

Appendix H – Ammaroo Phosphate project groundwater study

AMMAROO PHOSPHATE PROJECT GROUNDWATER STUDY

Report to: Verdant Minerals Pty Ltd

RJR-16-3-R001E

Revision	Issue Date	Revision Description	Document Author	Checked By	Approved By
a	29/05/2017	Draft	Ben Jeuken		
b	28/8/2017	Final Draft	Ben Jeuken	Anthony Knapton	Ben Jeuken
c	29/8/2017	Final Draft – amended figures	Ben Jeuken		
d	22/9/2017	Final – Incorporate Consultation Feedback	Ben Jeuken	Paul Magarey	Ben Jeuken
e	6/10/2017	Final – Updated figures	Ben Jeuken		Ben Jeuken

Contents

1	Executive Summary.....	5
2	Introduction.....	7
2.1	Aim.....	7
2.2	Scope.....	7
2.3	Legislative Framework.....	7
3	Study Area.....	8
3.1	Location.....	8
3.2	Climate.....	8
4	Hydrogeological Setting.....	9
4.1	Focus.....	9
4.2	Geological Setting.....	9
4.3	Hydrogeological Structure.....	13
4.3.1	Aquifers.....	13
4.4	Georgina Basin Carbonate Aquifer.....	15
4.4.1	Aquifer Type.....	15
4.4.2	Extent.....	15
4.4.3	Depth.....	15
4.4.4	Flow Paths and Catchments.....	15
4.4.5	Recharge.....	19
4.4.6	Discharge.....	19
4.4.7	Connectivity.....	19
4.4.8	Volumes / Capacities.....	19
4.4.9	Groundwater Chemistry.....	20
4.4.10	Environmental Values.....	23
4.5	Third Party Users.....	23
4.5.1	Community.....	23
4.5.2	Environment.....	23
5	Groundwater Impacts Assessment.....	27
5.1	Groundwater Affecting Activities.....	27
5.1.1	Project Water Supply.....	27
5.1.2	Construction Water Supply.....	27
5.1.3	Mine Pit Excavation.....	27
5.1.4	Tailings Handling.....	28
5.1.5	Spills.....	28
5.2	Receptors.....	28
5.2.1	Pastoral Water Supply.....	28
5.2.2	Community Water Supply.....	28

5.2.3	Groundwater Dependant Ecosystems.....	28
5.2.4	Western Davenport Water Control District	28
5.3	Project Water Supply Impact Study	29
5.3.1	Modelling Approach	29
5.3.2	Drawdown at Receptors.....	31
5.3.3	Flow from WDWCD	34
5.3.4	Conclusions.....	35
5.3.5	Construction Water Supply	37
5.3.6	Mine Pit Excavations	37
5.3.7	Tailings Seepage	37
5.3.8	Spills.....	40
5.4	Risk Register.....	41
6	Groundwater Management Plan.....	42
6.1	Overview	42
6.2	Monitoring and reporting	42
6.3	Model Calibration and refinement	43
6.4	Contingency	43
7	Appendices	46
7.1	Appendix 2 – Detailed Chemical Analysis	52
7.2	Appendix 4 – Borefield Modelling Peer Review	53
7.3	Appendix 4 – Borefield Modelling Report	54
7.4	Appendix 5 -PB01 Pumping Test.....	55

List of Figures

Figure 1: Regional Setting	10
Figure 2: Geological Setting	11
Figure 3: Hydrogeological Cross Section	12
Figure 4: Hydrogeological Setting	14
Figure 5: Investigation Hole Drill Logs- Borefield site	17
Figure 6: Groundwater Potentiometric Surface and Inferred Flow Direction	18
Figure 7: Groundwater Chemistry (Piper Plot). Grey symbols are the regional NTLIS dataset. Coloured symbols are samples taken by Verdant Minerals	21
Figure 8: Groundwater Chemistry (Bore Salinity)	22
Figure 9: Third-Party Users, Community and the Environment	24
Figure 10: Conceptual Cross Section	25
Figure 11: Depth to Groundwater	26
Figure 12: Mine Pit Cross Section	27
Figure 13: Numerical Model Extent	30
Figure 14 Probability distribution for a) transmissivity and b) storage coefficient	30
Figure 15: Drawdown at the Bore field (PB01)	31
Figure 16: Drawdown at Nearest Pastoral Bore (Hagens Bore, RN107717)	32
Figure 17: Drawdown at Nearest Community Water Supply (Ampilwatja, RN107717)	32
Figure 18: Drawdown contours at end of mining	33
Figure 19: Calculated Groundwater flux across the WDWCD boundary	34
Figure 20: Water Level Drawdown at Ampilwatja Community water supply bore	35
Figure 21: Project water use as a fraction of the estimated water in storage in the Southern Georgina Basin	36
Figure 22: Groundwater Monitoring Locations	45
Figure 23: Pumping Test Type Curve Match	56

List of Tables

Table 1: Hydraulic Testing of Georgina Basin Carbonate aquifer	20
Table 2: Calculated Groundwater flux across the WDWCD boundary	34
Table 3: Drawdown Impacts from Construction Water Supply Bores	37
Table 4: Tailing Leachate (Tailing Leachate quality (Environmental Geochemistry International, 2014) and Groundwater Quality compared to water quality guidelines	39
Table 5: Risk Register	41
Table 6: Groundwater Management Plan	42
Table 7: Groundwater Monitoring Locations	43

1 Executive Summary

Introduction

This report presents the hydrogeological (groundwater) study for the Ammaroo Phosphate Project (APP) Environmental Impact Statement (EIS) and Bankable Feasibility Study (BFS). This report covers the APP mine site, infrastructure (Power, rail) corridor and borefield with the major emphasis on impact assessment of groundwater extraction from the borefield during mine operation and closure.

Context

The mine plan comprises a mine production of up to 2MTPA Phosphate Rock from an open pit excavated to a maximum depth of approximately 50m below ground surface at a mining rate of up to 25MTPA. The mine pit remains above the water table and will not receive groundwater seepage. Waste rock and tails will be stored in the pit per strip mining methods.

Ore processing will require up to 500 m³/hour of process water for a mine life of 25 years. The water supply for the project comprises a borefield completed into the carbonate rocks of the South Georgina Basin (Georgina Basin Carbonate Aquifer - GBCA).

The project includes an infrastructure corridor containing a rail spur and power line from the mine site to a rail siding. Construction of the infrastructure corridor will require a small temporary water supply for material placement and dust suppression. This water will be sourced from the underlying Georgina Basin Carbonate Aquifer.

Impact Assessment

The requirements of the EPA Terms of Reference (ToR) for assessment of the project (NTEPA Dec 2014) are summarised in Table E1 below and addressed briefly. Cross references to the relevant detailed report sections are provided.

The main groundwater impact of the project is pumping from the water supply borefield. The extraction is within the capacity of the aquifer and removes a very small fraction of the immense volume in storage. Water table drawdown impacts at the nearest sensitive receptors (Pastoral bores and Ampilatwatja Community water supply) are unlikely (95% confidence interval) to exceed 3 m. This drawdown will not reduce water availability for these user's due to the very significant available drawdown at each site. There are no Groundwater Dependant Ecosystems identified within the zone of drawdown, due to the deep (>30m below ground surface) natural water table in this area.

Table E1: EPA ToR

EPA ToR	Description	Section Reference
Existing Environment		
Groundwater Regionally	Southern Georgina Basin Regional scale sedimentary basin aquifer system	4.2 4.3
Groundwater Locally		
<ul style="list-style-type: none"> Extent 	The Southern Georgina Basin Carbonate Aquifer is part of the regionally extensive Georgina Basin that underlies approximately one quarter of the Northern Territory and extends beneath the northwest of Queensland (Figure 1).	4.4.2
<ul style="list-style-type: none"> Connectivity 	Georgina Basin Carbonate Aquifer connected to the underling fractured rock in areas where the basin sediments on-lap the fractured rock	4.4.7
<ul style="list-style-type: none"> catchment Flow paths 	Regional scale catchment with flow converging to the Georgina Basin Carbonate Aquifer then eastward Groundwater flow divide to the west of the project between project and WDWCD	4.4.4 Figure 6
<ul style="list-style-type: none"> Volumes/capacities 	Regional scale, extensive and transmissive aquifer. Estimated drainable groundwater volume of 160 – 320 cubic kilometres	4.4.8
<ul style="list-style-type: none"> Depths 	ranges from pinch out at the margins to >1000m deep in thick parts of the basin	4.4.3
<ul style="list-style-type: none"> Types 	Regionally un-confined connected basin aquifer system comprising carbonate sediments	4.4.1
<ul style="list-style-type: none"> Chemistry 	Groundwater is generally fresh to brackish (500-3000 mg/L TDS). The salinity is suitable in many instances for potable use (<1000 mg/L), and most bores report water suitable for stock watering	4.4.9
<ul style="list-style-type: none"> areas of recharge 	Direct infiltration to outcropping or thinly covered aquifers and stream flood-outs. Rate estimates range from 0.2 to 12 mm/year.	4.4.5
<ul style="list-style-type: none"> environmental Values 	Potable use in most instances including around the mine site and pastoral use for stock watering at the borefield site.	4.4.10
<ul style="list-style-type: none"> Uses and third party users 	Pastoral bores (nearest 15km from borefield). Community water supply (nearest Ampilatwatja, 22km from borefield).	4.5
Pre-mining Hydrogeological Model	Numerical model constructed consistent with guidelines. Leading edge practice in uncertainty analysis	5.3
Prepared by qualified person	Modelling by Anthony Knapton Cloud GMS Pty Ltd Independent Review by Hugh Middlemis Hydrogeologic Pty Ltd	5.3
Risk Assessment		
Environmental Objective	Extraction of water within sustainable limit of aquifer without social or environmental impact	5.3
Water table drawdown	Unlikely (95% confidence interval) that drawdown of more than 3 m will result at any receptor including Pastoral users, Communities and GDEs	5.3 5.3.5
Seepage from pit process water / stockpiles including tailings	Tailings are non-acid forming (NAF) Seepage is not saline Neutral tailings exhibit low enrichment	5.3.7
Spills	Low risk to deep water table. Will be considered a soil contamination risk Standard storage and handling methods must be applied	5.3.8

2 Introduction

2.1 Aim

This report presents the hydrogeological (groundwater) study for the Ammaroo Phosphate Project (APP) Environmental Impact Statement (EIS) and Bankable Feasibility Study (BFS). This report covers the APP mine site, infrastructure (Power, rail) corridor and borefield with the major emphasis on impact assessment of groundwater extraction from the borefield during mine operation and closure.

2.2 Scope

This Groundwater assessment addresses:

1. The requirements of the EPA Terms of Reference for assessment of the project (NTEPA Dec 2014)¹.
2. Groundwater management and monitoring plan (GMMP) for planning and operation of the project.
3. Details of Groundwater related infrastructure (project water supply borefield, and infrastructure corridor construction water supply to inform the BFS for the project.

The mine plan being considered in this study is the Scenario A as defined in the project Pre-Feasibility Study (PFS) (Worely Parsons, 2014)². It comprises a mine production of up to 2MTPA Phosphate Rock from an open pit excavated to a maximum depth of approximately 50m below ground surface at a mining rate of up to 25MTPA. The mine pit remains above the water table and will not receive groundwater seepage. Waste rock and tails will be stored in the pit per strip mining methods.

Ore processing will require up to 500 m³/hour of process water for a mine life of 25 years. The water supply for the project comprises a borefield completed into the carbonate rocks of the South Georgina Basin (Georgina Basin Carbonate Aquifer - GBCA).

The project includes an infrastructure corridor containing a rail spur and power line from the mine site to a rail siding. Construction of the infrastructure corridor will require a small temporary water supply for material placement and dust suppression. This water will be sourced from the underlying Georgina Basin Carbonate Aquifer.

2.3 Legislative Framework

The Water Act (NT) 1992 (the Act) is the legislation which provides for the investigation, allocation for use, and management of water resources by the NT Government. This includes the protection of water supply for environmental, economic, recreational, social and cultural uses. The Legislation covers all aspects of sustainable water resource management including the investigation, use, control, protection and allocation. The Water Act provides for the declaration of Water Control Districts (WCDs) within the Territory to provide increased management of water. The Ammaroo project mine lease area lies outside the boundary of the Western Davenport WCD however impacts (water level drawdown and water movement) on the WCD have been considered in this study.

¹ NTEPA, 2014, *Terms of Reference for the Preparation of an EIS. Ammaroo Phosphate Project Dec 2014*

² Worely Parsons 2014 *Ammaroo Phosphate Project PFS Phase 3 Study Report*. Consultant's report to Rum Jungle Resources

3 Study Area

3.1 Location

The Ammaroo Phosphate Project is in the Northern Territory of Australia, close to the Sandover Highway, 350km north east of Alice Springs and 180km east of the town of Barrow Creek (Figure 1).

3.2 Climate

The site lies in the arid region of Australia with an annual rainfall of around 350 mm with a high coefficient of variation and a pan evaporation rate of about 4,000 mm. Regionally most of the rain is associated with thunderstorms during monsoonal wet season cyclonic activity. Over some drought years there is minimal or no rainfall.

4 Hydrogeological Setting

4.1 Focus

The focus of the hydrogeological assessment is the Georgina Basin Carbonate Aquifer which hosts the project water supply. Extraction of groundwater from this aquifer is the main groundwater impact of the project. The regional setting of the aquifer is studied to understand the long-term catchment scale impact of groundwater pumping.

4.2 Geological Setting

The Project is located in the southwestern extent of the Neoproterozoic to Devonian Georgina Basin which is a large intracratonic sedimentary basin containing un-metamorphosed Neoproterozoic to Devonian sedimentary rocks mostly within NT and partly within Queensland. A detailed analysis of the geology, structure, and resource potential of the Southern Georgina Basin is presented in Dunster et al (2007)³. The project location within this basin setting is presented on Figure 1.

The mine and borefield are within the Southern Georgina Basin, in the northern section where the Cambrian basin sediments thin and onlap the Proterozoic basement rocks of the Tennant Creek Block (Figure 2 and Figure 1). The lower sediments of the Georgina Basin (Arthur Creek Formation / Red Heart Dolostone) are the host to the phosphate deposit, and at the project site are approximately 30 to 50m thick. The Georgina Basin sediments thicken to the south of the site.

To the north and east of the site Proterozoic basement rocks are thinly covered and outcrop some 5 to 10 km distance from the site in the Davenport Ranges. Georgina Basin sediments deepen and thicken to the south and west of the site and dip to the south west. These sediments are overlain by the Devonian Dulcie Sandstone some 40km to the south west (Refer Cross Section Figure 3).

³ Dunster JN, Kruse PD, Duffett ML and Ambrose GJ. Geology and resource potential of the southern Georgina Basin. Northern Territory Geological Survey, Digital Information Package DIP007 (October 2007).

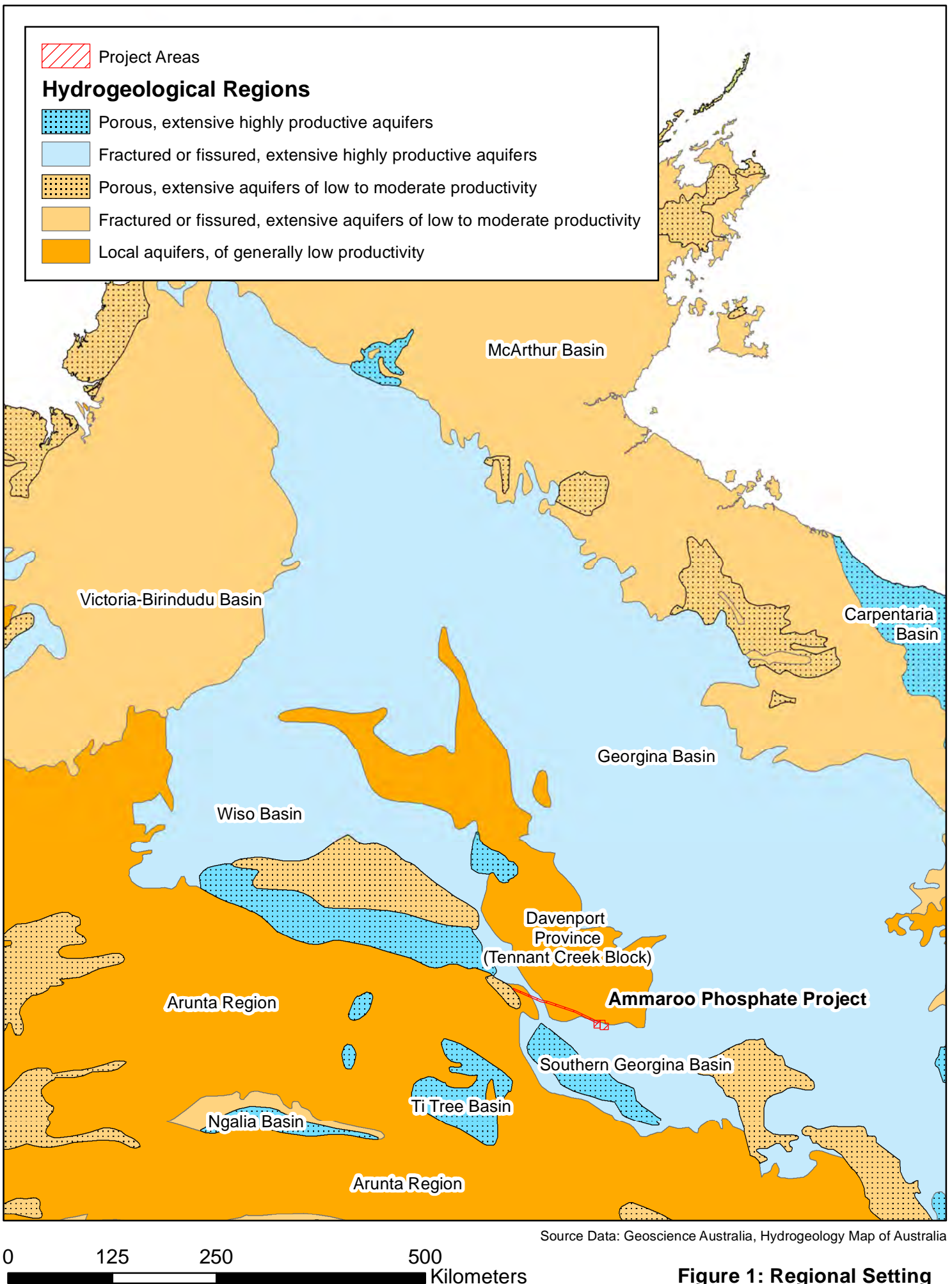


Figure 1: Regional Setting

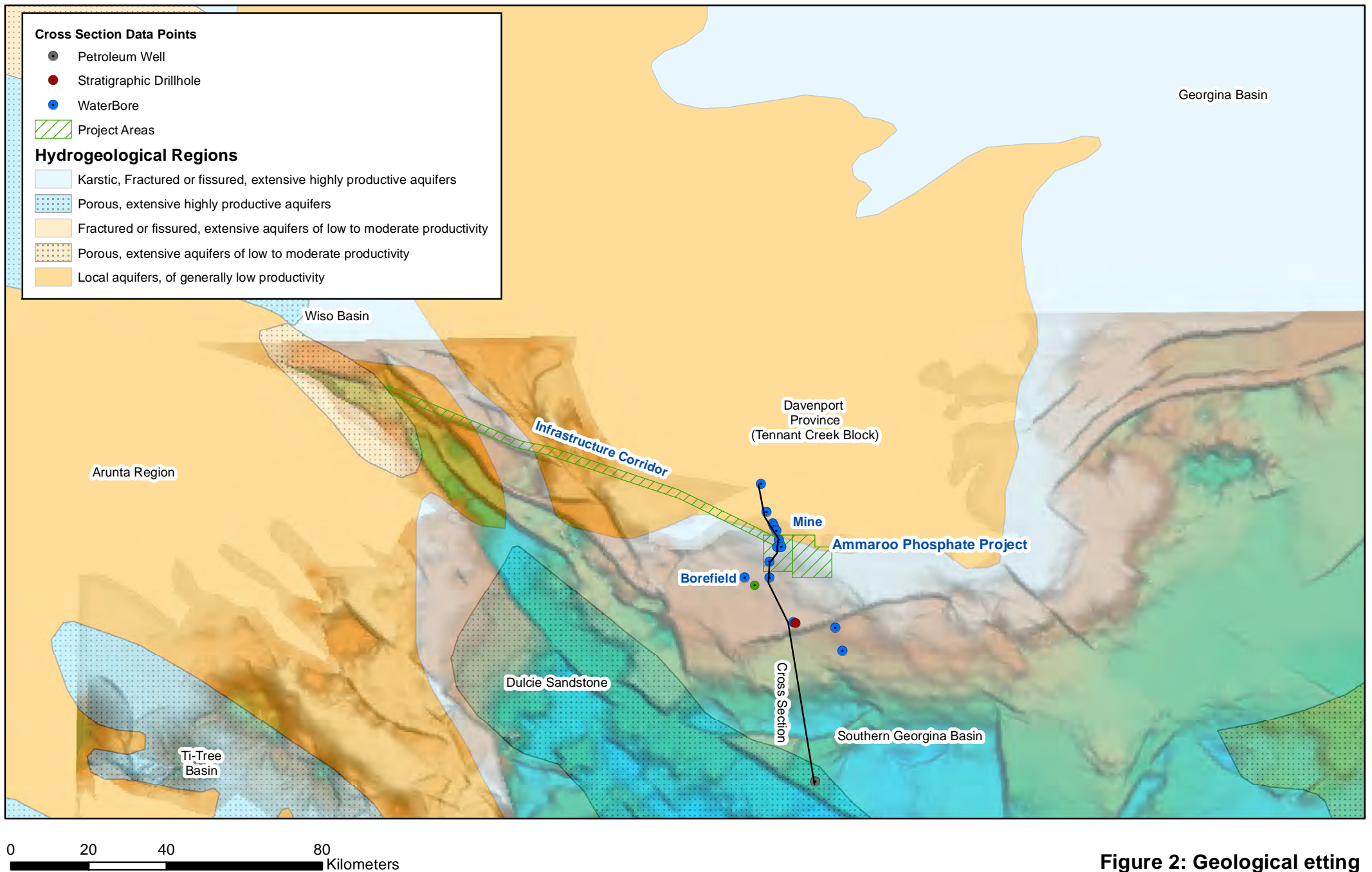


Figure 2: Geological setting

Base Image shows the inferred PreCambrian basement elevation beneath the younger sedimentary Basins. From Dunster et al, (2007), Geology and Resource Potential of the Southern Georgina Basin. NTGS Report DIP007

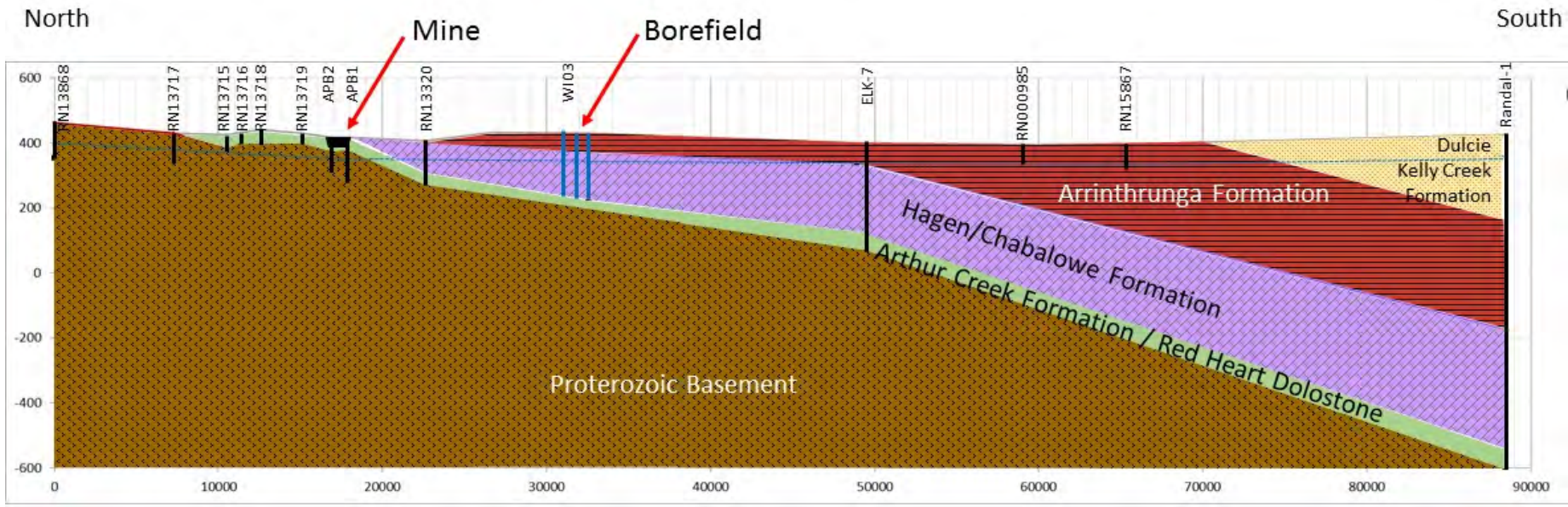


Figure 3: Hydrogeological Cross Section

4.3 Hydrogeological Structure

4.3.1 Aquifers

Recent Cover

Recent Quaternary cover in this area is generally shallow and unsaturated (above the water table) and thus not an aquifer.

Tertiary Basins

Tertiary sedimentary basins are deposited underneath the plains some 25 km to the north-west of the project between Wycliffe Well and the Osborne Range. These aquifers comprise alluvial and lacustrine sediment up to 100 meters thick. Sand, gravel and calcrete beds within the sediment form aquifers that yield generally less than 2 L/s with some higher yield from calcrete (Tickell, 2014)⁴.

Georgina Basin Carbonates

The Southern Georgina Basin carbonate sediments comprising the Arrinthrunga, Hagen, Chabalowe, Arthur Creek and Red Heart Dolostone Sequence are a very significant regional aquifer. The sandstone, limestone and dolostone units exhibit primary porosity, whilst fault structures and solution joints provide secondary porosity to facilitate well yields. These sediments host the aquifers accessed by nearly all successful bore drilled in the region and are the target water supply for the mine Borefield. The Aquifer is the source of groundwater for the project water supply and is described in more detail in Section 4.4.

Dulcie Sandstone

The southern margin of the Southern Georgina Basin hosts the Dulcie Sandstone (Figure 3), which overlies the Arrinthrunga Formation. This formation comprises a locally significant aquifer and was studied in some detail in 1981. The aquifer supports well yield of up to 20 L/s of potable quality water (Seidel 1998⁵, reporting field investigations of Knott 1981). The Dulcie Sandstone is located some 40 km west of the Ammaroo Project Site (Figure 2).

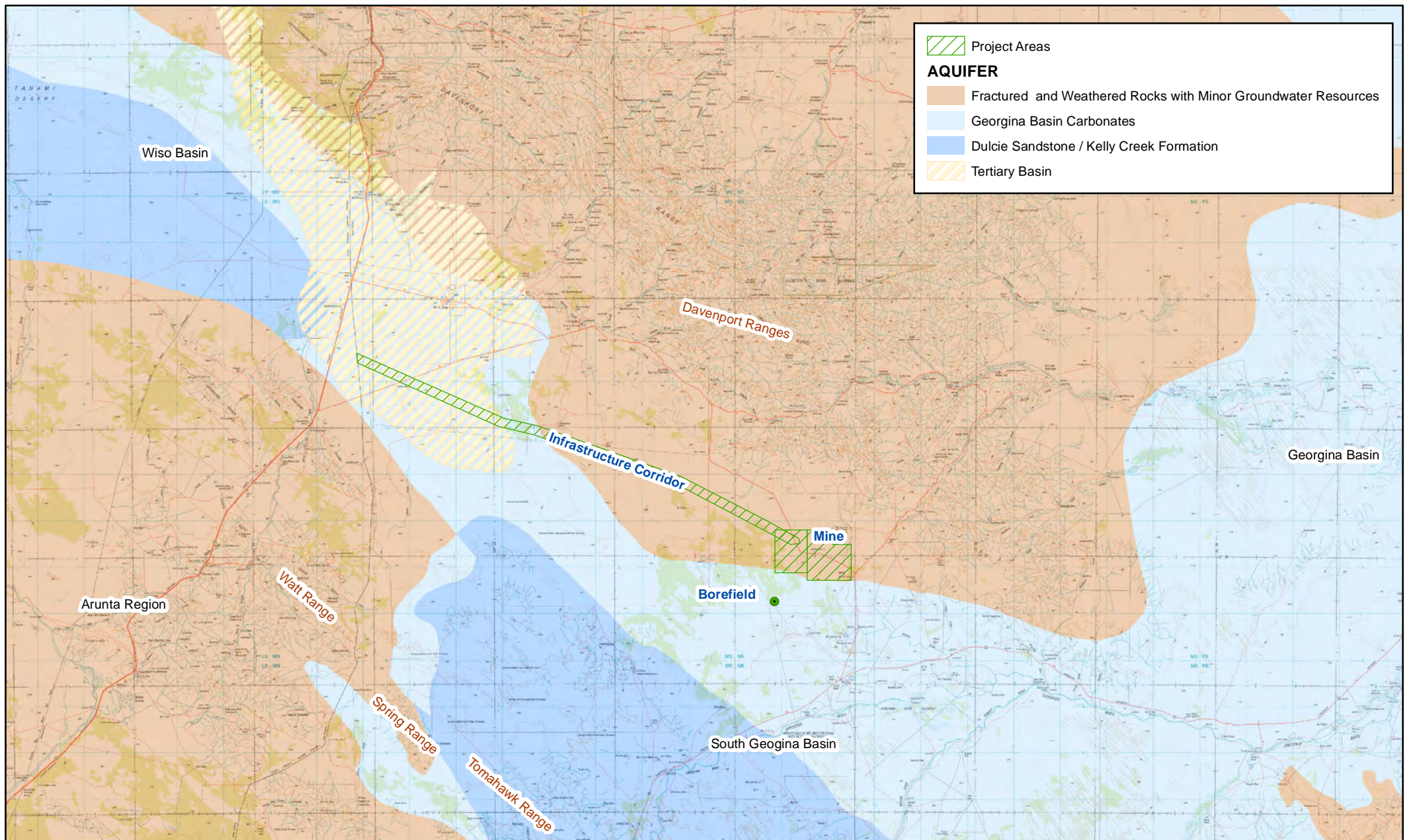
Proterozoic Basement

Aquifers in the Proterozoic basement rocks are low yielding. Some groundwater supplies will be found where the rock is fractured, however sustainable yields are likely to be uncertain due to the low primary porosity of the rock. These aquifers outcrop and sub-crop in the Davenport Range to the North of the Southern Georgina Basin, and the Watt, Spring, and Tomohawk Ranges to the South.

A north-south cross section presenting the hydrogeological setting at the project site is presented as Figure 3. The location of the section is presented on Figure 2.

⁴ Tickell, 2014, *Groundwater in the Western Davenport Water Control District*. Northern Territory Department of Land Resource Management, Water Resources Division

⁵ Seidel, 1999, *Groundwater Resources of the Dulcie Sand Stone*. Land Planning and Environment Report 22/1998a



0 15 30 60 Kilometers

Figure 4:Hydrogeological Setting

Tertiary Basin is from Tickell 2014 Groundwater of the Western Davenport Water Control District.
 Aquifer Data is from Tickell 2013 Groundwater of the Northern Territory

4.4 Georgina Basin Carbonate Aquifer

4.4.1 Aquifer Type

The Georgina Basin Carbonate Aquifer comprises carbonates; limestone, dolomite, dolostone and sandstone. Regionally the aquifer is un-confined and the entire basin is understood to comprise a connected aquifer system (Figure 3). Previous study of the GBCA system indicate the system behaves regionally as an unconfined system with specific yields of about 0.01 to 0.04 (Jolly, 2002; Jolly et al., 2004; Knapton, 2006)⁶.

4.4.2 Extent

The Georgina Basin Carbonate Aquifer is part of the regionally extensive Georgina Basin that underlies approximately one quarter of the Northern Territory and extends beneath the northwest of Queensland (Figure 1). Locally, the aquifer pinches out to the south of the mine site where it onlaps the basement rock of the Tennant Creek Block and the northern margin of the Southern Georgina Basin. The aquifer extends regionally to the east and extends to the west where it infills the stratigraphically equivalent Wiso Basin.

4.4.3 Depth

The Georgina Basin Carbonate Aquifer depth varies from the top of the water table at 30 to 80 m below ground level to over 1000m deep at the deeper parts of the basin (Refer Figure 3, and Dunster et al, 2007).

Drill logs of investigation pilot holes drilled at the Borefield site are presented as Figure 5. One hole, W104 was drilled to a maximum depth of 250m. The Carbonate aquifer was intersected at 65m depth (though the water table was at 80m). The base of the aquifer was not reached at the end of hole at 250m depth.

Stratigraphic Hole ELK7 (Figure 3) was drilled to a depth 328 m 15km to the southeast of the planned borefield. Cambrian carbonates of the Georgina Basin were intersected at 38m depth, while basement was tagged at 321 m depth defining an aquifer thickness of 283m.

Further south a 420m thickness of aquifer is intersected by Petroleum exploration hole Randall-1 from approximately 500 to 920m depth.

4.4.4 Flow Paths and Catchments

The potentiometric surface of the Fractured Rock aquifer and Georgina Basin aquifers has been inferred from the regional water bore dataset maintained by the NT Department of Land Resource Management (DLRM)⁷.

Water levels measured in wells referenced to datum (mAHD), provide information regarding the water table elevation for unconfined aquifers, or the potentiometric pressure for confined aquifers. This data can be used to infer groundwater flow regimes since groundwater will flow from areas of high pressure (water level elevation), to areas of low pressure via the most permeable pathway within the host rock.

Standing water level (depth to water) data from bore reports was used, and well collar elevations were assigned from a 1-second ground surface digital elevation data set (GA, 2011)⁸. Errors in this method include, accuracy of the water level measurement, accuracy of the bore location, accuracy of the DEM, and lack of data regarding the height of the measurement point above ground surface. Nonetheless the method provides an acceptable regional scale data set for inferring regional scale aquifer pressure and flow trends. Detailed data is presented in Appendix 1.

⁶ Jolly, P., (2002) Daly River catchment water balance. NTG Dept. of Lands, Planning and Environment, Natural Resources Division Technical Report WRD02010.

Jolly, P., Knapton A. and Tickell, S. (2004) Water Availability from the Aquifer in the Tindall Limestone South of the Roper River. NTG Dept of Infrastructure, Planning and Environment. Technical Report WRD04034.

Knapton, A., (2006) Regional Groundwater Modelling of the Cambrian Limestone Aquifer System of the Wiso Basin, Georgina Basin and Daly Basin. Alice Springs, NTG Dept. Natural Resources, Environment and The Arts. Technical Report WRA06029.

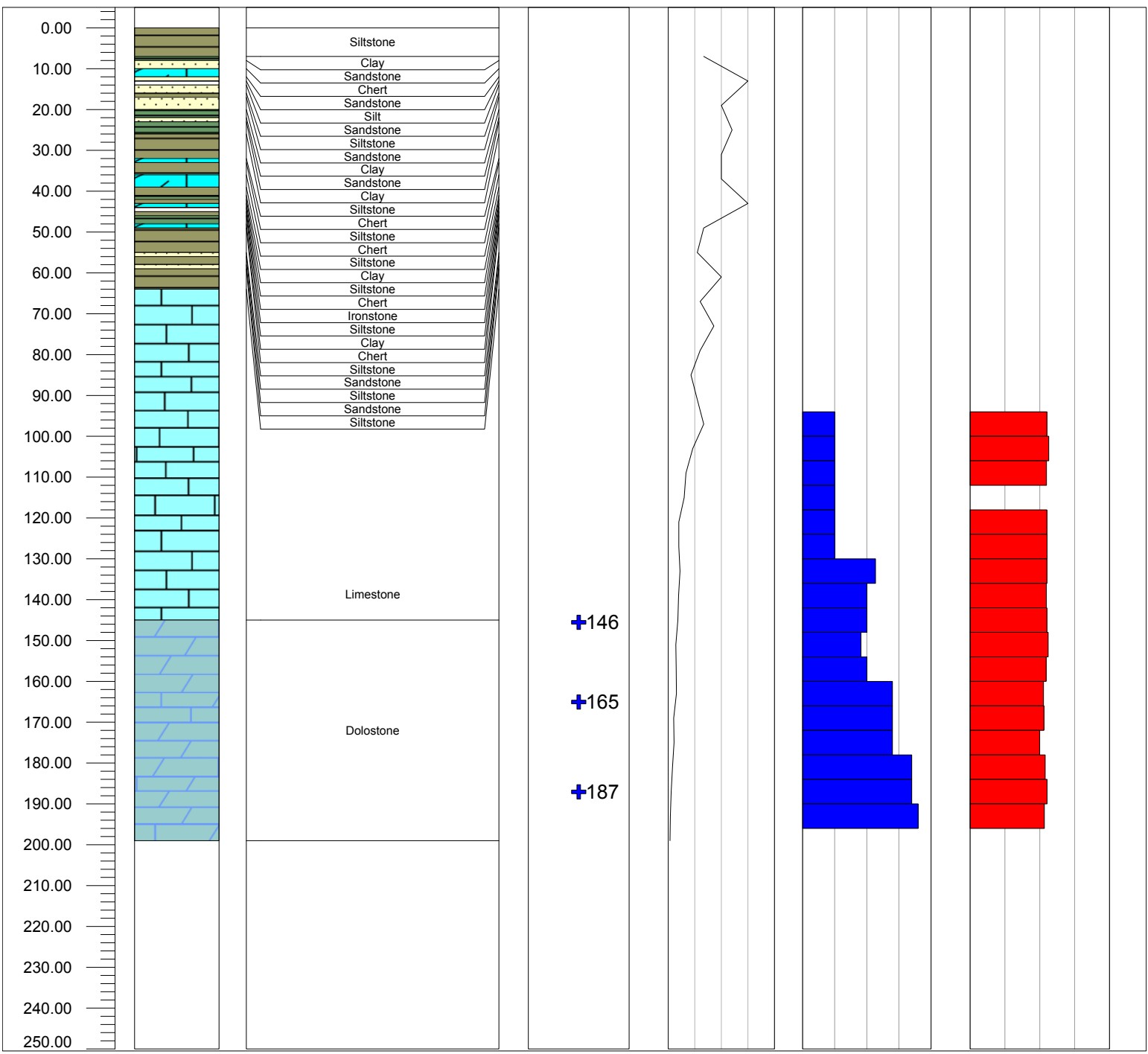
⁷ <http://www.ntlis.nt.gov.au/>

⁸ Geoscience Australia (2011) 1 second SRTM Derived Digital Elevation Models User Guide. Geoscience Australia www.ga.gov.au/topographic-mapping/digital-elevation-data.html

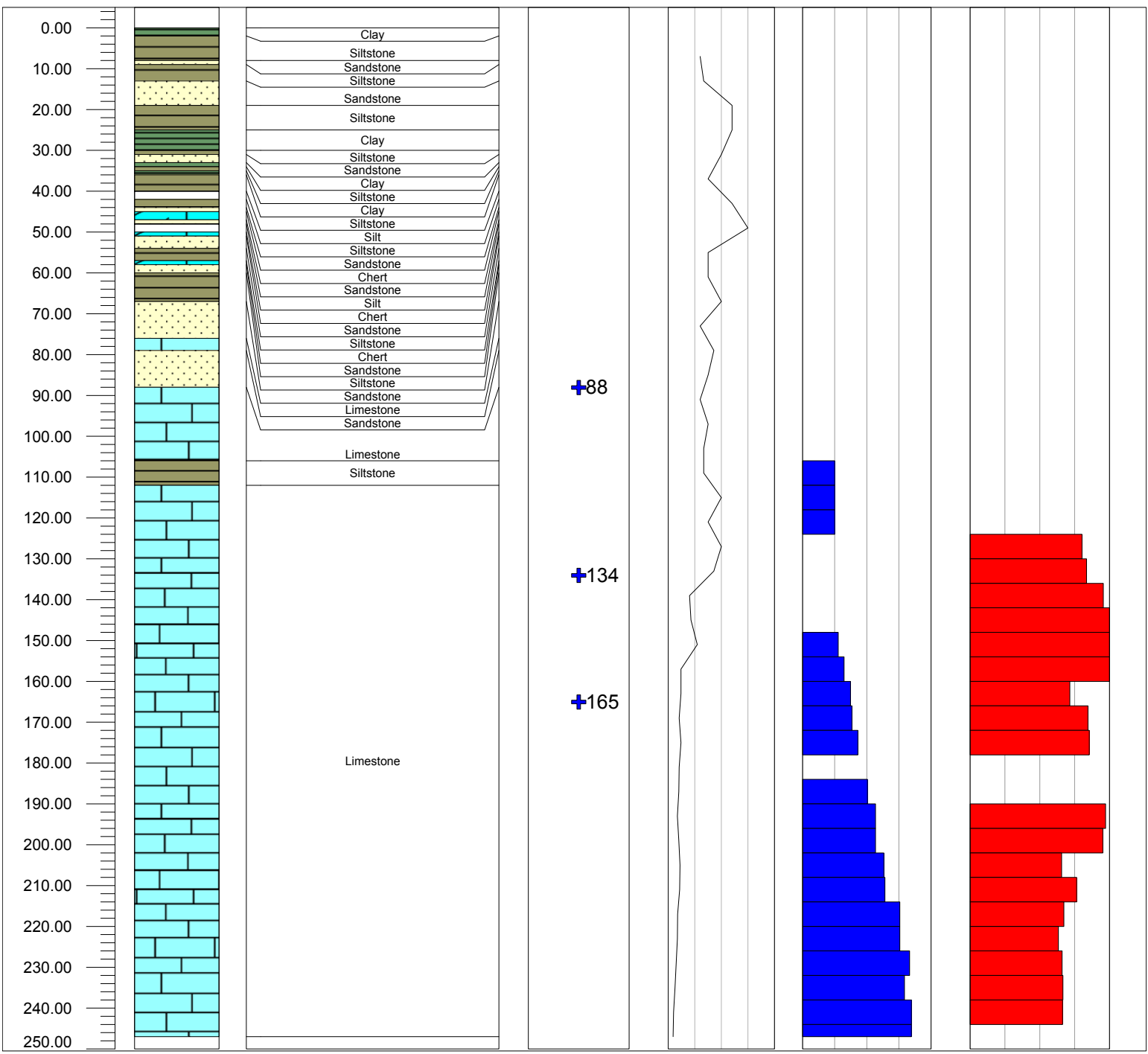
The aquifer potentiometric surface exhibits a convergence of flow from fractured rock aquifers toward the South Georgina Basin and the Wiso Basin. There is a groundwater flow divide 50km west of the mine site. To the west of the divide, groundwater flows northwest toward the Wiso Basin. East of the divide groundwater flows toward the east into the broader scale Georgina Basin.

Figure 5: Investigation Hole Drill Logs- Borefield site

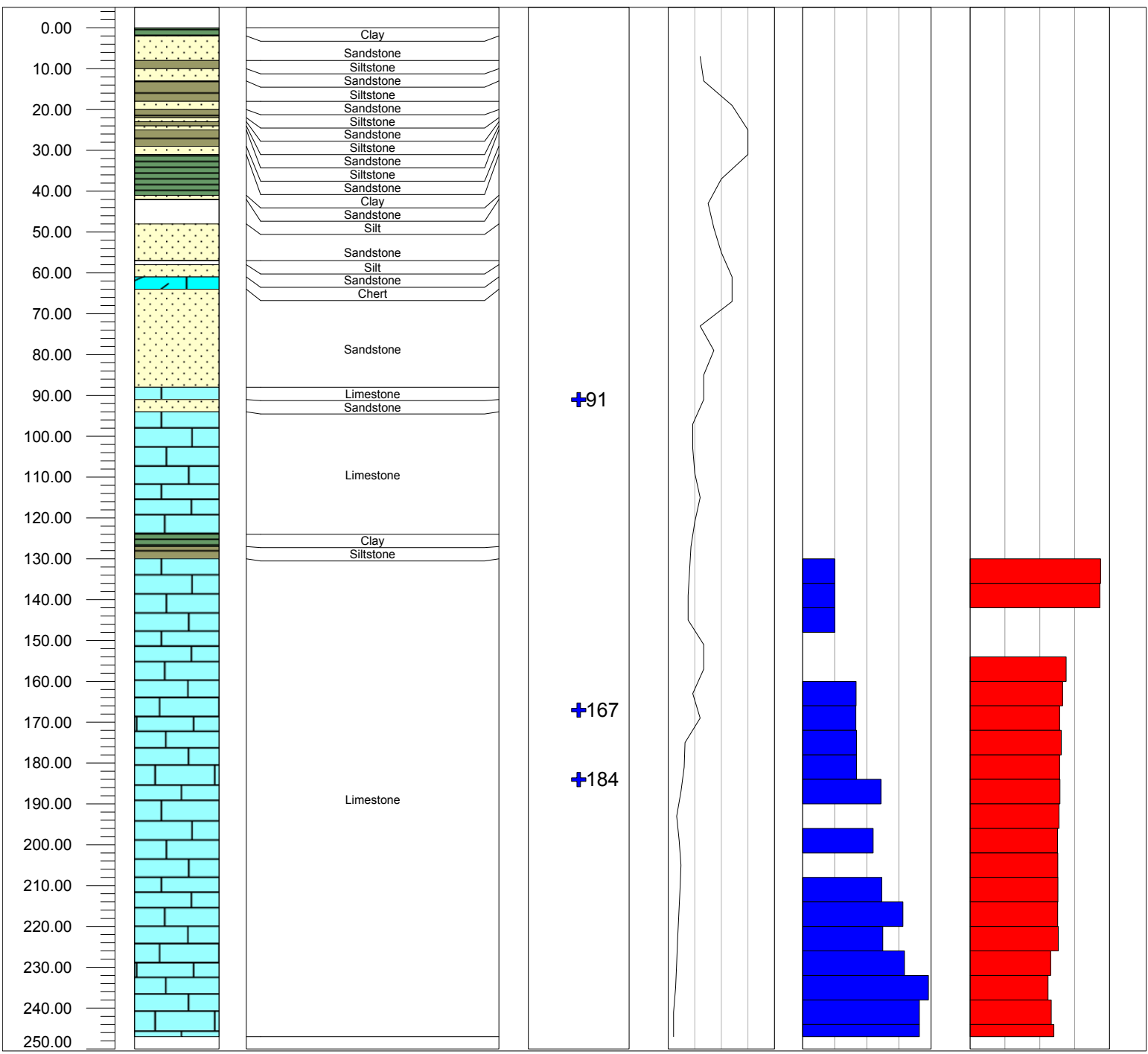
Well ID	WI03	Depth (m)	199			
Permit #		Yield (L/s)	1.8			
Easting	504178	Salinity (EC μs/cm)	1686	ROP (m/min)	Yield (L/s)	Salinity (mg/L TDS)
Northing	7617160	Static Water Level (m)	81.2	0.00 0.50 1.00 1.50 2.00	0.00 0.50 1.00 1.50 2.00	0.00 500.00 1000.00 1500.00 2000.00
Elevation (mAHD)	427					
	Lithology	Water Cuts				



Well ID	WI04	Depth (m)	247			
Permit #		Yield (L/s)	1.7			
Easting	505983	Salinity (EC $\mu\text{s}/\text{cm}$)	2570	ROP (m/min)	Yield (L/s)	Salinity (mg/L TDS)
Northing	7615030	Static Water Level (m)	81.9	0.00 0.50 1.00 1.50 2.00	0.00 0.50 1.00 1.50 2.00	0.00 500.00 1000.00 1500.00 2000.00
Elevation (mAHD)	429					
	Lithology	Water Cuts				



Well ID	WI05	Depth (m)	247			
Permit #		Yield (L/s)	1.8			
Easting	507368	Salinity (EC $\mu\text{s}/\text{cm}$)	1973	ROP (m/min)	Yield (L/s)	Salinity (mg/L TDS)
Northing	7613089	Static Water Level (m)	80.4	0.00 0.50 1.00 1.50 2.00	0.00 0.50 1.00 1.50 2.00	0.00 500.00 1000.00 1500.00 2000.00
Elevation (mAHD)	427					
		Lithology	Water Cuts			



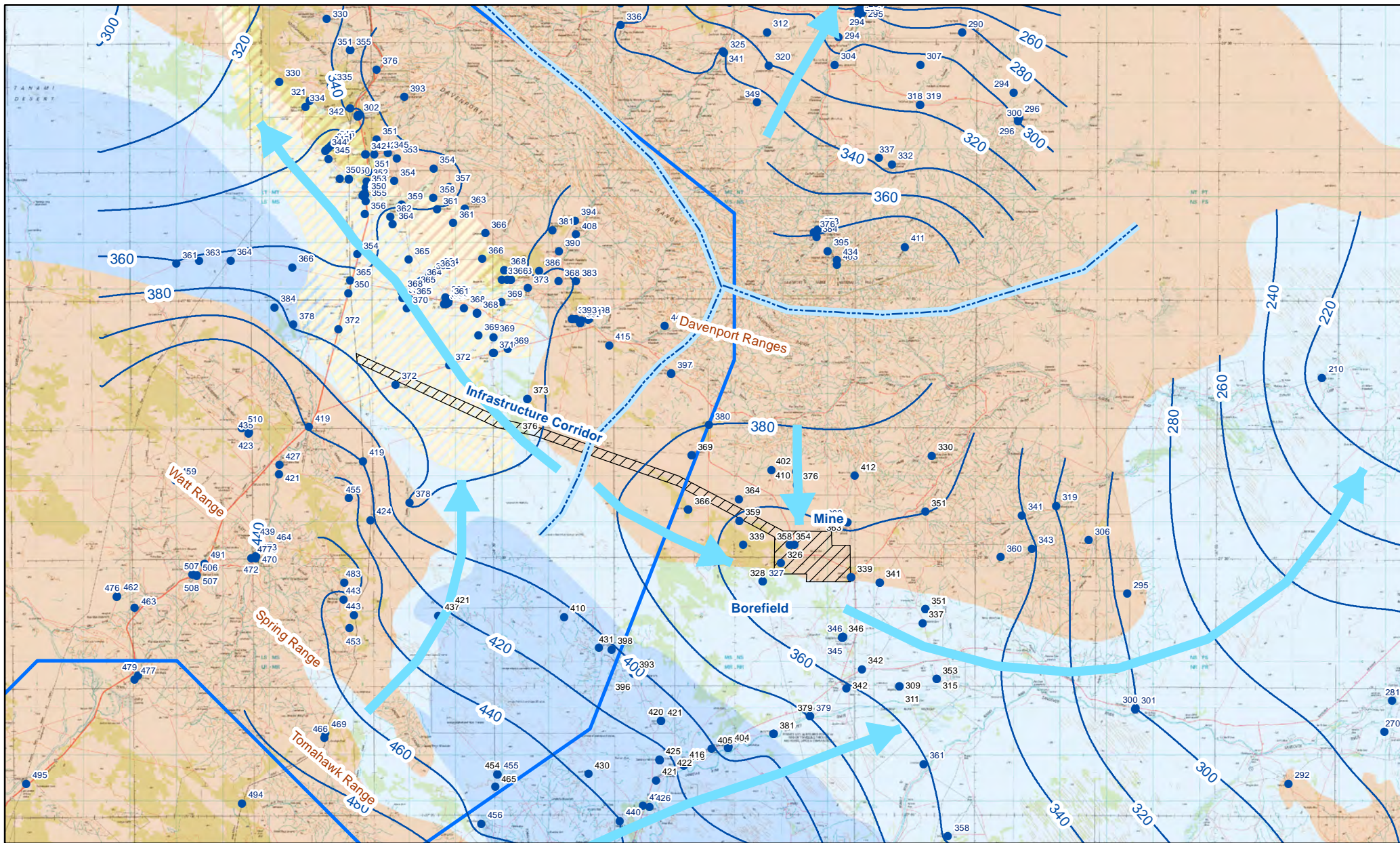
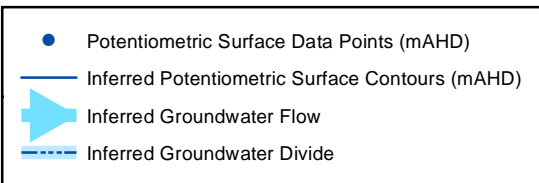


Figure 6: Groundwater Potentiometric Surface and Inferred Flow Direction



4.4.5 Recharge

Groundwater Recharge in this environment is generally via direct infiltration to outcropping or thinly covered aquifers such as the Fractured rock aquifers outcropping in the Davenport Range to the North of the Southern Georgina Basin, and the Watt, Spring, and Tomohawk Ranges to the South. Focussed Recharge occurs at stream flood-outs, where ephemeral streams flow from the ranges onto the plains after heavy rainfall events, for instance at the Sandover River Flood-Out to the south of the project site. The potentiometric surface which exhibits a gradient from the ranges toward the Georgina Basin indicate that these ranges are recharge areas in this setting. Likewise the string of low salinity stock bores along the Sandover River indicate riverbed recharge along this watercourse.

Recharge rates are difficult to measure, however estimates in this environment have been generated based on water balance methods (Rooke, 2009)⁹ and Chemical Tracers (Harrington, 2002)¹⁰. The water balance approach applied to the WDWCD by Rooke estimated recharge at 5 to 12mm per year averaged over the entire region. Harrington's 2002 study of chemical tracers and stable isotopes in groundwater within the Ti-Tree Basin indicated that significant recharge occurs mainly after heavy rainfall exceeding 150-200 mm per month, and that recharge beneath stream flood-outs averages 2mm per year, whilst recharge to the surrounding landscape averages around 0.2mm per year.

Recharge estimation for the Amaroo project area was undertaken applying the chloride mass balance method (Erickson and Khunakasem, 1969)¹¹ to this project setting. Chloride in Rainfall was defined as 0.7 mg/L (CSIRO, 2012¹² & Keywood Et al, 1997¹³) whilst chloride in groundwater at the site averages 166 mg/L (Appendix 2). For an annual rainfall of 350mm/year, this equates to an average groundwater recharge of approximately 1.5 mm/year.

4.4.6 Discharge

Groundwater from the Georgina Basin Carbonate Aquifer does not discharge to surface within the study area. The water table ranges from 30 to 80m below ground surface and there are no springs, soaks, wetlands or salt lakes associated with the aquifer. Groundwater flows from the Southern Georgina Basin, eastward into the broader regional Georgina Basin for eventual discharge many hundreds of kilometres from the study site.

4.4.7 Connectivity

The Georgina Basin Carbonate Aquifer, is understood to be connected to the underling fractured rock in areas where the basin sediments on-lap the fractured rock. Groundwater that recharges the fractured rock aquifer in areas of elevated terrain and ephemeral creeks will seep through the fractured rocks and discharge to the highly transmissive regional Georgina basin aquifers.

4.4.8 Volumes / Capacities

The Georgina Basin Carbonate Aquifer is a regional scale, thick, extensive and transmissive aquifer. Within the Southern Georgina Basin thickness approximates 200 to 400m with an area of 20,000 km² (Dunster Et, al 2007). These dimensions produce a rock volume of four to eight thousand cubic kilometres. For a drainable porosity (specific yield) of 4%, this equates to a drainable groundwater volume of 160 – 320 cubic kilometres or 160,000 to 320,000 gegalitres.

⁹ Rooke, 2009, Assessment of Groundwater Resources in the Western Davenport Plains Water Control District. Report to Department of Natural Resources, Environment The Arts and Sports. Hyro Tasmania Report Number E204629

¹⁰ Harrington, G.A., Cook, P.G. and Herczeg, A.L., 2002. Spatial and temporal variability of ground water recharge in central Australia: A tracer approach. *Ground Water*, 40(5): 518-527

¹¹ Eriksson, E., and V. Khunakasem. 1969. *Chloride concentration in groundwater, recharge rate and rate of deposition of chloride in Israel Coastal Plain*. *J Hydro*. 7, 178-197.

¹² CSIRO (2012) *New insights into the chemical and isotopic composition of rainfall across Australia*. CSIRO Water for a Healthy Country Flagship, Australia

¹³ Keywood, M.D., Chivas, A.R., Fifield, L.K., Cresswell, R.G. and Ayers, G.P., 1997. The accession of chloride to the western half of the Australian continent. *Australian Journal of Soil Research*, 35, 1177-89.

The specific yield estimate for this study of 4% is based on a 7-day pumping test undertaken at Test Bore PB01 (Appendix 5). Data analysis comprised analysis of drawdown data at Observation bore WI03 located 25m from the pumped bore. This value can be benchmarked against the specific yield values estimated for the geologically equivalent South Georgina Basin and Wiso Basins as part of the Hydrogeological study reported recently by DENR (Knapton, 2017)¹⁴. That study estimated an aquifer Specific yield of 4% based on calibration of a basin scale model to 45 years of groundwater pumping. It should be noted that the impact assessment for this study described in Section 5.1.1 applies a range of specific yield values ranging from 1 to 10% applying a mean of 4% and a standard deviation of 2%.

Aquifer testing at the borefield site undertaken by Verdant Minerals (Table 1), indicates that the aquifer has the capacity to support well yields of over 75 L/s. This is reasonably consistent with Tickell's (2013) regional scale assessment which reports potential well yields of 5 to 50 L/s in this area.

Table 1: Hydraulic Testing of Georgina Basin Carbonate aquifer.

Hole Tested	Coordinates	Nature of Tests	Aquifer Parameters	Reference
PB01	504154e, 7617169n	7 Day Constant rate test	T = 1060 m ² /day Sy = 0.04	Appendix 5 ¹⁵
WI03	504178e 7617160n	Airlift test while drilling. Drawdown by pressure transducer	T = 2600 m ² /day	GWS (2012b) ¹⁷
WI04	505983e 7615030n	Analysis by Logan ¹⁶ approximation	T = 40-64 m ² /day	
WI05	507368e 7613089n		T = 420 - 490 m ² /day	
RN011455	523377e 7605307n	Constant rate test	T =600 m ² /day	NTLIS Bore Reports
RN011454	523358e 7605212n	Constant rate test	T= 264 – 503 m ² /day	NTLIS Bore Report

Note: T = Transmissivity, Sy = Specific Yield

4.4.9 Groundwater Chemistry

Detailed chemical analysis was undertaken of groundwater samples obtained from the Borefield test bores and investigation pilot holes completed into the Georgina Basin Carbonate Aquifer and bores used for exploration water supply completed in the Tennant Block Proterozoic Basement Aquifer. Bore locations are presented in (Figure 8). Detailed data is presented in Appendix 2.

In addition, a regional groundwater quality dataset was obtained from NT Land Information System (NTLIS).

Groundwater is generally fresh to brackish (500-3000 mg/L TDS). The salinity is suitable in many instances for potable use (<1000 mg/L), and most bores report water suitable for stock watering.

The groundwater samples immediately beneath and adjacent the mine (Camp Bore, and Exploration Bore) completed in the Proterozoic Basement Aquifer exhibit Pastoral (stock) water quality with a mixed chemical composition dominated by Na-Mg-HCO₃-Cl. The water is not potable due to elevated Fluoride, Nitrate and Boron.

Groundwater from pilot and investigation bores at the Borefield site (WI03, WI04, WI05 and PB01) completed in the Georgina Basin Carbonate Aquifer exhibit marginal to non-potable water suitable for pastoral use. The water exhibits a chemical composition similar to the Proterozoic Basement Aquifer, however elevated in Ca, Mg and

¹⁴ Knapton, 2017, *Development of a Groundwater Model for the Western Davenport Plains version 0.2* Consultants report prepared for NT Department for Environmental and Natural Resources by Cloud GMS Pty Ltd.

¹⁵ GWS (2013), *Ammaroo Phosphate Project Water Supply Production Bore – Pump Installation and Testing Report*. Groundwater Science Report RJR-13-2-R002

¹⁶ Logan, J. 1964. *Estimating transmissivity from routine production tests of water wells*. Ground Water, 2, No. 1, 35-37.

¹⁷ GWS (2012b), *Barrow Creek Groundwater Supply Investigations – Pilot hole drilling report*. Groundwater Science Report RJR-12-2-R002

SO₄, indicative of equilibration with carbonates; calcite (CaCO₃) dolomite (CaMg[CO₃]₂) and Gypsiferous rock (CaSO₄).

Groundwater Composition of the project specific samples are presented against the spread of regional data in Figure 7.

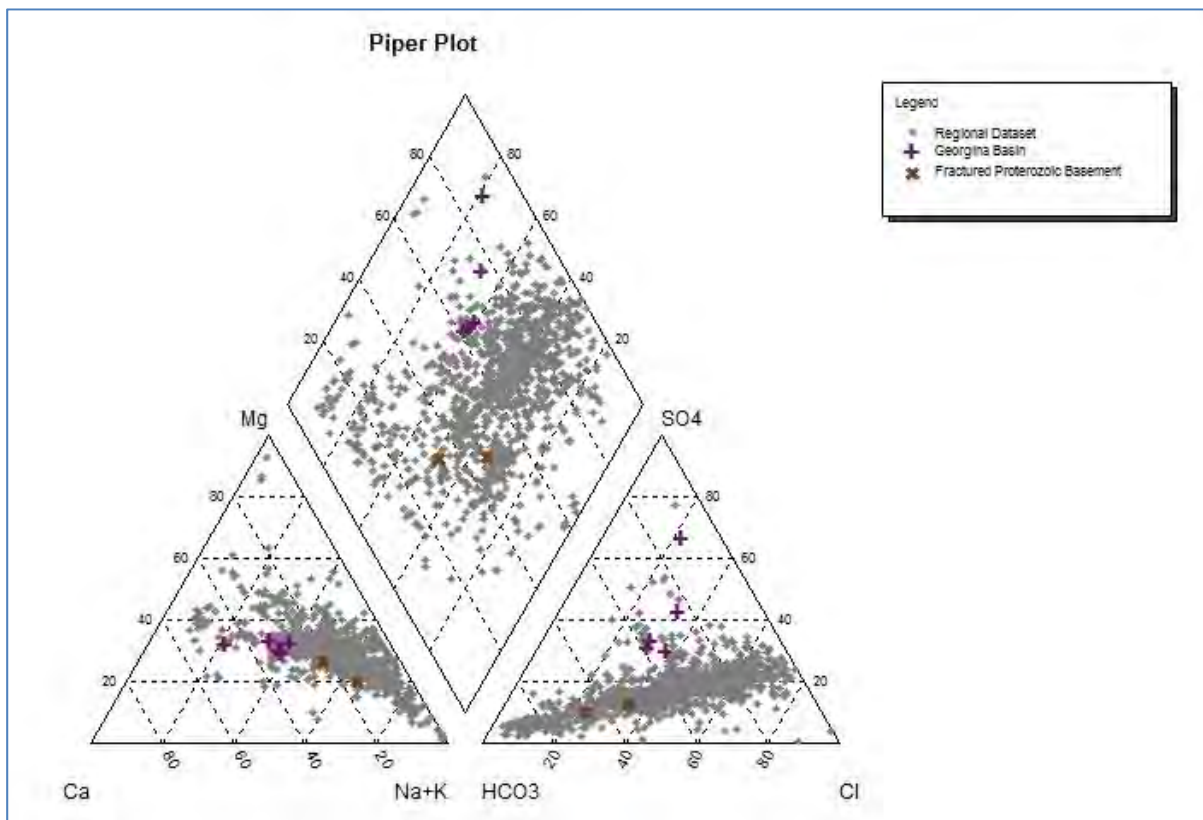


Figure 7: Groundwater Chemistry (Piper Plot). Grey symbols are the regional NTLIS dataset. Coloured symbols are samples taken by Verdant Minerals

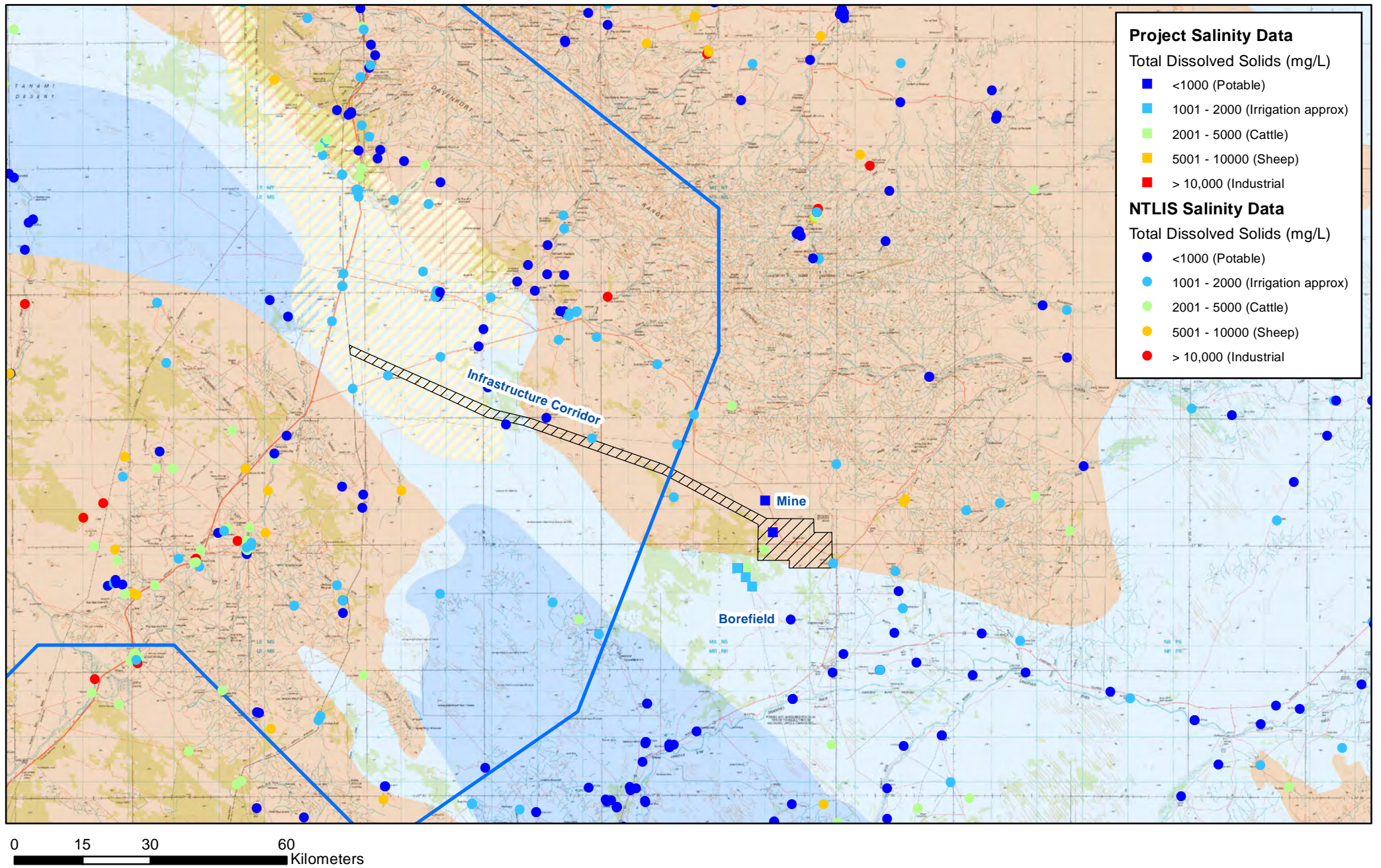


Figure 8: Groundwater Salinity

4.4.10 Environmental Values

The salinity of the Georgina Basin Carbonate Aquifer can support potable use in most instances, though around the mine site water quality is constrained to Pastoral due to elevated Nitrate, Boron and Fluoride. Groundwater at the bore field site is too saline for potable use but is suitable for Pastoral (Stock) use.

4.5 Third Party Users

4.5.1 Community

Third party users include pastoral bores used for stock watering and station water supplies, and community water supplies. Pastoral bores, community water supply bores and Water Protection Area Boundaries are presented on Figure 9.

Ammaroo Station and Murray Downs Station use bores completed in the Georgina Basin Carbonate aquifer for stock watering. The nearest stock bore, RN10717 (Hagen's Bore), is located 15 km southeast of the planned Borefield. This bore is in use and fitted with a solar submersible pump. Ammaroo Station utilises groundwater from the same aquifer and is located 30 km from the Borefield. Murray Downs station utilises groundwater from the Fractured Rock aquifer in the Davenport range and is located more than 60 km from the planned Borefield.

Ampilatwatja Community is located 22 km from the planned Borefield and uses groundwater from the Georgina Basin Carbonate Aquifer. There are records of two bores installed in 1976 (RN011454 and RN011454) to provide community water supplies in replacement of an older well, Honeymoon Bore (RN00985) which is now derelict. In 2003 Power Water Corporation drilled two new bores (RN018015 and 018016) to provide water to the community. All bores are drilled to 70 -80m depth and encounter the top of the Limestone aquifer at around 55m depth.

The mine and borefield is not located in a Groundwater Protection District. The Western Davenport Water Control District (WDWCD) boundary is located 21 km to the west of the planned Borefield. The infrastructure corridor to the railhead is within the Western Davenport Water Control District.

4.5.2 Environment

There are no identified groundwater dependant ecosystems (GDE's) within at least 60 kilometres of the borefield.

The depth to water of the water table in proximity to the Borefield is too deep to support GDE's (LWA,2009)¹⁸. Figure 11 presents the depth to water measured at bores within the study area. At the Borefield site the depth to water exceeds 80 m below ground surface. The closest site that records a water level within 15 m of the ground surface is RN14354, located approximately 60km northwest of the Borefield. The bore reports a standing water level of 14m below ground surface. In this area and further to the northwest, the ground surface elevation is relatively low (<390 mAHD) and a shallow water table is evident in the bore data.

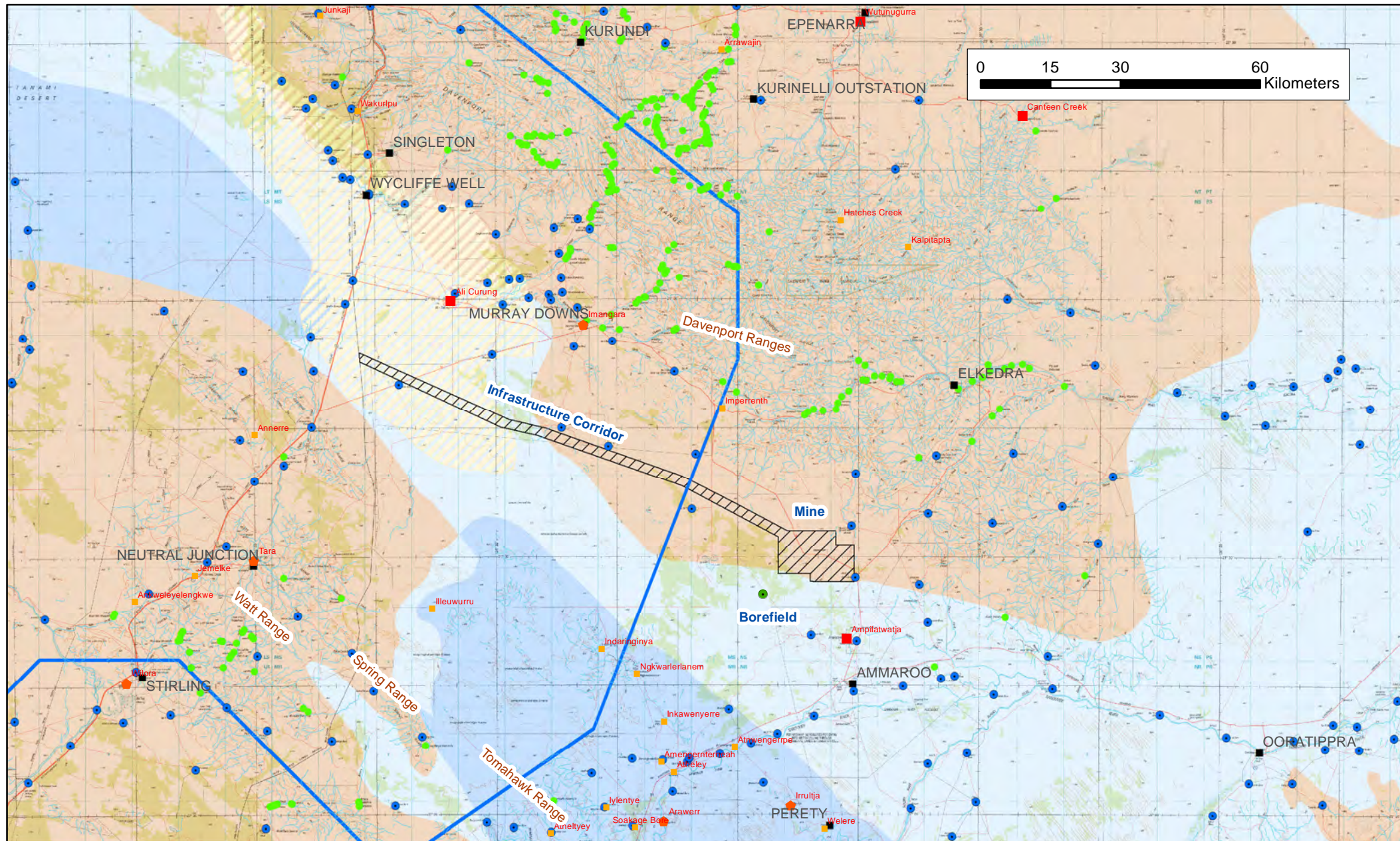
The Proterozoic Basement Aquifer does support water holes in the major creek lines in the Davenport Range to the North of the Southern Georgina Basin, and the Watt, Spring, and Tomohawk Ranges to the South. These waterholes are located more than 40 km from the planned Borefield (Figure 9).

A water hole is reported 17km east of Ammaroo Station (40km from the borefield) at the eastern margin of the Sandover River Flood-out. However, this feature is adjacent a water bore (Mud Tank Bore, RN000483) that reports depth to water of 28 m below ground surface. It is likely that the water hole receives periodic surface run-off and is not connected to the regional water table. Aerial Imagery reveals a dry feature resembling a perennial flood pan that is sometimes inundated.

Note the study area is not covered by the Commonwealth Atlas for potential GDEs (BOM, 2017)¹⁹ and does not contain any wetlands of National Significance.

¹⁸ Land and Water Australia, (2009), *A Framework for Assessing Environmental Water Requirements for Groundwater Dependent Ecosystems, Report 2; Field Studies*. <http://lwa.gov.au/node/3227>

¹⁹ <http://www.bom.gov.au/water/groundwater/gde/map.shtml>



NT_Aboriginal_Communities

- MAJOR
- MINOR
- TOWN CAMP
- FAMILY

Stations

- Water Bores
- Waterhole (Geoscience Australia 250K dataset)

- WatercourseLines

- ▭ Western Davenport Water Control District

- ▨ Project Infrastructure

AQUIFER

- Fractured and Weathered Rocks with Minor Groundwater Resources
- Georgina Basin Carbonates
- Dulcie Sandstone / Kelly Creek Formation

Figure 9: Third Party Groundwater Users Community and the Environment

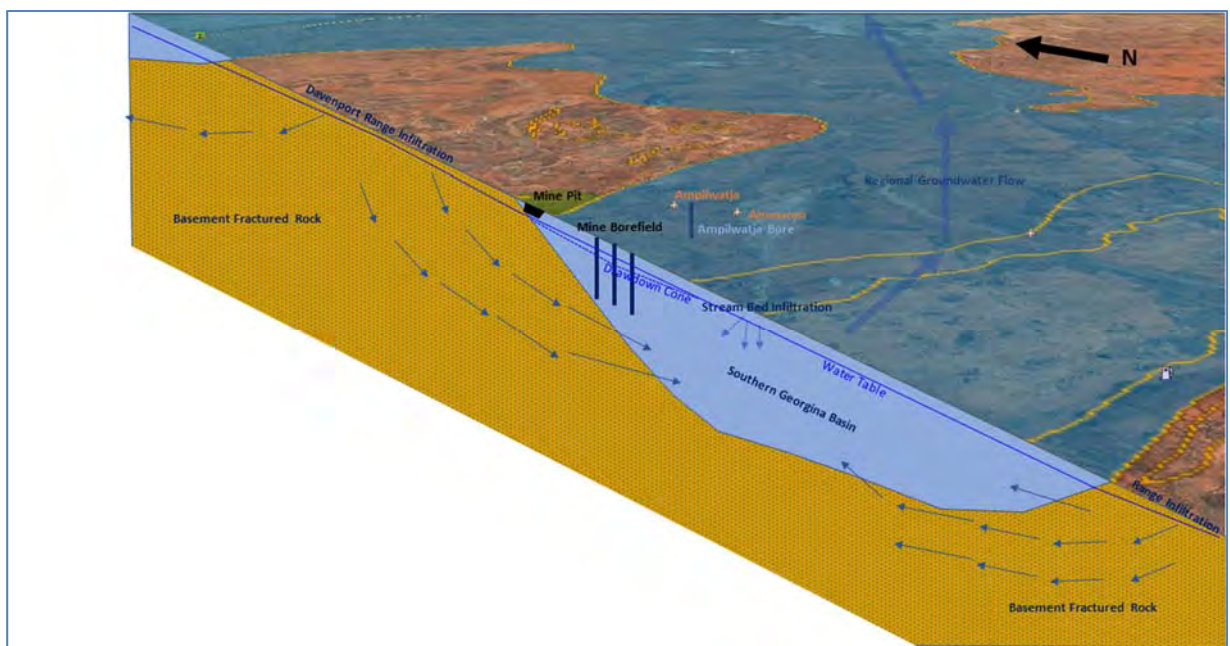
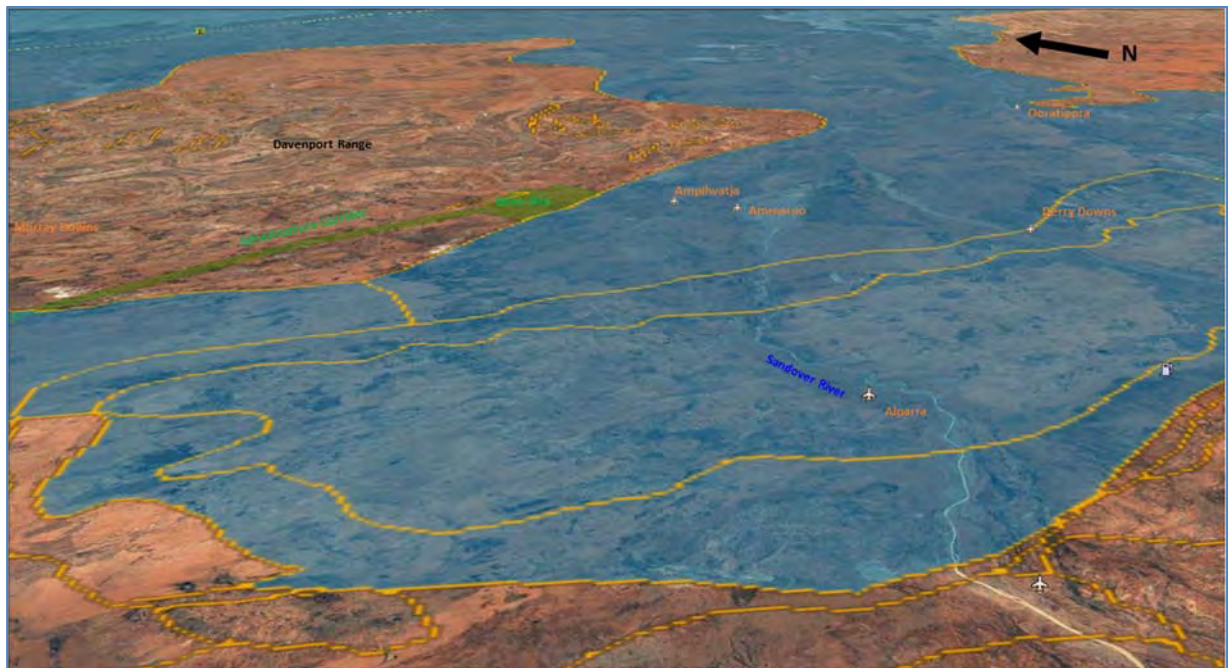


Figure 10: Conceptual Cross Section

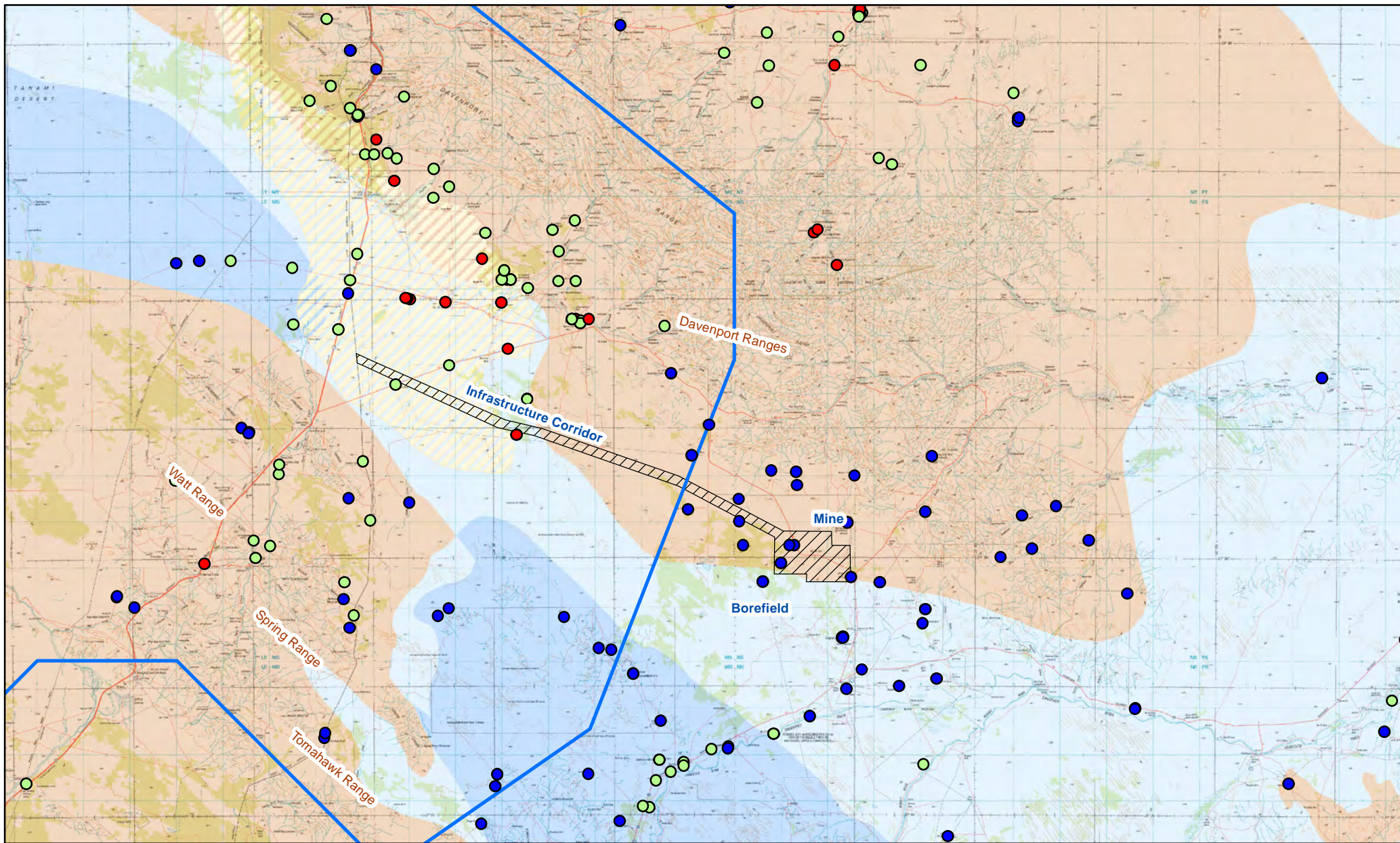


Figure 11: Depth to Groundwater

5 Groundwater Impacts Assessment

5.1 Groundwater Affecting Activities

5.1.1 Project Water Supply

The project water supply comprises three planned bores abstracting up to 12 ML per day (140 L/s, 4.4 GL/year) for 25 years. Bores will be completed into the Georgina Basin Carbonate Aquifer at a site 10km to the south of the mine site.

The borefield is currently designed as 3 bores each equipped to pump 75 L/s. This design provides a single redundant bore (33% redundant capacity) at any time which allows the water supply to be maintained during maintenance of a single bore.

Bore field construction will entail a staged approach of:

1. Drilling and pump-testing of each production bore.
2. Optimisation of pump specification and flow rate from each bore based on pump test result.
3. Possible increase in the number of bores if installed bores do not achieve the planned 75 L/s flow rate.
4. If required, an increased number of bores will fit within the planned footprint. The spacing between bores will be reduced.

5.1.2 Construction Water Supply

The construction water supply comprises a string of bores constructed at 20km intervals along the infrastructure corridor to provide water for dust suppression and material compaction. Each bore will yield approximately 0.4 ML/day (4.5 L/s) for a 1 year construction duration. Bores will be completed into the Georgina Basin Carbonate Aquifer.

5.1.3 Mine Pit Excavation

The Mine pit excavation will not extend below the water table (See cross section presented as Figure 12). The water table at the mine site has been measured at 358 mAHD (59m below ground level) at drillhole APWB1 located immediately adjacent the mine site. The maximum pit depth is 45 m below ground surface (approx. 365 mAHD) which mean the pit will not intersect the water table and groundwater seepage and dewatering is not expected.

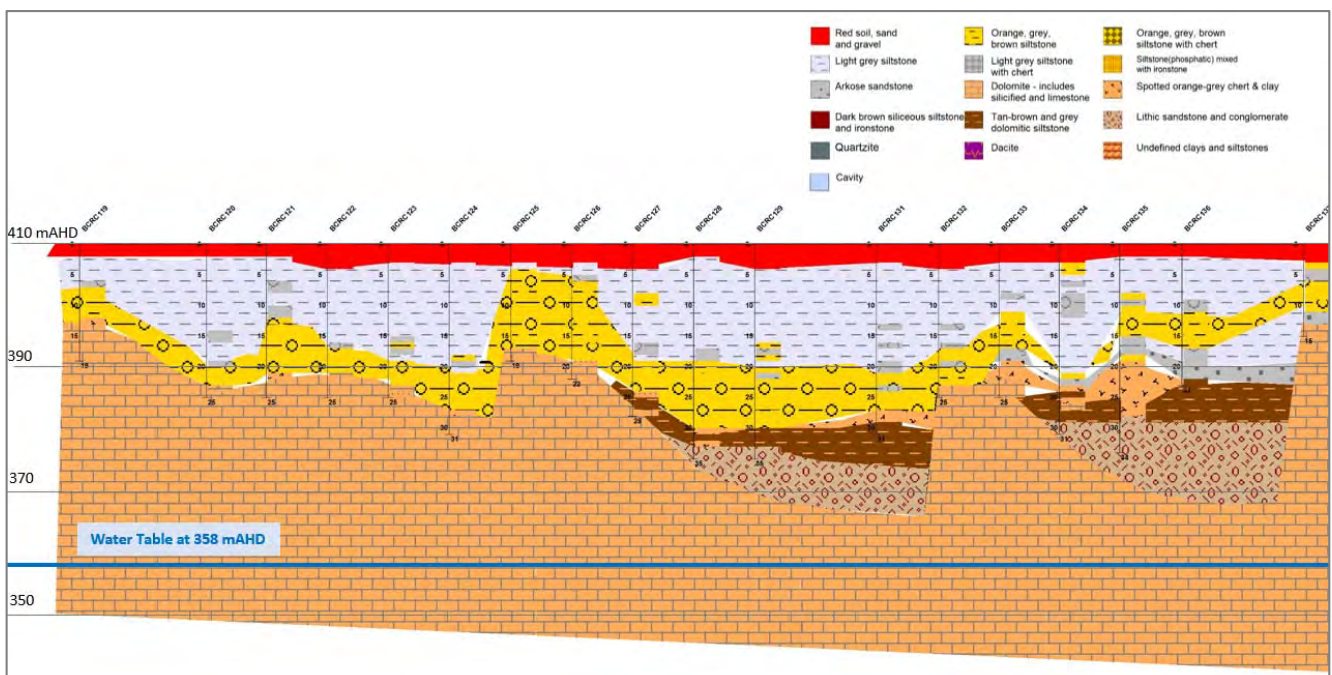


Figure 12: Mine Pit Cross Section

5.1.4 Tailings Handling

For the first months of the mine operation tailings will be stored in a tailings storage facility (TSF). Subsequently tailing will be stored in the pit as a strip mining method is implemented.

Some tailing liquor will seep from storage in the mine pit to the groundwater table. This will result in some increase in groundwater level and change to the chemical composition of groundwater.

5.1.5 Spills

Spills of processing reagents and hydrocarbons (fuel, lubricants) present a risk of groundwater contamination, though the significant depth to the water table of 60 to 80m provides a natural risk mitigation. Spills are considered a soil contamination risk rather than groundwater contamination.

Standard storage and handling protocols (bunded storage, spill kits etc) will be implemented.

5.2 Receptors

5.2.1 Pastoral Water Supply

The nearest pastoral water supply bores are:

15km: Hagen's Bore (RN10717)

20 km: McRobb Bore (RN00494)

28 km: Ammaroo Station Bore (RN10726)

5.2.2 Community Water Supply

The nearest community water supply bores are:

- 22 km: Ampilatwatja (RN018015 and RN018016)

5.2.3 Groundwater Dependant Ecosystems

There are no identified groundwater dependant ecosystems within 40 km of the planned borefield. The depth to water exceeds 15 m and is generally more than 30 m in proximity to the Borefield, precluding ecosystem use of the groundwater.

The nearest recorded Water Holes are in the Western Davenport Ranges some 40km north of the project along creek lines within the ranges. These water holes will be associated with the local fractured rock aquifers.

5.2.4 Western Davenport Water Control District

The western Davenport Water Control District (WDWCD) boundary is located 21 km to the west of the borefield. Water use within the WDWCD is managed subject to the Water Allocation Plan (DENR, 2017)²⁰ with the objective of:

- Maintain public water supply
- Support equitable access to water for sustainable regional economic development
- Protect water dependent ecosystems
- Support Indigenous culture and communities

The Draft Water Allocation Plan (DENR, 2017) allocates 0.5GL/yr to industry from the Central Plains region of which 0.2 GL/yr is currently licensed, leaving 0.3 GL/yr available. (This is a surprisingly small allocation to industry compared to the 29 GL/yr allocated to Agriculture and 21 GL allocated to Strategic Indigenous Reserve).

Groundwater Flux from the WDWCD is addressed in Section 5.3.3.

²⁰ DENR 2017 Draft Western Davenport Water Allocation Plan. NT Government Department of Environment and Natural Resources

5.3 Project Water Supply Impact Study

5.3.1 Modelling Approach

Groundwater modelling to calculate impacts of the project water supply bore field pumping was undertaken by CloudGMS Pty Ltd. CloudGMS are a specialist modelling firm with significant prior experience in the NT including modelling and assessment of the comparable Wiso and Southern Georgina Basin. The Ammaroo Project model report is attached as Appendix 4. The model was peer reviewed by independent expert modeller Hugh Middlemis. Hugh is an engineer, hydrogeologist and independent modelling specialist with more than 35 years' experience. The model review report is provided as Appendix 5.

To investigate the likely impacts of groundwater abstraction for the mine water supply on existing users, drawdown studies were conducted using a Monte Carlo approach and numerical uncertainty assessment methods to examine the probable magnitude and extent of the induced drawdown, consistent with the best practice modelling guidelines (Barnett et al. 2012)²¹.

The model extent is presented as Figure 13. The likely range of aquifer hydraulic parameters (transmissivity and storage) for the GBCA were determined from site specific pumping test results and other available information. The range of hydraulic parameters were then used to define a probability distribution function (PDF) for the transmissivity and the storage parameters (Figure 14). The drawdown at the locations of the existing users was then calculated for a period of 25 years using multiple combinations of transmissivity and storage generated from the PDF for 100 different realisations.

Parameter Definition

The hydraulic parameters exhibit a level of uncertainty in the range of hydraulic parameters due to the limited number of studies on the aquifers in the area (a typical problem for groundwater studies). The hydraulic parameters of these formations are poorly constrained and a probabilistic approach using Monte Carlo simulation methods has been applied to characterise the likely range of drawdowns and quantify the uncertainty of the predictions.

The hydraulic parameters that are to be changed during the analysis (i.e. transmissivity and storage coefficient) are assumed to be either normally or log-normally distributed.

Material properties that are directly related to hydraulic conductivity appear to have a log-normal distribution (Neuman, 1982)²² and this is true of transmissivity (product of hydraulic conductivity and saturated thickness). On the other hand, the distribution of porosity is usually regarded to exhibit a normal distribution

Transmissivity

The transmissivity probability distribution considered ranges from 320 – 3700 m²/d with an average transmissivity value of 1000 m²/d corresponding to the value determined from the long term pumping test at PB01. These values are considered to be representative of the CA and are consistent with the values implemented in DENR's model of the Southern Georgina Basin (Knapton, 2017)²³.

Storage coefficient

The storage coefficient has been normally distributed with a mean of 0.04 and a standard deviation of 0.005 this provides a distribution that spans the observed values where p5 is approximately 0.01 and p95 is approximately 0.10, which is considered to be representative of the semi-confined / unconfined CA. These values are consistent with the values implemented in DENR's model of the Southern Georgina Basin (Knapton, 2017).

²¹ Barnett et al, 2012, Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra

²² Neuman, S. P. (1982) Statistical characterization of aquifer heterogeneities: an overview. In: Recent Trends in Hydrogeology, 81-102. Spec. Pap. Geol. Soc. Am. no. 189.

²³ Knapton, 2017, Development of a Groundwater Model for the Western Davenport Plains version 0.2 Consultants report prepared for NT Department for Environmental and Natural Resources by Cloud GMS Pty Ltd.

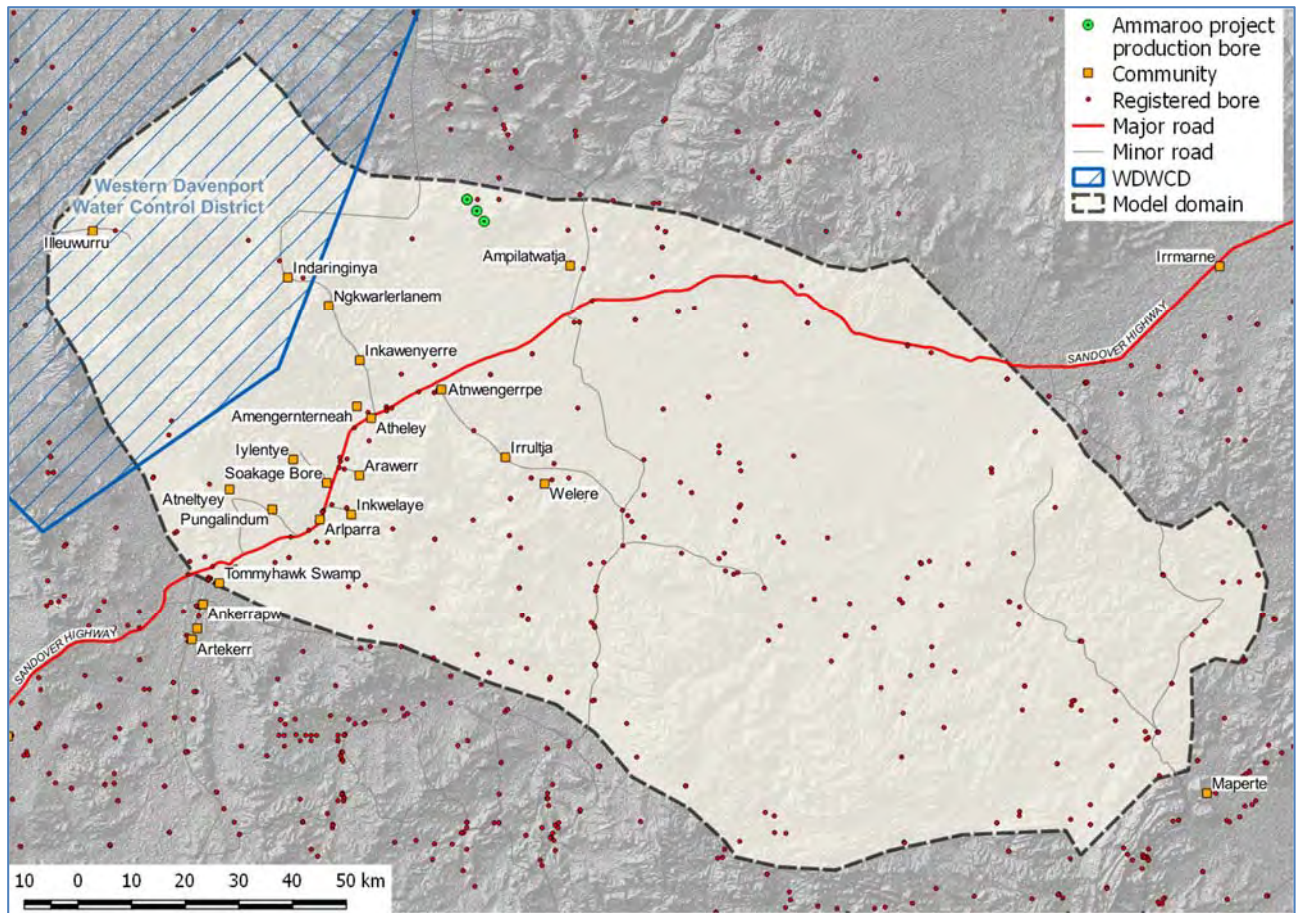


Figure 13: Numerical Model Extent

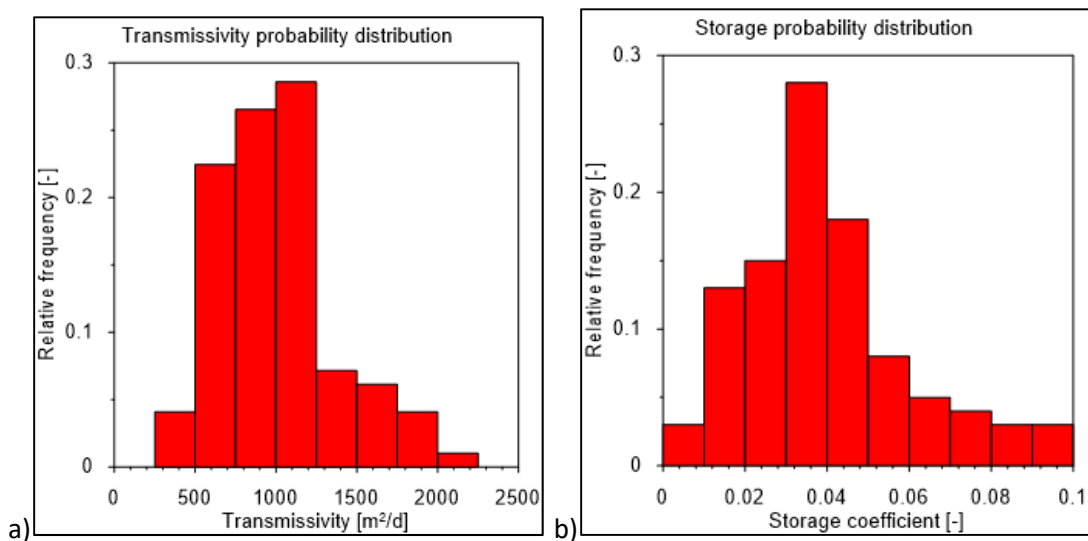


Figure 14 Probability distribution for a) transmissivity and b) storage coefficient.

5.3.2 Drawdown at Receptors

The closest pastoral bore Hagen’s Bore (RN010717) is about 15 km from the planned mine supply borefield. The borefield for Ampilatwatja Community (RN011454 & RN011455) is located about 22 km from the planned mine supply borefield.

Drawdown

The results from the drawdown analysis suggest that, for the 25 years scheduled life of mine, it is probable (5th-95th percentile) that a maximum drawdown of 1.5 – 3.7 metres can be expected at the closest pastoral bore Hagen’s Bore (RN010717). A drawdown of 0.6 – 2.7 metres will be observed at the Ampilatwatja Community borefield (RN011454 & RN011455).

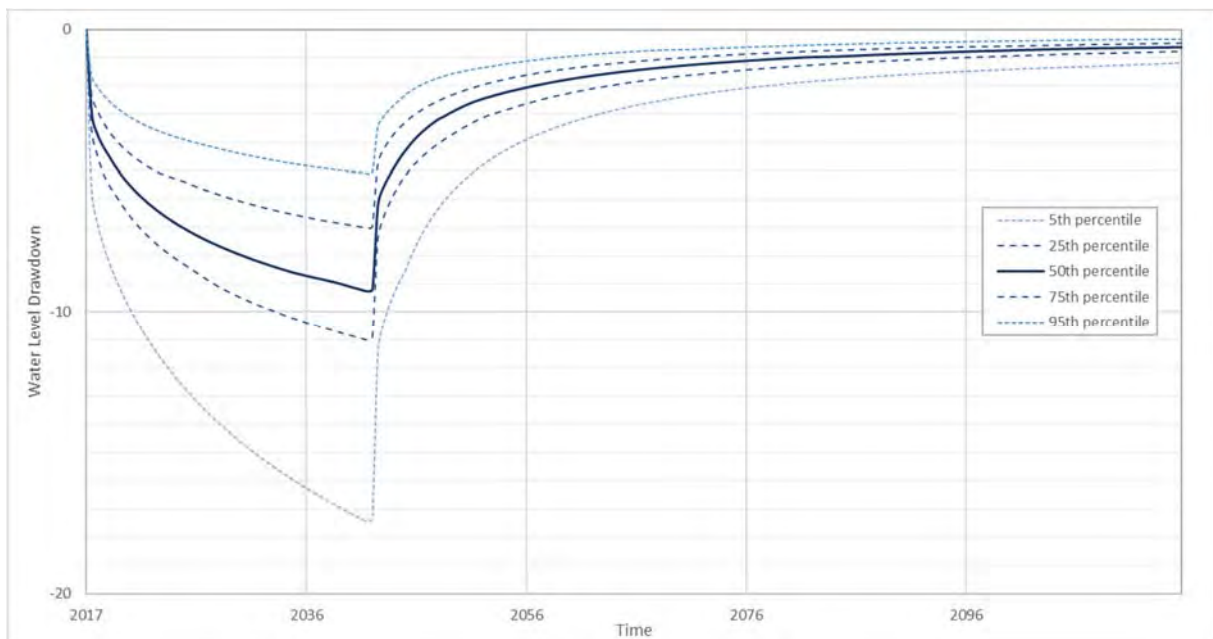


Figure 15: Drawdown at the Bore field (PB01)

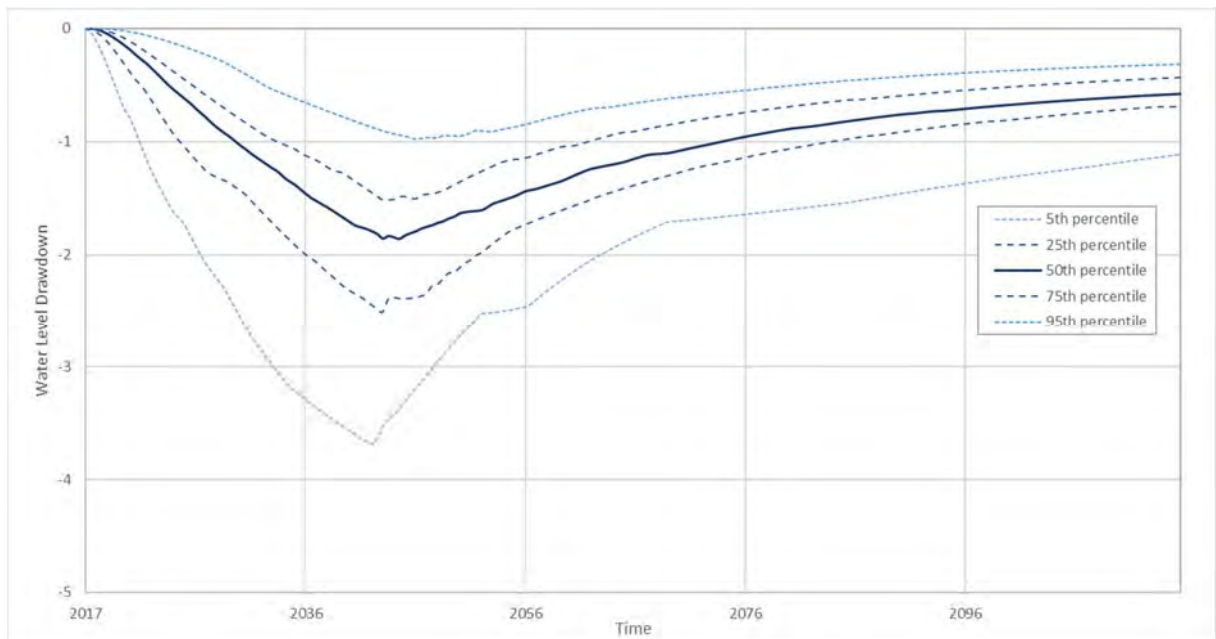


Figure 16: Drawdown at Nearest Pastoral Bore (Hagens Bore, RN107717)

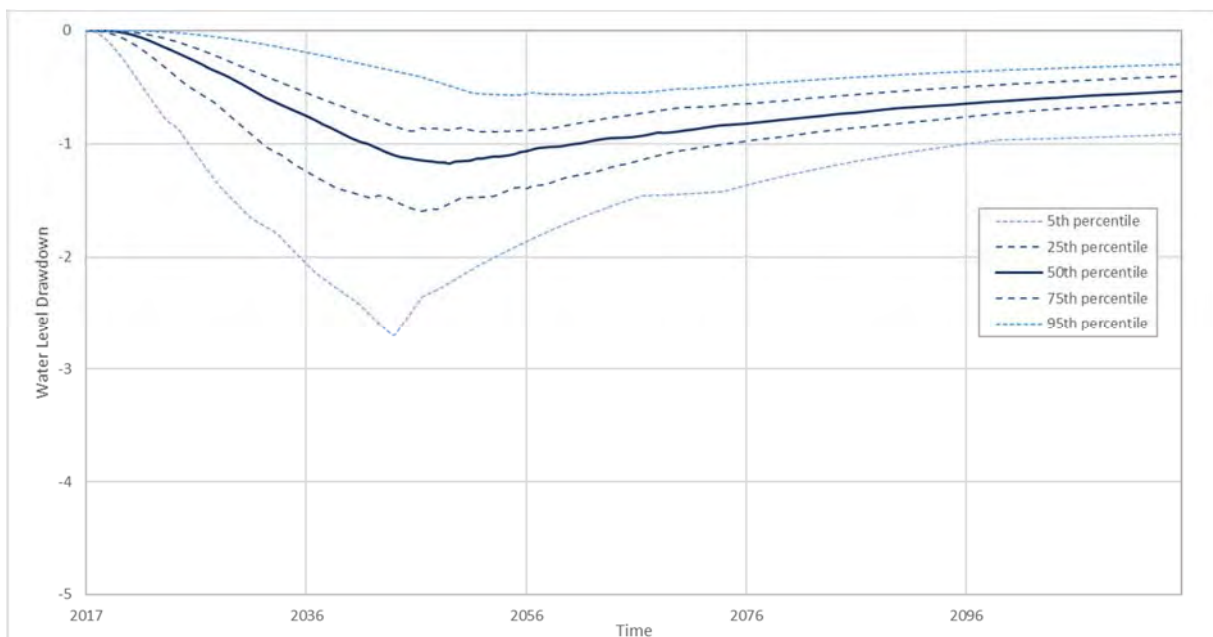


Figure 17: Drawdown at Nearest Community Water Supply (Ampilwatja, RN107717)

The drawdown contours are presented in Figure 18 to demonstrate the lateral extent of the drawdown cone at the end of mining. Drawdown contours are plotted at 0.5 metre intervals, and a drawdown of 0.5 metres is considered the extent that a response would be able to be measured/resolved in a practical way using manual methods such as a dipper and allowing for errors such as variations in atmospheric pressure.

b

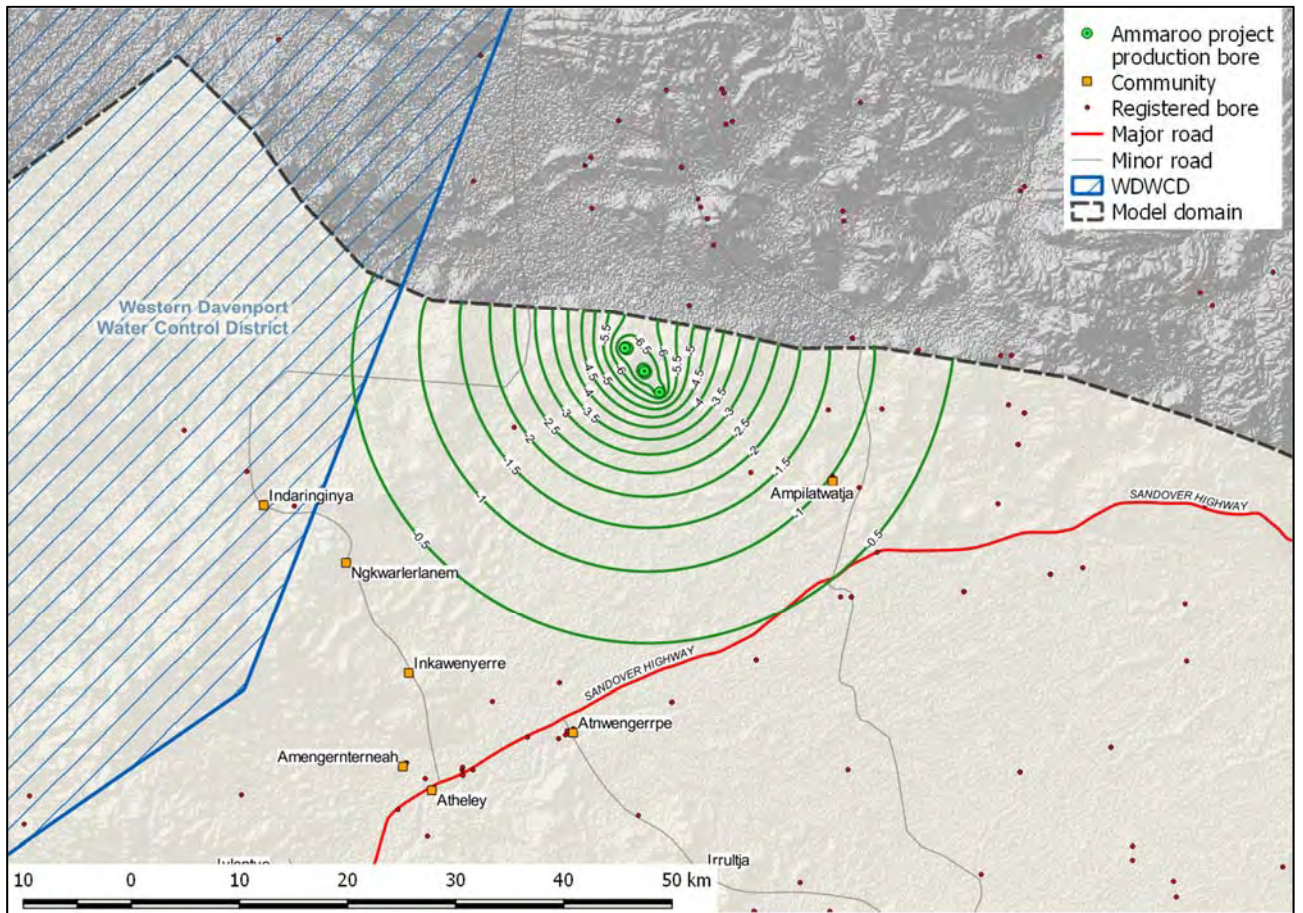


Figure 18: Drawdown contours at end of mining

5.3.3 Flow from WDWCD

Groundwater flux across the boundary of the Western Davenport Water Control District is predicted to range from 0 peaking at 0.5 GL/year at the completion of mining (Table 2, Figure 19).

Predicted drawdown at the WDWCD boundary at the completion of mining is less than 1m (Figure 18) which is considered a negligible impact given the significant (100s of meters) saturated thickness of the aquifer.

This estimate should be considered very conservative since the methodology is a storage depletion model that does not consider recharge. Recharge will mitigate the propagation of the drawdown cone and flux across the WDWCD boundary. For instance, diffuse recharge of 1.5 mm/yr (Section 4.4.5) applied over a 20 km radius drawdown cone will contribute 1.8 GL/year to the aquifer water balance.

Table 2: Calculated Groundwater flux across the WDWCD boundary.

Years of Operation	Calculated Flux across WDWCD boundary (GL/year) Base-case (50 th percentile) model
1-5	0.0
5-10	0.1
10-15	0.2
15-20	0.3
20-25	0.4
25-30 (post mining)	0.5
30-40	0.5
40-50	0.4
50-60	0.3
60-80	0.2
80-100	0.1

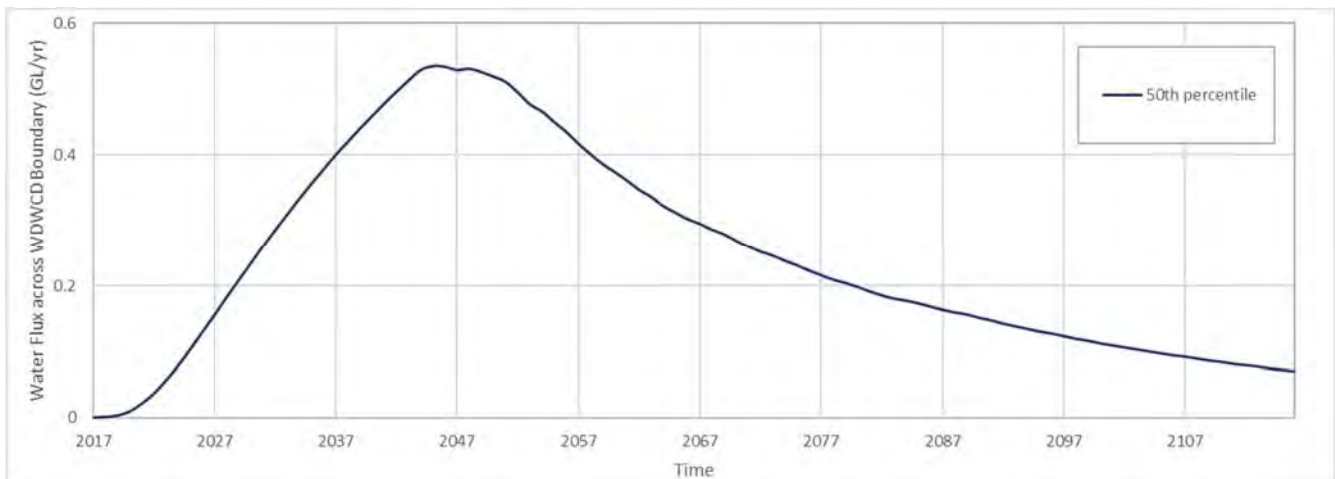


Figure 19: Calculated Groundwater flux across the WDWCD boundary.

5.3.4 Conclusions

The principal aquifer system, the Georgina Basin Carbonate Aquifer (GBCA) targeted for the proposed Ammaroo Phosphate Project supply Borefield is an extensive, regional aquifer. Groundwater extraction will cause declining water levels in the aquifer which will have impacts on existing groundwater users.

Groundwater modelling techniques consistent with best practice guidelines were applied to assess the likelihood of water level drawdown impacting existing groundwater users due to groundwater abstraction from the GBCA system for the life of mining operations. The assessment found that it is unlikely that drawdown of more than 3 m will result at any receptor. This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community water supplies.

Figure 20 presents the range of predicted drawdown at Ampilatwatja community water supply bore. The drawdown is negligible relative to the available drawdown at this bore.

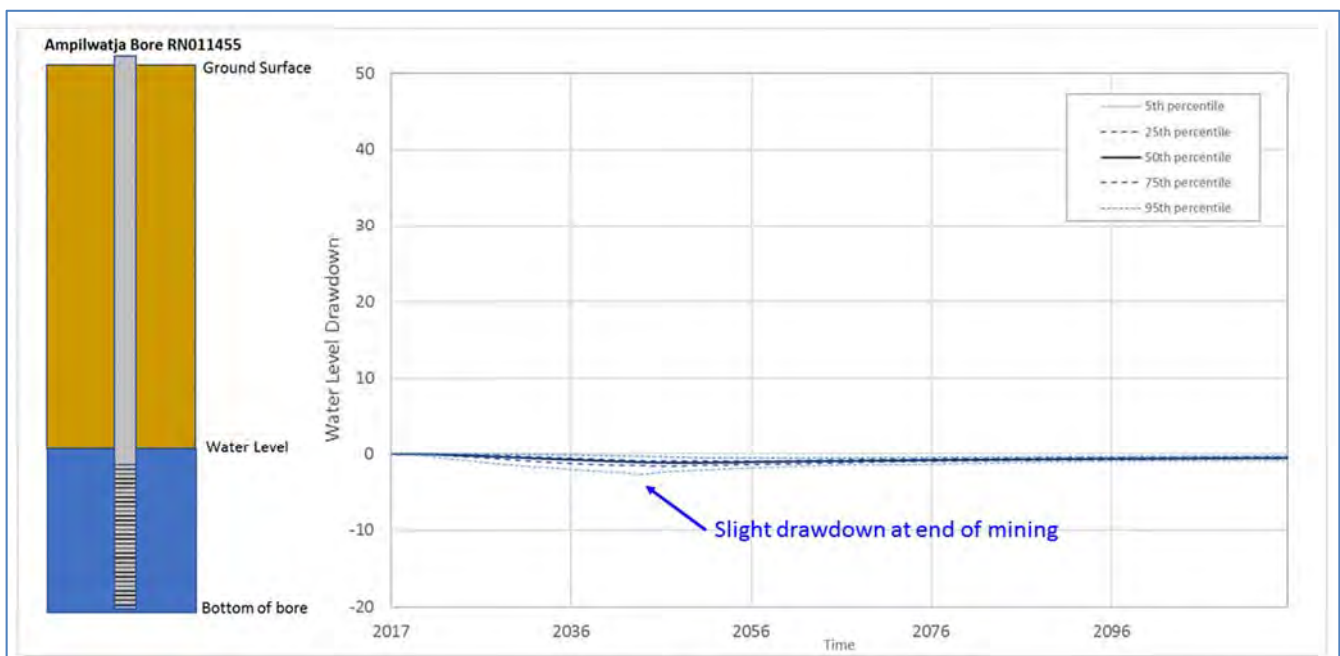


Figure 20: Water Level Drawdown at Ampilatwatja Community water supply bore

The project water supply borefield will extract a large volume of water at 4 GL/annum for 25 years however this water use is a very small fraction of the stored volume in the aquifer which is a massive regional scale resource. Figure 21 presents the project water use as a fraction of the estimated water in storage in the Southern Georgina Basin.

A conservative storage depletion modelling approach has been implemented that does not incorporate recharge.

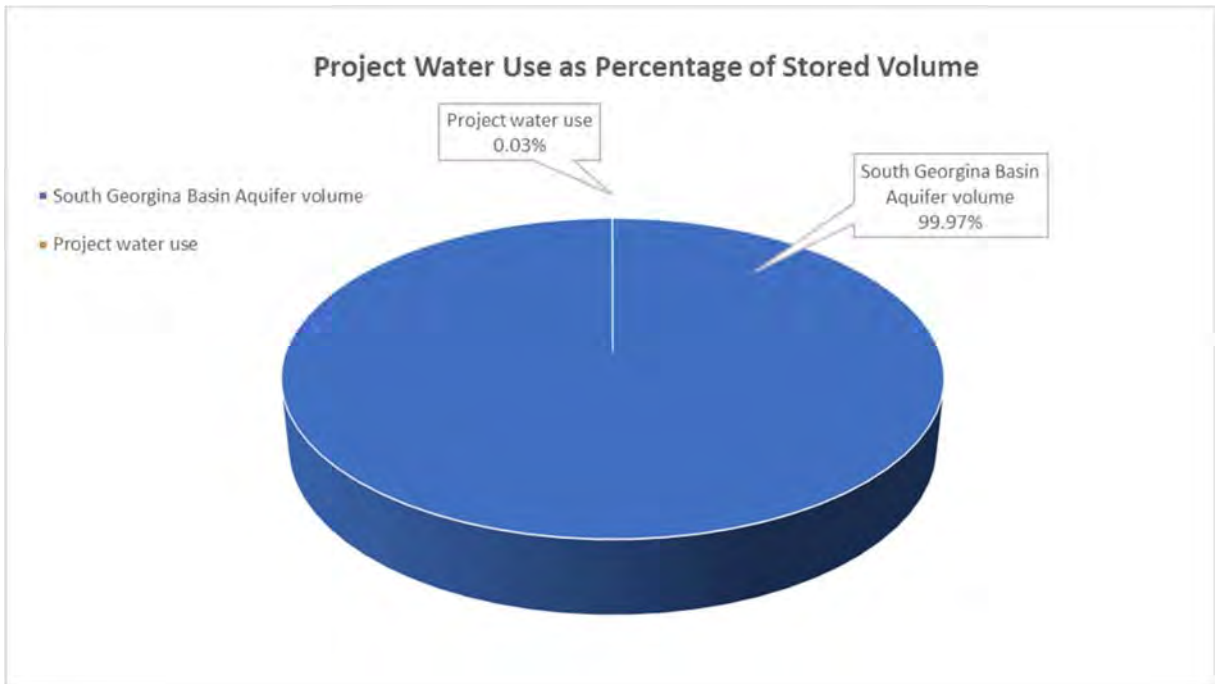


Figure 21: Project water use as a fraction of the estimated water in storage in the Southern Georgina Basin

5.3.5 Construction Water Supply

Modelling

Construction water supply pumping impacts have been assessed by calculating drawdown using analytical calculation. The Theis Equation is used to calculate drawdown for a range of aquifer parameters to consider the uncertainty of the estimate. After 1 year of pumping at 400 m³/day the distance from the pumped well to the calculated 0.5m water table drawdown contour ranges from 4 m in a highly transmissive aquifer with low storage, to 250 m in a less transmissive aquifer with high storage.

Table 3: Drawdown Impacts from Construction Water Supply Bores

Parameter set	Transmissivity (m ² /day)	Storage	Drawdown at the well (m)	Distance to 0.5m drawdown contour (m)
High Diffusivity	1000	0.1	0.7	<10
Base case	500	0.05	1.3	55
Low Diffusivity	200	0.01	3.4	850

Impacts to Receptors

There are no receptors within 850m of the planned construction water supply bores.

5.3.6 Mine Pit Excavations

The mine pit remains above the water table and no impacts to groundwater from excavation are expected.

5.3.7 Tailings Seepage

Tailing seepage from the in-pit and ex-pit tailings storage facilities present a low risk to groundwater at this project due to the benign nature of the tailings. Seepage from the TSF and in-pit tailings storage to the water table is expected.

Water table rise (mounding)

Groundwater mounding is not expected to be a significant impact. The natural groundwater table is at approximately 60 m below ground surface. Tailing will be placed in the pit below ground surface. Any mounding cannot result in surface expression of groundwater or tailing seepage to surface in proximately to the pit and tailings storage facility.

Chemical impacts of tailings seepage

Chemical impacts of tailing seepage are expected to be negligible since the water quality of groundwater and tailing leachate are comparable. In addition, there are no receptors (third party users) of groundwater within 15 km of the mine pit, hence there is no credible pathway for chemical impact on other groundwater users.

Baseline Groundwater Quality

Groundwater beneath the mine pit meets the ANZECC²⁴ water quality requirements for Stock use only due to elevated Nitrate, Fluoride and Boron (Table 4).

Tailing leachate water quality

Tailing leachate meets water quality requirements for stock use, except for fluoride which exceeds stock use levels. Elevated Fluoride is a well-documented characteristic of groundwater in the arid zone in the NT (Childs and McDonald, 1993)²⁵

²⁴ ANZECC/ARMCANZ 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

²⁵ Childs and McDonald, 1993, *A preliminary overview of groundwater in the Northern Territory*. AGSO Journal of Australian Geology & Geophysics, 14/4, 353-359

Acid and Metalliferous Mine Drainage

Geochemical test work demonstrates that the Tailings are non-acid forming (NAF) and exhibit low enrichment of neutral mine drainage. Saline drainage is not anticipated due to the low salinity of the process water stream and tailing liquor.

The static and kinetic AMD and geochemical testing indicates that the proposed waste rock, ore and pit wall material has a very low risk of generating acidic, metalliferous or saline leachate. The AMD risk is therefore considered very low (GHD, 2017)²⁶.

Saline mine drainage

Saline tailing seepage will not be generated due to the low salinity of process water.

Neutral Mine Drainage

Neutral tailing seepage exhibits low enrichment of leachate. The ore and tailing leachate are low in metals including uranium. Leachate quality is summarised in Table 4.

²⁶ GHD (201&7) *RJR - Ammaroo Phosphate – EIS AMD Assessment and Management Plan*. Consultants draft report to Rum Jungle Resources August 2017

Table 4: Tailing Leachate (Tailing Leachate quality (Environmental Geochemistry International, 2014)²⁷ and Groundwater Quality compared to water quality guidelines

Variable	Units	SA EPA	AWDG		ANZECC 2000		Tailing Leachate	Groundwater	
		EP(WQ)P	Potable	Irrigation	Stock Water	Exploration Bore		Camp Bore	
		Fresh							
General									
Colour (Hazen Units)		30							
Conductivity	µS/cm						779	869	1140
Total dissolved solids	mg/L				2000		506.35	640	640
pH	pH units	6.5-9.0	6.5 - 8.5	4.5 - 9.0			8.3	7.8	7.97
Turbidity	NTU	20	5					3	1.9
Suspended Solids		20						10	<5
Organic Carbon - Total	mg/L	15							
BOD (5-day test)	mg/L	10							
Grease & Oil		10							
Microbiology									
<i>E. coli</i>	Organisms/100mL		0	1000	100				
<i>Enterococci</i>									
Major Ions									
Total Hardness								215	174
Alkalinity as HCO ₃	mg/L							281	306
Bicarbonate	mg/L								
Carbonate	mg/L								
Hydroxide	mg/L								
Sulphate (S)	mg/L				1000				
Sulphate	mg/L		500		1000		58	32.3	58
Chloride	mg/L			250			86	59.2	117
Fluoride	mg/L		1.5	1	2		3	1.2	1.2
Calcium	mg/L				1000		9	38.8	30
Magnesium	mg/L				2000		5	28.6	24
Potassium	mg/L						4	22.4	6
Sodium	mg/L						141	92.1	144
Inorganics - Non Metals									
Ammonia (Total as N)	mg/L	0.5					ND	<0.005	0.16
Ammonia (NH ₃ as N)	mg/L	0.01							
Ammonia	mg/L								
Chlorine (total)	mg/L	0.003							
Cyanide	mg/L		0.08						
Hydrogen Sulphide (H ₂ S)	mg/L								
Nitrate	mg/L						ND		
Nitrate as N	mg/L		10		400		ND	24.5	6.75
Nitrite as N	mg/L		1		30		ND	0.03	<0.01
Nitrate + Nitrite as N	mg/L						ND		
TKN as N	mg/L								
Nitrogen - Total (as N)	mg/L	5		5.00000					
Phosphorus - Total (as P)	mg/L	0.5		0.05000			0.03	0.015	0.02
Phosphate total (P)	mg/L	0.5							
FRP	mg/L								
Iodide	mg/L		0.1						
Silica - Reactive	mg/L						23	40.4	36.4
Inorganics - Metals									
Aluminium (soluble) - Total ⁽⁶⁾	mg/L	0.1		5	5		0.02	0.2	0.06
Antimony - Total	mg/L	0.03	0.003					<0.002	<0.001
Arsenic - Total	mg/L	0.05	0.007	0.1	0.5		0.004	<0.005	<0.001
Arsenic III	mg/L								
Arsenic V	mg/L								
Barium - Total	mg/L		0.7				0.008	<0.05	0.004
Beryllium - Total	mg/L	0.004		0.1	ID		ND	<0.001	<0.001
Boron - Total	mg/L		0.3	0.5	5		0.4	0.5	0.48
Cadmium - Total	mg/L	0.002	0.002	0.01	0.01		ND	<0.0002	<0.0001
Chromium - Total	mg/L			0.1	1			<0.005	<0.001
Chromium (VI) - Soluble	mg/L	0.001	0.05						
Cobalt - Total	mg/L			0.05	1		ND	nr	nr
Copper - Total	mg/L	0.01	2	0.2	0.4		0.003	<0.01	0.002
Iron - Total	mg/L	1	0.3	0.2	ID		ND	0.18	<0.05
Lead - Total	mg/L	0.005	0.01	2	0.1		ND	<0.001	<0.001
Lithium - Total	mg/L			2.5					
Manganese - Total	mg/L		0.5	0.2	ID		0.04	<0.005	<0.001
Mercury - Total	mg/L	0.0001	0.001	0.002	0.002			<0.0001	<0.0001
Molybdenum - Total	mg/L		0.05	0.1	0.15		0.02	<0.005	0.002
Nickel - Total	mg/L	0.15	0.02	0.2	1		ND	<0.002	<0.001
Selenium - Total	mg/L	0.005	0.01	0.02	0.02		ND	0.002	<0.01
Silver - Total	mg/L	0.0001	0.1				ND	<0.01	<0.001
Thallium - Total	mg/L	0.004							
Tin - Total	mg/L						ND	<0.01	0.182
Uranium - Total	mg/L		0.02	0.01	0.2		0.01	0.0149	0.025
Vanadium - Total	mg/L			0.1	ID				
Zinc - Total	mg/L	0.05		2	20		ND	0.02	<0.005

²⁷ Environmental Chemistry International (2014) Ammaroo Phosphate Project - Geochemical Assessment of Phosphate Flotation Tailings. Consultant's report to Rum Jungle Resources

5.3.8 Spills

Spills of reagents or fuels presents a very low risk to groundwater at this site due to the very deep water table (~60m below ground surface). Spills constitute a soil impact rather than groundwater. Hazardous materials should be stored and handled in accordance with standard guidelines. E.g. bunded storage, provision of spill kits etc.

5.4 Risk Register

The risk register table for groundwater impacts is produced below. All risk ratings for groundwater risks are low. Details descriptions of each risk have been detailed in the preceding sections.

Table 5: Risk Register

Impact pathway		Initial Risk		Level of Certainty	Comment
Potential event	Consequence	Likelihood	Risk Rating		
Drawdown of shared groundwater aquifers in order to supply water to the project	Moderate	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> Modelling completed to understand drawdown impacts. State of the art uncertainty analysis. Drawdown less than 3m at receptors
Contamination of aquifers from acidic / metalliferous drainage	Minor	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> No Acid / Metalliferous mine drainage (Refer GHD Study). Low consequence due to deep water table and distant receptors.
Contamination of aquifers from neutral mine drainage	Minor	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> Low enrichment of neutral mine drainage Low consequence due to deep water table and distant receptors.
Contamination of aquifers from saline drainage	Minor	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> No Saline mine drainage Low consequence due to deep water table and distant receptors.
Contamination of aquifers from a spill of stored hazardous material	Minor	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> Low consequence due to deep water table and distant receptors. Standard storage and material handling Practices
Contamination of aquifers from a spill of hazardous material during transport	Minor	Rare	<i>Low</i>	High	<ul style="list-style-type: none"> Standard Control Practices for transport of hazardous material.

6 Groundwater Management Plan

6.1 Overview

Groundwater impacts are summarised in Table 6 below. Monitoring and management of impacts is described in the following sections

Table 6: Groundwater Management Plan

Impact	Management	Monitoring	Reporting	Leading Indicator
Drawdown from wellfield pumping exceeds predicted values and reduces water availability for other users	Ongoing re-calibration of model to drawdown from bore field pumping	Pumped volumes (monthly) Water level drawdown at observation bores (minimum monthly) logged electronically	Annual Reporting of monitoring, model validation and refined prediction of water level drawdown.	Predicted drawdown impacts at Third Party users generated with the validated groundwater model
Spills	Appropriate material storage and handling. E.G. bunded storage, spill kits etc	None	Reporting of spill and clean-up	Compliance with material storage and handling standards
Tailing Seepage	Per AMD Management Plan (GHD 2017)			

6.2 Monitoring and reporting

Groundwater monitoring will comprise:

1. Monitoring of drawdown in proximity to the project borefield
2. Monitoring of drawdown between the bore field and third-party bores
3. Monitoring at third-party bores
4. Monitoring adjacent the mine pit to assess seepage

Proposed monitoring locations are presented in Figure 22. Monitoring details are presented in Table 7.

Water levels should be recorded at a minimum monthly using automated data loggers and downloaded at nominally 12 monthly intervals to allow analysis of the data for annual reporting. Water quality should also be sampled and analysed annually at the borefield and in proximity to the mine pit. The volume of water pumped from each bore, and the bore field total should be monitored at least monthly, using totalizer flow meters at each borehead.

Table 7: Groundwater Monitoring Locations

Bore NAME	X	Y	Purpose	Monitoring		
				Water Level Measurement	Water Quality Analysis	Volume Pumped
ILBUMRIC BORE	524424	7629115	Third Party Impact Assessment	Monthly	None	N/A
HOGAN BORE	515779	7605608	Third Party Impact Assessment	Monthly	None	N/A
SHADY BORE	498094	7589676	Third Party Impact Assessment	Monthly	None	N/A
MC ROB BORE	525285	7617999	Third Party Impact Assessment	Monthly	None	N/A
NO 14 BORE	490114	7632728	Third Party Impact Assessment	Monthly	None	N/A
Ammaroo Station Bore	524859	7593518	Third Party Impact Assessment	Monthly	None	N/A
Ampilwatja Bore	522447	7605625	Third Party Impact Assessment	Monthly	None	From PWC
AmOBS1	511958	7624872	Tailing Seepage Assessment	Monthly	Quarterly	N/A
AmOBS2	510258	7609283	Drawdown Validation – Ampilwatja and Ammaroo Leading Indicator	Monthly	None	N/A
AmOBS3	494479	7611928	Drawdown Validation - WCD leading indicator	Monthly	None	N/A
AmOBS4	500431	7621943	Drawdown Validation	Monthly	None	N/A
AmOBS5	480118	7611739	Drawdown Validation - WCD boundary	Monthly	None	N/A
AmOBS6	510258	7631959	Drawdown Validation – Tenant Creek Block	Monthly	None	N/A
WI03	504179	7617158	Bore field Performance	Monthly	None	N/A
Production Bores			Bore field Performance	Monthly	Quarterly	Weekly

6.3 Model Calibration and refinement

Development of a Class 2 Groundwater flow model will be undertaken in accordance with the Australian Groundwater Modelling Guidelines (NWI, 2012)²⁸. Volumes pumped from the bore field and Ampilwatja community water supply will be used to define hydraulic stress for the model. Water level drawdown measured at the monitoring bores will be used to provide a calibration data set. Aquifer parameters applied in the model will be adjusted such that the model drawdown matches the measured drawdown.

The model set-up may require modification to better meet the model objective which is to predict the aquifer response to borefield pumping and borefield closure. Possible changes include:

- Model development in 3 dimensions.
- Definition of parameters zones to simulate varied geology.
- Modification of boundary conditions and the storage depletion approach.

Model revision and re-calibration will be undertaken annually if required. Drawdown predictions will be repeated for the life of mine and post closure period using the re-calibrated model.

6.4 Contingency

It is possible (though un-likely given the very broad uncertainty analysis applied in this impact assessment) that groundwater impacts (water level drawdown and reduced groundwater availability to other users) exceeds the magnitude predicted in this impact assessment.

Prediction of drawdown using the calibrated groundwater flow model will be a leading indicator of impact and monitoring of water level at the receptors will be used to confirm impacts. If impacts are greater than predicted, the following contingency measures will be implemented

1. Impact assessment – the revised magnitude of the impact will be assessed for the full project duration from mining to mine closure and aquifer recovery.
2. Make-good measures will be assessed and implemented if required, for instance deepening of existing users bores to ensure ongoing water availability.

²⁸ NWI 2012, Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra

3. Additional water recycling methods will be explored, for example enhanced water recovery from tailings.
4. Alternative water sources will be explored, for instance extending / relocating the borefield further from receptors into deeper parts of the Georgina Basin might be considered – though this is likely to be cost prohibitive.

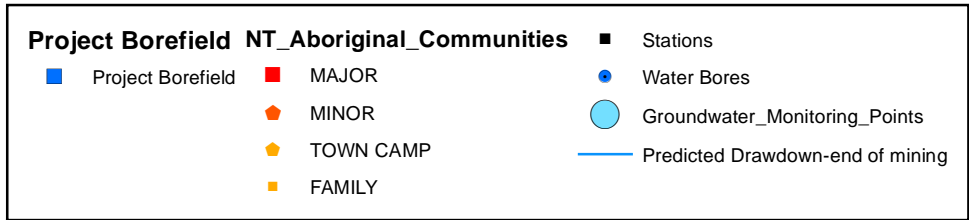
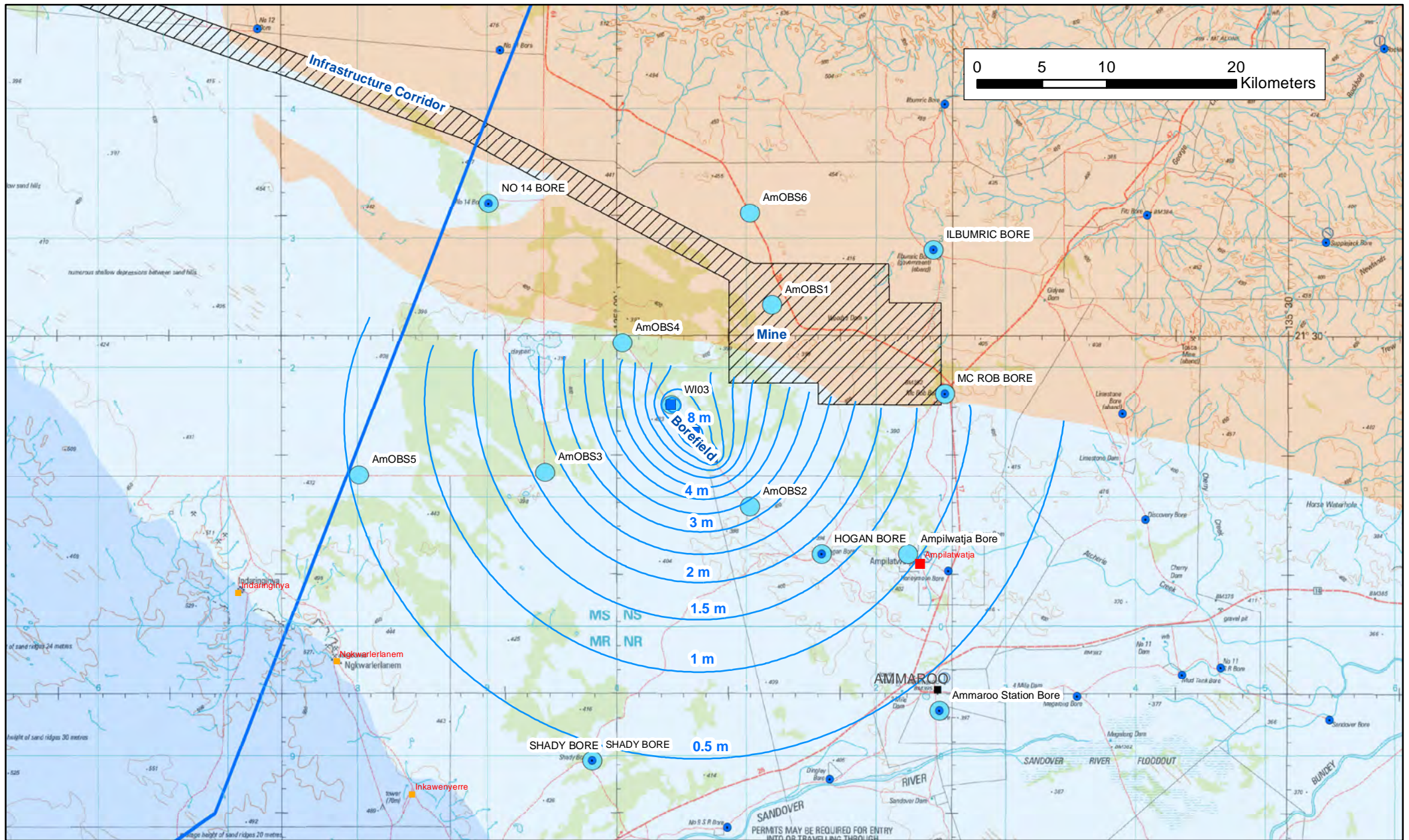


Figure 22: Groundwater Monitoring Plan

7 Appendices

Appendix 1 – Potentiometric Surface data.

RN	x	y	Collar RL (mAHD)	Bore Depth (mBGL)	Standing Water Level (mBGL)	Relative Standing Water Level (mAHD)
APWB1	512930	7625000	417	132	59	358
APWB2	511948	7625012	418	108	64	354
APWB3	501994	7624986	400	61	61	339
RN000483	543526	7596269	380	101	28	353
RN000484	508527	7584419	419	56	38	381
RN000488	489127	7578169	440	33	24	416
RN000494	525227	7618069	396	60	58	339
RN000560	542526	7644169	376	63	46	330
RN000695	501127	7630169	414	95	55	359
RN000696	501027	7634869	428	101	64	364
RN002783	448627	7573169	507	52	42	465
RN003983	541126	7611169	393	186	42	351
RN006089	489176	7578423	442	37	22	420
RN010278	490837	7644276	430	86	62	369
RN010611	483957	7578826	443	27	18	425
RN010615	468727	7575869	480	61	50	430
RN010726	524127	7594169	397	66	55	342
RN010787	541126	7611169	393	158	58	335
RN010818	540548	7608253	382	122	45	337
RN011454	523358	7605212	398	72	52	346
RN011455	523377	7605307	396	72	52	344
RN011884	535526	7594669	387	94	76	311
RN012675	478282	7597437	479	152	86	393
RN012802	483191	7574516	445	221	24	421
RN012803	489210	7577667	440	230	24	416
RN012804	495174	7581200	430	200	25	405
RN012806	484293	7587257	463	204	44	420
RN013319	535526	7594669	387	98	78	309
RN013320	510127	7621169	406	137	80	326
RN013325	490177	7632651	414	73	48	366
RN013326	513349	7640781	450	213	40	410
RN013327	513521	7637918	446	159	70	376
RN013331	506127	7617169	428	134	100	328
RN013722	463430	7609557	449	91	39	410
RN013868	508014	7641067	463	110	62	402
RN014073	470886	7602887	468	143	37	431
RN014074	473619	7602568	463	130	65	398
RN014186	525227	7618069	396	120	60	336
RN014187	543526	7596269	380	97	65	315
RN014309	525970	7639919	457	61	45	412
RN014354	453181	7648704	390	42	14	376
RN014355	455578	7656371	394	60	21	373
RN014681	478345	7597434	478	166	82	396
RN014688	483957	7578826	443	54	18	425
RN014877	438640	7611358	469	69	48	421
RN014878	436378	7609837	486	75	50	437
RN015606	541126	7632169	385	110	34	351
RN015755	486400	7576390	445	57	23	422
RN015756	498837	7581779	429	98	25	404
RN015757	484301	7587245	463	68	42	421
RN015867	527512	7598294	395	78	53	342
RN016053	516327	7588269	412	54	33	379
RN016173	508527	7584419	419	60	20	399
RN016228	498696	7581409	429	171	34	395
RN016795	483967	7578825	443	61	18	426
RN016998	449127	7575769	519	95	65	454
RN018015	523250	7605140	396	78	52	344
RN018016	523430	7605200	397	81	52	345
RN018310	531304	7616958	411	90	70	341
RN018314	524340	7629899	414	108	51	363
RN000436	419127	7717169	363	116	61	302
RN000437	420625	7700330	360	51	10	350
RN000441	394127	7650169	549	52	39	510
RN000442	402127	7640169	449	31	28	421
RN000443	408536	7650326	430	26	11	419
RN000445	386032	7621026	505	32	14	491
RN000682	438475	7677602	374	24	13	361
RN000683	438393	7677244	375	24	10	365
RN001476	418967	7687523	375	40	21	354
RN001800	437892	7678129	374	29	12	362
RN001958	522126	7686169	439	31	5	434
RN001959	522126	7685169	417	27	14	403

RN	x	y	Collar RL (mAHD)	Bore Depth (mBGL)	Standing Water Level (mBGL)	Relative Standing Water Level (mAHD)
RN002047	428520	7698124	368	31	8	359
RN002048	415202	7703750	355	31	5	350
RN002049	408746	7720504	338	31	17	321
RN002050	413258	7723655	355	32	20	335
RN002051	420665	7708879	359	35	17	342
RN002052	407793	7719216	340	6	6	334
RN002053	412793	7707965	350	5	5	345
RN002575	540006	7719599	330	19	12	318
RN002613	531126	7708169	361	37	24	337
RN002907	507126	7735169	335	55	23	312
RN003832	527616	7739351	301	30	17	284
RN005394	438464	7677342	375	63	13	362
RN005409	437910	7677193	375	22	14	361
RN005427	438316	7677171	375	36	12	363
RN005788	438089	7676786	375	34	12	363
RN005950	419383	7717456	365	62	24	341
RN005951	425479	7709189	368	38	23	345
RN005952	442159	7697388	376	72	13	363
RN006082	475385	7565718	473	46	33	440
RN006214	419127	7717169	363	75	38	325
RN006257	420626	7700259	360	21	6	353
RN006258	420798	7698806	360	49	5	355
RN006259	420773	7701852	360	12	7	353
RN006260	420995	7703169	359	9	7	352
RN006261	421380	7705125	361	16	10	351
RN006434	420503	7700404	359	46	9	350
RN006437	412178	7709759	349	35	5	344
RN006438	412684	7710305	349	33	5	345
RN006439	413264	7710911	350	34	5	344
RN006440	413845	7711518	350	33	5	345
RN006442	412064	7709637	349	19	4	344
RN006890	458065	7683884	398	47	12	386
RN006891	462332	7688100	408	46	18	390
RN006895	455601	7680162	391	61	18	373
RN006896	462229	7681680	398	88	30	368
RN006897	466010	7691732	418	93	10	408
RN006898	465817	7694780	424	116	30	394
RN007016	465947	7681679	407	61	24	383
RN007017	451148	7682108	387	69	21	366
RN007541	517126	7692169	391	71	15	376
RN007542	517990	7692762	388	31	15	373
RN007543	520126	7688169	407	24	12	395
RN007544	517723	7691208	397	68	13	384
RN010155	486501	7661797	458	76	61	397
RN010278	490837	7644276	432	86	61	371
RN010279	460990	7692745	411	63	30	381
RN010388	527126	7739169	310	34	18	292
RN010538	437618	7676730	375	37	12	363
RN010721	466024	7673619	408	24	15	393
RN010744	438389	7677143	375	61	12	363
RN010843	473166	7667923	423	50	8	415
RN011007	452006	7682067	388	84	20	368
RN011008	452006	7682068	388	36	18	370
RN011011	450006	7682067	387	55	16	371
RN011012	450646	7684067	386	114	18	368
RN011013	450646	7684068	386	60	18	368
RN011178	438666	7677775	375	181	8	367
RN011180	438570	7677067	374	119	9	365
RN011452	561189	7716798	336	59	40	296
RN011657	467127	7673169	410	105	19	391
RN011658	466932	7672699	410	40	18	392
RN011659	466932	7672699	410	49	18	392
RN011876	468765	7673602	412	30	14	398
RN011877	468638	7673437	412	49	13	399
RN012014	423127	7727169	412	80	36	376
RN012694	527126	7740169	309	23	15	294
RN012695	527126	7740169	309	35	15	294
RN012696	527126	7740169	309	21	14	295
RN012697	465110	7673625	406	31	16	390
RN012698	465110	7673625	406	27	16	390
RN012706	429069	7721305	419	65	26	393
RN012950	549015	7735119	303	38	13	290
RN012976	416001	7613315	480	58	37	443
RN013015	586304	7589952	351	88	51	300

RN	x	y	Collar RL (mAHD)	Bore Depth (mBGL)	Standing Water Level (mBGL)	Relative Standing Water Level (mAHD)
RN013201	417389	7681857	384	85	19	365
RN013323	430173	7634145	428	110	50	378
RN013324	486539	7661927	458	98	50	408
RN013325	490177	7632651	414	73	48	366
RN013331	506127	7617169	427	134	100	327
RN013345	396737	7625965	469	61	30	439
RN013753	417147	7703637	356	34	6	350
RN013754	417153	7703723	356	58	7	349
RN013755	417362	7718880	362	95	20	342
RN014354	453181	7648704	391	42	14	377
RN014355	455578	7656371	395	60	21	374
RN014356	438772	7663560	389	30	17	372
RN014357	427185	7659465	400	48	28	372
RN014360	507519	7728067	348	42	28	320
RN014519	436126	7697135	371	30	10	361
RN014528	420324	7700359	359	50	7	353
RN014562	405219	7672353	401	54	23	378
RN014602	402252	7642234	447	104	20	427
RN014604	522526	7734169	317	48	23	294
RN014787	379832	7638948	488	50	29	459
RN014789	402203	7724528	335	30	5	330
RN014825	533972	7706825	354	45	22	332
RN014827	521626	7728169	318	36	14	304
RN014832	396127	7622169	483	42	7	477
RN014833	397215	7622594	481	44	8	473
RN014944	397127	7622169	481	70	22	459
RN015174	420726	7708883	359	42	12	347
RN015175	420629	7700293	360	54	7	353
RN015176	414931	7671385	398	102	26	372
RN015244	420457	7700302	360	50	8	352
RN015245	420470	7700165	361	40	9	352
RN015315	526744	7739049	309	34	15	294
RN015316	526744	7739049	309	34	15	294
RN015320	526749	7739963	309	34	15	294
RN015578	422615	7708943	363	102	21	342
RN015580	423114	7712065	366	72	15	351
RN015581	427452	7708095	370	79	17	353
RN015583	438805	7702016	379	84	22	357
RN015584	435353	7699589	374	66	16	358
RN015585	426894	7703230	368	54	14	354
RN015639	561084	7716784	336	79	39	297
RN015964	400271	7624827	493	69	29	464
RN015965	417127	7635069	502	84	47	455
RN015966	401176	7676028	396	46	12	384
RN015967	420426	7699835	360	52	13	347
RN015968	420392	7700052	359	45	8	351
RN016049	445627	7565169	491	60	35	456
RN016052	540727	7577969	384	59	23	361
RN016053	516327	7588269	411	54	32	379
RN016055	497551	7731053	350	29	9	341
RN016057	497903	7730699	348	40	23	325
RN016058	536755	7689106	420	28	9	411
RN016079	475602	7741363	370	48	7	364
RN016080	540006	7719599	330	25	11	319
RN016141	644311	7604688	296	66	27	269
RN016147	371847	7596924	488	28	9	479
RN016148	371084	7596145	486	89	10	477
RN016149	347752	7573711	513	37	18	495
RN016173	508527	7584419	419	60	20	399
RN016175	561926	7631369	372	79	31	341
RN016196	419051	7717367	363	54	23	340
RN016197	371113	7611572	503	54	40	463
RN016206	561256	7716800	336	85	40	296
RN016228	498696	7581409	430	171	34	396
RN016345	560126	7722169	319	60	25	294
RN016346	561126	7715969	340	69	40	300
RN016372	527126	7740169	309	24	15	294
RN016373	527126	7740169	309	24	15	294
RN016660	540126	7728169	325	48	18	307
RN016661	499126	7741569	335	54	31	304
RN016665	504980	7720112	370	42	21	349
RN016693	584546	7614545	384	116	89	295
RN016782	395720	7649269	470	83	47	423
RN016795	483967	7578825	443	61	17	426

RN	x	y	Collar RL (mAHD)	Bore Depth (mBGL)	Standing Water Level (mBGL)	Relative Standing Water Level (mAHD)
RN016797	435373	7705885	383	76	29	354
RN016798	417327	7607169	486	91	33	453
RN016799	411943	7583654	509	122	43	466
RN016915	397209	7622587	481	43	9	472
RN016916	561326	7716844	336	76	37	299
RN016917	397217	7622569	480	44	10	470
RN016918	526846	7738619	310	28	17	293
RN016932	417085	7679120	388	102	38	350
RN016970	481797	7568709	453	175	27	426
RN016971	480457	7568979	452	174	27	425
RN016998	449127	7575769	519	95	64	455
RN017071	564118	7624255	382	60	39	343
RN017072	641528	7591560	303	96	22	281
RN017284	475627	7736669	382	94	46	336
RN017286	494600	7650800	449	110	69	380
RN017297	367265	7613859	495	74	19	476
RN017310	383472	7618637	515	72	7	508
RN017311	384374	7618612	513	72	6	507
RN017312	384351	7618559	512	81	6	507
RN017313	384436	7618346	513	56	7	506
RN017585	448218	7666282	381	85	10	371
RN017586	451378	7667108	384	100	15	369
RN017587	448240	7669678	381	109	12	369
RN017588	445017	7669990	379	92	10	369
RN017589	444707	7674813	377	92	9	368
RN017590	445835	7686497	381	73	15	366
RN017591	446472	7692028	382	80	16	366
RN017592	439632	7694146	374	73	13	361
RN017593	444734	7674841	377	91	9	368
RN017594	444750	7674858	377	37	9	369
RN017595	441911	7675947	375	92	8	368
RN017608	367307	7614029	495	74	33	462
RN017621	546026	7562447	395	60	37	358
RN017698	417497	7731267	392	84	41	351
RN017701	417403	7731296	393	108	38	355
RN017799	420242	7643009	436	30	17	419
RN017800	418277	7609939	473	156	30	443
RN017801	421757	7630369	453	72	29	424
RN017803	412128	7584670	508	72	39	469
RN017805	394228	7569560	501	48	7	494
RN018015	523250	7605140	397	78	52	345
RN018016	523430	7605200	397	81	51	346
RN018017	619260	7573689	343	84	51	292
RN018058	527582	7740226	307	54	13	294
RN018059	527532	7739959	308	66	13	295
RN018066	449907	7677121	384	60	15	369
RN018067	485115	7672059	458	50	16	442
RN018083	395602	7648937	473	64	38	435
RN018116	448315	7666347	381	70	11	370
RN018117	428475	7679349	377	85	9	368
RN018241	429958	7686319	371	207	6	365
RN018242	426584	7693879	366	127	2	364
RN018265	416200	7617000	506	42	23	483
RN018306	557365	7622383	399	78	39	360
RN018308	576311	7626056	346	96	40	306
RN018310	531304	7616958	411	90	70	341
RN018311	626485	7660929	276	96	66	210
RN018312	569251	7633427	359	84	40	319
RN018314	524340	7629899	414	108	51	363
RN018315	639884	7584875	317	84	47	270
RN018338	426070	7695450	366	233	3	362
RN018346	391771	7686081	390	91	26	364
RN018347	384994	7686057	402	61	39	363
RN018348	380004	7685512	401	60	40	361
RN018387	430360	7677762	379	60	14	365
RN018388	429731	7677994	381	73	14	367
RN018390	429341	7678081	380	80	14	366
RN018401	420572	7696102	364	225	7	356
RN018403	404986	7684605	384	136	18	366
RN018441	428724	7678019	379	106	11	368
RN018442	430430	7677641	379	112	13	366
RN018443	429639	7675816	382	42	12	370
RN018445	435530	7683615	373	46	10	363
RN018452	436197	7684117	372	73	8	364

RN	x	y	Collar RL (mAHD)	Bore Depth (mBGL)	Standing Water Level (mBGL)	Relative Standing Water Level (mAHD)
RN018453	434515	7683029	372	135	10	362
RN018454	435003	7683324	371	48	9	362
RN018455	432603	7681727	374	108	10	364
RN018456	431342	7680134	377	205	12	365
RN018458	435979	7683927	373	57	9	364
RN018460	435735	7683759	373	54	13	360
RN018461	412350	7738006	349	84	19	330
RN018502	586242	7589728	350	90	49	301

7.1 Appendix 2 – Detailed Chemical Analysis

Lab Report		EM1205970001	EM1205970002	EM1205970003	EM1312652001	EM1614899001	NT46452	EM1205970004
Sample date:		14/05/2012	20/05/2012	23/05/2012	26/11/2013	6/12/2016	27/10/2016	23/05/2012
Bore ID		WI03	WI04	WI05	PB01	PB01	Exploration Bore	Camp Bore
x		504178	505983	507368	504154	504154	510232	511948
y		7617160	7615030	7613089	7617169	7617169	7631969	7625012
aquifer		Georgina Basin Carbonate	Georgina Basin Carbonate	Georgina Basin Carbonate	Georgina Basin Carbonate	Georgina Basin Carbonate	Tennant Block Fractured Rock	Tennant Block Fractured Rock
pH Value	pH Unit	8.05	8.11	8.09	7.47	8	7.8	7.97
Electrical Conductivity @ 25°C	µS/cm	1590	2540	1900	nr	1560	869	1140
Total Dissolved Solids @180°C	mg/L	964	1430	1100	1010	1010	640	640
Suspended Solids (SS)	mg/L	24	28	34	nr	nr	10	<5
Turbidity	NTU	22.5	39.4	69	nr	nr	3	1.9
Total Hardness as CaCO3	mg/L	425	997	578	nr	nr	215	174
Hydroxide Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	mg/L	301	194	276	350	380	281	306
Total Alkalinity as CaCO3	mg/L	301	194	276	350	380	281	306
Sulfate as SO4 - Turbidimetric	mg/L	206	904	389	249	241	32.3	58
Chloride	mg/L	188	227	225	170	177	59.2	117
Calcium	mg/L	78	236	116	113	97	38.8	30
Magnesium	mg/L	56	99	70	62	56	28.6	24
Sodium	mg/L	112	110	116	136	117	92.1	144
Potassium	mg/L	27	23	27	33	26	22.4	6
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.2	0.06
Antimony	mg/L	<0.001	<0.001	<0.001	nr	nr	<0.002	<0.001
Arsenic	mg/L	<0.001	0.005	0.003	<0.001	<0.001	<0.005	<0.001
Beryllium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	0.04	0.023	0.027	0.038	0.036	<0.05	0.004
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	0.001	<0.005	<0.001
Cobalt		nr	nr	nr	0.001	<0.001	nr	nr
Copper	mg/L	0.002	<0.001	<0.001	0.004	0.005	<0.01	0.002
Nickel	mg/L	<0.001	0.002	0.003	nr	nr	<0.002	<0.001
Lead	mg/L	0.002	0.006	0.01	0.001	0.003	<0.001	<0.001
Zinc	mg/L	<0.005	0.037	0.008	0.024	0.074	0.02	<0.005
Manganese	mg/L	0.03	0.081	0.034	0.002	<0.001	<0.005	<0.001
Molybdenum	mg/L	0.002	0.084	0.048	0.001	<0.001	<0.005	0.002
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.002	<0.01
Silver	mg/L	<0.001	<0.001	<0.001	nr	nr	<0.01	<0.001
Vanadium	mg/L	nr	nr	nr	<0.01	<0.01	nr	nr
Tin	mg/L	<0.001	<0.001	<0.001	nr	nr	<0.01	0.182
Uranium	mg/L	0.01	0.006	0.012	0.011	0.008	0.0149	0.025
Boron	mg/L	0.28	0.32	0.31	0.3	0.28	0.5	0.48
Iron	mg/L	0.76	1.56	1.77	<0.05	<0.05	0.18	<0.05
Bromine	mg/L	1.2	1.3	1.5	nr	nr	0.732	0.9
Iodine	mg/L	0.4	0.4	0.4	nr	<0.0001	0.1	0.3
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	nr	<0.0001	<0.0001
Silica	mg/L	39.2	26.1	31.7	nr	nr	nr	36.4
Silicon	mg/L	nr	nr	nr	21.9	22.7	nr	nr
Silicate	mg/L	nr	nr	nr	nr	nr	40.4	nr
Fluoride	mg/L	1	1.9	1.3	nr	nr	1.2	1.2
Ammonia as N	mg/L	0.01	0.04	<0.01	<0.01	0.07	<0.005	0.16
Nitrite as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
Nitrate as N	mg/L	6.6	0.53	2.7	6.63	6.49	24.5	6.75
Nitrite + Nitrate as N	mg/L	6.6	0.53	2.7	6.63	6.49	nr	6.75
Total Kjeldahl Nitrogen as N		nr	nr	nr	0.4	<0.1	nr	nr
Total Nitrogen as N		nr	nr	nr	7	6.5	nr	nr
Total Phosphorus as P		nr	nr	nr	0.07	0.56	0.015	nr
Reactive Phosphorus as P		0.01	<0.01	0.01	<0.01	<0.01	nr	0.02

7.2 Appendix 4 – Borefield Modelling Peer Review

INDEPENDENT REVIEW STATEMENT

ATTENTION:	Anthony Knapton, Principal Groundwater Modeller, CloudGMS Pty Ltd	
CC:	Ben Jeuken, Principal Hydrogeologist, Groundwater Science Pty Ltd	
FROM:	Hugh Middlemis, Principal Groundwater Engineer, Hydrogeologic Pty Ltd	
REFERENCES:	14 March 2017	Project ref: Ammaroo Groundwater Impact Assessment
	HGL job#: 61.051	HGL doc#: Middlemis_2017_Ammaroo_review
SUBJECT:	Independent review of groundwater model for Ammaroo Phosphate Project Borefield	

This memo summarises the outcomes of an independent review of the groundwater modelling and impact assessment studies relating to the water supply borefield for the Ammaroo Phosphate Project being developed by Verdant Minerals. The project is sited between Alice Springs and Tennant Creek in the central Northern Territory, and the borefield is sited in the carbonate aquifers of the southwest Georgina Basin.

The model review was conducted in accordance with the best practice principles of the Australian Groundwater Modelling Guideline (Barnett et al., 2012). The 2012 guideline suggests a compliance checklist to summarise review outcomes, presented herein as Table 1 (see next page).

The main evidentiary basis for the review was the Groundwater Modelling Study report (Knapton 2017), and the review process involved the following:

- an informal meeting was held on 12 December 2016 with Mr Anthony Knapton and Mr Ben Jeuken (Groundwater Science) to discuss the hydrogeological conceptualisation and model design;
- several telephone discussions and email exchanges were held progressively with Mr Knapton during the model development to discuss the methods applied and results obtained;
- draft versions of the modelling and impact assessment report were reviewed between late February and early March 2017, and minor documentation issues were discussed with Mr Knapton; the issues were addressed in the final report, version 0.4, dated 10 March 2017.

It is my professional opinion that the hydrogeological modelling study has been undertaken consistent with best practice, including careful model design for the conservative storage depletion approach applied. Although the Ammaroo borefield is located within a few km of the northern no flow boundary of the model, this is physically realistic, reflecting the low permeability formations that bound this part of the Georgina Basin. The no flow boundaries applied to the model are a conservative setting that, together with no recharge applied, would over-estimate drawdown effects. The model is well designed and executed, and this review endorses the report commentary about model confidence level classification and the uncertainty approach applied. Most importantly, the Ammaroo modelling study is commended for the detailed analysis and quantification of predictive uncertainty (uncommonly good practice in this case), **indicating low risk of significant drawdown at the nearest existing users' bores.**

Yours sincerely, Hydrogeologic Pty Ltd



Hugh Middlemis (Principal Groundwater Engineer)

Declaration: For the record, the reviewer (Hugh Middlemis) is an engineer, hydrogeologist and independent modelling specialist with more than 35 **years' experience**. **Hugh** was principal author of the MDBA groundwater modelling guidelines (Middlemis et al, 2001) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling against international best practice. Hugh has not undertaken any work at Ammaroo, and there is no conflict of interest in relation to this review task.

Table 1 - Groundwater Model Compliance Checklist: 10-point essential summary

Question	Y/N	Comments re Ammaroo Phosphate project groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Borefield water supply impact assessment context. Southwest Georgina Basin, but not in Water Control District. Class 1 model confidence level target (achieved). Uncertainty methodology applied with effective simplification (Voss, 2011) of model design.
2. Are the objectives satisfied?	Yes	Highly competent model design and advanced methods of predictive uncertainty applied to 25-year project life and 75-year recovery period. Clear results presented as probability distributions of drawdown at key receptors, indicating low risk of drawdown >3-4m.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Conceptualisation is sound, consistent with available information and previous studies, appropriate for project context.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Model report is comprehensive and refers to previous investigations (reports by Groundwater Science and government agencies).
5. Does the model design conform to best practice?	Yes	The model software, design, extent, grid, boundaries, parameters and integrated quantitative uncertainty assessment form an excellent example of best practice in design and execution.
6. Is the model calibration satisfactory?	Yes	Calibration not warranted as methodology is designed around predictive uncertainty techniques and storage depletion model design (which over-estimates drawdown from initially flat watertable due to no flow boundaries and no recharge applied).
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Effective simplification principles (Voss, 2011) applied to model design and parameterisation, to facilitate comprehensive predictive uncertainty methodology. Water balance table reflects storage depletion methodology.
8. Do the model predictions conform to best practice?	Yes	Prediction scenarios of (25-year) project life and subsequent long term (75-year) recovery period, applied with predictive uncertainty techniques. Overall consistent with best practice, and uncertainty approach is a sound example of leading practice methods.
9. Is the uncertainty associated with the predictions reported?	Yes	Study is to be commended for the detailed analysis and quantification of predictive uncertainty scenarios (uncommonly good practice). Uncertainty analysis results indicate low risk of significant drawdown at the nearest existing users' bores .
10. Is the model fit for purpose?	Yes	My professional opinion is that the model is a sound example of best/leading practice in design and execution, notably including a comprehensive uncertainty analysis, and is fit for the impact prediction purpose.

References

Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra. URL: <http://archive.nwc.gov.au/library/waterlines/82>.

Knapton, A. (2017). Ammaroo Phosphate Project Borefield Groundwater Impact Assessment. Prepared by CloudGMS for Groundwater Science on behalf of Verdant Minerals Pty Ltd. March 2017.

Voss, C.I. (2011). **Editor's message: Groundwater modeling fantasies** – part 1, adrift in the details. Hydrogeol J. (19):1281-1284.

Voss, C.I. (2011) Editor's message: Groundwater modeling fantasies – part 2, down to earth. Hydrogeol J. (19):1455-1458.

7.3 Appendix 4 – Borefield Modelling Report

Ammaroo Phosphate Project Borefield Groundwater Impact Assessment

Prepared for	Groundwater Science	March 2017
--------------	----------------------------	------------

Version 1.0

Prepared for Groundwater Science by

Anthony Knapton

CloudGMS Pty Ltd

Contents

Executive summary	iii
1 Introduction	1
1.1 Background.....	1
1.2 Objectives.....	1
1.3 Scope.....	1
1.4 Assumptions and Limitations	1
2 Methodology	2
2.1 Numerical model setup	2
2.2 Monte Carlo simulations	3
3 Site Characteristics	4
3.1 Aquifer hydraulic parameters	4
3.1.1 Transmissivity	4
3.1.2 Storage coefficient.....	4
3.2 Hydraulic parameter uncertainty	4
3.2.1 Transmissivity	5
3.2.2 Storage coefficient.....	5
3.3 Borefield details	6
3.3.1 Production bore locations.....	6
3.3.2 Pumping schedule and water demand.....	6
3.4 Existing users	6
4 Base Case Predicted Impacts (Deterministic).....	6
4.1 Predicted drawdown from the proposed mining timeframe and water demand.....	6
4.1.1 Drawdown vs time hydrographs	6
4.1.2 Base case drawdown contours at end of mining.....	7
4.2 Predicted fluxes induced across the boundary of the WDWCD.....	8
4.3 Water balance	8
5 Predictive Uncertainty (Probabilistic).....	9
5.1 Predicted drawdown from the proposed life of mining water demand	9
5.2 Predicted fluxes induced across the boundary of the WDWCD.....	11
6 Conclusions.....	11
7 References	11
Appendix A Groundwater fluxes across the Western Davenport WCD boundary	13

Figures

Figure 2-1 Model domain showing communities, registered bores and the location of the proposed borefield.	3
Figure 3-1 Probability distribution for a) transmissivity and b) storage coefficient.	5
Figure 4-1 Drawdown vs time at a) Ammaroo borefield and b) Hagen’s Bore (RN010717) and Ampilatwatja (RN011454); assumes hydraulic parameters $T = 1000 \text{ m}^2/\text{d}$, $S_y = 0.04$ and discharge $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s).	7
Figure 4-2 Predicted drawdown contours at 25 years (assumes $T = 1060 \text{ m}^2/\text{d}$, $S = 0.04$, $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s)).	8

Figure 4-3 Estimated flow induced across the Western Davenport Water Control District.8

Figure 5-1 Drawdown vs time at the Ammaroo Project borefield based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s).9

Figure 5-2 Drawdown vs time at Hagen’s Bore based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s).....10

Figure 5-3 Drawdown vs time at the Ampilatwatja community production bore based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s). 10

Figure 5-4 Induced flux across the boundary of the Western Davenport WCD due to pumping at the Ammaroo Project borefield. 11

Tables

Table 1 Ammaroo project test production bore locations, Ampilatwatja community supply bore locations and hydraulic parameters derived from pumping tests.....4

Table 2 Transmissivity and storage coefficient probability distribution properties.5

Table 3 Summary details of nearest existing users’ groundwater extraction bores.6

Table 4 Maximum drawdown at the Ammaroo borefield and the existing user bores assuming parameters determined from long term pumping test.7

Table 5 Water balance for the 100 year modelled period (2017 – 2117).....9

Table 6 Predicted 5th – 95th percentile drawdowns at the Ammaroo Project borefield and the closest identified existing users assuming $Q = 139 \text{ L/s}$ and a duration of 25 years. 10

Prepared by	Anthony Knapton CloudGMS Pty Ltd (ABN 84 166 886 586) 3 Wright St, Edwardstown, South Australia 5039 M +61 428 798 665 E anthony.knapton@bigpond.com
Authors	Anthony Knapton (Principal Groundwater Modeller, CloudGMS)
Recommended citation	Knapton, A. (2017) Ammaroo Phosphate Project Borefield Groundwater Impact Assessment. Prepared by CloudGMS for Groundwater Science on behalf of Verdant Minerals Pty Ltd. March 2017.

Executive summary

Introduction

Groundwater supply bores for the Ammaroo Phosphate Project will be constructed in the South Western Georgina Basin Carbonate Aquifer (SWGCA). The South Western Georgina Basin hosts a regional carbonate aquifer with significant storage capacity. The projected water demand is estimated at 4380 ML/year (4.38 GL/yr) for the 25 year life of mine. Although this is a significant volume (110 GL) it represents a small fraction (0.034 – 0.07%) of the estimated groundwater storage of the south western Georgina Basin (Groundwater Science, 2017).

Groundwater abstraction for the project water supply will result in drawdown of groundwater levels which can impact existing groundwater users and/or the environment. This has potential to result in impaired capacity (i.e. reduced bore yields) in existing groundwater bores and a reduction in availability of groundwater for environmental water requirements. It is expected that there is low risk to environmental water requirements as the depth to groundwater in the area (typically more than 50 m) means that it is unlikely that there is any vegetation accessing the groundwater.

To investigate the likely impacts of groundwater abstraction for the mine water supply on existing users, drawdown studies were conducted using a Monte Carlo approach and numerical uncertainty assessment methods to examine the probable magnitude and extent of the induced drawdown, consistent with the best practice modelling guidelines (Barnett et al. 2012).

Existing users

The closest pastoral bore Hagen's Bore (RN010717) is about 11 km from the planned mine supply borefield. The borefield for Ampilatwatja Community (RN011454 & RN011455) is located about 22 km from the planned mine supply borefield.

Methodology

The likely range of aquifer hydraulic parameters (transmissivity and storage) for the SGCA were determined from site specific pumping test results and other available information. The range of hydraulic parameters were then used to define a probability distribution function (PDF) for the transmissivity and the storage parameters. The drawdown at the locations of the existing users was then calculated for a period of 25 years using random combinations of transmissivity and storage generated from the PDF for 100 different realisations.

Results

The results from the drawdown analysis suggest that, for the 25 years scheduled life of mine, it is probable (5th-95th percentile) that a drawdown of 0.6 – 2.7 metres will be observed at the Ampilatwatja Community borefield (RN011454 & RN011455) about 22 km from the planned mine supply borefield. A drawdown of 1.5 – 3.7 metres can be expected at the closest pastoral bore Hagen's Bore (RN010717), 11 km from the planned mine supply borefield.

The 5th and 95th percentile groundwater fluxes across the boundary of the Western Davenport Water Control District are predicted to peak at between 0.44 and 2.5 ML/d (~160 – 910 ML/yr) in the period between 1 and 8 years following mine closure.

Conclusions

The principal aquifer system South Western Georgina Carbonate Aquifer (SWGCA) underlying the proposed Ammaroo Phosphate Project supply borefield is an extensive, regional aquifer. Groundwater extraction will cause declining water levels in the aquifer which will have impacts on existing groundwater users.

Advanced groundwater modelling and uncertainty assessment techniques have been applied consistent with best practice guidelines to assess the likelihood of water level drawdown impacting existing groundwater users due to planned groundwater abstraction from the SWGCA system for mining operations. The assessment found that it is unlikely that significant drawdown (more than 3 – 4 m) will result. This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community water supplies.

1 Introduction

1.1 Background

CloudGMS was engaged by Groundwater Sciences on behalf of Verdant Minerals Pty Ltd to prepare a groundwater impact assessment to identify specific impacts to the groundwater system associated with the proposed supply borefield for the Ammaroo Phosphate Project.

The Ammaroo Phosphate Project is located between Tennant Creek and Alice Springs in the central Northern Territory, on the northern margin of the southwestern Georgina Basin.

The project is not within a Water Control District, however, it is about 20 km to the southeast of the declared Western Davenport Water Control District.

1.2 Objectives

The objectives of the drawdown assessment are to:

- Assess the likely magnitude and extent of groundwater level drawdown in the water table aquifer resulting from abstraction at the mining supply borefield;
- Identify the likely impact to third party users resulting from groundwater abstraction; and
- Indicate the possible magnitude of groundwater flow induced across the boundary of the Western Davenport Water Control District.

1.3 Scope

The scope of the drawdown modelling exercise was confined to the following tasks:

- Determine the likely range of hydraulic parameters in the vicinity of the proposed borefield based on site specific information and other available data;
- Estimate the drawdown with distance from the borefield at selected times for a range of hydraulic parameters; and
- Estimate the drawdown versus time at selected third party users for the range of hydraulic parameters considered.

To demonstrate the effects on groundwater levels of the groundwater abstraction, the outputs from the modelling were designed to include:

- Drawdown graphs displaying the minimum and maximum expected drawdown at each of the third party sites over the 25 year life of mine (to year 2042).
- Drawdown graphs displaying the minimum and maximum expected recovery at each of the third party sites for an additional 75 years (to year 2117) post mine closure.
- Forecast fluxes induced across the Western Davenport Water Control District boundary towards the planned borefield.
- Regional scale water level drawdown map showing the modelled cone of depression around the proposed borefield at the end of mining year 25 (2042).
- The water level drawdown maps identifying any landholder bores that fall within the zone of influence of the mine supply bores.

1.4 Assumptions and Limitations

- The assessment assumes a mine life of 25 years (to 2042) and a post closure period of 75 years (to 2117);
- The assessment assumes a continuous pumping rate based on the average water demand of 139 L/s (500 kL/hr);
- The groundwater impact assessment is based on and limited to the proposed Ammaroo Phosphate Project water supply borefield; and
- The drawdown analysis will not consider the cumulative drawdown resulting from the operation of landholder bores or interference resulting from the simultaneous pumping of community supply bores, simply the incremental effect of drawdown impacts from the Ammaroo project on existing users.

2 Methodology

The drawdown assessment was undertaken as a storage depletion model using numerical methods. The numerical model has been designed to operate with minimal run times to facilitate uncertainty analysis, consistent with best practice modelling guidelines (Barnett et al. 2016).

The groundwater model presented is deemed to be Class 1 using the classification presented by Barnett et al (2012). A Class 1 model is suitable for understanding groundwater flow processes under various hypothetical conditions and developing relationships between groundwater extraction locations, rates and associated impacts.

While the modelling study objectives deem a Class 1 confidence level appropriate at this stage of the project, the uncertainty analysis methodology that has been applied is at the level of leading best practice and does not specifically warrant definition of a model confidence level classification, consistent with guiding principles 7.1 and 7.2 (Barnett et al. 2016).

Guiding Principle	Description	Relevance to Ammaroo model.
7.1	Because a single “true” model cannot be constructed, modelling results presented to decision-makers should include estimates of uncertainty.	Uncertainty analysis presented herein utilises multiple parameter sets (100) to examine the variability in predicted groundwater drawdown.
7.2	Models should be constructed to address specific objectives, often well-defined predictions of interest. Uncertainty associated with a model is directly related to these objectives.	The Ammaroo storage depletion model was designed specifically to examine the effects of groundwater abstraction on groundwater drawdown on nearby existing users.

2.1 Numerical model setup

The drawdown analysis was conducted using a storage depletion model using a 1 layer model representing the Cambrian Aquifers in the south western portion of the Georgina Basin.

The model has been setup as a storage depletion model with assumptions similar to those used for an analytical model, that is: the model domain extends well beyond the area of influence, homogeneous and isotropic aquifer properties, uniform aquifer thickness a flat initial watertable. The storage depletion model setup is conservative, in that there is no recharge and all external boundaries are no flow type. While depth-dependent evapotranspiration is permitted in the model, the typical depth to water table of more than 50 m would not activate ET discharge. This means that the model is designed to deplete aquifer storage to meet pumping abstraction volumes, and this results in over-prediction of drawdown effects.

The model has been developed assuming that the regional system is initially in steady state and that the effects of pumping are superimposed on the regional system.

The extent of the model domain, location of the modelled production bores, communities and registered bores are presented below in Figure 2-1. Specific features of the model domain are detailed below:

- The model domain covers an area that extends east – west from 426000mE to 652750mE and south – north 7492000mN to 7643500mN; the model grid is 250 x 250 metres (uniform over the domain);
- The model domain encompasses the southwestern portion of the Georgina Basin and extends well beyond the area of interest to remove the effects of artificial model boundaries; these remote model boundaries are set as no-flow boundary conditions;
- The south western boundary coincides with the contact with the Arunta Complex;
- The north western boundary roughly corresponds with the groundwater divide between the Wiso Basin to the north and the Georgina Basin to the south;
- The northern and north eastern boundary is coincident with the contact between the igneous and metasediments of the Tennant Creek Inlier to the north and the carbonate aquifers of the south western Georgina Basin to the south (Groundwater Science, 2017);

- The boundary to the north of the borefield is about 3 km from the northern production bore PB01 and 6.5 km from the southern production bore WI05;
- The initial groundwater level is assumed to be flat and set at 0 m (a nominal datum). In this way pumping effects are easily identified as drawdowns below the initial 0 metre value;
- The base of the aquifer is set at 150 metres below the initial watertable elevation;
- The modelled scenarios assume that a maximum of three production bores pumping at 46.3 L/s are required to deliver the 500 kL/hr (139 L/s) demand, continuously for the 25 year life of mine to 2042.

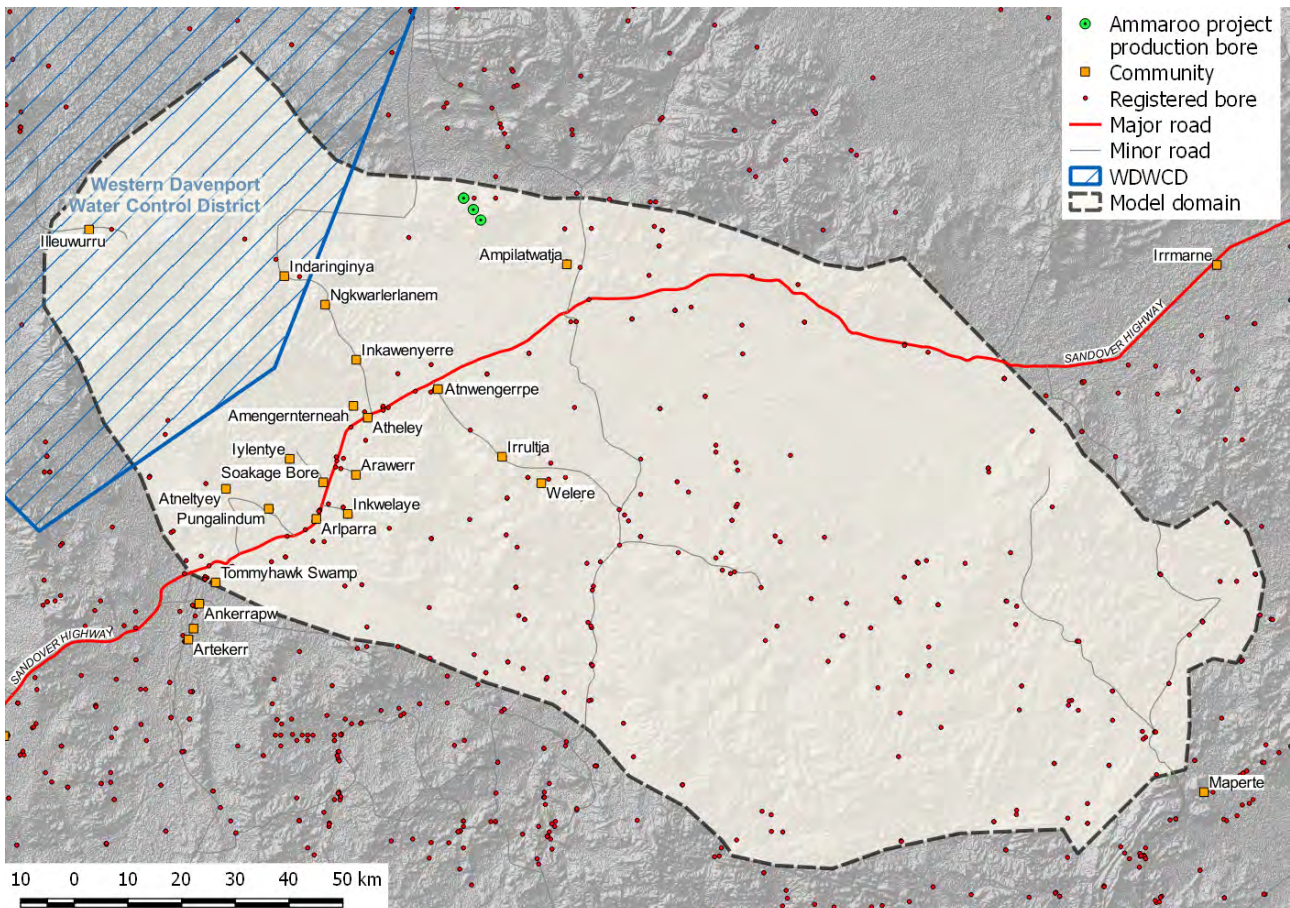


Figure 2-1 Model domain showing communities, registered bores and the location of the proposed borefield.

2.2 Monte Carlo simulations

Monte Carlo simulation is a versatile method for analysing the behavior of an activity, plan or process that involves uncertainty. Its core idea is to use random samples of parameters or inputs to explore the potential range of behavior of a complex system or process.

In groundwater modelling, Monte Carlo simulation is typically used to describe a method for propagating (translating) uncertainties in model inputs into uncertainties in model outputs (results). Hence, it is a type of simulation that explicitly and quantitatively represents uncertainties. Monte Carlo simulation relies on the process of explicitly representing uncertainties by specifying inputs as probability distributions. As the inputs describing a system are uncertain, the prediction of future performance is necessarily uncertain. That is, the result of any analysis based on inputs represented by probability distributions can be described by a probability distribution, thus quantifying the uncertainty in the predictions and providing information suitable for decision-making.

In Monte Carlo simulation, the entire system is simulated a large number of times (e.g., 100). Each simulation is equally likely, referred to as a realization of the system. For each realization, all of the uncertain parameters are sampled (i.e. a single random value is selected from the specified distribution describing each parameter). The

system is then simulated through time (given the particular set of input parameters) such that the performance of the system can be computed. This results in a large number of separate and independent results, each representing a possible “future” for the system (i.e. one possible path the system may follow through time, assuming one realization of the parameter set). The results of the independent system realizations are assembled into probability distributions of possible outcomes. The outputs are not single values, but probability distributions.

3 Site Characteristics

3.1 Aquifer hydraulic parameters

The aquifer system that the proposed production bores are abstracting from covers a large area and the hydraulic properties of the aquifer are expected to vary across the region. To assess the range of possible impacts a range of hydraulic parameters are investigated. The likely range of permeability and storage parameters were sourced from the baseline hydrogeological assessment (Groundwater Science, 2017) and are presented below in Table 1.

3.1.1 Transmissivity

The data presented above in Table 1 suggests that the transmissivity of the CA is relatively high with minimum likely value of around 300 m²/d, maximum of greater than 2600 m²/d and a mean value of around 1000 m²/d.

3.1.2 Storage coefficient

Previous water balance methods and groundwater modelling of the Cambrian Limestone Aquifer (CLA) system indicate the system behaves regionally as an unconfined system with specific yields of about 0.01 to 0.04 (Jolly, 2002; Jolly et al., 2004; Knapton, 2006). Unconfined storage coefficients of 0.01 to 0.10 are considered reasonable.

Table 1 Ammaroo project test production bore locations, Ampilatwatja community supply bore locations and hydraulic parameters derived from pumping tests.

Well ID	Easting	Northing	Transmissivity [m ² /d]	Storage coefficient [-]	Comments
PB01	504154	7617169	1060	0.04	7 Day Constant rate test
WI03	504178	7617160	2600	-	Airlift test while drilling. Drawdown by pressure transducer
WI04	505983	7615030	40 – 64	-	
WI05	507368	7613089	420 – 490	-	
RN011454	523358	7605213	81 – 236	-	Pumping tests included in NTLIS bore reports.
RN011455	523377	7605308	447 – 1280	-	

Datum = GDA94, Projection = MGA Zone 53

3.2 Hydraulic parameter uncertainty

The hydraulic parameters presented above in section 3.1 indicates that there is a level of uncertainty in the range of hydraulic parameters due to the limited number of studies on the aquifers in the area (a typical problem for groundwater studies). The hydraulic parameters of these formations are poorly constrained and a probabilistic approach using Monte Carlo simulation methods has been applied to characterise the likely range of drawdowns and quantify the uncertainty of the predictions.

The hydraulic parameters that are to be changed during the analysis (i.e. transmissivity and storage coefficient) are assumed to be either normally or log-normally distributed. Material properties that are directly related to hydraulic conductivity appear to have a log-normal distribution (Neuman, 1982) and this is true of transmissivity (product of hydraulic conductivity and saturated thickness). On the other hand, the distribution of porosity is usually regarded to exhibit a normal distribution. Assuming that the hydraulic conductivity is an exponential

function of porosity as suggested by some empirical formulas, then a normal distribution of porosity implies that the distribution of hydraulic conductivity and transmissivity must be log-normal (Neuman, 1982).

The input parameters to the model were generated using the PEST utility RANDPAR (RANDom PARAmeter). The RANDPAR utility takes a specified mean and standard deviation and generates a log normal distribution of the parameters of interest.

3.2.1 Transmissivity

The transmissivity probability distribution generated by RANDPAR used a log transformed T with mean of 3 (ie 1000 m²/d) and a standard deviation of 0.25. The resulting random transmissivity values range from 320 – 3700 m²/d with an average transmissivity value of 1060 m²/d, which coincides with the value determined from the long term pumping test at PB01 (refer Table 1). This range of values span the observed values and are considered to be representative of the SWGCA.

The resulting range, mean and standard deviation for the log transformed transmissivity generated by the RANDPAR utility are presented below in Table 2 and the corresponding probability distribution is presented in Figure 3-1.

3.2.2 Storage coefficient

The storage coefficient has been assumed to be normally distributed with a mean of 0.04 and a standard deviation of 0.02. This provides a distribution that spans the observed values and range from 0.009 to approximately 0.10, which is considered to be representative of the semi-confined / unconfined CA.

The resulting range, mean and standard deviation for the storage coefficients generated by the RANDPAR utility are presented below in Table 2 and the corresponding probability distribution is presented in Figure 3-1.

Table 2 Transmissivity and storage coefficient probability distribution properties.

Range	T (m ² /d)		Log T		S		
	Mean	Std Dev	Mean	Std Dev.	Range	Mean	Std Dev.
320-3700	1060	505	3	0.25	0.009 – 0.10	0.039	0.020

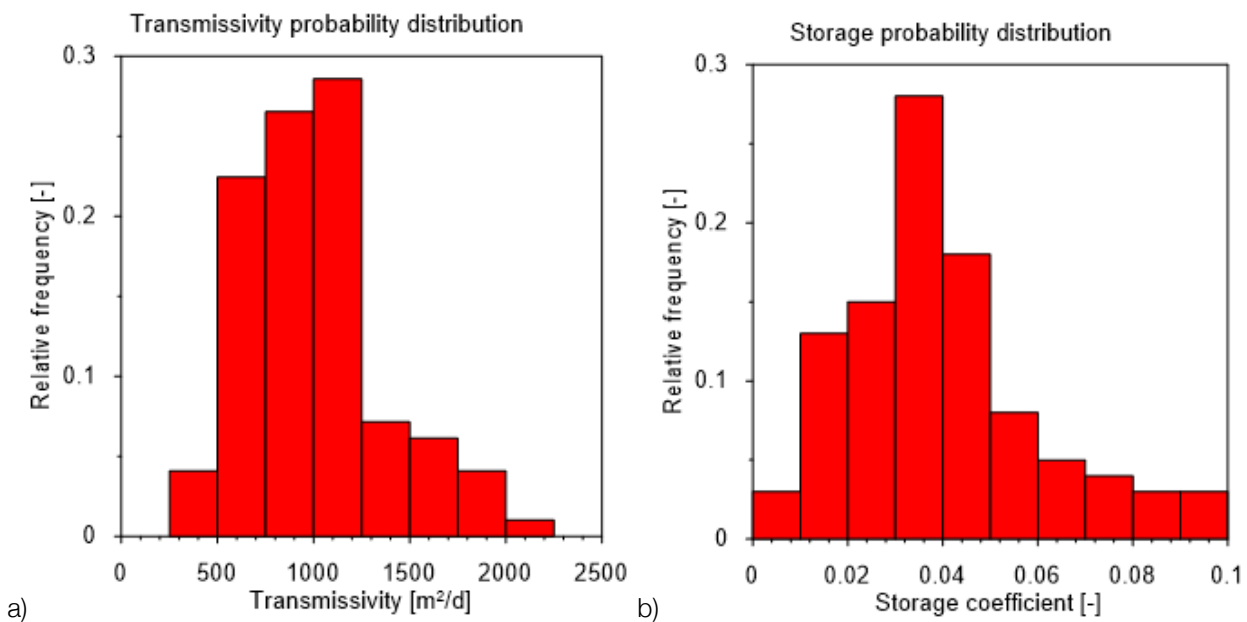


Figure 3-1 Probability distribution for a) transmissivity and b) storage coefficient.

3.3 Borefield details

3.3.1 Production bore locations

The locations of the production bores used to characterise the Ammaroo Phosphate Project supply borefield were presented above in Table 1.

3.3.2 Pumping schedule and water demand

The anticipated daily volume of water for the life of the mine is 12 ML (139 L/s). Assuming 3 production bores, each production bore is expected to pump 4 ML/d (46.3 L/s).

3.4 Existing users

The closest community to the Ammaroo Project supply borefield is Ampilatwatja community which is about 20 km to the southeast. The closest pastoral bore is Hagen’s bore, which is about 11 km from the borefield.

Table 3 Summary details of nearest existing users’ groundwater extraction bores.

Name	Well ID	Easting	Northing	Screened Interval [mBGL]	SWL [mBGL]	Available Drawdown [m]	Dist [km]
Hagen’s Bore	RN010717	515827	7605670	66.5	-	-	11
Ampilatwatja community	RN011454	523358	7605213	61.5 - 71.5	52.4	9.1	20
Ampilatwatja community	RN011455	523377	7605308	65.5 – 71.5	51.8	13.7	20

Datum = GDA94, Projection = MGA Zone 53

4 Base Case Predicted Impacts (Deterministic)

4.1 Predicted drawdown from the proposed mining timeframe and water demand

The aquifer parameters from the long term pumping test at PB01 were used to provide a ‘traditional’ base case scenario. The results are presented as drawdown hydrographs at the mine borefield and at the closest identified existing users and as a flux across the Western Davenport WCD towards the borefield.

4.1.1 Drawdown vs time hydrographs

Drawdowns were calculated assuming the hydraulic parameters ($T = 1060 \text{ m}^2/\text{d}$ and $S_y 0.04$) determined from the long term pumping test at PB01 presented above in Table 1. The drawdown was calculated for a total simulation period of 100 years and incorporated a period of 25 years of pumping from 3 bores with a total rate of 139 L/s followed by a recovery period of 75 years. The results are presented below in Figure 4-1 as time vs drawdown curves for the 100 years simulation period at the two sites. The maximum drawdown at the Ammaroo Project borefield occurs at the end of mining in 2042, however, there is a lag before the maximum drawdown is observed at Hagen’s Bore (RN010717 and Ampilatwatja community (RN011454). Table 4 presents the maximum expected drawdown at the Ammaroo Project borefield, at Hagen’s Boire and at Ampilatwatja community and the year it can be expected.

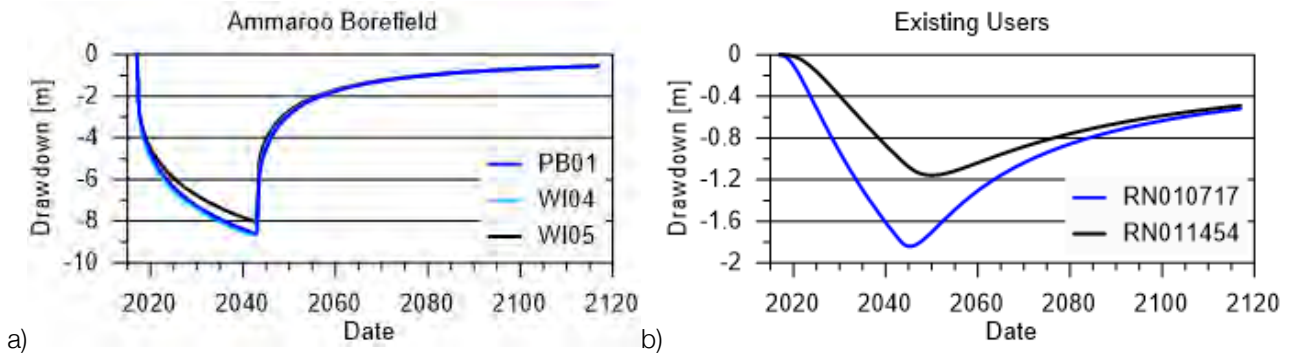


Figure 4-1 Drawdown vs time at a) Ammaroo borefield and b) Hagen’s Bore (RN010717) and Ampilatwatja (RN011454); assumes hydraulic parameters $T = 1000 \text{ m}^2/\text{d}$, $S_y = 0.04$ and discharge $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s).

Table 4 Maximum drawdown at the Ammaroo borefield and the existing user bores assuming parameters determined from long term pumping test.

Name	Well ID	Distance (kilometres)	Drawdown (metres)	Year
Ammaroo borefield	WI04	-	8.70	2042
Hagen’s Bore	RN010717	11	1.80	2045
Ampilatwatja community	RN011454 & RN011455	18 – 22	1.20	2050

4.1.2 Base case drawdown contours at end of mining

The drawdown contours are presented below to provide an appreciation of the lateral extent of the drawdown cone at the end of mining for the deterministic base case parameters. Drawdown contours are plotted at 0.5 metre intervals, and a drawdown of 0.5 metres is considered the extent that a response would be able to be measured/resolved in a practical way using manual methods such as a dipper and allowing for errors such as variations in atmospheric pressure.

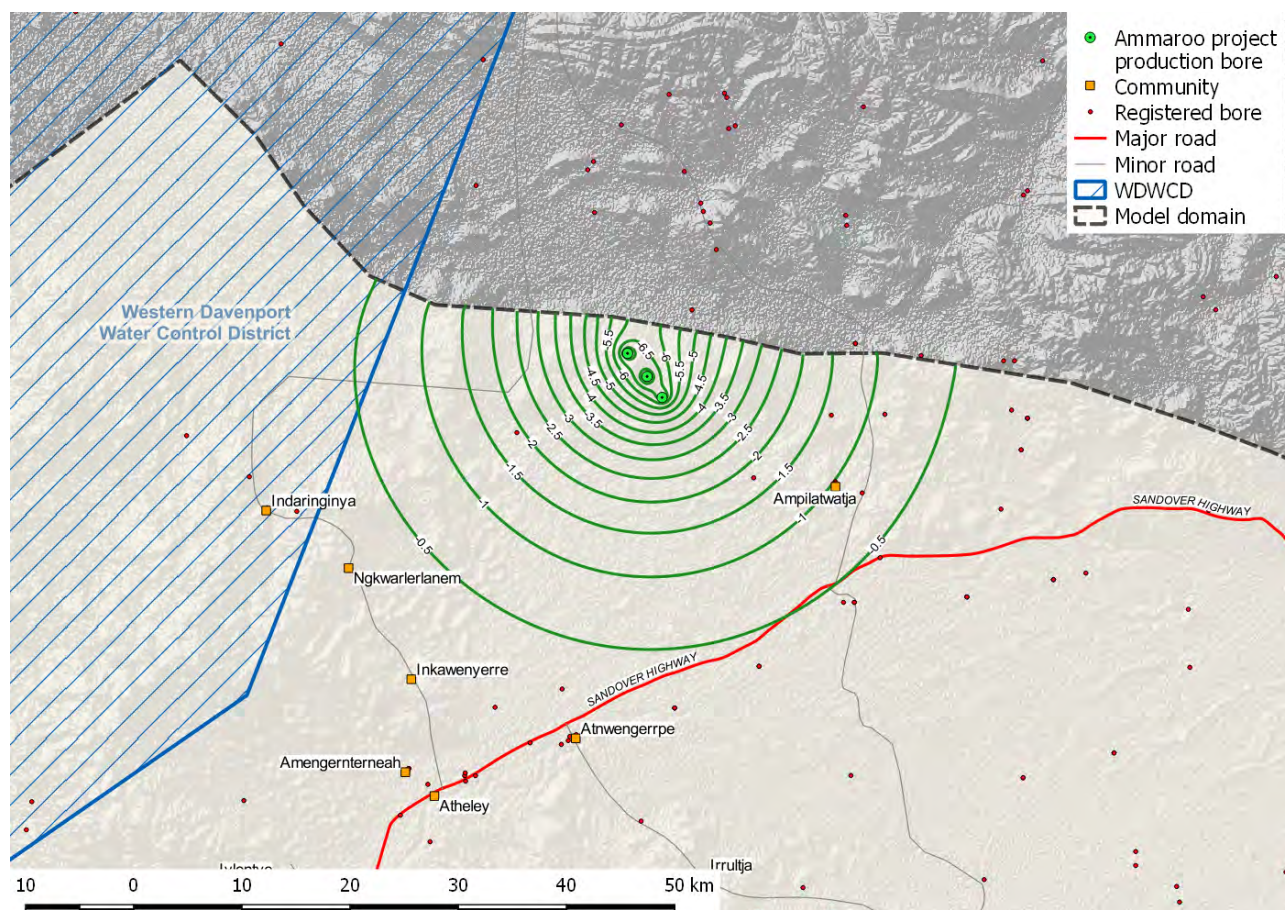


Figure 4-2 Predicted drawdown contours at 25 years (assumes $T = 1060 \text{ m}^2/\text{d}$, $S = 0.04$, $Q = 12000 \text{ m}^3/\text{d}$ (139 L/s)).

4.2 Predicted fluxes induced across the boundary of the WDWCD

The flux induced across the boundary of the Western Davenport Water Control District due to groundwater abstraction from the mine supply borefield is presented below in Figure 4-3 for the deterministic base case. The results indicate a peak/maximum total flow of 1.48 ML/d (~540 ML/yr) can be expected about 6 years after the end of mining in year 2048.

Note: The Western Davenport Water Allocation Plan has 500 ML/yr allocated for industry.

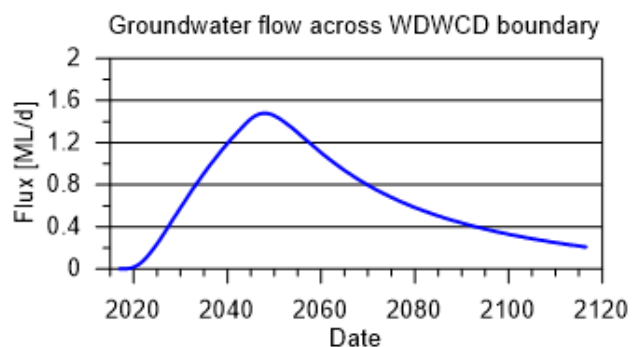


Figure 4-3 Estimated flow induced across the Western Davenport Water Control District.

4.3 Water balance

The water balance for the groundwater model for the period 2017 – 2117 is presented below in Table 5. The storage depletion nature of the model means the water balance is dominated by pumping abstraction and storage changes. The overall water balance error is less than 0.1%.

Table 5 Water balance for the 100 year modelled period (2017 – 2117).

Component	Volume (m ³)	Volume (GL)
Rech	0	0
ET	0	0
Bndry inflow	0	0
Bndry outflow	0	0
Pumping	-1.14E+11	-1.14E+05
Storage change	1.14E+11	1.14E+05
Error	9.80E+07	9.80E+01
Error %	0.09	0.09

5 Predictive Uncertainty (Probabilistic)

5.1 Predicted drawdown from the proposed life of mining water demand

Using the probability distribution functions of hydraulic parameters presented in section 3.2 the predicted drawdowns were calculated for 100 realisations. The results of the 100 realisations are presented below in Figure 5-1, Figure 5-2 and Figure 5-3 as time vs drawdown hydrographs at the Ammaroo Project borefield (WI04), Ampilatwatja community borefield (RN011455) and the closest pastoral bore (RN010717) sites. The drawdown hydrographs also show percentiles, which indicate the probability of occurrence based on the range of parameters considered. The 5th / 95th percentile of the drawdown data are represented with dashed lines and indicate the extreme values, the 25th / 75th or lower and upper quartiles are represented by thin continuous lines and the bold continuous centre-line is the median or 50th percentile. The drawdown contours presented previously in Figure 4-2 provide an appreciation of the lateral extent of the drawdown cone for the 50th percentile (median) results.

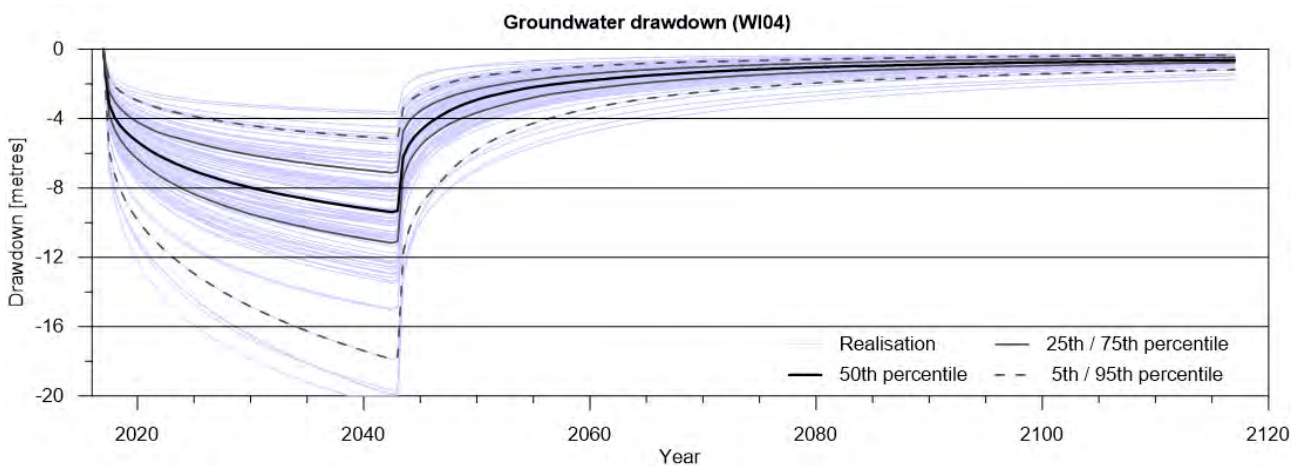


Figure 5-1 Drawdown vs time at the Ammaroo Project borefield based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge Q = 12000 m³/d (139 L/s).

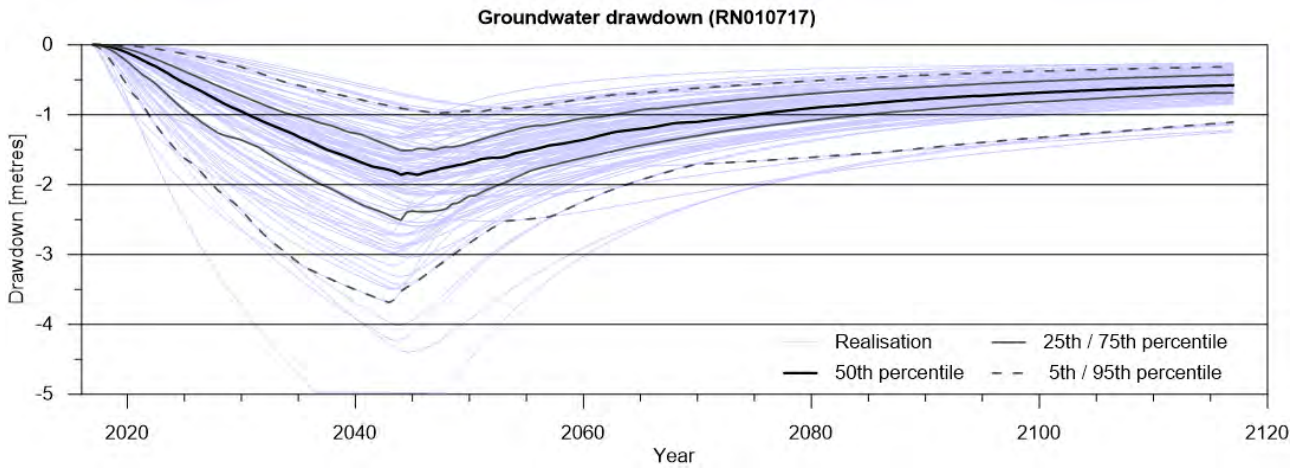


Figure 5-2 Drawdown vs time at Hagen’s Bore based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge Q = 12000 m³/d (139 L/s).

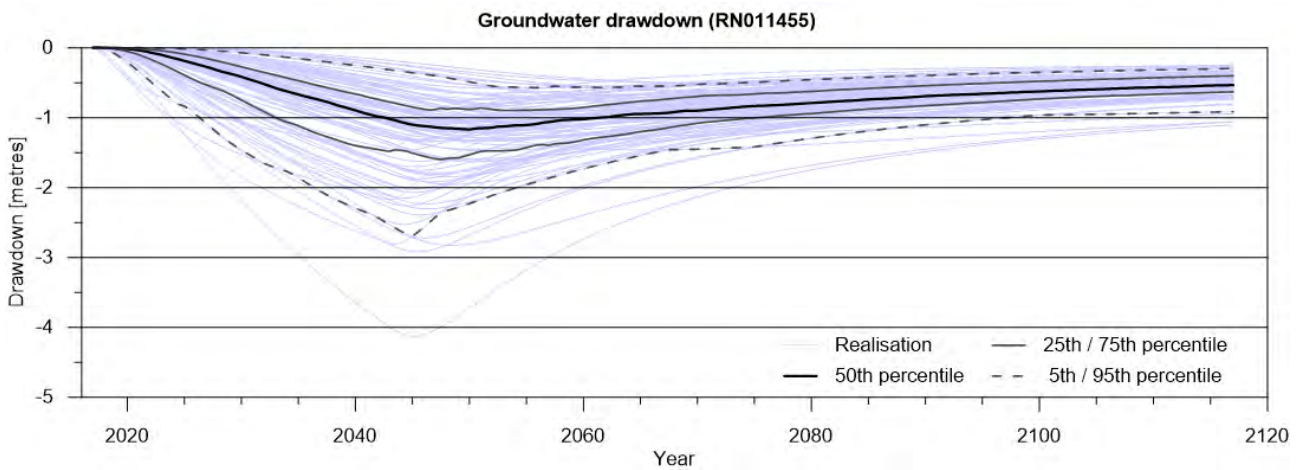


Figure 5-3 Drawdown vs time at the Ampilatwatja community production bore based on 100 realisations using the input hydraulic parameter pdfs from Table 1 and borefield discharge Q = 12000 m³/d (139 L/s).

The range of likely drawdowns (5th – 95th percentiles) at the Ammaroo Project borefield (WI04), Ampilatwatja community borefield (RN011455) and the closest pastoral bore (RN010717) sites is summarised below in Table 6.

Table 6 Predicted 5th – 95th percentile drawdowns at the Ammaroo Project borefield and the closest identified existing users assuming Q = 139 L/s and a duration of 25 years.

Site	Nearest bore	Distance (kilometres)	50 th Percentile (Median) Drawdown (metres)	5 th – 95 th Percentile Drawdown (metres)
Ammaroo borefield	WI04	-	8.6	5.2 – 17.9
Hagen’s Bore	RN010717	11	1.9	1.5 – 3.7
Ampilatwatja community	RN011454 & RN011455	18 - 22	1.2	0.6 – 2.7

5.2 Predicted fluxes induced across the boundary of the WDWCD

The flux induced across the Western Davenport Water Control District boundary (refer to Figure 2-1) due to pumping at the mine water supply bores was determined for each of the 100 realisations and are presented below as timeseries in Figure 5-4. The graph also show the calculated percentiles, which indicate the probability of occurrence based on the range of parameters considered. The 5th / 95th percentiles of the flux data are represented with dashed lines and indicate the extreme values, the 25th / 75th or lower and upper quartiles are represented by thin continuous lines and the bold continuous centre-line is the median or 50th percentile.

The 50th percentile (median) results indicate that about 1.45 ML/d (~530 ML/yr) can be expected to flow across the boundary to the southeast, very similar to the results obtained for the deterministic assessment (section 4.2). The likely range of fluxes that can be expected, indicated by the 5th – 95th percentile values, range between 0.44 and 2.5 ML/d (~160 – 910 ML/yr).

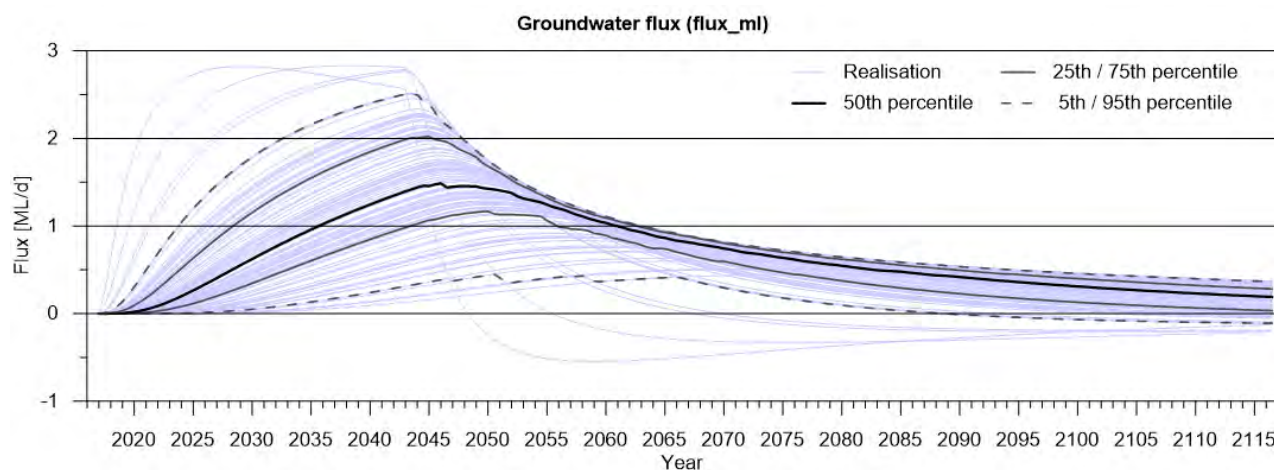


Figure 5-4 Induced flux across the boundary of the Western Davenport WCD due to pumping at the Ammaroo Project borefield.

6 Conclusions

The projected water demand for the Ammaroo Phosphate Project is estimated at 4380 ML/year (4.38 GL/yr) for the 25 year life of mine. Although this is a significant volume (110 GL) it represents a small fraction (0.034 – 0.07%) of the estimated groundwater storage of the south western Georgina Basin (Groundwater Science, 2017).

Based on the available aquifer properties and the pumping information supplied, a rigorous uncertainty analysis has identified that it is unlikely that significant drawdown will result at existing user bores (more than 3 – 4 m) due to groundwater abstraction from the SWGCA system for mining operations. The proposed Ammaroo project water supply borefield poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community borefields.

7 References

- Barnett B, Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner A.D., Knapp A. and Boronkay A. (2012) Australian groundwater modelling guidelines, Waterlines Report Series No. 82, National Water Commission, Canberra.
- Groundwater Science (2017), Ammaroo Phosphate Project Groundwater Study. Unpublished report to Verdant Minerals Pty Ltd.
- Jolly, P., (2002) Daly River catchment water balance. NTG Dept. of Lands, Planning and Environment, Natural Resources Division Technical Report WRD02010.

- Jolly, P., Knapton A. and Tickell, S. (2004) Water Availability from the Aquifer in the Tindall Limestone South of the Roper River. NTG Dept of Infrastructure, Planning and Environment. Technical Report WRD04034.
- Knapton, A., (2006) Regional Groundwater Modelling of the Cambrian Limestone Aquifer System of the Wiso Basin, Georgina Basin and Daly Basin. Alice Springs, NTG Dept. Natural Resources, Environment and The Arts. Technical Report WRA06029.
- Neuman, S. P. (1982) Statistical characterization of aquifer heterogeneities: an overview. In: Recent Trends in Hydrogeology, 81-102. Spec. Pap. Geol. Soc. Am. no. 189.
- Theis C. V. (1935) The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. Trans Amer Geophys Union 16: 519-524.

Appendix A Groundwater fluxes across the Western Davenport WCD boundary

Average annual fluxes in megalitres (ML) across the Western Davenport WCD boundary for the median, 5th and 95th percentile values.

Op. Year	Year	p5	p50	p95	Op. Year	Year	p5	p50	p95	Op. Year	Year	p5	p50	p95	Op. Year	Year	p5	p50	p95
1	2017	0	0	1	26	2042	107	496	906	51	2067	138	295	322	76	2092	-10	142	189
2	2018	0	1	19	27	2043	116	513	914	52	2068	126	286	313	77	2093	-12	138	186
3	2019	0	3	65	28	2044	125	529	899	53	2069	115	279	304	78	2094	-14	134	183
4	2020	0	9	128	29	2045	134	535	857	54	2070	105	269	296	79	2095	-16	130	180
5	2021	0	21	199	30	2046	143	534	794	55	2071	95	260	289	80	2096	-18	127	177
6	2022	0	36	269	31	2047	138	529	756	56	2072	87	252	282	81	2097	-20	123	174
7	2023	1	56	335	32	2048	146	531	711	57	2073	78	246	275	82	2098	-22	119	172
8	2024	2	78	395	33	2049	154	526	668	58	2074	71	238	268	83	2099	-24	116	169
9	2025	3	103	451	34	2050	162	519	629	59	2075	63	231	262	84	2100	-25	112	166
10	2026	6	129	502	35	2051	138	511	595	60	2076	56	223	256	85	2101	-27	109	164
11	2027	8	155	547	36	2052	131	495	563	61	2077	50	216	250	86	2102	-28	106	161
12	2028	11	182	589	37	2053	137	477	536	62	2078	44	209	245	87	2103	-29	103	159
13	2029	15	208	627	38	2054	143	466	511	63	2079	39	204	239	88	2104	-30	100	157
14	2030	20	234	661	39	2055	148	450	488	64	2080	33	198	234	89	2105	-32	97	155
15	2031	25	260	692	40	2056	153	435	468	65	2081	28	191	230	90	2106	-33	94	153
16	2032	31	285	721	41	2057	155	417	449	66	2082	24	185	225	91	2107	-34	92	151
17	2033	37	309	747	42	2058	152	401	432	67	2083	19	180	221	92	2108	-35	89	149
18	2034	43	333	771	43	2059	134	386	416	68	2084	15	177	217	93	2109	-35	86	147
19	2035	50	356	793	44	2060	136	374	401	69	2085	11	173	213	94	2110	-36	84	145
20	2036	58	378	813	45	2061	139	361	387	70	2086	8	168	209	95	2111	-37	81	143
21	2037	65	400	832	46	2062	142	347	374	71	2087	4	163	206	96	2112	-38	79	141
22	2038	73	420	849	47	2063	145	336	363	72	2088	1	159	202	97	2113	-38	77	139
23	2039	82	440	865	48	2064	148	322	351	73	2089	-2	156	198	98	2114	-39	74	137
24	2040	90	459	880	49	2065	150	312	341	74	2090	-5	151	195	99	2115	-40	72	135
25	2041	99	478	893	50	2066	150	302	331	75	2091	-7	147	192	100	2116	-40	70	134

7.4 Appendix 5 -PB01 Pumping Test

PB01 Pumping Test

The test production bore at the Amaroo project was test pumped for an extended 7 day duration in December 2017. The aim of the extended test was to assess the presence of boundary conditions to determine if the aquifer is extensive or limited in extent. The test was run for 7 days in accordance with the Australian Standard²⁹ requirement for high security water supplies. Bore Construction is described in GWS (2012)³⁰.

Test details are presented in **Error! Reference source not found.** and the raw data is archived in Attachment 2. Water level was measured in the observation well, and water quality and flow rate were measured at the pumped bore. Measurement of water level in the pumped bore was not possible with the equipment on site at the time of the test.

The bore was pumped with the installed Lowara submersible pump. Flow control was maintained with a knife gate valve at the discharge. Flow rate was measured using an Endress-Hauser Mag-flow meter and verified using a mechanical flow totaliser in-line with the magflow meter. A total of 15,281 m³ was pumped over 7.06 days for an average rate of 2163 m³/day. Water levels in the observation well were monitored manually using a water level probe. Water was discharged to surface 50 m from the pumped bore. Water samples were taken at regular intervals for conductivity and pH measurement. These parameters remained stable for the duration of the test. A water sample was taken for detailed laboratory analysis. Salinity was 1010 mg/L TDS. Detailed chemical analysis is presented as Attachment 1.

Table 1: Pumping Test Details

Pumped Well	WellID:	PB01
	X	
	Y	
	depth	153m
	swl	81.0 m (Dec 2012)
	pumping rate	2163 m ³ /day
	start date, time	5/12/2016 1:30 PM
	end date, time	13/12/2016 7:00 AM
	Aquifer Top	54 m depth
	Aquifer Base	> 153m
Observation Well	WellID:	WI03
	X	
	Y	
	depth	200m
	swl	80.73 (5/12/2016)
	Aquifer Top	64m
	Aquifer Base	>200

The aquifer is an unconfined aquifer on the basis that the standing water level in the production and observation bores is at approximately 81m depth, whilst the top of the limestone geological unit that comprises the aquifer is intersected above the water table at 54m depth.

Drawdown and recovery data were fitted to the Neumann (1975)³¹ type curve using the AQTESOLVE software package (Duffield, 2007)³². The derived aquifer parameters are presented in Table 2. The type curve match to the data is presented in Figure 23.

²⁹ AS 2368-1990 Test pumping of water wells

³⁰ GWS (2012) *Barrow Creek Groundwater Supply Investigations – Production Bore drilling report*. Groundwater Science Report RJR-12-2-R003

³¹ Neuman, S.P. 1975. *Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response*. Water Resources Res., Vol. 11, pp. 329-342.

³² Duffield, G.M., 2007. *AQTESOLV for Windows Version 4.5 User's Guide*, HydroSOLVE, Inc., Reston, VA.

Table 2: Pumping Test Results

Transmissivity	1060 m ³ /m/day
Storativity (confined storage)	4.8 x 10 ⁻⁵
Specific Yield (un-confined storage)	0.04
Vertical Anisotropy (Kh/Kz)	50
Aquifer Thickness	120 m
Bulk Horizontal Hydraulic Conductivity	9 m/day
Vertical Hydraulic Conductivity	0.2
Radius of drawdown over 7 days	650 m

The aquifer response to pumping is consistent with an unconfined aquifer with very high transmissivity of 1060 m³/day/m and typical unconfined storage (specific yield) of 4%. No boundaries are observed in the dataset which indicates that the aquifer extends at least as far as the 650 m radius of influence of the pumping tests. Inferred vertical hydraulic conductivity is 50 times smaller than horizontal conductivity, typical of a sedimentary aquifer with marked horizontal bedding.

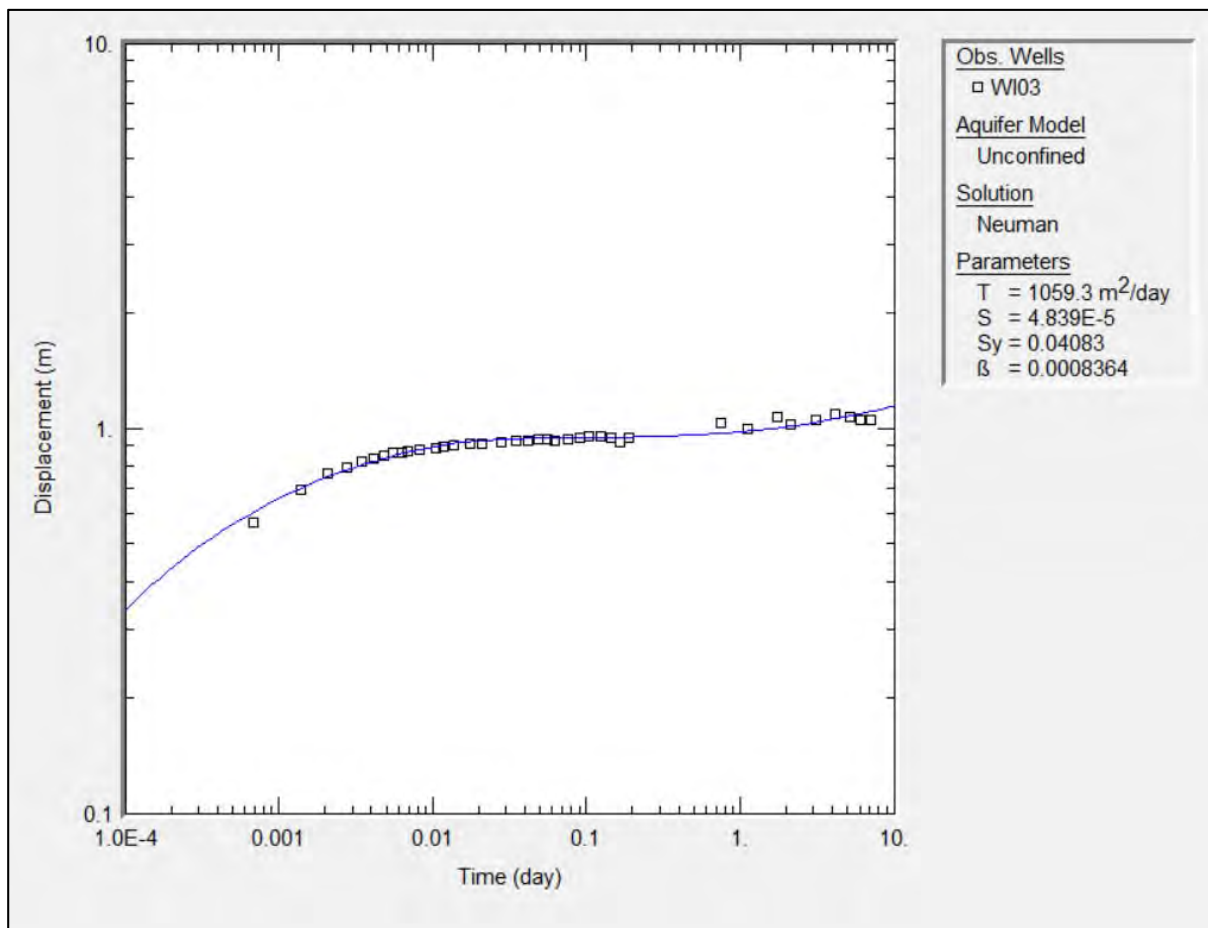


Figure 23: Pumping Test Type Curve Match

Other Hydraulic Testing

Other hydraulic tests undertaken on the Chabalowe Formation are summarised in Table 1Table 3. The results are consistent with the current test work and indicate that the formation is an extensive high transmissivity aquifer.

Table 3: Hydraulic Testing of Chabalowe Formation in proximity Amaroo Phosphate project.

Hole Tested	Coordinates	Nature of Tests	Aquifer Parameters	Reference
PB01	504154e, 7617169n	24 hr CRT	T = 770 m ² /day Sy = 0.08	GWS 2013 ³³
WI03	504178e 7617160n	Airlift test while drilling. Drawdown by pressure transducer Analysis by Logan ³⁴ approximation	T = 2600 m ² /day	GWS (2012b) ³⁵
WI04	505983e 7615030n		T = 40-64 m ² /day	
WI05	507368e 7613089n		T = 420 - 490 m ² /day	
RN011455 (Ampilwatja Water Supply Boire)	523377e 7605307n	CRT	T = 600 m ² /day	NTLIS Bore Report
RN011454 (Ampilwatja Water Supply Boire)	523358 7605212	CRT	T = 264 – 503 m ² /day	NTLIS Bore Report

³³ GWS (2013), *Amaroo Phosphate Project Water Supply Production Bore – Pump Installation and Testing Report*. Groundwater Science Report RJR-13-2-R002

³⁴ Logan, J. 1964. *Estimating transmissivity from routine production tests of water wells*. Ground Water, 2, No. 1, 35-37.

³⁵ GWS (2012b), *Barrow Creek Groundwater Supply Investigations – Pilot hole drilling report*. Groundwater Science Report RJR-12-2-R002

Attachment 1: Water quality data

Parameter	Units	Assay
pH Value	pH Unit	8
Electrical Conductivity @ 25°C	µS/cm	1560
Total Dissolved Solids	mg/L	1010
Hydroxide Alkalinity as CaCO ₃	mg/L	<1
Carbonate Alkalinity as CaCO ₃	mg/L	<1
Bicarbonate Alkalinity as CaCO ₃	mg/L	380
Total Alkalinity as CaCO ₃	mg/L	380
Silicon	mg/L	22.7
Sulfate as SO ₄ - Turbidimetric	mg/L	241
Chloride	mg/L	177
Calcium	mg/L	97
Magnesium	mg/L	56
Sodium	mg/L	117
Potassium	mg/L	26
Aluminium	mg/L	<0.01
Arsenic	mg/L	<0.001
Beryllium	mg/L	<0.001
Barium	mg/L	0.036
Cadmium	mg/L	<0.0001
Chromium	mg/L	0.001
Cobalt	mg/L	<0.001
Copper	mg/L	0.005
Lead	mg/L	0.003
Manganese	mg/L	<0.001
Molybdenum	mg/L	<0.001
Selenium	mg/L	<0.01
Uranium	mg/L	0.008
Vanadium	mg/L	<0.01
Zinc	mg/L	0.074
Boron	mg/L	0.28
Iron	mg/L	<0.05
Mercury	mg/L	<0.0001
Ammonia as N	mg/L	0.07
Nitrite as N	mg/L	<0.01
Nitrate as N	mg/L	6.49
Nitrite + Nitrate as N	mg/L	6.49
Total Kjeldahl Nitrogen as N	mg/L	<0.1
Total Nitrogen as N	mg/L	6.5
Total Phosphorus as P	mg/L	0.56
Reactive Phosphorus as P	mg/L	<0.01

Attachment 2: Pumping Test Data

Manual Field Data						
Time and Date	Time (days)	Drawdown (m) (WI03 Obs bore located 25m from pumped bore)	Flow Instant (L/s)	EC (us/cm)	pH	Flow Totaliser (m ³)
5/12/2016 13:30	0.0000	0.000	0.0	0	0	37
5/12/2016 13:31	0.0007	0.570	25.0			
5/12/2016 13:32	0.0014	0.690				
5/12/2016 13:33	0.0021	0.760				
5/12/2016 13:34	0.0028	0.790				
5/12/2016 13:35	0.0035	0.820				
5/12/2016 13:36	0.0042	0.835				
5/12/2016 13:37	0.0049	0.850				
5/12/2016 13:38	0.0056	0.860				
5/12/2016 13:39	0.0063	0.865				
5/12/2016 13:40	0.0069	0.870				
5/12/2016 13:42	0.0083	0.880				
5/12/2016 13:45	0.0104	0.890				
5/12/2016 13:47	0.0118	0.895				
5/12/2016 13:50	0.0139	0.900				
5/12/2016 13:55	0.0174	0.910				
5/12/2016 14:00	0.0208	0.910				
5/12/2016 14:10	0.0278	0.920				
5/12/2016 14:20	0.0347	0.925				
5/12/2016 14:30	0.0417	0.925				
5/12/2016 14:40	0.0486	0.935				
5/12/2016 14:50	0.0556	0.935				
5/12/2016 15:00	0.0625	0.930	25.0			
5/12/2016 15:20	0.0764	0.935	25.0	1608	7.07	
5/12/2016 15:40	0.0903	0.940				
5/12/2016 16:00	0.1042	0.950				
5/12/2016 16:30	0.1250	0.955	25.1			308
5/12/2016 17:00	0.1458	0.940	25.0	1616	7.3	351
5/12/2016 17:30	0.1667	0.920	24.9	1554	7.2	397
5/12/2016 18:00	0.1875	0.945	25.0	1625	7.4	441
6/12/2016 7:20	0.7431	1.030	24.9	1711	7.7	1637
6/12/2016 16:30	1.1250	1.000	25.0	1651	7.5	2458
7/12/2016 7:20	1.7431	1.070	24.9	1712	7.8	3806
7/12/2016 16:30	2.1250	1.020	25.1	1635	7.7	4636
8/12/2016 16:15	3.1146	1.050	25.0	1711	7.7	6776
9/12/2016 16:15	4.1146	1.090	25.0	1713	7.8	8935
10/12/2016 17:00	5.1458	1.070	25.0	1696	7.8	11165
11/12/2016 16:00	6.1042	1.050	25.0	1698	7.8	13256
12/12/2016 15:00	7.0625	1.050	25.0 (pump off)	1711	7.8	15317
13/12/2016 7:00	7.7292	0.090	0			