



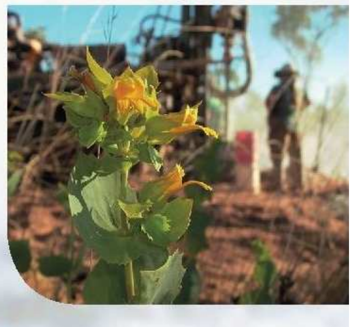

HYDROGEOLOGICAL ASSESSMENT OF PARADISE–VALHALLA–ASGARD PROJECT AREAS

REPORT FOR BURU ENERGY

SEPTEMBER 2016

Rockwater
HYDROGEOLOGICAL AND ENVIRONMENTAL CONSULTANTS

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76 Jersey Street Jolimont 6014 Western Australia Postal: PO Box 201 Wembley 6913 Western Australia
Ph: 61 8 9284 0222 Fax: 61 8 9284 1785 Email: consult@rockwater.com.au www.rockwater.com.au ABN: 43 008 804 653

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REVISION	AUTHOR	REVIEW	ISSUED
Rev 0	PHW, NE	JRP	21/9/16
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1. INTRODUCTION

Buru Energy (Buru) is planning the drilling of an additional exploration well at Valhalla Central, located between the Valhalla and Asgard wells in the Canning Basin. Water will be needed for drilling and well construction, hydraulic fracturing, and the operation of camp sites. Approximately 10,000 kL, and possibly up to 34,000 kL of water are required.

Buru’s existing prospects are in the Fitzroy Trough of the northern Canning Basin. They include Yulleroo, about 80 km east of Broome; Ungani, about 100 km east of Broome and 90 km south-west of Derby; Blina, 105 km east-south-east of Derby; Sundown 26 km north-west of Blina; and Paradise, Valhalla and Asgard, 150 km south-east of Derby (Fig. 1).

Rockwater was engaged to prepare this assessment of the hydrogeology of the Paradise–Valhalla–Asgard area, which includes Valhalla Central; and the results of monitoring during fracturing of reservoirs at Valhalla North and Asgard. It is an update of a report that has been prepared since 2013, and will be progressively updated as new projects are planned and additional data are collected.

Technical terms used in this report are described in Appendix I.

1.1 CLIMATE

The area has a tropical climate with hot wet summers and warm dry winters. Average rainfalls at Roebuck Plains (BoM Stn. 003023, 1902 to 2010), located 47 km west-south-west of Yulleroo 1; and at Ellendale (BoM Stn. 003008, 1919 to 2013) located 16 km north of Valhalla 1; are given in Table 1.

Table 1: Average Rainfalls (mm) at Roebuck Plains and Ellendale

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Roebuck Plains	186.2	162.9	105.3	29.9	17.0	17.5	4.2	1.7	1.8	2.7	14.4	88.1	637.7
Ellendale	170.6	155.7	106.1	16.7	12.0	5.5	4.8	0.7	2.0	9.3	26.7	91.6	614.8

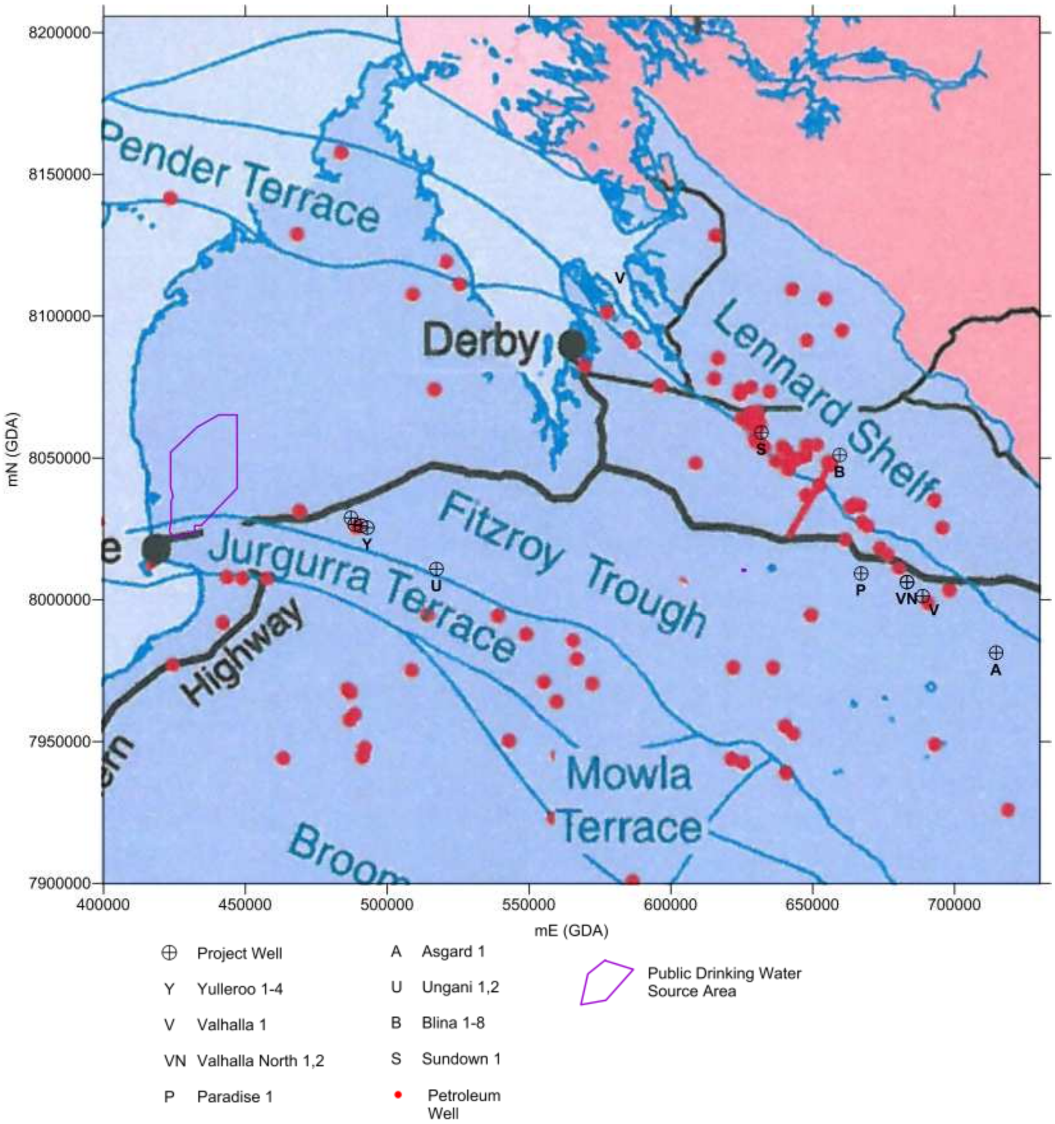
The monthly averages at both sites are remarkably similar, and indicate that about 85 % of the rain falls from December to March. Annual rainfalls do, however vary considerably, and at Ellendale have ranged from 212 mm to 1,409 mm.

Average dam evaporation at Camballin (Luke, Burke and O’Brien, 1988), located about 63 km west of Valhalla 1, is given in Table 2. It exceeds average rainfall in all months and average annual rainfall by a factor of four.

Table 2: Average Dam Evaporation (mm) at Camballin

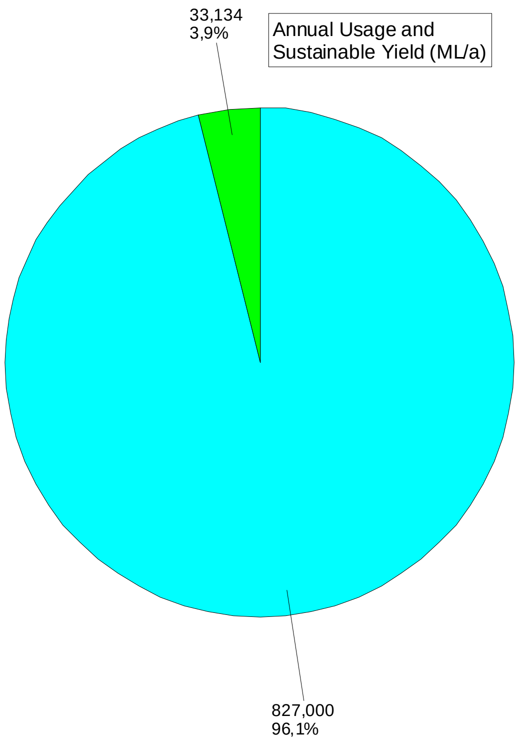
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
229	184	189	203	184	168	187	214	262	281	291	287	2,679

Figure 1: Wellfield Locations



2. HYDROGEOLOGICAL SETTING, CANNING BASIN

The Canning Basin is the second largest groundwater resource (by volume) in Australia (after the Great Artesian Basin) but there have been few studies carried out of the regional hydrogeology. Estimates of sustainable yield from the basin are about 615,000 ML/yr (WRC, 2001) and 827,000 ML/yr (ANRA, 2010). Of that, only 33,134 ML/a (less than four percent) were being consumed:



The sustainable yield is similar to that of the Lower Limestone Coast in South Australia (756,250 ML/yr) (NWC, 2005). As a comparison, the baseline groundwater allocation for the Integrated Water Supply Scheme that supplies water to Perth and some regional areas is 145,000 ML/yr; and the Water Corporation had planned to supplement the water supply with 45,000 ML/yr from the South-West Yarragadee in the southern Perth Basin where annual recharge was estimated to be about 350,000 ML/yr.

The geology of the basin has been well defined and described in publications such as Veevers and Wells (1961), Towner and Gibson (1983), and Middleton (1990).

Most of the demand for groundwater from the basin has been near Broome and Derby; and recently the western part of the basin has been investigated as a major source of water for Port Hedland.

Laws (1991a) prepared a hydrogeological map and explanatory notes for the Broome 1:250,000 sheet, and Smith (1992) completed the hydrogeological map and explanatory notes for the adjoining Derby 1:250,000 sheet. Laws (1991b) also presented a report on the groundwater resources of the wider basin at an international groundwater conference in Perth.

Ghassemi, Ferguson and Etminan (1991) used oil well data to describe the hydrogeology of deep (Permian and older) aquifers of the basin.

Harrington et al. (2011) investigated groundwater/surface water interactions in the Fitzroy River south and south-east of the Paradise – Valhalla area.

Searle (2012) produced a groundwater resource review for the Dampier Peninsula – the first regional review of the groundwater resources in part of the basin. Groundwater use on the Peninsula is concentrated on the Broome aquifer, with only minor development of the Superficial, Wallal and Liveringa aquifers. The Grant aquifer is undeveloped.

The DoW (2012) produced a West Canning Basin groundwater allocation limit report giving information on the hydrogeology of the area to be developed for the Port Hedland water supply.

The Buru wellfields lie within the Fitzroy Trough (Fig. 1), a major subdivision of the Canning Basin. The trough (Reeves, 1951) is a north-west trending graben bounded on its north-eastern side by the Beagle Bay Fault and on its south-western side by the Fenton Fault system. It is generally about 110 km wide and contains 10,000 m or more of Ordovician to Cretaceous sediments (mostly Devonian to Permian), with common folding and faulting of the Triassic and older rocks sub-parallel to the alignment of the trough.

The wellfields are remote from the Broome Public Drinking Water Source Area (PDWSA) shown in Fig. 1. There is another very small PDWSA at Camballin, 37 km west of Paradise 1, and several small circular PDWSA's south-east of Derby around individual production bores.

3. PARADISE-VALHALLA-ASGARD AREA

3.1 GEOLOGICAL SETTING

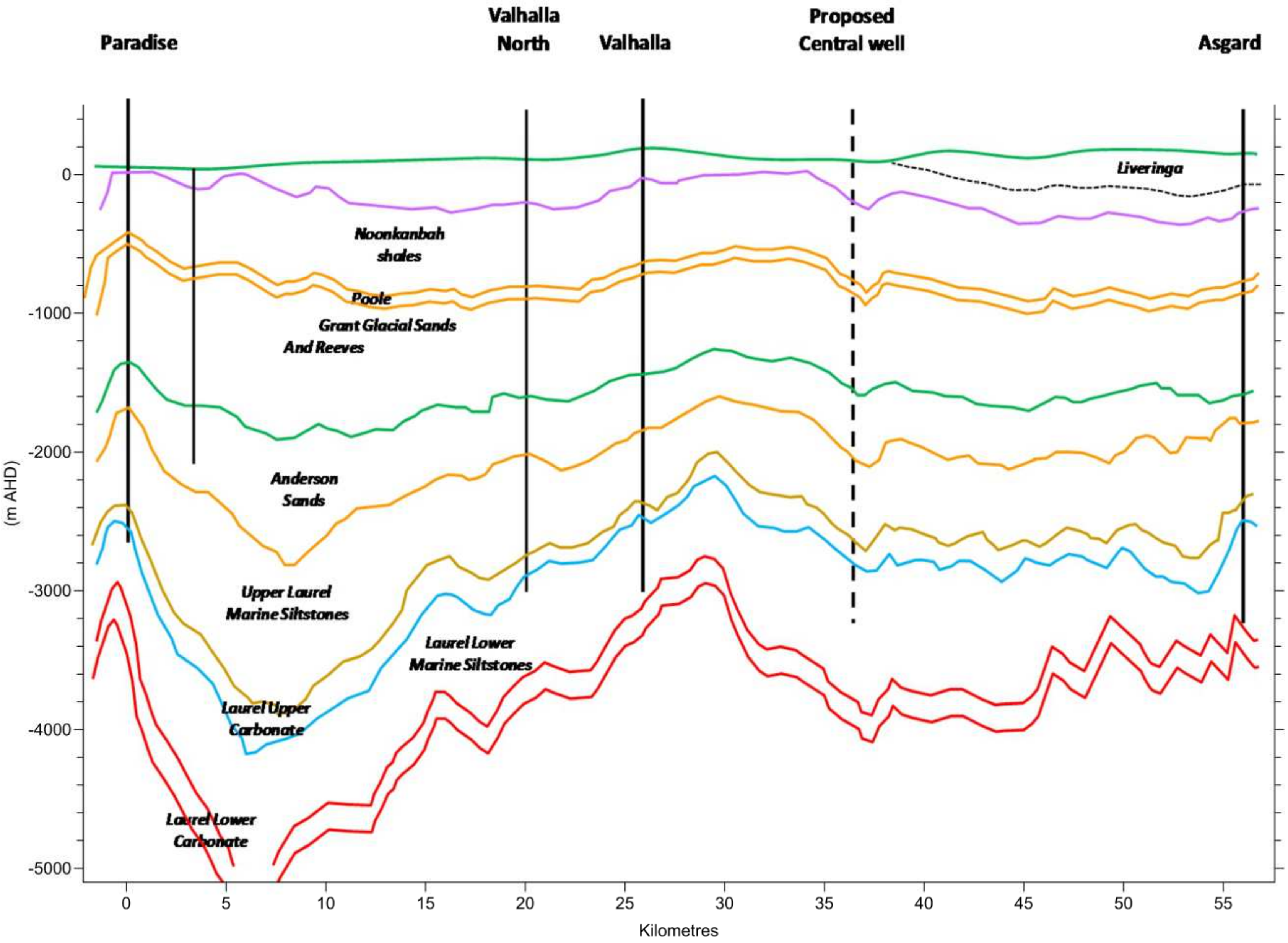
The hydrocarbon targets in this area are in the Laurel Formation, which is overlain by the Anderson and Reeves Formations of Carboniferous age; and the Grant Formation, Poole Sandstone, and Noonkanbah and Liveringa Formations of Carboniferous to Permian age. The formation boundaries of the Permian to Carboniferous sediments are at relatively consistent elevations, indicating only minor folding and faulting. The stratigraphy is summarised in Table 3.

Table 3: Stratigraphy and Aquifers in Paradise-Valhalla-Asgard Area

Formation	Dominant Lithology	Classification		Base Elevation (m AHD)			TDS (mg/L)
			Paradise 1	Valhalla 1	Valhalla Central	Asgard 1	
		Ground Level:	63.9	110		130	
Liveringa	Siltstone/shale/sandstone	Minor aquifer, Aquitard	NA	-84		-171	500 to 12,400
Noonkanbah	Shale	Aquiclude	-321	-441		-579	550 to 800
Poole Sandstone	Sandstone and Shale	Aquifer or Aquitard	-412	-524		-695	300
Grant	Sandstone	Aquifer	-1211	-1332		-1240	800-1000*
Reeves	Sandstone	Aquifer	-1309	-1588		-1606	
Anderson	sandstone, siltstone, shale	Minor aquifer, Aquitard	-1898	-1858		-1790	70,000 to 100,000?
Laurel	Limestone, shale, siltstone & sandstone	Minor aquifer, Aquitard	-3330?	<-3350		<-3,400	70,000 to 100,000?
* Estimate from Resistivity Logs							

A geological section through the area is shown in Figure 2.

Figure 2: Geological Section, Paradise-Valhalla-Asgard Area



3.2 HYDROGEOLOGY

The main aquifers are the Poole Sandstone and Grant Formation (Table 3). The Reeves Formation is also an aquifer that is generally considered as part of the Grant aquifer.

The Poole Sandstone is generally an aquifer, although the geophysical logs for Paradise 1, Valhalla North 1, and Asgard 1 indicate there is interbedded shale and sandstone in the formation in those wells, whereas sandstone dominates the Poole Sandstone in Valhalla 1. The Poole Sandstone is mainly fine grained with some medium to coarse sandstone towards the base.

The Grant Formation is much thicker than the Poole Sandstone and so a more substantial aquifer. It consists of three units (youngest to oldest): fine, and medium to coarse sandstone of the Carolyn unit; siltstone of the Winifred unit; and fine to coarse sandstone of the Betty unit (Ghassemi et al., 1991). The yield of the one WIR bore screened in the Grant Formation (Palm Spring No.1) was reported to be 655 kL/d. There are higher yields from the Formation of up to 2,400 kL/d at Ellendale. The Grant Formation forms a substantial aquifer – bore yields commonly depend on the quantity of water required and the thickness of sandstone screened. The aquifer is described in more detail in Section 4, below.

The Anderson and Laurel Formations are considered to be aquitards. The sandstone and limestone of these formations generally have low permeability but can be minor aquifers.

The Liveringa Formation forms a minor aquifer, as fine-grained sediments (siltstone and shale) dominate, and sandstone beds are less common. Bore yields given in the WIR database are generally low, and those recorded for the Liveringa and Noonkanbah Formations are all less than 100 kL/d. Drillers logs for the water bores at Valhalla, Valhalla North and Asgard 1 sites indicate the bores are screened in shale and/or siltstone with minor sandstone of the Liveringa Formation, and generally yield about 100 kL/d (maximum 200 kL/d in one bore at Asgard 1).

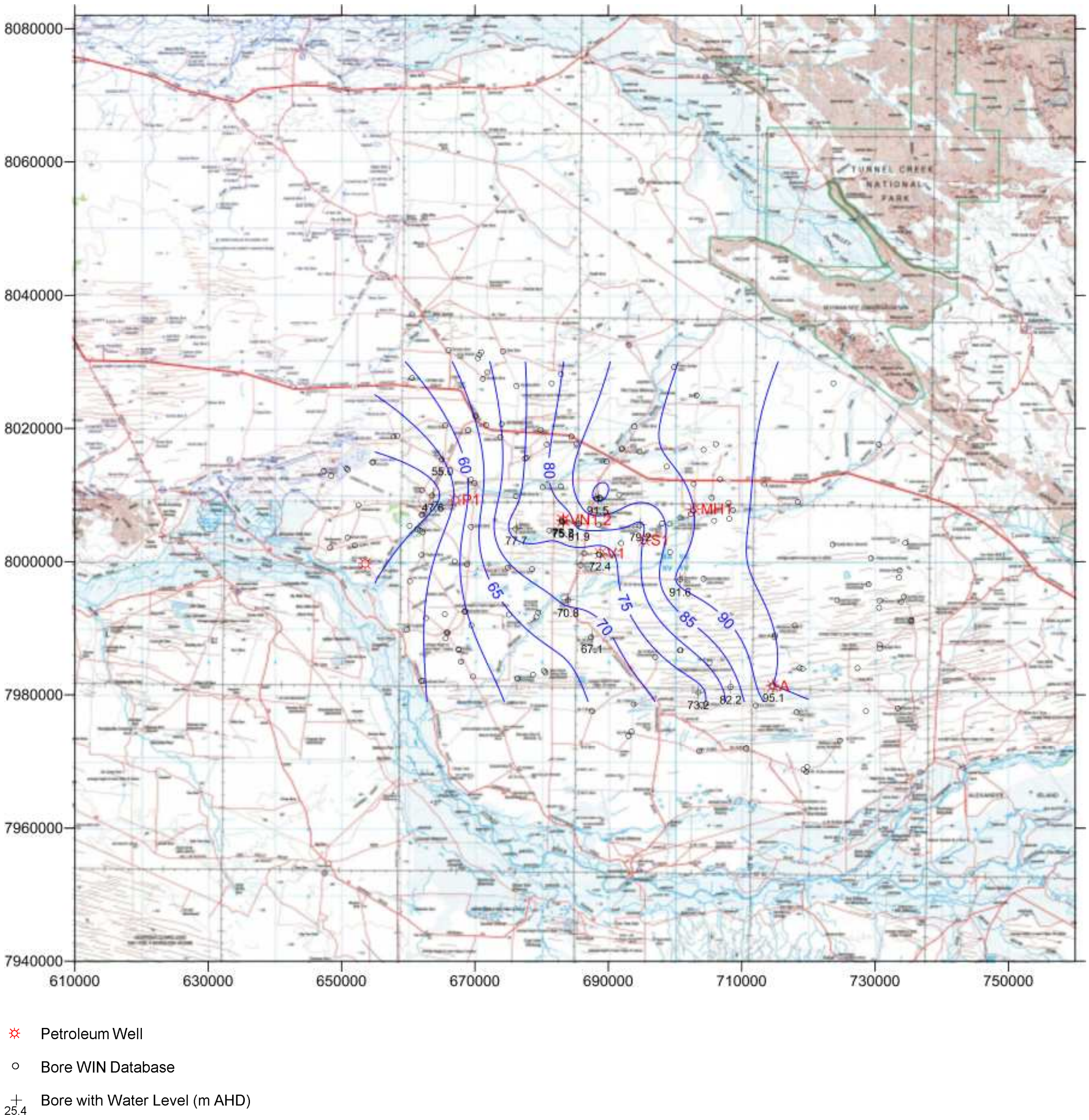
There are also some bores screened in the Noonkanbah Formation, which consists mainly of fine-grained sediments but does have some limestone and fine to medium grained sandstone interbeds. Those bores (in the Noonkanbah Formation) are mostly near and to the north of the Valhalla and Valhalla North wells. Two bores near Paradise 1 are reported to be in the Poole Sandstone, as are several others east of Mount Hardman. Some bores in the Asgard area, south-east of Valhalla are screened in the Blina Shale and others in the underlying Liveringa Formation.

3.2.1 Groundwater Levels

Groundwater levels measured in bores by Buru environmental staff, and in bores recorded in the WIR database (reduced to m AHD using approximate elevations given by Elevation Finder) have been used to construct the water level contour plan shown in Figure 3. They indicate that there is a westerly groundwater flow with some groundwater discharge to the Fitzroy River.

Recorded water table depths are 30 m (Valhalla North) and 36 m (Valhalla 1), and are likely to be similar at Valhalla Central.

Figure 3: Groundwater Levels (m AHD) Valhalla Area, Oct. 2012



3.2.2 Aquifer Parameters

Core data analysed and presented by Buru Energy indicate that permeabilities and porosities of all potential hydrocarbon reservoirs are highly variable, but in general:

- Most Grant Formation permeabilities range from 100 to 5000 milli-Darcys (mD) (0.08 to 4 m/d) and porosities 15 to 25 percent. Some higher permeabilities (8 to 20 m/d) have been measured by test-pumping at Ellendale where the formation crops out.
- Anderson Formation permeabilities range from 10 to 500 mD (0.008 to 0.4 m/d) and porosities 10 to 20 percent; and
- Laurel Formation permeabilities are mostly less than 1 mD (0.0008 m/d) and porosities less than 10 percent.

Ghassemi et al. (1991) also analysed data from cores and gave a permeability of 0.075 m/d and porosity 14 percent for the Poole Sandstone; and permeability of 0.10 m/d and porosity 11 percent for the Grant Formation.

There are no data for the minor aquifers/aquitards/aquicludes – the Blina Shale, and the Liveringa and Noonkanbah Formations.

3.2.3 Recharge, Flow Directions and Discharge

Groundwater in the shallow formations is recharged by the infiltration of rainfall. Recharge rates are probably low due to the predominance of fine-grained sediments near ground surface.

Groundwater in the surficial Blina Shale, and Liveringa and Noonkanbah Formations will be recharged from local infiltration of rainfall where they outcrop, or by downward movement from one formation to the other where they are layered. The infiltration will be retarded by clay, shale and siltstone layers, both above and below the water table. The water table depth ranges from 7 m at Paradise 1 water bore to 30 m at Valhalla 1 and Valhalla North water bores. Water is likely to take between 70 and 300 days to travel from the ground surface to the water table.

Outcrop and potential recharge areas for the Poole Sandstone and Grant Formation are generally small, such as in the Saint George Ranges to the south. Much of the recharge is probably by downward leakage from overlying formations and rainfall runoff from the Devonian Limestone of the Oscar Range to the east.

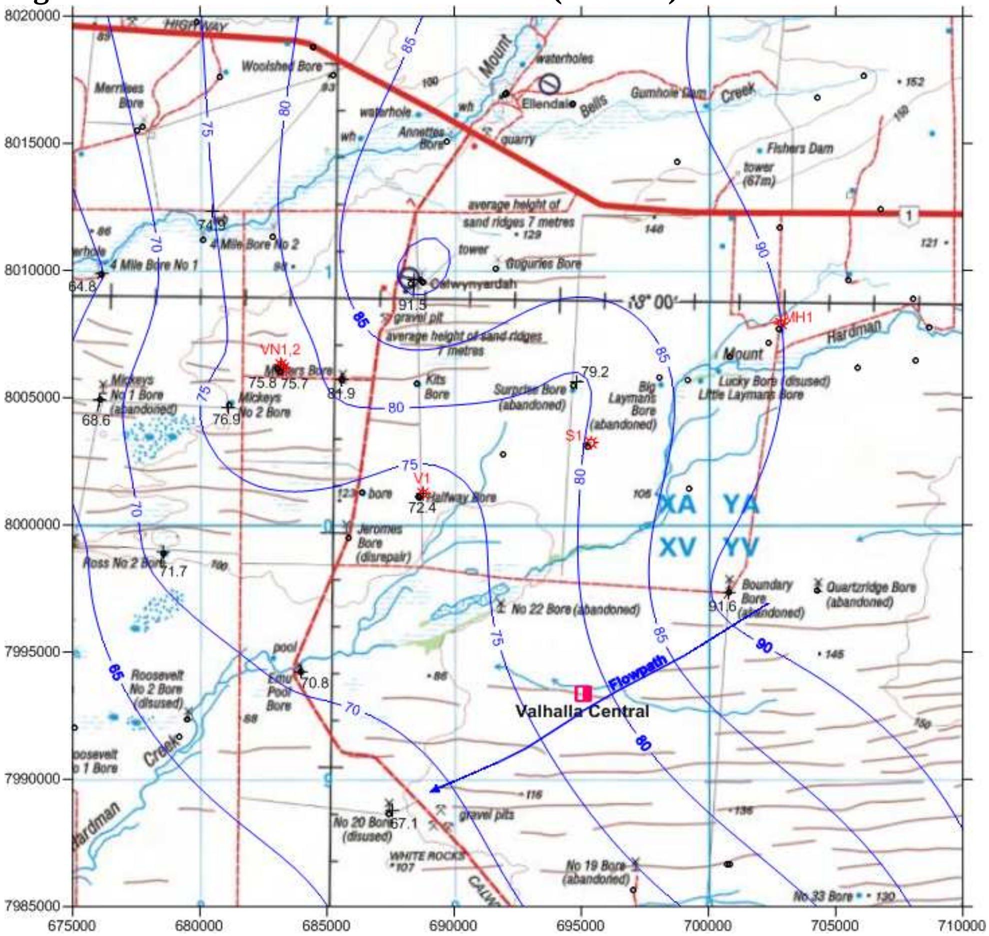
The water level contours (Fig. 3) indicate that groundwater in the Liveringa and Noonkanbah Formations generally flows westwards, and this is also expected to be the case for the deeper aquifers. There are also indications from the shape of contours which tend to be parallel to the Fitzroy River, that there is a southerly component to the flow with some flow towards, and discharge to the Fitzroy River from the shallow formations.

Harrington et al. (2011) found there was a strong connection between groundwater and the Fitzroy River south and south-east of the Valhalla area, with a calculated groundwater discharge of 102 ML/d over a 100 km reach of the river.

Assuming a hydraulic conductivity of 1 m/d for permeable beds within the Liveringa and Noonkanbah Formations, a specific yield of 0.1 and hydraulic gradients of about 0.00185 at Paradise 1 and 0.00058 at Valhalla 1; groundwater would take about 465 years to reach the closest receptor, Robbins Bore 3.14 km to the west, and about 3,600 years to move from Paradise 1 to the river. Similarly, the groundwater would take about 105 years to move from Valhalla 1 to Halfway Bore, 224 m to the south-west, and 16,000 years to move from Valhalla 1 to the river. The current status of those two station bores is not known.

Detail of groundwater-level contours near Valhalla Central and the direction of groundwater flow are shown in Fig. 4.

Figure 4: Groundwater Level Contours (m AHD) Near Valhalla Central



With a hydraulic gradient of about 0.0017 at Valhalla Central; groundwater would take at least 4,500 years to reach any waterhole in Hardman Creek, and about 7,300 years to move from Valhalla Central to the Fitzroy River.

Flow in the deeper formations probably continues to the west beneath the river. The flow velocities will be very low due to the low permeabilities – at least 150 times lower than in the shallow formations.

3.2.4 Water Quality

Salinities, where recorded in the WIR database and by Buru Energy, are generally less than 1,000 mg/L TDS in the Liveringa Formation, but range from 500 to 12,400 mg/L TDS. Salinities for Buru water bores in the Liveringa Formation range from 450 to 1,600 mg/L TDS. Those for bores screened in the Noonkanbah Formation generally range from 550 to 800 mg/L TDS, but are up to 2,300 mg/L TDS. The three salinities available for the Poole Sandstone range from 200 to 325 mg/L TDS. The one bore recorded that is screened in the Grant Formation had a salinity of 860 mg/L TDS.

Crowe and Towner (1981) reported salinity measurements made in 138 station bores and wells during mapping of the Noonkanbah geological sheet, and related them to the formations screened. Those for bores/wells on stations in the Paradise-Valhalla-Asgard area had the following salinity ranges recorded:

- Blina Shale; 10,000 to >15,000 mg/L TDS;
- Liveringa (Hardman) Formation; 220 to 3,900 mg/L TDS (average 1,600);
- Noonkanbah Formation; 340 to 7,000 mg/L TDS (average 2,500);
- Poole Sandstone; 200 to 900 mg/L TDS (average 420); and
- Grant Formation; 200 mg/L TDS (one bore).

Water samples have been taken from 10 bores in the Valhalla-Paradise-Asgard area on a number of occasions as part of baseline water quality sampling by Buru, and analysed by ChemCentre or SGS for a wide range of parameters. The results are included on the Buru website: http://www.buruenergy.com/2015-tight-gas-pilot-exploration-program/

The water samples were generally brackish to saline, with salinities ranging from 560 mg/L TDS (Homestead 1) to 22,000 mg/L TDS (Crossland Bore). With the elevated salinities, most samples exceeded Australian drinking water guidelines for salinity, sodium, chloride, sulphate and hardness. Also, boron, iron and manganese guideline values were exceeded in many of the samples.

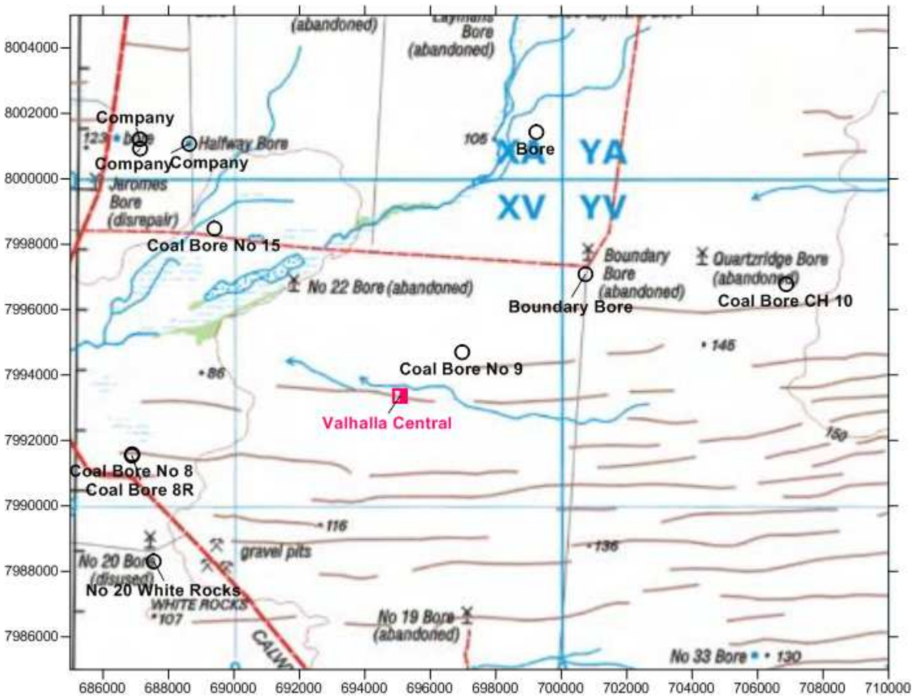
The elevated sulphate concentrations (96 to 752 mg/L) were similar to the chloride levels, which is unusual.

Field measurements of physico-chemical parameters are also being made on 10 bores in the area to provide background data. These results are also given in the Buru website.

3.3 IMPACT OF SITE ACTIVITIES, VALHALLA CENTRAL

Bores recorded in the WIR database within about 10 km of the Valhalla Central site are shown in Fig. 5. There are few details for these bores, but most appear to be coal exploration holes/bores that extended through the Liveringa Formation into the underlying Noonkanbah Formation and have probably been abandoned. Most or all of the station bores have also been abandoned, including Boundary Bore, the closest to the Valhalla Central site.

Figure 5: WIR Bores near Valhalla Central



It is very unlikely that there are any operating bores or wells that could be impacted by operations at the Valhalla Central site.

3.3.1 Groundwater Level Changes

A small quantity of groundwater is likely to be needed for camp construction and exploration well drilling in this area. This water might be available from the Liveringa

Formation, which can include minor aquifers, although the formation is quite thin at Valhalla Central.

Low hydraulic conductivity could result in relatively high water-level drawdown in the pumped bore, but measurable drawdowns would not be transmitted more than a few hundred metres from the bore, and groundwater levels would recover quickly once the pumping ceased.

This has been shown by close monitoring at the Valhalla North and Asgard sites, where extraction from bores with screened intervals at least 100 m deep in the Liveringa Formation had little or no impact on groundwater levels in nearby monitoring bores screened at shallow depths in the formation. For example at Valhalla North (Rockwater, 2016) pumping of the production bore caused small, short-term drawdowns of up to 0.07 m to 0.08 m in monitoring bores located only 27 m to 55 m away. For most of the period of extraction, no drawdowns were detected.

3.3.2 Water Quality Changes

Chloride concentrations were also closely monitored in bores at the Valhalla North and Paradise sites before, during and after hydraulic fracturing (HF) operations were conducted. That ion was selected as a key indicator, as concentrations in the HF fluid and in the flow-back water were several orders of magnitude higher than in the shallow groundwater. There were no indications from the monitoring (Figs. 6 and 7) of any impact from operations at the sites on groundwater quality. The dashed line in the figures (which were produced by Buru) represents the start of the HF operations.

Figure 6: Chloride Concentrations at Asgard 1 Well Site

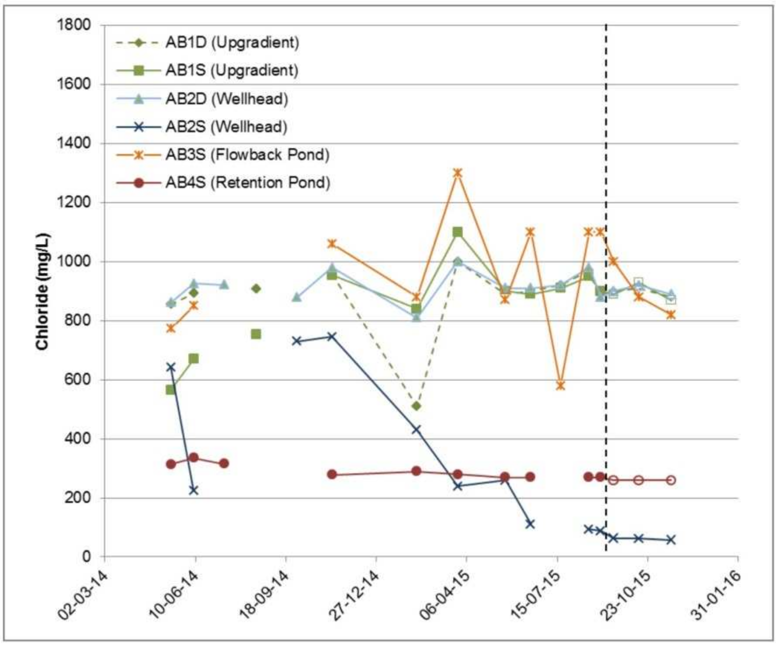
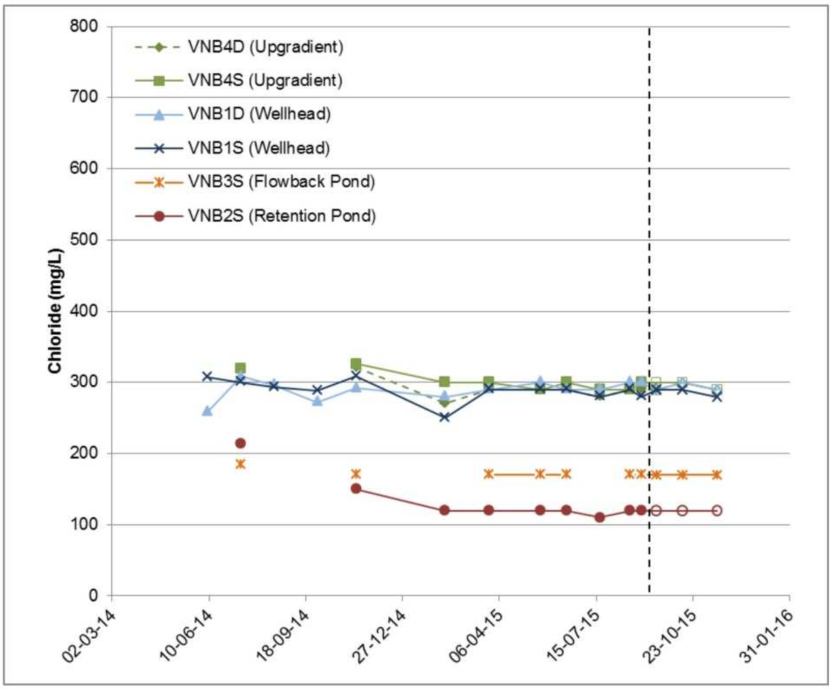


Figure 7: Chloride Concentrations at Valhalla North 1 Well Site



Similarly, it is considered very unlikely that the planned operations at Valhalla Central will have any impact on groundwater quality.

3.3.3 Numerical Modelling to Predict Impacts, Valhalla Central

A simple numerical groundwater model was constructed to predict potential groundwater-level drawdowns around a production bore at the planned Valhalla Central site. It consists of a rectangular grid of 57 rows, 57 columns and two layers covering an area of 5 km by 5 km centred on a production bore. Layer 1 extends to 50 m depth, and Layer 2 to 170 m depth. Model cell sizes range from 25 m by 25 m near the production bore, to 100 m by 100 m in peripheral areas. It utilises Processing Modflow Pro version 8.0.45, which incorporates MODFLOW, groundwater modelling software designed by the US Geological Survey (McDonald and Harbaugh, 1988).

The model was set up initially with parameters that are typical of a minor aquifer such as the Liveringa Formation, and then parameters were adjusted to calibrate the model to drawdowns observed in the two (relatively) deep monitoring bores at Valhalla North from 3 July to 8 July 2015, after which groundwater levels recovered rapidly to pre-pumping levels.

Water meter readings indicate that a total of 1,955 kL were pumped to 26 July – if all that was pumped over the five day period that would be an average of 390 kL/d, and that rate was simulated in the model. Drawdowns increased to 0.08 m in bore VNB1D located 55 m west of the production bore, and to 0.07 m in VNB4D, 27 m east of the bore. The production bore was modelled in Layer 2, and the monitoring bores in Layer 1.

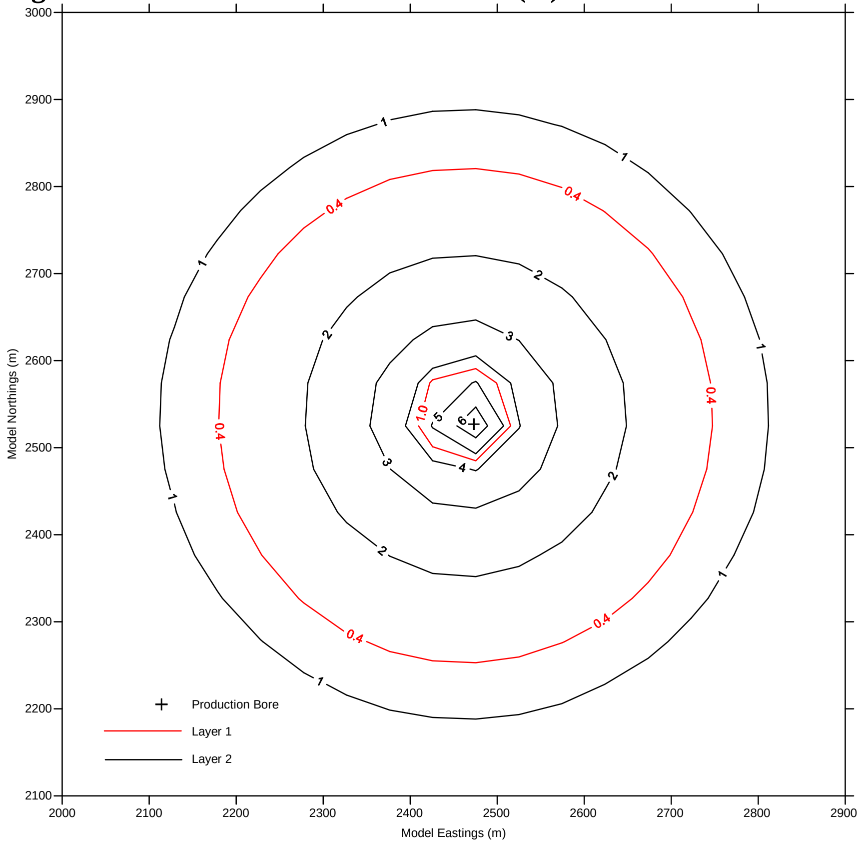
A close correspondence (within 0.01 m) was achieved between measured and model-calculated drawdowns with the parameters given in Table 4.

Table 4: Parameters Adopted in Model Calibration

Parameter:	Unit	Layer 1	Layer 2
Horiz. Hydraulic Conductivity	m/d	0.05	0.12
Vert. Hydraulic Conductivity	m/d	0.005	0.01
Specific Yield	v/v	0.05	NA
Storage Coefficient	v/v	NA	0.0003

The model was then run to predict groundwater-level drawdowns arising from pumping a bore over a six-month period (as at Valhalla North) at the average rate required to produce the total allocation for Valhalla North (33,400 kL), i.e. 183 kL/d. The calculated drawdowns after six months of extraction are shown for each model layer in Fig. 8.

Figure 8: Model-Calculated Drawdowns (m) after Six Months of Pumping 183 kL/d



They indicate that drawdowns of 1 m or more could extend up to 410 m from a production bore at the (deep) level of the screens in the production bore, but that there would be smaller drawdowns in the top 50 m of the Formation: 1.2 m close to the bore decreasing to 1 m at a distance of about 56 m from the bore, and 0.1 m at 690 m distance. Although the modelling is based on assumed parameters and the results are not unique, the calculated drawdowns are consistent with monitoring at Valhalla North and Asgard, where drawdowns at shallow depths (albeit with lower pumping rates) have been very small, and difficult to distinguish from normal seasonal fluctuations of about 0.2 to 1 m (depending on the frequency and magnitude of recharge events).

Sensitivity Analysis

As a sensitivity analysis, the modelling was repeated for pumping over six months to produce a volume of 10,000 kL (the quantity used in the last exploration programme); and for 100,000 kL, the likely volume that would be needed for a commercial field. The results are summarised with those for the licensed allocation (given above), in Table 5.

Table 5: Results of Sensitivity Analysis

Model Scenario	Max. Drawdown at Bore (m)		Distance from Bore of 1 m Drawdown (m)	
(Water Vol., kL)	Layer 1	Layer 2	Layer 1	Layer 2
10,000	0.35	2.8	N/A	106
33,400	1.2	9.5	56	410
100,000	3.5	28	340	780

Even with pumping for the maximum volume, groundwater levels would be expected to recover to within 0.2 m of the static water level within hours of the cessation of pumping, and to fully recover within weeks.

3.3.4 Potential for Impacting Stygofauna and Troglofauna

Likelihood of Occurrence, Valhalla Central

A brief desktop study was undertaken to assess the potential risk to stygofauna and troglofauna at the Valhalla Central project. As part of the desktop study, various literature and data were reviewed, including previous subterranean fauna studies in the region, WA Museum data, available hydrogeological reports, and project-specific data supplied by Buru.

The Liveringa Formation forms the upper-most aquifer in the Project area and consists of mainly fine-grained sediments (siltstone and shale) with more-permeable sandstone beds being less common. The shallow shale and siltstone sediments of the formation provide a potential habitat for stygofauna, although bore yields in the area suggest that permeability is low, and so it is less likely that stygofauna will be present.

Groundwater salinity is within a range that stygofauna are known to occur, with salinities of local bores ranging from 450 to 1,600 mg/L TDS.

Groundwater extraction is seen to be the principal activity that could potentially affect stygofauna at Valhalla Central. Any drawdown of groundwater level in surficial aquifers could reduce the habitat available for stygofauna. Indirect impacts such as groundwater contamination, changes to hydrology, and nutrient balances also have the potential to affect subterranean habitats.

The absence of caves or significant voids in the fine-grained sediments at Valhalla Central indicates that there is unlikely to be suitable habitat for troglofauna. Given the nature of disturbance of the Valhalla Central exploration proposal, there is unlikely to be a direct impact to any troglofauna habitat (if present).

Recorded Occurrence Elsewhere

Stygofauna

There are few published studies of stygofauna in the Kimberley and only one record of stygofauna sampling within 50 km of Valhalla. The results of published studies in the region are summarised below.

Nine species of stygofauna have been identified within rocks at the Ellendale Diamond Mine (Ellendale), 45 km north-east of Valhalla (Rockwater, 2015). At Ellendale, the diamond-bearing ore consists of olivine lamproite with tuffaceous margins. Groundwater occurs in shallow aquifers comprising weathered, calcified or calcretised lamproite; and in deep aquifers of tuffaceous sandstone and fractured lamproite, particularly along geological contacts. The stygofauna community at Ellendale included five species of copepod, three species of ostracod and an isopod. After consultation with DER, a stygofauna monitoring plan was adopted for the project and annual samples were taken from a number of reference sites to assess the long-term impacts of mining and dewatering. Ongoing sampling confirmed that the project was unlikely to have a negative impact on the local community, and the species collected were unlikely to be restricted.

A comprehensive stygofauna sampling programme was undertaken to assess the stygofauna values of the Browse LNG Development on the Dampier Peninsula, 60 km north of Broome (Rockwater 2012). The survey targeted shallow sandstone within the unconfined Broome aquifer. The Broome aquifer typically consists of unconsolidated coarse-grained sandstone and conglomerate with minor lenses of siltstone and claystone, and thin coal seams (Laws 1991a). The survey recorded 18 stygofauna species in total, although only nine occurred within the impact area of the Browse LNG Precinct. This represented a relatively rich stygofauna community and the first such community reported on the Dampier Peninsula. Regional sampling demonstrated that five of the nine species collected in the Precinct also occur at several regional locations, up to 75 km from the

Precinct. Regional stygofauna communities were identified at Barred Creek, Coconut Well, Broome townsite, Nita Downs Station, Beagle Bay and Kilto Station.

Two potential stygofauna species were collected at Nicolson's Find, a gold deposit approximately 280 km south-east of Valhalla. A widespread tubificid worm (*Pristina longiseta*) and a potential new species of *Strandesia* (Ostracoda) were collected from mineral exploration holes, drilled into metasediment (Rockwater, 2012b). Other taxa within the genus *Strandesia* are often found in surface water and it was considered unlikely that the Nicolson's Find species would be confined to the project area. It was determined that the stygofauna species recorded within the project area were stygophiles, having opportunistically colonized the local aquifers via passive dispersal.

The alluvial aquifers of the Ord River Irrigation Area (ORIA) are known to contain unique stygofauna communities in the north-east Kimberley. Humphreys (1999) and Ecowise (2005) identified stygofauna in areas of the Stage 2 (M2) ORIA development, approximately 500 km north-east of Valhalla. The studies identified syncarids, copepods, ostracods, oligochaetes and oribatid mites from alluvial sediments within the ORIA.

Stygofauna sampling for the Argyle Diamond Mine in the north-east Kimberley identified at least 15 species of stygofauna (EPA 2005). Cho, Park and Humphreys (2005) described six species of Parabathynellidae from the Kimberley region, including taxa recorded at Argyle and from the ORIA.

Sampling at Sorby Hills (550 km north-east of Valhalla) yielded ten species from six orders or higher level groups (Bennelongia, 2012). These included nematodes, an oligochate worm (order Tubificida) and four orders of crustacean – (Ostracoda, Copepoda, Syncarida and Isopoda). Sampling targeted river flood plains, as well as low sandstone hills and eroded limestone reefs.

<u>Troglofauna</u>

There are very few published records or results of troglofauna sampling in the Kimberley region. The Western Australian Museum lists records of troglofauna in the Kimberley, primarily from cave complexes. Three species of spider (*Myrmopopaea 'lipposa'*, *Wandella pallida* and *Opopaea phineus*) were collected from caves in the Ningbing Ranges north of Kununurra, with nearby caves recording pseudoscorpions (*Indohya gollum*, *Lagynochthonius* sp.), diplurans (*Cocytocampa humphreysi*) and cockroaches (*Nocticola brooksi*). Caves within the Oscar Ranges also recorded troglobitic pseudoscorpions (*Cheiridium* sp.nov) and schizomids (*Bamazomus hunti*). Napier Range caves recorded similar faunal groups, with pseudoscorpions (*Indohya napierensis*) and schizomids (*Apozomus eberhardi*). Two of the described schizomids (*Apozomus eberhardi* and *Bamazomus hunti*) have been categorised as troglobitic, although the specimens possess eye spots and it is likely that they are troglophiles, inhabiting sheltered environments within the gorges (Harvey, 2001).

Museum records also list troglobitic pseudoscorpions at the Argyle Diamond Mine in the north-east Kimberley. *Indohya* '*sp.Argyle Mine*' was collected from one site during a 2005 sampling programme.

An extensive sampling programme was undertaken for the Brown Range Project, near the WA–NT boarder (Outback Ecology, 2014). Sampling targeted the widesread and contiguous regolith, and weathered fractured rock. Over 160 samples were collected over five sampling rounds, yielding only two troglobitic species. Both species were also collected outside the project area and it was concluded that because of the continuity and extent of the subsurface habitiat, any species present were unlikely to be restricted.

A desktop assessment at Nicolson's Find, located approximately 280 km south-east of Valhalla, focused on strongly weathered oxidised metasediment (Rockwater, 2012b). The assessment concluded that the geological units within the project area and in the immediate area surrounding the deposits did not provide suitable subterranean habitat for troglofauna.

None of the listed studies represent sampling in comparable habitats to those at Valhalla Central.

Concluding Comments

Based on results of previous sampling, it appears that sandstone aquifers of the Kimberley contain moderately diverse stygofauna communities with very few stygofauna species restricted at small (project level) scales. The range of groundwater salinities recorded at Valhalla are within the tolerance levels recorded for stygofauna, and the shale and siltstone of the Liveringa Formation could potentially provide habitats for stygofauna. However, the reported low yields from bores screened in this formation suggest that suitable voids within sediments may be limited. The absence of more permeable sandstone lithologies previously reported to support stygofauna communities in the Kimberley may indicate that the potential for stygofauna is moderate to low. The regional extent of aquifers in the project area and absence of any geological barriers that may prevent dispersal suggest that any stygofauna community at Valhalla is unlikely have a restricted distribution.

Given the relatively small impact areas (drawdowns of at least one metre over a 400 m radius) surrounding production bores, it is unlikely that the project will have a significant impact on the stygofauna values of the area or that the disturbance of potential habitat at Valhalla would result in a level of impact that would result in unacceptable risks to the conservation status of any stygofauna community.

Based on results of the risk assessment, it is likely that low intensity sampling in accordance with relevant EPA guidelines would be appropriate for scenarios where approximately 100,000 kL of groundwater may be extracted from a bore over a six-month period. This would correspond to a commercial well pad which would likely be subject to an EPA assessment under the *Environmental Protection Act 1986*, in which case stygofauna may be considered as a relevant environmental factor.

Troglofauna records of the Kimberley are all associated either with cave complexes or subterranean habitats within ranges and gorges that are vastly different to those at Valhalla Central. The fine-grained sediments within the project area do not appear to provide suitable habitat for troglofauna.

4. GRANT AQUIFER

4.1 BACKGROUND

The Betty unit of the Grant aquifer is likely to be the deepest aquifer that could potentially be impacted by Buru's activities. That unit and the shallower Carolyn unit form the Grant aquifer. Buru is to conduct a risk assessment on the Grant aquifer, and so Rockwater was requested to review the available hydrogeological data for the aquifer to provide baseline information to be used in the risk assessment.

4.2 OCCURRENCE

The Grant Formation extends over most of the Canning Basin, including the Fitzroy Trough, and in the northern Canning Basin comprises three units – the Carolyn, Winifred and Betty (Ghassemi et al., 1991).

The depth and thickness of the Grant Formation generally increases from west to east through the Buru wellfields, although the base elevation and thickness are less at the eastern Asgard 1 bore (Table 6).

Table 6: Top and Base Elevations, Grant Formation, Buru Wells

Well	Ground Level	Elevation of Grant Fm		Thickness
	(m AHD)	Top (mAHD)	Base (mAHD)	(m)
Yulleroo 4				
Yulleroo 2	57	-376	-677	301
Ungani 1	78	-766	-1259	493
Paradise 1	64	-412	-1211	799
Valhalla North	109	-715	-1499	784
Valhalla 1	110	-524	-1332	808
Asgard 1	123	-695	-1246	551

Also, the Formation outcrops between Ungani 1 and Paradise 1 on the eastern side of the Fitzroy River in the Grant Range; and south-west of Ellendale it thickens from north-east to south-west.

The main area of outcrop is near the northern edge of the Canning Basin, along a south-easterly line extending from about 65 km east-north-east of Derby to south-east of Fitzroy Crossing. This area is about 40 km north-east of Valhalla and 30 km north-east of Asgard. The width of outcrop is up to 23 km.

The Grant Formation also outcrops 45 km south of Asgard in the Saint George Ranges. Both the Saint George and Grant Ranges are eroded anticlines within the Fitzroy Trough.

The top of the formation is shallowest at Yulleroo 2 (433 m below ground level) and deepest at Valhalla North (824 m below ground level). The base of the formation is also deepest at Valhalla North (1,609 m below ground level); and the formation is thickest at Valhalla 1 (808 m).

The Grant Formation, where saturated, is known as the Grant aquifer, which is one of the major aquifers of the Canning Basin, producing substantial quantities of water at Fitzroy Crossing and at the Ellendale diamond mine.

4.3 GEOLOGY

The Grant Formation is of Carboniferous to early Permian in age and unconformably overlies the Reeves Formation at Ungani; and the Anderson Formation in the Yulleroo and Valhalla –Paradise-Asgard areas. It is unconformably overlain by the Poole Sandstone at Ungani and in the Valhalla-Paradise-Asgard area, and by the Wallal Sandstone at Yulleroo, and so is in direct hydraulic connection with those aquifers.

The Formation is marine to lagoonal in origin and comprises massive fine to coarse grained sandstone, with minor siltstone and shale.

The Grant Formation in the northern Canning Basin consists of three units (youngest to oldest): fine to coarse grained sandstone with some conglomerate and shale of the Carolyn unit; siltstone of the Winifred unit; and fine to coarse sandstone of the Betty unit (Ghassemi et al., 1991, Smith, 1992). The youngest and oldest units are aquifers, and the middle unit is an aquiclude or aquitard.

4.4 HYDROGEOLOGY

4.4.1 Groundwater in Storage

Laws (1991b) estimated that the volume of groundwater stored in the Grant Formation in the Canning Basin is about 35,000 x 10^9 m^3 (35 million gigalitres (GL)). This compares with a volume of 1.1 million GL of water stored in the Yarragadee aquifer south of Bunbury in Western Australia (Water Corporation, 2005).

4.4.2 Aquifer Parameters

Ghassemi et al. (1991) analysed data from drill core and side-wall cores from petroleum wells and gave a permeability of 0.10 m/d and porosity of 11 percent for the Grant Formation. Core data analysed by Buru Energy indicate that Grant Formation permeabilities average 0.43 m/d and porosity averages 18 percent.

Hydrogeological information on the Grant Formation is available from bores at the Ellendale mine-site, 50 km north of Valhalla, where the Formation outcrops. There the aquifer has a saturated thickness of 110 to 250 m or more, and hydraulic conductivities range from 1.2 to 20 m/d and average about 8 m/d.

At Fitzroy Crossing sandstone of the aquifer is strongly cemented and generally of low permeability – successful bores intersect fractures and joints (DoW, 2008). Elsewhere such as at Ellendale, the permeability is mostly associated with primary porosity.

4.4.3 Recharge, Flow Directions and Discharge

The Grant aquifer is recharged directly by rainfall, and from flow in the Fitzroy River and other creeks, in outcrop areas such as along the northern edge of the basin and in the Saint George Ranges to the south. These areas are relatively small and so recharge volumes are probably low. The relationship with the overlying Poole and Wallal Sandstones is not known (Laws, 1991b) – there is likely to be recharge from them to the Grant aquifer in some areas, and discharge from the aquifer to them in other areas. Runoff from the Devonian limestone of the Oscar Range probably enhances the recharge in some areas such as at Ellendale.

Groundwater in the Grant aquifer generally flows westward from the main outcrop areas towards the coast in Roebuck Bay and King Sound, to discharge to the ocean off-shore.

Based on groundwater depths given in DoW (2008) and levels shown on the Derby Hydrogeological Sheet (Smith, 1992), heads in the aquifer fall from about 100 m AHD at Fitzroy Crossing to 50 m AHD on the Grant Range and would be about 5 m AHD near the coast.

4.4.4 Aquifer Development

The aquifer is poorly utilised at present but it has been developed in areas of outcrop or subcrop including the Fitzroy Crossing town borefield, bores on Gogo Station, and the borefield at the Ellendale diamond mine.

Potential bore yields for the aquifer in the Buru wellfield areas are not known, however bore yields of 600 to 2,400 m^3/d have been achieved at Ellendale, and up to 500 m^3/d from bores in the Fitzroy Crossing town water supply borefield (Lindsay and Commander, 2006). Palm Spring No. 1, located 30 km north-north-east of Valhalla 1 and not far from the outcrop area, intersected the Grant Formation at 142 m depth, and had a reported yield of 655 m^3/d (WIR database).

Yields are likely to be lower where the aquifer is deep, as there could be fewer open fractures and joints, and lower primary porosity.

4.4.5 Groundwater Quality

Groundwater salinity generally increases with distance from the recharge areas, and probably with depth in the aquifer.

The groundwater at Ellendale has salinity of about 300 mg/L TDS, and salinities are usually in the range 500 to 2,000 mg/L TDS elsewhere, i.e. fresh to brackish (Lindsay and Commander, 2006). The low salinity at Ellendale is attributed to runoff from the Devonian ranges nearby and consequent high rates of recharge. The water from the Fitzroy Crossing borefield is also fresh, with salinity of about 250 mg/L TDS based on the electrical conductivity values reported in DoW (2008).

In the Valhalla-Paradise area groundwater in the aquifer is likely to be fresh to brackish with salinity in the range 800 to 2,300 mg/L TDS, and one possible salinity of about 14,000 mg/L TDS, all estimated from the resistivity logs.

At Ungani, groundwater in the Grant Formation is estimated to have a salinity of 6,600 mg/L TDS, also from the resistivity logs. North of the Ungani area, Smith (1992) reports salinities for the basal Betty unit of 2,700 to 6,400 mg/L TDS, increasing up to 70,000 mg/L TDS on the Dampier Peninsula. The uppermost Carolyn unit and Poole Sandstone have salinities of 250 to 2,600 mg/L TDS north of Ungani near the outcrop area and up to 25,000 mg/L TDS on the Dampier Peninsula (Smith, 1992).

Groundwater salinity in the Yulleroo area is indicated from the resistivity and conductivity logs to be about 14,000 mg/L TDS.
The concentrations of other water-quality parameters for the aquifer are not known, except in the recharge areas at Ellendale and Fitzroy Crossing where the groundwater is fresh. For example, water from the Fitzroy Crossing bores is circum-neutral with pH 6.8 to 7.1; barium, boron, dieldrin, fluoride, nitrate, nitrite and uranium were all well within ADWG values (NH&MRC, 2011); and aluminium, iron and manganese were also low although in one sample iron just exceeded the aesthetic guideline value with a concentration of 0.34 mg/L (DoW, 2008).

Dated: 28 September 2016 **Rockwater Pty Ltd**

P H Wharton
Principal

REFERENCES

ANRA, 2010, Australian Natural Resources Atlas, based on records from 2000 to 2002.

Bennelongia (2012) Subterranean Fauna Desktop Study and Field Survey for the Sorby Hills Project. Report 2012/140 for Sorby Management Pty Ltd.

Cho, J. L., Park, J. G. and Humphreys, W. F. (2005). A New Genus and Six Species of the Parabathynellidae (Bathynellacea, Syncarida) from the Kimberley Region, Western Australia. Journal of Natural History, 39 2225-2255.

Crowe, R.W.A., and Towner, R.R., 1981, Noonkanbah 1:250 000 Geological Series, Western Australia, map and explanatory notes. Pub. Australian Govt. Publishing Service, Canberra.

DoW, 2008, Fitzroy Crossing Water Reserve drinking water source protection plan, Fitzroy Crossing town water supply. Dept. of Water, water resource protection series, Report 94.

DoW, 2012, West Canning Basin groundwater allocation limit report. Department of Water report no. 52, water resource allocation and planning series.

Ecowise Environmental (2005). Ord Stage 2 M2 Area – Subterranean Fauna Survey. Unpublished report for WA Department of Industry and Resources, dated May 2005.

Environmental Protection Authority (2005). Argyle Diamond Mine - Underground Project 110 km south of Kununurra, East Kimberley. Argyle Diamond Mines Pty Limited. Report and Recommendations of the Environmental Protection Authority, Perth, Western Australia. Bulletin 1205, dated November 2005.

Ghassemi, F., Ferguson, J., and Etminan, H., 1991, Hydrogeology of deep aquifers in the Canning Basin, Western Australia. In Proceedings of the International Conference on Groundwater in Large Sedimentary Basins, Perth, Western Australia, 1990: Australian Water Resources Council, Conference Series no. 20, p. 59-69.

Harvey, M.S., 2001, New cave-dwelling schizomids (Schizomida: Hubbardiidae) from Australia. Records of the Western Australia Museum Supplement **64;** 171-185.

Harrington, G.A., Stelfox, L., Gardner, W.P., Davies, P., Doble, R., and Cook, P.G., 2011, Surface water – groundwater interactions in the lower Fitzroy River, Western Australia. CSIRO: Water for a Healthy Country National Research Flagship. 54 pp.

Humphreys, W. F. (1999). Groundwater fauna sampling in the Kimberley north of 16^{o} S and east of 128^{o} E - A report to Kinhill Pty Ltd pertaining to Stage 2 (M2): Ord River Irrigation Area Project. Western Australian Museum of Natural Sciences, August 1999.

Laws, A. T., 1991a, Explanatory notes on the Broome 1:250 000 hydrogeological sheet: Western Australia Geological Survey, Hydrogeological Series.

Laws, A. T., 1991b, Outline of the groundwater resource potential of the Canning Basin, Western Australia. In Proceedings of the International Conference on Groundwater in Large Sedimentary Basins, Perth, Western Australia, 1990: Australian Water Resources Council, Conference Series no. 20, p. 47-58.

Lindsay, R.P., and Commander D.P., 2006, Hydrogeological assessment of the Fitzroy alluvium. Dept. of Water hydrogeological record series, Report HG 16.

Luke, G.J., Burke, K.L., and O'Brien, T.M., 1988, Evaporation data for Western Australia. Tech. Report No. 65 (2nd Ed), W.A. Dept. of Agriculture.

Middleton, M., F., 1990, Canning Basin. In Chapter 4, Geology and mineral resources of Western Australia. Memoir 3, Geological Survey of Western Australia.

McDonald, M.G., and A.W. Harbaugh, 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. Book 6, Chapter A1, Techniques of Water Resources Investigations. U.S. Geol. Surv., Washington, DC. (A:3980).

NHMRC, 2011, Australian drinking water guidelines Paper 6 National water quality management strategy. National Health and Medical Research Council and the Natural Resource Management Ministerial Council, Canberra.

NWC, 2005, Australian water resources 2005, National Water Commission, Australian Government.

Outback Ecology, 2014, Brown Range Project, Subterranean Fauna Assessment. Report for Northern Minerals Ltd.

Reeves, F, 1951, Australian oil possibilities. Bull. Of the American Assoc. of Petroleum Geologists 35 (12), 1479.

Rockwater, 2012a, Browse LNG Development, Stygofauna Survey Final Report (2011/2012). Report for Woodside Energy Ltd.

Rockwater, 2012b, Lamboo Gold Project, Subterranean Fauna Desktop Assessment and Pilot Study. Report for Bulletin Resources.

Rockwater (2015) Ellendale Project Annual Aquifer Review – January to December 2014. Report for Kimberley Diamond Company.

Rockwater, 2016, Impacts of groundwater extraction, Valhalla North. Report to Buru Energy.

Searle, J. A., 2012, Groundwater resource review, Dampier Peninsula. Hydrogeological record series, report no. HG57, Department of Water, Perth.

Smith, R. A., 1992, Explanatory notes on the Derby 1:250 000 hydrogeological sheet: Western Australia Geological Survey, Hydrogeological Series.

Towner, R.R., and Gibson, D.L., 1983, Geology of the onshore Canning Basin, Western Australia. Bureau of Mineral Resources geology and geophysics Bulletin 215.

Water Corporation, 2005, South West Yarragadee, hydrogeological investigations and evaluation, southern Perth Basin. Water Corporation IPB report.

WRC, 2001, Caring for Kimberley groundwater. Water and Rivers Commission water advice No. 15.

Veevers, J. J., and Wells, A. T., 1961, The geology of the Canning Basin, Western Australia. Bureau of Mineral Resources geology and geophysics Bulletin No. 60.

APPENDIX I

DEFINITIONS OF TECHNICAL TERMS USED

Term	Meaning
AHD	Australian Height Datum
Anticline	A structural fold that is convex upward
Aquiclude	Rock units of very low permeability that form barriers to fluid flow.
Aquifer	A geological formation able to receive, store and transmit significant quantities of water
Aquitard	A saturated unit of low hydraulic conductivity that can store and slowly transmit groundwater either upward or downward depending on the vertical hydraulic gradient
Brackish Water	Water containing between 1,000 and 3,000 mg/L of total dissolved solids, tasting slightly salty
Confining Layer	A bed of significantly lower hydraulic conductivity which retards the vertical movement of water
Discharge	The release or extraction of water from an aquifer. Typical mechanisms of natural discharge are evapotranspiration by phreatophytes, springs, and drainage to surface water bodies
DST	Drill Stem Test is a procedure for isolating and testing the pressure, permeability and productive capacity of a geological formation during the drilling of a petroleum well.
Electrical Conductivity (EC)	The measure of a solution's (or rock's) ability to conduct electricity. EC units are used to express salinity levels in water.
Fresh Water	Water containing less than 500 to 1,000 mg/L of total dissolved solids, and generally suitable for drinking
GPS	Global Positioning System: a satellite navigation system that provides location and time
Groundwater	Water occurring below the land surface in pores or fissures, generally in motion and part of the hydrological cycle
Graben	An elongated block that has been down-thrown along bounding faults
Hydraulic Conductivity	The capacity of a porous medium to transmit water through a unit cross-sectional area. Hydraulic conductivity is dependent upon the physical properties of the porous medium and the viscosity of the water
Hypersaline	Water of salinity greater than that of sea water (35,000 mg/L Total Dissolved Solids)
Outcrop	The exposure of rock or sediment at ground surface
Permeability	The ability of a porous medium to transmit water under a given hydraulic gradient. Similar to hydraulic conductivity
Pindan	A red soil composed of silty and clayey fine to medium sand typical of the south-western Kimberley
Porosity	A measure of the void or pore space within rocks and sediments (the ratio of the volume of void spaces to the total volume)
Resistivity	The measure of a solution or rock to resist the transmission of electricity. The inverse of electrical conductivity
Saline Water	Water containing more than about 3,000 mg/L of dissolved salts
Slug Test	An aquifer permeability test in which a slug, typically a volume of water, is instantaneously placed in a bore, displacing the water upward. Measurements of the falling water levels are used to estimate permeability
Sustainable Yield	Commonly the quantity of water that can be pumped from an aquifer without depleting the volume in storage and without causing deleterious environmental impacts. Definition is subject to debate.
Total Dissolved Solids (TDS), or Salinity	The total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, typically expressed in units of milligrams per litre of water (mg/L)
Water Table	The surface of the groundwater in an unconfined aquifer
Wetland	An area saturated with water either permanently or seasonally. Typically supports a distinct ecosystem. Can be an expression of the water table
Yield	The rate at which water can be pumped from a bore