



AGT Report no: 1148-11-DAN 24 February 2012

Cyclone Zircon Project Groundwater Feasibility Study

Prepared for Diatreme Resources



Document Control

Document Title

Cyclone Zircon Project Groundwater Feasibility Study

Report no

1148-11-DAN

Prepared for

Diatreme Resources

Author		Date			
Vic Waclawik		2011			
Reviewed by		Date			
Russell Martin		2011			
Approved by		Date			
Zac Sibenaler		2011			
Revision history					
Revision No.	Date Issued	Reason/Comments			
1	23 Dec 2011	Draft			
2	22 Feb 2012	Final			
3	24 Feb 2012	Final Revised			
Distribution					
Copy No.		Location			
Phil McMurtrie		Lost Sands/Diatreme Resources			

Note: This is a controlled document within the document control system. If revised, it must be marked SUPERSEDED and returned to the AGT QA Representative

Statement of Limitations

The services performed by AGT have been conducted in a manner consistent with the level of quality and skills generally exercised by members of its profession and consulting practice. This report is solely for the use of Diatreme Resources and may not contain sufficient information for purposes of other parties or for other uses. Any reliance on this report by third parties shall be at such parties' sole risk. The information in this report is considered to be accurate with respect to information provided or conditions encountered at the site during the investigation. AGT has used the methodology and sources of information outlined within this report and have made no independent verification of this information beyond the agreed scope of works. AGT assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that the information provided to AGT was false.

AUSTRALIAN GROUNDWATER TECHNOLOGIES PTY LTD ABN 97 110 928 928 Unit 5, 1 London Road, MILE END SOUTH SA 5031

PH: (08) 8352 4262 Fax: (08) 8354 3076 www.agwt.com.au

Со	nte	ents	
Doc	ume	nt Control	II
Con	Ш		
Figu	ires a	& Tables	v
<u>1</u>	<u>Intr</u>	oduction	1
	1.1	Background	1
	1.2	Scope of work	1
<u>2</u>	<u>Pro</u>	ject Setting	3
	2.1	Topography and Geomorphology	3
	2.2	Regional Water Resources	3
		2.2.1 Groundwater	3
		2.2.2 Surface Water	4
	2.3	Geology	4
		2.3.1 Officer Basin	4
		2.3.2 Eucla Basin	4
		2.3.3 Palaeodrainage	5
<u>3</u>	<u>Reg</u>	ional Hydrogeology	8
	3.1	Regional Yield and Salinity	8
		3.1.1 Yield	8
		3.1.2 Salinity	11
	3.2	Tertiary Palaeochannel Aquifers	13
	3.3	Officer Basin	14
	3.4	Eucla Basin	14
<u>4</u>	Pre	vious Water Drilling Campaigns	16
<u>5</u>	<u>Gro</u>	undwater Analysis	21
	5.1	Lost Sands Cyclone Project groundwater Requirements	21
	5.2	Palaeochannel Identifictaion	21

		5.2.1 Previous work	21
		5.2.2 DEM	21
		5.2.3 Radiometrics	24
		5.2.4 Gravity	26
		5.2.5 Magnetics	28
		5.2.6 Modis/NOAA-AVHRR	30
<u>6</u>	Pot	ential Targets	34
	6.1	Tertairy Palaeochannels	34
		6.1.1 Prospective Palaeochannel Locations	34
	6.2	Shallow Officer Basin Sediments	37
	6.3	Deep Officer Basin Sediments	39
	6.4	Eucla Basin Sediments	39
<u>7</u>	<u>Gro</u>	oundwater Supply Potential	40
	7.1	Tertiary Palaeochannels	40
	7.2	Shallow Officer Basin sediments	40
	7.3	Deep Officer Basin sediments	40
	7.4	Eucla Basin sediments	41
<u>8</u>	<u>Ris</u>	ks	42
<u>9</u>	<u>Est</u>	imated Costs	43
<u>10</u>	<u>Cor</u>	nclusions and Recommendations	44
	10.1	Conclusions	44
	10.2	2 Recommendations	44
11	Ref	erences	45



Figures & Tables

Figures

Figure 1: Locality showing extent of Officer and Eucla Basins2
Figure 2: Interpreted palaeochannels of the Eucla Basin (Hou et al. 2008)6
Figure 3: Stratigraphic correlation chart for the Eucla Basin and palaeovalleys (Hou et al. 2008)7
Figure 4: Comparison of reported well yield with depth (South Australia only)9
Figure 5: Reported yield of water wells within South Australia10
Figure 6: Comparison of reported well salinity with depth (South Australia only)11
Figure 7: Reported salinity of water wells within South Australia12
Figure 8: Locality plan for the Cyclone Prospect showing nearby groundwater drilling campaigns17
Figure 9: Shot hole groundwater intersections along AGSO Seismic Lines 5 & 6
Figure 10: Classified 1 sec Digital Elevation Model showing interpreted palaeochannels (after PIRSA
2007)
Figure 11: Subset of the Radiometric Map of Australia (Minty et al. 2010)
Figure 12: Bouger Gravity Anomalies (GA 2009)27
Figure 13: Magnetic Anomalies (GA 2010)29
Figure 14: NOAA-AVHRR pre-dawn image showing palaeodrainage of western South Australia
(Statham-Lee 1994)
Figure 15: Classified Modis thermal infrared image (Band 32) showing interpreted palaeochannels33
Figure 16: Proposed palaeochannel drilling targets
Figure 17: Section along seismic line 93AGS-6 showing the Rodinia water bores and selected shot
point water levels

Tables

Table 1: NOAA-AVHRR spectral intervals	
Table 2: Estimated costs for preliminary works program	43



1 Introduction

1.1 Background

Lost Sands Pty Ltd engages in exploration and mining of mineral sands which includes zirconium, titanium, thorium and tungsten. Lost Sands Pty Ltd is a wholly owned subsidiary of Diatreme Resources and operates the Cyclone Zircon Project and. Cyclone is a mineral sand deposit on the northern edge of the Eucla Basin in Western Australia near Serpentine Lakes approximately 25 km from the South Australian border and 300km north of Eucla (Figure 1).

The Cyclone Prospect and associated nearby Zephyr deposit have been developed to the stage where a pre-feasibility study for further development of the prospect is required. The proposed mine will require a suitable water source that is reliable and capable of supplying an estimated volume of 250 L/s. Hypersaline water can be used but low salinity water is preferred.

Diatreme Resources (through Lost Sands Pty Ltd) has engaged Australian Groundwater Technologies (AGT) to conduct a desktop study into the feasibility of finding suitable groundwater resources to meet the predicted demand.

Prospective targets within the region include buried palaeochannels which have been known to yield good supplies of saline to hypersaline groundwater as well as groundwater present within the deeper aquifers of the Officer Basin. Recent drilling by Rodinia Oil across the border in SA on their petroleum tenement reported reasonable quality groundwater (<15,000 mg/L) at depths of approximately 730 m below ground level and estimated yields of 600 to 900 Bbl/hr (27 – 40 L/s).

Two options available to Diatreme Resources are to investigate further the potential for groundwater to be intersected in the palaeochannels at suitable yields or to, alternatively, seek to drill into the deeper sandstone aquifer intercepted by Rodinia Oil.

1.2 Scope of work

The scope of work for the Cyclone Zircon Project groundwater feasibility study includes:

- Collating, from a review of the existing literature and information, the occurrence of palaeochannels within a 50 km radius of the Cyclone prospect;
- Acquiring the magnetic and gravity imagery for the area of interest;
- Overlaying all of the relevant drillhole information available (Rodinia Oil, State agencies and Diatreme Resources) to identify likely prospects; and'
- Prepare a costed program of works to investigate each of the two options.





Figure 1 | Locality showing extent of Officer and Eucla Basins

Australian Groundwater Technologies

AGT

February, 2012 | P:\(DAN)_Diatrme_Resources\Projects \1148-11-DAN_Lost_Sands_Deposit\GIS\Maps\DAN_1148_11_locality.mxd

2 Project Setting

2.1 Topography and Geomorphology

The Cyclone prospect is located within the Great Victoria Desert. This forms the southern part of the large anti-clockwise whorl of dunefields that covers much of central Australia (Callen & Benbow 1995). Sand plains and dunefields are the dominant landform but the desert also consists of many small sand hills, grassland plains, gibber plains, lunettes, rocky prominences and salt lakes. The longitudinal dunes typically trending East-West, can extend for up to a hundred kilometres, reach five to 30 m in height and have an average spacing of less than 300m (Watts & Berens 2011).

Along the southern margin of the Great Victoria Desert lies the Ooldea Range, a 650 km-long quartz sand ridge that extends west into Western Australia and southeast towards Ceduna. The range has a height of up to 300m AHD and is between 40 m and 160 m above the surrounding terrain with a width of 10-15 km. (Fairclough, Benbow and Rogers 2007). The Ooldea Range acts as a boundary between the Great Victoria Desert and the Nullabor Plain. With an area of 200,000 km², the Nullabor Plain is a vast flat and featureless limestone dominated terrain that is the largest semi-arid karst region in the world. The Plain has a general south-easterly decline in elevation with local undulations and subtle karstic features (Watts & Berens 2011).

2.2 Regional Water Resources

2.2.1 Groundwater

There are no regional reticulated water systems and no permanent surface water resources in the area. Local groundwater resources are the key source of water within the region. Water is primarily used for Aboriginal community water supplies and some pastoral activities. Demand for water has increased over time due to growing mining activity within the region.

Town water supplies for the majority of Aboriginal communities are extracted from low-yielding wells, from aquifers of limited extent. This includes weathered and fractured rock aquifers or dunefields where localised recharge creates discrete pockets of fresh water. Usage at the Oak Valley settlement is approximately 50 ML/yr. (AGT 2010)

Groundwater within the Officer Basin is extracted for stock and domestic purposes.

Groundwater within the Eucla Basin is extracted primarily from the Wilson Bluff Limestone aquifer for stock and domestic purposes. Iluka Resources' Jacinth-Ambrosia Mineral Sands Project obtains approximately 9500ML/y of highly saline groundwater from a Tertiary palaeovalley that extends from the Gawler Craton onto the Eucla Basin (PB 2008). No investigation into the sustainability of the aquifers in the Eucla Basin has been undertaken and there are few records of water usage or aquifer response (AGT 2010). The town of Eucla on the Western Australian border obtains water supplies from the Wilson's Bluff Limestone aquifer (Commander 1991).



2.2.2 Surface Water

No permanent creeks or rivers exist within the region due to the combination of topography and arid climate. Significant streamflow can occur but flow is generally only every few years after heavy rains. Additionally, flow may only occur for a short period and over small stream sections based on the location and intensity of rainfall events. Stream contribution (if any) to groundwater is poorly understood. (Watts & Berens 2011)

2.3 Geology

The region is located in an area dominated by two geological provinces:

- The Officer Basin, comprising late Proterozoic and early Palaeozoic sedimentary rocks such as sandstone, siltstone and shale; and,
- The Eucla Basin, comprising Tertiary limestones and siliclastic sediments underlain by sandstones of the Bight Basin.

2.3.1 Officer Basin

Spanning 525,000 km² the Officer Basin extends across central South Australia and Western Australia. A number of key features of the basin occur within South Australia. These include an extensive shelf-like region of undeformed sediment cover of less than one kilometre thick known as the Murnaroo Platform. Surrounding this platform are a series of troughs and depo-centres with significantly thicker sediment fills.

The basin consists of Neoproterozoic to early Palaeozoic clastic sedimentary rocks. The rock units including the Murnaroo and Trainor Hill Sandstones that are thought to dip gently towards the centre of the basin from the north and south (Martin *et al.* 1998). Tertiary sequences infill palaeovalleys incised into Officer Basin sediments. The Officer Basin is overlain primarily by undifferentiated Quaternary Aeolian sediments of the Great Victoria Desert.

2.3.2 Eucla Basin

The Eucla Basin is a marginal basin that contains a sequence of up to 300m thick sediments of marine, coastal and palaeochannel sediments of Tertiary age (Benbow *et al.* 1995). Its northern margin extends approximately 2000 km from Western Australia to South Australia and is composed of Tertiary sediments with related palaeodrainage that originates in the Musgrave Ranges to the north, the Gawler Craton to the east and the Yilgarn Craton to the west. The present landscape is dominated by extensive tracts of Quaternary deposits largely superimposed on the Tertiary morphology (Hou & Frakes 2004).

The Tertiary sequence is divided into the middle Eocene to Middle Miocene marine limestones of the Eucla Group, the Miocene to early Pliocene terrigenous sediments of the Immarna Group and the Middle to Late Eocene sediments of the Burdunga Subgroup (Benbow *et al.* 1995). The Eucla Group comprises the Wilson Bluff and Nullabor Limestones, the Immarna Group includes the Garford Formation, Narlaby Formation and the Yarle Sandstone, and the Pidinga Formation, Hampton Sandstone and Ooldea Sand make up the Burdunga Subgroup. Undifferentiated Quaternary Aeolian sediments overlie the Tertiary sequences in the far north of the basin and to



the south-east, with the Bridgewater Formation found along the north-west coast of the Eyre Peninsula (Watts & Berens 2011).

2.3.3 Palaeodrainage

The central palaeochannels that fed the Eucla basin occur in the vicinity of the Western Australian-South Australian border, rising in the western and southern margins of the Musgrave Province and traversing the Gibson and/or Great Victoria Deserts across the Officer basin. Away from the bedrock ranges this palaeochannel network is largely obscured by surficial cover. The upper reaches of the Western Australian palaeochannels which rise and trend west of the Musgrave province have been extensively diverted and disrupted by post-Eocene tectonic activity which has resulted in conflicting interpretations of the palaeodrainage network. In contrast to the palaeochannels of the east Yilgarn and Gawler Craton, the central palaeochannels draining south and east of the Musgrave Province and across the Officer Basin are poorly understood (Figure 2). (Magee 2009)

Two palaeochannel units have been identified. The Eocene Pidinga Formation and Miocene to Pliocene lacustrine Garford Formation (Figure 3). The Pidinga Formation commonly comprises up to 50 m of variable sediment types, including green-grey, poorly to moderately sorted fine quartz sand, granule conglomerate, fine to medium grained quartz sand, silt with minor clay, carbonaceous silt, and lignite. Coarser grained carbonaceous and lignitic sediments occur in palaeochannels and finer grained overbank sediments on palaeo-floodplains (Magee 2009).

The Garford Formation outcrops sporadically in some palaeochannels. It consists of predominantly lacustrine and floodplain deposits of pale green-grey and dark redbrown, poorly to moderately sorted, very fine to coarse sand, silt and clay. Some fluvial channel deposits occur at the base. The age of the Garford Formation is probably Mid Miocene to Early Pliocene (Magee 2009).



Figure 2: Interpreted palaeochannels of the Eucla Basin (Hou et al. 2008)



				al				~	e ons		Yilgarn C	raton 🔫	— Euc	la Basin	\rightarrow	Gawle	er Craton
AGE		Se St	ries & ages	nktonic aminifer es	Sp po	ore- llen	Sequence boundaries	outher	vustralia egional sgressi	AB ope uses	Cowan paleovalley	Lefroy paleovalley	Bunda Pl	ateau Eucla ↓	Oolde Barrie	a Barton Barrier	
Ма			9	Plai fora zon	201	les		0	tran	Hiat		\sim				paleovall	evs
0-	PL	EIS	T. <u>Ionian</u> Calabrian Placenzian	N23 N22 N21 N20/	Tubuli pleisto	ifloridites ocenicus	_lo 1 R _Cala 2 Ge 2 Pia 1	२	3lanville Hallett	←H15 ←H14 ←H13	Polar Bar Formation	Roysalt Formation	calcrete	ferruginisation Ilkina Formation	& silicificati	on calcrete	?Munjena Formation
5-	PI	ΒE	Messinian	N19 N18 N17	Myrta lij	iceidites psis igulatispo bifurcatu	-Za 1- -Me 2- prites /s Tor3/Me1	J F	Jove Jemmys Pt	 ←H12 ←H11 ←H10 	oracia	22		Narla Forma	iby ition Kingo	onya	-1-
			Tortonian	N16			-Tor 2			←Н9	erosio		Colville Sandstone	Yarle Sandstone	Mem aeoliar	ber ר	Garford Formation
10-	ENE		Serravallian	N15 N14 N13	tes bellus	Upper	-Ser4/Tor1		īambo ≀iver	←Н8	?	?			proces	s? ?	
15-	NEOG	OCENE	Langhian	N12 N11 N10 N9	oropolleni		Ser 3 Ser 2 Lan2/Ser1 Bur5/Lan1	-в	airnsdale Morgan/	H7 ←H6 ←H5	Cowan Dolomite	Gamma Island	Nullari Limest	bor one			
		Ā	Burdigaliar	N8 N7 N6	Trip	Lower	-Bur 4	B	latesford	← H4	M	Doioinite) Ooldea	ferrugin & silicif	isation ication
20-			Aquitaniar	N5			-Bur 2 Aq 3/Bur1 -Aq 2	U № L	Jpper Aannun- .ongford	<-H3 <-H2	Revenge Formation			? Abrakurrie	Sand?	eros	sion
25-			eter Chattian	P22	Prote	eacidites	·Ch 4/Aq 1 T Ch 3 R	F	Puebla	← H1		Revenge Formation		Limestone		Weatherin ?Munjena Formation	g-silcrete
30-		IGOCENE	<u>ک</u>	P21b P21a P20		culatus	Ch 2	T_J R	Jan Juc	←E	eros	ion?			aeol proc	ian ess? Barton	
		Ы		P19 - P18		Upper	Ru 2		Aldinga	~ D	silicific	ation?	Wilson B Limesto	luff ne	Doldea Sand	Sand	Khasta Formation
35-			Priabonian ete Late	P17 P16		Middle	Pr 3	-1 -1	Tuit Tuketja		Pallinup Silstone	Princess Royal Spongolite				Anthony	Member .
40-	GENE		Bartonian	P15	s asperus		Pr 1 Bart 1		ortachilla	← C	Norse Form	ation				Paling Formation	Format
	PALAEC	ш	iddle	P12	thofagidite	Lower	-Lu 4 R	-¥	Wilson Bluff	← A	Werr	ilup		7			idinga
45-		EOCEN	≥ Lutetian	P11	Noi	?	-Lu 3 -Lu 2								Mar	alinga Memt	Der C.
50-				P10 P9	Prote aspe	acidites propolus	-Lu 1		Burrungu	le	silicific	cation ?	? Ham	oton			2
			אךרesian שו	P7	Malva div	acipollis iersus	-Yp 7		Princetow Rivernool	/n k			Sand	ston –	? s	ilicification	
55-	2	ШN	Thanetiar	P5	lenites ei	Upper	-Yp 3	FF F	Rivernool Pebble Po Kings Par	к А oint k	erosi	on				erosion	
60-		ALEOCEI	Selandiar	P4	Lygistepol	Lower	-Th 2				deep wea	athering Mes	ozoic 🗤	ooprotozoia	de Palaas-	ep weath	ering
00		A		P3 A	1		-Sel 1-				\sim	~~~	han		AAAA		
			PR	E-TE	RT	IAR	Y				Precambr Yilgarn Cr	ian aton	ind	~~~~	~~~	Precan Gawler	nbrian Craton

Figure 3: Stratigraphic correlation chart for the Eucla Basin and palaeovalleys (Hou *et al.* 2008)



3 Regional Hydrogeology

3.1 Regional Yield and Salinity

There are few bores drilled within the study area and those that do occur do not always have associated groundwater salinity or yield information. This is particularly true of petroleum exploration wells.

The difference in data collection across jurisdictions also plays a role. The South Australian Department for Water (DFW) appears to collect more information and provides better GIS data delivery services. The Western Australian Department of Water (DoW) collects more information regarding the physical construction of boreholes but no salinity or yield information has been collected within the study area. Consequently the following analysis is predominantly based on data obtained from DFW Drillhole Enquiry System (https://des.pir.sa.gov.au/deshome.html).

3.1.1 Yield

Within the study area bores are generally low yielding. Figure 4 show the reported yield from each well plotted against the wells depth and Figure 5 shows the spatial distribution of yields.

It is evident that shallow wells (<50 m) are generally low yielding (in the order of 1-3 L/s). This largely corresponds with wells drilled in locally recharged perched aquifers.

At moderate depths (50 m- 120 m) yields increase ranging from 1-5 L/s and generally correspond to wells drilled within shallow Officer Basin sediments such as the Trainor Hill Sandstone.

Deep wells 200 m-400 m display a consistent yield of between 2-4 L/s and is likely to correspond to wells completed within the Observatory Hill Formation.

Four very deep wells have been drilled in the area. These bores are either petroleum or mineral exploration bores and specific data reported for groundwater is often vague or omitted.

Significantly the Mulyawara-1 petroleum well, drilled by Rodinia Oil in 2011, some 100 km east of the study area, has a reported yield of between 27-40 L/s. From the limited information available regarding this petroleum well, it appears that this rate is an estimate only:

"By 750 m we had high flow rates of between 600 and 900 Bbl/hr and could no longer air drill from 802 m due to high water production and our inability to dispose of it in spite of running triples continuously for over 12 hours per day." (pers. Comm. R. Parkes)

These high yields were obtained from the Murnaroo Formation and were encountered directly beneath the Dey Dey Mudstone at 730 m.



The Birskgate-1 petroleum well was drilled by the Continental Oil Company of Australia to the north of the study area in 1967. Two water wells were drilled alongside the petroleum well; Birksgate Water and Birksgate Strat. The reported yield for:

- Birksgate Water was 2.9 L/s (1600 bwpd) at 169 m (555 ft).
- Birksgate Strat was 7.4 L/s (4000 bwpd) at 374 m (1230 ft)

No groundwater yield data is presented for Birksgate-1 but drilling notes indicate a prolific water zone was encountered at 840 m (2757 ft) within a carbonate sequence, possibly the Observatory Hill Formation (COC 1967).

The Lake Maurice West and Lake Maurice East bores were drilled near Oak Valley by Aquitane Australia Minerals searching for Uranium and other mineralisation. Both of these holes were completed in the Murnaroo Formation but, unlike Mulyawara-1, the yield reported for Lake Maurice East is very low (0.1 L/s). It is of note that this bore is completed shallower than Mulyawara-1 and encountered the top of the Murnaroo Formation at a shallower depth (approximately 460 m).



Figure 4: Comparison of reported well yield with depth (South Australia only)







Figure 5 | Reported yield of water wells within South Australia

February, 2012 | P:\(DAN)_Diatrme_Resources\Projects \1148-11-DAN_Lost_Sands_Deposit\GIS\Maps\DAN_1148_11_yield spatial distribution.mxd

3.1.2 Salinity

Salinity within the region varies greatly but is largely considered as highly saline to hyper saline. There are a number of bores that display low salinities (<10 000 mg/L) that are associated with shallow bores drilled into locally recharged perched aquifers. However, shallow bores do not necessarily display low salinity. Figure 6 presents groundwater salinity with depth. Bores shallower than 150 m vary across a wide range of reported salinities with groupings around 10 000 mg/L, 30 000 mg/L 100 000 mg/L and 150 000 mg/L.

Below 150 m groundwater is reported to be less saline (<30 000 mg/L). This lower salinity water is associated with Officer Basin Sediments.











Figure 7 | Reported salinity of water wells within South Australia

3.2 Tertiary Palaeochannel Aquifers

Water supplies in Western Australia have commonly been sourced from palaeochannel aquifers that arise on the Yilgarn Craton. These aquifers make attractive targets for groundwater resources because palaeochannels such as the Roe Palaeovalley that services Kalgoorlie with its water supply requirements are deeply incised and contain thick sequences of sediments. Often there is a permeable basal sand and gravel unit that can be targeted to underdrain the overlying low permeability silty layer (Pennington Scott 2009).

Roe Palaeovalley (Yilgarn Craton)

Data on the aquifer response associated with significant abstraction of palaeochannel groundwater resources are only available from a number of mine processing borefields in the Roe Palaeovalley. Commander *et al.* (1992) and Turner *et al.* (1993) demonstrated that rates of abstraction for mine processing water in the Roe Palaeovalley were not sustainable with respect to down-valley recharge, even though the recharge rate was poorly quantified. However, both studies drew attention to the unquantified impact of enhanced lateral recharge. Later studies (Johnson 2007) demonstrated that initial water level decline as a result of abstraction was followed by steady-state conditions that indicated a sustainable balance between abstraction and groundwater inflow. This was demonstrated following groundwater allocation on a managed depletion basis and long-term monitoring of water levels (Magee 2009).

Quantification of enhanced indirect lateral recharge in other palaeochannels as a response to abstraction will be important for an accurate resource estimation and assessment of the sustainability of groundwater abstraction (Magee 2009)

Officer Basin Palaeochannel Groundwater

Within the Officer Basin rainfall varies from 150-200 mm per year and mean annual pan evaporation rates are 3,000 – 3,600 mm in the Musgrave Ranges. Surface water and connected drainage systems are absent and the Great Victoria Desert dunefield is the dominant landform. The regional groundwater potentiometric surface indicates flow towards discharge points in playas and at depth to the Eucla Basin e.g. beneath the Eocene Ooldea Sand shoreline deposits (Lau *et al.* 1995). It is likely that deposits in some of the palaeochannels are above the regional watertable and are unsaturated. Dodds *et al.* (1995) reported that the watertable at the southern end of the Lindsay Palaeovalley is 40 m below ground level. They also reported that fresh potable palaeochannel groundwater is common in valley calcrete deposits at Maralinga, Oak Valley and Waldana Well. This association reflects enhanced local recharge due to runoff from hard calcrete surface. In the adjacent Western Australian part of the Officer Basin recharge to saline trunk palaeochannels occurs from the interfluves and bores located on the interfluves are likely to intersect potable water supplies (Magee 2009).

At Oak Valley bores obtain groundwater from a palaeochannel sand aquifer situated near the indigenous community. This aquifer has a relatively high yield (~350 m³/day) but the water is very saline (30,000 to 60,000 mg/L)/ Furthermore groundwater is acidic (pH<4), iron-rich and contains abundant radioactive elements. Low acidity and elevated iron levels are probably derived from oxidation of pyrite in the Pidinga Formation; thus most palaeochannel groundwater from the Pidinga Formation aquifer in this region will likely have similar characteristics (Dodds 1997)



3.3 Officer Basin

Groundwater occurrence in the Officer Basin is poorly understood due to limited information. Main aquifers on a regional scale are postulated to be the Trainor Hill Sandstone and the Wirrildar Beds (Martin *et al.* 1998). From the limited data available it is inferred that groundwater generally flows in a southerly direction (GHD 2009).

Groundwater in the southern part of the basin has a very high salinity, exceeding 35,000 mg/L. Towards the northern boundary of the basin, however, salinity can be lower in sediments occurring between 60 m and 300 m below the surface, as reported in several wells south of Birksgate and Everard Ranges. In addition one well (Birksgate-1) penetrated aquifers where salinity was reported to be less than 1,000 mg/L at depths to 1,220m (Martin *et al.* 1998).

In the Officer Basin, groundwater is expected to be saline and pH neutral. The permeability of the formations varies laterally and sequentially and may result from either basic rock porosity or from fracturing, so there is no guarantee that water will be found at any given location or depth. There are indications that the water may be subartesian, which would encourage upward movement into fractures in the overlying Observatory Hill Formation or into Tertiary sediments. The formations can yield generous supplies (Dodds 1997).

3.4 Eucla Basin

Bores in the Eucla Basin supply water for pastoral purposes, small settlements, roadhouses and for water supplies along the Trans Australian Railway and Eyre Highway.

The main aquifer used as a groundwater resource in the Eucla Basin is the middle to upper Eocene Wilson Bluff Limestone. This unconfined limestone aquifer overlies the relatively impermeable Cretaceous Madura Formation and underlies the Nullabor Limestone, which is largely unsaturated. These Eocene age sediments range from 20 m to over 400 m thick, thickening towards the centre of the basin (PB 2007).

The groundwater in the Wilson Bluff Limestone is generally saline with TDS exceeding 10,000 mg/L. In the northwestern part of the Eucla Basin in Western Australia, low salinity potable water is available where more appreciable recharge occurs. Occasional perched fresh water has been found in underground caves after rainfall, which then infiltrates into the aquifer proper (PB 2007). The watertable is relatively deep, ranging up to 100 m below surface along the Trans Australian Railway (Commander 1991).

Due to the high porosity and cavernous nature of the Wilson Bluff Limestone, the aquifer should exhibit high transmissivity and storage coefficients in common with Tertiary marine limestone aquifers elsewhere in South Australia. However, there is little recorded information to corroborate this (PB 2007).

The spatially extensive cretaceous Loongana Sandstone of the Bight Basin is a deep confined aquifer that is generally less than 33 m thick, with a maximum thickness of 190 m. The groundwater salinity is generally high with values exceeding 14,000 mg/L (PB 2007). It is overlain by the impermeable Madura Formation, except around the inland margin of the basin, and itself overlies the granitic bedrock. The sandstone aquifer is several hundred metres below the surface at Eucla. In the northwest of the basin and along the Trans Australian Railway, the watertable is around 150 m below





surface whereas, on the Roe Plains in WA, bores may be artesian (Commander 1991).

Of the Eucla Basin sediments the Pidinga Formation, Hampton Sandstone, Ooldea Sand and the Wilson Bluff Limestone have been identified as potential aquifers. The Nullabor Limestone is largely unsaturated and the Bridgewater Formation is not considered a significant aquifer due to its elevation above the watertable (PB 2005)

The Hampton Sandstone is Middle to Late Eocene in age and equivalent to the palaeochannel sands in the Eastern Goldfields. It occurs around the western margin of the Eucla Basin where it overlies granite bedrock or Cretaceous sediments (Madura Formation or Loongana Sandstone). The sandstone interfingers laterally with the Wilson Bluff Limestone. Groundwater is mainly saline or hypersaline due to the discharge of hypersaline water from the palaeochannels. There has been no significant development of the aquifer (Commander 1991).



4 **Previous Water Drilling Campaigns**

Previous drilling campaigns provide by far the most certain data regarding the likely groundwater supplies that can be obtained. This is particularly true in a fractured rock environment such as the study area where indications of geological structure that influence well yields are largely obscured by recent cover.

Brief summaries of previous drilling campaigns are detailed below. The locations of these drilling campaigns are shown in Figure 8.

Read 1986 and 1987

Read embarked on two drilling campaigns in 1986 and 1987 searching for a potable or "desal" water supply for the Oak Valley community. Drilling targeted mainly shallow Tertiary sediments. One well, OV-2 yielded 0.3 L/s and 3000 mg/L and was drilled 15 m deep into a limited perched water table. This bore is still in use as the Oak Valley water supply.

Aldam 1993

In 1993 Aldam drilled 12 holes for water supply to support a seismic drilling program. Bores were drilled into the upper Officer Basin sediments and encountered variable conditions:

- Salinity 1,100 mg/L to 150,000 mg/L; and
- Yields 0.15 to 3 L/s

Drilling targets were located based on project requirements (i.e. no other information was used to locate wells) and all wells were successful in meeting the project water requirements. Some difficulty in completing wells was experienced due to the instability of the unconsolidated cover sands.

In addition to the water wells drilled some record was made of waters cut in the seismic shot holes drilled for the AGSO seismic lines.

Seismic Shot Hole Drilling Records

Water cut during drilling of shot holes for the 1993 AGSO Line 5 and 6 Seismic Survey were recorded in drillers daily log sheets. These records have been reviewed and recorded water cuts are shown on Figure 9. In general the incidence of water cut seems to be related to the depth of water. Shot holes were drilled to 40m and where the watertable is within 40 m of the ground surface, water cuts were recorded. This is consistent with the results of Aldam (1994) where water was intersected in all wells drilled to beneath the water table. In most instances yield and salinity of shot holes is not reported hence this data is only of limited value in identifying water supply drilling targets.







Australian Groundwater Technologies



Figure 9: Shot hole groundwater intersections along AGSO Seismic Lines 5 & 6



Dodds 1995 and 1997

Dodds conducted two campaigns in 1995 and 1997 with the aim of utilising Transient Electromagnetic (TEM) geophysical techniques to identify potable water supplies for the Oak Valley community. Dodds had no marked success using TEM transect to identify potable water supplies and encountered poor quality water residing within the Pidinga Formation that infills the palaeochannels.

Tjunttjuntjarra Community Bores 1997

Data supplied by the Department of Water WA indicates that in 1997 a drilling campaign was conducted by Drilling & Grouting Services on behalf of the Aboriginal & Torres Strait Islander Commission to supply water to the remote Tjuntjuntjarra Community.

These bores are located within the Eucla basin and are drilled to depths of 150m.

Minor database notes indicate that:

- Bore B (the production bore) was screened from approximately 54 m to 150 m;
- Groundwater in these bores was hyper-saline (Bore A=104,000 mg/L, Bore B= 95,000 mg/L);
- Water level was 8.82m below Top of Casing in Bore B;
- Bore B was developed by pumping at 300 m³/day (3.5 L/s) for 8 hours;
- Drawdown associated with well development was 57 m; and
- Water quality data indicates concentrations exceed water quality guidelines for a range of analytes.

Iluka Jacinth-Ambrosia Project 2008

The Jacinth-Ambrosia Project is a heavy mineral sand mining project operated by Iluka Resources Ltd beginning operations around 2008. It is situated in the same geomorphic and geologic setting as the Cyclone Prospect and targets the same minerals for extraction.

Water for processing operations is sourced from a hyper saline palaeochannel and borefield located 34 kilometres from the process plant. The water drawn from the palaeochannel is approximately 7 GL per annum and is expected to consume in the order of 6% of the entire palaeochannel volume over the life of the mine (Iluka 2011).

AGT 2011

In 2011 Rodinia Oil engaged AGT to manage a drilling program of water supply wells to support Rodinia Oil's planned exploration drilling program. Wells were drilled to supply road construction and drilling and camp supplies for exploration drill sites.

The water requirements for the project were identified as:

- 20 kL/day (0.25 L/s) at each drill site for drilling and camp supplies
- 200 to 500 kL/day (2 to 5 L/s) for road construction supplies.

Desktop investigations indicated that, in the north of the project area Tertiary sediments are uplifted above the regional water table.

A total of 15 water wells were drilled with well yields ranging from 0.8 to 4 L/s, whilst salinity ranged from brackish, 3800 mg/L to saline, 59000 mg/L.

North of the Ooldea range the productive aquifer was the Trainor Hill sandstone. In general the productive zones were found in the top 80 to 100 m of the formation and deeper wells did not result in greater yields.

South of the Ooldea Range productive zones were found in siltstone and limestone units of the Wirrildar Beds

Rodinia Oil 2011

Following the development of water supply by AGT, Rodinia Oil commenced their oil exploration drilling program. Two wildcat exploratory wells were drilled and abandoned; Mulyawara-1 and Kutjara-1.

Information obtained from Rodinia Oil company reports indicates that high water flow rates were encountered in Mulyawara-1 in the Murnaroo Formation immediately below the Dey Dey Mudstone at a depth of 730 m. Yields were significant with flow rates estimated between 27 to 40 L/s and salinity <15 000 mg/L.

Lost Sands 2011

In order to provide their mining operations with water, Lost Sands conducted a water prospecting program within the region between July and October 2011. Groundwater supplies in palaeochannel deposits were targeted using a Digital Elevation Model (DEM) to locate potential palaeochannel targets. 22 wells were drilled targeting shallow Tertiary sediments. Flow rates achieved from drilling targets was generally <1 L/s. from localised perched aquifers.

Australasian Groundwater and Environmental (AGE) prepared the background work using analysis of DEM and other available data on palaeochannel occurrence to identify prospective targets for this drilling program.



5 Groundwater Analysis

5.1 Lost Sands Cyclone Project groundwater Requirements

The pre-feasibility requirements for the proposed processing plant at the cyclone prospect are:

- Palaeochannels within a 50 km radius of the Cyclone prospect;
- Groundwater supply totalling 250 L/s (~7.9 GL/yr);
- Low salinity water;
- Alternative groundwater sources capable of meeting requirements

5.2 Palaeochannel Identifictaion

5.2.1 Previous work

Palaeochannels are a source of interest for a variety of reasons ranging from the purely scientific, to locating oil and gas, and mineral deposits. A range of methods have been developed to investigate palaeochannels and, since the invention of satellites, remote sensing has played a major role in their identification.

Within the study area Statham-Lee (1994) examined NOAA-AVHRR (National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer) imagery to identify Tertiary palaeodrainage systems over the Officer Basin and Musgrave Block.

Hou has had a long association identifying potential economic targets within the palaeochannels of SA (Hou & Frakes 2004, Hou *et al.* 2007, Hou *et al.* 2008) largely through the use of Digital Elevation Model interpretation.

In 2011 Australasian Groundwater and Environmental undertook an analysis of palaeochannel occurrence within the Cyclone Prospect region on behalf of Diatreme Resources. This analysis used DEM and other available data to identify prospective drilling targets.

5.2.2 DEM

Palaeodrainage has often been identified according to the drainage patterns that appear out of scale with contemporary conditions (e.g. dryland conditions in Central Australia). The identified palaeochannels are delineated using topographic information or Digital Elevation Models to determine the distribution of past drainage lines based on the principle of inheritance.

The remoteness of the Cyclone Prospect and the focus of previous studies on the South Australian side of the border have resulted in a lack of identification of palaeochannels on the Western Australian side of the border,

Hou & Frakes (2004) and Hou *et al.* (2007) appear to have heavily utilised the DEM method to define Neogene and Palaeogene palaeovalleys. These classifications may define palaeovalleys but not necessarily palaeovalley fills. Contemporary fluvial





21

processes may exploit the subtle topographic relief that remains from palaeodrainage lines (inherited drainage) and, within the Australian context, streamflow and rainfall may operate at several degrees of scale such that dryland channels commonly display a compound form. A widespread style is of narrow, high-sinuosity, meandering or anastomosing rivers at low-discharges (annual floods), but at high discharge (irregular, decadal large floods) they have a braided behaviour, occupying much of the low-stage 'floodplain'. Failure to recognise that dryland rivers can have multiple styles of behaviour dependent on the magnitude of flood can lead to misinterpretation of an obvious channel system as the active system and the larger pattern as a relict system (Tooth & Nanson 1995).

While palaeodrainage may be interpreted via DEMs, it should be ground-truthed using topographic information measured on-site and via geological sections and borehole information. Using the palaeovalleys of Hou *et al.* (2007) for groundwater prospecting may be problematic. The palaeovalleys of Hou *et al.* (2007) may show the location of palaeovalleys but they do not identify the presence or absence of palaeovalley fill. Mis-interpretation of this dataset may explain the lack of success in groundwater prospecting that has targeted palaeochannels on the West Australian side of the border.

Figure 10 shows a section of the 1 second DEM (GA 2011a) in the Cyclone Prospect region. On the South Australian side of the border are shown palaeochannels as interpreted by Hou et al. (2007). The classified DEM shows a strong correlation with interpreted palaeochannels. If this correlation holds on the western Australian side of the border it follows that these areas should be highly prospective for groundwater drilling.

The results from the Lost Sands groundwater drilling program have, however, been disappointing with only very small volumes of water located despite the drillholes being sited in apparent highly prospective areas according to the interpreted DEM.

This suggests that the DEM interpreted palaeochannels may not be a reliable means of locating groundwater and alternative methods of identifying palaeochannels may be needed.





Figure 10 | Classified 1 sec Digital Elevation Model showing interpreted palaeochannels (after PIRSA, 2007)

Australian Groundwater Technologies

February, 2012 | P:\(DAN)_Diatrme_Resources\Projects \1148-11-DAN_Lost_Sands_Deposit\GIS\Maps\DAN_1148_11_DEM_palaeochannels.mxd

5.2.3 Radiometrics

The radiometric, or gamma-ray spectrometric method is a geophysical process used to estimate concentrations of the radioelements potassium, uranium and thorium by measuring the gamma-rays which the radioactive isotopes of these elements emit during radioactive decay. Changes in lithology, or soil type, are often accompanied by changes in the concentrations of the radioelements (Geoscience Australia 2011b).

Figure 11 shows a subset of the Radiometric Map of Australia (Minty *et al.* 2010) for the Cyclone Prospect region. There are large data gaps in this area specifically in the region of the prospect making this information of little use. In addition the data set is assembled from different surveys conducted at different scales.

An examination of those areas that are visible is not very informative. The margin of the Eucla Basin is highlighted from a change from Potassium-rich sediment (red) within the basin to Thorium-rich sediment (green) north of the Basin. The green Thorium-rich area appears to be a dissected plateau; however, detail is difficult to make out.

Magee (2009) states that the stand-alone use of radiometric surveys has little potential for delineating groundwater characteristics, which appears to be the case here.







Figure 11 | Subset of the Radiometric Map of Australia (Geoscience Australia, 2010)

5.2.4 Gravity

The Earth's gravity field is not uniform, with denser rocks producing a stronger gravity field and less dense rocks producing a weaker gravity field. The ability to measure these small changes in gravity due to changes in the density of the rocks which make up the Earth provides a method which makes it possible to remotely map the distribution of different rock types and the structure of the rocks. Gravity data are part of the suite of data which is used to map the 3D structures of the subsurface rocks (GA 2011b).

There is a significant density difference between Cenozoic palaeovalley infilling sediments and surrounding basement rocks. Thus there is excellent potential for gravity surveys to detect the mass deficit resulting from the replacement of denser rocks by the palaeovalley infill. However, some geological conditions can compromise the interpretation of gravity data for palaeochannel delineation such as the presence of older sediments underlying palaeovalley infill (Magee 2009).

Gravity surveys have been the most useful method to define palaeovalley subsurface profiles in parts of the Yilgarn Craton, especially where palaeovalleys are eroded into homogeneous bedrock such as granite. Survey results were most effective when combined with other geophysical methods such as Transient Electromagnetism (TEM) (Magee 2009).

Figure 12 shows an image of the gravity anomalies within the Cyclone Prospect region. The image is dominated by the Munyarai Subdomain (magenta) which is interpreted as a felsic-metasedimentary gneiss terrane. The rectilinear zone extending across the southeast corner of the image is likely to be related to basement faulting along which the more dense Nurrai Intrusives have been emplaced (Teasdale *et al.* 2001).

The gravity image (Figure 12) highlights basement and crustal features rather than channel sediments. A sinusoidal moderate to high gravity anomally extends across the Western Australian-South Australian Border along a southeast-northwest trajectory. This feature could be interpreted as a palaeochannel however, this is highly speculative and it is more likely that the feature represents minor mafic intrusions within the basement.





Figure 12 | Bouguer Gravity Anomalies *(Geoscience Australia, 2009)*

Australian Groundwater Technologies

February, 2012 | P:\(DAN)_Diatrme_Resources\Projects \1148-11-DAN_Lost_Sands_Deposit\GIS\Maps\DAN_1148_11_Gravity.mxd

5.2.5 Magnetics

The magnetic method measures variations in the intensity of the Earth's magnetic field caused by the contrasting content of rock-forming magnetic minerals in the Earth's crust. The content of magnetic minerals ranges from negligible in most sedimentary rocks to appreciable amounts in igneous and metamorphic rocks. The magnetic method is a valuable technique for mapping the boundaries of extensive rock units which contain only a small percentage of magnetic minerals, but with enough contrast in magnetic mineral content to distinguish them from neighbouring rock units (GA 2011b)

Figure 13 shows the magnetic anomalies in the Cyclone Prospect region. Magnetic data provides the structural fabric of the basement. Major basement structures can be inferred from consistent discontinuities and/or pattern breaks in the magnetic fabric (Teasdale *et al.* 2001). Consistent with the gravity anomalies (Figure 12) areas of high magnetic response appear to be associated with the Nurrai Intrusives and areas of low magnetic response are associated with Munyarai subdomain metasediments. It is unlikely that any information identifying palaeochannels is discernable from this image.







Figure 13 | Magnetic Anomalies (Geoscience Australia, 2010)

February, 2012 | P:\(DAN)_Diatrme_Resources\Projects \1148-11-DAN_Lost_Sands_Deposit\GIS\Maps\DAN_1148_11_Magnetics.mxd

5.2.6 Modis/NOAA-AVHRR

The NOAA-AVHRR satellite measures various wavelengths of emitted and reflected radiation from the earth's surface in various channels (Table 1). The channels have a spatial resolution of 1.1 km at nadir. The radiant temperature recorded by NOAA-AVHRR is a product of a material's kinetic temperature and its emissivity (emissivity being a measure of a materials ability to absorb and radiate thermal energy). This varies greatly depending on moisture content, mineral composition and texture of the land surface. The subsurface material retains heat, cooling more slowly during the night. The overlying sands of the Great Victoria Desert cool gradually overnight reaching their lowest temperature before sunrise. By contrasting a pre-dawn image and a daytime image the maximum thermal contrast between surface sediments and underlying material can be obtained. (Statham-Lee 1994).

Statham-Lee (1994) mapped palaeodrainage in the Officer Basin identifying major trunk streams where the palaeodrainage was much darker than the surrounding sediments (Figure 14).

Within the Cyclone Prospect region (near Serpentine Lakes on Figure 14) the mapped palaeodrainage is evident; however delineating it clearly for the purposes of water prospecting is difficult at this scale.

Channel	Wavelength (μm)	Band
1	0.55-0.9	Visible red
2	0.725-1.1	Near IR
3	3.55-3.93	Thermal IR
4	10.5-11.5	Thermal IR
5	11.5-12.5	Thermal IR

Table 1: NOAA-AVHRR spectral intervals





Figure 14: NOAA-AVHRR pre-dawn image showing palaeodrainage of western South Australia (Statham-Lee 1994)



In order to better delineate the thermally identified palaeochannels, data was examined from the MODIS-TERRA satellite (which collects spectral bands similar to the NOAA-AVHRR).

The Moderate Resolution Imaging Spectrometer (MODIS) is the key instrument onboard the Terra (EOS AM-1) satellite acquiring data in 36 spectral bands over a 2330 km swath. For the purposes of this study the pre-dawn image of MODIS band 32 (spatial resolution 1000 m, thermal infrared 11.770-12.270 μ m) was obtained and relatively crudely analysed by classifying the image to highlight areas of higher thermal radiance focussing on the region surrounding the Cyclone Prospect. The thermal imaging results suggest that there is a broad palaeochannel running northeast-southwest across the West Australian –South Australian border and that drilling to date has been located either outside the palaeochannel or located on the margins (Figure 15).

The most highly prospective location for water drilling is located south of Serpentine lakes on the Western Australian side of the border (outside the Mamungari C P in SA) and within an area where the palaeochannel is broad.





Australian Groundwater Technologies Figure 15 | Classified Modis thermal infrared (Band 32) showing interpreted palaeochannels

6 Potential Targets

6.1 Tertairy Palaeochannels

On the margins of the Officer Basin palaeochannels have incised the Yilgarn and Gawler Cratons, carving relatively deep channels into crystalline basement rocks. These have subsequently been filled with sediment and supply large quantities of water to several mines in different locations.

Where the palaeochannels have incised the sediment of the Officer Basin the capacity of these palaeochannels to supply large volumes of water seems to be less clear.

Palaeochannels are incised into the Trainor Hill Sandstone and infilled with Tertiary sediments. To the north of the study area, the elevation of these palaeochannels places them above the regional water table, hence they are likely to be unsaturated and not a viable water supply target.

Dodds (1997) identified water quality in the Tertiary Palaeochannels in the Oak Valley region as very poor. Groundwater in these palaeochannels was reported to be generally saline to very saline ($30\ 000 - 60\ 000\ mg/L$), acidic (pH<4) and rich in iron and radioactive elements. The infilling sediments of the Pidinga Formation are likely to be responsible for the poor water quality. It is possible that better water quality might be found in other palaeochannels than those identified in the region so far, but none is currently known in this area.

6.1.1 Prospective Palaeochannel Locations

There is considerable uncertainty about the capability of any water supply from proposed palaeochannels within the study area to meet both quality and quantity requirements. However, there is insufficient information currently available to discount the possibility.

To date Lost Sands groundwater exploration program has failed to identify sufficient quantities of groundwater. This appears to stem from the misinterpretation of the geomorphology of palaeochannels and how they interact with the landscape; relying solely on interpretations from DEMs.

Of the methods used within this study to determine the distribution of palaeochannels:

- DEM mapping identifies excavated palaeochannels but not palaeochannel fills;
- MODIS mapping identifies one probable in-filled palaeochannel;
- Gravity data correlates with the MODIS interpretation but may be indicative of basement structures or igneous features rather than a palaeochannel; and
- Radiometric and Total Magnetic Intensity methods do not provide any clear correlation with palaeochannels.



In addition to the location of the interpreted palaeovalley features it is necessary to account for the gradient of the watertable which is more likely to intersect palaeovalley features towards the south.

Other barriers to locating water within palaeochannels come from the legal boundaries placed on the operation. The investigation site abuts two reserves; the Great Victoria Desert Nature Reserve in West Australia, and the Mamungari C P in South Australia. For the most part these two reserves dominate the prospective areas for palaeochannel groundwater. It is considered that approval for mining related activities within the reserve boundaries' would be highly unlikely. Installation of a wellfield may be possible but negotiations for such an activity are likely to be protracted involving numerous state regulatory agencies.

It is considered highly unlikely that approval will be given for mining related activities to occur within the reserve boundaries; including the construction of a borefield. Locations for groundwater prospecting are consequently limited to the few areas that remain outside the reserve boundaries. Given the volume of water required for the mine and the small amount of interpreted palaeochannel area available outside the reserve boundaries finding a reliable supply of suitable quality water from within the palaeochannel network will be challenging.

Prospective drillhole locations are ranked in order of potential:

- SE of Cyclone Deposit an apparent palaeochannel is located to the southeast of the cyclone deposit. This smaller spur from the main trunk stream may contain water as evidenced by the interpretation of the MODIS satellite data; however, it is unlikely to contain large volumes. Site 1 is located close to the interpreted trunk stream and is more likely to contain significant volumes of water;
- SE of Cycone Deposit within the same spur as Site 1, Site 2 is located near the head of the interpreted palaeochannel and is not likely to contain significant volumes of water; and,
- SW of Cyclone Deposit a broad palaeochannel extends south into the Great Victoria Desert Nature Reserve. A small portion of the interpreted palaeochannel remains north of the reserve boundary and Site 3 is located here.







6.2 Shallow Officer Basin Sediments

The main regional aquifer is the Trainor Hill Sandstone described as very fine to fine grained kaolinitic sandstone with some medium to coarse grained material towards the top. This formation is likely to have low primary permeability, hence intersection of fractures will be required to provide reasonable well yields. This formation is the target for nearly all recorded successful wells drilled in the area to date.

The likelihood of intersecting fractures is far greater in areas where there is some structural disturbance to the formation, at faults, or intrusive structures.

Figure 17 shows information from the AGT/Rodinia water supply bores drilled along the pre-existing seismic line 93AGS-6. The regional watertable can be relatively deep (up to approximately 90m in Mulyawara 1 water supply bore) and essentially follows the land surface.

Salinity within the Trainor Hill Sandstone is variable but generally below 30,000 mg/L. Due to the limited primary porosity of the Trainor Hill Sandstone, yields are generally low ranging from 1 - 5 L/s.

As evidenced by the drilling campaigns of Aldam 1993 and AGT 2011, boreholes may be located where convenient provided they are located within the aquifer.





Figure 17: Section along seismic line 93AGS-6 showing the Rodinia water bores and selected shot point water levels



6.3 Deep Officer Basin Sediments

There are few bores drilled into the deeper sediments of the Officer Basin (>200 m). Those that have been drilled are largely petroleum wells or mineral exploration wells.

Of these Mulyawara-1 is located closest to the Cyclone Prospect. This well displays excellent groundwater yields at reasonable salinity with groundwater sourced from the Murnaroo Formation directly below the Dey Dey Mudstone.

Birksgate-Strat is located further northeast of the Cyclone Prospect. This well also reports relatively good flows and lower salinity but is completed within what is interpreted as the Wirrildar Beds, the Murnaroo Formation being intersected in Biksgate-1 at approximately 1840 m bgl. Significant volumes of water were also reported from a depth of 840 m bgl which is interpreted to be within a geological unit equivalent to the Observatory Hill Formation.

The Lake Maurice East bore was drilled at the edge of the Officer Basin and intersected the Murnaroo Formation at a relatively shallow 460 m bgl. Groundwater yields for this well are extremely low, reported as 0.1 L/s.

The intersection of the top of the Murnaroo Formation indicates that it is dipping to the north. The results from Mulyawara-1 and Lake Maurice East suggest that yields are greater closer to the centre of the basin. Given that the Lost Sands tenements are also located close to the centre of the basin, groundwater supply boreholes completed within the Murnaroo Formation can likely be located wherever it is convenient to do so.

6.4 Eucla Basin Sediments

Eucla Basin sediments are located to the south of the Cyclone Project. The edge of the Eucla Basin is approximately marked by the Ooldea Range. There are several bores within the region that source water from the Eucla Basin. These are the AGT/Rodinia water supply bores to the southeast and two bores drilled for the Tjuntjuntjarra Community to the southwest. All of these bores have been successful in locating water but have reported relatively low yields (1.4 - 5 L/s). Salinity is generally poor (approximately 29 000 mg/L – 104 000 mg/L) and bores are drilled to 100 m – 150 m deep.

Potential water supply bores within the Eucla Basin need to be located sufficiently far from the basin margin to encounter a reasonable thickness of aquifer and far enough south to ensure the aquifer is saturated. Other than these requirements bores may be sited where convenient.

There is a high likelihood of locating water between 100 m - 150 m but this water is likely to be of poor quality and yields are likely to be low within this area (when compared to other locations within the Eucla Basin to the South and East).

The location of bores within the Eucla Basin is hampered by the presence of the Great Victoria Desert Nature Reserve which is likely to restrict access for mining and water supply opportunities.





7 Groundwater Supply Potential

The target water supply provision is for 250 L/s = 8GL/yr

7.1 Tertiary Palaeochannels

Rates of groundwater supply from known Tertiary palaeochannels within the area are low (0.3 -3 L/s). At these rates (using an average flow of 2 L/s) a borefield of 150 wells would be required to meet the mine's water supply demands. Given the low rates of recharge assumed to occur in this area, it is probable that the palaeochannel would struggle to meet the demand over the long term. The mine would result in a significant depletion of the water resources exploited within the palaeochannel. Potentially the palaeochannel water may not be sustainable for the life of the mine.

In addition, the size of the borefield has implications for the operation. If the system design allows for groups of shallow wells joined to a suction box to allow pumping, it is possible that the borefield could be economically viable. If, however, each bore requires its own pump, the cost of operational logistics and management will likely prove to be too great for effective operation of the mine.

But other palaeochannels elsewhere supply sufficient groundwater to meet the estimated demand. The Iluka Jacinth-Ambrosia water supply pumps at a rate equivalent to 221 L/s from a ten well borefield (22.1 L/s per well) (PB 2008).

Flow rates of this order have not been reported within the area of interest and palaeochannels near the Cyclone Prospect could be unsaturated if they are located above the water table. Even if they do contain water it is probable that the nature of the hosting sediment will result in the groundwater being of very poor quality – highly saline, acidic and rich in iron and radionuclides (Dodds 1997).

7.2 Shallow Officer Basin sediments

Assuming an average supply for groundwater wells within the Trainor Hill Sandstone of 2.5 L/s a borefield of 100 wells would be needed to meet the mine water supply requirements.

Wells would need to be adequately spaced to prevent the development of a significant cone of drawdown and would be subject to economic and logistic restrictions due to the large number of bores required.

7.3 Deep Officer Basin sediments

Assuming an average supply for groundwater wells within the Murnaroo Formation of 33 L/s (as encountered in Mulyawara-1) a borefield of 8 wells would be needed to meet the mine water supply requirements.

Wells would be required to be constructed to deeper than 700 m and additional costs would be incurred in the drilling and operation of the bores as specialist equipment is required due to their depth.



There is also no confirmed information regarding the aquifer potentiometric surface for the Murnaroo Formation. A low potentiometric surface (e.g. >300 m bgl) would require highly specialised pumps to lift water from these depths.

The use of water from the Murnaroo may have implications for the granting of a groundwater license. Since the Murnaroo Formation is assumed to have limited recharge the effect of pumping from this formation is that the borefield would effectively be mining fossil water that may take decades or longer to replenish. This level of impact may not be acceptable to regulatory authorities, however, there is insufficient information available to make a definitive statement regarding sustainable levels of extraction and further work will be required in this area.

7.4 Eucla Basin sediments

Bores drilled in the Eucla Basin have high salinity (in the order of 67 000 mg/L) and low yields (approximately 3 L/s). A well field consisting of 84 bores would be required to supply water to the mine.

A borefield of this size is not likely to be viable given the depth that the bores are required to be drilled in this region. It is of note, however, that along the Eyre Highway near the Iluka Jacinth-Ambrosia Project wells drilled for stock water within the Eucla Basin are quoted as having salinity in the order of 13,000 mg/L with variable yields from 0.1 to 22.7 L/s. Assuming these values are representative for the central Eucla Basin, with an average well yield of approximately 11 L/s, 23 wells could potentially supply the Cyclone Prospect its water requirements. However, the Eucla Basin is at a significant distance from the project site and saturated sediments of the Eucla Basin may be some additional distance beyond that.



8 Risks

Operational issues and risks that need to be considered include: the remote locality of any borefield; security issues; power supply; pipeline and pumping station infrastructure and maintenance and the economics of supply.

Environmental issues in securing a suitable supply include: current nearby resource users; potential impact on groundwater dependent environmental systems; sustainability of the groundwater resource over the life of the mine; land clearing and disturbance for infrastructure components; and, community issues along pipeline delivery routes.

None of these issues necessarily preclude development of a water supply should a sustainable groundwater resource be located within reasonable distance.



9 Estimated Costs

In order to delineate the groundwater resources available near the Cyclone Prospect, a preliminary works program is proposed for the supervision and drilling of one deep and one shallow borehole. Estimated costs for this program are presented in Table 2.

Task	Description	Estimated Cost (ex GST)		
	PROFESSIONAL FEES	From	То	
	Project			
1	Management/Admin/Computing/Communications	\$6,225	\$7 <i>,</i> 550	
	Drilling Preliminaries including tender			
	specifications, Permit & permit applications,			
2	preparation of OH&S + EMP Plans	\$4,800		
	Hydrogeological supervision deep well (assumes			
3	20 days)	\$27,900	\$33,000	
	Hydrogeological supervision shallow well (assumes			
4	7 days)	\$8,960	\$10,960	
5	Reporting	\$4,600	\$7,800	
	DISBURSEMENTS			
1	Vehicle hire	\$4,380	\$5 <i>,</i> 380	
2	Field allowance/ Equipment /utilisation	\$2,500	\$3,375	
3	Camping equipment hire (if required)	\$1,800	\$2,430	
4	Drilling Deep borehole to 750 m	\$770,000	\$1,000,000	
5	Drilling shallow borehole to 150m	\$75,000	\$120,000	
	Total cost ex GST	\$906,165	\$1,190,495	

Table 2: Estimated costs for preliminary works program

Note: This does not include costs associated with liaison with indigenous communities. Time on this activity would be costed at a per hour rate of \$210 for R. Martin.



10 Conclusions and Recommendations

10.1 Conclusions

There are four main target aquifers within the study area:

- Tertiary Palaeochannels;
- Shallow Officer Basin sediments;
- Deep Officer Basin sediments; and
- Eucla Basin sediments

Of these targets only the Shallow Officer Basin sediments and Deep Officer Basin sediments have acceptable salinity levels.

The Deep Officer Basin sediments are the only sediments that are likely to have a sufficiently high yield to meet the mine water requirements but may result in mining fossil water for the processing plant and mine operations.

Eucla Basin sediments may potentially supply sufficient volumes of water for mine operations. This is dependent on as yet unproven yields in deeper parts of the Eucla Basin. Any such borefield will be at a considerable distance from the mine site and is hampered by the presence of the Great Victoria Desert Nature Reserve where development of infrastructure is likely to be prohibited.

Groundwater supplies from Tertiary Palaeochannels are also likely to be hampered by the presence of the reserves. The highly prospective zones identified are all located within or adjacent to the boundaries of the Great Victoria Desert Nature Reserve. Any groundwater extraction from these areas, particularly from shallow bores, is likely to impact on groundwater dependent ecosystems. These may be present within the reserve boundaries and as a result a permit to extract water may not be granted. A major risk with utilising palaeochannel sediments for water supply is that the groundwater present will be exhausted during the life of the mine. If good volumes of groundwater are identified studies will need to be conducted to ensure the sustainability of the supply.

Shallow Officer Basin sediments offer the least prospect for a mine groundwater supply. Yields within these sediments are low and salinities can be hyper-saline. The size of the borefield constructed would preclude its viable operation.

10.2 Recommendations

- An initial trial bore be drilled within the MODIS identified palaeochannel to confirm or disprove this interpretation.
- An investigative well be trialled near the proposed mine site targeting the Murnaroo Formation. Quotes obtained for deep water bore drilling indicate a cost in the order of \$700 000 to \$2m for one bore drilled to 800 m.



11 References

AGT (2010) Alinytjara-Wilurara Natural Resources Management Region Groundwater Review, Report No. 2009/993 Australian Groundwater Technologies.

Benbow, M.C., Lindsay, J.M. & Alley, N.F. (1995). *Eucla basin and palaeodrainage.* In: Drexel J.F. & Preiss, W.V. (eds.) *The Geology of South Australia, Vol. 2: The Phanerozoic.* Bulletin 54, Primary Industries and Resources SA.

Callen, R.A. & Benbow, M.C. (1995) 'The Deserts – Playas, Dunefields and Watercourses' in Drexel, J.F. & Preiss, W.V. (eds), The Geology of South Australia, Vol. 2: The Phanerozoic, Bulletin 54, Primary Industries and Resources SA.

Continental Oil Company (1967) *Birksgate 1 well completion report.* PIRSA Open File Envelope No. 768, OEL28, Officer Basin.

Commander, D.P., Kern, A.M. and Smith, R.A. (1992) *Hydrogeology of the Tertiary palaeochannels in the Kalgoorlie region (Roe palaeodrainage).* Western Australia Geological Survey, Record 1991/10.

Costar, A. & Sampson, L.D. (2004) Interim Report on Monitoring Groundwater Bores in Aboriginal Trust Lands, South Australia. Monitoring Period October 2003 to April 2004. DWLBC Report 2004/46

Dodds, A.R. (1997) An assessment of the groundwater resources of the lake Maurice area, northwest South Australia, for the Oak Valley community, Maraling Tjrrutja Aboriginal Lands. Mines and Energy Resources, South Australia Report 97/56.

Fairclough, M.C., Benbow, M.C. & Rogers, P.A. (2007) *Explanatory Notes for the Ooldea 1:250 000 Geological Map*, Department of Primary Industries and Resources, Report Book 2007/11, Geological Survey of South Australia.

Geoscience Australia (2011a) *SRTM-derived 1 Second Digital Elevation Models Version 1.0.*

Geoscience Australia (2011b) Online: http://www.ga.gov.au. Accessed 22/12/11

GHD (2009) Report for Future Management of Water resources, Consolidated Report for Stages 3,4 and 5. Prepared for Alinytjara-Wilurara NRM Board by GHD. GHD Report no. 31/23569/161042.

Hou, B. & Frakes, L.A. (2004) *Tertiary sea levels and heavy mineral deposition in the eastern Eucla Basin, SA.* In: Roach, I.C. (ed.) *regolith 2004.* CRC LEME.

Hou, B., Zang, W., Fabris, A., Keeling, J., Stoian, L. And Fairclough, M. (2007) Palaeodrainage and Coasal Tertiary Barriers of South Australia Digital Geological Map of South Australia, 1:2 000 000 Series (1st edition). CRC LEME, Geological Survey Branch, Primary Industries and Resources, South Australia.

Hou. B., Frakes, L.A., Sandiford, M., Worral, L., Keeling, J., Alley, N.F. (2008) Cenozoic Eucla Basin and associated palaeovalleys, southern Australia – Climatic



and tectonic influences on landscape evolution, sedimentation and heavy mineral accumulation. Sedimentary Geology 203 (2008) pp. 112-130

Iluka (2011) Electronic Resource: http://<u>www.iluka.com</u>. Accessed: 16 December 2011.

Johnson, S.L. (2007) *Groundwater abstraction and aquifer response in the Roe Palaeodrainage (1990-2001).* Western Australia, Department of Water, Hydrogeological Record Series, report HG23.

Magee, J.W. (2009) Palaeovalley Groundwater Resources in Arid and SemiArid Australia – A Literature Review. Geoscience Suatralia Record 2009/03.

Martin, R., Sereda, A. And Clarke, D. (1998) *Spencer regions strategic water management strategy.* Primary Industries and Resources Report Book DME 37/95.

Minty, B.R.S., Franklin, R., Milligan, P.R., Richardson, L.M. and Wilford, J. (2010) *Radiometric Map of Australia (Second Edition)*. Scale 1:15 000 000, Geoscience Australia, Canberra.

PB (2007) *Hydrogeological Environmental Impact Assessment Jacinth-Ambrosia Project.* Parsons Brinckhoff Report No. 07-0288-final-2102716B. Prepared for Iluka resources Ltd.

PB (2008) Jacinth-Ambrosia Mineral Sands mining Project – Mining and Rehabilitation *Program (Early Works).* Parsons-Brinckerhoff

Pennington Scott (2009) *Tropicana Gold Project, Water Supply Area Investigation*. Report prepared for Tropicana Joint Venture – Anglogold Ashanti Australia Ltd & Independece Group NL. Report No. 08A1020|Rev2.

Statham-Lee, L. (1994) *Palaeodrainage and its economic potential in the Officer Basin and Musgarve Block.* Department of Mines and Energy South Australia Report Book 94/30.

Teasdale, J., Pryer, L., Etheridge, M., Romine, K., Stuart-Smith, P., Cowan, J., Loutit, T., Vizy, J. And Henley, P. (2001) Officer Basin SEEBASE Project SRK Consulting report for Primary Industries and resources South Australia

Tooth, S. & Nanson, G.C.(1995) *The geomorphology of Australia's fluvial systems: retrospect, perspect and prospect.* Progress in Physical Geography vol. 19, no.1 pp.35-60.

Turner, J.V., Rosen, M.R., Milligan, N., Sklask, M. And Townley, L.R. (1993) *Groundwater recharge studies in the Kalgoorlie region.* Minerals and Energy Research Institute of Western Australia. Report No. 98.

Watts, E. & Berens, V. (2011) Non-prescribed groundwater resources assessment – Alinytjara-Wilurara Natural Resources Management Region: Phase 1- Literature and Data Review. Science, monitoring and Information Division Department for Water Technical Report DFW 2011/18

