2, where pumping is only assumed to continue during active mining, water demands are mostly met, but decrease to significantly lower than the projected demand by Year 10. Total predicted borefield yield decreases to 50L/s by Year 20.

As mentioned above, in the above simulations there are areas on the (modelled) orebody where saturated CID remains below the base of mining. This offers opportunity for additional drawdown and abstraction should additional water actually be required after Year 9.

Drawdown Impact

The predicted impact of water supply and dewatering development on the regional piezometric levels for Case 2 is presented for after Year 5, 10, 15 and 20 in Figure 4.14. The drawdown is at a maximum of 40m below pre mining levels in the western end of the orebody to facilitate dry mining conditions. The drawdown reduces with distance from the main pit area. The predicted drawdown in piezometric levels extends northwards across the Fortescue Valley and southwards from the mine area to beneath the Hamersley Ranges. Drawdown is elongated northwest-southeast in alignment with the general strike of the detrital orebody.

The predicted drawdown is extensive based on the following factors:

- The mining time frame and the 15km long strike length of the proposed mining/dewatering area.
- The thickness and lateral continuity of the calcrete.
- The minimal groundwater throughflow in this system means that the majority of dewatering coming from storage in the target orebody aquifer, and the adjacent calcrete aquifers.

Model predicted water levels for Case 2 and for the no pumping case or transient prediction at observation locations between the CID and Weeli Wolli Creek, in the CID, along Weeli Wolli Creek and in the Fortescue Marsh are presented in Figure 4.15 (refer Figure 4.11 for observation locations). The results suggest that:

- At the observation location between the CID and Weeli Wolli Creek, predicted water levels are drawn down by 15 metres by Year 10, and drawn down another 3 metres by the end of Year 20.
- At the CID observation location, the maximum water level drawdown is predicted, with water levels drawn down by 25 metres by the end of Year 10. By Year 20, there is some minor water level recovery as pumping bores are no longer able to maintain water levels at close to the base of mining.
- Along Weeli Wolli Creek, water levels are drawn down by 5 metres by Year 10. It is also predicted that the water level peaks resulting from creek recharge are smoothed out due to the available storage created from ongoing pumping from the orebody aquifer. By Year 20, water levels are predicted to be drawn down by 8 metres.
- In the Fortescue Marsh, there is no predicted impact from water supply pumping over the life of the mine.

On that basis, the dewatering zone of influence as represented by the model is likely to be a conservative “worst case” scenario. If the calcretes are less extensive, or discontinuous in nature, the drawdown cone is likely to be significantly reduced.

It should also be noted that:

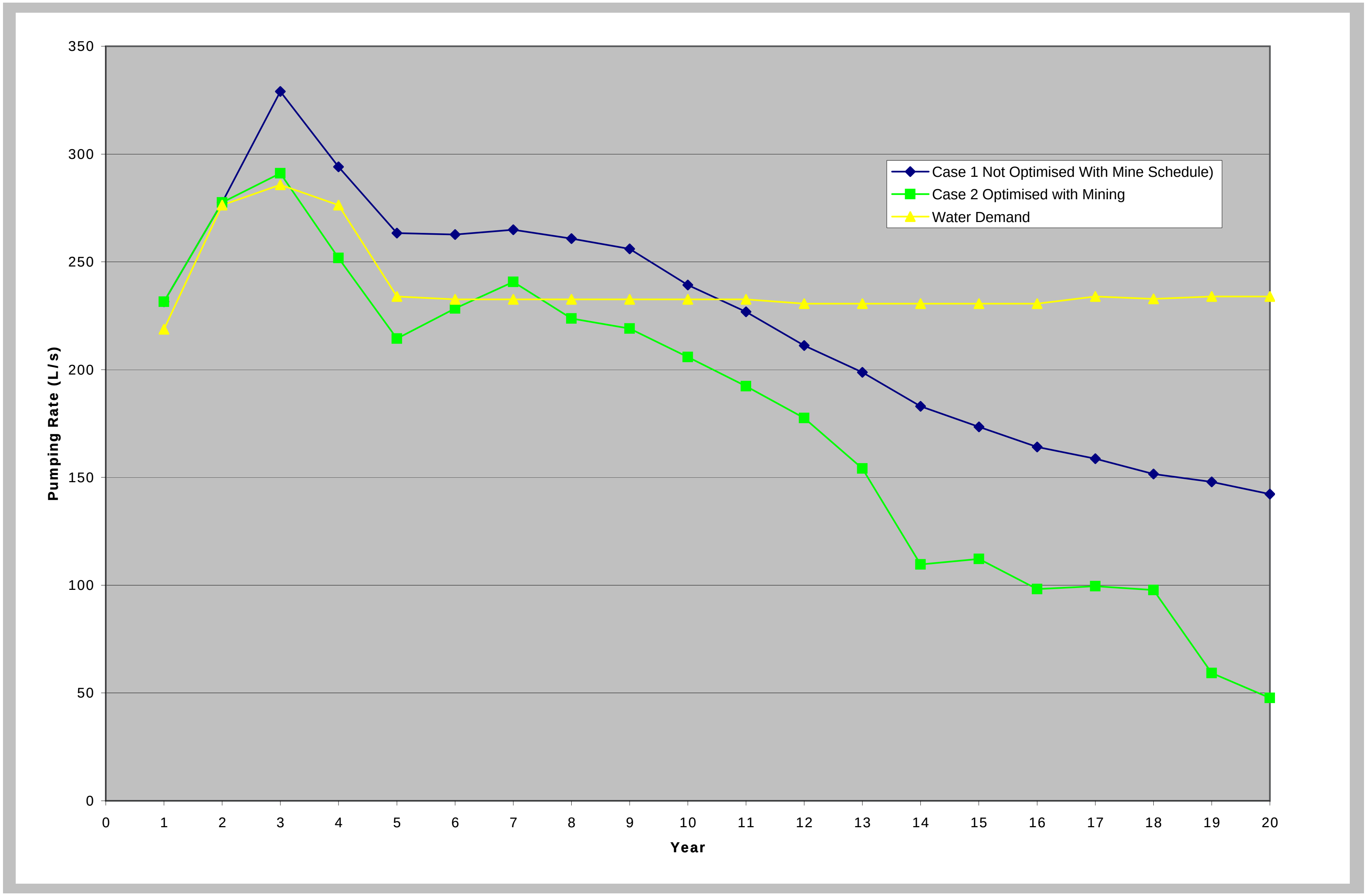
- Over most of the affected area, the impacts of dewatering represent a drop in the potentiometric surface. However other than in the immediate vicinity of the mine, no geological units are dewatered.
- The reduction in potentiometric surface under the marsh is negligible and will not affect inundation frequency as this is driven by surface water events.

Water Balance

Predicted model water balance values for Case 2 (assuming dewatering during active mining only) after 5, 10, 15 and 20 years of mining are presented in Table 4.6 and suggest that for the dry season conditions considered, groundwater pumping represents a significant proportion of the predicted water balance after five years of water supply pumping. The source of the water is storage. However as shown in Table 4.4, groundwater storage is replenished during the modelled wet season (of the order of 50,000kL/d). After ten years the proportion is similar however after fifteen and twenty years, when pumping is reduced the overall water balance is similar to that predicted prior to development.

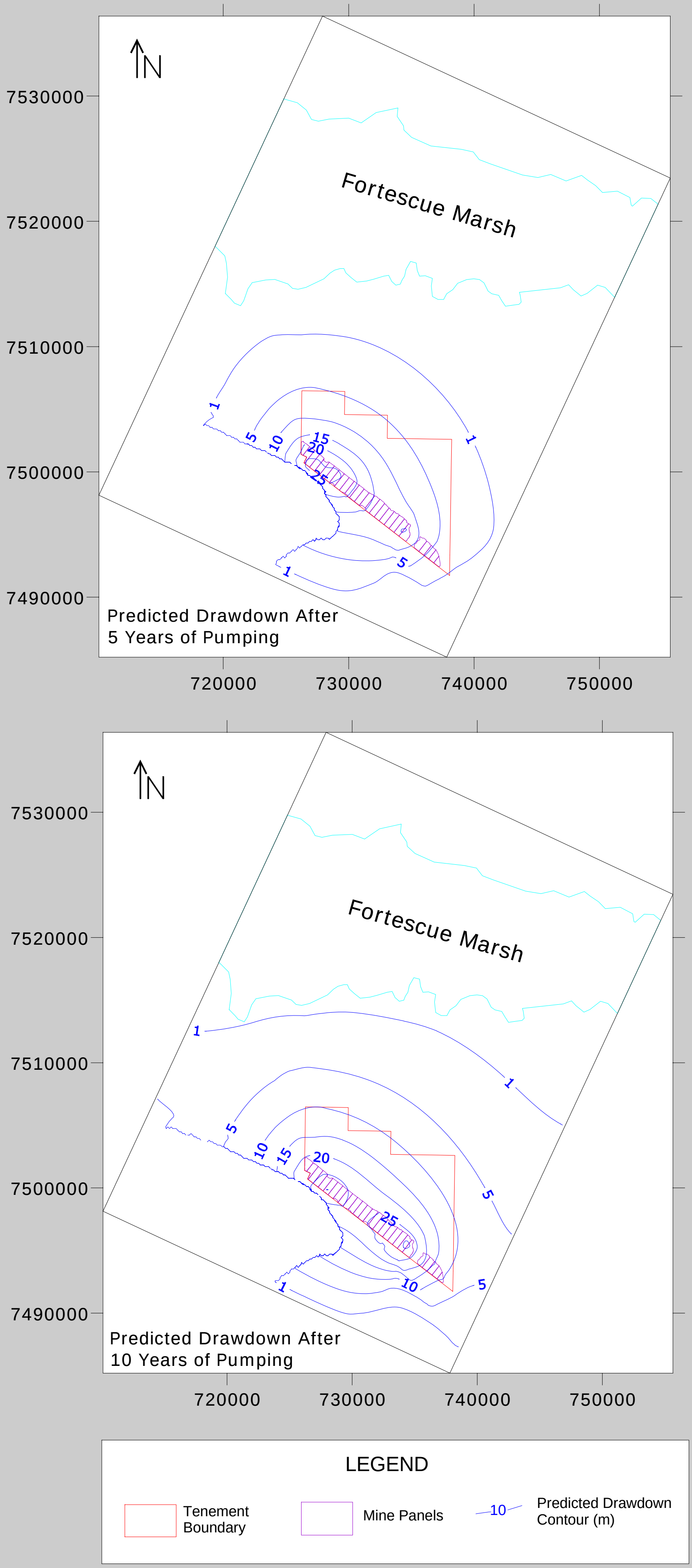
Table 4.6: Model Predicted Water Balances (End of Dry Season)

		In (kL/d)	Out (kL/d)
After 5 Years	Storage	20760	0
	Constant/General Head Boundaries	1630	0
	Recharge	14500	0
	Evaporation	0	18770
	Groundwater Pumping	0	18130
	TOTAL	36880	36900
After 10 Years	Storage	18900	190
	Constant/General Head Boundaries	1700	0
	Recharge	14500	-
	Evaporation	0	17690
	Groundwater Pumping	0	17220
	TOTAL	35100	35100
After 15 Years	Storage	10360	140
	Constant/General Head Boundaries	1780	0
	Recharge	14500	0
	Evaporation	0	16780
	Groundwater Pumping	0	9720
	TOTAL	26640	26640
After 20 Years	Storage	6020	2210
	Constant/General Head Boundaries	1840	0
	Recharge	14500	0
	Evaporation	0	16030
	Groundwater Pumping	0	4120
	TOTAL	22360	22360



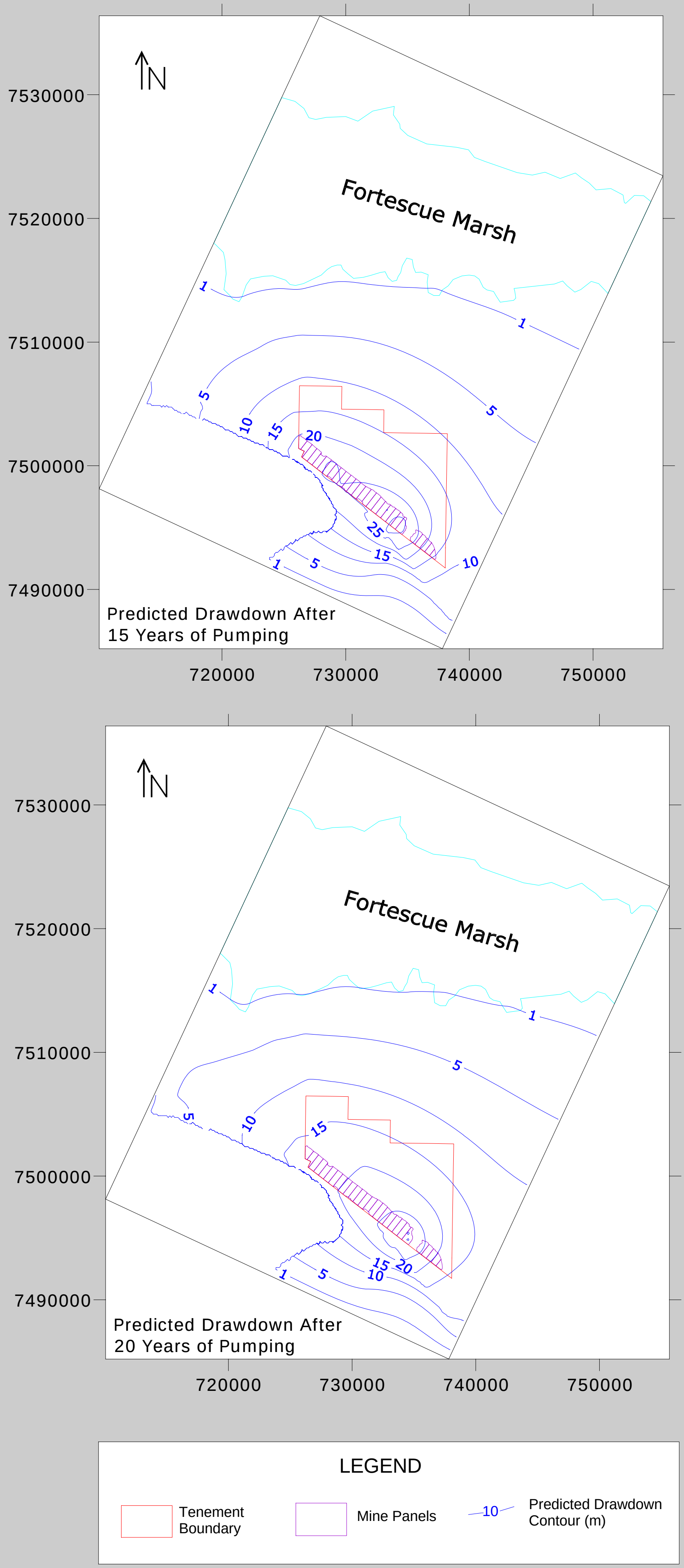
PREDICTED WATER SUPPLY / DEWATERING FIGURE 4.13

F:\Jobs\832G\G7 - DFS Reporting\145a_Figures\[145a_Figure4.9&4.12.xls]Fig4.13



PREDICTED DRAWDOWN AFTER 5 & 10 YEARS FIGURE 4.14a

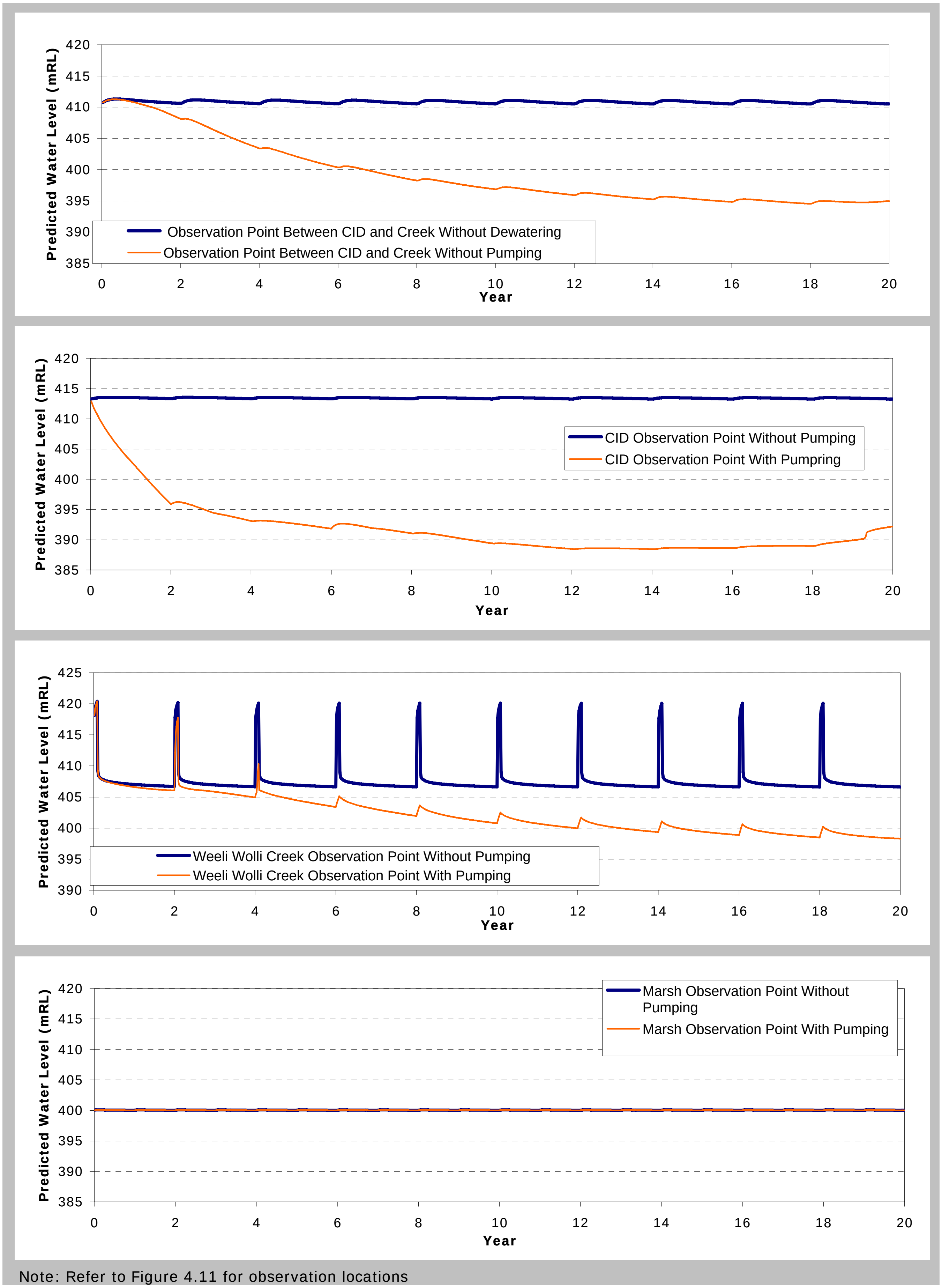
f:/jobs/832g/g7145a figs/145afig4.14a/srf



aquaterra

PREDICTED DRAWDOWN AFTER 15 & 20 YEARS FIGURE 4.14b

f:/jobs/832g/g7145a figs/145afig4.14b/srf



Note: Refer to Figure 4.11 for observation locations

PREDICTED WATER LEVELS WITH AND WITHOUT WATER SUPPLY PUMPING

FIGURE 4.15

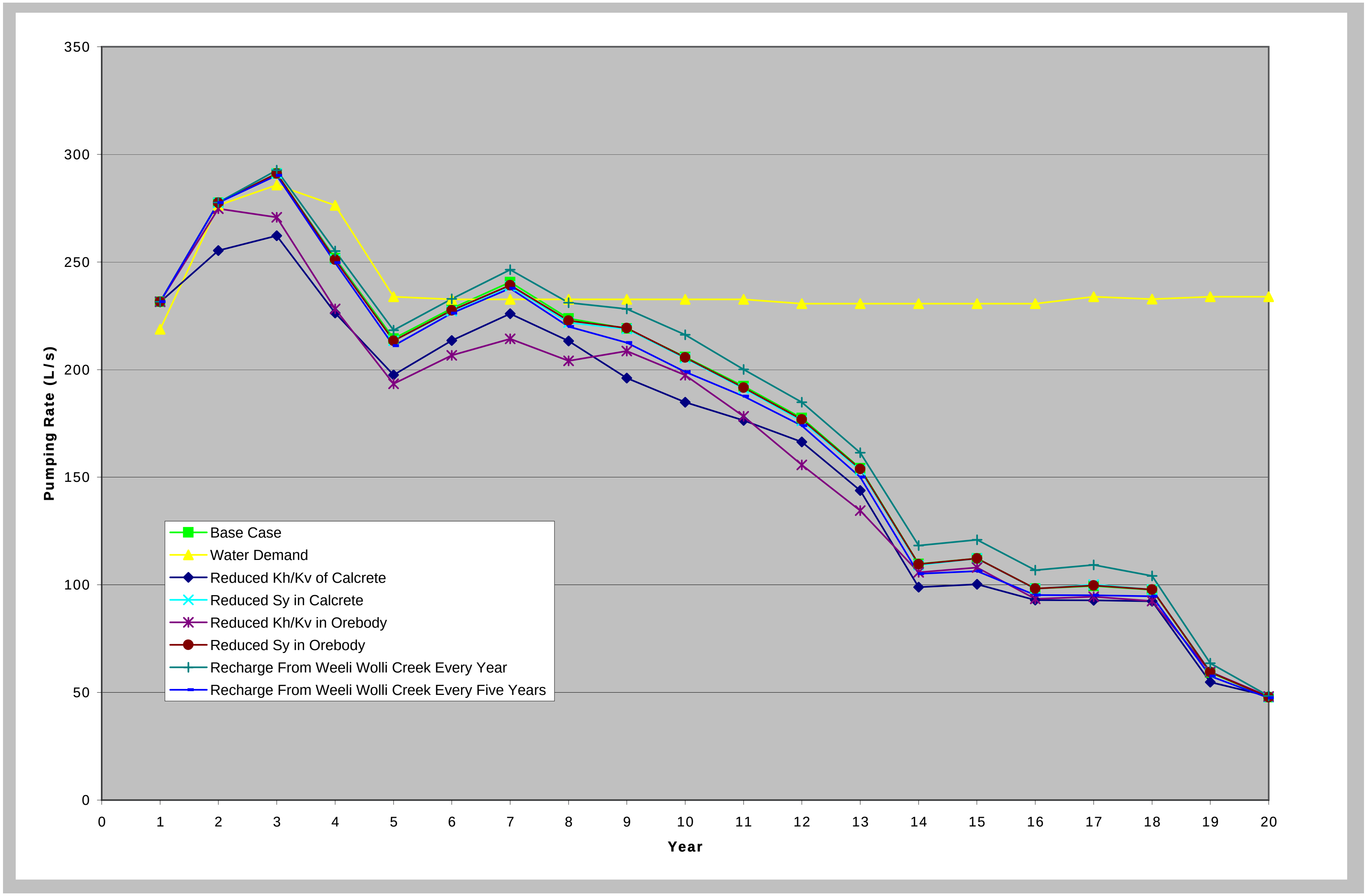
4.6 MODEL SENSITIVITY

While a reasonable calibration of the groundwater flow model has been achieved, there remains inherent uncertainty in the parameters adopted to describe the hydrogeological system and associated risks in the estimates of long-term sustainable yields owing to the absence of historical monitoring data. Sensitivity analysis has been conducted on the optimised model prediction (Case 2) to assess the uncertainty and risk. By adjusting parameter values to those lower than those adopted in the base case predictions (with the exception of increased recharge) provides further conservatism and provides a lower limit on predicted water supply potential. Details of the sensitivity runs, including a brief description of the results are outlined in Table 4.7.

Table 4.7: Summary of Sensitivity Runs

Sensitivity Run	Description	Sensitivity Ranking	Results
Run 1	Horizontal and Vertical Hydraulic Conductivity (Kh and Kv) values for the calcrete halved (from 6m/d and 0.6 m/d to 3m/d and 0.3m/d)	Equal 1st	Results equally most sensitive, in terms of total borefield yield, to this parameter change (along with Run 3). Borefield yield predicted to be up to 10% lower until Year 8 when compared to the base case
Run 2	Unconfined storage of calcrete aquifer halved (reduced from 0.05 to 0.025)	Equal 4th	Results not sensitive in terms of overall borefield yield, to this parameter change over the mine life
Run 3	Horizontal and Vertical Hydraulic Conductivity (Kh and Kv) values for the orebody aquifer halved (from 15m/d and 1.5 m/d to 7.5m/d and 0.75m/d)	Equal 1st	Results equally most sensitive, in terms of total borefield yield, to this parameter change (along with Run 1). Borefield yield predicted to be up to 10% lower until Year 8.
Run 4	Unconfined storage of orebody aquifer halved (reduced from 0.03 to 0.015)	Equal 4th	Results not significantly sensitive to this parameter change, in terms of total borefield yield over the mine life
Run 5	Recharge from Weeli Wolli Creek applied every year	2nd	Medium sensitivity of model results to this change. Predicted borefield yields increased by around 5% when compared to the base case
Run 6	Recharge from Weeli Wolli Creek applied every five years	3rd	Medium sensitivity of model results to this change. Predicted borefield yields decreased by less than 5% when compared to the base case

Predicted pumping rates for the sensitivity runs are presented in Figure 4.16 and suggest model predictions are most sensitive to changes in the hydraulic conductivity (both horizontal and vertical) of both the calcrete and CID with the greatest reduction in borefield yield predicted when these changes are made. A reduction in unconfined aquifer storage in both these hydrogeological units is predicted to result in less reduction in borefield yield that the adjustment in hydraulic conductivity. A reduction or increase in the frequency of recharge is predicted to have less impact (either increase or decrease) on borefield yield than the change in aquifer hydraulic conductivity, but more impact that the change in unconfined storage. All these changes, however, are predicted to result in an increase or decrease in annual borefield yield of less than 10%.



aquaterra

PREDICTED WATER SUPPLY / DEWATERING FIGURE 4.16

F:\Jobs\832G\G7 - DFS Reporting\145a_Figures\[145a_Figure4.9&4.12.xls]Fig4.15

4.7 CLOSURE PREDICTIONS

4.7.1 POST-CLOSURE GROUNDWATER LEVELS

The groundwater model was also used to predict the long term impact on water levels of the proposed in-pit fines rejects and waste rocks disposal scheme. As this prediction was completed to predict the final water levels that results from the proposed infill configuration outlined below, the prediction was completed under steady state conditions (ie no change in aquifer storage). The prediction was completed assuming:

- A backfill configuration consistent with the current conceptual backfill plan consisting of areas of fines rejects backfill and waste rock (Coffey, 2009).
- Aquifer parameters (horizontal and vertical hydraulic conductivity) for the waste rock of 1m/d, to allow for the variation in waste rocks and 0.001m/d for the fines rejects backfill material.
- That the mine path is backfilled to a level such that there is no potential for evaporative loss from mine void lakes (ie groundwater in the mine path does not daylight above the backfill).
- No enhanced rainfall recharge to the mine path that may occur due to the change in surface conditions.

Predicted water levels prior to development and after mining is complete are shown in Figure 4.16. Model results suggest that:

- Long-term changes in groundwater level are less than 3 metres.
- At the most upstream end of the mine path, predicted water levels are higher than the natural case, as groundwater flow is reduced consistent with the placement of tailings and waste rock of lower hydraulic conductivity than the existing orebody aquifer.
- At the downstream end of the mine path, due to the restriction in groundwater flow, predicted water levels are up to 3 metres lower.
- Further downstream, between the mine path and Fortescue Marsh, predicted water levels are not impacted by the proposed in pit waste rock and tailings scheme.

4.7.2 GROUNDWATER RECOVERY TIMES

The groundwater model was also used, with Modflow Surfact, to predict the time required for groundwater levels to return to pre-mining levels. This code, which is identical to Modflow adopted for the remainder of the groundwater modelling allows a more rigorous treatment of saturated and unsaturated groundwater conditions. Both the steady state calibration and a prediction run were completed using Modflow Surfact. The steady state calibration was unchanged from that described in Section 4.4. The prediction run however, assumed dewatering to the base of each mine panel, consistent with the current schedule. This dewatering was achieved using the Drain Package (DRN) in Modflow Surfact with the dewatering level set consistent with the base of the proposed mining panel and a conductance value of 1000m^2/d.

The recovery prediction was completed assuming:

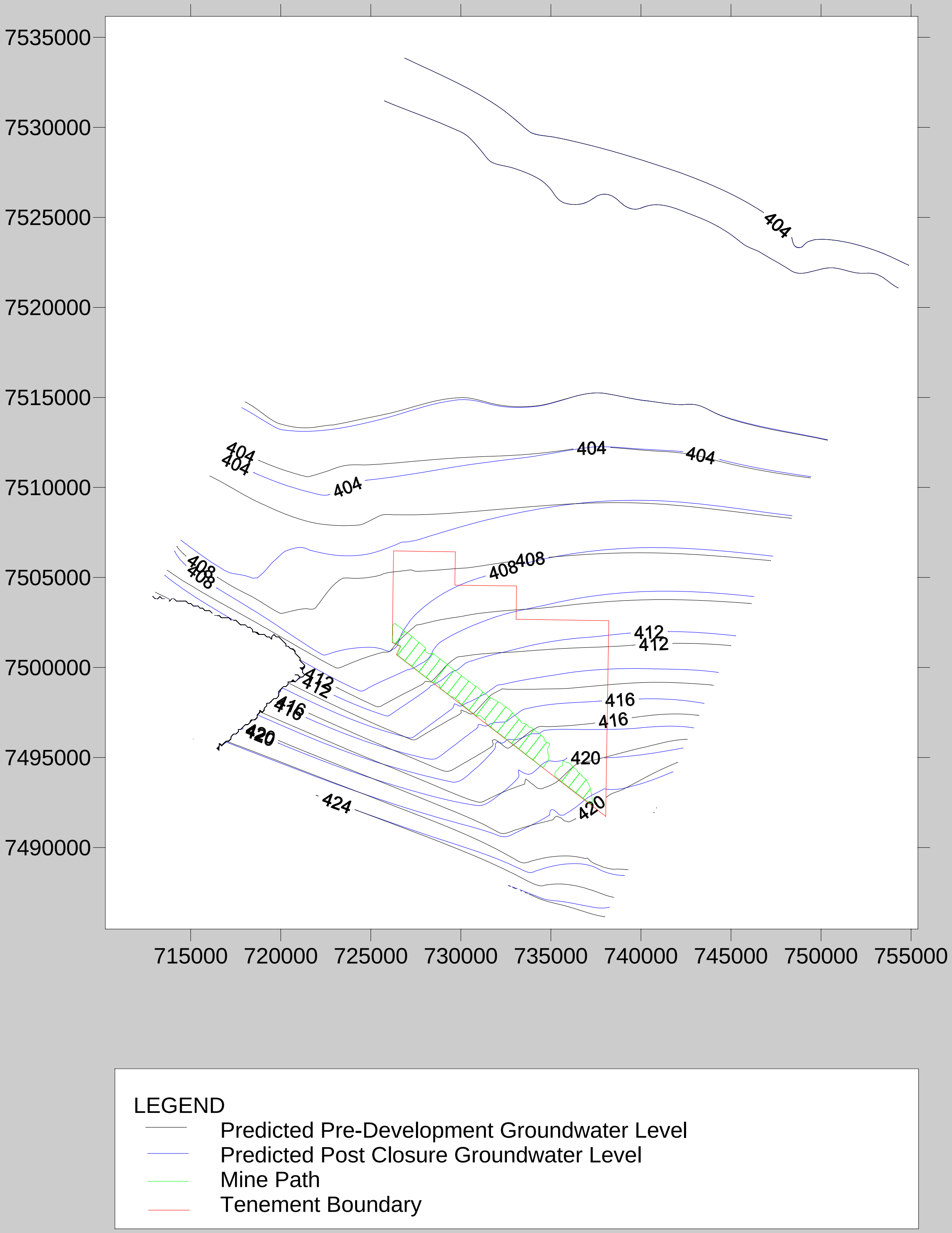
- Initial conditions from the end of the dewatering prediction run which assumed dewatering of all mining panels in sequence. This assumed some recovery of water levels in some panels prior to the end of projected mining.
- Infill levels in mined out panels are placed to above the pre-mining water table.
- A base case recharge of one month every two years.
- The backfill configuration consistent with the current conceptual backfill plan, with fines rejects and waste rock. Aquifer hydraulic conductivity values were 1m/d for waste rock material, and 0.001m/d for the fines rejects material.
- A specific yield of 3% adopted for the waste rock, and 1% for the fines rejects.

- No enhanced rainfall recharge to the mine path that may occur due to the change in surface conditions.

The modelling results suggest that:

- The depressed groundwater levels recover to 80% of their pre-mining levels in the first 50 years, although full recovery to pre development is predicted to take 120 years.

However, it is likely that the site will receive enhanced rainfall recharge to the mine path post-closure (due to the nature of the backfill strategy). Groundwater throughflow is this area is low, and recovery relies upon recharge events. Above-average rainfall events will therefore shorten the groundwater recovery period for the project.



aquaterra

PREDICTED PRE-DEVELOPMENT & POST-CLOSURE GROUNDWATER LEVELS

FIGURE 4.17

f:/jobs/832G/G7/145a_Figures/fig4.17.srf

4.8 MODEL LIMITATIONS

The groundwater flow model has been developed with data limitations in mind, ie no time series data, and is of a complexity that is consistent with the available data. The model is calibrated to the available data and fit for the purpose of predicting the feasibility of a long-term water supply and dewatering infrastructure requirements at pre feasibility. The potential impacts of the development on the hydrological system are readily identified from the model output.

As with all models, there are limitations associated with the data availability, conceptualisation, and representation of dynamic flow processes. Although the model includes the known essential features of the hydrogeological system, and is calibrated to available data, the predictions are simulations based on the best available knowledge and techniques, and should not be regarded as matters of fact. Modelling has consistently adopted a conservative position with respect to the data limitations, with “worst-case” assumptions made in many instances where actual data is unavailable. The model should be refined as additional data becomes available (specifically time series water level and rainfall events) and dewatering predictions up-dated in the fullness of time.

The following list of limitations identifies areas where the model features and/or data availability could be improved during future work programmes:

- With additional field investigation programmes and construction phase of the project, further hydrogeological information will be available, and should be used to test and improve the reliability of the conceptual model. This detail should then be incorporated into groundwater model.
- To date no long term groundwater monitoring data are available to calibrate the model to transient or seasonally varying groundwater conditions. This data when available can be used to calibrate the model and provide greater confidence in model predictions.
- There is no substantial pumping stress on the system that could be used to calibrate the model. Dewatering abstractions (i.e. pumping from the orebody aquifer) are required, along with monitoring data, to assess the model validity for the purpose of predicting the long term dewatering impacts. Recalibration of the model and re-simulation of dewatering predictions should be undertaken as operational dewatering data is obtained.
- Currently the model assumes groundwater inflow from the south east consistent with the groundwater system associated with Weeli Wolli Creek. While this flow system is well understood further upstream, there still remains uncertainty in the behaviour of the flow system as it is defined by the current south eastern model boundary. It is possible that the flow processes associated with this boundary would be better simulated if the current model boundary was extended further south and/or southeast.
- The Marillana development is situated in a region where significant groundwater development is ongoing and will continue into the future. It is likely that the current development may need to be considered in conjunction with other development in the region, including dewatering, reinjection and dewatering discharge at Rio Tinto Iron Ore’s existing Yandi and Hope Downs operations and other developments planned for the future. This would best be addressed using a regional groundwater model; however the exact nature of this modelling could only be defined once requirements from regulators (Department of Water) are clearly defined.

5 MAR OPTIONS ASSESSMENT

5.1 BACKGROUND

The Marillana project's dewatering requirements are anticipated to generate a surplus of water (above forecast water demands) for the first three years of operations. It is projected that the site will be "water neutral" from year 4 to year 9, i.e., that dewatering production will equal water demands and thus there will be no surplus or shortfall. Beyond year 9 of the project, decreasing dewatering volumes are no longer able to meet the site water demand requirements, and supplementary water supply is required. Table 5.1 shows the projected site water balance for the life of mining.

Managed Aquifer Recharge (MAR) is being considered to manage the surplus water volumes in the first few years of operations to efficiently utilise the groundwater resource that is available at the project. The predicted surplus volumes are 100L/s in year 1, 80L/s in year 2, 50L/s in year 3, then "water neutral" in year 4. Therefore any MAR option is only required for a relatively short duration.

The MAR options assessment objectives are to:

- Achieve a "proof-of-concept" technical justification for selected MAR options.
- Assess the potential impacts that MAR might have to environmental and operational considerations.
- The outcomes of the above assessment would inform the groundwater management plan and contingency actions that best achieve the requirements at this site.
- Provide enough detail to Brockman to make a balanced and informed decision on the preferred MAR option to be carried forward in future studies.

These objectives have been achieved through the following work:

- An options assessment, outlining the details relating to each option. This includes spatial requirements and relative capital and operating costs.
- Numerical groundwater modelling of the options to assess technical viability and impacts to the environment and operations.

Table 5.1: Preliminary Site Water Balance - Life of Mine

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Water Demand (L/s)	220	280	280	280	230	230	230	230	230	230
Dewatering (L/s)	320	360	330	280	230	230	230	230	230	210
Surplus / Shortfall (L/s)	100	80	50	0	0	0	0	0	0	-20
Year (continued)	11	12	13	14	15	16	17	18	19	20
Water Demand (L/s)	230	230	230	230	230	230	230	230	230	230
Dewatering (L/s)	190	180	160	120	120	100	100	100	60	50
Surplus / Shortfall (L/s)	-40	-50	-70	-110	-110	-130	-130	-130	-170	-180

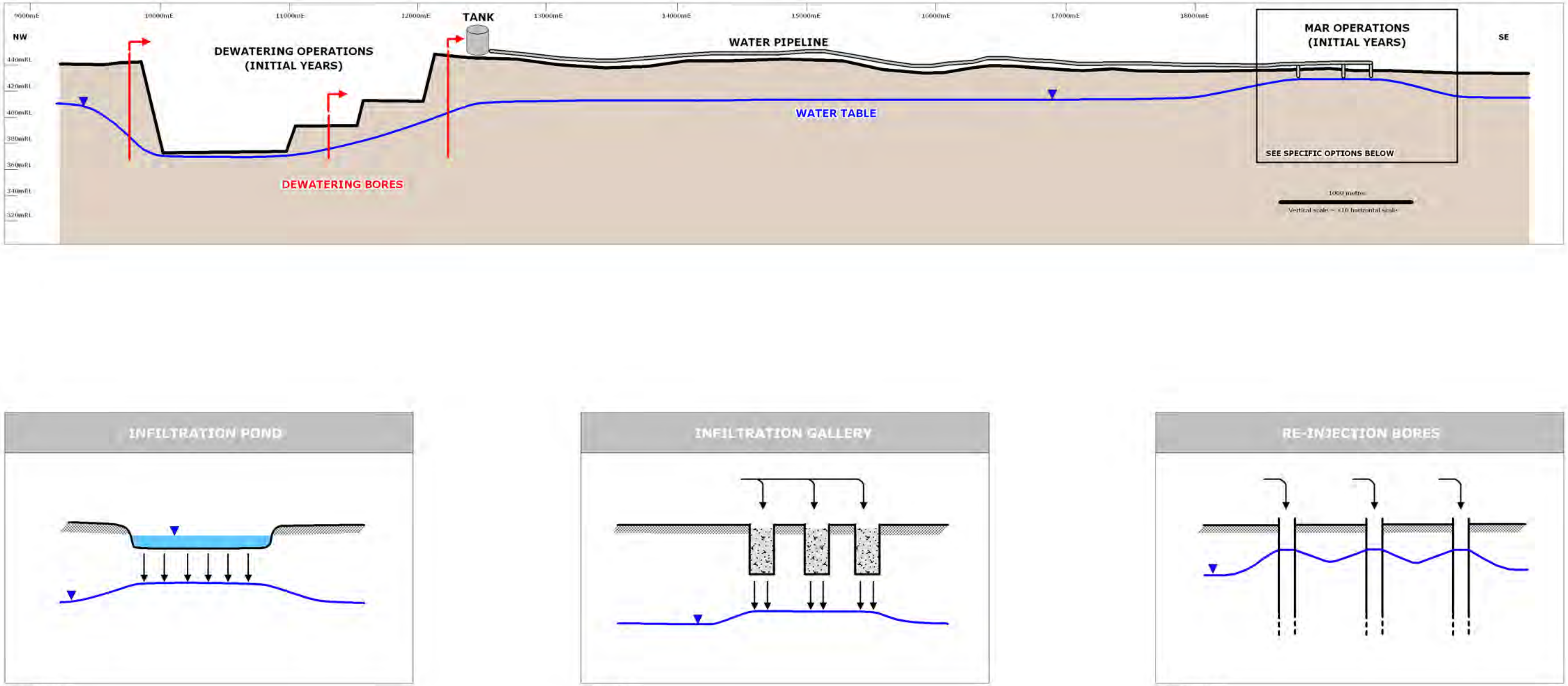
5.2 APPROACH

5.2.1 BASIS OF APPROACH

Options to manage the surplus water in the first few years of operation were developed after addressing the preferred options as outlined in the Department of Water's hierarchy of water disposal options (DoW, 2009) within the context of project-specific considerations, in particular the local hydrogeological environment, the operating environment, and the preference to preserve surplus water for future use. The outcomes of this approach are outlined below in Table 5.2.

Table 5.2: Hierarchy of Disposal Options: Assessment for Marillana Project

Ranking	Preferred Option (DoW hierarchy)	Project-Specific Assessment
1	▼ Efficient on-site use, including mitigation of any impacts	▼ The site water demand has considered and implemented efficient on-site use, and the adoption of MAR will mitigate the effects of drawdown impacts in the vicinity of recharge
2	▼ Used for fit-for-purpose activities (such as processing and dust suppression). The proponent needs to demonstrate that the water is of suitable quality for the end use	▼ The existing site water balance already accounts for processing and dust suppression as suitable uses for the fresh to brackish water, so the existing short-term surplus is not able to be utilised it this way
3	▼ Transferred to meet other demand, including other proponents in the area, as approved by the DoW	▼ Due to the relatively isolated location of this project, combined with the relatively short timeframe that surplus water is anticipated, it is not feasible to transfer this water for off-site use. Also, due to a shortfall later in mine life, preference is given to storing the water on site for later utilisation
4	▼ Injection back into the aquifer at designated sites determined by the proponent and agreed by the DoW	▼ MAR was the preferred option to manage the anticipated short-term surplus water, as a measure that utilises the water resource effectively, allowing Brockman to draw upon it during later stages of mining, when water demand is anticipated to exceed supply
5	▼ Controlled release to the environment where the dewater release is allowed to flow (either through a pipe or overland) into a designated watercourse or wetland determined by the proponent and agreed by the DoW	▼ Will not be undertaken at the Project



OPTION A

OPTION B

OPTION C

aquaterra

AUTHOR:	DJ
DRAWN:	MS
DATE:	03/02/2010
JOB NO:	832I
REPORT NO:	145e
REVISION:	a

F:\Jobs\832I\Mapinfo\Figures\Figure 5.1.wor

FIGURE 5.1

MARILLANA PROJECT
CONCEPTUAL MANAGED AQUIFER RECHARGE OPTIONS
NATIONAL SYSTEM ARRANGEMENT

5.3 MAR OPTIONS

5.3.1 CONCEPT

Managed Aquifer Recharge (MAR) is a water resource management technique by which water is recharged to a suitable aquifer during periods of surplus. Where conditions are appropriate for MAR, the technique is generally endorsed by water resource and environmental managers as being both effective and environmentally superior to the alternative of solely surface water storage/discharge.

The critical hydrogeological requirements of the receiving aquifer are that it must be sufficiently permeable to accept the recharge volumes/rates, and it must have sufficient available storage capacity to allow recharge to be sustainable for the required period of time. In this case, the volumes are manageable, and the duration is only a few years

Various methods of recharging an aquifer may be employed, the most appropriate being governed by site specific conditions. Methods include infiltration basins and spreading grounds, recharge trenches and pits/shafts, and injection wells (that can be either pressurised or gravity-driven). Three methods under consideration at the Marillana project are listed here and presented in Figure 5.1:

- Infiltration pond.
- Infiltration galleries.
- Re-injection Bores.

5.3.2 KEY ISSUES FOR MAR

Factors that may affect the feasibility of a MAR project include:

- The availability of permeable geological units at an appropriate depth to accept artificial recharge (in the case of Marillana, the most obvious target would be the Tertiary CID and overlying detrital sequence).
- The ability of potential aquifers to accept additional recharge, largely governed by the difference in pressure between the receiving formation and the pressure developed by the injection system (at Marillana, up to 30m of gravity driven pressure head is available).
- The presence of geological features that may be activated by an increase in aquifer pressure caused by reinjection, including such things as faults and slope stability issues (not anticipated to be an issue at Marillana).
- Assessment of the quality of the injected water and the receiving formation water. At Marillana, the water qualities are expected to be essentially the same, and no aquifer degradation or chemical reactions are anticipated (although this may require further site investigations).
- The presence of other groundwater users that may be affected by the MAR scheme (there are no competing groundwater users in the areas that may be affected near Marillana).
- The anticipated flow-path and time of the recharged water (for example, if after only a short period of time, the MAR scheme results in substantial increases in the dewatering requirements at the downstream mine, then the costs may outweigh the benefits. In this case, modelling is being undertaken to assess this).
- The regulatory and political environment associated with the approval process.

Specific Issues for Re-injection

Additional factors may affect the ongoing operation of a re-injection scheme and result in the need for pre-treatment of the water, and ongoing maintenance of any injection wells, including:

- Suspended sediment in the injection water could cause clogging of the injection well and aquifer. This may result in the need for pre-treatment and frequent maintenance of the injection wells. However, the water abstracted from dewatering bores should contain few suspended sediments, though this may not be the case from sumps.

- Aeration of the water during the injection process can result in entrained air in the formation, reducing injection rates.
- Microbiological growth may inhibit the formation permeability, reducing injection rates. Such growth may be stimulated by many factors including oxygenation, sunlight and several biochemical reactions.
- Temperature differences between the injection water and the formation water can both inhibit and enhance injection rates.
- The injection well design should maximise the permeability of the well / receiving formation interface, and minimise ongoing maintenance requirements.

5.3.3 ADVANTAGES OF MAR

The advantages of Managed Aquifer Recharge into the Marillana orebody include:

- Limit surface discharge to the sensitive creek ecosystem, and prevent the establishment of a 'water discharge' dependent ecosystem flora.
- Mitigate the extent of the cone of depression in the Weeli Wolli creek area resulting from drawdown impact associated with Marillana dewatering activities.
- Bank the water for potential future redraw.

5.3.4 GENERAL SCHEME DESCRIPTION

It is currently planned that mining of the 14km long orebody will commence at the north western end, and proceed to the southeast over the projected 20 year mine life. Dewatering surplus is expected in the first three years of operation, and mining operations will be in the northwest of the project area at this time. Therefore, the selected MAR option will be located at the southeast end of the project area, at a location that will minimise recirculation of surplus water through dewatering operations. All three options would require the installation of a water delivery system from the dewatering borefield to the location of the MAR system, and would be located on the footprint of the future mining development.

5.3.5 COMMON DESIGN ELEMENTS

The key common design elements that are required for all three MAR options being considered are:

- A water pipeline to deliver water from the dewatering operations area to the MAR operations area.
- To minimise siltation and clogging and maximise efficiencies, all water intended for MAR will be sourced from dewatering bores, and not from sumps, to ensure sediment-free water is utilised in the system.
- MAR location selection will consider the potential for interference between individual bores or galleries, along with assessing the potential for recirculation of recharged groundwater with dewatering.
- It should be noted that any such infrastructure could be utilised in later mine life to deliver water back to the processing plant from dewatering operations in the southeast of the orebody; and could also deliver water from a third party off-take if off-site infrastructure brought it to the southeast of the tenement.

5.3.6 INFILTRATION POND

Description

An infiltration pond is excavated in the ground, and retains the recharge water until it has infiltrated through the floor of the basin. In locations where the soil material is fine, a covering of sands and gravels can aid infiltration and delay clogging of the floor of the pond, therefore extending the recharge periods and efficiency of the facility. The area of land available for an infiltration pond and the infiltration rate determines the volume of recharge achievable.

The dimensions of the infiltration pond required to handle the volumes of water anticipated in the first few years of operations is currently estimated at 500m long, 500m wide, and a few metres deep. The actual dimensions will be dependent upon ground conditions, particularly the permeability of the material in the base of the pond, which will be a controlling factor of the infiltration rate possible.

In terms of achieving easy access for maintenance of the infiltration pond floor, a design consideration may be to construct the pond with several internal cells, which will therefore allow access for heavy machinery to scrape the pond floor of a cell, while maintaining use of the facility for surplus water disposal.

Pros

- Double-ring infiltrometer testing at similar locations in the greater Fortescue valley area indicate favourable infiltration rates can be expected for such pond disposal (Adam Pratt, SWC, pers. comm. 2010).
- In the event of clogging, the base of the infiltration pond can be mechanically scraped to remove any filter skins that may have developed over time, which is a simple solution that keeps the pond operating efficiently.
- Any excavation for the infiltration pond could be considered a pre-strip for future planned mining in the southeast of the orebody, so equates to expenditure brought forward in the financial modelling, as opposed to additional spending above what is already planned.

Cons

- The large area that an infiltration pond would cover is a drawback for a project with infrastructure already condensed due to spatial restrictions, and therefore needs to be considering in light of overall project infrastructure decisions.
- Due to the large surface area of ponded water, there will be a degree of water loss via evaporation processes, so it is therefore not the most water efficient means of MAR.

5.3.7 INFILTRATION GALLERIES

Description

An infiltration gallery is excavated in the ground, and retains recharge water until it has infiltrated through the floor of the gallery. Typically, galleries are excavated narrow and long, a few metres in depth. In particular with this location, these may be able to be excavated deeper than an infiltration pond, with the intention of intersecting more permeable formations. Depending on the stability of the formation, they may be lined with geo-textile fabric before being filled with gravel/blue-metal. Water can either be added at a single point, or via a pipe system over the length of the trench.

The dimensions of the infiltration galleries required to handle the volumes of water anticipated in the first few years of operations is estimated at up to four trenches, each 500m long, 5m wide, and 5m deep. The actual dimensions will be dependent upon ground conditions, particularly the permeability of the material in the base of the galleries, which will be a controlling factor of the infiltration rate possible.

Pros

- If permeable soil horizons were deeper below the surface than suitable for an infiltration pond to be constructed, the galleries are able to be achieve greater depths to intersect suitable ground, while not requiring excessive excavation.

Cons

- The large area that a infiltration galleries would require is a drawback for a project with infrastructure already condensed due to spatial restrictions, and therefore needs to be considering in light of overall project infrastructure decisions.
- Difficulties in maintenance due to the construction style of the galleries.

5.3.8 RE-INJECTION BORES

Description

Re-injection bores are constructed as per dewatering bores, screened across the target re-injection aquifer. The surplus water is injected via suitably designed pipes and headworks into the bores to be stored in the aquifer.

It is expected that four re-injection bores will initially be required, with 25L/s being re-injected into individual bores. As surplus water volumes decrease, fewer re-injection bores will be required to operate.

Pros

- The re-injection bore infrastructure is able to be located in future dewatering locations. This will allow for the bores to be utilised as abstraction boreholes later in the mine life, and will mean only minor alterations to water piping infrastructure will be required. It also means that existing bore costs can be brought forward, as opposed to additional capital being required.
- The minor space requirements of re-injection bores means that this infrastructure will not intrude upon other project infrastructure space requirements.

Cons

- Regular maintenance is required to sustain injection well efficiencies.

5.3.9 COMPARATIVE ANALYSIS

CAPEX

The capital expenditure for each option ranges from $1M to $3M, although these capital expenditures could perhaps be assessed as existing deferred capital expenditure brought forward to the commencement of the project. In the case of the infiltration pond, the excavation works can be considered pre-strip for future mining. While the installation of re-injection bores could be considered the early instalment of future dewatering infrastructure.

All of the above costs exclude the cost of the water delivery pipeline, as for the purpose of comparison the water delivery pipeline would be virtually identical in all three options. The water pipeline may also be considered an early installation of the future water pipeline to deliver supplementary water supply back to the processing facilities beyond year 9 of operations (when potential third-party infrastructure to the project would be installed).

OPEX

The operating expenditure for these options are wide-ranging, with the infiltration pond being the lowest maintenance, perhaps requiring an occasional scraping of the pond floor to remove any clogging films that may have developed.

The infiltration galleries will require moderate maintenance, with their more intricate design making for more complex de-clogging activities. Access to the surfaces requiring maintenance may be difficult, and it may therefore be easier to construct replacement galleries nearby.

The re-injection bores will require moderate to high maintenance to ensure they are efficient and effective. Redevelopment of these bores may be required regularly, although this will be dependent on such things as sediment load in the water and chemical precipitation. Other specific design aspects can assist in simplifying the maintenance process.

Spatial Requirements

It is noted that the spatial requirements of the three MAR options varies drastically, with the infiltration pond option requiring approximately 250,000m^2, while the infiltration galleries require a fraction of that area, with 10,000m^2 estimated. Re-injection bores will require virtually no space, and would likely be located at future dewatering locations.

Table 5.3: MAR Options Summary Table: Comparative Analysis

Option	CAPEX	OPEX	Spatial Requirements*
Infiltration Pond	$3M	Moderate	250,000 m^2
Infiltration Galleries	$1M	Moderate	10,000 m^2
Re-injection Bores	$1M	High	Virtually Nil

* All options will also require a water delivery pipeline corridor from the dewatering operations to the MAR site

5.4 NUMERICAL MODELLING

5.4.1 SET-UP

The calibrated model was used to predict the water level impact of the three MAR strategies outlined in this Section. The location adopted for the three scenarios described below was Abalone East. This location was chosen at it is greatest distance from active dewatering during the early years of mining where there is predicted to be a surplus of water (ie dewatering requirements exceed water supply requirements). Predictive modelling as outlined in Section 4 suggests that there will be an excess for the first three years of mining. Each MAR strategy was modelled for a period of six years to allow for any measurable recirculation effects in the dewatering volumes to be assessed.

Each MAR strategy was based on the base case water supply prediction outlined in Section 4. This scenario predicted a surplus of water of 100L/s in year 1, 80L/s in year 2 and 50L/s in year 3. Recharge for each MAR strategy was modelling at these rates for the first three years with no recharge adopted for the remaining three years.

For each MAR scenario a number of observation points were included to observe the predicted groundwater levels with time resulting from each MAR option. These are located in the immediate MAR strategy area as well as 500 metres southeast and northwest of the MAR system. The location of these observation points is shown in Figure 5.2.

Please note that for the case of the infiltration pond and the infiltration galleries, dewatering surplus is assumed to recharge the water table directly. As such no time is allowed for infiltration time or a wetting front to be developed. This represents the worse case in terms of water level increase and potential for recirculation as the greatest surplus of water is predicted during the first three years of mine life. However, it also means that the infiltration process has not been modelled. Understanding the long-term infiltration rate will require further work to confirm this is not a limitation on scheme operation.

5.4.2 SCENARIOS

Option A – Infiltration Pond

- Surplus dewatering was applied to an infiltration pond as recharge for the first three years of mine life.
- The infiltration pond was assigned an area 250,000m2. The pond location and extent is shown in Figure 5.2.
- Recharge to the infiltration pond was assigned evenly over the pond area at the rates outlined in Section 5.4.1 consistent with the surplus water available.
- No allowance was made for any system of evaporative losses.
- No recharge was applied to the infiltration pond for years 4 to 6 of mine life.

Option B – Infiltration Galleries

- Surplus dewatering was applied to four drainage galleries as recharge for the first three years of mine life.
- The infiltration gallery locations and extents are shown in Figure 5.2. Each gallery was assigned an area of 5,000m^2, resulting in a total infiltration area of 100,000m^2.

- It is noted here, that due to the minimum model cell-size of 50m x 50m, a trench of 5m width could not be simulated, and the minimum possible 50m width was assumed for modelling purposes.
- Recharge was applied evenly to all four galleries for a period of three years at the rates outlined in Section 5.4.1.
- No allowance was made for any system losses. Minimal evaporative losses are expected due to the construction of the drainage galleries below surface (refer Figure 5.1).
- No recharge was applied to the infiltration galleries for years 4 to 6 of mine life.

Option C – Re-Injection Bores

- Surplus dewatering was applied to reinjection bores for the first three years of mine life.
- Re-injection bores were spaced 500 metres apart and assigned a maximum injection rate of 25L/s each.
- Consistent with the projected water surplus, four bores were assumed to operate during year 1, three bores in year 2 and two bores in year 3.
- No allowance was made for any system losses.
- The injection pressure required to operate injection bores was not included during the prediction.

5.4.3 RESULTS

The location of the modelled observation points, along with the water level contours after two years of mining, when the maximum groundwater level rise is predicted, are shown in Figure 5.2. Hydrographs of predicted water levels at modelled observation points are shown in Figure 5.3. Modelling results indicate that:

- The predicted water level increases for Options A and B are almost identical, with a maximum increase in water level of around 16m (to ~5mbgl) at the MAR location (i.e., at observation point 2). The predicted water level rise is 7m (to ~14mbgl) approximately 500m east of the MAR location (i.e. at observation point 3) and 6m (to ~15mbgl) approximately 500m west of MAR location.
- The predicted water level increase for Option C is 11m (to ~10mbgl) at the centre of the borefield (i.e. at observation point 2). The water level increase is 7m (to ~14mbgl) approximately 500m east of the centre of the re-injection borefield (i.e. at observation point 3), and 5m (to ~16mbgl) approximately 500m west of the re-injection borefield.

The hydrograph responses for the three scenarios (Figure 5.3) show that the maximum predicted water levels at these locations is approximately two years after the commencement of MAR operation. For all three cases considered, predicted water levels remain below ground surface level and are between 5 and 10m below ground level.

The observed response in all three scenarios of mounding being lower on the western side of the MAR operations is consistent with the location of the dewatering operations to the northwest of the MAR, and the minor recirculation effects observed in the dewatering volumes pumped.

Maximum predicted water level responses are shown in Table 5.5.

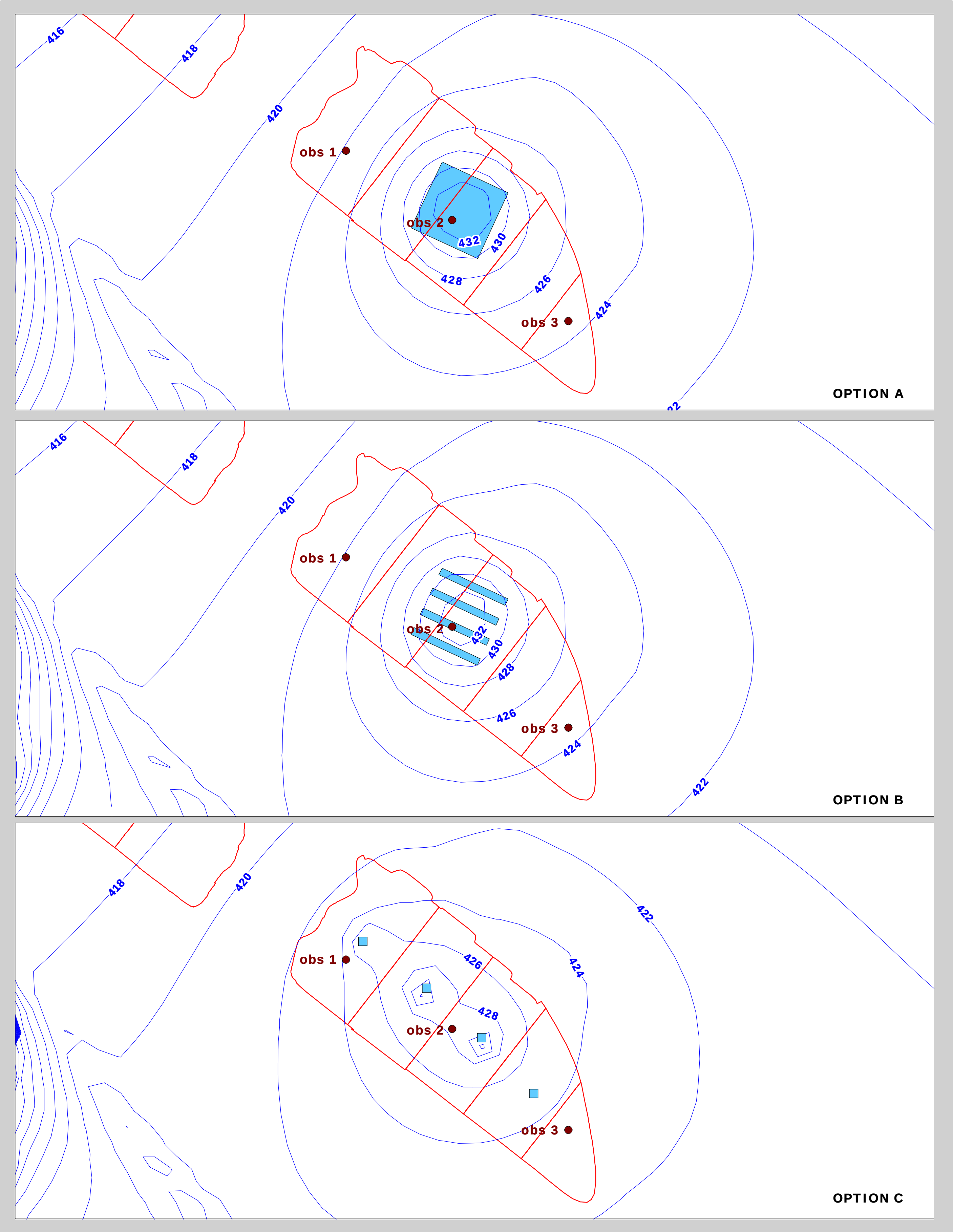
Table 5.5: Predicted Peak Groundwater Mounding Levels

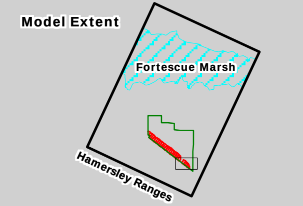
	A: Pond (mbgl)	B: Galleries (mbgl)	C: Bores (mbgl)
West of MAR (obs 1)	15	15	16
Beneath the MAR (obs 2)	5	5	10
East of MAR (obs 3)	14	14	14

The MAR modelling scenarios predict that groundwater mounding occurs up to 5mbgl, and tends to be localised to the vicinity of the MAR operations, as can be observed in the predicted groundwater contour levels (see Figure 5.2). Also, the hydrographs of predicted groundwater levels (Figure 5.3) suggest that the groundwater mounding effects of the MAR are relatively short-lived, with groundwater levels 500m to the west of the MAR system returning to pre-mining levels a few months after MAR operations cease, while taking approximately 2 years to return to pre-mining levels 500m to the east of the MAR system.

Modelling predictions to date indicate that MAR has an impact on water levels during operation and shortly after the end of operation, after which time, the long-term dewatering operations result in regional drawdown and mitigate any longer term impacts of MAR.

Predicted dewatering rates for Options A, B and C and the base case are shown in Figure 5.3, and summarised in Table 5.4. Prediction results suggest some minor recirculation due to MAR for the three cases. The maximum predicted increase in dewatering is less than 3%.





AUTHOR:	AN
DRAWN:	MS
DATE:	04/02/2010
JOB NO:	832I
REPORT NO:	145e
REVISION:	a
PROJECTION:	GDA94, Z50
SCALE:	1:35,000

0 500 1000m

FIGURE 5.2

MARILLANA PROJECT

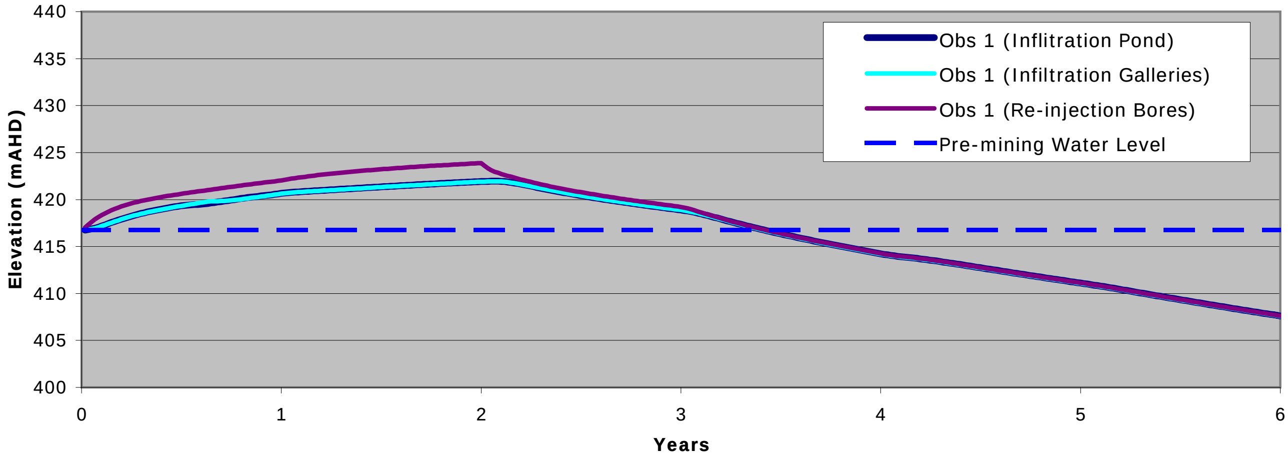
MODELLED MAR SCENARIOS:

PREDICTED WATER LEVEL CONTOURS

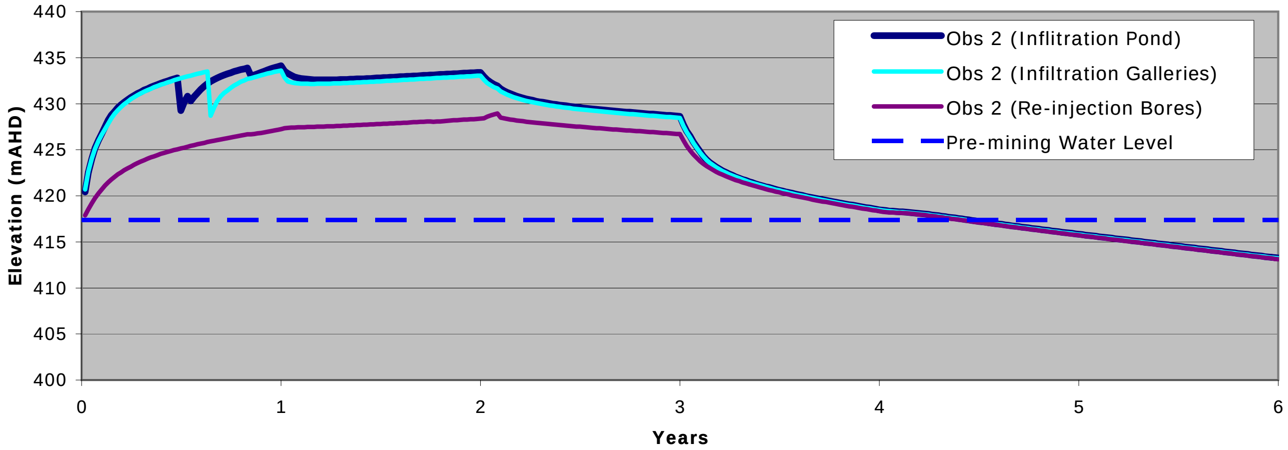
LEGEND

- ■ Infiltration Bores
- ● Modelled Observation Points
- — Water Level 2m Countours
- — Mine Panels
- ▬ Recharge Galleries
- ■ Recharge Pond

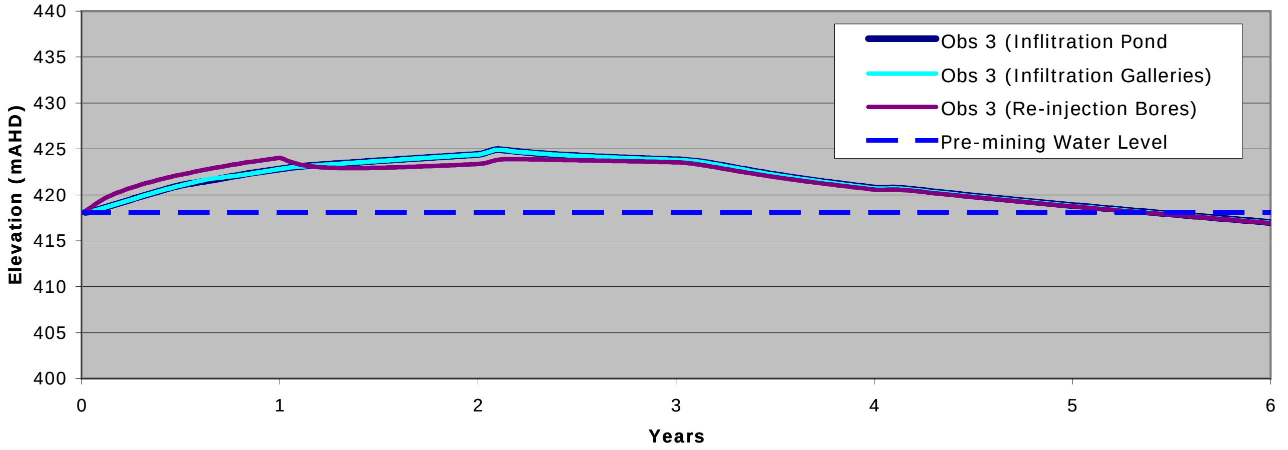
Location: F:\Jobs\832I\Mapinfo\Figures\Figure 5.2.wor



Observation Point 1 (West of MAR)



Observation Point 2 (Central to MAR)



Observation Point 3 (East of MAR)

aquaterra

MODELLED MAR SCENARIOS HYDROGRAPHS OF PREDICTED WATER LEVELS

FIGURE 5.3

F:\Jobs\832I\I2 - GW Modelling\Model Results\[MODELLED MAR SCENARIOS HYDROGRAPHS OF PREDICTED WATER LEVELS FIGURE 5.3.xls]Fig Hydrographs

Table 5.4: Predicted Pumping Rates - Base Case versus All Scenarios

Year	Base Case (L/s)	Option A (L/s)	% Increase	Option B (L/s)	% Increase	Option C (L/s)	% Increase
1	230	230		230		230	
2	280	280		280		280	
3	330	330		330		330	
4	295	300	1.0	300	1.0	300	1.0
5	260	270	2.5	270	2.5	270	2.5
6	260	270	2.5	270	2.5	270	2.5

5.4.4 ADDITIONAL MODEL PREDICTIONS

Two additional prediction runs were completed to assess the impact of a different MAR location (Option D) and increased rates of water disposal (Option E) as outlined below:

Option D

- The recharge pond was located in the more centrally to the mine path, approximately 4.5km west of the Abalone East location.
- All other prediction details were unchanged from Option A (the previous infiltration pond prediction run).
- Hydrographs of predicted water levels at modelled observation points it are shown in Figures F3 (Appendix F). The location centrally location infiltration pond and modelled observation points, along with the water level contours after one year of mining, at the time of maximum predicted water levels rise, are shown in Figure F4 (Appendix F).

The results suggest that the maximum increase rise in water level of 7m (to ~14mbgl) is predicted one year into mine life in the vicinity of the infiltration pond (i.e, at observation point 2). The predicted water level increase is 2m (to ~19mbgl) approximately 500m west of recharge pond (i.e. at observation point 1), and 4m (~17mbgl) approximately 500m east of the infiltration pond (i.e, at observation point 3). The modelled dewatering rates for the original base case, along with the Option A scenario and Option D are shown in Figure F3 (Appendix F). Predicted recirculation of recharged water is a maximum of 7.5% of predicted dewatering rates. As expected, locating the infiltration pond closer to active dewatering has increased the predicted amount of recirculation due to MAR.

Table 5.6: Predicted Pumping Rates - Option A and Option D

Year	Base Case (L/s)	Option A (L/s)	% Increase	Option D (L/s)	% Increase
1	230	230	-	230	-
2	280	280	-	280	-
3	330	330	-	340	3.0
4	295	300	1.0	315	6.0
5	260	270	2.5	285	7.5
6	260	270	2.5	280	6.0

Option E

- Total injection rates to a proposed re-injection borefield were increased to 200L/s, 160L/s and 100 L/s for years 1, 2 and 3 respectively of mine life.
- All other prediction details were unchanged from option C.

- Hydrographs of the predicted water levels at the modelled observation points are shown in Figure F5 (Appendix F). The location of the modelled observation bores, along with the water level contours after two years of MAR at the time of maximum water level increase are shown in Figure F6 (Appendix F). The results suggest that the maximum predicted increase in water level is 20m (to ~1mbgl) at the centre of borefield (i.e, at observation point 2). The water level rise is 14m (to ~7mbgl) approximately 500m east of the MAR (i.e, observation point 3), and 11m (to ~10mbgl) approximately 500m west (i.e., at observation point 1). The modelled dewatering rates for Option C and Option E are shown in Figure-F5 (Appendix F) and suggest that the recirculation results in additional dewatering requirement of around 6%.

5.5 PREFERRED MAR OPTION

5.5.1 BASIS FOR PREFERRED OPTION

On the basis of the current understanding at the project, and preliminary cost assessment, a re-injection borefield is the preferred option for undertaking MAR at the project. The groundwater modelling indicates that the groundwater mounding is least with this option, and that the groundwater mound is a short-term feature that is mitigated by ongoing dewatering operations.

From a cost basis, the re-injection bore infrastructure is able to be utilised later in the mine life as dewatering infrastructure. It is acknowledged that re-injection borefields require significant maintenance, however, ongoing investigations and design work will seek to optimise the efficiency of the system, and therefore minimise maintenance requirements.

5.5.2 SCHEME DESCRIPTION

Currently it is assumed a re-injection borefield of four bores would be installed at a location distant from dewatering operations and within the defined orebody. The location is selected on the basis of the mine plans, particularly the first few years of mining. Currently this indicates that Abalone East, the southeastern end of the orebody, is the site for the MAR operations. Currently, the notional design is four bores, spaced 500m apart, with each bore re-injecting ~25L/s. This means that in year 1, four bores will be operational; in year 2, three bores will be operational; and in year 3, two bores will be operational. It is likely that extra re-injection capacity will be installed, allowing for the rotation of re-injection duties and cyclical maintenance of standby bores.

It should be noted that optimisation of the scheme particulars, including final location, the number of bores, and bore spacing, will be undertaken as part of ongoing investigations. Optimising the distance from the dewatering operations is particularly important, as this will control the amount of water pipeline infrastructure required for system installation, and therefore impacting on capital and operational expenditure.

It is noted that in the event that long-term sustainable re-injection rates are lower than currently projected, a larger re-injection borefield would be required to adequately recharge the surplus volumes.

5.5.3 CONTINGENCY

Contingency planning to cover both short-term maintenance requirements and the possibility (unlikely though it is) that surplus water volumes are larger than predicted include the following elements (Further detail is supplied in the Appendix A Groundwater Management Plan):

- Data from detailed monitoring will be used to validate the groundwater model and expected surplus volumes. In this way, any additional dewatering surplus discharge requirements will be identified early which will allow for the timely planning of the contingency items listed below.
- The start-up injection borefield will include five injection bores (NB these bores will be located in target locations for future dewatering bores and will eventually be used for dewatering beyond year 3). Only four bores (operating efficiently) are required to accommodate the predicted dewatering surplus and the fifth bore will be used rotationally to allow for regular borefield maintenance. If ongoing operational data (and ongoing groundwater modelling) indicate the need for additional injection bores, these will be installed, again at locations targeted for future dewatering bores.

- Investigation work completed elsewhere in the region (see Section 5.3.6) shows that infiltration capacity of disturbed shallow sediments overlying the orebody is such that the infiltration capacity of ongoing pre-stripped mine areas is more than sufficient to accommodate the entire dewatering surplus. Should there be any short-term deficit in the capacity of the injection borefield, surplus water would be discharged onto pre-stripped areas of the mine path.
- In the event that the injection borefield or the pre-strip infiltration systems are unavailable (eg. short-term breakdown if overland pumping system from the active mining area to the disposal sites), then surplus dewatering production would be discharged to the nearby open or infilled mine voids.
- For all contingency plans, in all options, no water will be discharged to the environment.

5.6 EXISTING LOCAL EXAMPLES

5.6.1 YANDICOOGINA RE-INJECTION

Rio Tinto Iron Ore (RTIO) have successfully implemented aquifer re-injection at its Yandicoogina mining operation, just 20km south of the Marillana project, further up the same catchment, and injecting into what is interpreted to be the same palaeochannel as present at the Marillana project. The major technical issues identified and managed were prediction of re-injection rates and the control of clogging in the well screens and aquifer. The former was managed through a thorough understanding of the hydrogeology of the project area. Clogging was controlled by selection of pumping and re-injection aquifers with similar water chemistry. Five re-injection bores were commissioned at the Yandi site, and around 16.5ML per day (~190L/s) has been successfully re-injected since 2006.

5.7 POTENTIAL SITE-SPECIFIC ISSUES

5.7.1 GROUNDWATER MOUNDING

Groundwater mounding is when the water table rises toward the ground surface, and forms beneath sources of groundwater recharge. At this location, modelling results suggest that groundwater mounding will peak at 12m below ground surface at the centre of the re-injection borefield, and significantly less than that, only a few hundred metres away.

Due to the short-term nature of the re-injection operations (and therefore mounding) along with the fact that phreatophytic vegetation does not occur at this location (or anywhere on the orebody), so will not be affected by temporarily rising groundwater levels associated with the MAR operations.

5.7.2 WATER QUALITY

It should also be noted that the water quality and chemistry in the orebody is relatively homogenous along its length, and therefore the surplus water chemistry will be similar to the receiving water chemistry. This alleviates potential challenges that can sometimes be present with MAR techniques in terms of chemical differences in source and receiving waters.

5.7.3 RECIRCULATION

Numerical modelling results indicate that for a MAR operation located at the eastern end of the mine path and operating for three years will increase dewatering requirements by 2.5%. If the MAR operation were located ~4.5 kilometres further west, mid-way down the mine path, we see recirculation effects increasing dewatering requirements to ~7%. The results indicate that due to the separation of dewatering and MAR operations, along with the short lifespan of MAR operations, there is not anticipated to be significant impact of dewatering requirements due to recirculation.

5.7.4 CLOGGING

Settling of fine material and subsequent clogging of the aquifer is the main problem encountered in these types of MAR schemes. Clogging can be from suspended sediment load, microbiological growth, chemical precipitation and, in the case of well injection, entrained air bubbles blocking pore spaces. The situation can usually be managed by reducing the potential clogging problem prior to infiltration, together with periodic renovation of the infiltration surface through scraping, pumping or other physical and chemical means.

5.8 CONCLUSIONS & FURTHER WORK

5.8.1 CURRENT UNDERSTANDING

For hydrogeological, operational and cost considerations, the preferred MAR option for the project is a re-injection borefield. This re-injection borefield will be located distant from dewatering operations to minimise recirculation effects. A suitable number of bores will be operated to maintain groundwater mounding sufficiently beneath the ground surface and ensure all the surplus water can be recharged.

The modelling results for this option indicate that peak groundwater mounding (which occurs at ~2 years operation) will be 11m above the pre-mining water level (12mbgl at the Abalone East site). Recirculation effects increase dewatering requirements by less than 3%.

A conservative numerical modelling approach has been applied with regards to assessing groundwater mounding associated with the MAR options, for the following reasons:

- The pre-mining groundwater level is shallowest beneath the currently modelled MAR location, ~23mbgl at Abalone East. Alternate MAR locations have an increased depth to water table, and therefore the same mounding would be deeper beneath the ground surface.
- The extreme distance between the dewatering operations and MAR operations minimises the effects of recirculation, and therefore maximises the groundwater mounding predictions.
- The direct application of recharge to the water table in the model is conservative, as it does not account for any system losses such as evaporation (a consideration for the infiltration pond and galleries options).

5.8.2 OPTIMISATION OF MAR DESIGN

Preliminary cost comparisons (CAPEX and OPEX) along with MAR numerical modelling and sensitivities have shown that the actual arrangement of the MAR system (number of bores and bore spacing) and location can undergo further optimisation. Such optimisation will be undertaken as part of an ongoing Definitive Feasibility Study (DFS) as mining and backfill plans and schedules are confirmed, allowing for suitably detailed designs to be refined.

5.8.3 FIELD TRIAL

It is recommended that a re-injection field trial be undertaken at the project prior to installation of the complete reinjection system. This will allow for the validation of the numerical modelling results, and give further confidence in the potential injection rates and interference distances that can be expected at the project.

It is expected that such a field trial is likely to involve the following:

- The drilling and installation of a second production bore within 200m of a previously installed production bore.
- The drilling and installation of 2-3 further piezometers for utilisation as strategic monitoring points during the re-injection field trial.
- A month long field re-injection trial. This would consist of a pump in a production bore (the pumping bore) delivering a constant supply of water to a second production bore (the re-injection bore) for a duration of one month. This will allow further quantification of the effectiveness of the reinjection infrastructure to manage the volumes of surplus water predicted at the project.

5.8.4 MODEL VALIDATION

In addition to the data provisions outlined in Section 4.8, the numerical modelling would benefit from the gathering of data related to the field trial, to further validate and calibrate the modelled re-injection response to the measure aquifer response of a small scale field trial.

6 SALINITY MODELLING

6.1 MODELLING OBJECTIVES

The aim of the salinity modelling was to assess the potential for changes in water quality during the life of the project. The modelling was completed using the numerical groundwater flow modelling package FeFlow (Version 5.4). For this work the two-dimensional (vertical slice), model approach, including density coupling and variably saturated conditions was used (ie along the inferred groundwater flow direction).

6.2 MODEL SET UP

The schematic model set up and extents are shown in Figure 6.1. This is based on a southwest to northeast trending section in the centre of the proposed mine path aligned with panel 12, where maximum water level drawdown due to groundwater pumping is expected. The section covers a length of 27km extending approximately 8km south west of the mine path to the Hamersley Ranges and 19km north east to the Fortescue Marsh respectively. The model grid is designed to closely replicate hydrogeological units and the projected pit elevations such that the pit can be dewatered over a number of years consistent with projected mine development. The model is set up such that there is groundwater inflow at the upstream boundary and groundwater inflow and outflow at the marsh boundary consistent with the expected salinity profile. There is also groundwater outflow associated with the dewatering of the pit.

The location and type of boundary conditions are shown schematically in Figure 6.1. A fixed head groundwater inflow boundary is set at the south western boundary at an elevation of 425mRL and it is assumed that the inflowing groundwater has a salinity of 1000mg/L. The boundary that simulates the groundwater inflow and outflow processes associated with the Fortescue Marsh is set at an elevation of 400mRL, also shown in Figure 6.1. The salinity of water associated with this boundary condition is also shown in Figure 6.1.

Complete dewatering of the modelled pit is assumed to be achieved over 6 years. The location and depth of the proposed pit, relative to the mining area only, including the timing of the assumed dewatering are also shown in Figure 6.2.

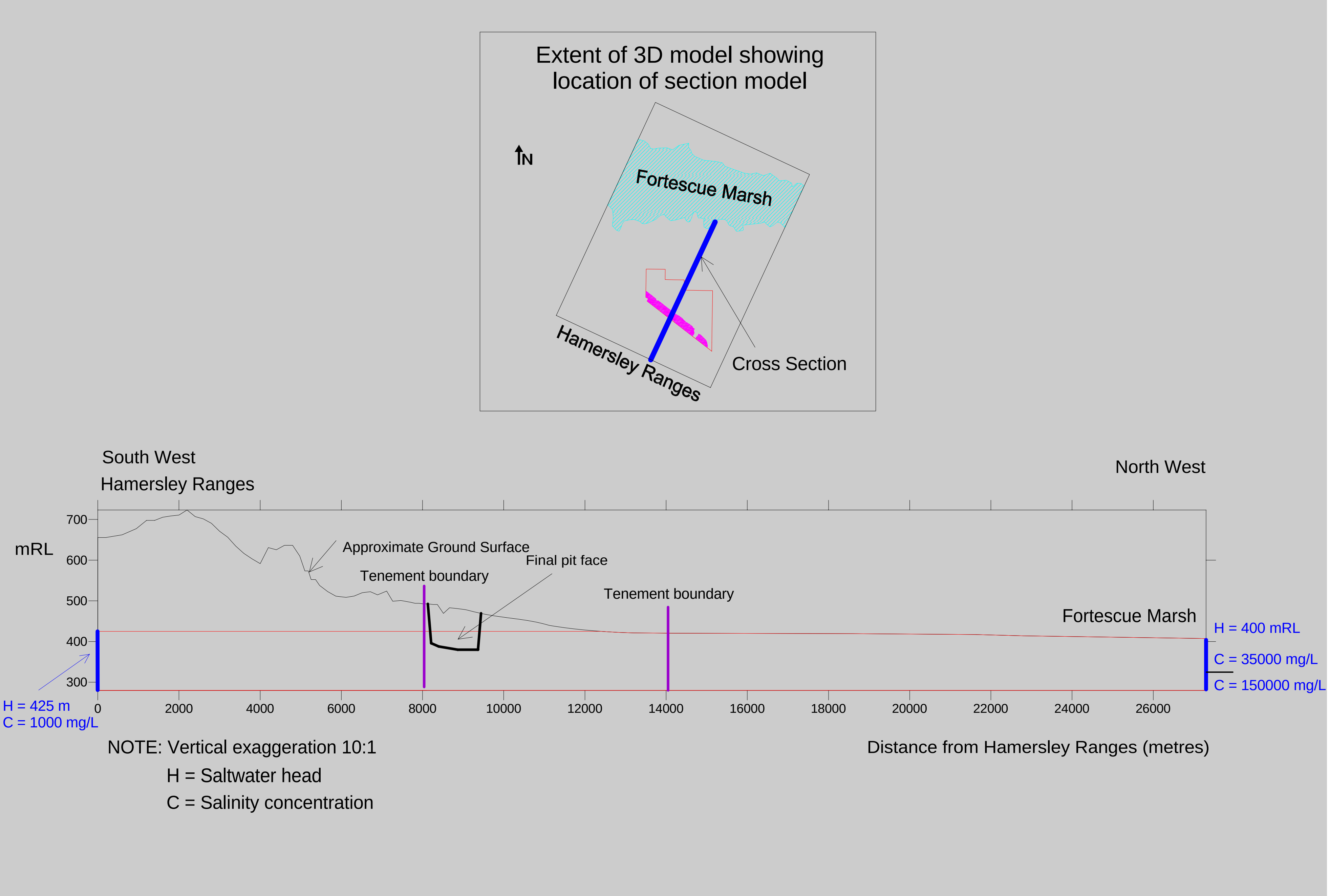
6.3 AQUIFER PARAMETERS

Model elements within the finite element grid are configured such that the extents of aquifer/aquitard units are represented by groups of common elements. For example, elements are configured to represent the orebody, calcrete, detritals and underlying basement. The distribution of hydrogeological units in the immediate mine area is shown in Figure 6.2. Aquifer parameters are assigned consistent with the groundwater flow model and are also summarised on Figure 6.2. Please note that the section model includes an allowance for orebody thickness that is close to the minimum anticipated thickness to provide conservatism in prediction of salinity impacts.

6.4 MODEL CALIBRATION

The assigned aquifer parameters and boundary conditions (ie groundwater inflow and outflow via the fixed head boundaries only) resulted in the predicted water levels along the section as shown in Figure 6.3 which are consistent with measured water level in the mine area and the surrounding areas. These groundwater levels were used as initial conditions for the model predictions as outlined in Section 6.5.

A calibration to available salinity data for both the shallower and deeper hydrogeological units was attempted; however, the measured salinity distribution could not be replicated assuming reasonable ranges of aquifer parameters and boundary conditions. This suggested that the current salinity distribution resulted from a range of prevailing conditions over very long periods of time. As a result, an assumed salinity distribution was used for model predictions as outlined in Section 6.5.



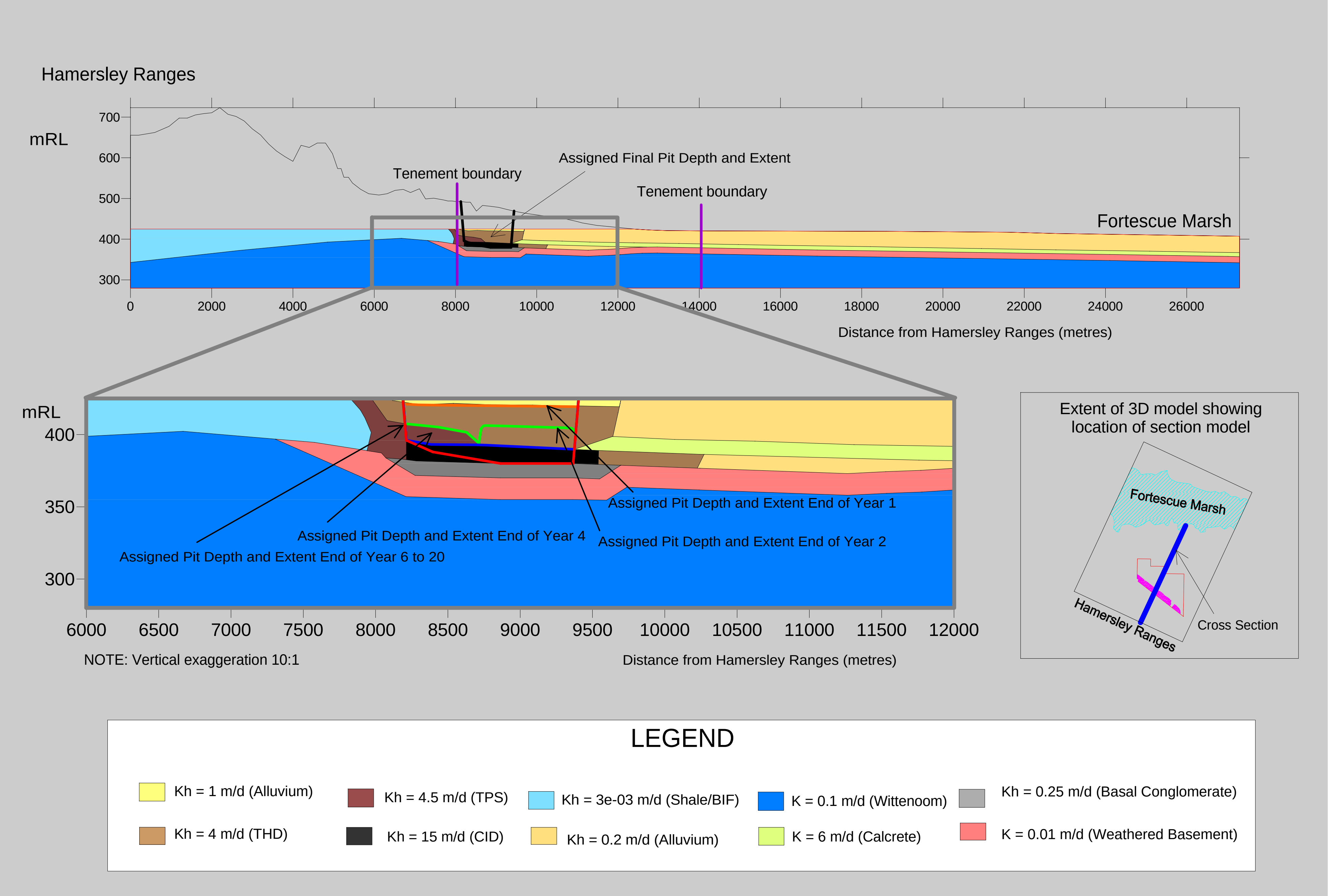
NOTE: Vertical exaggeration 10:1

H = Saltwater head

C = Salinity concentration

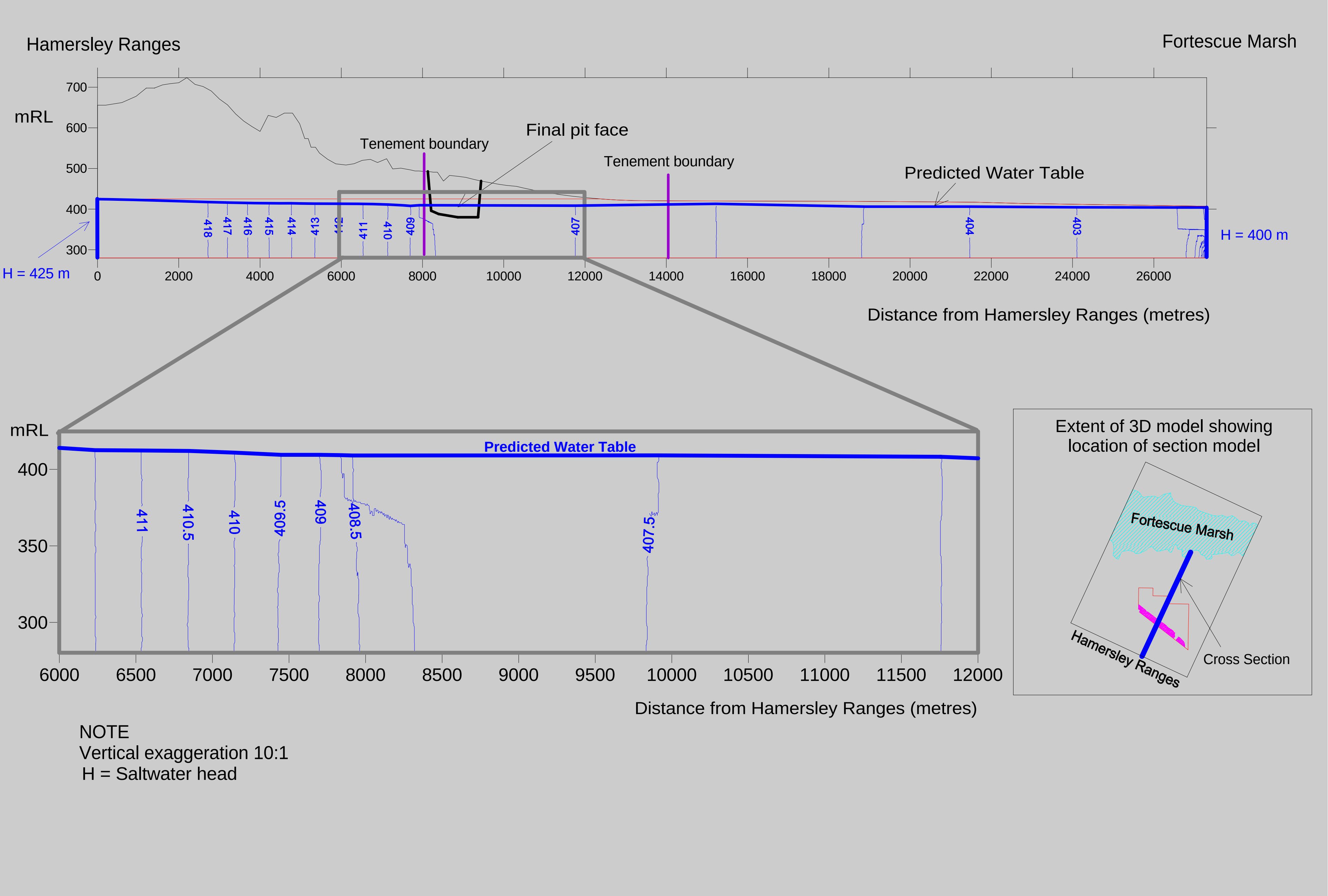
SCHEMATIC MODEL EXTENT AND BOUNDARY CONDITIONS FIGURE 6.1

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.1.srf



HYDROGEOLOGICAL UNITS AND SCHEMATIC PIT DEVELOPMENT FIGURE 6.2

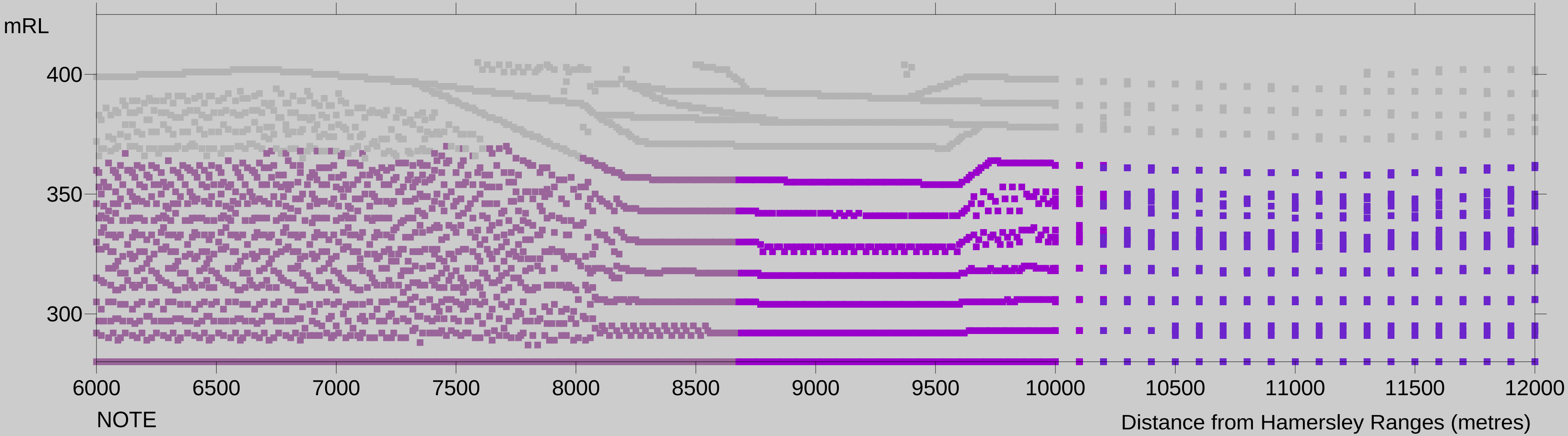
F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.2.srf



aquaterra

PREDICTED WATER LEVELS (MINE AREA) FIGURE 6.3

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.3.srf

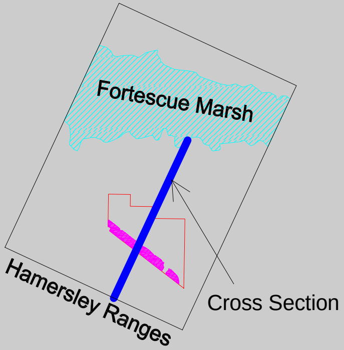


NOTE
Vertical exaggeration 10:1
Section displayed from 6000m to 12000m only

LEGEND

● 1000 - 2000 mg/L	● 5000 - 6000 mg/L	● 9000 - 10000 mg/L	● 30000 - 40000 mg/L
● 2000 - 3000 mg/L	● 6000 - 7000 mg/L	● 10000 - 15000 mg/L	
● 3000 - 4000 mg/L	● 7000 - 8000 mg/L	● 15000 - 20000 mg/L	
● 4000 - 5000 mg/L	● 8000 - 9000 mg/L	● 200000 - 30000 mg/L	

Extent of 3D model showing
location of section model



INITIAL ASSIGNED SALINITY DISTRIBUTION FIGURE 6.4

6.5 MODEL PREDICTIONS

The model was run to predict the resulting groundwater salinity distribution assuming:

- Initial water level conditions as outlined in Section 6.4.
- An initial groundwater salinity distribution assigned to the model based on available monitoring data as shown in Figure 6.4. This distribution assumes that groundwater in the upper hydrogeological units (ie above the basement) has a salinity of between 1,000 m/L on the Hamersley Range side of the proposed mine, increasing to 7,000mg/L at the Fortescue Marsh. The assigned salinity of the basement rocks varies from 20,000mg/L below the mining area to 150,000mg/L at the Fortescue Marsh.
- Dewatering of the pit is completed over a 6 year period, broadly consistent with the anticipated time taken to mine an individual panel, The model was run for a further 14 years (total prediction time of 20 years) to assess the potential for long term groundwater drawdown to cause a deterioration of water quality.

6.6 RESULTS

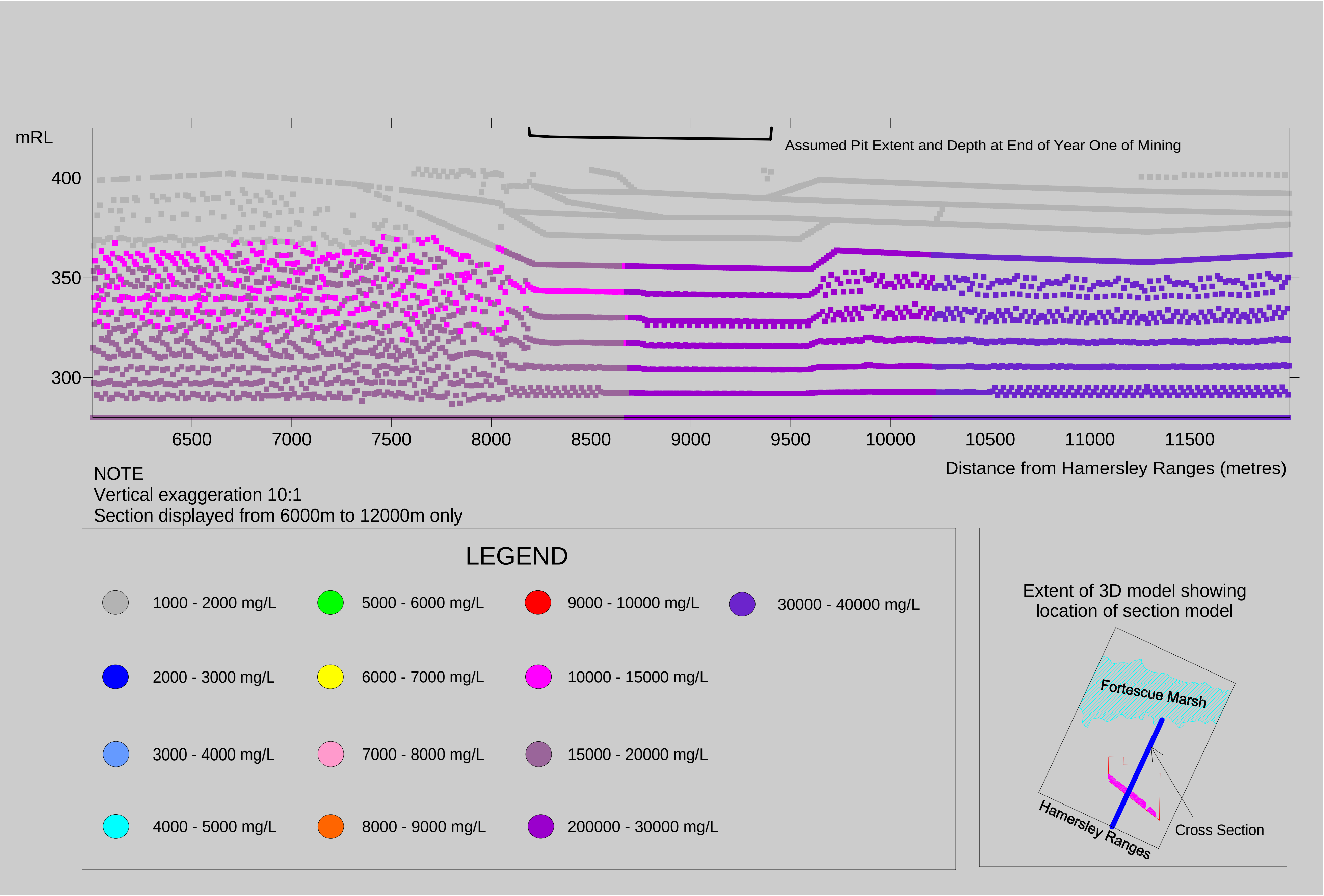
The predicted salinity distribution in the immediate pit area after 1, 6, 10, 15 and 20 years of continuous groundwater pumping that maintains water levels at the base of the projected pit are shown in Figures 6.5 to 6.9. Please note that this in fact may be more drawdown than that created by water supply pumping only. The results suggest that:

- After a year of groundwater pumping (refer Figure 5.5) and associated drawdown in the immediate pit area, there is no predicted impact on groundwater quality in the aquifer immediately surrounding the pit.
- After six years of pumping, and assuming the final pit depth (refer Figure 6.6) groundwater salinity of between 2,000 and 4,000mg/L is predicted under the pit. North of the pit, the predicted salinity is between 2,000 and 3,000mg/L, while south of the pit groundwater salinity is predicted between 3,000 and 4,000mg/L.
- Predicted salinity after 10, 15 and 20 years of pumping respectively are presented in Figures 6.7 to 6.9. It is unlikely that pumping would be maintained in any one panel over these periods of time due to the current operational and backfilling strategies; however it provides an indication of the salinity change that might occur if pumping was to continue over this period. The predicted groundwater salinity in the immediate pit area after ten years (Figure 6.7) is generally between 3,000 and 5,000mg/L, while below the pit there is some potential for water quality to reach 8,000 and 9,000mg/L below the pit floor. Water quality at this time is predicted to be 2,000 to 3,000 mg/L to the north of the pit, and between 4,000 and 5,000mg/L to the south of the pit.
- After fifteen years (Figure 6.8) predicted salinity of dewatering volumes is 3,000 to 6,000mg/L, while water quality below the pit has increased to between 10,000 and 15,000mg/L; 3,000 to 4,000 mg/L north of the pit and 5,000 to 6,000 mg/L south of the pit.
- After a further five years, or after twenty years of pumping (refer Figure 6.9), the salinity is predicted to be between 3,000 to 6,000 mg/L in the pit, and up to 15,000mg/L below the pit, however the salinity south and north of the pit has remained at 5,000 to 6,000mg/L and 3,000 to 4,000mg/L respectively.

It should be noted that these results are likely to be conservative (ie. modelled salinity higher than actual), on the basis of the following factors:

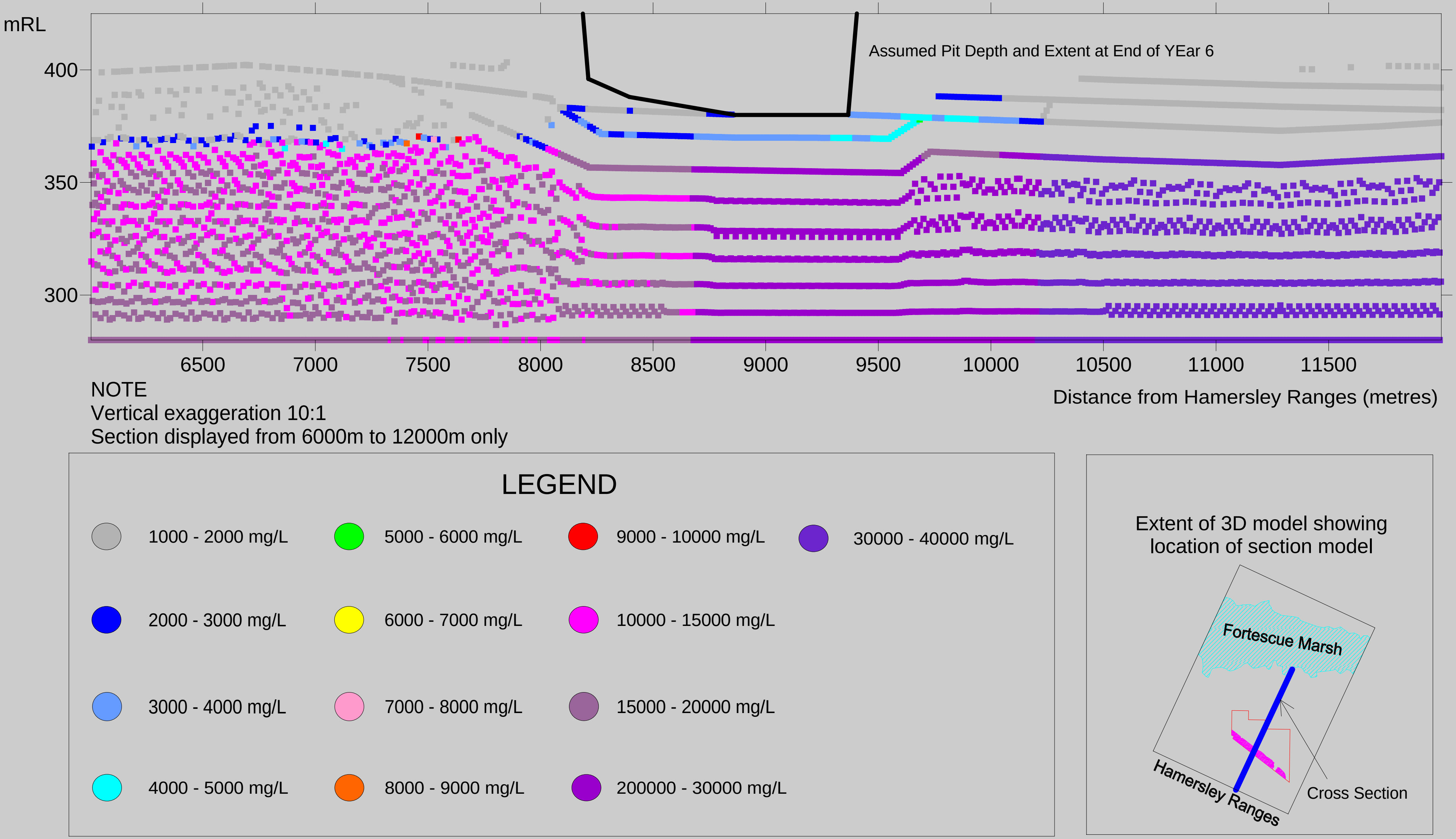
- Generally, there will be a thicker Tertiary sequence below the base of mining, meaning that a more extensive “buffer zone” of fresh water will be present, and therefore minimising the up-coning of more saline waters. This section is also located where deeper than average mining is planned.

- Generally, mining of a particular panel will be completed in 3 to 4 years, and after completion of mining, backfill to above the water table will be undertaken. Therefore, an abstraction period of 20 years for a particular panel location is conservative, and it is likely that water level recovery would commence sooner than this beneath backfilled panels.
- Recent drilling undertaken by Brockman indicates that the Tertiary sequence is significantly thicker at many locations than originally anticipated; making the geometry adopted within the section model "worst-case" rather than typical.
- The section model does not consider the effects of fresh water recharge associated with episodic seasonal inundation events. Any such event would introduce fresh groundwater recharge to the modelled system, thereby lowering the salinity compared to what has been modelled here.



PREDICTED SALINITY DISTRIBUTION END OF YEAR 1 FIGURE 6.5

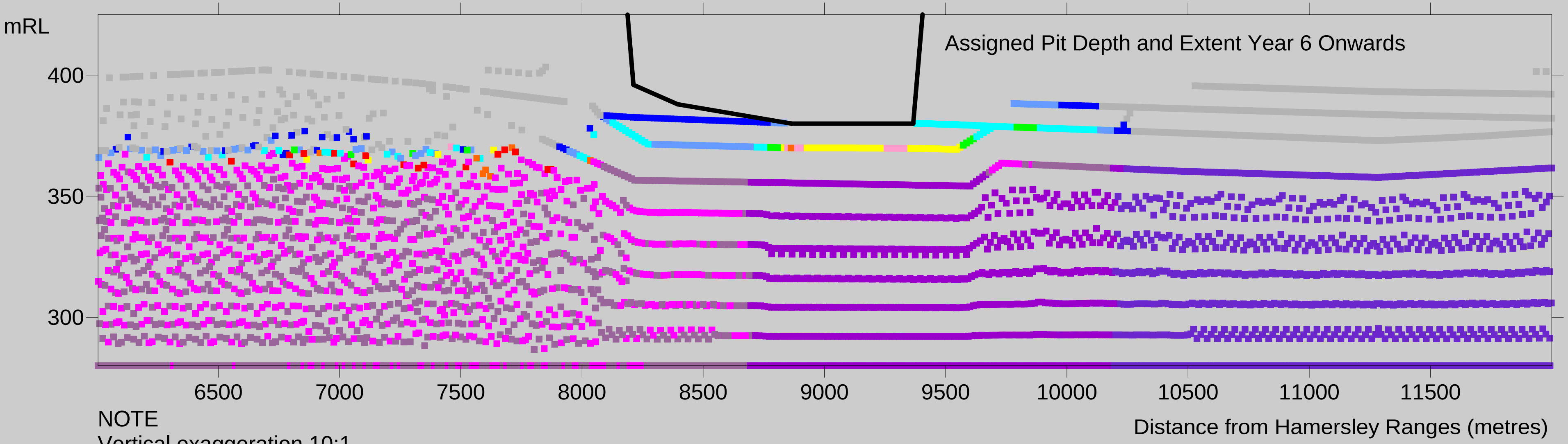
F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.5.srf



NOTE
Vertical exaggeration 10:1
Section displayed from 6000m to 12000m only

PREDICTED SALINITY DISTRIBUTION END OF YEAR 6 FIGURE 6.6

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.6.srf

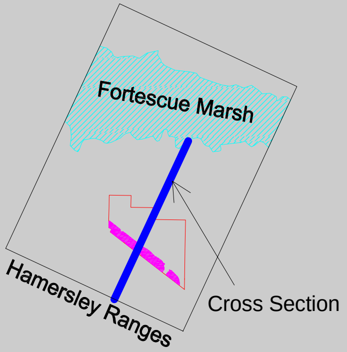


NOTE
Vertical exaggeration 10:1
Section displayed from 6000m to 12000m only

LEGEND

● 1000 - 2000 mg/L	● 5000 - 6000 mg/L	● 9000 - 10000 mg/L	● 30000 - 40000 mg/L
● 2000 - 3000 mg/L	● 6000 - 7000 mg/L	● 10000 - 15000 mg/L	
● 3000 - 4000 mg/L	● 7000 - 8000 mg/L	● 15000 - 20000 mg/L	
● 4000 - 5000 mg/L	● 8000 - 9000 mg/L	● 200000 - 30000 mg/L	

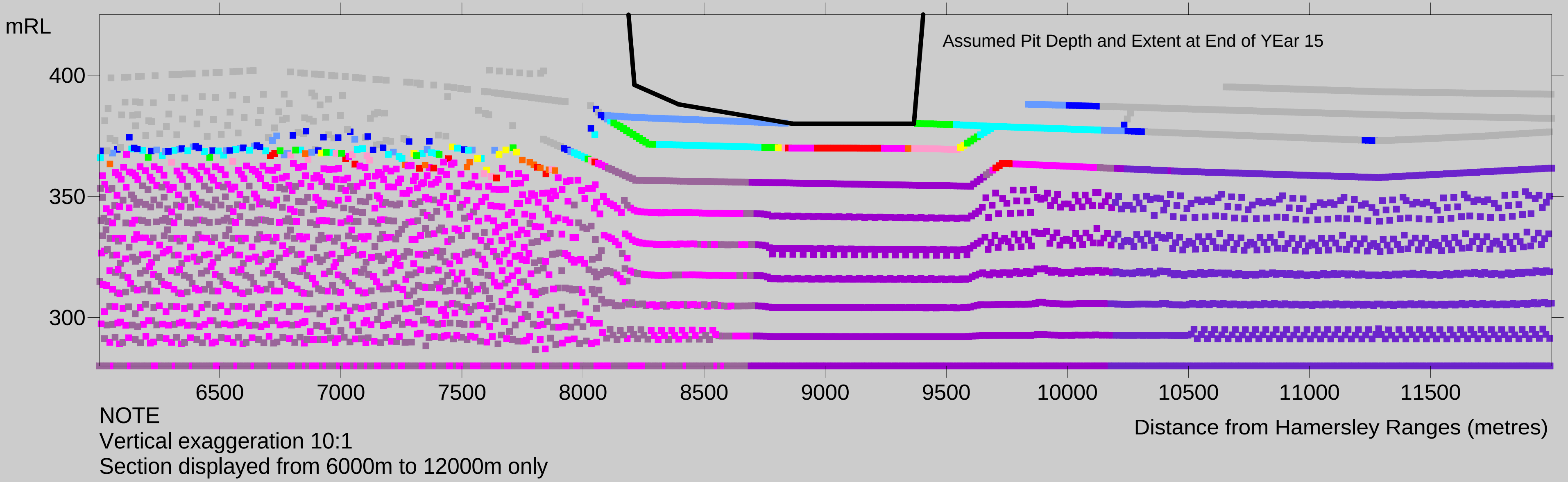
Extent of 3D model showing
location of section model



aquaterra

PREDICTED SALINITY DISTRIBUTION END OF YEAR 10 FIGURE 6.7

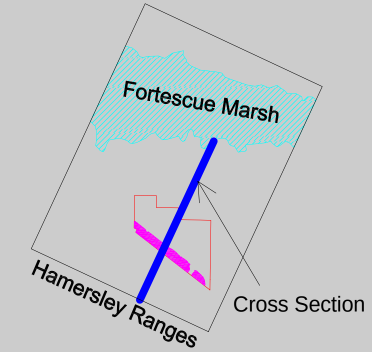
F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.7.srf



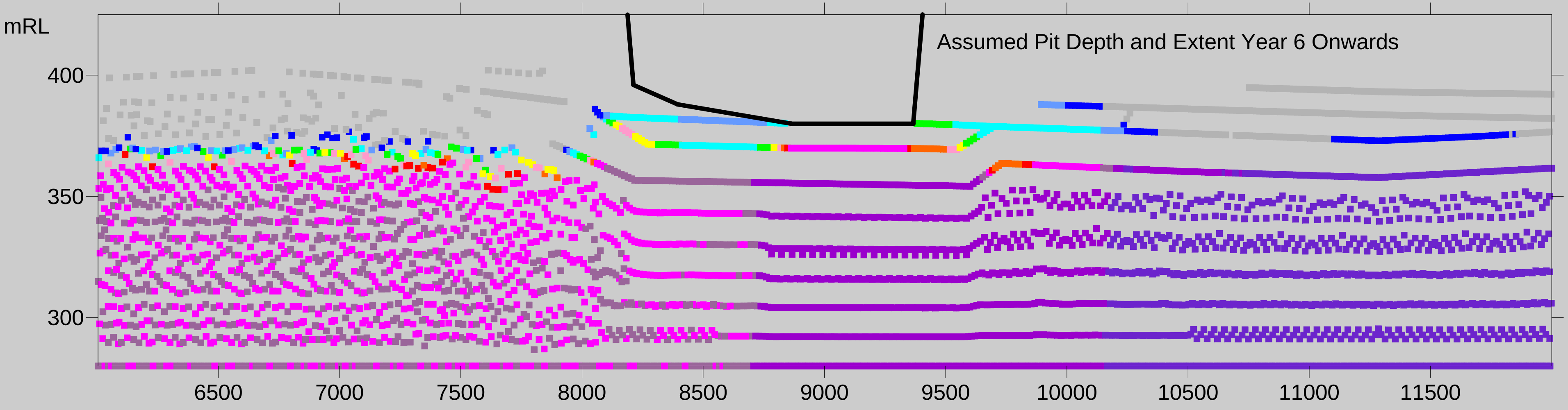
LEGEND

● 1000 - 2000 mg/L	● 5000 - 6000 mg/L	● 9000 - 10000 mg/L	● 30000 - 40000 mg/L
● 2000 - 3000 mg/L	● 6000 - 7000 mg/L	● 10000 - 15000 mg/L	
● 3000 - 4000 mg/L	● 7000 - 8000 mg/L	● 15000 - 20000 mg/L	
● 4000 - 5000 mg/L	● 8000 - 9000 mg/L	● 200000 - 30000 mg/L	

Extent of 3D model showing location of section model



PREDICTED SALINITY DISTRIBUTION END OF YEAR 15 FIGURE 6.8

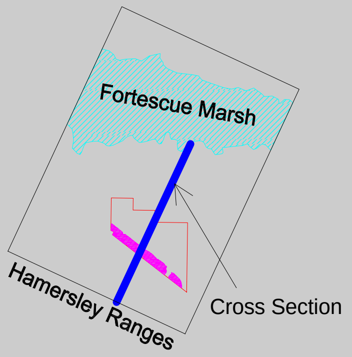


NOTE
Vertical exaggeration 10:1
Section displayed from 6000m to 12000m only

LEGEND

- ● 1000 - 2000 mg/L
- ● 2000 - 3000 mg/L
- ● 3000 - 4000 mg/L
- ● 4000 - 5000 mg/L
- ● 5000 - 6000 mg/L
- ● 6000 - 7000 mg/L
- ● 7000 - 8000 mg/L
- ● 8000 - 9000 mg/L
- ● 9000 - 10000 mg/L
- ● 10000 - 15000 mg/L
- ● 15000 - 20000 mg/L
- ● 200000 - 30000 mg/L
- ● 30000 - 40000 mg/L

Extent of 3D model showing location of section model



aquaterra

PREDICTED SALINITY DISTRIBUTION END OF YEAR 20 FIGURE 6.9

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_fig6.9.srf

7 CONCLUSIONS

7.1 CONCEPTUAL GEOLOGY & HYDROGEOLOGY

On the basis of the recent field campaign (cf. Sections 2 & 3) and desktop study to incorporate all available data, the following conceptual geological understanding has been developed:

- A CID palaeochannel incised into weathered basement (BIF/shale/dolomitic shale). The CID subsequently underwent significant weathering, likely being dissected by palaeo-drainages off the Hamersley Range. The remnant CID therefore formed a series of discontinuous mesas.
- A period of calcrete precipitation followed, which is interpreted (on the basis of the data currently available) to be regionally extensive and laterally continuous.
- A period of scree deposition followed, burying the CID and calcrete beneath a sequence of pisolite gravels and hematite detritals.
- This was then buried beneath non-mineralised transported overburden, which is modern-day ground surface.

The hydrogeological aspects relating to the project are:

- Groundwater level of 20-30mbgl in the vicinity of the proposed orebody, shallowing to 10mbgl in the northern reaches of the tenement.
- Groundwater quality in the Tertiary sequence less than 2,500mg/L TDS on tenement, and generally <1,000mg/L in the orebody.
- Groundwater quality in the deep basement units ranges from 20,000 to 75,000mg/L TDS on tenement, but is not hydraulically connected to the overlying Tertiary system.
- The CID, calcrete, pisolite gravels (TPS) and hematite detritals (THD) units have varying aquifer properties that have been incorporated into subsequent numerical modelling.
- The estimated groundwater throughflow is quite low (~1,000kL/d), and most of the groundwater volumes are coming from storage.
- Seasonal recharge is a significant factor that has been represented through transient modelling, and will be verified as long-term water level data becomes available.

7.2 GROUNDWATER MODELLING

Groundwater modelling was conducted to assess the potential for dewatering of the CID/detrital orebody to supply the project water demand. Model predictions suggest that the proposed borefield, with one bore located in each mining panel, operated consistent with the proposed mining sequence will be sufficient to satisfy water supply requirements until Year 9 of the project.

The MAR modelling results for preferred re-injection option indicates that peak groundwater mounding (which occurs at ~2 years operation) will be 11m above the pre-mining water level (12mbgl at the Abalone East site). Recirculation effects increase dewatering requirements by less than 3%.

As no long term monitoring data and hydraulic testing are available, there remains uncertainty in the aquifer parameters used to construct the model. Sensitivity analysis suggests that the model is most sensitive to changes in the adopted hydraulic conductivity of the orebody and the adjacent calcrete. Despite this, overall borefield yields are predicted to decrease by less than 10% when aquifer hydraulic conductivity values for these two units are halved.

The proposed closure strategy, which includes backfilling on the mine path with waste rock and fines rejects to above the pre-mining watertable has also been modelled. Model results suggest that water levels within the mine path are not significantly impacted by this closure strategy with little to no impact to the groundwater system predicted outside of the mine path.

- Salinity modelling was conducted to assess the potential water quality fluctuations that might be encountered during dewatering operations. The predicted salinity of dewatering volumes after six years of continuous groundwater pumping that maintains water levels at the base of the projected pit is up to 4,000mg/L TDS, with some associated increases in salinity with the rock formations below the base of mining.

7.3 WATER SUPPLY & DEWATERING

To achieve the initial mine schedule dewatering targets, the pumping drawdown may generate more water than required for project activities. Surplus water is predicted for the first three years of mining. This water will not be discharged to the environment, but rather, will be re-injected back into the orebody aquifer. This strategy puts the surplus water back into storage in the orebody aquifer, making it available for later utilisation, and minimising the impacts of dewatering where possible. In the long-term as dewatering continues, it is projected that further supplementary water supply (above what is produced through dewatering) will be required for the operations beyond year 9.

Brockman's preferred option (in alignment with DoW hierarchy of water management options) is to source water via a pipeline from a neighbouring operation that is discharging significant surplus water. Water supply solutions are also available through water supply borefields on-tenement, or in the vicinity of the Brockman tenement, should an off-take arrangement not eventuate.

Table 7.1: Preliminary Site Water Balance - Life of Mine

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Water Demand (L/s)	220	280	280	280	230	230	230	230	230	230
Dewatering (L/s)	320	360	330	280	230	230	230	230	230	210
Surplus / Shortfall (L/s)	100	80	50	0	0	0	0	0	0	-20
Year (continued)	11	12	13	14	15	16	17	18	19	20
Water Demand (L/s)	230	230	230	230	230	230	230	230	230	230
Dewatering (L/s)	190	180	160	120	120	100	100	100	60	50
Surplus / Shortfall (L/s)	-40	-50	-70	-110	-110	-130	-130	-130	-170	-180

7.3.1 IMPACTS

The main impact on the groundwater system from the Marillana project will be a decline in groundwater levels in the area around the dewatering borefield and a reduction in groundwater outflow to adjacent areas. However, it is anticipated that these impacts will be minimal for the following reasons:

- Groundwater levels beneath the orebody at the base of the Hamersley Ranges are naturally deep, and generally do not support phreatophytic vegetation.
- The exception to this is the phreatophytic vegetation localised in the vicinity of the Weeli Wolli Creek channel. The drawdown effects in this area are expected to be mitigated by channel flow events numerous times per year that will recharge the creek channel groundwater level.
- Elsewhere over the project area, while there is reduction in overall potentiometric levels, no geological units will be dewatered.
- The only existing groundwater user in the area is the Marillana Station bores utilised for cattle watering points. Any potential shortfall would be supplemented from Brockman water supply.
- The area is characterised by low rates of groundwater recharge and throughflow. As such a reduction in outflow from the Marillana area to adjacent areas affects relatively small volumes of water.
- Groundwater modelling shows that watertable levels beneath the Fortescue Marsh will not be affected.

Re-injection of surplus water will, for a few years, lead to elevated groundwater levels in the vicinity of the MAR operations. Modelling indicates that ongoing dewatering operations will quickly mitigate any impact associated with MAR.

It is considered likely that there will be minimal detrimental impact caused by MAR-related groundwater mounding for the following reasons:

- Groundwater levels are predicted to remain greater than 10m below ground level during re-injection operations.
- The groundwater mounding feature is predicted to be short-lived, being completely gone only two years after MAR operations cease.
- Groundwater mounding will be localised to a few square kilometres directly surrounding the MAR operations.

There is also potential for groundwater quality to deteriorate at the Marillana project over time. However, it is anticipated that these impacts will be minimal for the following reasons:

- Groundwater quality abstracted during dewatering/water supply will generally remain in the range of fresh to brackish, and will be utilised in the beneficiation process.
- The beneficial use of this water resource will not be affected. The only groundwater users in the area relate to Marillana Station stock water points. Water quality in the fresh to brackish range is currently found in most bores to the north of the project area.

7.3.2 MANAGEMENT

Comprehensive groundwater monitoring will take place to ensure water level changes, relating to both dewatering and re-injection, are consistent with those that have been predicted and where required, the groundwater model will be updated with the results of operational monitoring data to confirm predictions remain valid.

The proposed monitoring programme will include:

- Regional groundwater levels on a monthly basis.
- Pumping water levels and pumping volumes from abstraction bores on a monthly basis.
- Water quality monitoring from production bores (and selected piezometers screened in Tertiary and basement aquifers) on a quarterly basis.
- Annual review and assessment of all monitoring data.

Further details regarding planned management and contingency plans are provided in the Appendix A Groundwater Management Plan.

8 GROUNDWATER STUDY RECOMMENDATIONS

8.1 GROUNDWATER STUDY RECOMMENDATIONS

The following key recommendations are made:

- It is recommended that the project water supply and dewatering be integrated such that overall water requirements will initially be sourced from dewatering bores on the orebody, and managed to maximise the time period that dewatering volumes can supply project water demands.
- Actively pursue an off-take agreement with neighbouring operations.
- It is recommended that a secondary water supply option be developed as an additional water source as identified as being required later in operations (in the event that an off-take agreement does not eventuate).
- It is recommended that a “fallback option” to meet the project water demands (in the event that either of the above options proves to be unsustainable or water demands increase beyond their capacity) be identified, and should likewise be investigated further.

Brockman is currently pursuing all of the above key recommendations.

In relation to future work requirements, the following recommendations are made:

- Additional work (both field and modelling) is recommended to confirm the extent and continuity of hydraulic parameters in the calcrete aquifer in the vicinity of the orebody and northwards into the Fortescue Valley, as this will further refine and potentially significantly decrease the extent of the drawdown cone northward into the Fortescue Valley. It may also have implications for the longevity of dewatering volumes to meet water demand for the project.
- MAR field trial to further confirm and validate existing conceptual assumptions.
- Further assessment of the groundwater resources on tenement is recommended. Confirmation and refinement of the depth and extent of the Tertiary aquifer below the base of proposed mining. This will achieve additional confidence in the long-term sustainability of this resource.
- A small exploration programme is recommended in the vicinity of the proposed camp and mine offices to investigate the potential of installing a low-yielding potable water supply; alluvium and calcrete has been identified as a potential aquifer.
- It is recommended that dewatering requirements are re-assessed once Feasibility-level mine plans are available. A key outcome from this work is to determine whether revised dewatering requirements will affect the period of time for which the dewatering borefield can meet the project water supply needs (and thus timing for the development of the off-take arrangement or supplementary supply borefield).
- A groundwater monitoring regime should be established as soon as possible to provide baseline data and help in future water resources assessment work in the area.

9 REFERENCES

Aquaterra 2008a, *Marillana Iron Ore Project – Hydrogeological Investigation*, Prepared for Brockman Resources, November 2008, 832C/037c

Aquaterra 2008b, *Potable Bore – Initial Site Investigations*, Prepared for Brockman Resources, December 2008, 832D/003a

Aquaterra 2009a, *Marillana Groundwater Pre-Feasibility Report*, Prepared for Brockman Resources, July 2009, 832G/143b

Aquaterra 2009b, *Marillana Surface Hydrology Assessment*, Prepared for Brockman Resources, July 2009, 832H/016f

Coffey 2009, *Conceptual Design of In-pit Fines Rejects Storage, Newman Western Australia*, Prepared for Brockman Resources Marillana Iron Ore Project, August 2009, MWP00706AE-AB rev 0

Department of Water 2007, *Hydrogeological Reporting Associated With a Groundwater Well Licence*, Statewide Policy Report No. 19, May 2007

Department of Water 2009, *Pilbara Water In Mining Guideline*, Water Resource Allocation Planning (WRAP) series, Report No. 34, September 2009

APPENDIX A GROUNDWATER MANAGEMENT PLAN

GROUNDWATER MANAGEMENT PLAN

GROUNDWATER DEVELOPMENT AND MANAGEMENT

GROUNDWATER MANAGEMENT OBJECTIVES

- To prevent or minimise detrimental impacts on the groundwater system resulting from mining operations.
- To ensure that the quality of water returned to local and regional groundwater resources will not result in significant deterioration of the beneficial use of those resources.
- To prevent or minimise mining related impacts on Weeli Wolli Creek and Fortescue Marsh.

GROUNDWATER DEVELOPMENT STRATEGY

As has been demonstrated through Brockman's proposed approach to groundwater management of dewatering and MAR operations onsite (cf. Section 4 and 5), the value of water to the project has been recognised, and water management strategies developed that best utilise the available orebody water resource throughout the life of operations.

To achieve the initial mine schedule dewatering targets, the pumping drawdown may generate more water than required for project activities. Surplus water is predicted for the first three years of mining. This water will not be discharged to the environment, but rather, will be re-injected (or infiltrated) back into the orebody aquifer. This strategy puts the surplus water back into storage in the orebody aquifer, making it available for later utilisation, thus reducing the need for supplementary water supplies and reducing the overall impacts of dewatering. In the long-term, it is projected that supplementary water supply (above what is produced through dewatering) will be required for the operations beyond year 9.

Table 1: Preliminary Site Water Balance - Life of Mine

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Water Demand (L/s)	220	280	280	280	230	230	230	230	230	230
Dewatering (L/s)	320	360	330	280	230	230	230	230	230	210
Surplus / Shortfall (L/s)	100	80	50	0	0	0	0	0	0	-20
Year (continued)	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Water Demand (L/s)	230	230	230	230	230	230	230	230	230	230
Dewatering (L/s)	190	180	160	120	120	100	100	100	60	50
Surplus / Shortfall (L/s)	-40	-50	-70	-110	-110	-130	-130	-130	-170	-180

MANAGED AQUIFER RECHARGE

The preferred option for Managed Aquifer Recharge (MAR) is via re-injection. A re-injection borefield of four bores would be installed at a location distant from dewatering operations and within the defined orebody. The location has been selected on the basis of the current mine plan; currently Abalone East, the southeastern end of the orebody, is the target site for the MAR operations. A conceptual system arrangement of four bores spaced 500m apart has been adopted, with each bore re-injecting approximately 25L/s. This means that in year 1, four bores will be operational; in year 2, three bores will be operational; and in year 3, two bores will be operational.

Details of the process of assessment of the various MAR options considered are detailed in Section 5 of this report, and further details regarding proposed management and contingency measures are detailed in this management plan.

DIRECT OFF-TAKE WATER SUPPLY OPTION

It is the preference of Brockman, in alignment with the philosophy of the Department of Water (DoW) hierarchy of water management options, to source the supplementary supply from nearby operations that are discharging significant surplus water. To this end, discussions have progressed on the following option:

- To develop an off-take agreement with a neighbouring operation that is discharging surplus water, and delivers this as a water supply supplement to dewatering at Brockman Marillana.

There are a number of mining operations in the vicinity of the Marillana project that are currently discharging significant surplus water via direct surface discharge to the creeks, or via re-injection into a down gradient palaeochannel aquifer. As part of the DoW Water in Mining Guidelines (DoW 2009), a hierarchy of disposal options has been developed. In terms of the options being discussed, direct off-take (relocation for nearby use) is the preferred option, and is to be justified as being unsuitable for the project prior to implementing a scheme further down the hierarchy.

This option would require a pipeline corridor from the discharge point to the Marillana operations. Any pipeline corridor would require a vegetation survey to be carried out, and it is likely to be the preferred option that the pipeline be buried.

ALTERNATE WATER SUPPLY

The extent and thickness of tertiary aquifer below the base of proposed mining is anywhere between 20 and 60m where the palaeochannel thickens to the north. This means that there will be further groundwater available on-tenement to meet water demand after year 9 of the Project, should a water off-take agreement not eventuate. Numerical groundwater modelling of any such abstraction would be undertaken to adequately assess the potential impacts of this option in the event that direct off-take is unable to be adopted.

Other off-tenement water solutions have also been identified and have undergone preliminary investigations, particularly options that target the identified groundwater throughflow excess within the Weeli Wolli groundwater system. This elevated groundwater throughflow is related to the excess dewatering disposal of up-gradient mining operations. Therefore there is a high level of confidence that the water resource is available should it be required later in the life of mining operations.

OREBODY DEWATERING BORES

The main process water supply will be obtained from bores constructed on the orebody. The proposed borefield characteristics are:

- Comprise up to thirty bores.
- Bores will be up to 80m in depth (generally 50-60m).
- Long-term average pumping rates from individual bores will range up to 2000kL/d.

CAMP AND OFFICE WATER SUPPLY

It is proposed to obtain water for the Mine office and camp from low capacity bores installed into alluvium and calcrete in the vicinity of the camp and offices. Two production bores are anticipated at each location, and would operate on a duty/standby basis.

Hydrogeologically, relatively low yields (<2 L/s) were obtained from the alluvium/calcrete aquifer in the northeast of the tenement (Aquaterra 2008b), and it is likely that smaller capacity supplies to meet camp water supply requirements can be obtained from a combination of local calcretes and overlying alluvium close to creek channels. The location of bores close to creek channels will enhance the prospects of groundwater recharge after significant rainfall events.

A small exploration programme will be undertaken in the vicinity of the proposed offices and camp to identify and install a low-yield potable water supply. Any potable bores would be appropriately equipped with suitable treatment/filtration equipment, and the minor abstraction volume is likely to have negligible effect on the regional groundwater system.

MONITORING AND ENVIRONMENT

ENVIRONMENT

Groundwater Levels

Impact

The main impact on the groundwater system from the Marillana project will be a decline in groundwater levels in the area around the dewatering borefield and a reduction in groundwater outflow to adjacent areas. This will result from the abstraction of groundwater for mine dewatering. The extent of this cone of depression as predicted by groundwater modelling was illustrated in Figure 4.14a & b; and the drawdown effects at various locations over the project mine life are shown in Figure 4.15.

Dewatering

The predicted impact of water supply and dewatering development on the regional piezometric levels is presented for the end of year 20 mine life in Figure 4.14. The drawdown is at a maximum of 40m below pre-mining levels in the western end of the orebody to facilitate dry mining conditions and reduces with distance from the main pit area. Predicted drawdowns in piezometric levels extends northwards across the Fortescue Valley and southwards from the mine area to beneath the Hamersley Ranges. Drawdown is elongated northwest-southeast in alignment with the general strike of the detrital orebody.

The extent of the predicted drawdown is related to following factors:

- The mining timeframe of 20 years and the 15km long strike length of the proposed mine/dewatering area;
- The thickness and assumed lateral continuity of the calcrete (a conservative modelling assumption); and
- The minimal groundwater throughflow in this system means that the majority of dewatering coming from storage in the target orebody aquifer, and the adjacent calcrete aquifers.

On this basis, the lateral extent of the dewatering zone of influence as represented by the model represents the “worst-case” scenario, and is considered unlikely to eventuate. For example, if the calcretes are less extensive or less continuous in nature than simulated (NB calcretes in the Pilbara are typically “patchy” in nature), the lateral extent of drawdown to the north will be significantly reduced.

It should be noted that:

- Over most of the affected area, the dewatering drawdowns represent a drop in potentiometric surface (hydrostatic heads in confined aquifers). Other than in the immediate vicinity of the mine, no hydrogeological units are dewatering.
- The rate of expansion of the drawdown zone of influence is very slow, particularly late in the mine life when the extent of drawdown approaches the Fortescue Marsh. The 1m drawdown contour approaches the southern margin of the Fortescue Marsh in the last five years of operation only. The predicted 5m drawdown contour remains some 5km south of the Marsh at the end of mining.
- While research (by joint industry-government) into the hydrogeological nature of the Marsh continues, it is generally accepted that the Marsh is a surface water driven system.

The predicted worst-case reduction in potentiometric surface under the Marsh is negligible and even these predicted drawdowns are not expected to have any impact over the life of the mine to Fortescue Marsh. As a surface water driven system, drawdowns in the potentiometric surface of the calcretes (if any) are not expected to affect inundation frequency, ponding, or infiltration rates.

It is considered likely there will be minimal detrimental impact related to this water level drawdown for the following reasons:

- Groundwater modelling (as discussed in Section 4 and demonstrated in Figure 4.14) shows that the watertable levels beneath the Fortescue Marsh will not be significantly affected (less than 1m predicted drawdown after 20 years dewatering for the worst-case scenario)

- Groundwater levels beneath the orebody at the base of the Hamersley Ranges are naturally deep, and generally do not support phreatophytic vegetation.
- The exception to this is the phreatophytic vegetation localised in the vicinity of the Weeli Wolli Creek channel. The drawdown effects in this area are expected to be mitigated by channel flow events numerous times per year that will recharge the creek channel groundwater level. Natural seasonal fluctuations in groundwater level are not currently well-understood, but are estimated (on the basis of experience in the region) to be up to several metres (potentially significantly larger in the vicinity of the creek channel).
- Elsewhere over the project area, while there is reduction in overall potentiometric levels, no geological units will be dewatered.
- The only existing groundwater user in the area is the Marillana Station bores utilised for cattle watering points. Any potential shortfall would be supplemented from Brockman water supply.
- The area is characterised by low rates of groundwater recharge and throughflow. As such a reduction in outflow from the Marillana area to adjacent areas affects relatively small volumes of water.

Surplus Water Disposal

Managed Aquifer Recharge (MAR) will, for a few years, lead to elevated groundwater levels in the vicinity of the MAR operations. Modelling indicates that ongoing dewatering operations will quickly mitigate any impact associated with MAR.

It is considered likely that there will be minimal detrimental impact caused by MAR-related groundwater mounding for the following reasons:

- Groundwater levels are predicted to remain greater than 10m below ground level during re-injection operations.
- The groundwater mounding feature is predicted to be short-lived, being completely gone only two years after MAR operations cease.
- Groundwater mounding will be localised to a few square kilometres directly surrounding the MAR operations.

Management

Brockman will implement the following management actions to reduce the potential for and severity of impacts to groundwater. These management actions include several layers of contingencies to ensure adequate monitoring of any impacts, improved forward predictions of future impacts, and the development of appropriate management strategies.

Dewatering

As outlined above, a conservative approach was adopted in the prediction of the impacts of dewatering (using numerical groundwater modelling). Worst case predictions indicate that the drawdown zone of influence will expand very slowly away from the immediate mine area, with the 1m drawdown contour approaching the southern Marsh boundary in the last five years of operation only. It should be noted that the 5m drawdown contour is still approximately 5km south of the southern Marsh boundary at the end of mining. It should also be noted that, even if such drawdowns did eventuate, it is unlikely that these drawdowns would have any impact on the Fortescue Marsh.

Contingency planning to minimise the possible impacts of dewatering includes:

1. Minimising total groundwater abstraction.
2. Extensive monitoring of local and regional drawdowns, and further investigation of key hydrogeological features.
3. Ongoing validation of prediction models and ongoing revised predictions.
4. Modification to pumping and MAR discharge as/when required.
5. Infilling of all pits to facilitate full and rapid recovery of post-mining groundwater levels.

6. Contribution of ongoing research programmes on the hydrogeological nature of the Fortescue Marsh.

These are outlined in more detail below:

1. Mine dewatering and water supply abstraction will be integrated to reduce, as much as possible and practicable, overall groundwater abstraction. For the majority of mine life (year 4 onwards), some of the dewatering bores will be operated to provide the project water supply requirements, rather than solely to achieving dewatering targets. In the event of short-term surplus water being generated due to storm or recharge events, this water would be utilised in preference to operating the dewatering bores that are more distant from active mining areas.

2. Comprehensive groundwater modelling will include the following:

- Regional groundwater levels on a monthly basis.
- Pumping water levels and pumping volumes from abstraction bores on a monthly basis.
- MAR re-injection volumes on a monthly basis.

Also, further work to install monitoring piezometers between the project and the southern Marsh boundary will allow for ongoing assessment of background seasonal fluctuations in groundwater levels and quality, monitoring longer-term drawdowns and confirming the nature of the calcretes (continuous aquifer or discontinuous patchy aquifer system).

The above expansion to the monitoring system will require drilling off-lease and will require approval from relevant land-holders and authorities.

3. Annual review and assessment of all monitoring data, including validation of the groundwater model against observed aquifer responses and recalibration and refined prediction as required. In this way, the reliability of the predictions improve with time.

4. In the unlikely event that drawdowns in response to dewatering (and water supply pumping) do reach the Fortescue Marsh and in the further unlikely event that it is found to be negatively impacting upon the Marsh system, the operation of the dewatering and MAR systems would be modified to manage the extent of drawdown. This might include refocussing of dewatering pumping from bores to pit sumps and/or re-direction of some MAR discharge to the calcrete aquifer. It should be noted that any requirement for this would be towards the end of mine life when there will be significantly more information available on aquifer response/performance which will allow for optimum design of any reconfigured dewatering/MAR system.

5. Once mining and groundwater abstraction in the project area ceases, water levels are expected to recover to pre-mining conditions and no significant permanent impact will occur. Mine closure strategies have been developed, including in-pit dumping of waste rock, along with coarse and fine rejects, to backfill pits to above the regional watertable, to facilitate sustainable aquifer recovery.

6. In the interim, Brockman is continuing its involvement in government-led research initiatives such as the Fortescue Marsh Working Group, which seeks to improve the level of conceptual understanding of the dynamic processes involved with the Fortescue Marsh system.

Additional work to confirm the extent and continuity of calcrete in the vicinity of the orebody and northwards into the Fortescue Valley will be undertaken to better constrain the extent of drawdown zone of influence. Such work will also increase confidence in the longevity of dewatering to meet project water supply requirements.

Once mining and groundwater abstraction in the Marillana area ceases, water levels are expected to recover to pre-mining conditions and no significant permanent impact will occur. Mine closure strategies have been developed, including in-pit dumping of waste rock, along with coarse and fine rejects, to backfill pits to above the regional water table to facilitate sustainable aquifer recovery.

Surplus Water Disposal

It is predicted that there will be surplus water generated in achieving dewatering targets in the initial stages of mining (years 1 to 3), above what is required for project water supply requirements.

It is proposed to dispose of this water back into the orebody aquifer system via a Managed Aquifer Recharge (MAR) scheme. A re-injection borefield of four bores will be installed at a location distant from dewatering operations and within the defined orebody. The location will be selected on the basis of the mine plan. Currently, Abalone East, at the southeastern end of the orebody, is the identified site for the MAR operations. Aquifer re-injection has the added benefits that it will mitigate drawdown effects and make maximum use of water, that is, storing early surplus volumes for later utilisation for water supply when there will be a net water deficit.

Details of the assessment of the MAR scheme are presented in Section 5. This assessment shows that the aquifer system has more than sufficient capacity to accept the required volumes of discharge for the limited time required (first three years of mining), and could, if required, accept discharge for longer. However, it is recognised that, while the aquifer easily has the capacity to accept the required discharge, MAR schemes rely on the efficiency of the aquifer injection/recharge system, and that these do require regular maintenance.

Contingency planning to cover both short-term maintenance requirements and the possibility (unlikely though it is) that surplus water volumes are larger than predicted include the following elements:

1. Monitoring to validate prediction models and refine predictions of surplus discharge requirements.
2. Extra capacity built into the start-up injection borefield.
3. Use of pre-stripped areas of the mine path as infiltration ponds.
4. Use of open mine voids and/or infilled voids as temporary storage areas.

These are discussed in more detail below:

1. Data from the detailed monitoring, as outlined in the previous section, will be used to validate (and recalibrate if necessary) the groundwater model, which will then be used on an ongoing basis to confirm dewatering requirements and surplus discharge requirements. In this way, any additional dewatering surplus discharge requirements will be identified early which will allow for the timely planning of the implementation of contingency planning items 2, 3, and 4 (see below).

2. The start-up injection borefield will include five injection bores (NB these bores will be located in target locations for future dewatering bores and will eventually be used for dewatering beyond year 3). Only four bores (operating efficiently) are required to accommodate the predicted dewatering surplus and the fifth bore will be used rotationally to allow for regular borefield maintenance. If ongoing operational data (and ongoing groundwater modelling) indicate the need for additional injection bores, these will be installed, again at locations targeted for future dewatering bores.

3. Investigation work completed in a similar setting in the greater Fortescue Valley area shows that the infiltration capacity of disturbed shallow sediments overlying the orebody is such that the infiltration capacity of ongoing pre-stripped mine areas is more than sufficient to accommodate all the dewatering surplus. Should there be any short-term deficit in the capacity of the injection borefield, surplus water would be discharged onto the pre-stripped areas of the mine path.

4. In the event that the injection borefield or the pre-strip infiltration systems are unavailable (eg. short term breakdown of overland pumping system from the active mining area to the disposal sites), then surplus dewatering production would be discharged to nearby open or infilled mine voids.

Please note that, for all contingency plans, in all options, no water will be discharged to the environment, and that it is the intention of Brockman to conserve the early surplus volumes for later in the mine life, when supplementary water supply is predicted to be required.

Groundwater Quality

Impact

The potential impacts on groundwater quality from mining and dewatering activities at the Marillana project are:

- Pollution from chemical and hydrocarbon materials and waste water streams from the operation.
- Increases in salinity caused by the concentration of salts by evaporation of water in mined-out pit voids.
- Increases in salinity caused by the lateral movement of groundwater from the Fortescue Valley. Salinity modelling indicates that some deterioration of water quality is likely during dewatering operations, although still within the limits of what can be utilised for beneficiation.
- Increases in salinity caused by the up-coning of saline groundwater from within the underlying basement. Due to further Tertiary aquifer below the base of mining, and a weathered, clay-rich, basement interface, the effects of upconing are likely to be mitigated due to low permeabilities.

The potential for groundwater quality to deteriorate at the Marillana project over time has been assessed as part of ongoing water investigations. It is currently considered that these impacts will be minimal for the following reasons:

- Groundwater salinity modelling indicates that groundwater quality abstracted during dewatering will generally remain in the range of fresh to brackish, and will be utilised in the beneficiation process.
- The beneficial use of this water resource will not be affected. The only groundwater users in the area relate to Marillana Station stock water points. Water quality in the fresh to brackish range is currently found in most bores to the north of the project area.
- In the case of MAR, the source and receiving aquifer is the orebody aquifer, and the water quality and chemistry is similar along the length of the proposed orebody. Therefore, water quality is not anticipated to be significantly affected by MAR operations.

Management

- The prevention of groundwater pollution and contamination will be achieved through appropriate waste management practices.

Salinity modelling currently predicts that groundwater quality will be maintained in the range of fresh to brackish during the dewatering operations, and thereby still suitable for the beneficiation process.

Comprehensive groundwater quality monitoring will include the following:

- Quarterly water quality sampling and analysis from the pumping bores and a selection of piezometers (screened in alluvial and basement sequences). Samples to be analysed for major ions, salinity and pH as a minimum.
- Annual review and assessment of all monitoring data, including updating the groundwater model to confirm that predictions remain valid on the basis of the operational data.

Further work to constrain the thickness and extent of the Tertiary sequence below the base of mining will improve confidence in the conservatism of salinity modelling completed to date.

Contingency planning, to cover the unlikely event that dewatering discharge water quality deteriorates to a level that makes it unsuitable for beneficiation processing use (>7,000 mg/L TDS) or dewatering related drawdowns induce a change in water quality for other groundwater users include the following:

1. Blending with supplementary water source.
2. Aquifer re-injection of saline water to source.
3. Providing “fresh” water to other users if required.

These contingency plans are detailed below:

1. Should dewatering discharge become brackish (>7,000 mg/L TDS), the water would be blended or “shandied” with fresh water from supplementary sources to bring it in line with process water requirements.

2. In the extreme case that dewatering water quality is too poor to be unable to be shadied to less than 7,000 mg/L TDS, this would indicate that the basement aquifer (the source of saline water at depth below the orebody aquifer) is more permeable than currently understood. If this is the case, the aquifers would be suitable for aquifer re-injection and any excess saline water would be re-injected specifically back into this saline aquifer.

3. In the unlikely event that water quality deteriorates significantly in areas surrounding the proposed mine, and the beneficial use of the water resources tapped by other users is affected, then supplementary water supplies would be made available to these existing users (station watering points) from the mine water supply system.

Groundwater Recovery

Following cessation of dewatering, natural recharge and inflow processes will results in water levels recovering to pre-mining levels. All areas mined below the watertable will be backfilled to at least two metres above original watertable level. There will therefore be no long-term pit-lake or void in the watertable. Consequently, there will be no significant long-term impacts on water quality or groundwater flow.

Cumulative Impacts

Currently there are no other operations within the local vicinity of the proposed Marillana project. However, should there be further operations commencing in the region, Brockman will make pertinent data available for inclusion into a regional groundwater model to ensure that cumulative impacts are considered adequately.

MONITORING

Objectives

During this study, transient calibration of the groundwater model has been complicated by the lack of time-series water level monitoring (a normal issue for such a greenfields development project). Moreover, the current baseline, against which water resource availability and environmental impacts will be compared, is a snapshot and takes no account of natural temporal variation in the groundwater system. A regime of regular groundwater monitoring will address the following key issues:

- Collection of time-series data that can be used to re-calibrate the groundwater model in the future and improve predictions and optimisation of mine water management requirements.
- Determination of the extent of natural variation within the groundwater system (eg. natural water level recession during dry periods, etc).
- Establishment of a more comprehensive environmental baseline against which future changes and effects can be compared.
- Once construction and operations commence, regular monitoring of water levels, groundwater abstraction and water quality, will be required to comply with licence conditions and to optimise dewatering and water supply performance.

Monitoring Strategy

Brockman will implement a monitoring strategy in two phases:

- Phase 1: monitoring water levels in both regional and orebody bores until implementation of the project. The objective of this phase is to establish a time series of background data, and confirm the environmental baseline. It will also monitor the water usage as it relates to the pre-mining operations construction demand. Recommendations for water level monitoring (Table A1), and water quality monitoring (Table A2) as shown.

- Phase 2: monitoring of water levels, groundwater abstraction and water quality during mine operations. The details of this second stage of monitoring should be confirmed during the detailed design work and will take account of the final borefield designs, mine plans and dewatering and any conditions or constraints resulting from the environmental review process. The Phase 2 monitoring programme would be outlined in the “Operating Strategy” that will be submitted to Department of Water as part of the groundwater licencing process for mining operations requirements.

Water levels may be recorded either manually or by automatic piezometer and data logger (in which case periodic download of data is required within the timeframe of logger battery life). Where the responsibility to manage the monitoring programme is most appropriately allocated will depend on internal Brockman logistics but options would include: Brockman environmental staff, corporate environmental staff who would have to visit site regularly, Brockman site-based geologists/field technicians.

Table A.1: Groundwater Level Monitoring Regime (Pre-Project Development)

Bore Name	Location Details			Construction Information				Base Hydrogeology		Monitoring
	Easting (MGA mE)	Northing (MGA mN)	Elevation (mAHD)	Cased Depth (m)	Casing	Dia (mm)	Slotted Interval (mbgl)	SWL (mbgl)	Date	
PB1	730770.73	7497751.53	443.96	63	Steel	254	50-62	31.96	11/06/09	Water level, monthly
PB2	734322	7495004	-	53	Steel	254	38-50	24.80	11/06/09	Water level, monthly
Obs1	727623.23	7501474.39	433.14	44	Class 12 uPVC	50	21-44	22.86	11/06/09	Water level, monthly
Obs2	727111.93	7500620.07	444.56	76	Class 12 uPVC	50	28-76	33.74	11/06/09	Water level, monthly
Obs3	728087.16	7499727.17	451.09	75	Class 12 uPVC	50	33-75	40.75	11/06/09	Water level, monthly
Obs4	731878.66	7496654.33	442.39	70	Class 12 uPVC	50	30-60	29.07	11/06/09	Water level, monthly
Obs5	734293	7495041	-	58	Class 12 uPVC	50	22-58	22.10	11/06/09	Water level, monthly
Obs6	730745.49	7497771.48	444.45	64	Class 12 uPVC	50	34-64	32.55	11/06/09	Water level, monthly
Obs7	730758.63	7497786.91	444.33	148	Class 12 uPVC	50	100-148	33.59	11/06/09	Water level, monthly
Obs8	731349.16	7498264.88	431.43	53	Class 12 uPVC	50	22-53	20.65	11/06/09	Water level, monthly
Obs9	730560.62	7500151.45	423.49	41	Class 12 uPVC	50	23-41	13.15	11/06/09	Water level, monthly
Obs10	730750.63	7497779.80	444.44	77	Class 12 uPVC	50	65-77	32.47	11/06/09	Water level, monthly
Obs11	737306	7500645	-	29	Class 12 uPVC	50	4-28	13.96	11/06/09	Water level, monthly
Obs12	734758.87	7495192.14	432.97	39	Class 12 uPVC	50	22-39	17.65	11/06/09	Water level, monthly
Obs13	734285	7495051	-	147.5	Class 12 uPVC	50	110-146	22.10	11/06/09	Water level, monthly
Obs14	734781.09	7499348.39	425.15	28	Class 12 uPVC	50	4-28	14.77	11/06/09	Water level, monthly
Obs15	726291.50	7504601.43	419.38	34	Class 12 uPVC	50	7-31	9.58	11/06/09	Water level, monthly
Obs16	727138.43	7501008.75	440.94	62	Class 12 uPVC	50	32-62	30.05	11/06/09	Water level, monthly

Bore Name	Location Details			Construction Information				Base Hydrogeology		Monitoring
	Easting (MGA mE)	Northing (MGA mN)	Elevation (mAHD)	Cased Depth (m)	Casing	Dia (mm)	Slotted Interval (mbgl)	SWL (mbgl)	Date	
Obs17	736728.04	7493174.87	442.91	46	Class 12 uPVC	50	22-46	21.40	11/06/09	Water level, monthly
Pz1 (shallow)	726938	7500765	445	60	Class 12 uPVC	50	24-60	33.80	13/06/09	Water level, monthly
Pz1 (deep)	726939	7500764	445	75	Class 12 uPVC	50	69-75	33.72	13/06/09	Water level, monthly
Pz2 (shallow)	727777	7500900	438	57	Class 12 uPVC	50	21-57	26.73	13/06/09	Water level, monthly
Pz2 (deep)	727777	7500902	438	72	Class 12 uPVC	50	66-72	26.76	13/06/09	Water level, monthly
Pz3 (shallow)	728190	7502288	425	42	Class 12 uPVC	50	21-36	14.35	13/06/09	Water level, monthly
Pz4 (deep)	728806	7503163	419	114	Class 12 uPVC	50	72-114	9.74	13/06/09	Water level, monthly

Table A.2: Groundwater Quality Monitoring Regime (Pre-Project Development)

Bore Name	Location Details			Construction Information				Base Water Quality		Monitoring
	Easting (MGA mE)	Northing (MGA mN)	Elevation (mAHD)	Cased Depth (m)	Casing	Dia (mm)	Slotted Interval (mbgl)	Water Quality (mg/L TDS)	Date	
PS1PB	726937	7500772	445	58	Steel	254	22-58	1,300	31/05/09	Water quality, quarterly
PB1	730770.73	7497751.53	443.96	63	Steel	254	50-62	540	27/05/09	Water quality, quarterly
PB2	734322	7495004	438	53	Steel	254	38-50	680	05/06/09	Water quality, quarterly
Obs7	730758.63	7497786.91	444.33	148	Class 12 uPVC	50	100-148	22,000	13/06/09	Water quality, quarterly
Obs8	731349.16	7498264.88	431.43	53	Class 12 uPVC	50	22-53	780	13/06/09	Water quality, quarterly
Obs9	730560.62	7500151.45	423.49	41	Class 12 uPVC	50	23-41	1,000	13/06/09	Water quality, quarterly
Obs11	737306	7500645	424	29	Class 12 uPVC	50	4-28	980	09/06/09	Water quality, quarterly
Obs13	734285	7495051	438	147.5	Class 12 uPVC	50	110-146	22,000	05/06/09	Water quality, quarterly
Obs14	734781.09	7499348.39	425.15	28	Class 12 uPVC	50	4-28	1,000	10/06/09	Water quality, quarterly
Obs15	726291.50	7504601.43	419.38	34	Class 12 uPVC	50	7-31	2,300	11/06/09	Water quality, quarterly
Obs17	736728.04	7493174.87	442.91	46	Class 12 uPVC	50	22-46	600	30/05/09	Water quality, quarterly
Pz4 (deep)	728806	7503163	419	114	Class 12 uPVC	50	72-114	44,000	28/06/08	Water quality, quarterly

APPENDIX B COMPOSITE BORE LOGS

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: PB1

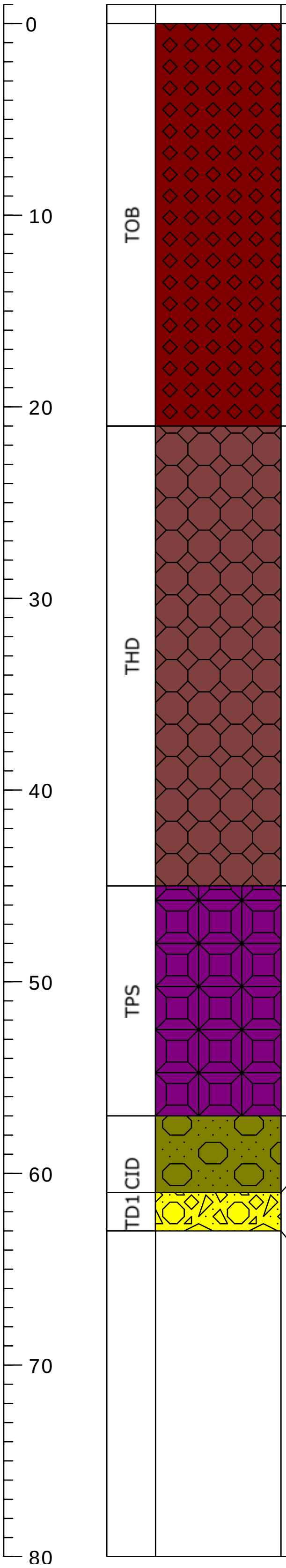
Client: Brockman Resources **Project:** MAR 2

Commenced: 17 May 2009
Completed: 18 May 2009
Drilled: Barber Drilling
Logged By: Ashley Price

Method: Dual Rotary
Fluid: Water
Bit Record: 16" (0-63mbgl)

Area: Marillana
East: 730774
North: 7497753
Projection: MGA94 Z50

Static Water Level: 31.96mbgl **Date:** 11 June 2009



Geology	Lithological Description
TOB	DETRITAL: red-brown and blue-grey BIF and chert fragments. Minor sub-round pisolites and goethite fragments. Poorly consolidated.
THD	HAEMATITE: red-brown and dark blue-grey BIF fragments. Pisolites up to 1cm increasing with depth bound in red-brown clay. Minor angular to sub-anguler fragments of calcrete and chert. Large BIF fragments (up to 6cm).
TPS	PISOLITE: red-brown pisolites up to 5mm but mostly 1-2mm. High clay content with pisolites bound. Some partially consolidated peds of clay and pisolites.
CID	CID: yellow-brown, weathered goethitic clay, poorly consolidated.
TD1	GRAVEL: grey, ferruginised chert gravel and quartz sand.

Field Notes

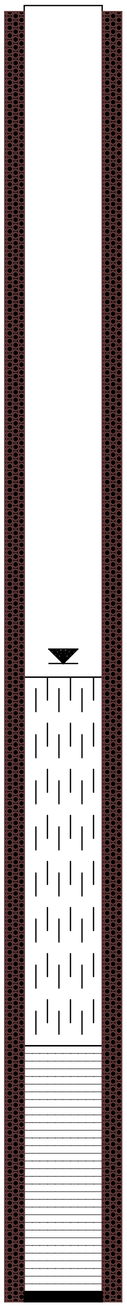
57mbgl: ~2L/s

63mbgl: ~8L/s
EC: 994uS/cm pH:8.17

Sampling when drilling 16"diameter holes is problematic with dual rotary drilling techniques. Therefore lggging of these drill holes will be less accurate than similar 6"drill holes.

Well Completion

Diagram



Notes

10" Blank Steel
(+0.3 to 32.5mbgl)

10" Slotted Steel
(32.5-50.5mbgl)

10" Stainless Steel
Screens
(50.5-62.5mbgl)

10" Steel Blank Sump
with end cap
(62.5-63mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: PB2

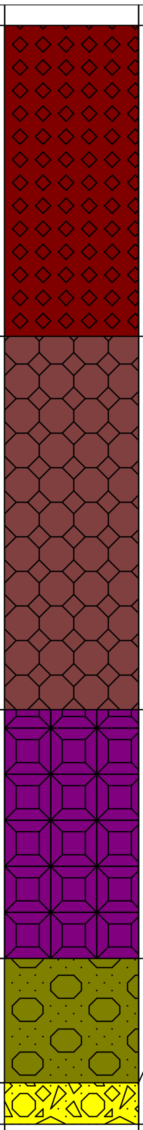
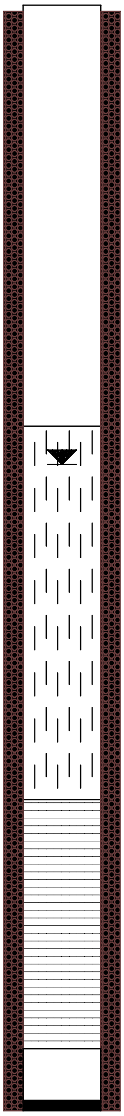
Client: Brockman Resources
Project: MAR 2

Commenced: 12 May 2009
Completed: 13 May 2009
Drilled: Barber Drilling
Logged By: Ashley Price

Method: Dual Rotary
Fluid: Water
Bit Record: 16" (0-53mbgl)

Area: Marillana
East: 734330
North: 7495004
Projection: MGA94 Z50

Static Water Level: 24.8mbgl
Date: 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
0 10	TOB		DETRITAL: red-brown and dark blue-grey angular to sub-angular fragments of BIF, Chert. Minor sub-round pisolites. Low clay content at 6 and 18m, higher clay content at 12m.			10" Blank Steel (surface to 20mbgl)
20 30	THD		HAEMATITE: red-brown and blue-grey fragments of BIF and Chert. Some round pisolites increasing with depth.			10" Slotted Steel (20-38mbgl)
40	TPS		PISOLITE: Well rounded pisolites up to 5mm but mostly 1-2mm. High clay content (>50%). Minor fragments of BIF and Chert.			
50	CID		CID: weathered yellow brown goethitic material, poorly consolidated.	45mbgl: ~8L/s EC: 1496uS/cm		10" Stainless Steel Screens (38-50mbgl)
	TD1		GRAVEL: grey ferruginised chert gravel and quartz sand.	51mbgl: ~10L/s EC: 1494uS/cm		10" Stainless Steel Blank Sump with end cap (50-53mbgl)
60 70 80						

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs1

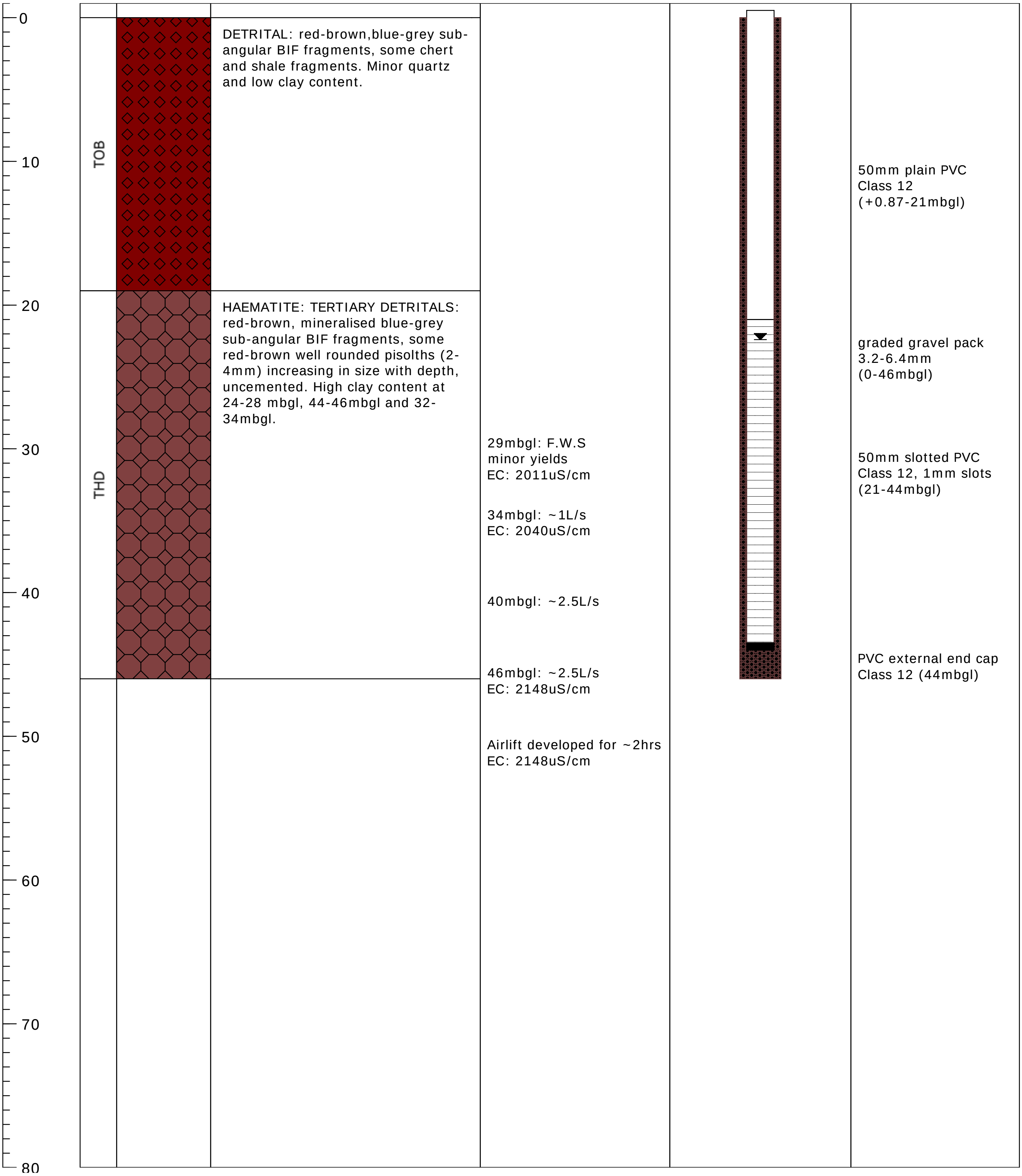
Client: Brockman Resources
Project: MAR 2

Commenced: 22 April 2009
Completed: 22 April 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: Dual Rotary
Fluid: Water
Bit Record: 6" (0-46mbgl)

Area: Marillana
East: 0727626
North: 7501485
Projection: MGA94 Z50

Static Water Level: 22.86mbgl
Date: 11 June 2009



Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
	TOB		DETRITAL: red-brown,blue-grey sub-angular BIF fragments, some chert and shale fragments. Minor quartz and low clay content.			50mm plain PVC Class 12 (+0.87-21mbgl)
	THD		HAEMATITE: TERTIARY DETRITALS: red-brown, mineralised blue-grey sub-angular BIF fragments, some red-brown well rounded pisolths (2-4mm) increasing in size with depth, uncemented. High clay content at 24-28 mbgl, 44-46mbgl and 32-34mbgl.	29mbgl: F.W.S minor yields EC: 2011uS/cm 34mbgl: ~1L/s EC: 2040uS/cm 40mbgl: ~2.5L/s 46mbgl: ~2.5L/s EC: 2148uS/cm		graded gravel pack 3.2-6.4mm (0-46mbgl) 50mm slotted PVC Class 12, 1mm slots (21-44mbgl) PVC external end cap Class 12 (44mbgl)
				Airlift developed for ~2hrs EC: 2148uS/cm		

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 2

Client: Brockman Resources **Project:** MAR 2

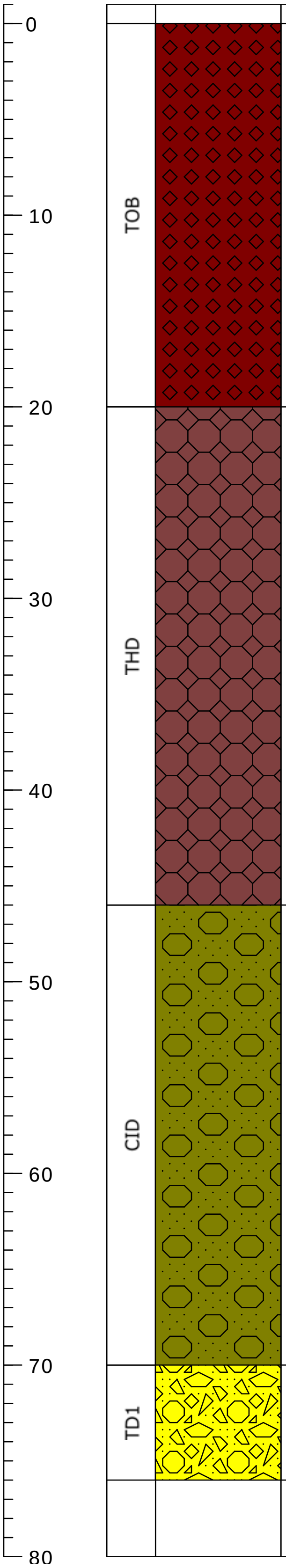
Commenced: 20 April 2009
Completed: 21 April 2009
Drilled: Barber Drilling
Logged By: Damien Jansen

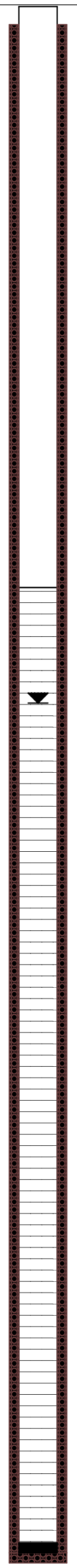
Method: Dual Rotary
Fluid: Water
Bit Record: 6" (0-76mbgl)

Area: Marillana
East: 727102
North: 7500623
Projection: MGA94 Z50

Static Water Level: 33.74mbgl **Date:** 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
	TOB		DETRITAL: red-brown, fragments of BIF, shale and chert, BIF content increasing with depth, poorly consolidated.			50mm plain PVC Class 12 (+0.9-28mbgl)
	THD		HAEMATITE: TERTIARY DETRITALS: red-brown, fragments of mineralised BIF, sub-angular to sub-rounded, some red-brown well rounded pisoliths (3mm). Pisolith content increasing with depth. Poorly consolidated.	40mbgl: F.W.S minor yields EC: 1699uS/cm		graded gravel pack 3.2-6.4mm (0-76mbgl) 50mm slotted PVC Class 12, 1mm slots (28-76mbgl)
	CID		CID: red-brown, mineralised, vuggy, haematite/goethite, pisoliths increasing in size (up to 6mm), increasing gethite content below 63mbgl.	46mbgl: EC:1746uS/cm 52mbgl: ~2L/s EC: 1845uS/cm 58mbgl: ~4L/s EC: 1878uS/cm 64mbgl: ~5-6L/s EC: 3970uS/cm		
	TD1		GRAVEL: yellow-brown, pisoliths, BIF/shale, minor quartz fragments, increasing clay content, minor calcrete.	70mbgl: ~5-6L/s EC: 6740uS/cm		
				76mbgl: EC: 5370uS/cm		PVC external end cap Class 12 (76mbgl)





aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

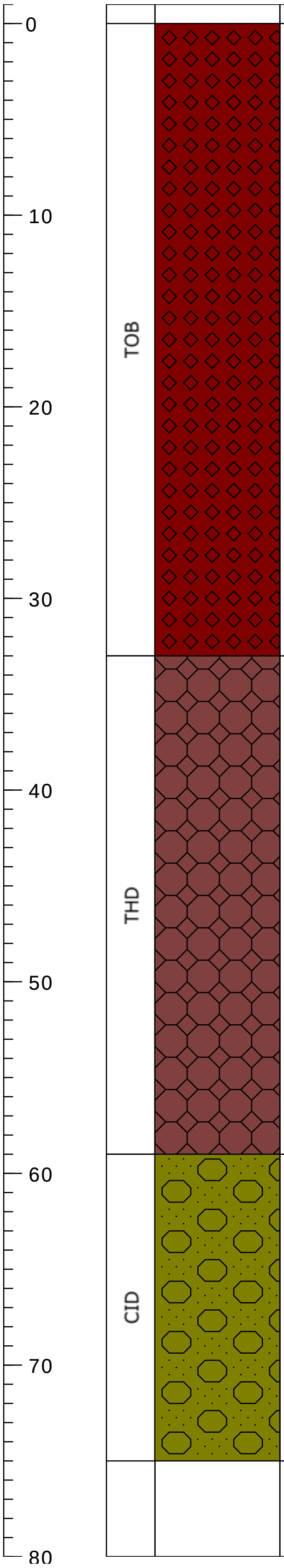
Well No: Obs 3

Client: Brockman Resources **Project:** MAR 2

Commenced:	3 June 2009	**Method:**	D.R.	**Area:**	Marillana
Completed:	5 June 2009	**Fluid:**	Water	**East:**	7499722
Drilled:	Barber Drilling	**Bit Record:**	6" (0-75m)	**North:**	728089
Logged By:	Sam Cook			**Projection:**	MGA94 Z50

Static Water Level: 40.75mbgl **Date:** 11 June 2009

Depth (mbgl) | **Geology** | **Graphic Log** | **Lithological Description** | **Field Notes** | **Well Completion** — **Diagram** | **Notes**



Lithological Description

DETRITAL: light brown, mixed fragments of BIF chert and shale, sub angular to sub rounded, medium to coarse grained, low clay content.

HAEMATITE: DETRITALS: red brown, mineralised blue grey BIF fragments, sub angular to sub rounded, medium to course grained, some well rounded, red brown, fine (1-3mm) pisolith gravel increasing in content with depth.

CID: CHANNEL IRON DEPOSIT: blue grey, cemented, vuggy goethite fragments with minor clay. Increased clay content at 74-75m.

Field Notes

Airlift developed for 3.5 hours at 5L/s
EC:1812 uS/cm pH:8.18

46mbgl: FWS
<0.5L/sec

48mbgl:
EC:994uS/cm pH:7.95

54mbgl:2.51L/s
EC:1045uS/cm pH:7.89

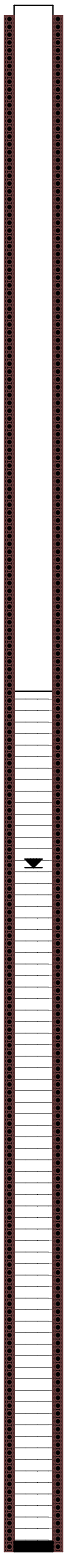
60mbgl: 5L/s
EC:1067uS/cm pH:7.85

66mbgl: 6L/s
EC:1402uS/cm pH:8.12

72mbgl: 6L/s
EC:1755uS/cm pH:8.1

75mbgl: 6L/s
EC:3.61mS/cm pH:8.06

E.O.H: 75mbgl



Notes

Dual Rotary
(0-75mbgl)

50mm plain PVC
Class 12
(0.65-33mbgl)

graded gravel pack
3.2-6.4mm
(0-75mbgl)

50mm slotted PVC
Class 12, 1mm slots
(33-75mbgl)

PVC external end cap
Class 12 (75mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 4

Client: Brockman Resources **Project:** MAR 2

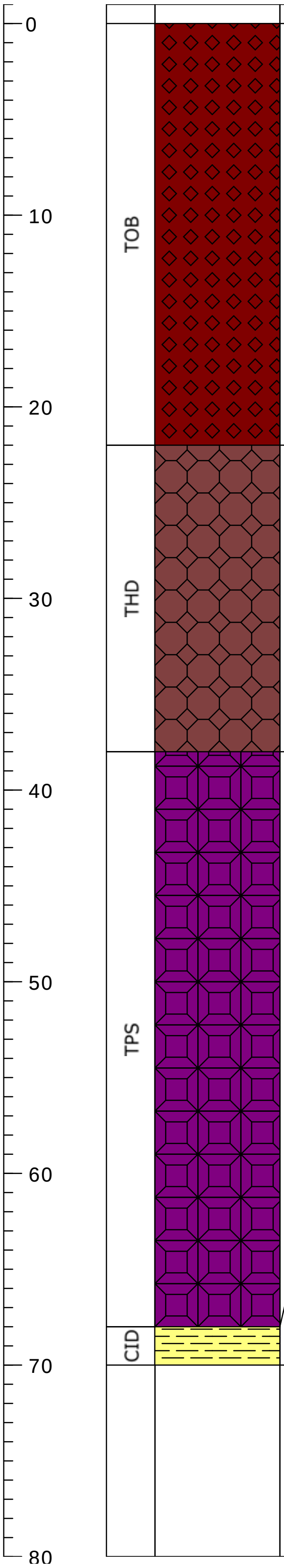
Commenced: 30 May 2009
Completed: 31 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-69m)
5"3/4' (69-70m)

Area: Marillana
East: 731879
North: 7496657
Projection: MGA94 Z50

Static Water Level: 29.07mbgl
Date: 11 June 2009

Depth (mbgl) | **Geology** | **Graphic Log**



Geology	Lithological Description
TOB	DETRITAL: red brown, fragments of BIF and chert, sub angular to sub rounded, fine to coarse grained, minor shales and low clay content.
THD	HAEMATITE: DETRITALS: red brown, mineralised blue grey BIF fragments, sub angular to sub rounded, some well rounded, red brown, fine (1-3mm) pisolith gravel incresasing in content with depth.
TPS	PISOLITE: red brown, well rounded, fine to medium grained (2-5mm), pisolith gravel, increased clay content at 50-58mbgl, pisoliths increasing in size with depth. Some blue grey BIF fragments.
CID	CLAY: yellow, weathered, goethitic, high clay content minor pisolith gravel.

Field Notes

40mbgl: F.W.S.
minor drilling yields

46mbgl: ~0.5L/s
EC :1289 uS/cm pH:7.65

52mbgl: ~1L/s
EC :1540uS/cm pH:7.57

58mbgl: ~1L/s
EC :1433uS/cm pH:7.62

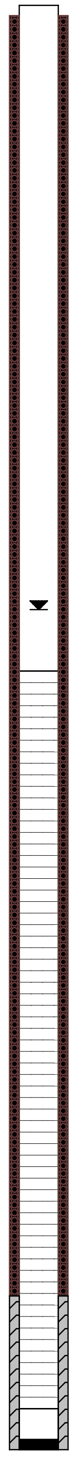
69mbgl: 0L/s
Sealed off in clays

Airlift developed for 45 mins at <1L/s
EC :1775uS/cm pH:7.91

E.O.H: 70mbgl

Well Completion

Diagram



Notes

Dual Rotary
(0-69mbgl)

50mm plain PVC
Class 12
(+0.58-32mbgl)

graded gravel pack
3.2-6.4mm
(0-62.5mbgl)

50mm slotted PVC
Class 12, 1mm slots
(32-68mbgl)

fallback in annulus
(62.5-70mbgl)

50mm plain PVC
Class 12
(68-70mbgl)

PVC external end cap
Class 12 (70mbgl)

Open hole
(69-70mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 5

Client: Brockman Resources
Project: MAR 2

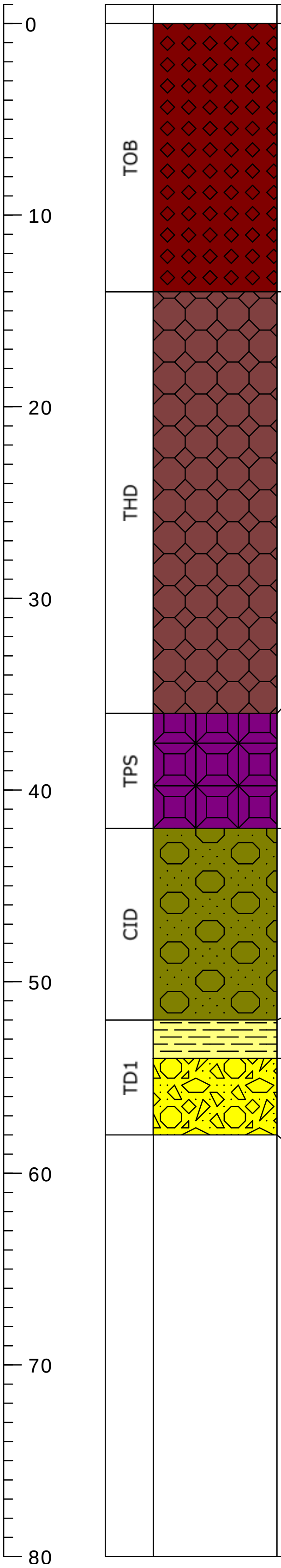
Commenced: 27 May 2009
Completed: 28 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-58m)

Area: Marillana
East: 734271
North: 7495036
Projection: MGA94 Z50

Static Water Level: 22.1mbgl
Date: 11 June 2009

Depth (mbgl) | **Geology** | **Graphic Log** | **Lithological Description** | **Field Notes** | **Well Completion** — **Diagram** / **Notes**



Lithological Description

DETRITAL: red-brown, sub-angular fragments of BIF, chert and shale, poorly consolidated, sub angular, BIF content increasing with depth, clay band at 9-10m.

HAEMATITE: DETRITALS: red-brown, weathered, fragments of sub-angular mineralised blue-grey BIF and red-brown well rounded pisolith gravels (2-3mm) increasing in content with depth. High clay content at 38-42m.

PISOLITE: DETRITALS: red-brown, well rounded pisolith gravels (2-4mm), increasing in sizewith depth, unconsolidated, high clay content at 38-40m and 4.1-42m.

CID: red brown and yellow, fragmented mineralised, vuggy goethite, some well rounded, large pisoliths (4-5mm), calcite at 50-52m.

CLAY: greenish grey, clay band.

GRAVEL: grey, fragments of goethite some BIF and chert gravel, sub angular transported material.

Field Notes

33mbgl: F.W.S.
minor drilling yields

34mbgl: <2L/s
EC :1271uS/cm pH:7.95

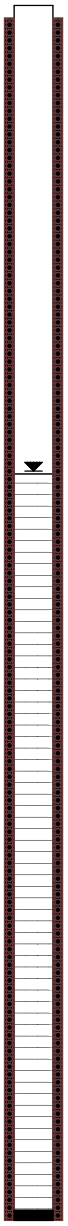
44mbgl: ~2L/s
EC :1243uS/cm pH:7.03

46mbgl: ~2L/s
EC :1464uS/cm pH:8.01

52mbgl: 0 L/s

E.O.H: 58mbgl

Well Completion



Notes

Dual Rotary
(0-58mbgl)

50mm plain PVC
Class 12
(+0.75-22mbgl)

graded gravel pack
3.2-6.4mm
(0-58mbgl)

50mm slotted PVC
Class 12, 1mm slots
(22-58mbgl)

PVC external end cap
Class 12 (58mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 6

Client: Brockman Resources **Project:** MAR 2

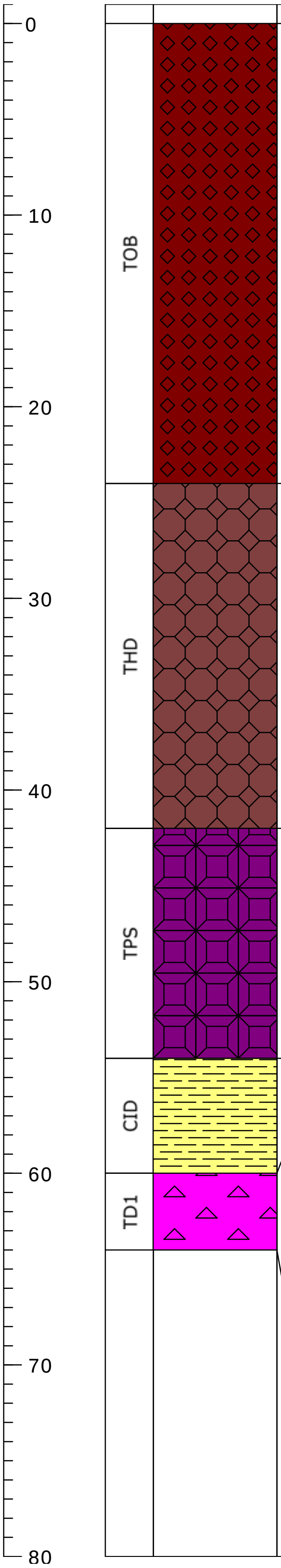
Commenced: 3 May 2009
Completed: 4 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R. / D.H.H.
Fluid: Water
Bit Record: 6" (0-63m)
5"7/8' (63-64m)

Area: Marillana
East: 730788
North: 7497749
Projection: MGA94 Z50

Static Water Level: 32.55mbgl **Date:** 11 June 2009

Depth (mbgl) | **Geology** | **Graphic Log** | **Lithological Description** | **Field Notes** | **Well Completion** **Diagram** | **Notes**



Geology	Lithological Description
TOB	DETRITAL: red-brown, sub-angular fragments of BIF, chert and shale, poorly consolidated. Low clay content.
THD	HAEMATITE: DETRITALS: red-brown, weathered, fragments of sub-angular mineralised blue-grey BIF, red-brown well rounded pisoliths (2-3mm) increasing in content with depth.
TPS	PISOLITE: DETRITALS: red-brown, well rounded pisolith balls (2-6mm) increasing in size with depth, some clay at 53-54mbgl.
CID	CLAY: yellow-brown limonitic clay, low permeability, minor transported gravels (pisoliths, chert fragments).
TD1	CHERTY GRAVEL: yellow-brown, red-brown coarse sub-angular ferruginised chert, some mineralised vuggy vitreous goethite and blue-grey BIF, minor white/opaque quartz. Semi-cemented, poorly consolidated, minor clay content.

Field Notes

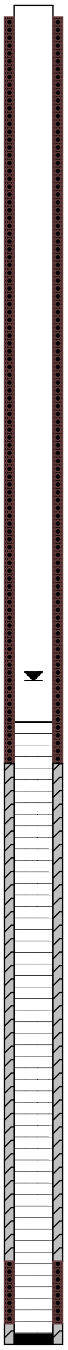
32mbgl: F.W.S.
minor drilling yields

38mbgl: <0.5L/s
EC :1505uS/cm pH:7.85

44mbgl: ~1L/s
EC :1579uS/cm pH:7.93

50mbgl: ~1L/s
EC :1462uS/cm pH:7.9

56mbgl: 0L/s
EC :1079uS/cm pH:7.94



Notes

Dual Rotary
(0-63mbglmbgl)
Open Hole
(63-64mbgl)

50mm plain PVC
Class 12
(+0.5-34mbgl)

graded gravel pack
3.2-6.4mm
(0-36mbgl & 60-64mbgl)

50mm slotted PVC
Class 12, 1mm slots
(34-64mbgl)

Fallback in annulus
(36-60mbgl)

PVC external end cap
Class 12 (64mbgl)

Fallback in annulus
(63-64mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 7

Client: Brockman Resources
Project: MAR 2

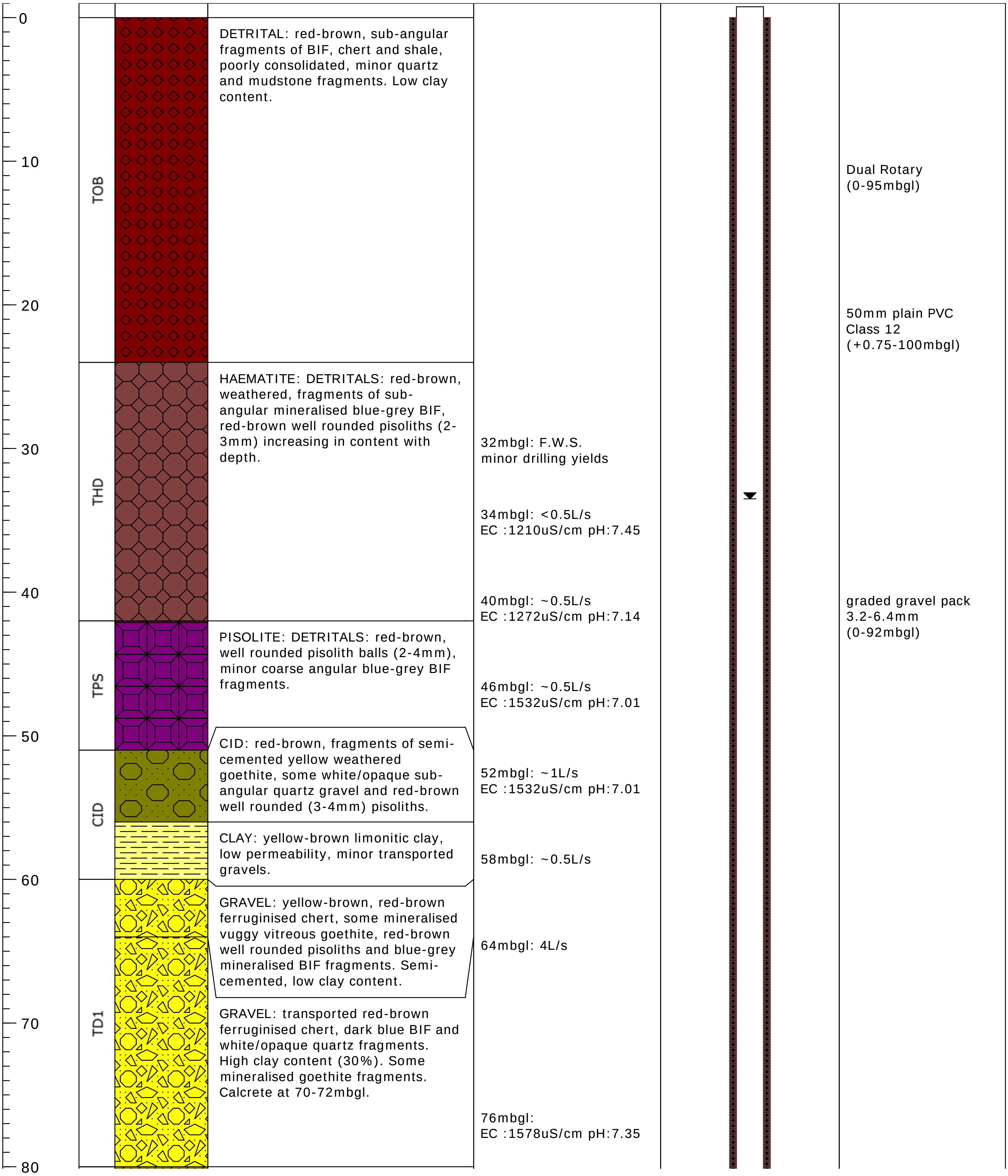
Commenced: 23 April 2009
Completed: 30 April 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R. / D.H.H.
Fluid: Water
Bit Record: 6" (0-95m)
5" 7/8' (95-148.5m)

Area: Marillana
East: 730760
North: 7497788
Projection: MGA94 Z50

Static Water Level: 33.59mbgl
Date: 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion: Diagram	Well Completion: Notes



DETRITAL: red-brown, sub-angular fragments of BIF, chert and shale, poorly consolidated, minor quartz and mudstone fragments. Low clay content.

HAEMATITE: DETRITALS: red-brown, weathered, fragments of sub-angular mineralised blue-grey BIF, red-brown well rounded pisoliths (2-3mm) increasing in content with depth.

PISOLITE: DETRITALS: red-brown, well rounded pisolith balls (2-4mm), minor coarse angular blue-grey BIF fragments.

CID: red-brown, fragments of semi-cemented yellow weathered goethite, some white/opaque sub-angular quartz gravel and red-brown well rounded (3-4mm) pisoliths.

CLAY: yellow-brown limonitic clay, low permeability, minor transported gravels.

GRAVEL: yellow-brown, red-brown ferruginised chert, some mineralised vuggy vitreous goethite, red-brown well rounded pisoliths and blue-grey mineralised BIF fragments. Semi-cemented, low clay content.

GRAVEL: transported red-brown ferruginised chert, dark blue BIF and white/opaque quartz fragments. High clay content (30%). Some mineralised goethite fragments. Calcrete at 70-72mbgl.

32mbgl: F.W.S.
minor drilling yields

34mbgl: <0.5L/s
EC :1210uS/cm pH:7.45

40mbgl: ~0.5L/s
EC :1272uS/cm pH:7.14

46mbgl: ~0.5L/s
EC :1532uS/cm pH:7.01

52mbgl: ~1L/s
EC :1532uS/cm pH:7.01

58mbgl: ~0.5L/s

64mbgl: 4L/s

76mbgl:
EC :1578uS/cm pH:7.35

Dual Rotary
(0-95mbgl)

50mm plain PVC
Class 12
(+0.75-100mbgl)

graded gravel pack
3.2-6.4mm
(0-92mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

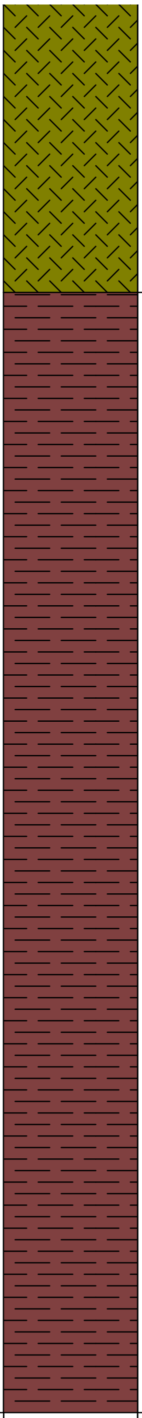
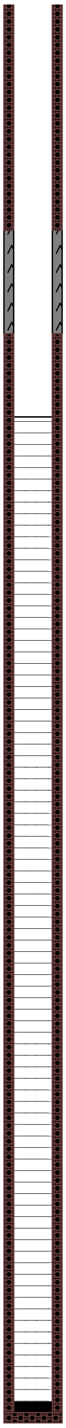
COMPOSITE WELL LOG

Well No: Obs 7

Client: Brockman Resources **Project:** MAR 2

Commenced:	23 April 2009	**Method:**	D.R. / D.H.H.	**Area:**	Marillana
Completed:	30 April 2009	**Fluid:**	Water	**East:**	730760
Drilled:	Barber Drilling	**Bit Record:**	6" (0-95m) 5" 7/8' (95-148.5m)	**North:**	7497788
Logged By:	Sam Cook			**Projection:**	MGA94 Z50

Static Water Level: 33.59mbgl **Date:** 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
80	Basement (Mt Sylvia Formation)		WEATHERED BASEMENT: green-grey, residual clay, some transported gravels, chert and quartz minor sandstone, weathered and unconsolidated matrix.	82mbgl: ~2L/s EC :1578uS/cm pH:7.35 88mbgl: EC:5.99mS/cm pH:7.17		
90			SHALE AND CHERT: blue-grey, fresh rock, very coarse and hard, angular chippings, some black shale horizons with interbedded white chert. High silica content.	94mbgl: EC:13.0mS/cm pH:7.3		bentonite grout seal (92-97mbgl)
100				100mbgl: 1.25L/s EC:13.63mS/cm pH:7.44		Down Hole Hammer (95-148mbgl)
110				112mbgl: 1.25L/s EC:13.73mS/cm pH:7.63 118mbgl: 1.5L/s EC:13.55mS/cm pH:7.69		50mm slotted PVC Class 12, 1mm slots (100-148mbgl)
120				124mbgl: 1.25L/s EC:13.19mS/cm pH:7.62		graded gravel pack 3.2-6.4mm (96-148mbgl)
130				124mbgl: 1L/s EC:12.75mS/cm pH:7.6 136mbgl: 1.25L/s EC:12.93mS/cm pH:7.71		
140				142mbgl: 1L/s EC:17.76mS/cm pH:7.34 148mbgl: 1L/s EC:22.25mS/cm pH:7.77		PVC external end cap Class 12 (148mbgl)
150				E.O.H: 148.5mbgl		Fallback (148-148.5mbgl)
160						

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 8

Client: Brockman Resources
Project: MAR 2

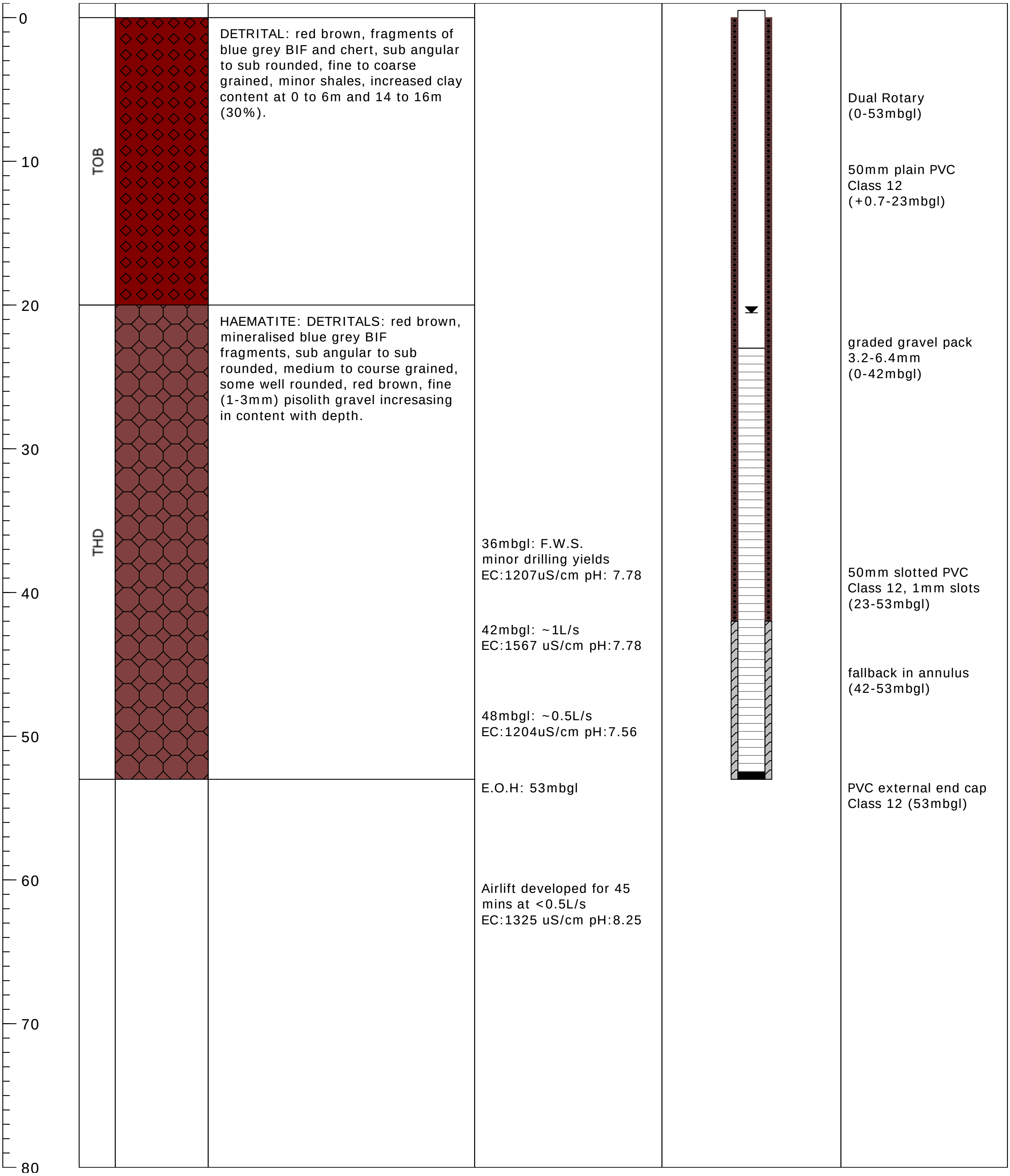
Commenced: 1 June 2009
Completed: 3 June 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-53m)

Area: Marillana
East: 731351
North: 7498261
Projection: MGA94 Z50

Static Water Level: 20.65mbgl
Date: 11 June 2009

Depth (mbgl)	**Geology**	**Graphic Log**	**Lithological Description**	**Field Notes**	**Well Completion** Diagram	**Well Completion** Notes



Lithological Description

DETRITAL: red brown, fragments of blue grey BIF and chert, sub angular to sub rounded, fine to coarse grained, minor shales, increased clay content at 0 to 6m and 14 to 16m (30%).

HAEMATITE: DETRITALS: red brown, mineralised blue grey BIF fragments, sub angular to sub rounded, medium to course grained, some well rounded, red brown, fine (1-3mm) pisolith gravel incresasing in content with depth.

Field Notes

36mbgl: F.W.S.
minor drilling yields
EC:1207uS/cm pH: 7.78

42mbgl: ~1L/s
EC:1567 uS/cm pH:7.78

48mbgl: ~0.5L/s
EC:1204uS/cm pH:7.56

E.O.H: 53mbgl

Airlift developed for 45 mins at <0.5L/s
EC:1325 uS/cm pH:8.25

Notes

Dual Rotary (0-53mbgl)

50mm plain PVC Class 12 (+0.7-23mbgl)

graded gravel pack 3.2-6.4mm (0-42mbgl)

50mm slotted PVC Class 12, 1mm slots (23-53mbgl)

fallback in annulus (42-53mbgl)

PVC external end cap Class 12 (53mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

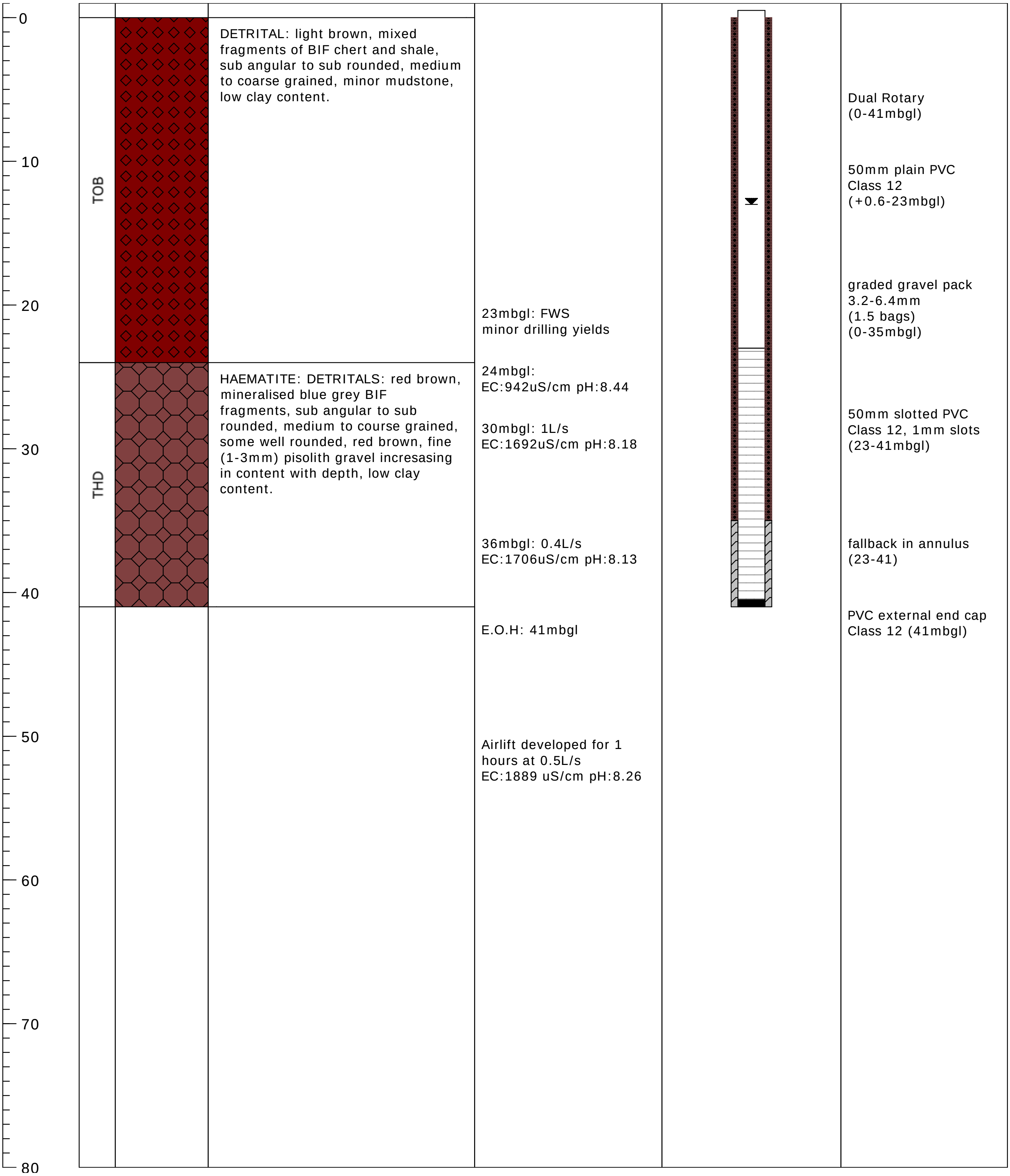
Well No: Obs 9

Client: Brockman Resources
Project: MAR 2

Commenced:	7 June 2009	**Method:**	D.R.	**Area:**	Marillana
Completed:	7 June 2009	**Fluid:**	Water	**East:**	730564
Drilled:	Barber Drilling	**Bit Record:**	6" (0-41m)	**North:**	7500148
Logged By:	Sam Cook			**Projection:**	MGA94 Z50

Static Water Level: 13.15mbgl
Date: 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
0–24	TOB		DETRITAL: light brown, mixed fragments of BIF chert and shale, sub angular to sub rounded, medium to coarse grained, minor mudstone, low clay content.	23mbgl: FWS minor drilling yields		Dual Rotary (0-41mbgl) 50mm plain PVC Class 12 (+0.6-23mbgl) graded gravel pack 3.2-6.4mm (1.5 bags) (0-35mbgl)
24–41	THD		HAEMATITE: DETRITALS: red brown, mineralised blue grey BIF fragments, sub angular to sub rounded, medium to course grained, some well rounded, red brown, fine (1-3mm) pisolith gravel incresasing in content with depth, low clay content.	24mbgl: EC:942uS/cm pH:8.44 30mbgl: 1L/s EC:1692uS/cm pH:8.18 36mbgl: 0.4L/s EC:1706uS/cm pH:8.13		50mm slotted PVC Class 12, 1mm slots (23-41mbgl) fallback in annulus (23-41)
41–				E.O.H: 41mbgl Airlift developed for 1 hours at 0.5L/s EC:1889 uS/cm pH:8.26		PVC external end cap Class 12 (41mbgl)



aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 10

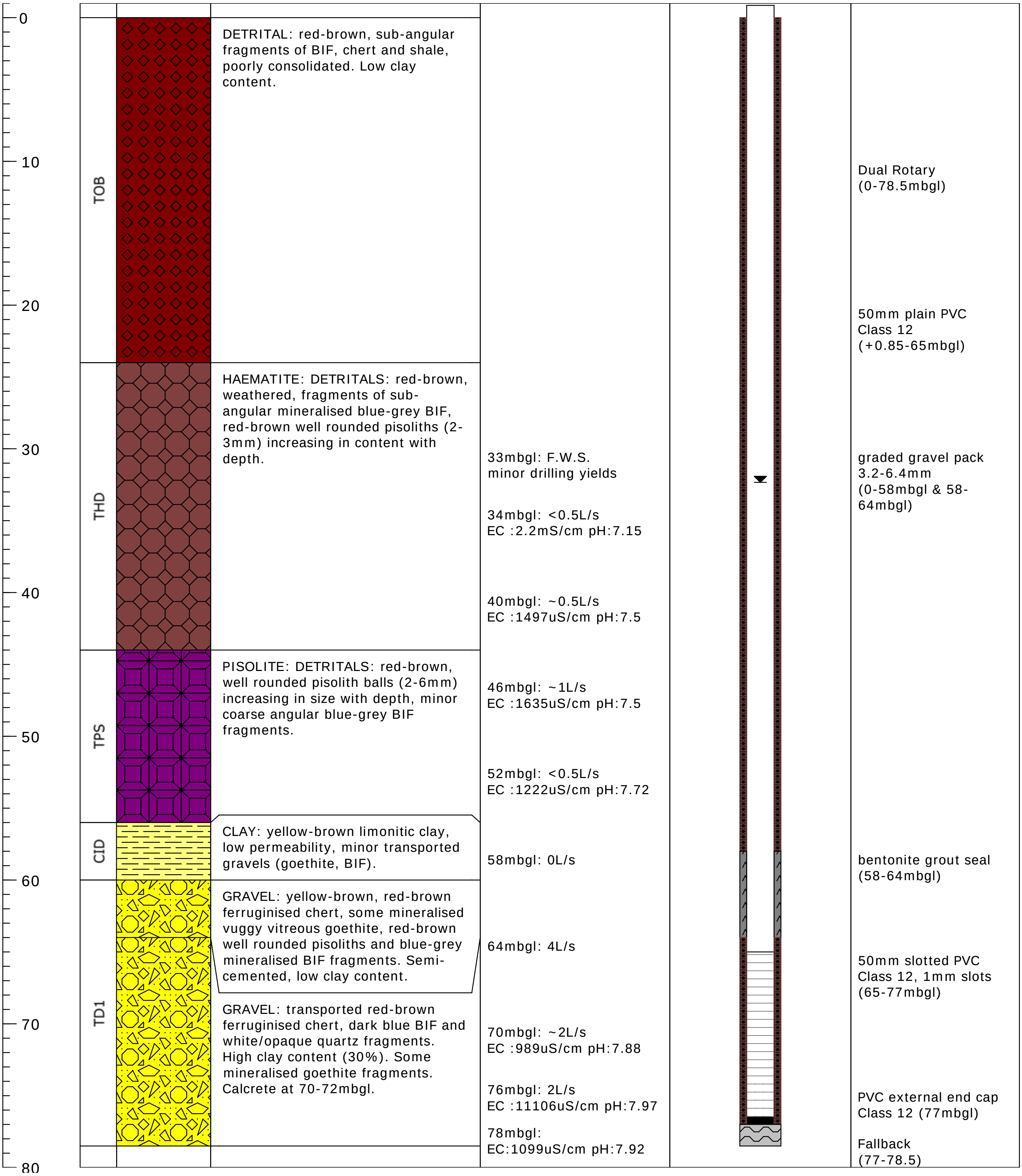
Client: Brockman Resources
Project: MAR 2

Commenced: 30 April 2009
Completed: 2 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-78.5m)

Area: Marillana
East: 730755
North: 7497784
Projection: MGA94 Z50

Static Water Level: 32.47mbgl
Date: 11 June 2009



Geology	Lithological Description
TOB	DETRITAL: red-brown, sub-angular fragments of BIF, chert and shale, poorly consolidated. Low clay content.
THD	HAEMATITE: DETRITALS: red-brown, weathered, fragments of sub-angular mineralised blue-grey BIF, red-brown well rounded pisoliths (2-3mm) increasing in content with depth.
TPS	PISOLITE: DETRITALS: red-brown, well rounded pisolith balls (2-6mm) increasing in size with depth, minor coarse angular blue-grey BIF fragments.
CID	CLAY: yellow-brown limonitic clay, low permeability, minor transported gravels (goethite, BIF).
TD1	GRAVEL: yellow-brown, red-brown ferruginised chert, some mineralised vuggy vitreous goethite, red-brown well rounded pisoliths and blue-grey mineralised BIF fragments. Semi-cemented, low clay content.
	GRAVEL: transported red-brown ferruginised chert, dark blue BIF and white/opaque quartz fragments. High clay content (30%). Some mineralised goethite fragments. Calcrete at 70-72mbgl.

Field Notes

33mbgl: F.W.S.
minor drilling yields

34mbgl: <0.5L/s
EC :2.2mS/cm pH:7.15

40mbgl: ~0.5L/s
EC :1497uS/cm pH:7.5

46mbgl: ~1L/s
EC :1635uS/cm pH:7.5

52mbgl: <0.5L/s
EC :1222uS/cm pH:7.72

58mbgl: 0L/s

64mbgl: 4L/s

70mbgl: ~2L/s
EC :989uS/cm pH:7.88

76mbgl: 2L/s
EC :11106uS/cm pH:7.97

78mbgl:
EC:1099uS/cm pH:7.92

Notes

Dual Rotary
(0-78.5mbgl)

50mm plain PVC
Class 12
(+0.85-65mbgl)

graded gravel pack
3.2-6.4mm
(0-58mbgl & 58-64mbgl)

bentonite grout seal
(58-64mbgl)

50mm slotted PVC
Class 12, 1mm slots
(65-77mbgl)

PVC external end cap
Class 12 (77mbgl)

Fallback
(77-78.5)

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 11

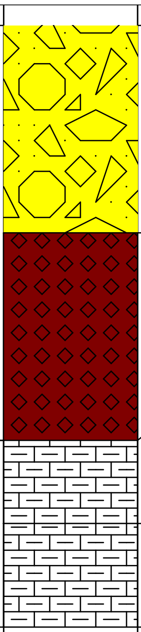
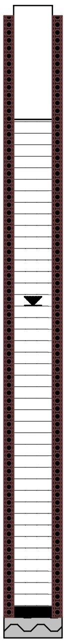
Client: Brockman Resources **Project:** MAR 2

Commenced: 8 June 2009
Completed: 9 June 2009
Drilled: Barber Drilling
Logged By: Damien Jansen

Method: D.R.
Fluid: Water
Bit Record: 6" (0-29m)
5.75"(29-30m)

Area: Marillana
East: 737306
North: 7500645
Projection: MGA94 Z50

Static Water Level: 13.96mbgl **Date:** 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
0	TOB		Alluvium: red-brown, sub-angular to sub rounded gravel (BIF, chert and shale), minor fragments of weathered calcrete. Variable clay content, relatively high.			50mm plain PVC Class 12 (+0.5-5mbgl) Dual Rotary (0-29mbgl)
10			DETRITAL: red-brown, sub angular to sub-rounded, BIF, chert and shale, minor mineralisation and pisolitic gravel.			50mm slotted PVC Class 12, 3mm slots (5-29mbgl) graded gravel pack 3.2-6.4mm (0-29mbgl)
20	XCC		CALCRETE: red brown, clay rich, weathered calrete, minor hematite pisolith gravel. CALCRETE: cream-white, hard, siliceous to 28mbgl and calcareous from 28mbgl.	24mbgl: EC :1235uS/cm pH:8.38		PVC external end cap Class 12 (29mbgl)
30				30mbgl: ~1L/s EC :1794uS/cm pH:8.34 EOH 30mbgl.		Fallback (29-30mbgl)
40						
50						
60						
70						
80						

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 12

Client: Brockman Resources
Project: MAR 2

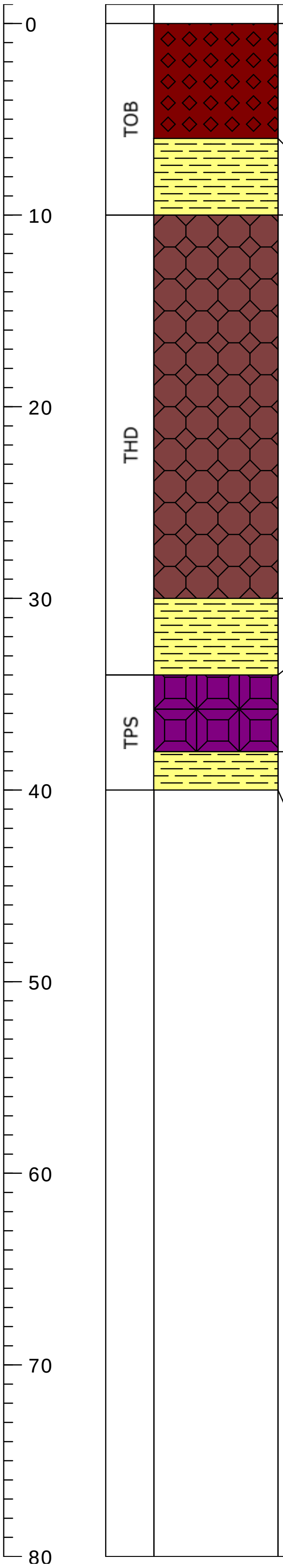
Commenced: 27 May 2009
Completed: 28 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-40m)

Area: Marillana
East: 734763
North: 7495192
Projection: MGA94 Z50

Static Water Level: 17.65mbgl
Date: 11 June 2009

Depth (mbgl) | **Geology** | **Graphic Log** | **Lithological Description** | **Field Notes** | **Well Completion** – **Diagram** | **Notes**



Lithological Description

DETRITAL: red-brown, sub-angular fragments of BIF, some chert and shale, poorly consolidated, sub angular, BIF content increasing with depth.

CLAY: red brown.

HAEMATITE: DETRITALS: red-brown, fragments of mineralised BIF, sub angular with some fine grained well rounded pisolith gravel (1-2mm).

CLAY: red brown, thick clay band.

PISOLITE: red brown well rounded, fine grained (1-2mm), pisolth gravel.

CLAY: red brown, thick clay band, minor pisolith gravel.

Field Notes

22mbgl: F.W.S.
minor drilling yields

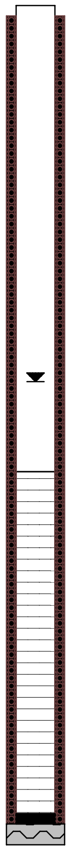
28mbgl: <2L/s
EC :1421uS/cm pH:7.88

34mbgl: <2L/s
EC :1135uS/cm pH:7.82

Airlift developed for 40 mins at <2L/s
EC :1127uS/cm pH:8.28

E.O.H: 40mbgl

Well Completion Diagram



Notes

Dual Rotary
(0-40mbgl)

50mm plain PVC
Class 12
(+0.5-22mbgl)

graded gravel pack
3.2-6.4mm
(0-40mbgl)

50mm slotted PVC
Class 12, 1mm slots
(22-39mbgl)

fallback
(39-40mbgl)

PVC external end cap
Class 12 (39mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 13

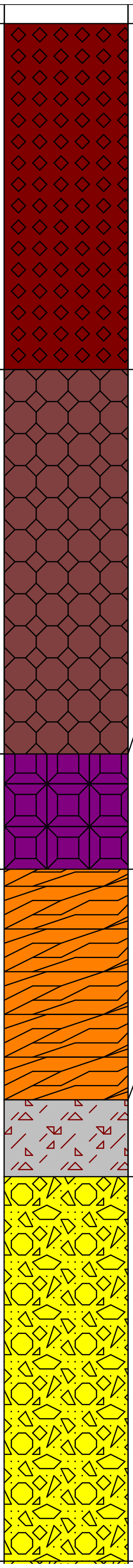
Client: Brockman Resources
Project: MAR 2

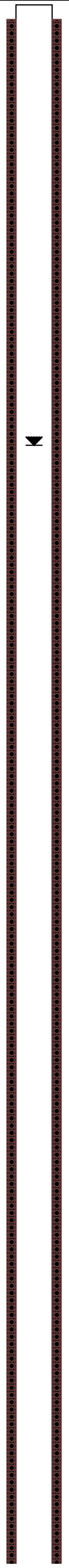
Commenced: 20 May 2009
Completed: 25 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: Dual Rotary
Fluid: Water
Bit Record: 6" 0-107m)
5 "3/4' (107-148m)

Area: Marillana
East: 734293
North: 7495041
Projection: MGA94 Z50

Static Water Level: 22.1mbgl
Date: 26 May 2009





Depth (mbgl)	**Geology**	**Lithological Description**	**Field Notes**	**Well Completion Notes**
0 10	TOB	DETRITAL: red brown, blue fragmented BIF and chert, unconsolidated loose material, sub angular. Increased clay content at 8-12m.		Dual Rotary (0-107mbgl)
20 30	THD	HAEMATITE: DETRITALS, red brown, fragmented BIF mineralised and well weathered, some well rounded red brown pisoliths (2-3mm grains), content increasing with depth, uncemented and low clay content.		50mm plain PVC Class 12 (+0.8-113.5mbgl)
40	TPS	PISOLITE: DETRITALS, red brown, well rounded pisolith gravel, medium to coarse grained increasing in grain size with depth (2-5mm), unconsolidated with low clay content.	First water strike at 40m.	graded gravel pack 3.2-6.4mm (0-106mbgl)
50	CID	GOETHITE & CLAY: red brown and yellow to white, fragmented and mineralised goethite, vuggy and weathered, evidence of cementing with minor pisolite gravels and BIF fragments.	46mbgl: ~0.5L/s EC :1336uS/cm pH:7.98 52mbgl: ~2L/s EC :2005uS/cm pH:8.07	
		CLAY AND GRAVEL: yellow and white goethitic clay with fragmented goethite and well rounded pisolite gravels.		
60 70 80		GRAVEL: white and grey, well weathered, mineralised, vuggy, fragmented, brown goethite gravels some chert and BIF fragments. Low grade.	70mbgl: 3.5L/s EC :1604uS/cm pH:8.25 76mbgl: 4.5L/s EC :1585uS/cm pH:8.18	

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

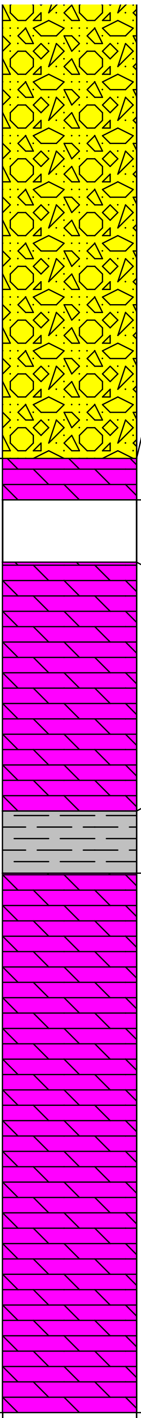
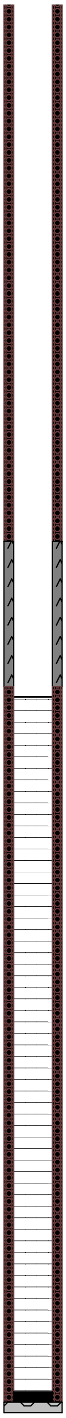
COMPOSITE WELL LOG

Well No: Obs 13

Client: Brockman Resources **Project:** MAR 2

Commenced:	20 May 2009	**Method:**	Dual Rotary	**Area:**	Marillana
Completed:	25 May 2009	**Fluid:**	Water	**East:**	734293
Drilled:	Barber Drilling	**Bit Record:**	6" 0-107m)	**North:**	7495041
Logged By:	Sam Cook		5 "3/4' (107-148m)	**Projection:**	MGA94 Z50

Static Water Level: 22.1mbgl **Date:** 26 May 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
80–101.8	TD1		GRAVEL: grey blue, fragmented sub rounded to sub angular chert gravels, colluvial deposit some BIF and quartz, high clay content at 74-78m.	76mbgl: EC :1493uS/cm pH:7.95 94mbgl: 2.5L/s EC :1304uS/cm pH:8.09		
101.8–104	BASEMENT (Wittenoom Formation)		DOLOMITE: light blue, white calcite veining, very course fresh rock, angular returns.	100mbgl: ~2.5L/s EC :2021uS/cm pH:8.05		
104–107			VOID: cavity, some orange clay infill.	106mbgl: ~2L/s EC :2.67mS/cm pH:7.95		bentonite grout seal (106-113mbgl)
107–119			DOLOMITE: light blue, white calcite veining, very course fresh rock, angular returns.	112mbgl: 6L/s EC :3.2mS/cm pH:8.1		graded gravel pack 3.2-6.4mm (113.5-147.5mbgl)
119–122			SHALE: dark grey to black, coarse and hard, angular returns.			Down Hole Hammer (107-148mbgl)
122–148			DOLOMITE: light blue, white calcite veining, very course fresh rock, thin layers of dark grey shale at 133-140 and 148-148..	122mbgl: 7L/s EC :3.8mS/cm pH:8.27 128mbgl: 8.5L/s EC :6.56mS/cm pH:8.16 134mbgl: EC :8.33mS/cm pH:8.26 140mbgl: EC :6.82mS/cm pH:8.19 146mbgl: EC :7.35mS/cm pH:8.16		50mm slotted PVC Class 12, 1mm slots (113.5-147.5mbgl) PVC external end cap Class 12 (147.5mbgl) Fallback (147.5-148mbgl)
148–160				E.O.H: 147.5mbgl		

Depth scale: 80, 90, 100, 110, 120, 130, 140, 150, 160

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

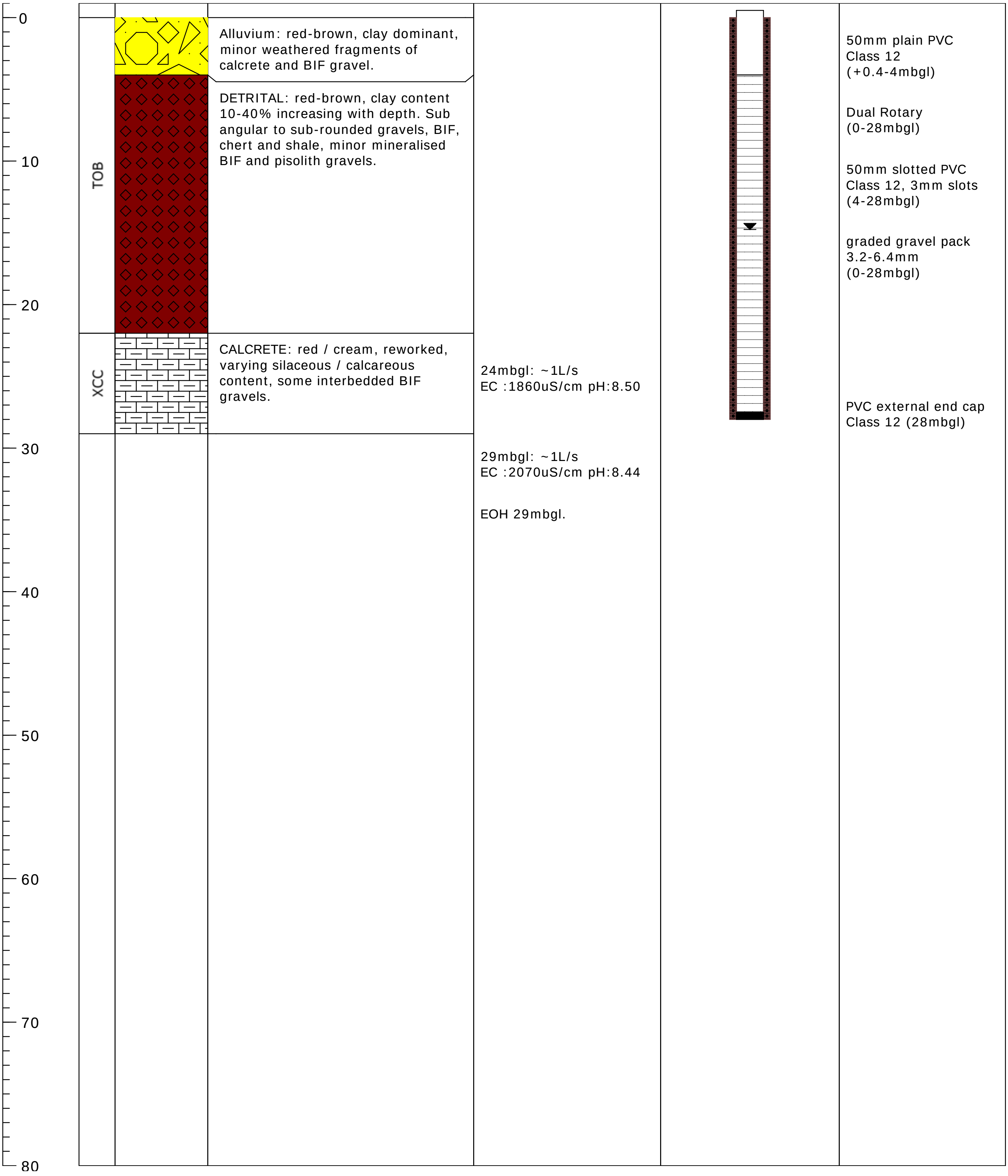
Well No: Obs 14

Client: Brockman Resources **Project:** MAR 2

Commenced:	9 June 2009	**Method:**	D.R.	**Area:**	Marillana
Completed:	10 June 2009	**Fluid:**	Water	**East:**	734779
Drilled:	Barber Drilling	**Bit Record:**	6" (0-28m)	**North:**	7499356
Logged By:	Damien Jansen		5.75"(28-29m)	**Projection:**	MGA94 Z50

Static Water Level: 14.77mbgl **Date:** 13 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



Alluvium: red-brown, clay dominant, minor weathered fragments of calcrete and BIF gravel.

DETRITAL: red-brown, clay content 10-40% increasing with depth. Sub angular to sub-rounded gravels, BIF, chert and shale, minor mineralised BIF and pisolith gravels.

CALCRETE: red / cream, reworked, varying silaceous / calcareous content, some interbedded BIF gravels.

24mbgl: ~1L/s
EC :1860uS/cm pH:8.50

29mbgl: ~1L/s
EC :2070uS/cm pH:8.44

EOH 29mbgl.

50mm plain PVC
Class 12
(+0.4-4mbgl)

Dual Rotary
(0-28mbgl)

50mm slotted PVC
Class 12, 3mm slots
(4-28mbgl)

graded gravel pack
3.2-6.4mm
(0-28mbgl)

PVC external end cap
Class 12 (28mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 15

Client: Brockman Resources
Project: MAR 2

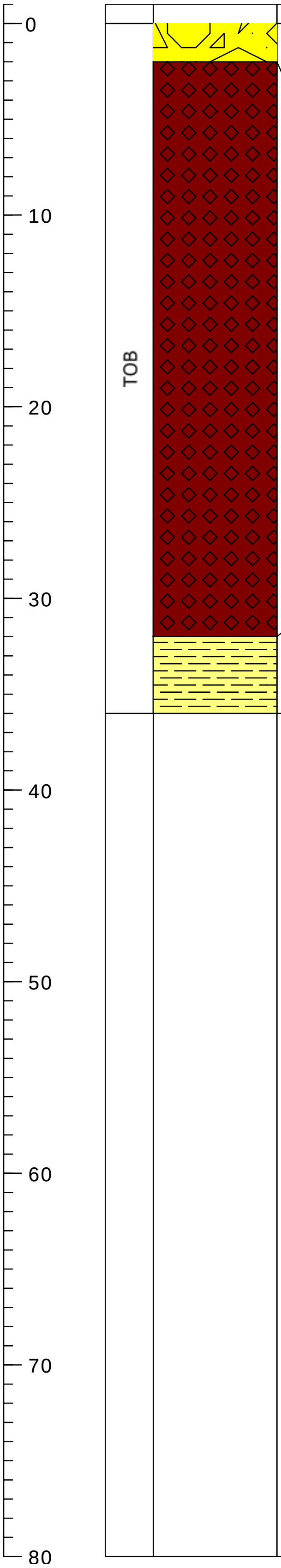
Commenced: 10 June 2009
Completed: 11 June 2009
Drilled: Barber Drilling
Logged By: Damien Jansen

Method: D.R.
Fluid: Water
Bit Record: 6" (0-36)

Area: Marillana
East: 726296
North: 7504594
Projection: MGA94 Z50

Static Water Level: 9.58mbgl
Date: 13 June 2009

Depth (mbgl)	**Geology**	**Graphic Log**	**Lithological Description**	**Field Notes**	**Well Completion** Diagram	**Well Completion** Notes



Alluvium: red-brown, clay rich, minor angular gravel.

DETRITAL: garvels sub angular to sub-rounded, red-brown, BIF, shale and chert, generally low clay content, clay rich at 20-24m and 26-28m.

CLAY: red-brown, minor fragments of detrital gravels, BIF, chert and shale.

12m: FWS

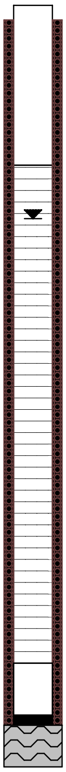
15mbgl: <1L/s
EC :3.22mS/cm pH:8.52

24:1L/s
EC:3.46mS/cm pH:8.37

30mbgl: ~1L/s
EC :4.14mS/cm pH:8.37

EOH 36mbgl.

Final airlift : ~1L/s
EC: 4.30mS/cm pH:8.58



50mm plain PVC
Class 12
(+0.7-7mbgl)

Dual Rotary
(0-34mbgl)

50mm slotted PVC
Class 12, 3mm slots
(7-31mbgl)

graded gravel pack
3.2-6.4mm
(0-34mbgl)

50mm plain PVC
Class 12
(31-34mbgl)

PVC external end cap
Class 12 (34mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 16

Client: Brockman Resources
Project: MAR 2

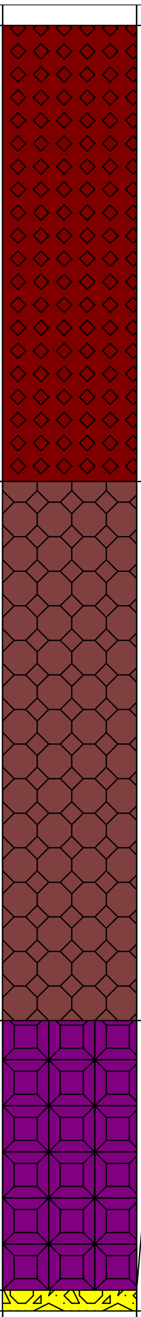
Commenced: 18 April 2009
Completed: 19 April 2009
Drilled: Barber Drilling
Logged By: Damien Jansen

Method: Dual Rotary
Fluid: Water
Bit Record: 6" (0-62m)

Area: Marillana
East: 727141
North: 7501009
Projection: MGA94 Z50

Static Water Level: 30.05mbgl
Date: 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description
0	TOB		DETRITAL: TERTIARY DETRITALS: red-brown, fragments of BIF, thinly bedded shales and chert, very minor red-brown clay.
10			
20	THD		HAEMATITE: TERTIARY HAEMATITE DETRITALS: red-brown, blue-grey BIF fragments, sub-angular to sub-rounded, pisolitic gravel (content increasing with depth), minor clay.
30			
40			
50	TPS		PISOLITE: red-brown, pisolitic gravels (1-4mm), blue-grey BIF fragments, goethitic sections, increasing clay content 54-61m.
			GRAVEL: yellow-brown colour change, high clay content, fragments of blue-grey BIF, minor yellow-brown and white chert, occassional clear quartz fragments, transported material.
60	TD		
70			
80			



Field Notes

First water strike at 32m minor drilling yield.

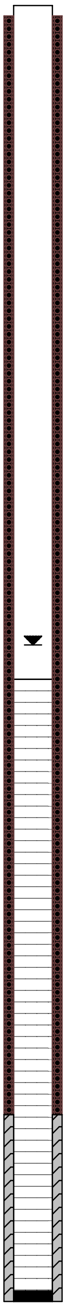
Minor drilling yield (40mbgl)

Drilling yield <0.5L/s
EC : 2.87mS/cm
(58mbgl)

Airlift developed for 2.5hrs
EC : 3.15mS/cm

Well Completion

Diagram



Notes

50mm plain PVC Class 12 (+0.56-32mbgl)

graded gravel pack 3.2-6.4mm (0-53mbgl)

50mm slotted PVC Class 12, 1mm slots (32-62mbgl)

fallback in annulus (53-62mbgl)

PVC external end cap Class 12 (62mbgl)

aquaterra

Suite 4, 125 Melville Parade
Como WA 6152
Australia
Tel: (+61) (08) 9368 4044
Fax: (+61) (08) 9368 4055
www.aquaterra.com.au

COMPOSITE WELL LOG

Well No: Obs 17

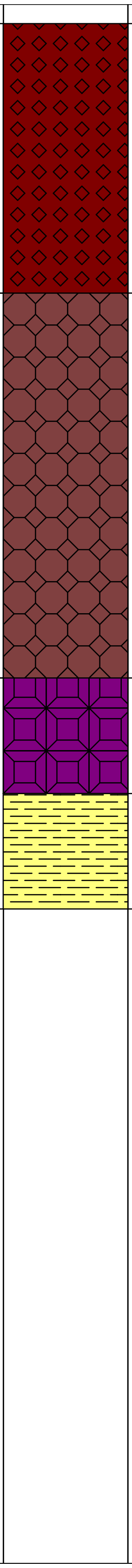
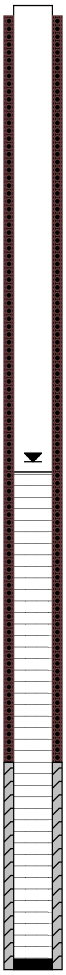
Client: Brockman Resources **Project:** MAR 2

Commenced: 29 May 2009
Completed: 30 May 2009
Drilled: Barber Drilling
Logged By: Sam Cook

Method: D.R.
Fluid: Water
Bit Record: 6" (0-46m)

Area: Marillana
East: 736731
North: 7493174
Projection: MGA94 Z50

Static Water Level: 21.4mbgl **Date:** 11 June 2009

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
0 10	TOB		DETRITAL: red-brown, sub-angular to sub-rounded fragmented BIF and chert, poorly consolidated, some coarse BIF (8 to 12mbgl).			Dual Rotary (0-46mbgl)
20 30	THD		HAEMATITE: DETRITALS: red-brown, fragments of mineralised blue-grey BIF, sub angular with some fine grained well rounded pisolith gravel (2-3mm) increasing in content with depth.	24mbgl: F.W.S. minor drilling yields 28mbgl: ~2L/s EC :1045 uS/cm pH:6.11 34mbgl: <2L/s EC :735uS/cm pH:6.63		50mm plain PVC Class 12 (+0.5-22mbgl) graded gravel pack 3.2-6.4mm (0-36mbgl) 50mm slotted PVC Class 12, 1mm slots (22-46mbgl)
	TPS		PISOLITE: red brown well rounded, fine grained (2-3mm), pisolth gravel, some BIF fragments, some clay (20%) at 34-48mbgl.			fallback in annulus (36-46mbgl)
40			CLAY: red brown, dense thick clay band, low permeability, some pisolith gravel.	Airlift developed for 40 mins at <2L/s EC :560uS/cm pH:7.39		
50 60 70 80				E.O.H: 46mbgl		PVC external end cap Class 12 (46mbgl)

APPENDIX C 26D LICENCES

Department of Water
Government of Western Australia

3 0 MAR 2009

Our ref: RF2841
WRD061078

Enquiries: Kevin Hopkinson
Telephone: (08) 9144 2000

Brendan Hynes
Brockman Resources Limited
PO Box 141
Nedlands
PERTH WA 6909

Dear Mr. Hynes,

Re: Issue of a Licence to Construct or Alter Well
Licence: CAW168340/CAW168341
Expiry: 23rd March 2011
Property: E47/1408-Marillana Iron Ore Project

I refer to your application for a 26D Licence to Construct or Alter Wells which was received by the Department of Water on the 22nd December 2008 for the construction of 20 non-artesian well(s) within tenement E47/1408.

Preliminary assessment indicates that there are several populations of Priority 4 mammals located within the project area. If you have any queries, please contact the Department of Environment and Conservation on (08) 9182 2000 for further information.

Please find enclosed your Licence, authorising you to Construct or Alter a Well, subject to certain terms, conditions or restrictions.

It is important that you read the conditions of your licence carefully. If you do not understand your licence, please contact the Department as soon as possible, as there are penalties for failing to comply with all of your licence conditions. Under Section 26GI of the *Rights in Water and Irrigation Act 1914*, you have a right to apply to the State Administrative Tribunal for a review of the decision to Issue a *Licence to Construct or Alter a Well.* You have 28 days from the date you received this letter to request that the decision be reviewed.

For further information please contact the State Administrative Tribunal:

State Administrative Tribunal
12 St Georges Terrace
PERTH WA 6000

GPO Box U1991
PERTH WA 6845

Telephone: (08) 9219 3111
Toll-free: 1300 306 017
Facsimile: (08) 9202 1180
www.sat.justice.wa.gov.au

Under section 21 of the *State Administrative Tribunal Act 2004*, you have a right to request a written statement of reasons for the decision to Issue a *Licence to Construct or Alter a Well.* This request must be made, in writing, to the Department of Water within 28 days after the day on which you received this letter.

Within one month of completing the well, you are required to submit **Form L – Particulars of Completed Borehole** to the Department of Water Office in Karratha. A penalty of $150 applies for failure to submit this Form.

If the water from this well is being improperly used, is being wasted or is having a harmful effect, the Commission may direct the closing of this well.

Compliance with the terms, conditions or restrictions of this licence does not absolve the licensee from responsibility for compliance with the requirements of all Commonwealth and State legislation.

If you have any queries relating to the above matter, please contact myself on telephone number (08) 9144 2000.

Yours faithfully

Kevin Hopkinson
Senior Natural Resource Management Officer
Department of Water
Pilbara Region

March 26, 2009

File No: RF3111

Government of **Western Australia**
Department of **Water**

Page 1 of 1

Instrument No. CAW168340(1)

LICENCE TO CONSTRUCT OR ALTER WELL

Granted by the Minister under section 26D of the Rights in Water and Irrigation Act 1914

Licensee(s)	Brockman Resources Limited	
Description of Water Resource	Pilbara Hamersley - Fractured Rock	
Location of Well(s)	E47/1408	
Authorised Activities	**Activity**	**Location of Activity**
	Construct 17 non-artesian well(s).	E47/1408
Duration of Licence	From 24 March 2009 to 23 March 2011	

This Licence is subject to the following terms, conditions and restrictions:

1 That water discharged during the pump test, is to be disposed of in such a manner as to cause no undesirable environmental impact

2 The well must be constructed by a driller having a current class 1 water well drillers certificate issued by the Western Australian branch of the Australian Drilling Industry Association or other certification approved by the Department of Water as equivalent.

3 The licensee is required to provide to the Department of Water a completed ' Particulars of Completed Bore Hole Form ' on completion of the approved drilling programme.

4 That no well shall be sunk within 400 metres of an existing well without the written permission of the owner of that well.

5 The water drawn from the bore shall be limited to well development, test pumping and sampling

End of terms, conditions and restrictions

This Licence is granted subject to the Rights in Water and Irrigation Regulations 2000.

File No: RF3111

Government of **Western Australia**
Department of **Water**

Page 1 of 1

Instrument No. CAW168341(1)

LICENCE TO CONSTRUCT OR ALTER WELL

Granted by the Minister under section 26D of the Rights in Water and Irrigation Act 1914

Licensee(s)	Brockman Resources Limited	
Description of Water Resource	Pilbara Wittnoom - Wittnoom	
Location of Well(s)	E47/1408	
Authorised Activities	**Activity**	**Location of Activity**
	Construct 3 non-artesian well(s).	E47/1408
Duration of Licence	From 24 March 2009 to 23 March 2011	

This Licence is subject to the following terms, conditions and restrictions:

1 That water discharged during the pump test, is to be disposed of in such a manner as to cause no undesirable environmental impact

2 The well must be constructed by a driller having a current class 1 water well drillers certificate issued by the Western Australian branch of the Australian Drilling Industry Association or other certification approved by the Department of Water as equivalent.

3 The licensee is required to provide to the Department of Water a completed ' Particulars of Completed Bore Hole Form ' on completion of the approved drilling programme.

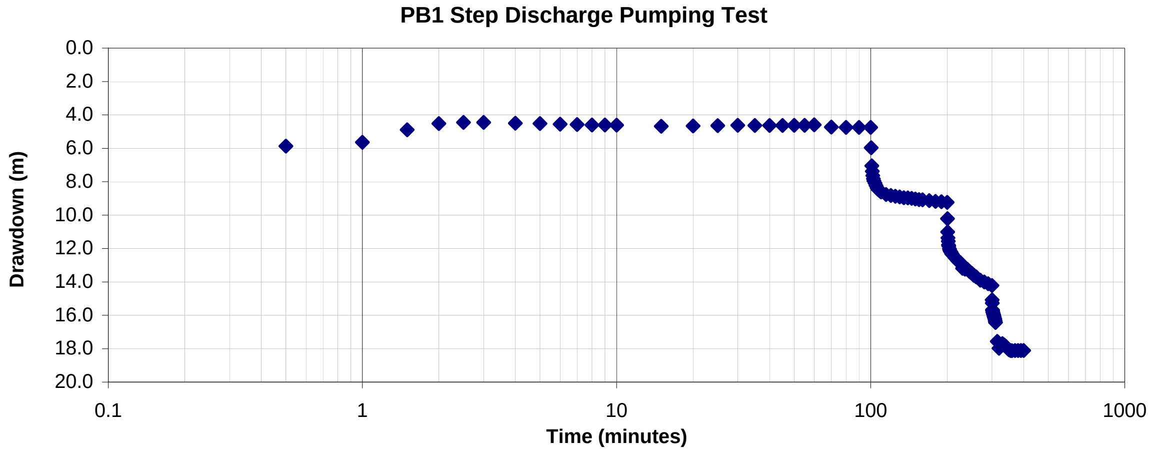
4 That no well shall be sunk within 400 metres of an existing well without the written permission of the owner of that well.

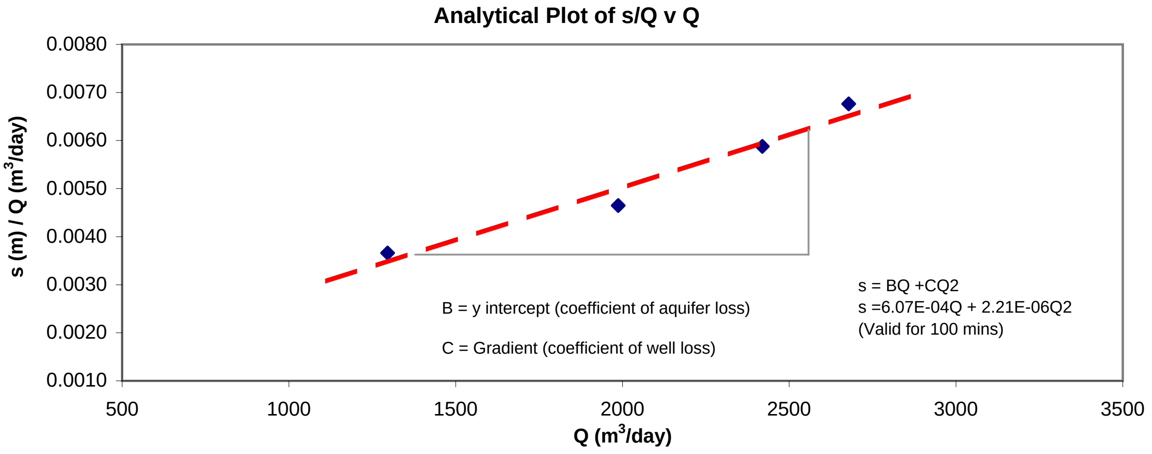
5 The water drawn from the bore shall be limited to well development, test pumping and sampling

End of terms, conditions and restrictions

This Licence is granted subject to the Rights in Water and Irrigation Regulations 2000.

APPENDIX D HYDRAULIC TESTS





$s_{w(n)} = BQ_n + CQ^P_n$ (Rorabaugh's equation)

Where, B = Intercept with y axis (coefficient of aquifer loss or laminar flow)
C = Gradient (coefficient of turbulent flow loss or apparent well loss)
s = Drawdown in the borehole
P = Value determined using Rorabaugh's method of superposition

Components of the equation BQ and CQ^2 are termed the aquifer loss and apparent well loss respectively.
They give an indication of the proportion of total drawdown caused by laminar and turbulent flow.

It should be noted: 1. In thin or fissured aquifers large components of well loss are due to high flow velocities in the aquifer rather than inefficient bore design. Therefore, the term "apparent well loss" is better than well loss.

2. In aquifers where the flow horizons are vertically anisotropic, changes in bore performance often relate to changes in the rest water level with respect to the primary aquifer horizons.

$Ew = (BQ/(BQ + CQ^P) \times 100$

Ew or Well Efficiency represents the proportion of drawdown caused by laminar flow

Comparison of Observed and Predicted Drawdowns

Step (100 min steps)	Discharge (L/s)	Discharge (Q) (m3/d)	Observed Corrected Drawdown (s) (metres)	Predicted Drawdown (metres)	s/Q	Apparent Efficiency (Ew) %
1	15.0	1296	4.75	4.50	0.0037	17.5
2	23.0	1987	9.24	9.93	0.0046	12.1
3	28.0	2419	14.22	14.40	0.0059	10.2
4	31.0	2678	18.12	17.48	0.0068	9.3

Step Rate Test (4 x 100 minute)

Job No.: 832G Job Name: Marillana IOP Client: Brockman Resources

Location: Marillana Logged by: TPA Date: 24/05/2009 Time: 10:30

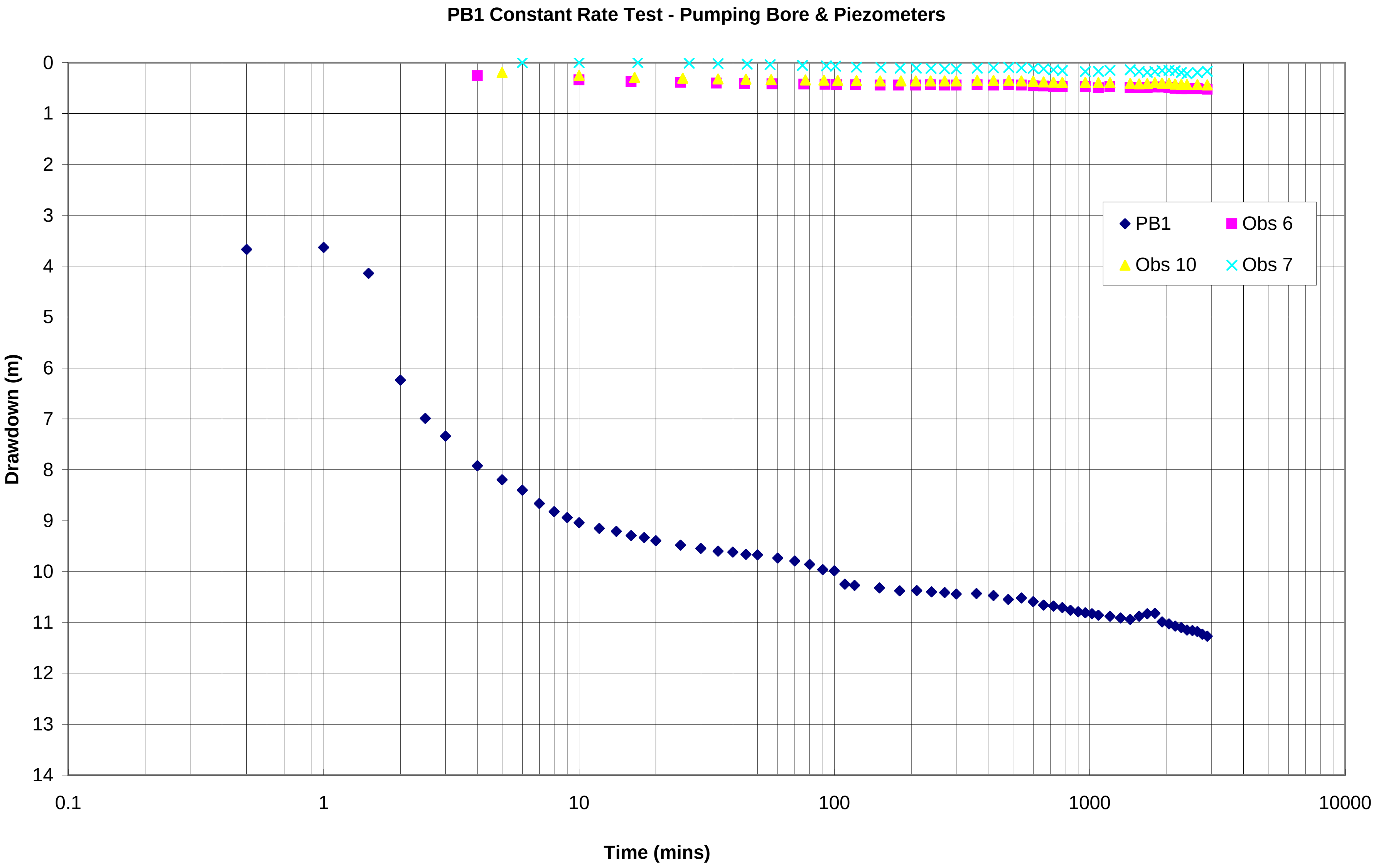
Details		Pumping Bore		Comment		Details	Pumping Bore		Comment	
Bore No.		PB1								
Reference point (magl)		1								
Static water level (mbrp)		32.935								
Time		Step 1 (L/s):	15.0	Comment		Time	Step 2 (L/s):	23.0	Comment	
Real Time	Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)			Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)		
	0.5	38.81	5.875			100.5	38.9	5.965		
	1.0	38.58	5.645			101	39.99	7.055		
	1.5	37.83	4.895			101.5	40.31	7.375		
	2.0	37.45	4.515			102	40.57	7.635		
	2.5	37.39	4.455			102.5	40.76	7.825		
	3.0	37.39	4.455			103	40.89	7.955		
	4.0	37.435	4.5			104	41.025	8.09		RATE UP
	5.0	37.45	4.515			105	41.17	8.235		
	6.0	37.49	4.555			106	41.31	8.375		
	7.0	37.51	4.575			107	41.395	8.46		
	8.0	37.535	4.6			108	41.445	8.51		
	9.0	37.535	4.6			109	41.5	8.565		
	10	37.545	4.61			110	41.55	8.615		
	15	37.615	4.68			115	41.7	8.765		
	20	37.6	4.665			120	41.76	8.825		
	25	37.58	4.645			125	41.81	8.875		
	30	37.56	4.625			130	41.85	8.915		
	35	37.57	4.635			135	41.89	8.955		
	40	37.565	4.63			140	41.9	8.965		
	45	37.57	4.635			145	41.935	9		
	50	37.56	4.625			150	41.97	9.035		
	55	37.56	4.625			155	42.01	9.075		
	60	37.53	4.595			160	42.02	9.085		
	70	37.665	4.73		RATE UP	170	42.065	9.13		
	80	37.68	4.745			180	42.115	9.18		
	90	37.68	4.745			190	42.138	9.203		
	100	37.68	4.745			200	42.17	9.235		

Step Rate Test (4 x 100 minute)

Job No.: PB1 Job Name: Marillana IOP Client: Brockman Resources

Location: Marillana Logged by: TPA Date: 24/05/2009 Time: 10:30

Details		Pumping Bore		Comment		Details	Pumping Bore		Comments	
Bore No.		PB1								
Reference point (magl)		1								
Static water level (mbrp)		32.935								
Time		Step 3 (L/s):	28.0	Comment		Time	Step 4 (L/s):	31.0	Comment	
Real Time	Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)			Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)		
	200.5	43.155	10.22			300.5	48.01	15.075		
	201	43.95	11.015			301	48.21	15.275		
	201.5	44.3	11.365			301.5	48.61	15.675		
	202	44.5	11.565			302	48.65	15.715		
	202.5	44.725	11.79			302.5	48.735	15.8		
	203	44.79	11.855			303	48.77	15.835		
	204	44.95	12.015			304	48.86	15.925		
	205	45.05	12.115			305	48.92	15.985		
	206	45.11	12.175			306	49	16.065		
	207	45.16	12.225			307	49.08	16.145		
	208	45.225	12.29			308	49.17	16.235		
	209	45.27	12.335			309	49.27	16.335		
	210	45.315	12.38			310	49.37	16.435		rate up
	215	45.5	12.565		RATE UP	315	50.5	17.565		
	220	45.67	12.735			320	50.91	17.975		rate down
	225	45.765	12.83		RATE UP	325	50.7	17.765		to 30L/s
	230	46.125	13.19			330	50.635	17.7		
	235	46.17	13.235			335	50.71	17.775		
	240	46.185	13.25			340	50.8	17.865		
	245	46.315	13.38			345	50.9	17.965		
	250	46.42	13.485			350	51	18.065		
	255	46.55	13.615			355	51.05	18.115		
	260	46.63	13.695			360	51.055	18.12	end of measuring probe	
	270	46.835	13.9			370	51.05	18.115		
	280	46.94	14.005			380	51.05	18.115		
	290	47.05	14.115			390	51.05	18.115		
	300	47.155	14.22			400	51.05	18.115		


PB1 Constant Rate Test - Pumping Bore & Piezometers
Drawdown (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0.1
1
10
100
1000
10000
Time (mins)
PB1
Obs 6
Obs 10
Obs 7

Constant Rate (Pumping Bore)

Job No.: 832G
Job Name: Marillana Iron Ore Project
Client: Brockman Resources
Location: Marillana
Date:
Time:

Details						Comments			
Bore No.		PB1							
Discharge rate (L/s)		25	Pump set @ 50mbgl						
Reference point (magl)		1							
Static water level (mbrp)		32.94							
Dist. from PB (m)		-							
Time		Pumping Bore							
Real Time	Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)			FLOW L/SEC	CUM FLOW M3		
	0.5	36.61	3.67						
	1.0	36.57	3.63						
	1.5	37.08	4.14						
	2.0	39.18	6.24						
	2.5	39.93	6.99			25.07			
	3.0	40.28	7.34			25.19	3		
	4.0	40.86	7.92			25.05	4		
	5.0	41.135	8.195			25.12	6		
	6.0	41.34	8.4			24.82	7		
	7.0	41.605	8.665			25.15	9		
	8.0	41.765	8.825			25.46	10		
	9.0	41.88	8.94			25.07	12		
	10	41.98	9.04			25.47	13		
	12	42.09	9.15			25.31	16		
	14	42.15	9.21			25.3	19		
	16	42.235	9.295			25.08	22		
	18	42.27	9.33			25.31	26		
	20	42.335	9.395			25.44	29		
	25	42.42	9.48			25.04	36		
	30	42.485	9.545			25.2	43		
	35	42.54	9.6			25.33	51		
	40	42.56	9.62			24.92	58		
	45	42.6	9.66			25.93	66		
	50	42.61	9.67			25.17	74		
	60	42.675	9.735			25	89		
	70	42.73	9.79			25.17	104		
	80	42.8	9.86			24.79	119		
	90	42.9	9.96			24.9	135		
	100	42.925	9.985			24.56	149		rate up
	110	43.19	10.25			25.59	164		
	120	43.21	10.27			25.35	180		
	150	43.26	10.32			25.04	225		
	180	43.32	10.38			25.3	270		
	210	43.315	10.375			25.23	317		
	240	43.34	10.4			25.18	362		
	270	43.355	10.415						
	300	43.38	10.44			25.07	450		
	360	43.37	10.43			25			
	420	43.41	10.47			25.2	635		
	480	43.49	10.55			25.25	723		
	540	43.46	10.52			25.08	815		
	600	43.53	10.59			25.2	904		
	660	43.6	10.66			25.2	997		
	720	43.62	10.68			25.3	1084		
	780	43.65	10.71			25.2			
	840	43.7	10.76			25.3			
	900	43.73	10.79						
	960	43.75	10.81			25.26			
	1020	43.77	10.83						
	1080	43.8	10.86			25.06	1627		
	1200	43.82	10.88			25.1			
	1320	43.85	10.91						
	1440	43.88	10.94			25.1	2170		
	1560	43.82	10.88			25.2	2352		
	1680	43.77	10.83			25	2528.3		
	1800	43.76	10.82			24.65			rate up
	1920	43.93	10.99			25.2	2888.4		
	2040	43.97	11.03			25.28			
	2160	44.01	11.07			25.3	3251		
	2280	44.04	11.1			25.3			
	2400	44.09	11.15			25.3	3168		
	2520	44.1	11.16			25			
	2640	44.12	11.18			25.3			
	2760	44.17	11.23			25.4			
	2880	44.21	11.27			25.3	4350		

Constant Rate (Observation)

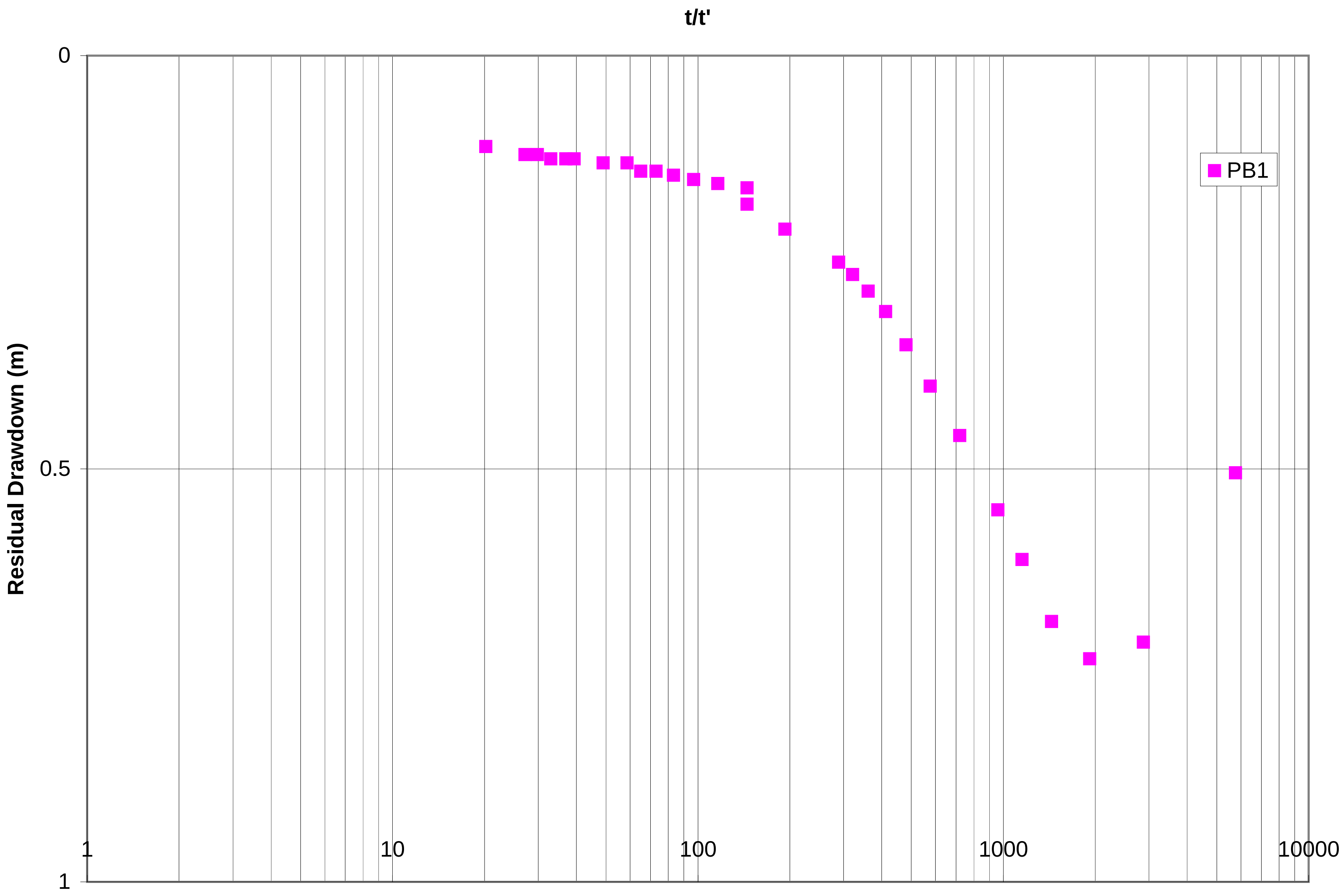
Job No.: 832G
Location: Marillana
Pumping Bore: PB1

Job Name: Marillana Iron Ore Project

Client: Brockman Resources
Date:
Time:

Observation Bore			Observation Bore			Observation Bore			Observation Bore		
	Obs 6			Obs 10			Obs 7				
SWL	33.315		SWL	33.245		SWL	33.38		SWL		
Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown
(mins)	(mbrp)	(m)	(mins	(mbrp)	(m)	(mins)	(mbrp)	(m)	(mins)	(mbrp)	(m)
4	33.57	0.255	5	33.440	0.195	6	33.38	0			
10	33.655	0.34	10	33.495	0.25	10	33.38	0			
16	33.685	0.37	16.5	33.535	0.29	17	33.38	0			
25	33.705	0.39	25.5	33.550	0.305	27	33.39	0.01			
34.5	33.715	0.4	35	33.565	0.32	35	33.4	0.02			
44.5	33.725	0.41	45	33.570	0.325	45.5	33.41	0.03			
57	33.73	0.415	57	33.580	0.335	56	33.42	0.04			
76	33.735	0.42	77	33.585	0.34	75	33.435	0.055			
92	33.74	0.425	91	33.590	0.345	93	33.445	0.065			
102	33.745	0.43	103	33.595	0.35	101	33.45	0.07			
121	33.75	0.435	122	33.600	0.355	122	33.465	0.085			
151	33.755	0.44	151	33.605	0.36	152	33.475	0.095			
178	33.755	0.44	182	33.605	0.36	181	33.485	0.105			
208	33.755	0.44	208	33.605	0.36	209	33.485	0.105			
238	33.75	0.435	238	33.605	0.36	239	33.49	0.11			
270	33.755	0.44	270	33.605	0.36	270	33.5	0.12			
300	33.755	0.44	300	33.605	0.36	300	33.5	0.12			
362	33.75	0.435	362	33.595	0.35	362	33.485	0.105			
420	33.755	0.44	420	33.595	0.35	420	33.48	0.1			
482	33.75	0.435	482	33.595	0.35	482	33.47	0.09			
540	33.755	0.44	540	33.605	0.36	540	33.48	0.1			
600	33.77	0.455	600	33.61	0.365	600	33.49	0.11			
660	33.775	0.46	660	33.625	0.38	660	33.5	0.12			
720	33.785	0.47	720	33.63	0.385	720	33.52	0.14			
780	33.79	0.475	780	33.635	0.39	780	33.535	0.155			
960	33.79	0.475	960	33.635	0.39	960	33.555	0.175			
1080	33.81	0.495	1080	33.64	0.395	1080	33.55	0.17			
1200	33.79	0.475	1200	33.64	0.395	1200	33.53	0.15			
1440	33.805	0.49	1440	33.65	0.405	1440	33.52	0.14			
1560	33.81	0.495	1560	33.66	0.415	1560	33.555	0.175			
1680	33.805	0.49	1680	33.655	0.41	1680	33.57	0.19			
1800	33.80	0.48	1800	33.64	0.395	1800	33.555	0.175			
1920	33.795	0.48	1920	33.645	0.4	1920	33.535	0.155			
2040	33.805	0.49	2040	33.65	0.405	2040	33.53	0.15			
2160	33.82	0.505	2160	33.665	0.42	2160	33.54	0.16			
2280	33.83	0.515	2280	33.67	0.425	2280	034	0.195			
2400	33.83	0.515	2400	33.675	0.43	2400	33.6	0.22			
2640	33.83	0.515	2640	33.675	0.43	2640	33.575	0.195			
2880	33.84	0.525	2880	33.68	0.435	2880	33.55	0.17			

Recovery Test Bore



Recovery Test (Pump Bore)

Job No.: 832G Job Name: Marillana Iron Ore Project Client: Brockman Resources

Location: Marillana Logged by: Date: 27/05/2009 Time: 7:10

CRT Duration (mins): 2880

Details			Pumping Bore							
Bore No.			PB1							
Reference point (magl)										
Static water level (mbrp)			32.94							
Dist. from PB (m)										
Time (mins)			Pumping Bore							
Time since started (t)	Time since stopped (t')	(t/t')	Reading (mbrp)	Drawdown (m)						
2880.5	0.5	5761.0	33.445	0.505						
2881	1.0	2881.0	33.65	0.71						
2881.5	1.5	1921.0	33.67	0.73						
2882	2.0	1441.0	33.625	0.685						
2882.5	2.5	1153.0	33.55	0.61						
2883	3.0	961.0	33.49	0.55						
2884	4.0	721.0	33.4	0.46						
2885	5.0	577.0	33.34	0.4						
2886	6.0	481.0	33.29	0.35						
2887	7.0	412.4	33.25	0.31						
2888	8.0	361.0	33.225	0.285						
2889	9.0	321.0	33.205	0.265						
2890	10	289.0	33.19	0.25						
2895	15	193.0	33.15	0.21						
2900	20	145.0	33.12	0.18						
2900	25	145.0	33.1	0.16						
2905	30	116.2	33.095	0.155						
2910	35	97.0	33.09	0.15						
2915	40	83.3	33.085	0.145						
2920	45	73.0	33.08	0.14						
2925	50	65.0	33.08	0.14						
2930	60	58.6	33.07	0.13						
2940	75	49.0	33.07	0.13						
2955	80	39.4	33.065	0.125						
2960	90	37.0	33.065	0.125						
2970	100	33.0	33.065	0.125						
2980	110	29.8	33.06	0.12						
2990	120	27.2	33.06	0.12						
3000	150	25.0								
3030	180	20.2	33.05	0.11						
3060	201	17.0								
3081	240	15.3								
3120	270	13.0								
3150	300	11.7								
3180	420	10.6								
3300		7.9								

Source Reliable Output Calculations **Bore No:** PB1

Notes:
Calculates SRO and expected pumping water levels for newly constructed bores
Pumping Test Analysis must have been undertaken first
Pumping water levels calculated from assumed average conditions - as seen during drilling
Assumes transient radial flow conditions prevail (eg Theis Equation)

Data Input

Rest Water Level = 31.96 mbgl
Top of Aquifer/Max PWL = 63 mbgl

Step Test Data

Enter parameters of step test equation $s=BQ+CQ^2$

B = 6.07E-04
C = 2.21E-06
valid time 100 mins

Constant Rate Test Data

Enter parameters from constant rate analysis

T = 580 m^2/d (transmissivity)
s = 4.14E-06 (storativity)
r = 0.127 m (radius of bore)

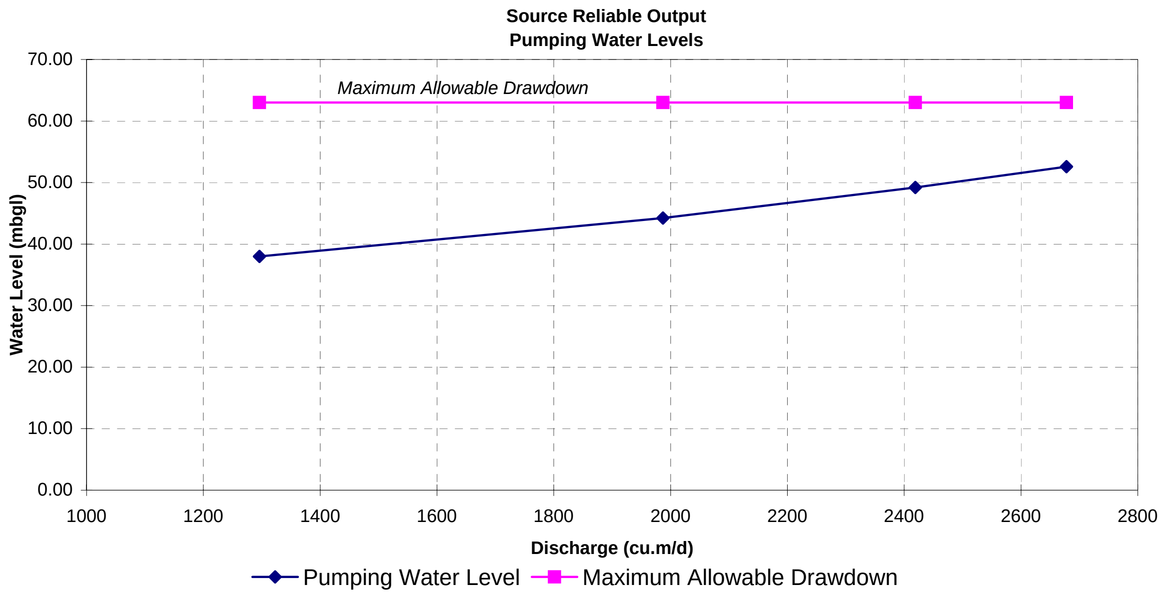
Enter Operational Data

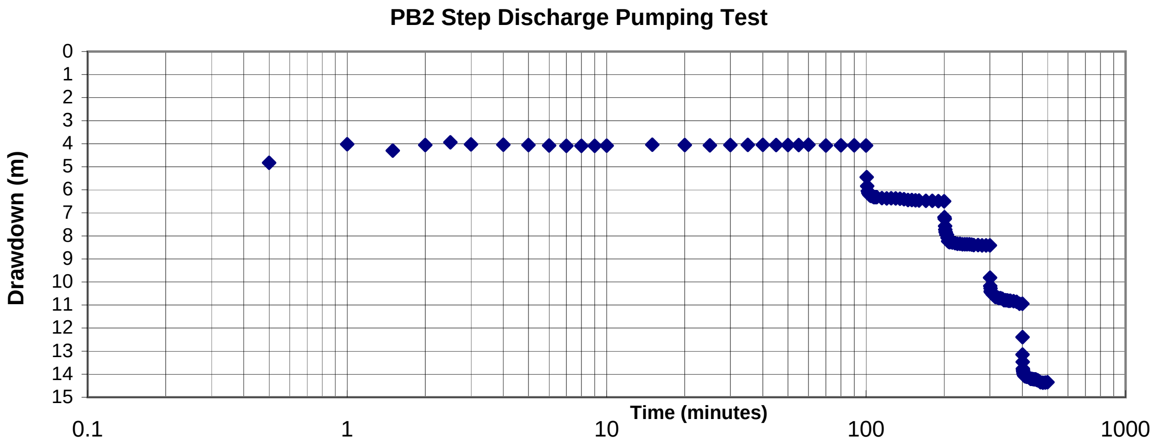
Assumed period between recharge events t2 = 365 days
Range of discharges to be considered
Q1 1296 m^3/d
Q2 1987 m^3/d
Q3 2419 m^3/d
Q4 2678 m^3/d

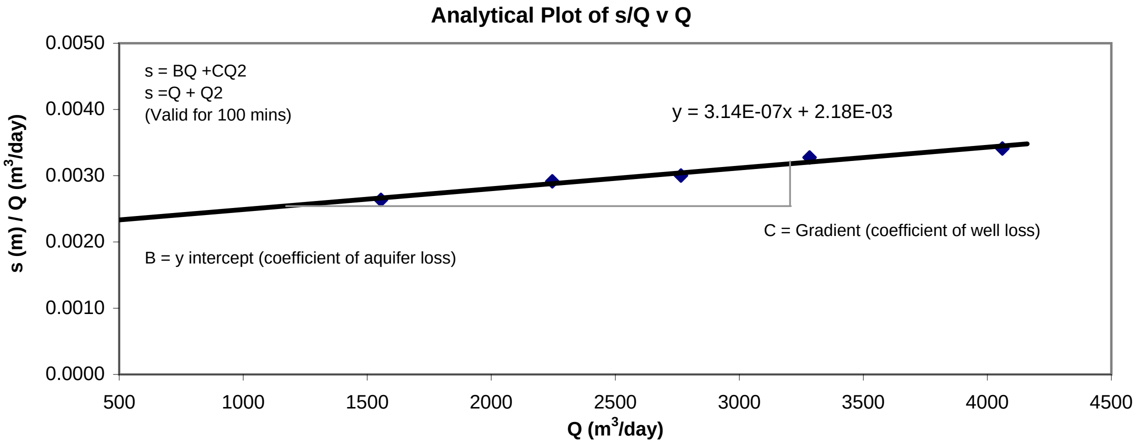
Are there interference effects (Y/N) n
Dist to first bore m
pumping rate m^3/d
Dist to second bore m
pumping rate m^3/d

Calculations of Drawdown

Discharge	Short Term Drawdown	Long Term Drawdown	Interference Effects	Total Drawdown	Pumping Water Level
1296	4.50	1.52	0.00	6.02	37.98
1987	9.93	2.33	0.00	12.26	44.22
2419	14.40	2.84	0.00	17.24	49.20
2678	17.47	3.14	0.00	20.62	52.58







$s_{w(n)} = BQ_n + CQ^P{}_n$ (Rorabaugh's equation)

Where, B = Intercept with y axis (coefficient of aquifer loss or laminar flow)
C = Gradient (coefficient of turbulent flow loss or apparent well loss)
s = Drawdown in the borehole
P = Value determined using Rorabaugh's method of superposition

Components of the equation BQ and CQ^2 are termed the aquifer loss and apparent well loss respectively.
They give an indication of the proportion of total drawdown caused by laminar and turbulent flow.

It should be noted:
1. In thin or fissured aquifers large components of well loss are due to high flow velocities in the aquifer rather than inefficient bore design. Therefore, the term "apparent well loss" is better than well loss.
2. In aquifers where the flow horizons are vertically anisotropic, changes in bore performance often relate to changes in the rest water level with respect to the primary aquifer horizons.

$Ew = (BQ/(BQ + CQ^P) \times 100$
Ew or Well Efficiency represents the proportion of drawdown caused by laminar flow

Comparison of Observed and Predicted Drawdowns

Step (100 min steps)	Discharge (L/s)	Discharge (Q) (m3/d)	Observed Corrected Drawdown (s) (metres)	Predicted Drawdown (metres)	s/Q	Apparent Efficiency (Ew) %
1	18.0	1555	4.10	4.15	0.0026	81.7
2	26.0	2246	6.55	6.48	0.0029	75.6
3	32.0	2765	8.30	8.43	0.0030	71.5
4	38.0	3283	10.75	10.54	0.0033	67.9
5	47.0	4061	13.85	14.03	0.0034	63.1

F:\Jobs\832G\G5 - Fieldwork\Test Pumping\PB2\[PB2 STEP_Analysed.xls]Step Plot_analysed

Step Rate Test (5 x 100 minutes)

Job No.: 832G Job Name Marillana Iron Ore Project Client Brockman Resources

Location: Marillana Date: 2/06/2009 Time: 7:00

Details		
Pumping Bore No.	PB2	pump setting @ 51 metres
Reference point (magl)	1	
Static water level (mbrp)	22.96	

Rate 1 (L/s):	**18**					**Rate 2 (L/s):**	**26**				
Time	water level	drawdown	instant flow	cum flow		Time	water level	drawdown	instant flow	cum flow	
	Reading		l/sec	m3	Rate		Reading		l/sec	m3/hr	Rate
(mins)	(mbrp)				up/down	(mins)	(mbrp)				up/down
0.5	27.785	4.825				100.5	28.41	5.45			
1.0	26.98	4.02				101	28.8	5.84			
1.5	27.26	4.3				101.5	29.015	6.055	23.39		
2.0	27.015	4.055	15.31			102	29.1	6.14	23.13		
2.5	26.9	3.94	18.46			102.5	29.14	6.18	23.13		
3.0	26.95	4.03	18.4	3.18		103	29.18	6.22	26.15		
4.0	26.99	4.04	18.43	4.26		104	29.22	6.26	26.3	6.32	
5.0	27	4.06	18.46	5.39		105	29.22	6.26	26.75	7.81	
6.0	27.02	4.075	18.25	6.7		106	29.24	6.28	26.6	9.6	
7.0	27.035	4.09	18.23	7.69		107	29.28	6.32	26.3	11.2	
8.0	27.05	4.09	18.61	8.66		108	29.28	6.32	26.6	12.6	
9.0	27.05	4.09	18.43	9.79		109	29.28	6.32	26.5	14.2	
10	27.05	4.085	18.33	10.38		110	29.28	6.32	26.6	15.8	
15	27.045	4.04	18.38	18.73		115	29.32	6.36	26.5	24.8	
20	27	4.06	18.3	21.91		120	29.33	6.37	26.7	31.7	
25	27.02	4.07	18.35	27.63		125	29.325	6.365	26.6	39.4	
30	27.03	4.06	18.14	32.86		130	29.33	6.37	26.6	47.7	
35	27.02	4.05	18.35	38.45		135	29.345	6.385	26.4	55.5	
40	27.01	4.05	18.34	43.97		140	29.37	6.41	26.7	63.6	
45	27.01	4.055	18.43	49.53		145	29.4	6.44	26.9	71.63	
50	27.015	4.055	18.49	55.04		150	29.4	6.44	26.7	79.58	
55	27.015	4.055	18.3	60.4		155	29.415	6.455	26.7	87.43	
60	27	4.04	18.12	66.15		160	29.42	6.46	26.7	95.6	
70	27.04	4.08	18.04	77.3		170	29.435	6.475	26.7	111.77	
80	27.03	4.07	18.33	87.76		180	29.438	6.478	26.8	127.74	
90	27.03	4.07	18.31	98.23		190	29.45	6.49	26.8	143.91	
100	27.035	4.075	18.34	107.8		200	29.46	6.5	26.9	160.18	

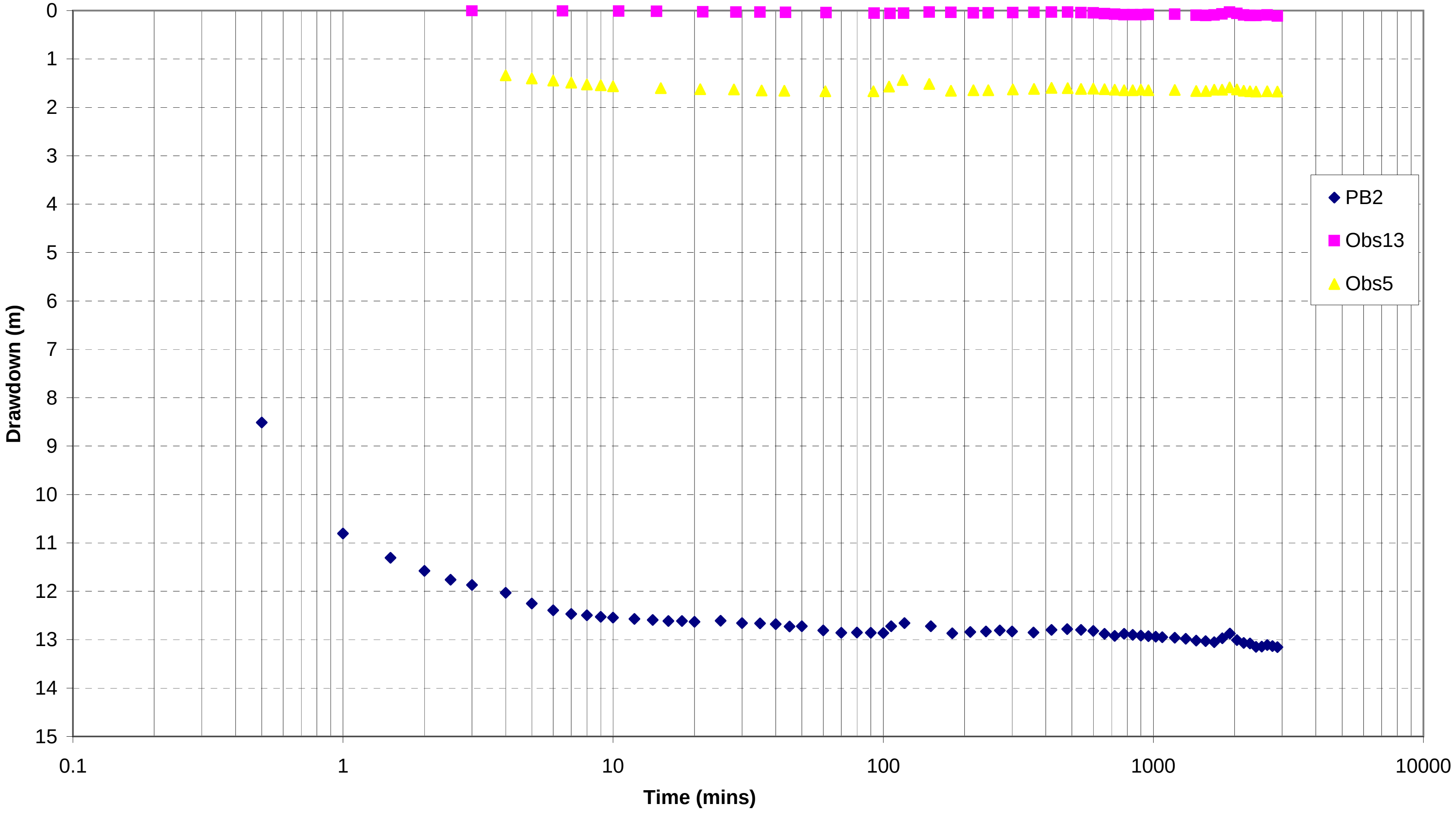
Step Rate Test (5 x 100 minutes)

Rate 3 (L/s):	32						Rate 4: (L/s)	38			
(mins)	Reading (mbrp)	drawdown	instant flow l/sec	cum flow m3/hr	Rate up/down	(mins)	Reading (mbrp)	drawdown	instant flow l/sec	cum flow m3/hr	Rate up/down
200.5	30.15	7.19				300.5	32.77	9.81		0	
201.0	30.22	7.26				301	33.13	10.17	31		
201.5	30.53	7.57				301.5	33.24	10.28	30.96		
202.0	30.685	7.725				302	33.36	10.4	31.31		
202.5	30.785	7.825				302.5	33.385	10.425	30.99		
203.0	30.82	7.86	31.83	5.61		303	33.4	10.44	38.7	6.77	
204.0	30.905	7.945	32.4	7.43		304	33.42	10.46	38.5	8.69	
205.0	30.915	7.955	31.9	9.27		305	33.43	10.47	38.4	11.25	
206.0	31.04	8.08	32.4	11.36		306	33.45	10.49	38.4	13.44	
207.0	31.19	8.23	32.6	13.23		307	33.475	10.515	38.5	15.95	
208.0	31.2	8.24	32.9	15.29		308	33.51	10.55	38.4	18.41	
209.0	31.225	8.265	32.7	17.23		309	33.51	10.55	38.5	20.47	
210	31.235	8.275	32.6	19.22		310	33.53	10.57	38.4	22.92	
215	31.25	8.29	32.6	28.97		315	33.615	10.655	38.8	34.7	
220	31.275	8.315	32.5	38.48		320	33.62	10.66	38.3	46.22	
225	31.305	8.345	32.7	48.76		325	33.66	10.7	38.6	57.55	
230	31.305	8.345	32.4	58.42		330	33.66	10.7	38.4	69.58	
235	31.325	8.365	32.3	67.98		335	33.69	10.73	38.8	80.6	
240	31.325	8.365	32.9	77.92		340	33.75	10.79	38.8	92.7	
245	31.325	8.365	32.7	87.93		345	33.75	10.79	38.8	104.76	
250	31.32	8.36	32.6	97.8		350	33.76	10.8	38.3	115.53	
255	31.335	8.375	32.9	107.33		355	33.78	10.82	38.5	127.3	
260	31.355	8.395	32.8	116.99		360	33.77	10.81	39.1	139.7	
270	31.355	8.395	32.7	136.94		370	33.79	10.83	38.85	162.4	
280	31.37	8.41	32.4	156.21		380	33.82	10.86	39	188	
290	31.37	8.41	32.5	177		390	33.9	10.94	38.9	209.8	
300	31.375	8.415	32.3	197.3		400	33.9	10.94	38.6	232	

Step Rate Test (5 x 100 minutes)

Rate 5: (L/s)	**47 L/SEC**				
(mins)	Reading (mbrp)	drawdown	instant flow l/sec	cum flow m3/hr	Rate up/down
400.5	35.35	12.39			
401	36.105	13.145			
401.5	36.43	13.47			
402	36.72	13.76			
402.5	36.78	13.82	47.3		
403	36.85	13.89	47.3		
404	36.93	13.97	47.6	11.39	
405	36.95	13.99	47.3	14.02	
406	36.99	14.03	47.6	16.87	
407	37.02	14.06	47.3	19.96	
408	37.035	14.075	47.4	22.79	
409	37.04	14.08	47.3	25.39	
410	37.05	14.09	47.9	28.47	
415	37.07	14.11	47.9	43.14	
420	37.07	14.11	47.5	56.47	
425	37.11	14.15	47.7	71.5	
430	37.165	14.205	47.2	84.97	
435	37.165	14.205	47.3	98.95	
440	37.175	14.215	47.3	113.65	
445	37.18	14.22	47.3	127.6	
450	37.18	14.22	47.5	141.8	
455	37.21	14.25	47	156.82	
460	37.235	14.275	47.2	171.03	
470	37.31	14.35	47.8	199.02	
480	37.328	14.368	47.1	227	
490	37.32	14.36	47.3	255.74	
500	37.31	14.35	47.6	283.79	

PB2 Constant Rate Test - Pumping Bore & Piezometers



Constant Rate (Pumping Bore)

Job No.: 832G Job Name: Marillana Iron Ore Project Client: Brockman Resources
Location: Marillana Logged by: TPA Date: 3/06/2009 Time: 7:00

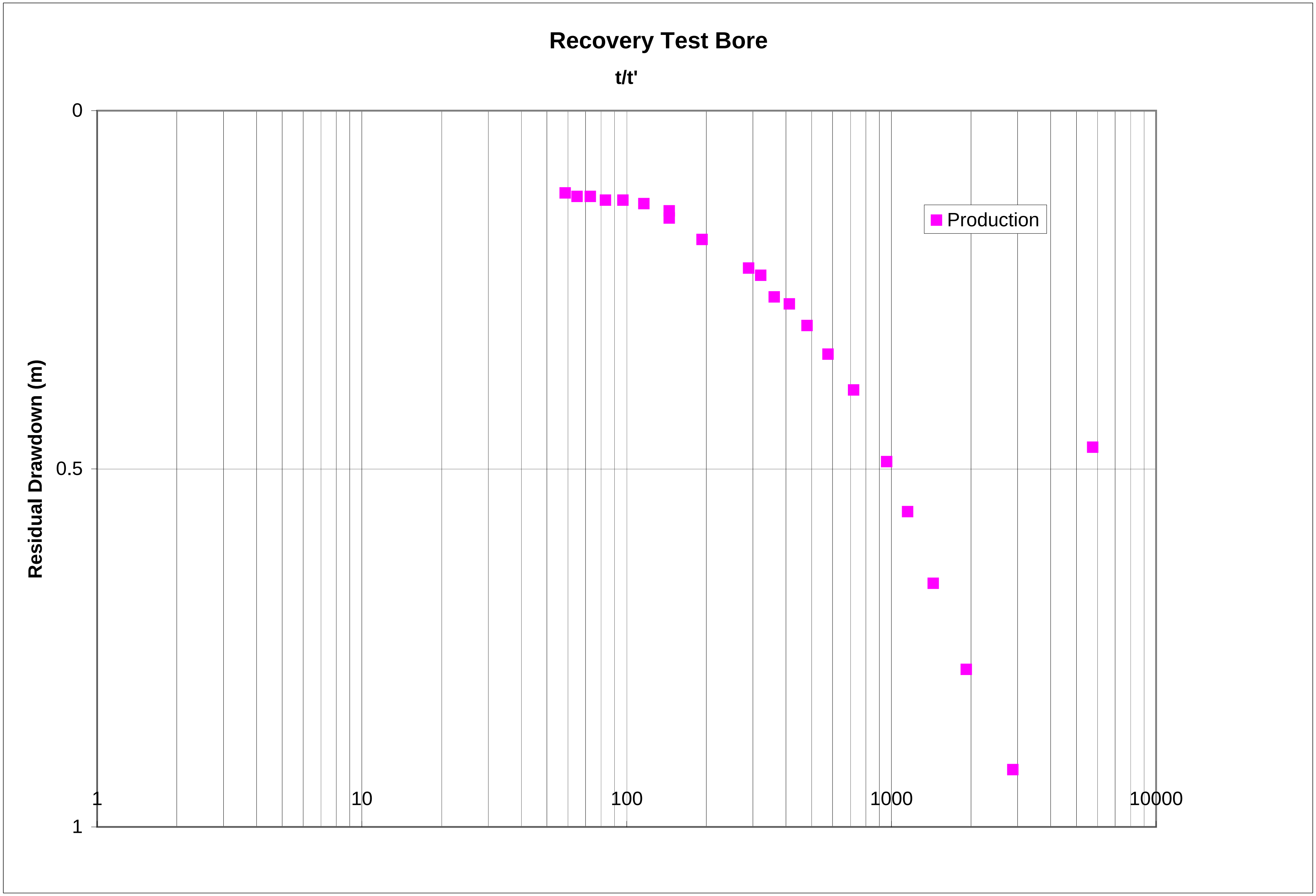
Details			Comments
Bore No.	PB2		
Discharge rate (L/s)	43 pump set @ 52mbgl		
Reference point (magl)	1		
Static water level (mbrp)	22.87		
Dist. from PB (m)	-		

Time		Pumping Bore							
Real Time	Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)			FLOW L/SEC	CUM FLOW M3		
	0.5	31.38	8.51						
	1.0	33.675	10.805						
	1.5	34.18	11.31						
	2.0	34.45	11.58						
	2.5	34.63	11.76						
	3.0	34.74	11.87			42.7	7.52		
	4.0	34.9	12.03			42.8	9.92		
	5.0	35.125	12.255			42.7	12.36		
	6.0	35.265	12.395			43.5	14.88		
	7.0	35.34	12.47			43.9	17.61		
	8.0	35.365	12.495			43.1	20.05		
	9.0	35.4	12.53			43.3	22.74		
	10	35.415	12.545			43.5	25.26		
	12	35.44	12.57			43	30.47		
	14	35.465	12.595			43.5	35.7		
	16	35.485	12.615			43.5	41.04		
	18	35.485	12.615			43.3	46.06		
	20	35.5	12.63			43.4	51.34		
	25	35.48	12.61			43.5	64.33		
	30	35.53	12.66			43.2	77.98		
	35	35.535	12.665			43.4	90.32		
	40	35.55	12.68			43.2	104.6		
	45	35.6	12.73			43.3	116.6		
	50	35.59	12.72			43.4	129.5		
	60	35.68	12.81			43.7	155		
	70	35.725	12.855			43.1	181.6		
	80	35.72	12.85			43.4	207		
	90	35.725	12.855			43.4	233.1		
	100	35.73	12.86						
	107	35.59	12.72	RC Rigs started drilling		43.2			
	120	35.525	12.655			43.3	310.5		
	150	35.59	12.72			42.98	388.5	rate up	
	180	35.74	12.87			43.2			
	210	35.71	12.84			43.2			
	240	35.7	12.83			43.26	627		
	270	35.68	12.81			43.13	701		
	300	35.7	12.83			43.13	780		
	360	35.72	12.85			43.18	931		
	420	35.67	12.8			43.11	1088.8		
	480	35.65	12.78			43	1243		
	540	35.67	12.8			43.22	1396		
	600	35.69	12.82			43.2	1556		
	660	35.75	12.88			43.1	1709		
	720	35.79	12.92			43.2			
	780	35.75	12.88			43.5	2022		
	840	35.77	12.9			43.5			
	900	35.785	12.915			43.5	2336		
	960	35.8	12.93			43.2	2493		
	1020	35.81	12.94			43.3			
	1080	35.82	12.95			43.4			
	1200	35.83	12.96			43.7	3125		
	1320	35.85	12.98			43.3			
	1440	35.89	13.02			43.5	3748		
	1560	35.9	13.03			43.6	4064		
	1680	35.92	13.05			43.7	4377		
	1800	35.84	12.97			43.8	4692		
	1920	35.745	12.875			43.4	5010		
	2040	35.88	13.01			43.6	5320		
	2160	35.94	13.07			43.7	5634		
	2280	35.95	13.08			43.5			
	2400	36.02	13.15			43.7	6266		
	2520	36.015	13.145			43.8			
	2640	35.98	13.11			44.2	6900		
	2760	36	13.13			43.9			
	2880	36.025	13.155			43.6	7538		

Constant Rate (Observation)

Job No.:	832G	Job Name:	Marillana Iron Ore Project	Client:	Brockman Resources
Location:	Marillana	Logged by:	TPA	Date:	
Pumping Bore:	PB2			Time:	

Observation Bore			Observation Bore			Observation Bore			Observation Bore		
Obs13			Obs5								
SWL	23.03		SWL	22.625		SWL			SWL		
Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown
(mins)	(mbrp)	(m)	(mins	(mbrp)	(m)	(mins)	(mbrp)	(m)	(mins)	(mbrp)	(m)
3	23.03	0	4	23.965	1.34						
6.5	23.035	0.005	5	24.030	1.405						
10.5	23.04	0.01	6	24.070	1.445						
14.5	23.045	0.015	7	24.115	1.49						
21.5	23.055	0.025	8	24.150	1.525						
28.5	23.06	0.03	9	24.170	1.545						
35	23.06	0.03	10	24.190	1.565						
44	23.07	0.04	15	24.230	1.605						
62	23.075	0.045	21	24.250	1.625						
93	23.085	0.055	28	24.255	1.63						
106	23.09	0.06	36	24.275	1.65						
119	23.085	0.055	43	24.280	1.655						
148	23.06	0.03	61	24.295	1.67						
178	23.07	0.04	92	24.295	1.67						
216	23.08	0.05	105	24.195	1.57						
245	23.08	0.05	118	24.060	1.435						
302	23.075	0.045	148	24.140	1.515						
362	23.07	0.04	178	24.280	1.655						
420	23.06	0.03	216	24.270	1.645						
482	23.06	0.03	245	24.27	1.645						
540	23.075	0.045	302	24.255	1.63						
600	23.08	0.05	362	24.245	1.62						
660	23.095	0.065	420	24.225	1.6						
720	23.105	0.075	482	24.23	1.605						
780	23.115	0.085	540	24.245	1.62						
840	23.12	0.085	600	24.24	1.615						
900	23.115	0.085	660	24.25	1.625						
960	23.11	0.08	720	24.26	1.635						
1200	23.105	0.075	780	24.27	1.645						
1440	23.125	0.095	840	24.27	1.645						
1564	23.135	0.105	900	24.26	1.635						
1682	23.12	0.09	960	24.27	1.645						
1796	23.1	0.07	1200	24.265	1.64						
1918	23.06	0.03	1440	24.29	1.665						
2040	23.09	0.06	1564	24.29	1.665						
2160	23.12	0.09	1682	24.26	1.635						
2280	23.135	0.105	1796	24.26	1.635						
2400	23.135	0.105	1918	24.21	1.585						
2640	23.12	0.09	2040	24.255	1.63						
2880	23.145	0.115	2160	24.28	1.655						
			2280	24.295	1.67						
			2400	24.3	1.675						
			2640	24.295	1.67						
			2880	24.3	1.675						



Recovery Test Bore
t/t'
Residual Drawdown (m)
0
0.5
1
1
10
100
1000
10000
Production

Recovery Test (Pumping Well)

Job No.:

Job Name:

Client: BROCKMAN RESOURCES

Location: MARILLANA

Logged by:

Date: 5/06/2009

Time: 7:04

CRT Duration (mins): 2880

Details	Pumping Bore
Bore No.	PB2
Reference point (magl)	
Static water level (mbrp)	22.87
Dist. from PB (m)	

Time (mins)			Pumping Bore							
Time since started (t)	Time since stopped (t')	(t/t')	Reading (mbrp)	Drawdown (m)						
2880.5	0.5	5761.0	23.34	0.47						
2881	1.0	2881.0	23.79	0.92						
2881.5	1.5	1921.0	23.65	0.78						
2882	2.0	1441.0	23.53	0.66						
2882.5	2.5	1153.0	23.43	0.56						
2883	3.0	961.0	23.36	0.49						
2884	4.0	721.0	23.26	0.39						
2885	5.0	577.0	23.21	0.34						
2886	6.0	481.0	23.17	0.3						
2887	7.0	412.4	23.14	0.27						
2888	8.0	361.0	23.13	0.26						
2889	9.0	321.0	23.1	0.23						
2890	10	289.0	23.09	0.22						
2895	15	193.0	23.05	0.18						
2900	20	145.0	23.02	0.15						
2900	25	145.0	23.01	0.14						
2905	30	116.2	23	0.13						
2910	35	97.0	22.995	0.125						
2915	40	83.3	22.995	0.125						
2920	45	73.0	22.99	0.12						
2925	50	65.0	22.99	0.12						
2930	60	58.6	22.985	0.115						
2940	75	49.0		-22.87						
2955	80	39.4		-22.87						
2960	90	37.0		-22.87						
2970	100	33.0		-22.87						
2980	110	29.8		-22.87						
2990	120	27.2		-22.87						
3000	150	25.0		-22.87						
3030	180	20.2		-22.87						
3060	201	17.0		-22.87						
3081	240	15.3								
3120	270	13.0		-22.87						

Source Reliable Output Calculations **Bore No:** PB2

Notes:
Calculates SRO and expected pumping water levels for newly constructed bores
Pumping Test Analysis must have been undertaken first
Pumping water levels calculated from assumed average conditions - as seen during drilling
Assumes transient radial flow conditions prevail (eg Theis Equation)

Data Input

Rest Water Level = 24.8 mbgl Top of Aquifer/Max PWL = 53 mbgl

Step Test Data

Enter parameters of step test equation $s=BQ+CQ^2$

B = 2.05E-03
C = 3.73E-07
valid time 100 mins

Constant Rate Test Data

Enter parameters from constant rate analysis

T = 5.00E+02 m^2/d (transmissivity)
S = 4.14E-06 (storativity)
r = 0.127 m (radius of bore)

Enter Operational Data

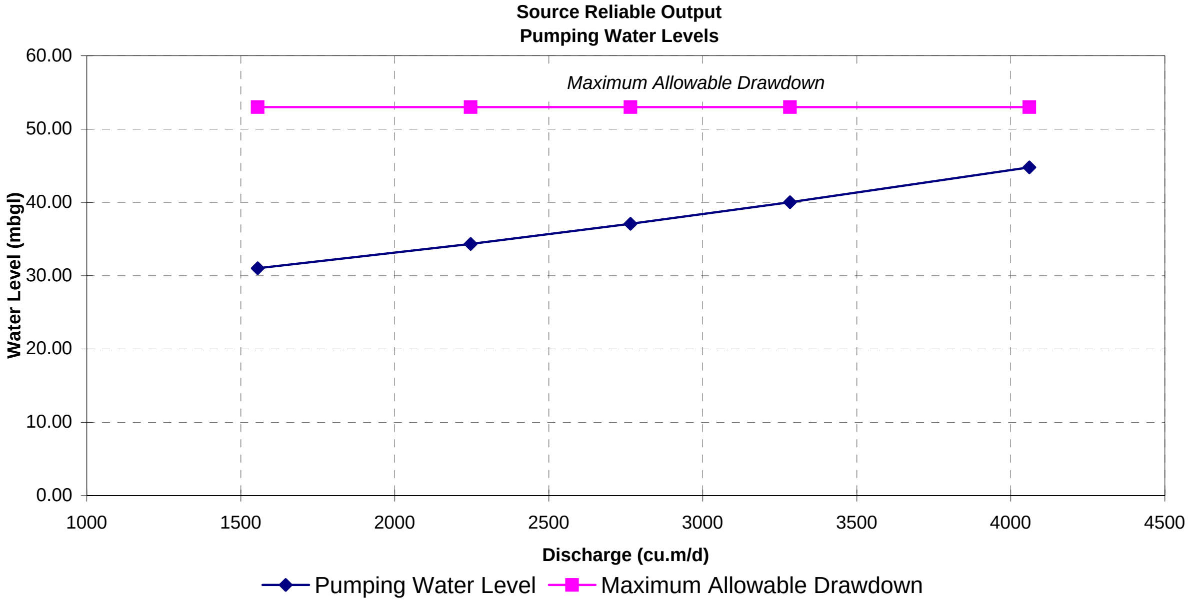
Assumed period between recharge events t2 = 365 days
Range of discharges to be considered

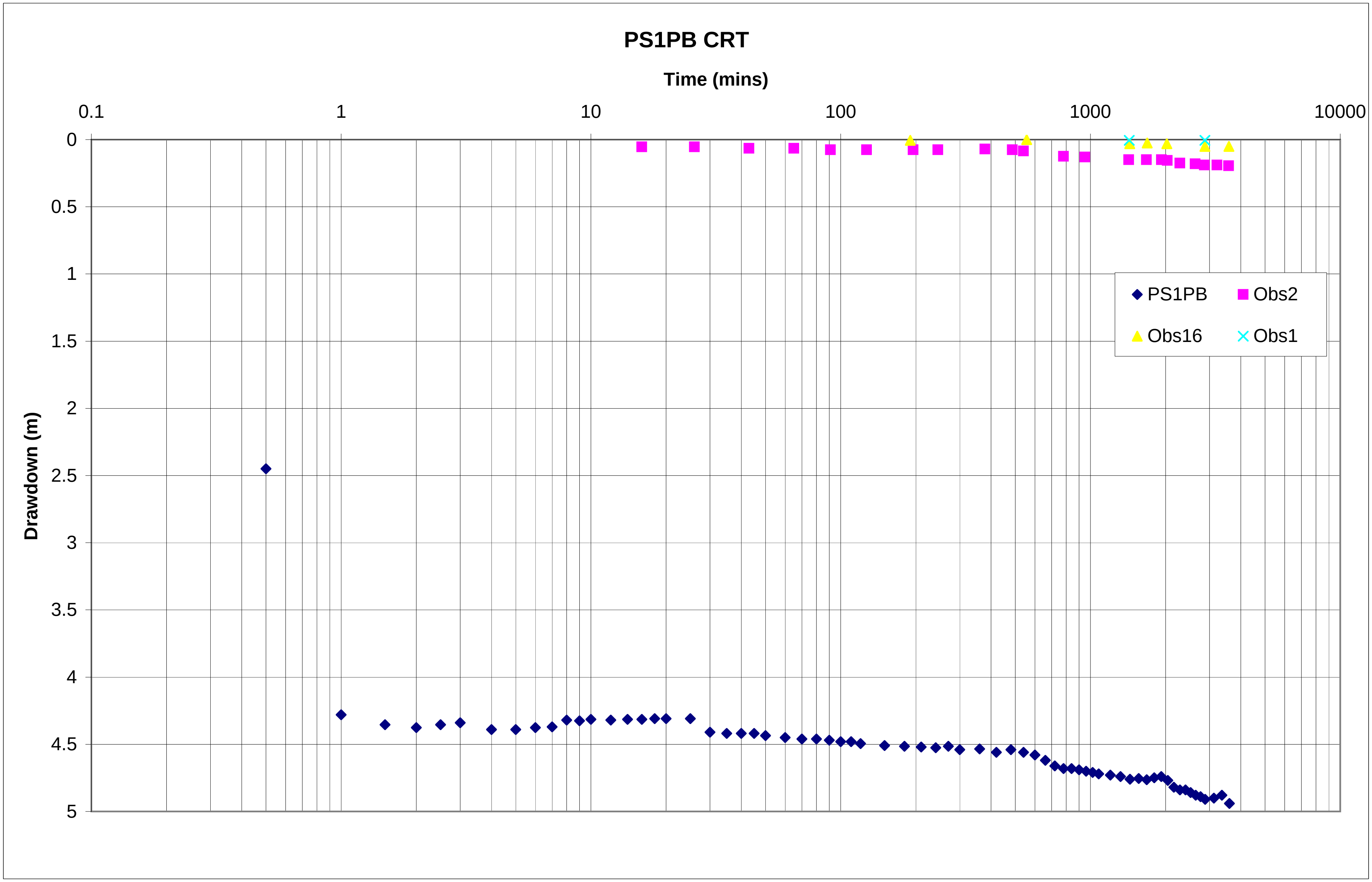
Q1 1555 m^3/d
Q2 2246 m^3/d
Q3 2765 m^3/d
Q4 3283 m^3/d
Q5 4060 m^3/d

Are there interference effects (Y/N) N
Dist to first bore m
pumping rate m^3/d
Dist to second bore m
pumping rate m^3/d

Calculations of Drawdown

Discharge	Short Term Drawdown	Long Term Drawdown	Interference Effects	Total Drawdown	Pumping Water Level
1555	4.09	2.12	0.00	6.20	31.00
2246	6.48	3.06	0.00	9.54	34.34
2765	8.51	3.77	0.00	12.28	37.08
3283	10.74	4.47	0.00	15.21	40.01
4060	14.46	5.53	0.00	19.99	44.79




PS1PB CRT
Time (mins)
0.1
1
10
100
1000
10000
Drawdown (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
◆ PS1PB
■ Obs2
▲ Obs16
× Obs1

Constant Rate (Pumping Well)

Job No.:
Job Name:
Client: BROCKMAN RES
Location: MARILLANA
Logged by: TPA
Date: 29/05/2009
Time: 7:03

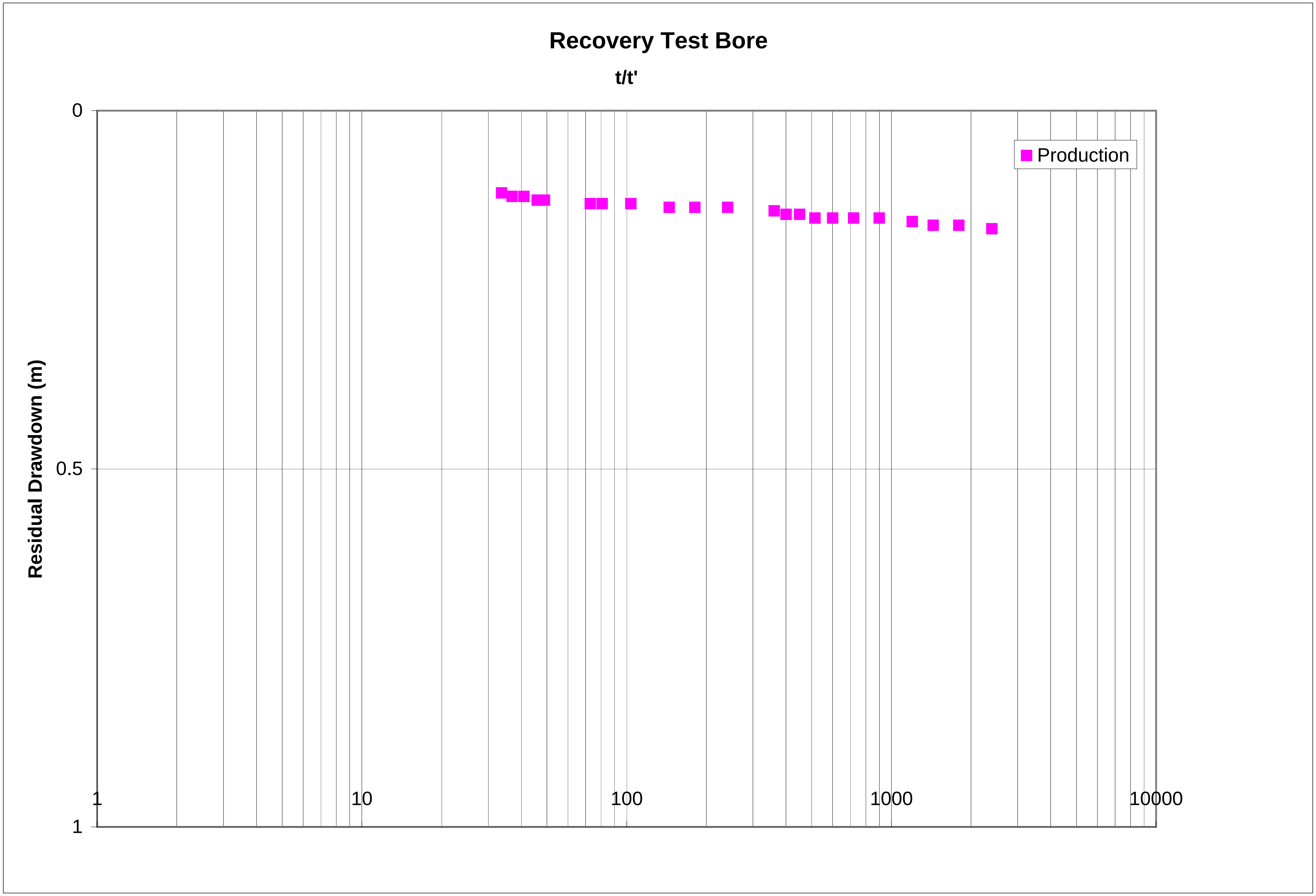
Details			Comments
Bore No.	PS1PB		
Discharge rate (L/s)	42	PUMP SETTING 44 METRES	
Reference point (magl)	1		
Static water level (mbrp)	34.64		
Dist. from PB (m)	-		

Time		Pumping Bore							
Real Time	Elapsed Time (mins)	Reading (mbrp)	Drawdown (m)			FLOW L/SEC	CUM FLOW M3		
	0.5	37.09	2.45						
	1.0	38.92	4.28						
	1.5	38.995	4.355						
	2.0	39.015	4.375						
	2.5	38.995	4.355						
	3.0	38.98	4.34						
	4.0	39.03	4.39			42.3			
	5.0	39.03	4.39				11.7		
	6.0	39.015	4.375			42.18			
	7.0	39.01	4.37			42.34			
	8.0	38.96	4.32			42.07	19.32		
	9.0	38.965	4.325			42.28			
	10	38.955	4.315			42.51	24.74		
	12	38.96	4.32			41.5	29.22		
	14	38.955	4.315			42.23			
	16	38.955	4.315			42.82			
	18	38.95	4.31			41.92			
	20	38.95	4.31			42.1	49.4		
	25	38.95	4.31			41.94		rate up	
	30	39.05	4.41			42.05			
	35	39.06	4.42			42.1			
	40	39.06	4.42			42.18	100.26		
	45	39.06	4.42			42.28			
	50	39.075	4.435			42.23			
	60	39.09	4.45			42.39	150.4		
	70	39.1	4.46			42.2			
	80	39.1	4.46			42.02			
	90	39.11	4.47			42.02			
	100	39.12	4.48			42.1	250.2		
	110	39.12	4.48			42.02			
	120	39.135	4.495			42.02			
	150	39.15	4.51			42.8			
	180	39.155	4.515			42.8			
	210	39.16	4.52			42.1	532		
	240	39.165	4.525			42.5			
	270	39.155	4.515			42.08	676.7		
	300	39.18	4.54			42.5	flow meter problem		
	360	39.175	4.535						
	420	39.2	4.56						
	480	39.18	4.54			42.7			
	540	39.2	4.56						
	600	39.22	4.58				flow meter problem		
	660	39.26	4.62						
	720	39.3	4.66						
	780	39.32	4.68						
	840	39.32	4.68						
	900	39.33	4.69						
	960	39.34	4.7			42.25			
	1020	39.35	4.71						
	1080	39.36	4.72						
	1200	39.37	4.73			42.25			
	1320	39.38	4.74						
	1440	39.4	4.76			42.8	2828 new reading at 1440 mins		

Constant Rate (Observation)

Job No.: 832G
Job Name: Marillana
Client: Brockman resources
Location: Marillana
Logged by: TPA
Date:
Pumping Bore: PS1PB
Time:

Observation Bore			Observation Bore			Observation Bore			Observation Bore		
Obs2			Obs16			Obs1					
SWL	34.545		SWL	31.27		SWL	23.615		SWL		
Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown	Time	Reading	Drawdown
(mins)	(mbrp)	(m)	(mins	(mbrp)	(m)	(mins)	(mbrp)	(m)	(mins)	(mbrp)	(m)
16	34.6	0.055	190	31.275	0.005	315	23.6	-0.015			
26	34.6	0.055	305	31.265	-0.005	550	23.6	-0.015			
43	34.61	0.065	556	31.270	0	1430	23.62	0.005			
65	34.61	0.065	1435	31.300	0.03	2026	23.61	-0.005			
91	34.62	0.075	1688	31.295	0.025	2870	23.62	0.005			
127	34.62	0.075	2020	31.300	0.03	3190	23.61	-0.005			
195	34.62	0.075	2875	31.320	0.05	3600	23.61	-0.005			
245	34.62	0.075	3585	31.320	0.05						
378	34.615	0.07									
487	34.62	0.075									
540	34.63	0.085									
780	34.67	0.125									
950	34.675	0.13									
1425	34.695	0.15									
1675	34.695	0.15									
1927	34.695	0.15									
2030	34.7	0.155									
2280	34.72	0.175									
2625	34.725	0.18									
2860	34.735	0.19									
3210	34.735	0.19									
3580	34.74	0.195									


Recovery Test Bore
t/t'
Residual Drawdown (m)
0
0.5
1
1
10
100
1000
10000
Production

Recovery Test (Pumping Well)

Job No.:

Job Name:

Client: BROCKMAN RESOURCES

Location: MARILLANA

Logged by:

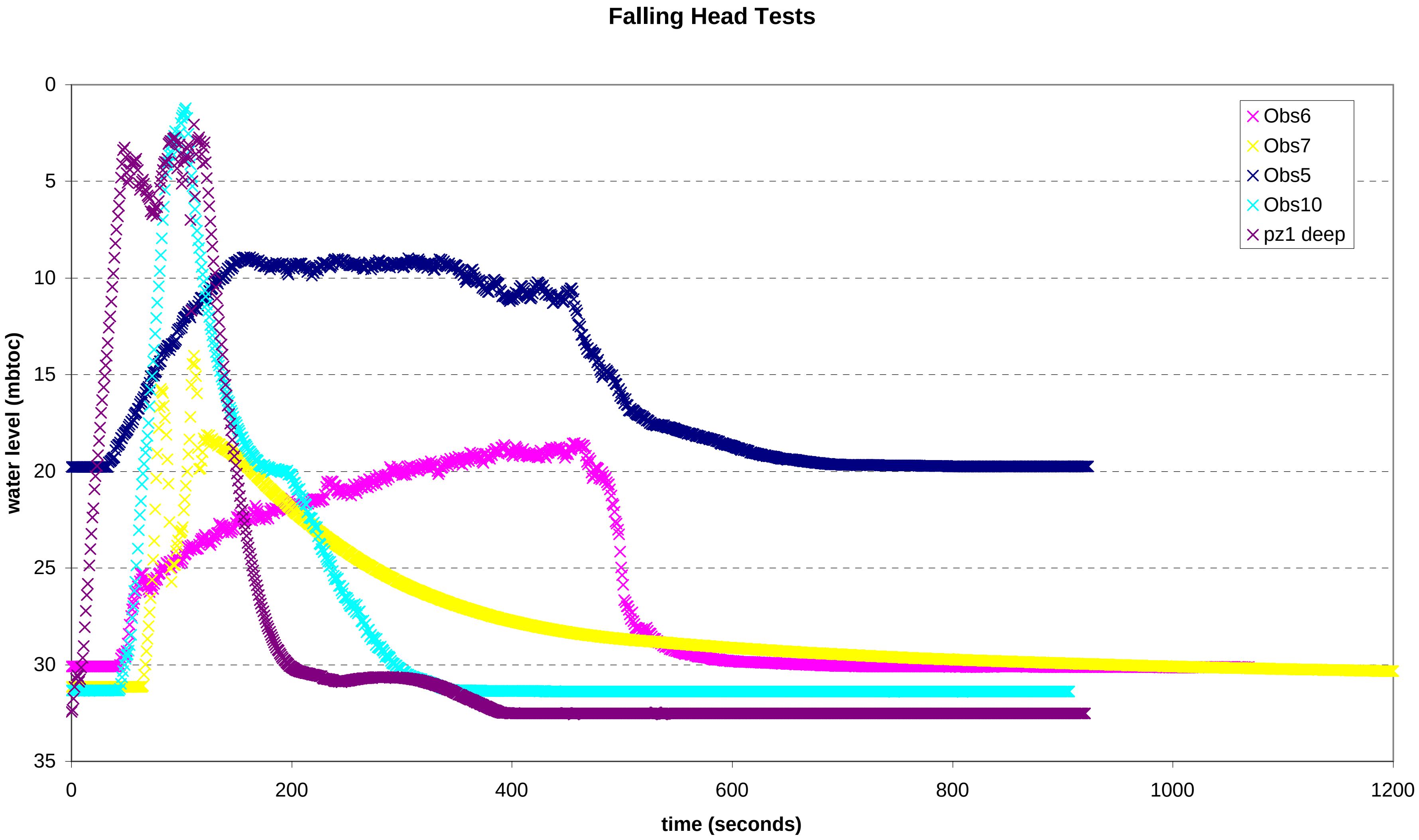
Date: 31/05/2009

Time: 19:03

CRT Duration (mins): 3600

Details	Pumping Bore
Bore No.	PS1PB
Reference point (magl)	
Static water level (mbrp)	34.64
Dist. from PB (m)	

Time (mins)			Pumping Bore								
Time since started (t)	Time since stopped (t')	(t/t')	Reading (mbrp)	Drawdown (m)							
3600.5	0.5	7201.0	34.115	-0.525							
3601	1.0	3601.0	34.635	-0.005							
3601.5	1.5	2401.0	34.805	0.165							
3602	2.0	1801.0	34.8	0.16							
3602.5	2.5	1441.0	34.8	0.16							
3603	3.0	1201.0	34.795	0.155							
3604	4.0	901.0	34.79	0.15							
3605	5.0	721.0	34.79	0.15							
3606	6.0	601.0	34.79	0.15							
3607	7.0	515.3	34.79	0.15							
3608	8.0	451.0	34.785	0.145							
3609	9.0	401.0	34.785	0.145							
3610	10	361.0	34.78	0.14							
3615	15	241.0	34.775	0.135							
3620	20	181.0	34.775	0.135							
3620	25	181.0									
3625	30	145.0	34.775	0.135							
3630	35	121.0									
3635	40	103.9	34.77	0.13							
3640	45	91.0									
3645	50	81.0	34.77	0.13							
3650	60	73.0	34.77	0.13							
3660	75	61.0									
3675	80	49.0	34.765	0.125							
3680	90	46.0	34.765	0.125							
3690	100	41.0	34.76	0.12							
3700	110	37.0	34.76	0.12							
3710	120	33.7	34.755	0.115							
3720	150	31.0									
3750	180	25.0									
3780	201	21.0									
3801	240	18.9									
3840	270	16.0									


Falling Head Tests
water level (mbtoc)
0
5
10
15
20
25
30
35
time (seconds)
0
200
400
600
800
1000
1200
Obs6
Obs7
Obs5
Obs10
pz1 deep

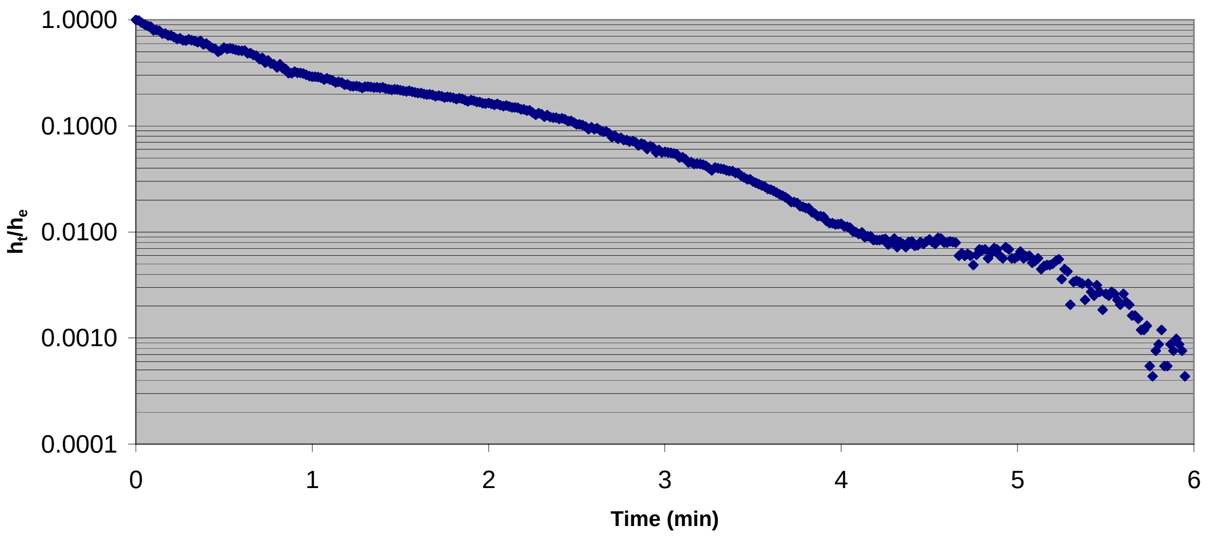
FALLING HEAD TEST

Bore No: Obs5	**Test No:** #1	**Job No:** 832G	**Date:** 9-Jun-00	**Logged by:** DJ

Borehole co-ordinates: **Easting:**	**Northing:**	Collar elevation (m):	0.5
Depth to top of test section (m):	22	Length of test section, **L** (m):	33
Depth of static water level, $\mathbf{H_w}$ (m):	19.744	Radius of borehole, **r** (m):	0.15
Excess head, $\mathbf{h_e}$ (m):	9.20	Radius of standpipe or casing, $\mathbf{r_c}$ (m):	0.025

Time (min)	**Depth to water, h_w (m)**	**Excess head, h_t=H_w-h_w (m)**	**h_t/h_e**
0	10.53	9.22	1.00
0.0167	10.69	9.05	0.98
0.0333	11.08	8.66	0.94
0.05	11.47	8.28	0.90
0.0667	11.66	8.08	0.88
0.0833	11.82	7.93	0.86
0.1	12.42	7.32	0.80
0.1167	12.39	7.36	0.80
0.1333	12.50	7.25	0.79
0.15	12.93	6.82	0.74
0.1667	12.93	6.82	0.74
0.1833	13.22	6.53	0.71
0.2	13.20	6.54	0.71
0.2167	13.42	6.32	0.69
0.2333	13.68	6.06	0.66
0.25	13.61	6.14	0.67
0.2667	13.83	5.91	0.64
0.2833	13.88	5.87	0.64
0.3	13.72	6.02	0.65
0.3167	13.86	5.88	0.64
0.3333	13.91	5.83	0.63
0.35	14.07	5.67	0.62
0.3667	13.94	5.80	0.63
0.3833	14.37	5.38	0.58
0.4	14.23	5.51	0.60
0.4167	14.53	5.21	0.57
0.4333	14.76	4.99	0.54
0.45	14.85	4.89	0.53
0.4667	15.14	4.61	0.50
0.4833	14.98	4.77	0.52

Head - time graph (slope of graph is S)



Calculations:

h_1			
t_1			
h_2			
t_2			
S			
k			

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)
where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: Not amenable to analysis. ~1300L added to obs6, with only 10m of water level added to the column. Suggests moderate to high permeability (as anticipated from geology - THD / TPS / CID)

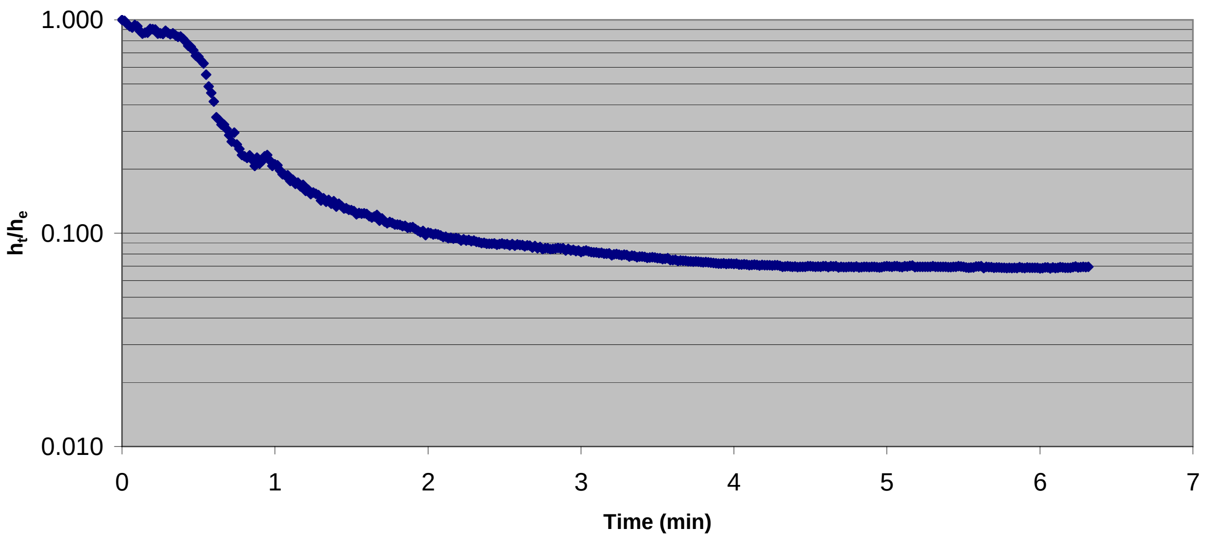
FALLING HEAD TEST

Bore No: Obs6	**Test No:** #1	**Job No:** 832G	**Date:** 9-Jun-00	**Logged by:** DJ

Borehole co-ordinates: **Easting:**		**Northing:**	Collar elevation (m):	0.5
Depth to top of test section (m):	34		Length of test section, **L** (m):	30
Depth of static water level, $\mathbf{H_w}$ (m):	30.95		Radius of borehole, **r** (m):	0.075
Excess head, $\mathbf{h_e}$ (m):	12.29		Radius of standpipe or casing, $\mathbf{r_c}$ (m):	0.025

Time (min)	**Depth to water, h_w (m)**	**Excess head, h_t=H_w-h_w (m)**	**h_t/h_e**
0	18.661	**12.29**	**1.00**
0.0167	18.792	12.158	0.99
0.0333	19.197	11.753	0.96
0.05	19.495	11.455	0.93
0.0667	19.635	11.315	0.92
0.0833	19.328	11.622	0.95
0.1	19.465	11.485	0.93
0.1167	20.071	10.879	0.89
0.1333	20.342	10.608	0.86
0.15	20.229	10.721	0.87
0.1667	20.242	10.708	0.87
0.1833	19.798	11.152	0.91
0.2	19.831	11.119	0.90
0.2167	19.869	11.081	0.90
0.2333	20.346	10.604	0.86
0.25	20.307	10.643	0.87
0.2667	20.397	10.553	0.86
0.2833	20.024	10.926	0.89
0.3	20.23	10.72	0.87
0.3167	20.419	10.531	0.86
0.3333	20.323	10.627	0.86
0.35	20.55	10.4	0.85
0.3667	20.703	10.247	0.83
0.3833	20.667	10.283	0.84
0.4	20.943	10.007	0.81
0.4167	21.24	9.71	0.79
0.4333	21.676	9.274	0.75
0.45	21.745	9.205	0.75
0.4667	22.087	8.863	0.72
0.4833	22.601	8.349	0.68

Head - time graph (slope of graph is S)



Calculations:

h_1			
t_1			
h_2			
t_2			
S			
k			

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: Not amenable to analysis. ~1100L added to obs6, with only 10m of water level added to the column. Suggests moderate to high permeability (as anticipated from geology - TPS / CID)

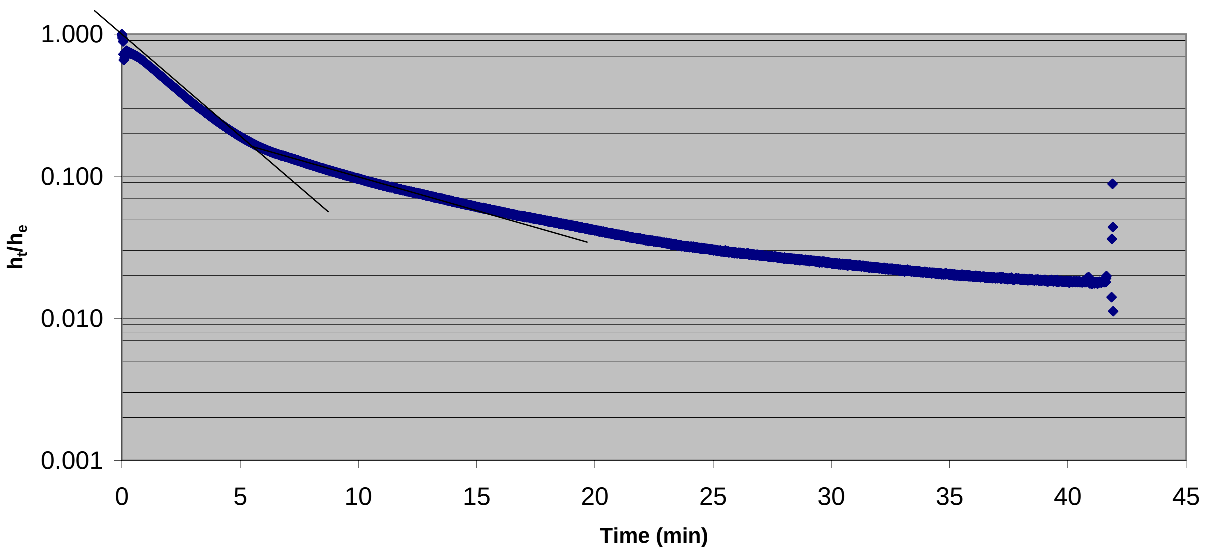
FALLING HEAD TEST

Bore No: Obs 7	**Test No:** #1	**Job No:** 832G	**Date:** 9-Jun-00	**Logged by:** DJ

Borehole co-ordinates: **Easting:**	**Northing:**	Collar elevation (m):	0.5
Depth to top of test section (m):	100	Length of test section, **L** (m):	48
Depth of static water level, $\mathbf{H_w}$ (m):	31.15	Radius of borehole, **r** (m):	0.075
Excess head, $\mathbf{h_e}$ (m):	17.13	Radius of standpipe or casing, $\mathbf{r_c}$ (m):	0.025

Time (min)	Depth to water, h_w (m)	Excess head, $h_t=H_w-h_w$ (m)	h_t/h_e
0	14.02	**17.13**	**1.00**
0.0167	14.476	16.674	0.97
0.0333	15.062	16.088	0.94
0.05	15.976	15.174	0.89
0.0667	18.803	12.347	0.72
0.0833	19.872	11.278	0.66
0.1	19.859	11.291	0.66
0.1167	19.455	11.695	0.68
0.1333	19.005	12.145	0.71
0.15	18.292	12.858	0.75
0.1667	18.459	12.691	0.74
0.1833	18.433	12.717	0.74
0.2	18.096	13.054	0.76
0.2167	18.366	12.784	0.75
0.2333	18.125	13.025	0.76
0.25	18.42	12.73	0.74
0.2667	18.349	12.801	0.75
0.2833	18.308	12.842	0.75
0.3	18.463	12.687	0.74
0.3167	18.469	12.681	0.74
0.3333	18.5	12.65	0.74
0.35	18.554	12.596	0.74
0.3667	18.669	12.481	0.73
0.3833	18.591	12.559	0.73
0.4	18.606	12.544	0.73
0.4167	18.716	12.434	0.73
0.4333	18.745	12.405	0.72
0.45	18.759	12.391	0.72
0.4667	18.81	12.34	0.72
0.4833	18.863	12.287	0.72

Head - time graph (slope of graph is S)



Calculations:	h_1	1.00	0.14	
	t_1	0.0	7	
	h_2	0.25	0.06	
	t_2	4.0	14.5	
	S	1.5E-01	4.9E-02	
	k	**2.61E-07**	**8.50E-08**	

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)
where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: More amenable to analysis. ~70L slug of water added 15m to water level in the column. Water levels took 20 minutes to return to previous conditions. This behaviour is more typical of very low permeability geology (Bee Gorge Member, Wittenoom Formation). Permeability range of 0.007 to 0.002 m/d

FALLING HEAD TEST

Bore No: Obs 10	**Test No:** #1	**Job No:** 832G	**Date:** 9-Jun-00	**Logged by:** DJ

Borehole co-ordinates: **Easting:** **Northing:**

Depth to top of test section (m): 65

Depth of static water level, **H_w** (m): 31.34

Excess head, **h_e** (m): 30.11

Collar elevation (m): 0.5

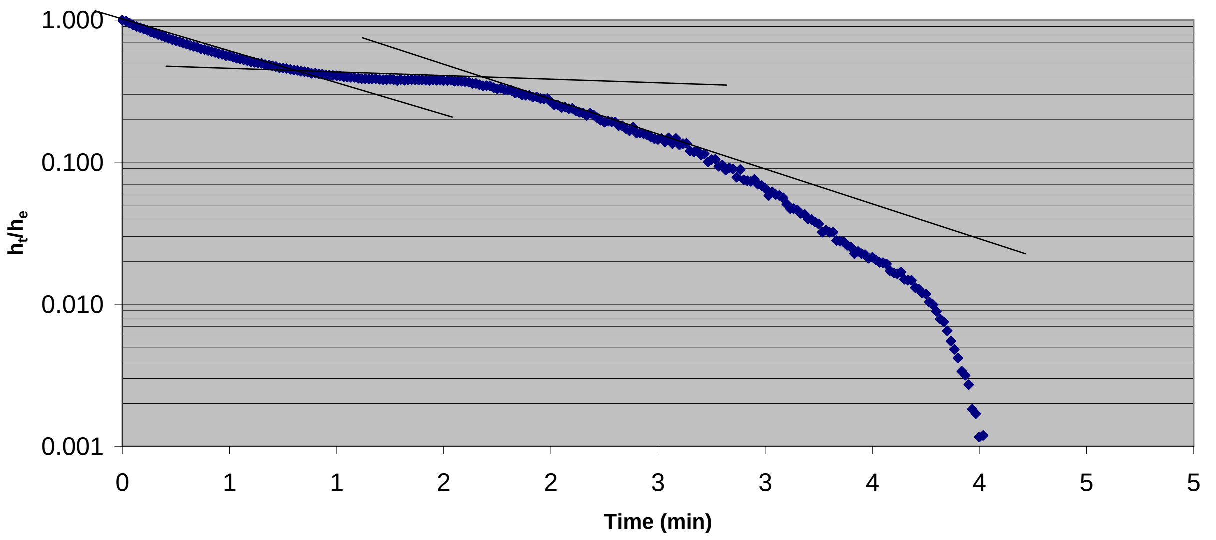
Length of test section, **L** (m): 12

Radius of borehole, **r** (m): 0.15

Radius of standpipe or casing, **r_c** (m): 0.025

Time (min)	Depth to water, h_w (m)	Excess head, h_t=H_w-h_w (m)	h_t/h_e
0	1.227	**30.11**	**1.00**
0.0167	1.72	29.62	0.98
0.0333	2.544	28.796	0.96
0.05	3.431	27.909	0.93
0.0667	4.129	27.211	0.90
0.0833	4.727	26.613	0.88
0.1	5.243	26.097	0.87
0.1167	5.854	25.486	0.85
0.1333	6.445	24.895	0.83
0.15	7.048	24.292	0.81
0.1667	7.551	23.789	0.79
0.1833	8.044	23.296	0.77
0.2	8.436	22.904	0.76
0.2167	8.933	22.407	0.74
0.2333	9.429	21.911	0.73
0.25	9.816	21.524	0.71
0.2667	10.182	21.158	0.70
0.2833	10.632	20.708	0.69
0.3	10.944	20.396	0.68
0.3167	11.367	19.973	0.66
0.3333	11.699	19.641	0.65
0.35	12.011	19.329	0.64
0.3667	12.434	18.906	0.63
0.3833	12.656	18.684	0.62
0.4	12.966	18.374	0.61
0.4167	13.269	18.071	0.60
0.4333	13.503	17.837	0.59
0.45	13.834	17.506	0.58
0.4667	14.073	17.267	0.57
0.4833	14.367	16.973	0.56

Head - time graph (slope of graph is S)



Calculations:

h_1	1.00	0.39	0.35
t_1	0.00	1.17	1.67
h_2	0.56	0.38	0.04
t_2	0.50	1.40	3.17
S	5.1E-01	4.9E-02	6.3E-01
k	**3.50E-06**	**3.40E-07**	**4.35E-06**

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: More amenable to analysis. ~180L slug of water added 30m to water level in the column. Water levels took several minutes to return to previous conditions. This behaviour is more typical of low permeability geology (basal conglomerate). Permeability range of 0.03 to 0.3m/d

FALLING HEAD TEST

Bore No:	**PZ1 Deep**	**Test No:**	#1	**Job No:**	832G	**Date:**	9-Jun-00	**Logged by:**	DJ

Borehole co-ordinates: **Easting:**

Northing:

Collar elevation (m): 0.5

Depth to top of test section (m): 21

Length of test section, **L** (m): 23

Depth of static water level, $\mathbf{H_w}$ (m): 34.18

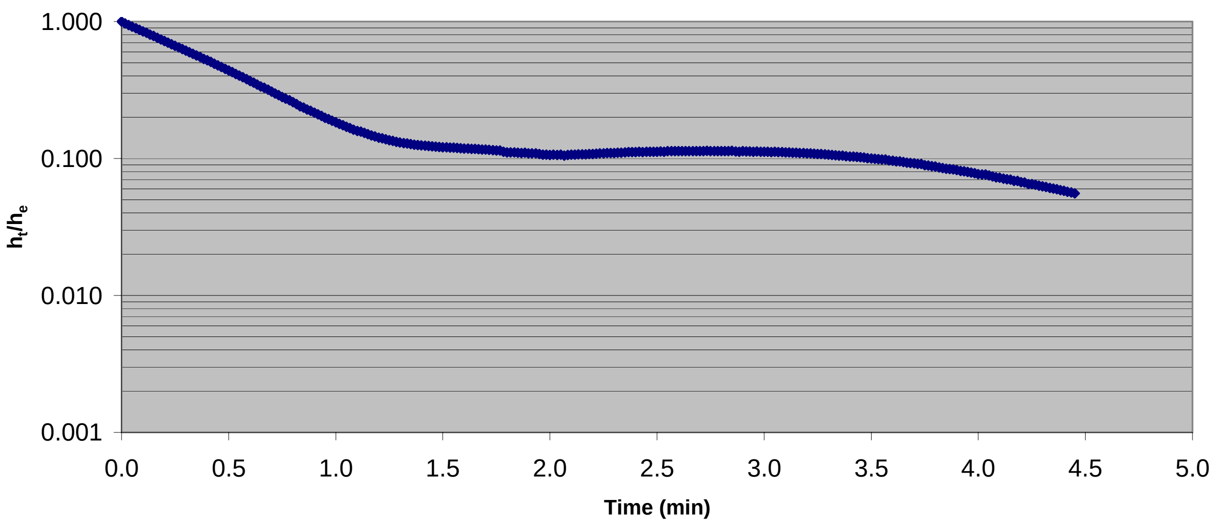
Radius of borehole, **r** (m): 0.15

Excess head, $\mathbf{h_e}$ (m): 31.19

Radius of standpipe or casing, $\mathbf{r_c}$ (m): 0.025

Time **(min)**	**Depth to water, h_w (m)**	**Excess head, h_t=H_w-h_w (m)**	**h_t/h_e**
0	2.991	31.189	1.00
0.0167	4.002	30.178	0.97
0.0333	4.836	29.344	0.94
0.05	5.592	28.588	0.92
0.0667	6.295	27.885	0.89
0.0833	7.087	27.093	0.87
0.1	7.723	26.457	0.85
0.1167	8.376	25.804	0.83
0.1333	9.126	25.054	0.80
0.15	9.736	24.444	0.78
0.1667	10.47	23.71	0.76
0.1833	11.05	23.13	0.74
0.2	11.674	22.506	0.72
0.2167	12.27	21.91	0.70
0.2333	12.874	21.306	0.68
0.25	13.422	20.758	0.67
0.2667	13.975	20.205	0.65
0.2833	14.573	19.607	0.63
0.3	15.038	19.142	0.61
0.3167	15.528	18.652	0.60
0.3333	16.069	18.111	0.58
0.35	16.591	17.589	0.56
0.3667	17.032	17.148	0.55
0.3833	17.532	16.648	0.53
0.4	17.882	16.298	0.52
0.4167	18.365	15.815	0.51
0.4333	18.818	15.362	0.49
0.45	19.22	14.96	0.48
0.4667	19.687	14.493	0.46
0.4833	20.115	14.065	0.45

Head - time graph (slope of graph is S)



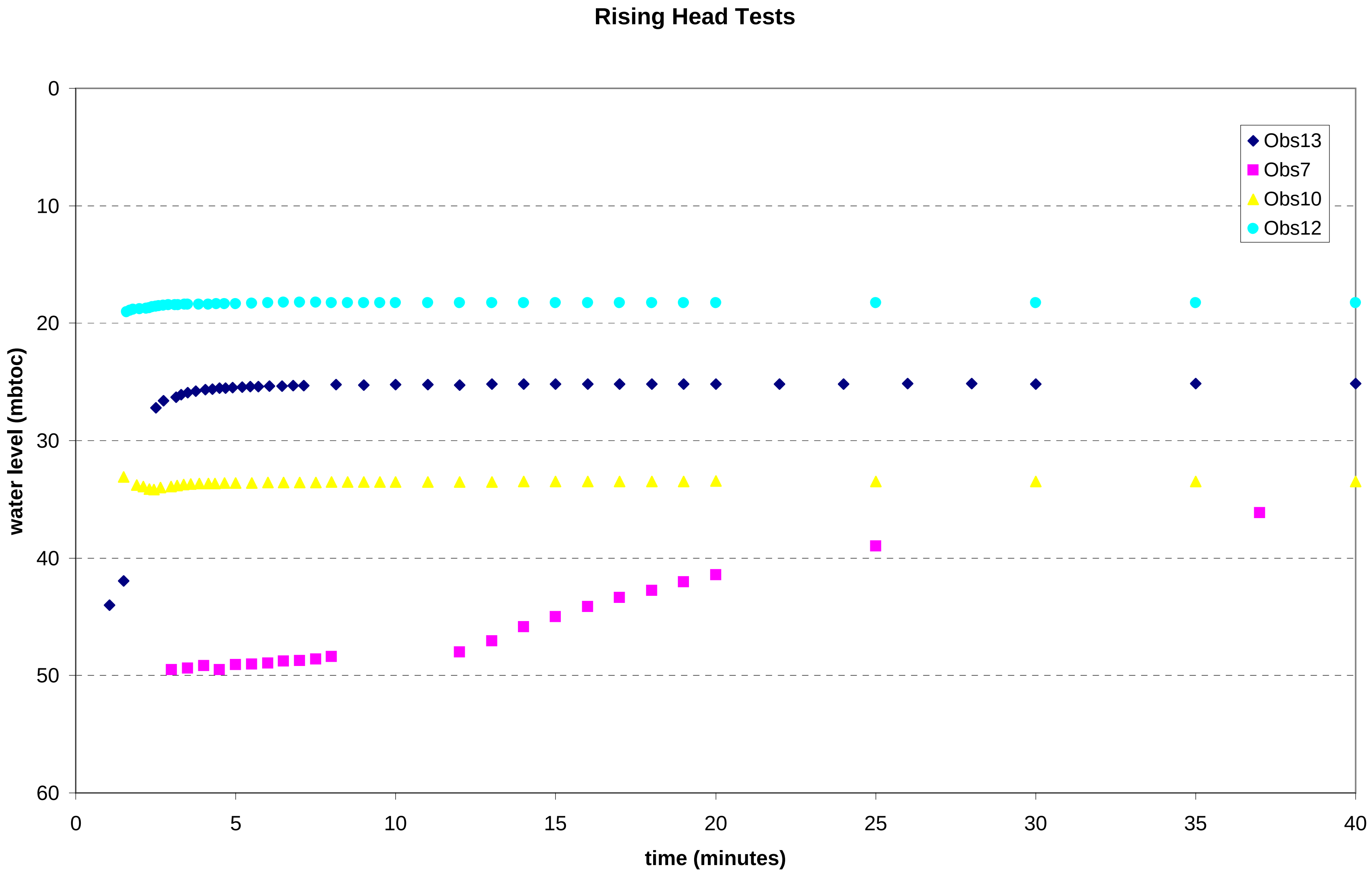
Calculations:

h_1	1.00	
t_1	0.0	
h_2	0.18	
t_2	1.0	
S	7.4E-01	
k	**2.66E-06**	

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: More amenable to analysis. ~400L slug of water added 30m to water level in the column. Water levels took several minutes to return to previous conditions. This behaviour is more typical of low permeability geology (basal conglomerate). Permeability of 0.2 m/d

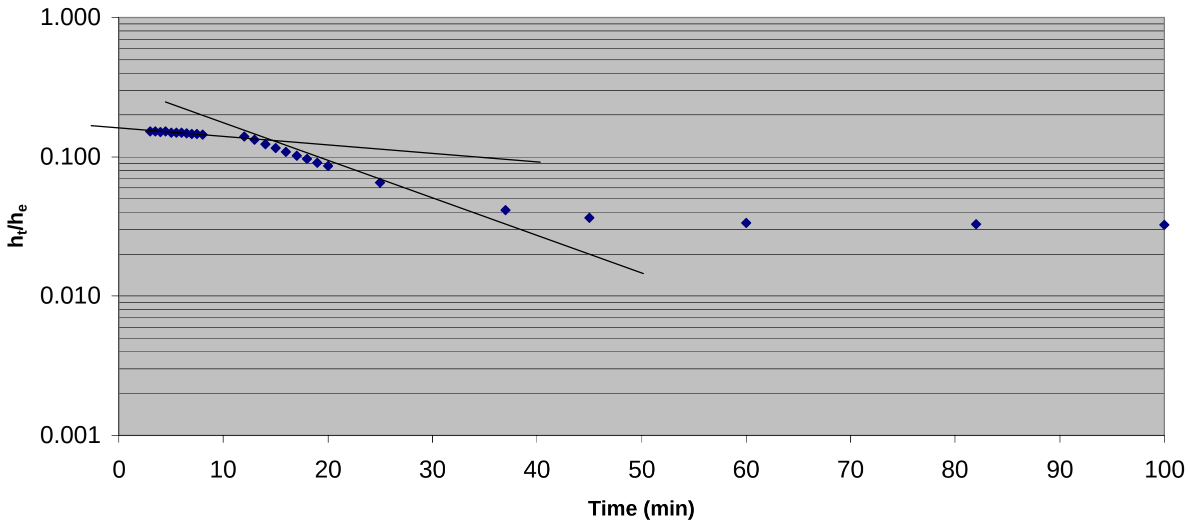

Rising Head Tests
water level (mbtoc)
0
10
20
30
40
50
60
time (minutes)
0
5
10
15
20
25
30
35
40
◆ Obs13
■ Obs7
▲ Obs10
● Obs12

Bore No:	**Obs 7**	**Test No:**	**#1**	**Job No:**	832G	**Date:**	9-Jun-09	**Logged by:**	DJ

Borehole co-ordinates: **Easting:**		**Northing:**	Collar elevation (m):	0.5
Depth to top of test section (m):	100		Length of test section, **L** (m):	48
Depth of static water level, $\mathbf{H_w}$ (m):	31.15		Radius of borehole, **r** (m):	0.075
Excess head, $\mathbf{h_e}$ (m):	-120.00		Radius of standpipe or casing, $\mathbf{r_c}$ (m):	0.025

Time (min)	**Depth to water, h_w (m)**	**Excess head, $h_t=H_w-h_w$ (m)**	**h_t/h_e**
3	49.5	**-18.35**	**0.15**
3.5	49.4	-18.25	0.15
4	49.18	-18.03	0.15
4.5	49.5	-18.35	0.15
5	49.1	-17.95	0.15
5.5	49.04	-17.89	0.15
6	48.97	-17.82	0.15
6.5	48.79	-17.64	0.15
7	48.74	-17.59	0.15
7.5	48.59	-17.44	0.15
8	48.39	-17.24	0.14
12	48	-16.85	0.14
13	47.05	-15.9	0.13
14	45.87	-14.72	0.12
15	44.98	-13.83	0.12
16	44.13	-12.98	0.11
17	43.36	-12.21	0.10
18	42.76	-11.61	0.10
19	42.05	-10.9	0.09
20	41.42	-10.27	0.09
25	39	-7.85	0.07
37	36.13	-4.98	0.04
45	35.51	-4.36	0.04
60	35.18	-4.03	0.03
82	35.07	-3.92	0.03
100	35.04	-3.89	0.03
150	35.01	-3.86	0.03
180	34.985	-3.835	0.03
260	34.95	-3.8	0.03

Head - time graph (slope of graph is S)



Calculations:	$\mathbf{h_1}$	0.15	0.14	
	$\mathbf{t_1}$	3.0	8	
	$\mathbf{h_2}$	0.14	0.04	
	$\mathbf{t_2}$	8.0	45	
	S	7.7E-03	1.6E-02	
	k	**1.33E-08**	**2.74E-08**	

Permeability, k = 0.133 x S x (r_c^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes:

Recovery of water level relatively slow.

Permeabilities of 0.001 to 0.002 m/d

Bore No: Obs 10 **Test No:** #1 **Job No:** 832G **Date:** 9-Jun-09 **Logged by:** DJ

Borehole co-ordinates: **Easting:** **Northing:**

Depth to top of test section (m): 65

Depth of static water level, $\mathbf{H_w}$ (m): 31.34

Excess head, $\mathbf{h_e}$ (m): -30.00

Collar elevation (m): 0.5

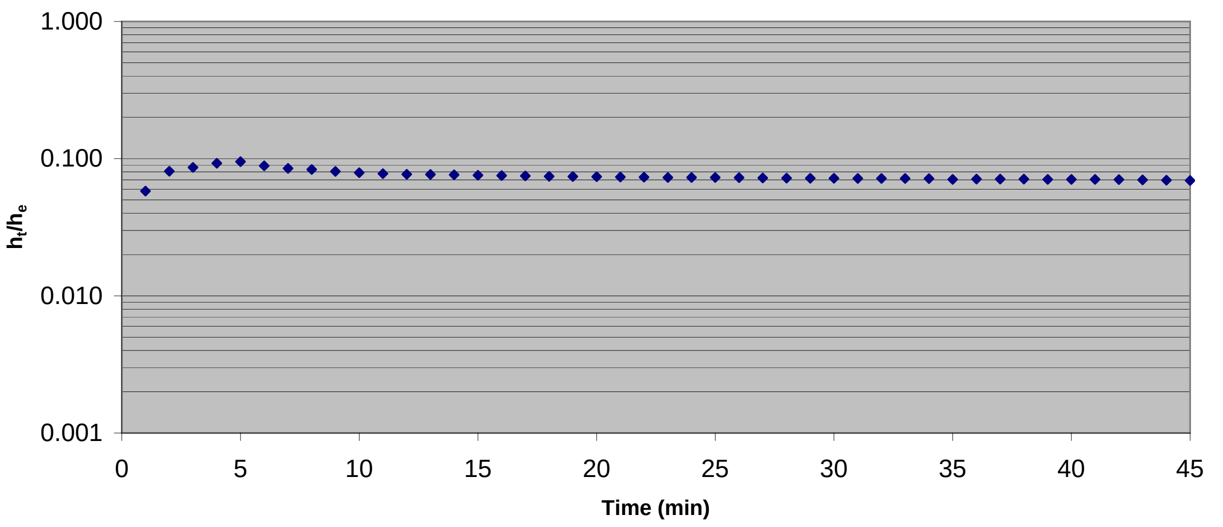
Length of test section, **L** (m): 12

Radius of borehole, **r** (m): 0.075

Radius of standpipe or casing, $\mathbf{r_c}$ (m): 0.025

Time (min)	**Depth to water, h_w (m)**	**Excess head, h_t=H_w-h_w (m)**	**h_t/h_e**
1.5	33.08	**-1.74**	**0.06**
1.9	33.77	-2.43	0.08
2.12	33.93	-2.59	0.09
2.3	34.12	-2.78	0.09
2.45	34.19	-2.85	0.09
2.65	34	-2.66	0.09
2.98	33.89	-2.55	0.09
3.17	33.84	-2.5	0.08
3.38	33.76	-2.42	0.08
3.6	33.71	-2.37	0.08
3.87	33.67	-2.33	0.08
4.15	33.65	-2.31	0.08
4.35	33.64	-2.3	0.08
4.65	33.63	-2.29	0.08
5	33.61	-2.27	0.08
5.5	33.6	-2.26	0.08
6	33.585	-2.245	0.07
6.5	33.57	-2.23	0.07
7	33.56	-2.22	0.07
7.5	33.555	-2.215	0.07
8	33.545	-2.205	0.07
8.5	33.54	-2.2	0.07
9	33.53	-2.19	0.07
9.5	33.53	-2.19	0.07
10	33.525	-2.185	0.07
11	33.52	-2.18	0.07
12	33.51	-2.17	0.07
13	33.505	-2.165	0.07
14	33.5	-2.16	0.07
15	33.5	-2.16	0.07
16	33.495	-2.155	0.07

Head - time graph (slope of graph is S)



Calculations:

h_1	0.06			
t_1	1.5			
h_2	0.08			
t_2	4.7			
S	-3.8E-02			
k	**-2.62E-07**			

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

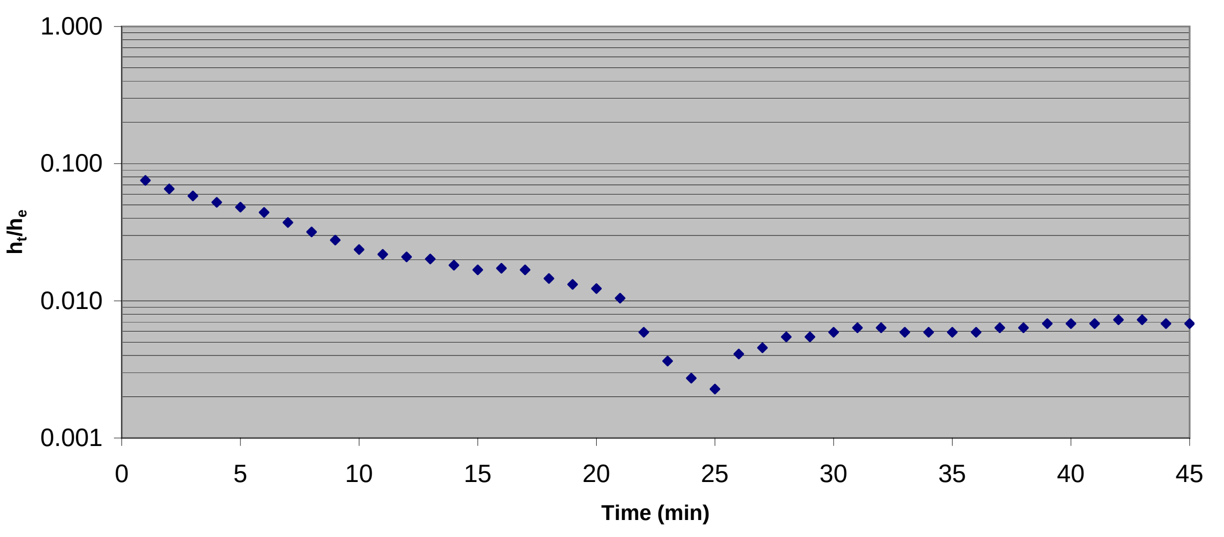
Notes: Potentially screened in basal CID as well as conglomerate. Predominaltyy recovered in first few minutes. Infer moderate permeability

Bore No: Obs 12
Test No: #1
Job No: 832G
Date: 9-Jun-09
Logged by: DJ

Borehole co-ordinates: **Easting:**
Northing:
Depth to top of test section (m): 22
Depth of static water level, **H_w** (m): 18.2
Excess head, **h_e** (m): -11.00
Collar elevation (m): 0.5
Length of test section, **L** (m): 12
Radius of borehole, **r** (m): 0.075
Radius of standpipe or casing, **r_c** (m): 0.025

Time (min)	Depth to water, h_w (m)	Excess head, h_t=H_w-h_w (m)	h_t/h_e
1.6	19.03	**-0.83**	**0.08**
1.7	18.92	-0.72	0.07
1.8	18.84	-0.64	0.06
2	18.775	-0.575	0.05
2.2	18.73	-0.53	0.05
2.3	18.685	-0.485	0.04
2.4	18.61	-0.41	0.04
2.5	18.55	-0.35	0.03
2.6	18.505	-0.305	0.03
2.75	18.46	-0.26	0.02
2.9	18.44	-0.24	0.02
3.1	18.43	-0.23	0.02
3.2	18.422	-0.222	0.02
3.4	18.4	-0.2	0.02
3.5	18.385	-0.185	0.02
3.85	18.39	-0.19	0.02
4.15	18.385	-0.185	0.02
4.4	18.36	-0.16	0.01
4.65	18.345	-0.145	0.01
5	18.335	-0.135	0.01
5.5	18.315	-0.115	0.01
6	18.265	-0.065	0.01
6.5	18.24	-0.04	0.00
7	18.23	-0.03	0.00
7.5	18.225	-0.025	0.00
8	18.245	-0.045	0.00
8.5	18.25	-0.05	0.00
9	18.26	-0.06	0.01
9.5	18.26	-0.06	0.01
10	18.265	-0.065	0.01

Head - time graph (slope of graph is S)



Calculations:

h_1			
t_1			
h_2			
t_2			
S			
k			

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)
where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes: screened across THD and TPS
Recovered too quickly for useful data to be analysed.
Can infer a moderate to high permeabilty

Bore No: **Obs 13** | **Test No:** #1 | **Job No:** 832G | **Date:** 9-Jun-09 | **Logged by:** DJ

Borehole co-ordinates: **Easting:**

Northing:

Depth to top of test section (m): 113.5

Depth of static water level, **H_w** (m): 24.95

Excess head, **h_e** (m): -120.00

Collar elevation (m): 0.5

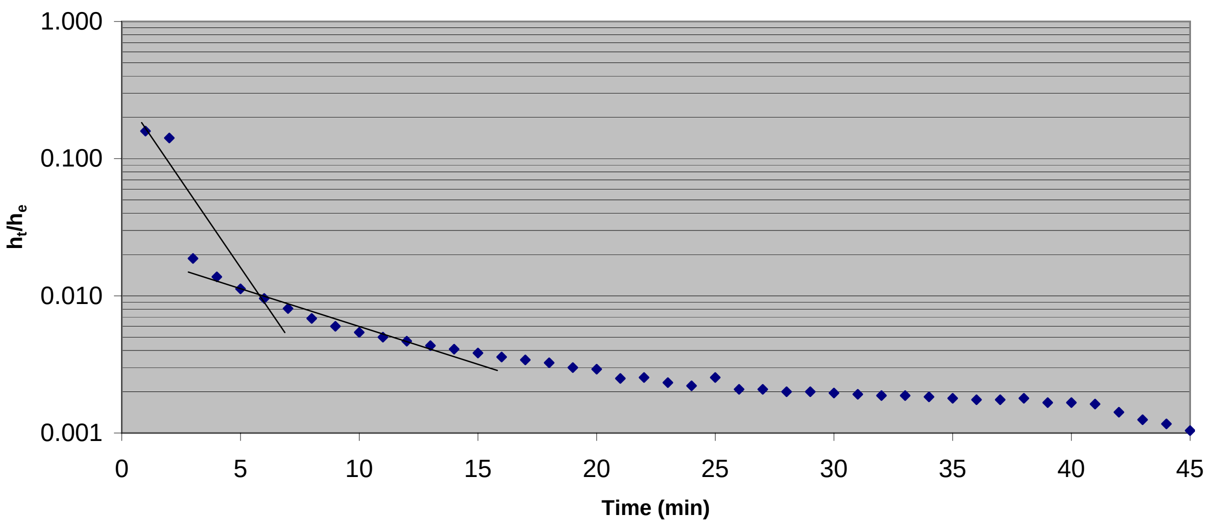
Length of test section, **L** (m): 34

Radius of borehole, **r** (m): 0.075

Radius of standpipe or casing, **r_c** (m): 0.025

Time (min)	**Depth to water, h_w (m)**	**Excess head, $h_t=H_w-h_w$ (m)**	**h_t/h_e**
1.05	44.03	**-19.08**	**0.16**
1.5	41.94	-16.99	0.14
2.5	27.2	-2.25	0.02
2.75	26.6	-1.65	0.01
3.14	26.3	-1.35	0.01
3.3	26.1	-1.15	0.01
3.5	25.92	-0.97	0.01
3.75	25.77	-0.82	0.01
4.05	25.67	-0.72	0.01
4.27	25.6	-0.65	0.01
4.5	25.55	-0.6	0.01
4.68	25.51	-0.56	0.00
4.9	25.47	-0.52	0.00
5.2	25.44	-0.49	0.00
5.45	25.41	-0.46	0.00
5.7	25.38	-0.43	0.00
6.05	25.36	-0.41	0.00
6.45	25.34	-0.39	0.00
6.8	25.31	-0.36	0.00
7.13	25.3	-0.35	0.00
8.13	25.25	-0.3	0.00
9	25.255	-0.305	0.00
10	25.23	-0.28	0.00
11	25.215	-0.265	0.00
12	25.255	-0.305	0.00
13	25.2	-0.25	0.00
14	25.2	-0.25	0.00
15	25.19	-0.24	0.00
16	25.19	-0.24	0.00
17	25.185	-0.235	0.00
18	25.18	-0.23	0.00

Head - time graph (slope of graph is S)



Calculations:

h_1	0.16	0.01	
t_1	1.1	3.3	
h_2	0.01	0.00	
t_2	3.3	4.9	
S	5.3E-01	2.2E-01	
k	**1.31E-06**	**5.27E-07**	

Permeability, k = 0.133 x S x (rc^2/L) (m/sec)

where S = (log (h1/h2)/(t2 - t1), (ie slope of plot, t in mins)

Notes:

Recovery of water level relatively slow.

Permeabilities of 0.04 to 0.1 m/d

APPENDIX E WATER QUALITY ANALYSES

ANALYTICAL REPORT

19 June 2009

Client Details

Client	:	**Aquaterra**
Contact	:	Damien Janssen
Address	:	Suite 4, 125 Melville Parade COMO COMO WA 6152

Job Details

Client Reference	:	Marillana, Job# 832G, Task# G5
Report No	:	PE023451
Report Version	:	00
Samples	:	15 Waters
Received	:	15/06/2009

Comments:

This report cancels and supercedes any preliminary results provided

---

For and on Behalf of SGS Environmental Services

Client Services Manager:	Matthew Deaves	Matthew.Deaves@sgs.com
Sample Receipt:	Cecilia Tadena	AU.Environmental.Perth@sgs.com
Laboratory Manager:	Said Hirad	Said.Hirad@sgs.com

Results Approved and/or Authorised by:

Said Hirad

SAID HIRAD
NATA Signatory

Brief Water Analysis Client Reference Sample No Date Sampled Type of Sample	Units	PB1 PE023451-1 27/05/2009 Water	PB2 PE023451-2 05/06/2009 Water	PS1PB PE023451-3 31/05/2009 Water	OBS1 PE023451-4 07/06/2009 Water	OBS2 PE023451-5 13/06/2009 Water
Date Extracted		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
Date Analysed		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
pH	pH Units	7.1	7.5	7.6	8.3	7.3
Conductivity @25^{o}C	µS/cm	890	1,100	2,200	2,100	1,600
TDS (Calculated)	mg/L	540	680	1,300	1,200	970
Soluble Iron, Fe	mg/L	0.03	<0.02	<0.02	<0.02	<0.02
Sodium, Na	mg/L	120	150	380	370	270
Potassium, K	mg/L	15	17	37	38	28
Calcium, Ca	mg/L	26	41	35	30	29
Magnesium, Mg	mg/L	35	42	51	43	41
Chloride, Cl	mg/L	180	240	540	490	380
Carbonate, CO_3	mg/L	<1	<1	<1	<1	<1
Bicarbonate, HCO_3	mg/L	210	210	190	230	190
Sulphate, SO_4	mg/L	70	69	160	170	130
Nitrate, NO_3	mg/L	1.2	7.0	3.7	3.5	5.1
Cation/Anion balance	%	-2.4	1.7	4.0	2.6	1.7
Sum of Ions (calc.)	mg/L	657.0	774.0	1,390	1,373	1,084

Brief Water Analysis Client Reference Sample No Date Sampled Type of Sample	Units	OBS4 PE023451-6 13/06/2009 Water	OBS5 PE023451-7 06/06/2009 Water	OBS6 PE023451-8 06/06/2009 Water	OBS7 PE023451-9 13/06/2009 Water	OBS8 PE023451-10 13/06/2009 Water
Date Extracted		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
Date Analysed		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
pH	pH Units	7.2	8.1	8.3	7.3	7.5
Conductivity @25^{o}C	µS/cm	1,600	1,500	920	37,000	1,300
TDS (Calculated)	mg/L	980	920	550	22,000	780
Soluble Iron, Fe	mg/L	0.05	<0.02	<0.02	1.7	<0.02
Sodium, Na	mg/L	250	200	120	8,900	200
Potassium, K	mg/L	37	22	16	600	25
Calcium, Ca	mg/L	31	47	26	230	30
Magnesium, Mg	mg/L	49	51	34	700	40
Chloride, Cl	mg/L	370	330	170	13,000	260
Carbonate, CO_3	mg/L	<1	<1	<1	<1	<1
Bicarbonate, HCO_3	mg/L	220	260	210	360	250
Sulphate, SO_4	mg/L	120	92	50	4,000	110
Nitrate, NO_3	mg/L	1.4	6.1	1.3	<0.2	<0.2
Cation/Anion balance	%	2.8	0.8	1.8	1.3	1.1
Sum of Ions (calc.)	mg/L	1,077	1,009	632.0	27,807	924.0

Brief Water Analysis Client Reference Sample No Date Sampled Type of Sample	Units	OBS9 PE023451-11 13/06/2009 Water	OBS10 PE023451-12 07/06/2009 Water	OBS11 PE023451-13 09/06/2009 Water	OBS12 PE023451-14 06/06/2009 Water	OBS13 PE023451-15 05/06/2009 Water
Date Extracted		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
Date Analysed		16/06/2009	16/06/2009	16/06/2009	16/06/2009	16/06/2009
pH	pH Units	7.8	8.3	8.0	8.1	8.0
Conductivity @25^{o}C	µS/cm	1,700	1,500	1,600	1,300	36,000
TDS (Calculated)	mg/L	1,000	870	980	780	22,000
Soluble Iron, Fe	mg/L	<0.02	<0.02	0.02	<0.02	1.2
Sodium, Na	mg/L	290	230	240	130	8,300
Potassium, K	mg/L	28	28	30	12	590
Calcium, Ca	mg/L	34	30	51	74	310
Magnesium, Mg	mg/L	42	41	49	62	940
Chloride, Cl	mg/L	370	330	360	290	14,000
Carbonate, CO_3	mg/L	<1	<1	<1	<1	<1
Bicarbonate, HCO_3	mg/L	270	230	310	290	270
Sulphate, SO_4	mg/L	140	99	120	82	3,700
Nitrate, NO_3	mg/L	3.6	1.3	22	3.2	<0.2
Cation/Anion balance	%	1.6	1.4	-0.4	-0.8	1.0
Sum of Ions (calc.)	mg/L	1,178	1,001	1,188	940.0	27,643

Brief Water Analysis Client Reference Sample No Date Sampled Type of Sample	Units	OBS14 PE023451-16 10/06/2009 Water	OBS15 PE023451-17 11/06/2009 Water
Date Extracted		16/06/2009	16/06/2009
Date Analysed		16/06/2009	16/06/2009
pH	pH Units	7.3	7.9
Conductivity @25^{o}C	µS/cm	1,700	3,900
TDS (Calculated)	mg/L	1,000	2,300
Soluble Iron, Fe	mg/L	0.03	0.03
Sodium, Na	mg/L	240	720
Potassium, K	mg/L	43	66
Calcium, Ca	mg/L	64	54
Magnesium, Mg	mg/L	52	76
Chloride, Cl	mg/L	370	1,100
Carbonate, CO_3	mg/L	<1	<1
Bicarbonate, HCO_3	mg/L	250	240
Sulphate, SO_4	mg/L	140	330
Nitrate, NO_3	mg/L	15	3.6
Cation/Anion balance	%	3.7	0.0
Sum of Ions (calc.)	mg/L	1,177	2,586

QUALTY CONTROL Brief Water Analysis	UNITS	LOR	METHOD	Blank	Duplicate	Sample || Dup || %RPD	Spike	Spike % Recovery
Date Extracted				16/6/09	[NT]	[NT]		18/06/09
Date Analysed				16/6/09	[NT]	[NT]		18/06/09
pH	pH Units	0.1	AN101	<0.1	[NT]	[NT]		100%
Conductivity @25^{o}C	µS/cm	2	AN106	<2	[NT]	[NT]		100%
TDS (Calculated)	mg/L	5	AN106	<5	[NT]	[NT]	[NR]	[NR]
Soluble Iron, Fe	mg/L	0.02	AN020-AN321	<0.02	[NT]	[NT]		103%
Sodium, Na	mg/L	0.5	AN020-AN321	<0.5	[NT]	[NT]		110%
Potassium, K	mg/L	0.1	AN020-AN321	<0.1	[NT]	[NT]		107%
Calcium, Ca	mg/L	0.2	AN020-AN321	<0.2	[NT]	[NT]		106%
Magnesium, Mg	mg/L	0.1	AN020-AN321	<0.1	[NT]	[NT]		106%
Chloride, Cl	mg/L	1	AN274	<1	[NT]	[NT]		105%
Carbonate, CO_3	mg/L	1	AN135	<1	[NT]	[NT]	[NR]	[NR]
Bicarbonate, HCO_3	mg/L	5	AN135	<5	[NT]	[NT]		94%
Sulphate, SO_4	mg/L	1	AN275	<1	[NT]	[NT]		106%
Nitrate, NO_3	mg/L	0.2	AN258	<0.2	[NT]	[NT]		106%
Cation/Anion balance	%		Calculation	[NT]	[NT]	[NT]	[NR]	[NR]

Method ID	Methodology Summary
AN101	pH is measured electrometrically using a combination electrode (glass plus reference electrode) and is calibrated against 3 buffers purchased commercially. For soils, an extract with water is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN106	Conductivity is measured by meter with temperature compensation and is calibrated against a standard solution of potassium chloride. Conductivity is generally reported as µmhos/cm or µS/cm @ 25°C. For soils, an extract with water is made at a ratio of 1:5 and the EC determined and reported on the extract, or calculated back to the as-received sample. Salinity can be estimated from conductivity using a conversion factor, which for natural waters, is in the range 0.55 to 0.75. Reference APHA 2520 B.
AN020-AN321	After preservation with 10% nitric acid, a wide range of metals and some non-metals in solution can be measured by ICP. Solutions are aspirated into an argon plasma at 8000-10000K and emit characteristic energy or light as a result of electron transitions through unique energy levels. The emitted light is focused onto a diffraction grating where it is separated into components. Photomultipliers or CCDs are used to measure the light intensity at specific wavelengths. This intensity is directly proportional to concentration. Corrections are required to compensate for spectral overlap between elements. Reference APHA 3120 B
AN274	Chloride reacts with mercuric thiocyanate forming a mercuric chloride complex. In the presence of ferric iron, highly coloured ferric thiocyanate is formed which is proportional to the chloride concentration. Reference APHA 4500Cl-
AN135	The sample is titrated with standard acid to pH 8.3 (P titre) and pH 4.5 (T titre) and permanent and/or total alkalinity calculated. The results are expressed as equivalents of calcium carbonate or recalculated as bicarbonate, carbonate and hydroxide. Reference APHA 2320. Internal Reference AN135
AN275	Sulphate is precipitated in an acidic medium with barium chloride. The resulting turbidity is measured photometrically at 405nm and compared with standard calibration solutions to determine the sulphate concentration in the sample. Reference APHA 4500-SO42-. Internal reference AN275.
AN258	In an acidic medium, nitrate is reduced quantitatively to nitrite by cadmium metal. This nitrite plus any original nitrite is determined as an intense red-pink azo dye at 540 nm following diazotisation with sulphanilamide and subsequent coupling with N-(1-naphthyl) ethylenediamine dihydrochloride. Without the cadmium reduction only the original nitrite is determined. Reference APHA 4500-NO3- F.
Calculation	NaCl is calculated in mg in the volume of sample as received by summing the Na & Cl results.

Result Codes

[INS]	:	Insufficient Sample for this Test	[RPD]	:	Relative Percentage Difference
[NR]	:	Not Requested	*	:	Not part of NATA Accreditation
[NT]	:	Not Tested	[N/A]	:	Not Applicable
LOR	:	Limit of Reporting			

Report Comments

The requested LOR for some samples could not be achieved due to high concentration of sodium ions. The reported results reflect the lowest achievable concentration quantifiable by the method quoted.
Samples analysed as received.
Solid samples expressed on a dry weight basis.

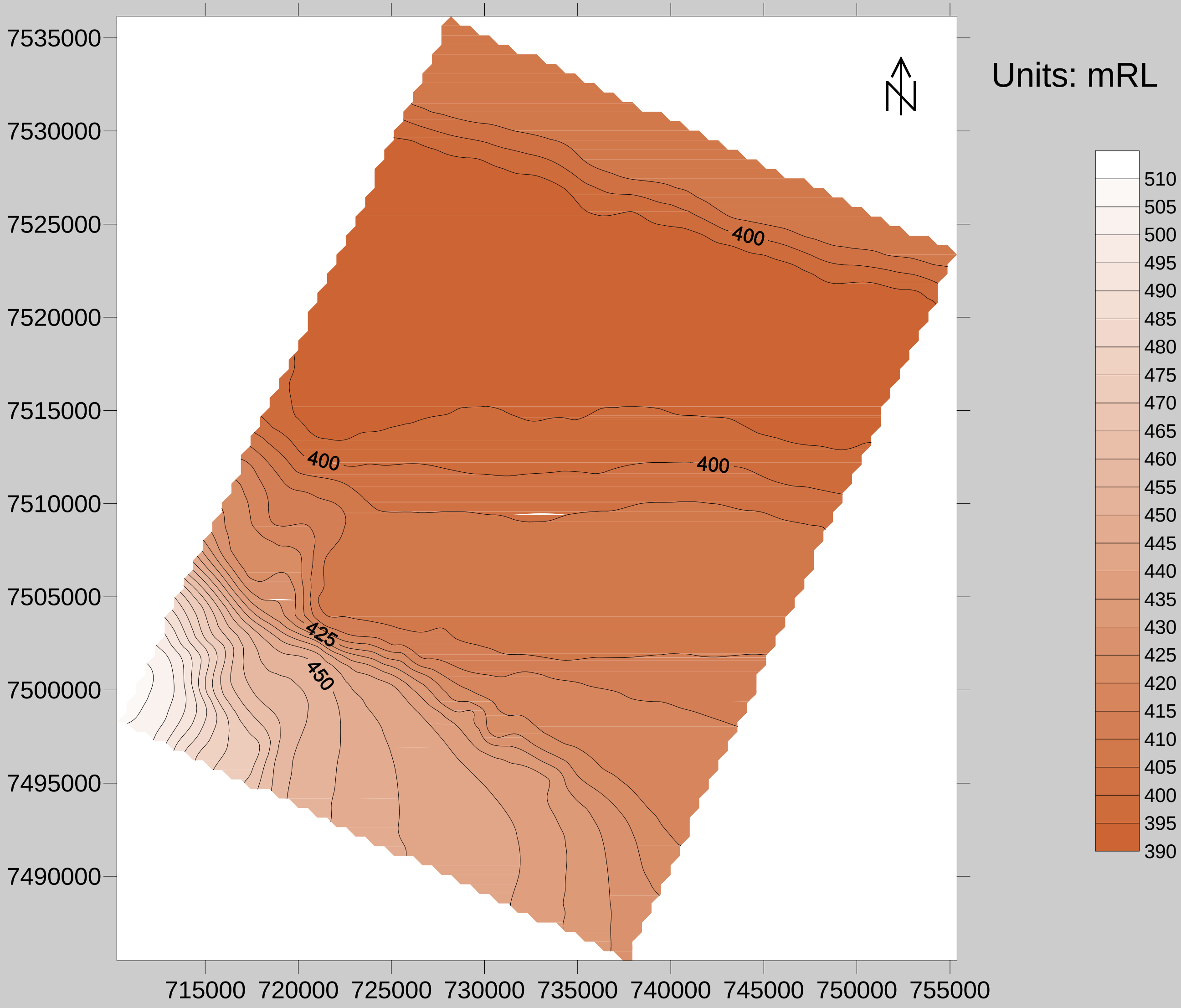
Quality Control Key

Method Blank (MB): An analyte free matrix to which all reagents are added in the same volume or proportions as used in sample processing. The method blank should be carried through the complete sample preparation and analytical procedure A method blank is prepared every 20 samples.
Duplicate (D): A separate portion of a sample being analysed that is treated the same as the other samples in the batch. One duplicates is processed at least every 10 samples.
Surrogate Spike (SS): An organic compound which is similar to the target analyte(s) in chemical composition and behaviour in the analytical process, but which is not normally douns in environmental samples. Surrogates are added to samples before extraction to monitor extraction efficiency and percent recovery in each sample.
Internal Standard (IS): Added to all samples requiring analysis for organics (where relevant) or metals by ICP after the extraction/digestion process; the compounds/elements serve to give a standard instrument retention time and /or response, which is invariant from run-to-run.
Laboratory Control Sample (LCS): A known matrix spiked with compound(s) representative of the target analytes. it is used to document laboratory performance. When the results of the marix spike analysis indicates a potential problem due to the sample matrix itselft, the LCS results are used to verify that the laboratory can perform the analysis in a clean matrix.
Matrix Spike (MS): An aliquot of sample spiked with a known concentration of target analyte(s). The spiking occurs prior to sample preparation and analysis. A matrix spike is used to document the bias of a method in a given sample matrix.
Relative Percentage Difference (RPD): The difference between an original and a duplicate result divided by the average of the original and duplicate results, expressed as a percentage.

Quality Acceptance Criteria

The QC criteria are subject to internal review according to the SGS QAQC plan and may be provided on request or alternatively can be found here: http://www.au.sgs.com/sgs-mp-au-env-qu-022-qa-qc-plan-en-09.pdf

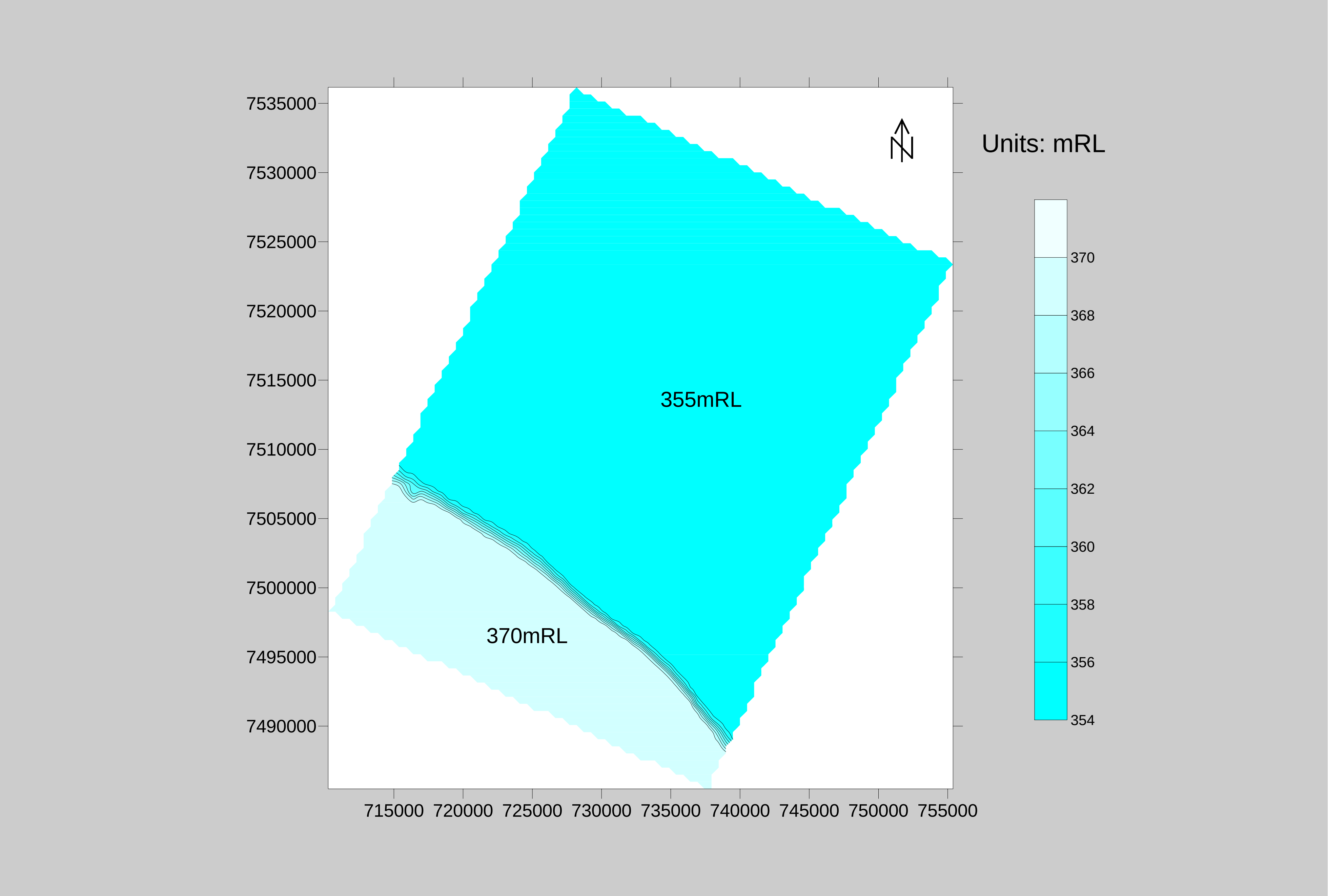
APPENDIX F GROUNDWATER MODELLING



aquaterra

BASE OF LAYER 1 CONTOURS Figure F1

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_figA1.srf



BASE OF LAYER 4 CONTOURS Figure F2

F:/Jobs/832G/G7 - DFS Reporting/145a_Figures/145a_figA4.srf

In Australia

Perth
Suite 4
125 Melville Parade
Como WA 6152
Tel +61 8 9368 4044
Fax +61 8 9368 4055
perth@aquaterra.com.au

Adelaide
Ground Floor
15 Bentham Street
Adelaide SA 5000
Tel +61 8 8410 4000
Fax +61 8 8410 6321
adelaide@aquaterra.com.au

Sydney
Suite 9
1051 Pacific Highway
Pymble NSW 2073
Tel +61 2 9440 2666
Fax +61 2 9449 3193
sydney@aquaterra.com.au

Echuca
Unit 1
213 Anstruther Street
Echuca VIC 3564
Tel +61 3 5480 3140
Fax +61 3 5480 3140
echuca@aquaterra.com.au

In Europe

Lewes
Cobbe Barns
Beddingham, Lewes
East Sussex BN8 6JU
United Kingdom
Tel +44 1273 858 223
Fax +44 1273 858 229
lewes@aquaterra.uk.com

Dublin
Sandyford
PO Box 11580
Dublin 18
Ireland
Tel +35312069920
Fax +35312069920
dublin@aquaterra.ie

In Mongolia

Ulaanbaatar
701 San Business Center
8th khoroo
Sukhbaatar District
Ulaanbaatar
Mongolia
Tel +976 95854921
ub@aquaterra.mn

aquaterra
Water and Environment