Wheatstone Social Infrastructure Development

New Onslow Water Plant Alternative Water Supply Options - Identification of Sources and Reliability Assessment

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Chevron Australia Pty Ltd

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Prepared for

Chevron Australia Pty Ltd

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Prepared by Timothy Smith and Todd Hodgkin

Reviewed by Todd Hodgkin and Adam Ansted

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Abbreviations

The following abbreviations, as shown in Table 1 have been used in this report.

Table 1 Glossary of Terms

Terms and Abbreviations	Definition
ANSIA	Ashburton North Strategic Industrial Area
Capex	Capital expenditure
DMP	Department of Minerals and Petroleum
DoW	Department of Water
ERMP	Environmental review and Management Programme
GL	Giga-litre (= 1,000 ML)
GWL	Groundwater Well Licence
kL	Kilo-litre = 1,000 litres = 1m3
LNG	Liquified natural gas
m	Metre
mbgl	Metres below ground level
ML	Mega-litre = 1,000 litres
Opex	Operating expenditure
TDS	Total dissolved solids

Executive Summary

Chevron is defining a base case solution to cater for residential water demand associated with an additional 1,500 persons to the Onslow town population; this base case is currently defined as a seawater reverse osmosis (SWRO) desalination plant with the capacity to produce 2 ML/day of potable water.

This report represents the findings of a Phase 1 study that identifies and assesses the 'reliability' of alternative water sources to the base case seawater desalination system. The reliability criteria consider the:

- Extent to which the physical characteristics of the source are known and suitable for the requirements of the project.
- The potential environmental and regulatory issues likely to be associated with each source and the probability of securing a licensed water allocation from the Department of Water.
- Long term viability and sustainability of the source. The definition of long-term has been taken from current Water Corporation design standards for potable water supply systems, which range between 50 – 100 years depending on the system component.

The results of the reliability assessment are summarised in Table 2 and discussed below.

For the 2 ML/day potable supply base case, on the basis of potential source yields and/or water salinity, five of the eight sources are not considered adequate to be considered as reliable supply options (Birdrong – Upper Cane River, Coastal Plain Sediments – Dunal Sands Beach Wells, Coastal Plain Sediments – Alluvium, Coastal Plain Sediments – Trealla Limestone and Cane River Alluvium.

Of these five sources, the Cane River Alluvium is also not considered to be unreliable in terms of both licensing and long-term viability criteria. The Birdrong – Upper Cane River source is considered to be unreliable in terms of the potential to licence the required supply.

The aquifer sources that have a strong connection to recharge from river systems (the Ashburton River alluvium, Cane River Birdrong and alluvium and Lower Robe River sources) have the greatest potential to be affected by any long-term declines to rainfall and runoff. Climate change predictions by CSIRO (2007) indicate that the probability for lower rainfall in the Onslow region by 2070 (under high or low carbon emission scenarios) is higher than the probability of increased rainfall. However, in more absolute terms, the predicted probability of annual rainfall declines in the Onslow region only exceeds 50% for the 2070 high emissions case for a rainfall decrease of the order of 10 – 20%. These predictions suggest that annual rainfall is not likely change significantly in the Onslow region by 2070 compared to 1990.

The Birdrong Aquifer in the Onslow area, the Ashburton River alluvium and Lower Robe River alluvium sources are considered to have sufficient reliability criteria to warrant further assessment as supply options. However, in terms of uncertainty associated with the assigned reliability factors, the Birdrong source has high levels of uncertainty, whilst the Ashburton River alluvium source is considered to have less, but still significant uncertainty associated with it. The Lower Robe River source has the least amount of uncertainty of the three sources and consequently is considered the highest ranked source in terms of reliability.

It is important to note that the sources have been assessed as singular 'stand-alone' supply options. Assessment of the combination of two or more sources as a supply option should potentially be considered, perhaps moreso for the longer-term 4ML/day supply scenario.

Adjustment of the various reliability criteria to the higher demand scenario of a 4 ML/day potable water system does not effectively change the results from the 2 ML/day base case assessment. The same five sources as above are not considered suitable in terms of source yields and/or salinity.

The greater abstraction rates required potentially diminishes the reliability rating of the Birdrong and Ashburton River alluvium sources, however, this is influenced to a large degree by the relatively high uncertainties associated with these two sources compared to the Lower Robe River alluvium source.

Based on the approach to further assessment developed on 8 March 2012 and the findings of this study, we recommend that the Birdrong, Ashburton River alluvium and Lower Robe River alluvium sources be considered further as potential alternative options for the new Onslow water supply by:

- Estimating the various tasks, time and costs likely to be involved with investigation and development of each source to the point where water licences, land tenure/access and other regulatory approvals can be secured.
- Undertaking a Class 1 capital and operating cost-benefit analyses (+50% / -30%) for each source option.
- Define and apply water quality and water conditioning criteria for the water treatment and supply system to each source option.
- Comparing the results of the above tasks to the base case seawater desalination system to assess whether any of the three source options warrant further detailed assessment as alternative water supply options.

Table 2 Water Source Reliability Assessment – 2 ML/day Potable Supply System

Factor	Seawater Desalination Base Case	Potential Alternative Water Source							
		Birdrong Aquifer – Onslow	Birdrong Aquifer – Upper Cane River	Coastal Plain Sediments – Dunal Sands Beach Wells	Coastal Plain Sediments – Alluvium	Coastal Plain Sediments – Trealla Limestone	Cane River Alluvial Aquifer	Ashburton River Alluvial Aquifer	Lower Robe River Alluvial Aquifer
Summary Source Information									
Potential or known salinity of source (mg/L TDS)	~35,000	6,000 – 20,000	300 – 3,500	25,000 – 75,000	35,000 – 125,000	75,000 – 150,000	300 – 1,700	2,000 – 8,000	500 – 1,300
Potential Source Volumes required (GL/year)[1]	2.43	~ 1.22	0.73	>2.43	>2.43	>>2.43	0.73	~1.22	0.73
Physical Characteristics Criteria									
Is source well defined ?	yes	no	no	yes	Yes	no	yes	no	yes
Probability of adequate source yields	certain	moderate - high	low - moderate	moderate - high	moderate - high	moderate - high	low – moderate	moderate	v. high
Salinity compared to seawater base case	n/a same	favourable, potentially 2 to 3 times lower	very favourable, fresh to brackish resource	Similar to seawater, but significant proportions unfavourable, potentially up to 2 times higher than seawater	unfavourable, potentially up to 3 times higher than seawater	unfavourable, potentially up to 3 – 4 times higher than seawater	very favourable, fresh to brackish resource	favourable, fresh to brackish resource	very favourable, fresh to brackish resource
Potential number of bores to meet required volumes	n/a	1 – 2	7 - 15	50 - 200	25 - 100	40 - 150	5 - 15	10 - 30	3 - 5
Overall uncertainty level	v. low	moderate - high	low - moderate	low	low	low - moderate	low	moderate - high	low
Water Licensing Criteria									
Source included in current DoW allocation system?	n/a	yes	uncertain	yes	yes	uncertain	yes	no	yes (in mid-2012)
Sufficient available allocations exist to meet potential source volumes required?	n/a	no	n/a	no	no	n/a	no	n/a	yes

Factor	Seawater Desalination Base Case	Potential Alternative Water Source							
		Birdrong Aquifer – Onslow	Birdrong Aquifer – Upper Cane River	Coastal Plain Sediments – Dunal Sands Beach Wells	Coastal Plain Sediments – Alluvium	Coastal Plain Sediments – Trealla Limestone	Cane River Alluvial Aquifer	Ashburton River Alluvial Aquifer	Lower Robe River Alluvial Aquifer
Probability of securing required 5C Licence from DoW	n/a	high	low	moderate	moderate - high	high	v. low	moderate - high	high
Overall uncertainty level	n/a	moderate	low	moderate	moderate	low	low	low	low
Long-term Viability Criteria									
Potential for significant declines to source water levels and yields	nil	low - moderate	moderate	low	low	low	moderate	low	low
Potential for adverse changes to water salinity and quality	nil	low - moderate	low	low	low	low	moderate	low - moderate	low
Overall uncertainty level	n/a	high	high	low -moderate	low-moderate	moderate	low	moderate	low

1.0 Introduction

Chevron Australia Pty Ltd (Chevron) is currently planning the development of Social Infrastructure in the Onslow area of Western Australia for the Wheatstone Project. Work completed to date indicates that the capacity of Onslow's current power and potable water supply infrastructure cannot meet the projected demand forecast in 2016 (primarily attributable to the Wheatstone Project). Consequently, the existing Onslow supply infrastructure needs to be upgraded.

It has been established that Chevron will be responsible for delivering the upgrade to Onslow's power and water infrastructure to Horizon Power and the Water Corporation, who will become the asset owners, by early to mid-2015. The upgrade will follow a staged approach, as described in the Project Framing Document (AECOM, 2011):

- Phase 1 - Identify and Assess Opportunities.
- Phase 2 - Generate and Select Alternatives.
- Phase 3 - Develop Preferred Alternative.
- Phase 4 - Build and Deploy.
- Phase 5 - Transfer and Operate.

AECOM Australia Pty Ltd (AECOM) has been engaged by Chevron through Work Package CTR 21 to undertake the Phase 1 studies.

The current "Base Case" for upgrading the Onslow potable water supply involves a seawater reverse osmosis (SWRO) desalination plant with an output of 2 ML/day potable water, potentially located within the Ashburton North Strategic Industrial Area (ANSIA). As a component of the Phase 1 studies, Chevron seek to understand if alternative water supplies in the Onslow region have sufficient potential to warrant further assessment in Phase 2 as an alternative to the base case.

This report presents the Phase 1 findings of the alternative water source identification and high level assessment of the identified sources based on 'reliability' criteria stipulated by Chevron. The assessment also incorporates consideration of the longer-term potable water capacity requirement for Onslow, which Chevron has advised may be of the order of 4 ML/day.

2.0 Study Methodology

The alternative water source identification and assessment has been completed at a desktop level by principally reviewing reports provided by Chevron and public-domain geological and hydrogeological reports accessed by AECOM:

Key Documents Provided By Chevron

- *Onslow Town Water Supply: Results of Exploratory Drilling and Testing for Additional Water Sources,* 2009, unpublished report prepared by Rockwater for Water Corporation.
- *Water Source Option Assessment for Wheatstone Project,* 2009, unpublished report prepared by URS for Chevron.
- *Final Pumping Test Report Chevron Wheatstone Development Project,* 2010, unpublished report prepared by Coffey for Chevron.
- *Wheatstone – Beach Wells as preferred water supply*, 2009, memorandum prepared by URS for Chevron.
- *Wheatstone Downstream project – Study Report for Water Supply and Treatment 4.3 MTPA BOD Update CTR-51E,* 2009, unpublished report prepared by Bechtel for Chevron.
- *Wheatstone Project LNG Plant – Water Study Report for Plant Operation,* 2010, unpublished report prepared by Bechtel for Chevron.

Public Domain Reports

- *Hydrogeology of the Robe River alluvium, Ashburton Plain, Carnarvon Basin,* 1994, Western Australian Geological Survey.
- *Lower Cane groundwater allocation limit report*, 2011, Department of Water.
- *The Pilbara Coast Water Study,* 2009, Department of Water.
- *Development of an Integrated Water Resource Planning Tool for the Pilbara Region*, 2008 URS.
- *Geology of the Carnarvon Basin Western Australia*, 1987, Western Australia Geological Survey.
- *Petroleum Geology of the Peedamullah Shelf and Onslow Terrace, Northern Carnarvon Basin, Western Australia*, 2000, Western Australia Geological Survey.
- *Development of an Integrated Water Resource Planning Tool for the Pilbara Region*, 2008 URS.
- *Lower Robe Groundwater Model*, 2010, SKM.
- *Wheatstone Project Groundwater Studies,* 2010, URS.
- *Pilbara Planning and Infrastructure Framework,* 2011, Department of Planning.
- *Carnarvon Artesian Basin Water Management Plan*, 2007, Department of Water.
- *Coral Bay Drinking Water Source Protection Plan*, 2010, Department of Water.

In addition to the above reports, information was also sourced by AECOM from water bore and water licence databases maintained by the Department of Water (DoW).

Surface water resources of the Robe, Cane and Ashburton rivers were not considered to be potentially viable alternative water sources based on previous work by URS and the DoW (2009), which identified the uncertain ephemeral flows, costs, heritage and environmental issues as being significant hurdles to surface water development. Thus, only groundwater sources within a nominal distance of 80 km from Onslow were identified and assessed.

For each water source identified, a brief summary of the known physical features of the water source such as distance from Onslow, potential yield, water quality, are given. A qualitative assessment was then made on each source in the context of the 'reliability' of the source, as defined by the following criteria:

- Extent to which the physical characteristics of the source are known and suitable for the requirements of the project.
- The potential environmental and regulatory issues likely to be associated with each source and the probability of securing a licensed water allocation from the Department of Water.
- Long term viability and sustainability of the source. The definition of long-term has been taken from current Water Corporation design standards for potable water supply systems, which range between 50 – 100 years depending on the system component.

These reliability criteria were developed in conjunction with Chevron and have been applied as the first level of 'filtering' to determine, which, if any, of the identified sources warrant further consideration. We understand that the sources we have determined that pass the first stage reliability filter will be subject to further filtering at a later date based on the following criteria:

- Likely time and costs to develop the alternative water source to the point of securing the necessary approvals and licences from relevant regulatory agencies.
- Potential capital and operating expenditure costs for alternative source options in comparison to the base case seawater desalination system.
- Water quality and conditioning criteria.

The assessments of reliability factors in this report consider source potential in terms of the base case demand of 2 ML/day and the potential longer term demand rate of 4 ML/day.

3.0 Groundwater Sources

Six groundwater systems were identified as possible alternative sources for the Onslow potable water upgrade (Figure 1):

- Birdrong Sandstone – In the Onslow area.
- Birdrong Sandstone – In the Upper Cane River area.
- Lower Cane River Alluvium.
- Lower Robe River Alluvium.
- Lower Ashburton River Alluvium.
- Coastal Plain Quaternary and Tertiary Sediments. This system encompasses 3 sub-aquifer systems that have previously been considered as individual potential supply options by Chevron, URS, Bechtel and Coffey:
    - Coastal Plain Dunal Sands / Seawater Interface (shallow beach wells).
    - Coastal Plain Alluvium.
    - Trealla Limestone.

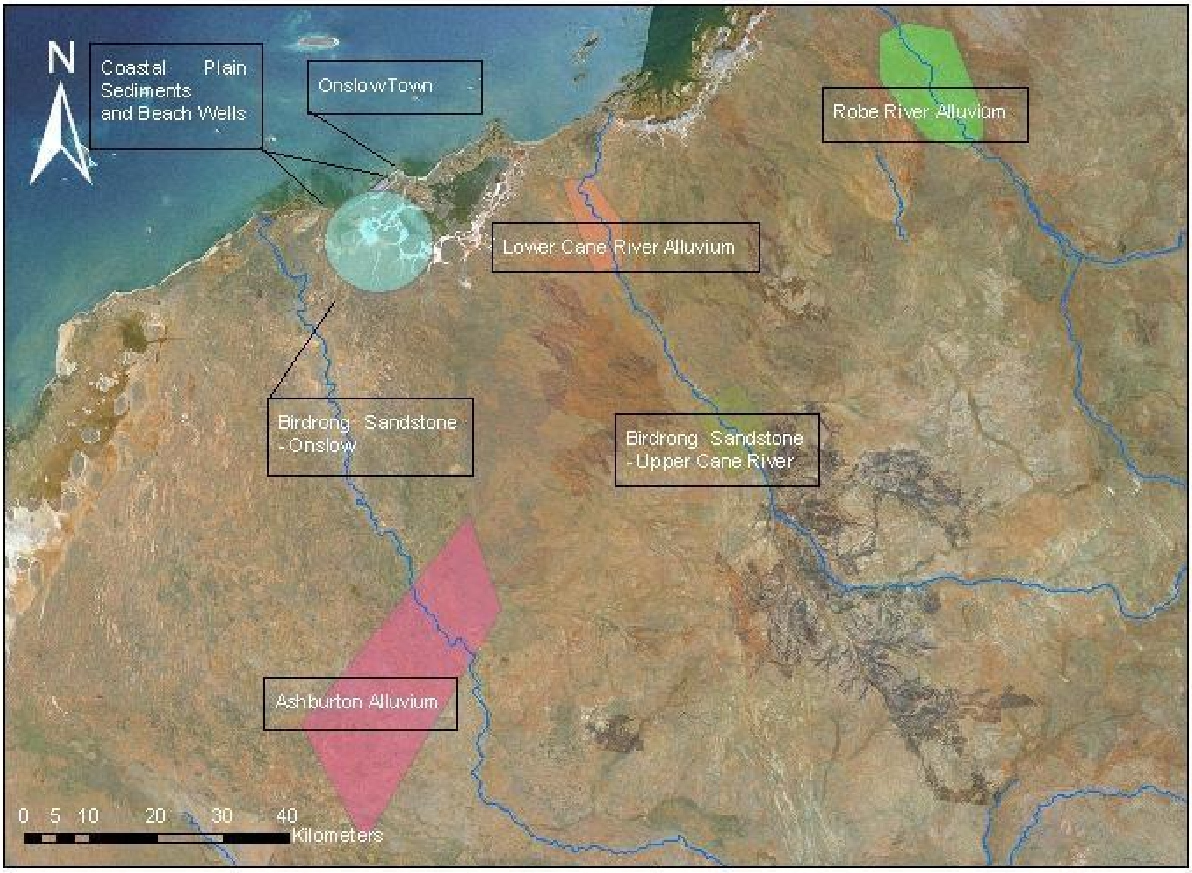

Figure 1 Groundwater Source Locations.

3.1 Birdrong Sandstone – Onslow

The Birdrong Sandstone is the main confined aquifer of the Carnarvon Basin and is utilised for various purposes by many users in the southern part of the Basin. Based on a Groundwater Well Licence (GWL) application advertised in the public domain on 23 February 2012, it appears that BHP Billiton Petroleum Pty Ltd (BHP Billiton) has recently installed a production bore into the Birdrong Aquifer as part of its Macedon LNG project. The next closest active Birdrong Aquifer bore is for potable supply to the town of Coral Bay located approximately 200 km south-west of Onslow.

3.1.1 Previous Investigations in the Onslow Region

Much of the current knowledge regarding the Birdrong Sandstone Aquifer in the Onslow region is based on surrounding oil and gas exploration wells (Figure 2). The only known water bore records are for Onslow Artesian No. 2); this bore was drilled in 1896 to a depth of 527 m but did not intersect any significant aquifer zones and was abandoned in 1899.

The Coral Bay town supply bore(s) was constructed in 2005 and is just over 800 m deep; the aquifer intersected is 34 m thick and yields brackish water (~ 5,000 mg/L TDS) at elevated temperatures (~ 60 degrees C) and near neutral pH (DoW, 2010).

There is no public-domain information yet available regarding the production bore installed by BHP Billiton, presumably located within the Ashburton North Strategic Industrial Area (ANSIA) as part of the Macedon LNG Project. Access to any information for this bore would require a request to be made by Chevron directly to BHP Billiton.

Bechtel (2010) reported that a test bore was installed by Chevron into the Birdrong Aquifer, however, this is not the case; a test bore was considered by Chevron but was not installed based on concerns regarding the potential for encountering gas during drilling (L.Cooper pers. comm.)

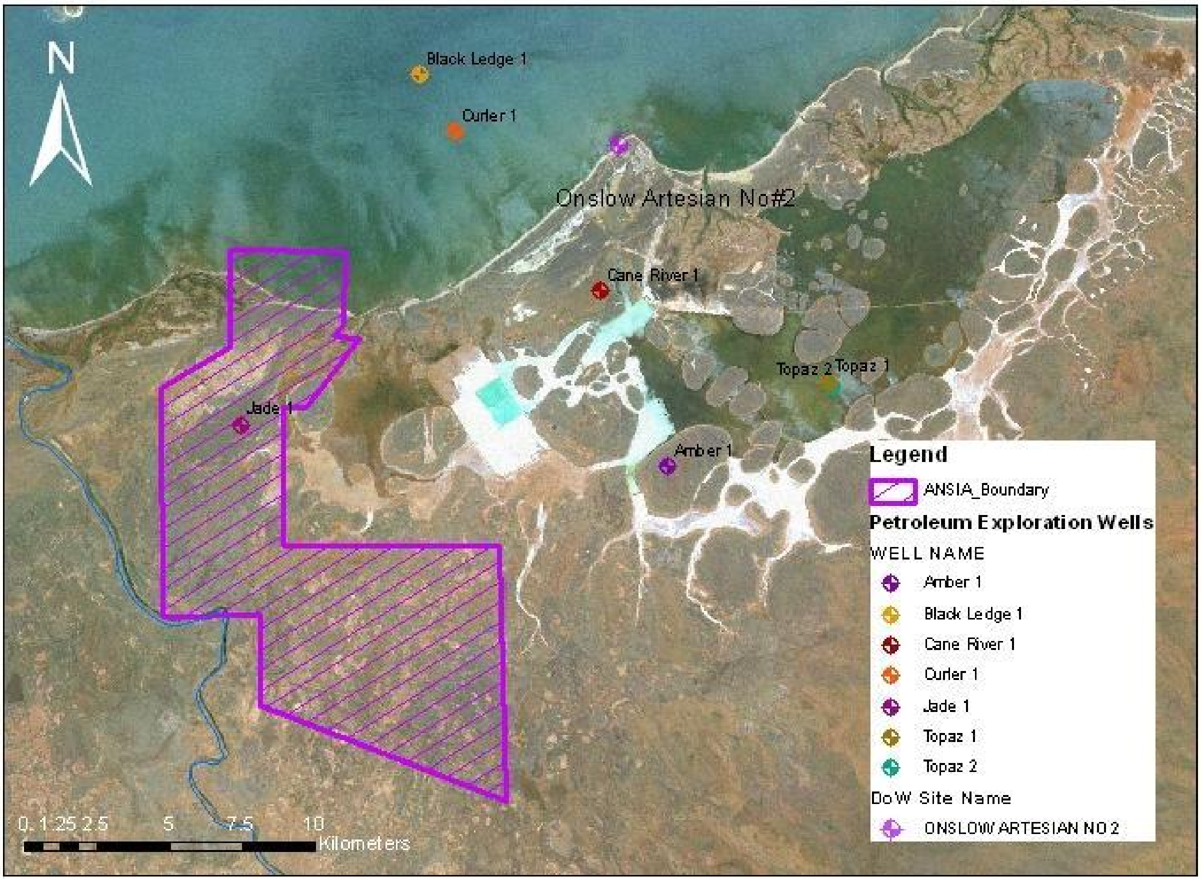

Figure 2 Petroleum wells in the Onslow area

3.1.2 Geology

The geology descriptions of the Birdrong Sandstone and surrounding sedimentary units provided here are primarily taken from Crostella et al (2000) and Hocking et al (1987).

The Birdrong Sandstone is the basal unit of the Cretaceous Winning Group of the Carnarvon Basin (Figure 3). It is described as a quartzose, commonly glauconitic and friable, sandstone and silty sandstone. Two main facies are present in outcrop. The principal facies is a fine- to coarse-grained, moderately well-sorted, relatively featureless, quartz sandstone. It is commonly silty (to a variable degree) and glauconitic. The second facies in outcrop is small- to medium-scale, cross-bedded, fine- to very coarse grained sandstone, locally silty and pebbly, and poorly to moderately sorted (Hocking et al, 1987).

In the subsurface, the Birdrong Sandstone is a pale-grey to white, locally greenish, glauconitic sandstone and greensand. Bedding ranges from thin planar-bedded units to tabular and trough cross-stratified units. Siltstone beds occur, locally grading into silty claystone and shale (Hocking et al, 1987).

Other sedimentary units occur adjacent to the Birdrong Sandstone (Mardie Greensand Member, Flacourt Formation, Nanaturra Formation and Yarraloola Conglomerate) (Figure 3). These are not described here, but are typically sandy facies of fluvial and shallow marine origin that have some potential to be considered with the Birdrong Sandstone as one single aquifer unit.

Specific information from surrounding petroleum wells (Crostella et al, 2000) regarding the Birdrong Sandstone and Flacourt Formation are provided in Table 3.

Table 3 Summary Information from Petroleum Wells (after Crostella et al, 2000)

Feature	Unit	Well					
		Amber 1	Black Ledge 1	Cane River 1	Curler 1	Jade 1	Topaz 1
Year drilled	-	1994	1992	1971	1997	1993	1995
Depth drilled	m	683	2,680	694	759	604	423
Datum level (Kelly bushing)	mAHD	18.4	31.9	10	29	10.9	6
Depth below datum to top of Birdrong Sandstone	m	365.5	722.5	347.5	np	476.5	335.7
Thickness of Birdrong Sandstone (m)	m	6.5	15	45.5	np	13.5	1.5
Depth below datum to top of Flacourt Formation	m	372	737.5	393	615	490	337
Thickness of Flacourt Formation	m	17	35	20	34	11.5	32
Combined Birdrong Sandstone and Flacourt Formation thickness	M	23.5	50	65.5	34	25	33.5
Gas shows	-	poor	nil	nil	poor	nil	good
Oil shows	-	fair	poor	nil	poor	nil	good

Notes np = not present

Crostella et al (2000) noted that many of the intersections described by the oil companies as Birdrong Sandstone are more typical of the Flacourt Formation and re-interpreted the stratigraphy of these and other wells as shown in Table 3**Error! Reference source not found.**. Their descriptions depict the Birdrong Sandstone in the petroleum wells near Onslow as being typically finer grained and less permeable then the underlying Flacourt Formation, suggesting the Flacourt Formation would provide higher groundwater yields.

In Jade 1, the interval from 490 – 501.5 m was reported as being entirely water-bearing with good reservoir characteristics and an average porosity of 25%. Sandstones in the Mungaroo Formation underlying the Flacourt Formation were also reported as being extremely porous and water bearing.

The petroleum well data indicates that the depth to the Birdrong Sandstone and Flacourt Formation increases in a north-westerly direction. This may be a function of regional stratigraphic dip, but also may be a result of displacement along faults interpreted by Crostella et al (2000) which strike north-easterly to north north-easterly with downthrown blocks on the north-west side of the fault structures.

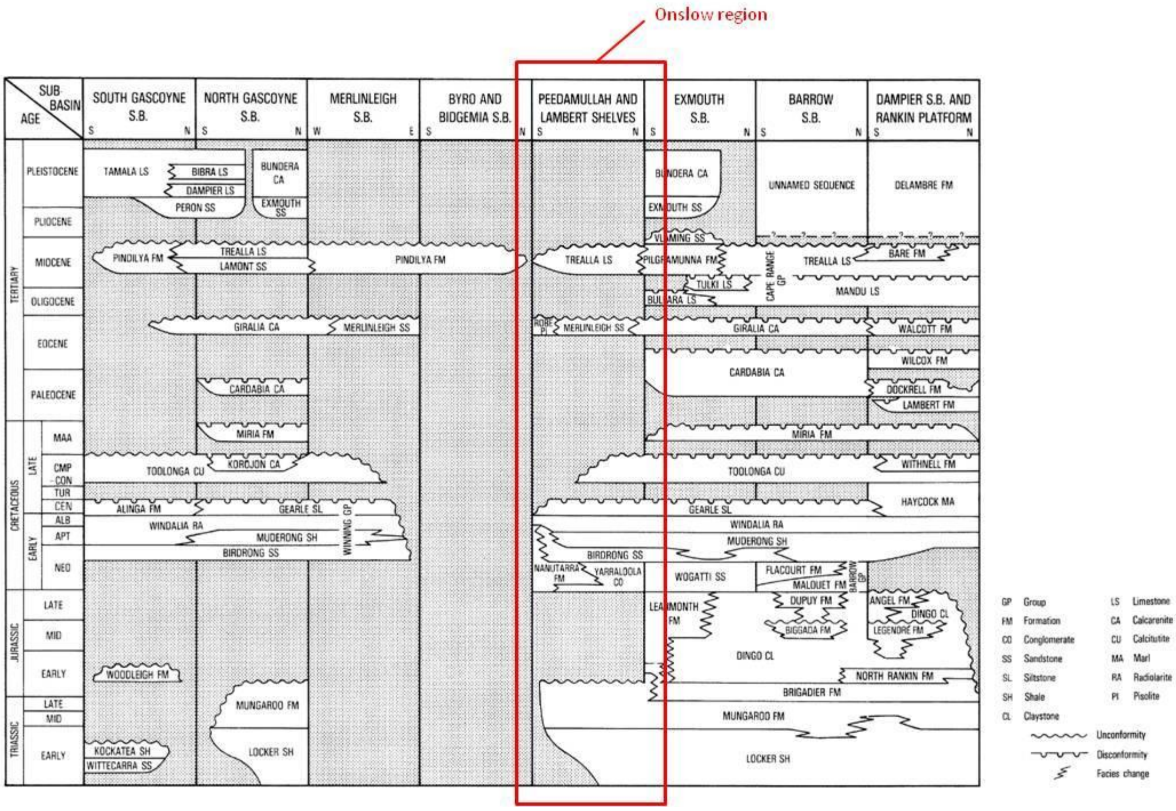

Figure 3 Stratigraphy of the Carnarvon Basin (after Hocking et al, 1987)

3.1.3 Hydrogeology

Much of the published understanding of the Birdrong Aquifer in the Onslow region is considered to be based on regional interpretations from petroleum exploration wells and water bores by A.D. Allen in Hocking et al (1987). Figure 4 shows these interpretations as depth to the top of the aquifer, groundwater levels, salinity and temperature contours.

In the Onslow area, the Birdrong Aquifer is confined and overlain by the Muderong Shale and the Windalia Radiolarite, which were reported as indistinguishable in the sub-surface (Hocking et al 1987). At the inland margin of the Carnarvon Basin, where the Muderong Shale and Windalia Radiolarite are absent, the aquifer is unconfined.

Hocking et al (1987) describe recharge mechanisms to the Birdrong Aquifer over the wider Carnarvon Basin being direct rainfall on outcrops; river flow where the major rivers cross areas of outcrop; and from the unconfined groundwater, where the formation subcrops immediately below younger sediments. Upward recharge from the underlying Palaeozoic sediments may also take place at unconformities where there are sandstone on sandstone contacts, or via faults. In the Onslow region, recharge to the unconfined Birdrong system by the Ashburton and Cane rivers is probably significant. The Department of Environment (2004) as cited by URS (2009A) suggest an annual total recharge for the entire Carnarvon Basin of approximately 17GL.

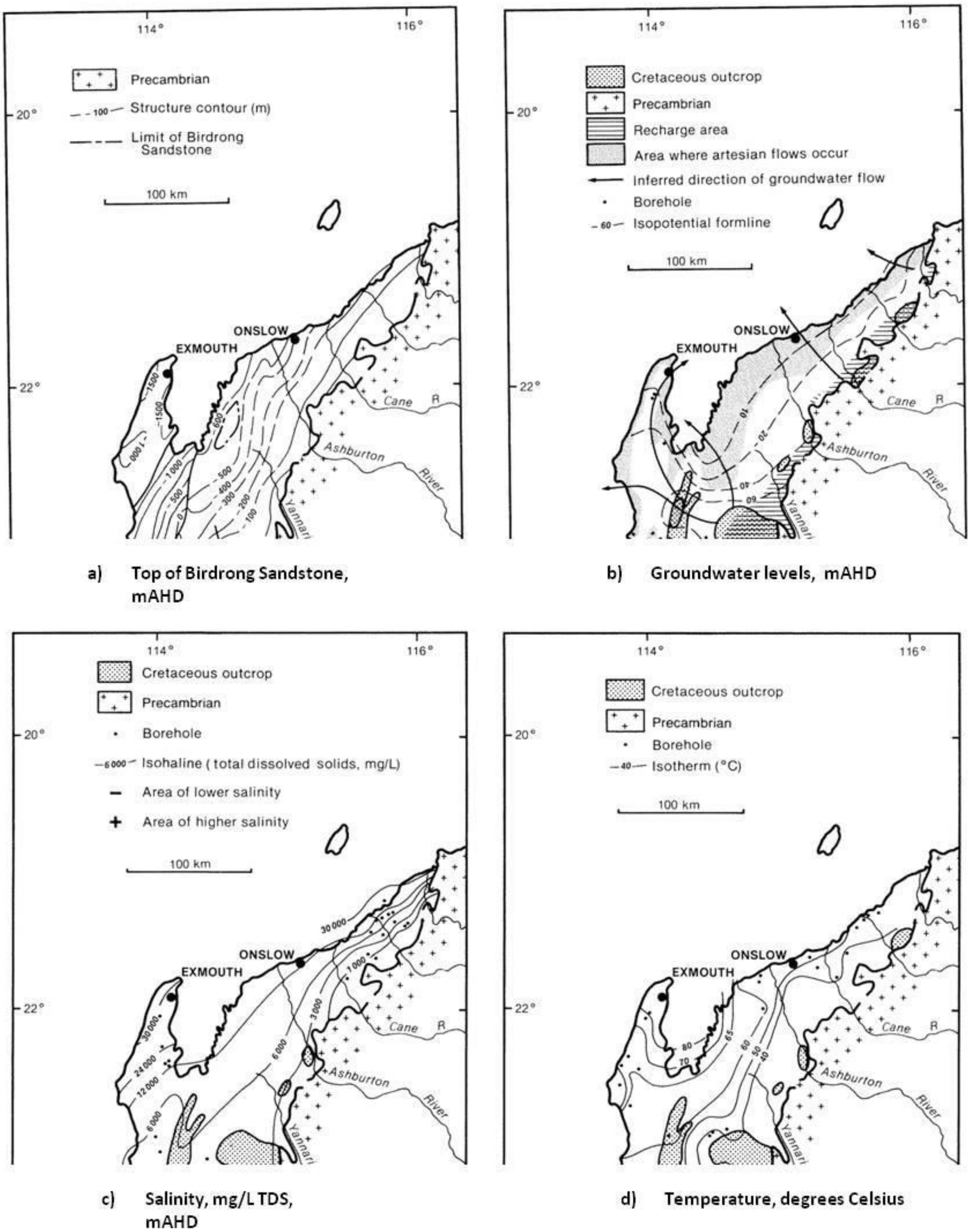

Figure 4 **Birdrong Sandstone Aquifer - Regional Distribution (after Hocking et al, 1987)**

The yield potential of individual bores is unknown but is likely to be high, perhaps of the order of 1 – 4 ML/day based on the reported thickness and nature of the Birdrong Sandstone and Flacourt Formation by Crostella et al (2000) and know bore yields from further south in the Carnarvon Basin.

URS (2009A) state that the Birdrong Aquifer in the project area may be capable of a sustainable yield of up to 4.5 GL/year (~ 12.3 ML/day) but do not provide any details for this estimate.

Groundwater quality of the Birdrong Aquifer in the project area is uncertain but is likely to be brackish to saline as fresh water is considered to be restricted to recharge areas to the east of Onslow where the aquifer is unconfined and is 'traversed' by current drainage lies such as the Ashburton and Cane rivers.

Rockwater (2009) indicate that the salinity of groundwater from the Birdrong Aquifer near "is expected to be about around 15,000 mg/L"; the basis for this is uncertain but may be an inference from the interpretations of Hocking et al (1987) (Figure 4). URS (2009A) estimated salinity of the Birdrong Sandstone in the petroleum well Jade 1 (located about 15 km south-west of Onslow) to be about 6,000 based on an assessment of down-hole geophysical data. There is no groundwater quality data associated with the abandoned water bore Onslow Artesian # 2 in the DoW database.

Groundwater temperatures within the Birdrong Aquifer are elevated. The artesian bore installed by the water Corporation for Coral bay intersected groundwater with a temperature of 63 degrees Celsius and pH of 7.1. Based on the interpretations of Hocking et al (1987), temperature of groundwater in close to Onslow is expected to be in the range from 45 – 60 degrees.

3.1.4 DoW Allocation Status and Other Groundwater Users

Onslow and the ANSIA area occur within the Ashburton Subarea of the Pilbara Groundwater Management Area. A water licence search and aquifer allocation report was obtained from the DoW on the 13 February 2012 and indicates that, within the Ashburton Subarea:

- The Birdrong Sandstone Aquifer has an allocation limit of 300 ML/year and that 270 ML/year of this limit occurs as licensed allocations (in July 2011 the allocation limit was set at 250 ML/year). No allocation volumes are currently ascribed to 'committed' or 'requested' allocation categories, which typically reflect water licence applications currently in progress within the DoW.
- There are currently only two licences to take and use groundwater from the Birdrong Sandstone Aquifer within 100 km of Onslow. These are both held by BHP Billiton petroleum Pty Ltd (BHP Billiton):
  - GWL 171202 (2), 250 ML/year, issued 19/09/2011, expiry 31/12/2012, Lot 153 On Plan 220110 under Licence Number 995/2008_1_194 (Sec 91)
  - GWL 172797 (3), 10 ML/year, issued 19/12/2011, expiry 18/12/2016, Main Roads Western Australia Road Reserve - Onslow Road, Talandji.

GWL 171202 (2) held by BHP Billiton licence is presumably associated with their Macedon LNG project in the ANSIA. A public notice was displayed in the West Australian newspaper on 23rd February 2012 which indicates that BHP Billiton is seeking to increase their allocation from the Birdrong Aquifer to 900 ML/year under GWL171202.

The recent application by BHP Billiton for a 900 ML/year allocation from the Birdrong Aquifer exceeds the allocation limit. This situation is not atypical, as the DoW often receive and assess applications for allocations in excess of stated limits in areas where there is a poor understanding of the aquifer resource and its true sustainable allocation limit. In these cases, the DoW often assess applications on a project-by-project risk basis and revise the stated aquifer allocation limit at irregular intervals as knowledge of the aquifer system increases.

A draft Water Allocation Plan (WAP) for the Pilbara region is currently being prepared. The DoW recently advised AECOM that they anticipate release of the plan for public comment in May 2012, however, the work completed by the DoW has not included a review of the allocation limit for the Birdrong Sandstone (M Braimbridge, per. comm.).

3.2 Birdrong Sandstone – Eastern Margin of Carnarvon Basin

3.2.1 Previous Investigations

The Birdrong Sandstone, near the eastern margin of the Carnarvon Basin at distances of about 50 to 60 km south-east of Onslow (Figure 1), was described by Haig (2009) as a potential groundwater supply source for Onslow.

A drilling and testing program was undertaken by the Water and Rivers Commission (WRC) in 1994 to assess the aquifer potential of the Birdrong Sandstone upstream of the existing Onslow borefield where the aquifer is likely to be recharged with good quality water from the Cane River. Figure 5 shows the location of the investigation area and the six monitoring bores installed.

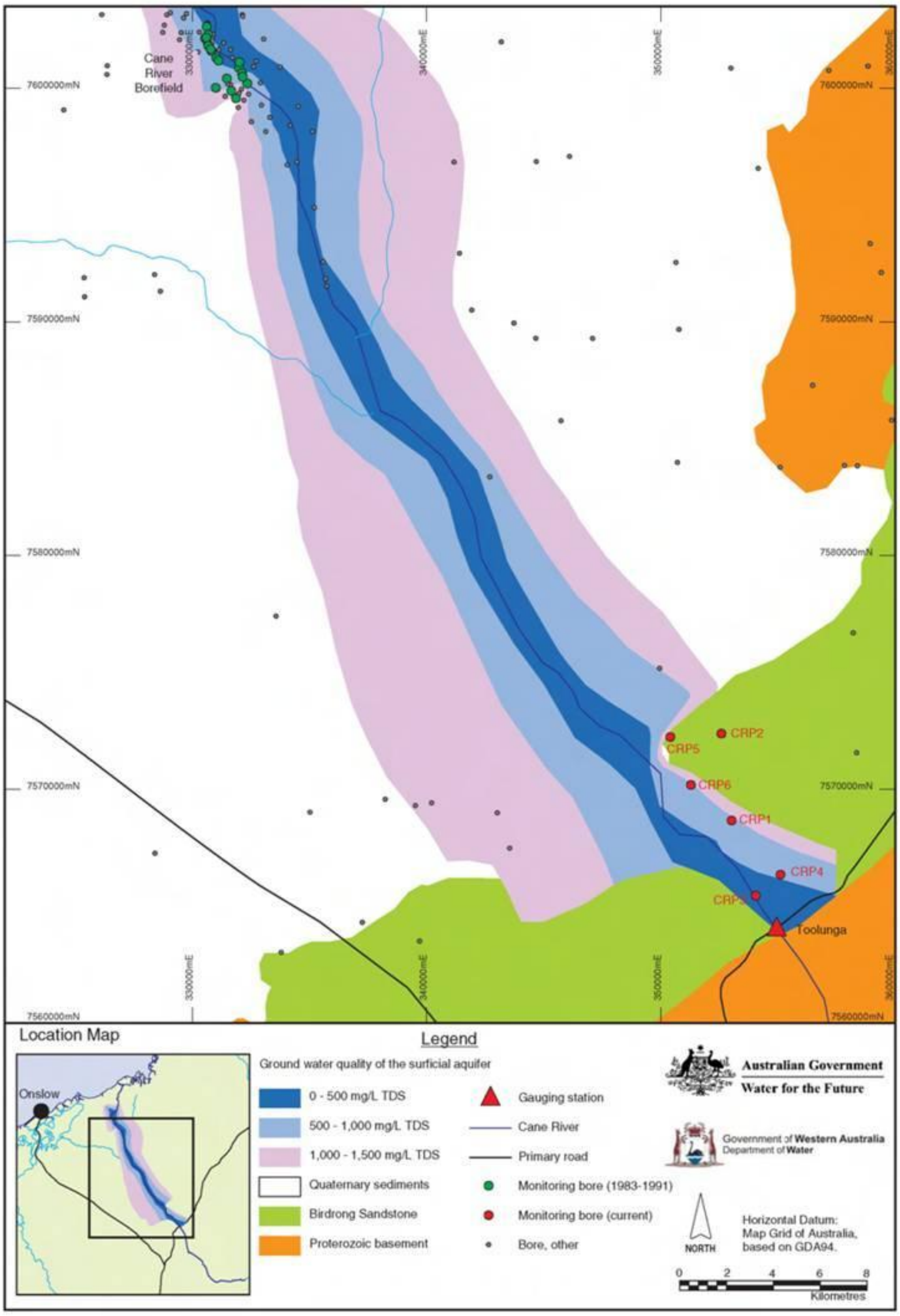

Figure 5 **Upper Cane River Area (after Haig, 2009)**

3.2.2 Geology

The geology and hydrogeology descriptions provided below are sourced from Haig (2009) and are based on the WRC investigation of the Upper Cane River area in 1994.

The general geology of the Birdrong Sandstone is described above in Section 3.1.2. Near the eastern margin of the Basin, the marine Flacourt Formation described above is not recognised, instead the fluviatile Yarraloola Conglomerate and continental to shallow marine Nanaturra Formation are present beneath the Birdrong Sandstone as time-equivalent facies of the Flacourt Formation (Figure 3). In the investigation area, drilling recorded a typical combined thickness of the Birdrong Sandstone and Yarraloola Conglomerate of about 30 m, located beneath about 30 m of overlying fine grained sediments of the Muderong Shale and/or Windalia Radiolarite.

Proterozoic quartzite outcrops to the east of the 1994 WRC investigation area, extending west beneath the Carnarvon Basin sediments. The quartzite is unconformably overlain by both Cretaceous sediments and Quaternary alluvial sediments. Overlying Quaternary sediments in the area consist predominantly of alluvium and eolian deposits 1 – 5 m thick.

3.2.3 Hydrogeology

The WRC investigation delineated two aquifers; the Birdrong/Yarraloola Aquifer and the underlying fractured quartzite bedrock aquifer. Whilst Haig (2009) describes these two aquifers separately, it is possible they form one confined to semi-confined aquifer system.

Groundwater levels in the aquifer were found to be from 10 to 30 m below ground, and about 10 – 20 m above the base of the confining Muderong Shale or 10 – 20 m above the water bearing zones in the fractured quartzite. Groundwater flow direction in the investigation area is north-easterly and generally away from the source of recharge – the Cane River.

Recharge is from the unconfined and outcropping portions of the Birdrong Sandstone. Minor recharge occurs from direct rainfall and most of the recharge is from river flow where the Cane River crosses the outcropping Birdrong Sandstone.

Individual bore yields from the Birdrong in the Upper Cane area ranged from 26 kL/day to 309 kL/day, and from 75 kL/day to 184 kL/day in the fractured quartzite aquifer. Haig (2009) considered the chances of developing a significant supply of potable water from this groundwater source to be limited.

Salinity within the Birdrong Sandstone varies over the investigation area, ranging from 890 mg/: to 3,450 mg/L (Haig 2009). The higher salinities were reported up to 2.5 km from the Cane River. Within the fractured quartzite aquifer, groundwater salinity was lower, ranging from 200 mg/L to 570 mg/L), but was expected to decrease away from the river.

3.2.4 DoW Allocation Status and Other Groundwater Users

There are no known licensed users of the Birdrong Sandstone or fractured quartzite aquifer in the 1994 WRC investigation area. However, this aquifer system, either in the WRC investigation area, or elsewhere along the inland margin of the Carnarvon Basin in the wider Onslow region, may be used by pastoral leaseholders for stock or domestic purposes. These users are not typically licensed by the DoW.

In terms of allocation status, the Birdrong Aquifer in the upper Cane River area would be considered as part of the confined aquifer resource as already discussed in Section 3.1.4.

3.3 Cane River Alluvium

The Lower Cane River borefield is located about 30 km east of Onslow Township (Figure 1) and is operated by the Water Corporation to provide the current potable water supply to Onslow.

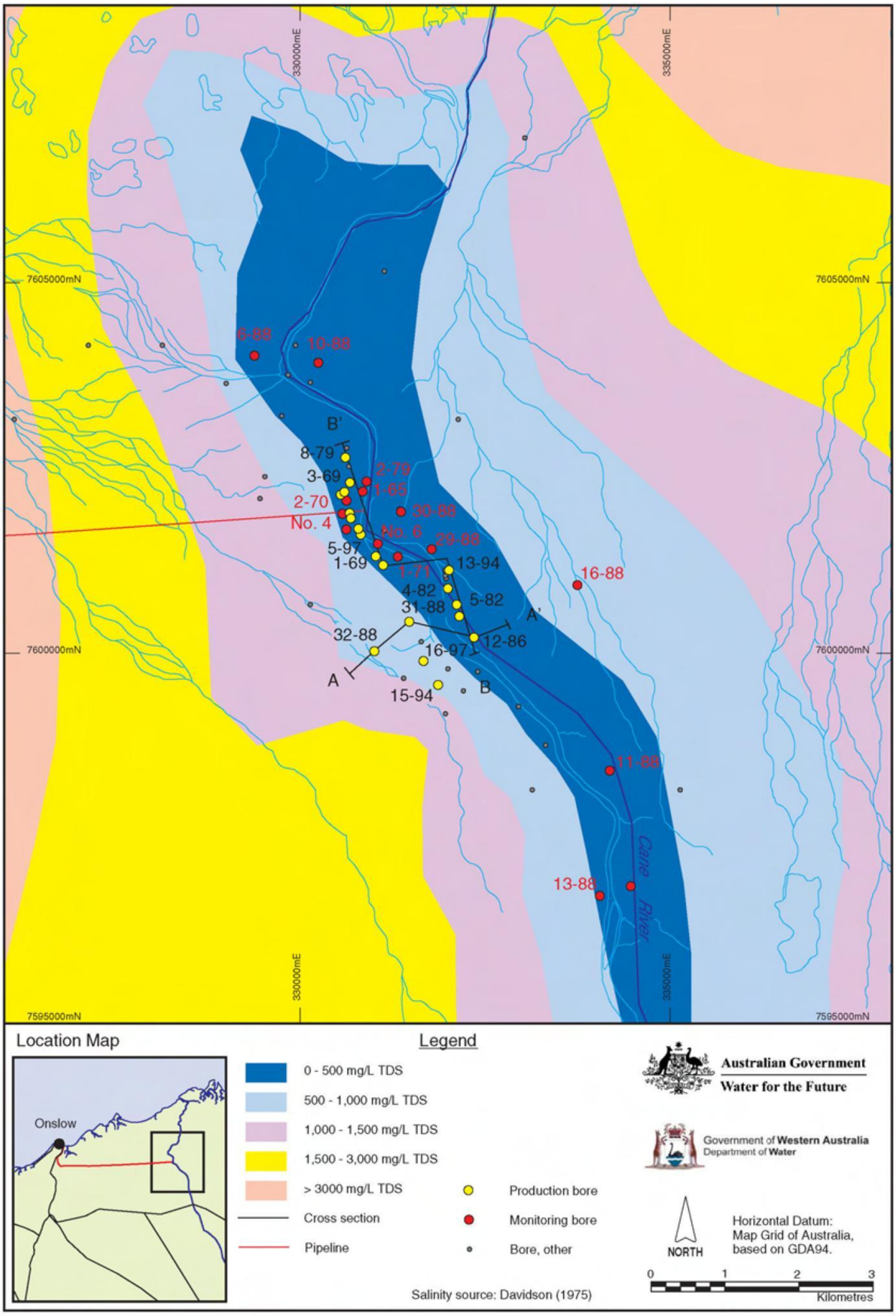

Figure 6 Cane River Borefield (after Haig, 2009)

3.3.1 Previous Investigations

Initially developed in 1955, development of the Cane River Borefield was limited to the northern side of the Cane River. These bores are currently still utilised (Rockwater, 2009).

From 1967 to 1997, there were several phases of groundwater investigations, geophysical surveys and production bore construction (Rockwater, 2009). This included expansion of the borefield in 1988 by the Western Australian Geological Survey to the south side of the river, to meet increased water demands.

In 2008, Rockwater conducted a drilling and test pumping program to assess the potential to further expand the Cane River borefield. Twelve exploration holes were drilled, intersecting the Cane River alluvium and Trealla Limestone.

3.3.2 Geology

The Lower Cane River flows over and through Quaternary alluvium of the coastal plain. The alluvium consists of poorly sorted silt, sand, gravel, clay and calcrete. The sand is commonly cemented to ferruginised sandstone (Rockwater, 2009). The alluvium has been observed up to 25 m thick, with lenses of sand and gravel limited to about 5 m thick (URS, 2009A).

The Quaternary alluvium unconformably overlies the Tertiary-aged Trealla Limestone. The limestone has alternating hard and soft layers (DoW, 2009).

3.3.3 Hydrogeology

Two aquifers are present in the Lower Cane River area; the Cane River Alluvial aquifer and the Trealla Limestone aquifer. The aquifers are hydraulically connected, with the alluvials having a saturated thickness ranging from 7 m to 18 m, averaging around 10 m (URS, 2009A).

Groundwater flows adjacent to the river, south to north. Depth to groundwater ranges from 15 m to 6 m due to the gradient of the land being shallower than the groundwater gradient (Martin 1989, cited in Haig 2009).

Recharge to the alluvial aquifer occurs mainly via river flooding, whilst recharge by direct infiltration of rainfall occurs to a lesser extent (Haig, 2009). Annual recharge was estimated at 4 GL/yr (Forrest and Coleman, 1996 cited by URS, 2008) and at 1.25 GL/yr (URS,2008). Recharge of the Trealla Limestone occurs via a downward hydraulic gradient from the alluvial aquifer. Recharge estimates for the combined aquifer system have not been conducted (DoW, 2009)

Discharge from the aquifer occurs downstream to the Indian Ocean and to the tidal flats (Haig, 2009), as well as the current borefield. An estimate of the overall (pre-pumping) discharge from the aquifer suggested 0.1 GL/yr of outflow occurred, per kilometre of length adjacent to the Cane River (Tomlinson, 1994, cited in Haig, 2009). This equates to a total of 4.0 GL/yr of outflow over the length of the aquifer from the Northwest Coastal Highway to the tidal flats.

Water quality within the Cane River aquifer is highly variable (Haig, 2009). Low salinity groundwater extends laterally about 2 km from the river. Water quality was reported as fresh to slightly brackish, ranging from 320 mg/L to 1,650 mg/L (Rockwater, 2009).

URS (2008) estimated the total area of the aquifer to be 1798 km^2, with a total storage of 697 GL.. Rockwater (2009) suggested that further borefield development could add an additional 0.4 GL/yr to the current capacity.

Bore yields appear to vary throughout the aquifer, dependant on the screen strata. Investigation yields ranged from very little to 170 kL/day (Martin 1989, cited in URS, 2009A). Rockwater (2009) reported air lift yields ranged from 40 kL/day to 260 kL/day.

The more significant yields from the borefield are apparent from the contact zone between the alluvium and the underlying limestone. Variable yields were reported in the limestone where bores targeted bedding plane partings, fractures and joints (URS, 2009A).

3.3.4 DoW Allocation Status and Other Groundwater Users

The Lower Cane River alluvial aquifer lies within the Ashburton subarea of the Pilbara groundwater area. The DoW has recently set the allocation limit to 1 GL/yr, with 0.9 GL/yr set aside for public water supply (Dow, 2011) for the resource area shown in Figure 7.

The DoW estimated an average annual groundwater outflow of 4.0 GL/year from the Cane River system, and following a risk-based approach, set the allocation limit to 25% of this outflow. Currently there is one licence holder (Water Corporation), licensed to 550 ML/yr.

The available (remaining) allocation available from this system (~ 450 ML/year) is insufficient to meet the base case project potable water capacity of 2.0 ML/day (~ 730 ML/year).

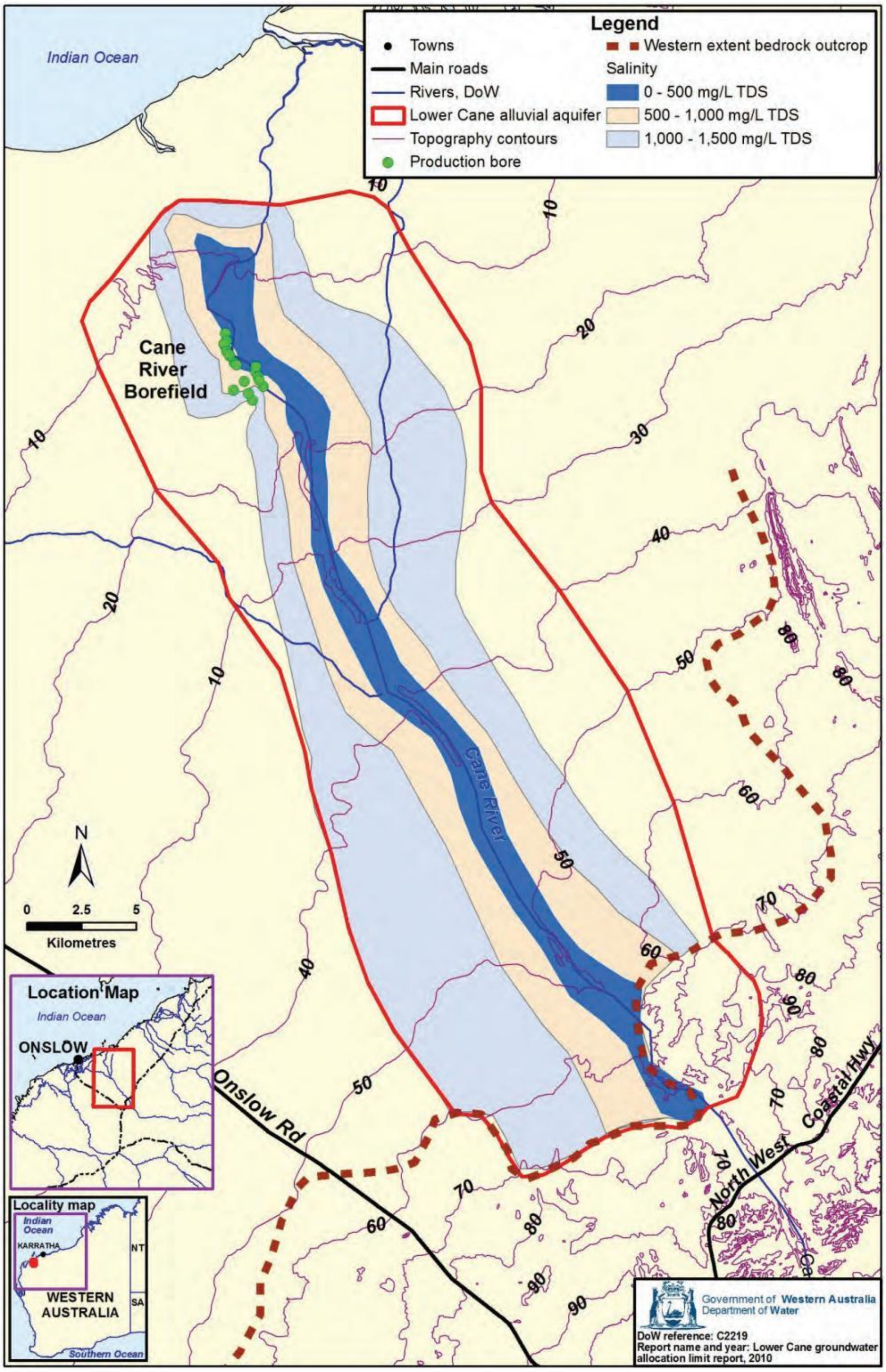

Figure 7 **Lower Cane River Alluvial Aquifer resource Boundary (after DoW, 2011)**

3.4 Ashburton River Alluvium

The lower Ashburton River flows northerly, traversing around 150 km of coastal plain. The mouth of the Ashburton River flows into the Indian Ocean, about 20 km west of Onslow Township.

3.4.1 Previous Investigations

Investigations into the water supply potential of the shallow alluvial aquifer associated with the Ashburton River were undertaken by the Water and Rivers Commission in 1994 (URS, 2009A) (DoW, 2011). The drilling and testing program focused on an area about 80 km south of the current Wheatstone Project Area, see Figure 8.

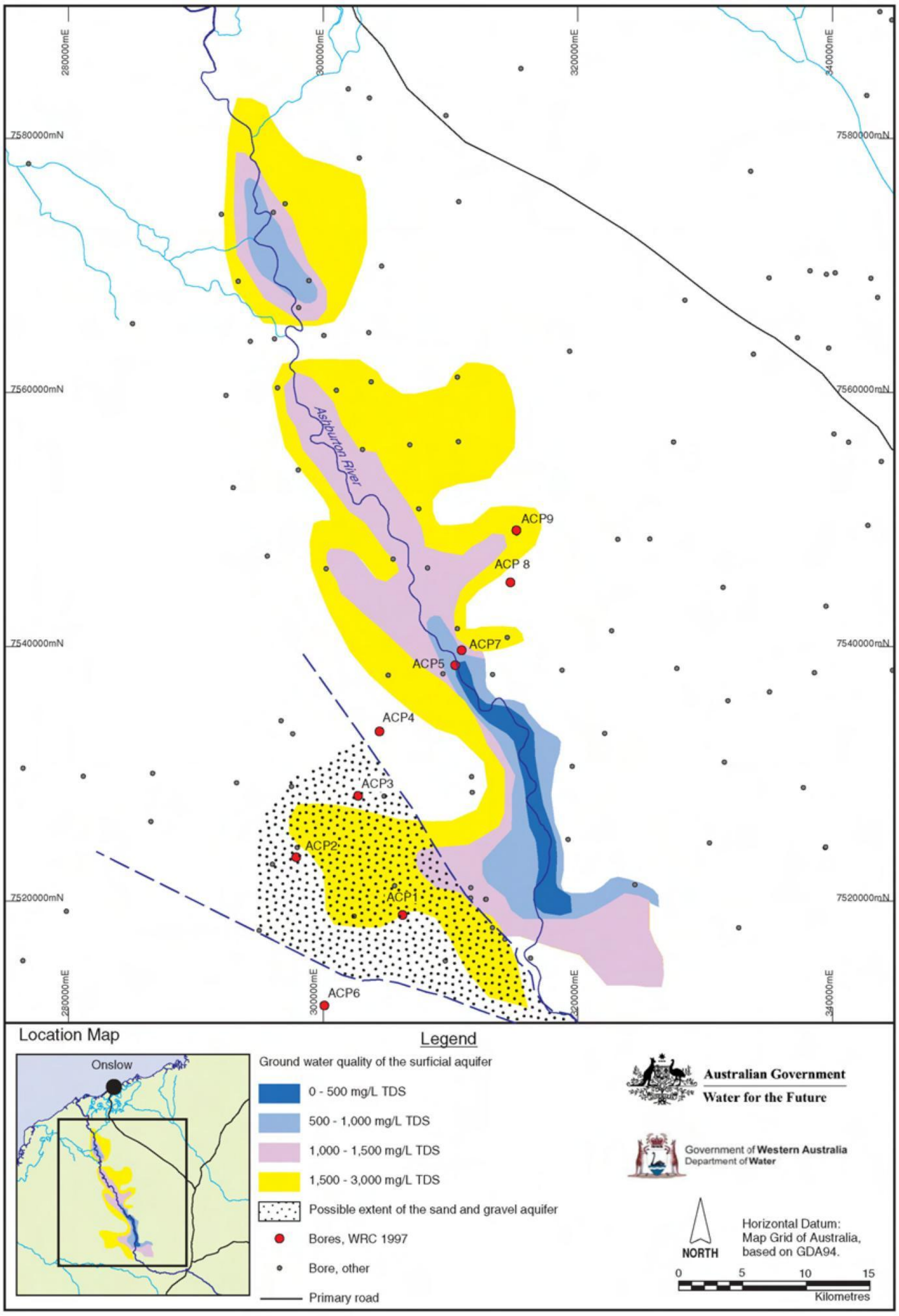

Figure 8 Ashburton River Area (after Haig, 2009)

3.4.2 Geology

The lower Ashburton River flows over the Onslow plain Quaternary alluvium. The Ashburton Alluvium is underlain by the Trealla Limestone; however the Trealla Limestone was not identified in previous investigations, in the Ashburton River area.

Haig (2009) summarised the Quaternary alluvium of the Ashburton River area as consisting of clay, calcrete, sand and gravel.

3.4.3 Hydrogeology

The major aquifer identified in previous investigations is formed of alluvial palaeochannel gravel and sand deposits of the ancient river bed. This is known to extend up to 18 km laterally from the Ashburton River. It is suggested that the ancient river deposits may also extend towards the coast (URS, 2009A).

The sand and gravel deposits are up to 37 m in thickness; with the basal 14 m saturated.

Recharge is expected to occur through direct infiltration along a short section of the river during flooding events (URS, 2009A).

Groundwater is of a sodium-chloride type, with salinity ranging from 2000 mg/L to 8000 mg/L in the investigated area. Limited supply of fresh groundwater is anticipated close to the river. It is expected that salinity increases towards the coast (URS, 2009A).

Regional yields from the Ashburton River alluvium have been recorded as poor. Investigation bores yield as much as 131 kL/day, typically ranging from 15 kL/day to 42 kL/day.

The aquifer is estimated to cover an area of approximately 100,000 km^2, of which about 40 km^2 is of a salinity less than 2000 mg/L. Storage is estimated at 100GL.

Potential individual bore yields are likely to be low, which would necessitate numerous bores to meet supply demands.

3.4.4 DoW Allocation Status and Other Groundwater Users

The Ashburton River alluvial aquifer lies within the Ashburton subarea of the Pilbara groundwater area. At present, an allocation limit has not been set for the Ashburton River alluvial. Assessment of the DoW WIN database sites suggests there are, or have been, minor users of the Ashburton River alluvial aquifer.

3.5 Quaternary and Tertiary Coastal Plain Sediments – Onslow

3.5.1 Previous Investigations

Rockwater was commissioned in 2009 to conduct investigations into the future water supply potential of the coastal plain alluvium in the area of Onslow. Rockwater undertook a drilling and testing program within the Coastal Plain Aquifer about three kilometres southwest of the town (Figure 10).

URS was commissioned in 2009 to conduct investigations into the hydrogeology of the Wheatstone LNG project area as part of the environmental impact assessments. Investigations comprised of drilling, testing and sampling programs of the Quaternary and Tertiary sediments throughout the Wheatstone LNG project area (Figure 10). Investigation results were published as a technical appendix (URS, 2010) to the Wheatstone ERMP document.

Coffey (2010), as part of their geotechnical studies of the Wheatstone LNG project area, undertook a pumping test of a water bore (BH504a) at the direction of Chevron, to test the 'beach well' water supply option concept. The location of the tested bore BH504a is shown on Figure 10.

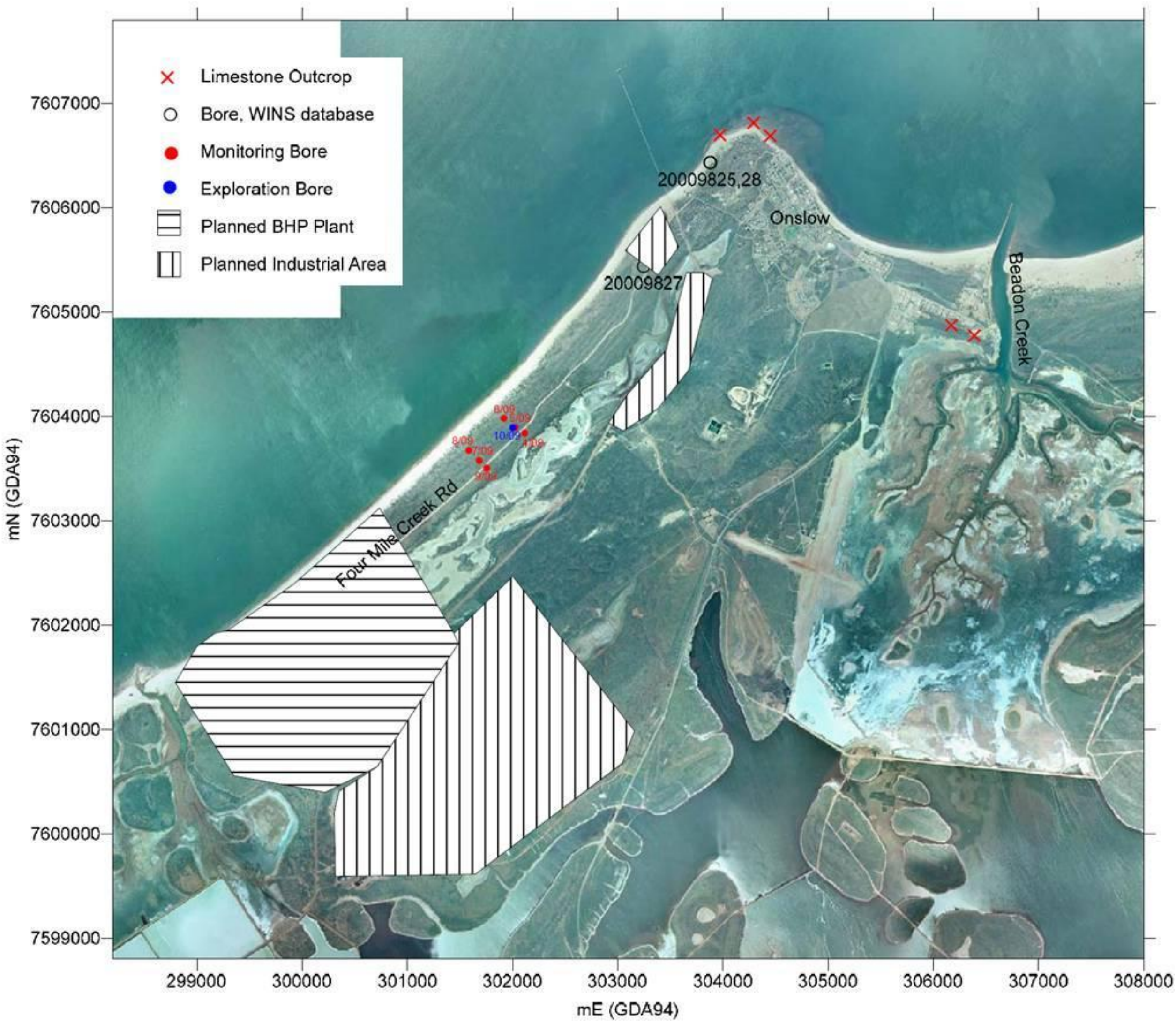

Figure 9 Onslow Coastal Locality Map (after Rockwater, 2009)

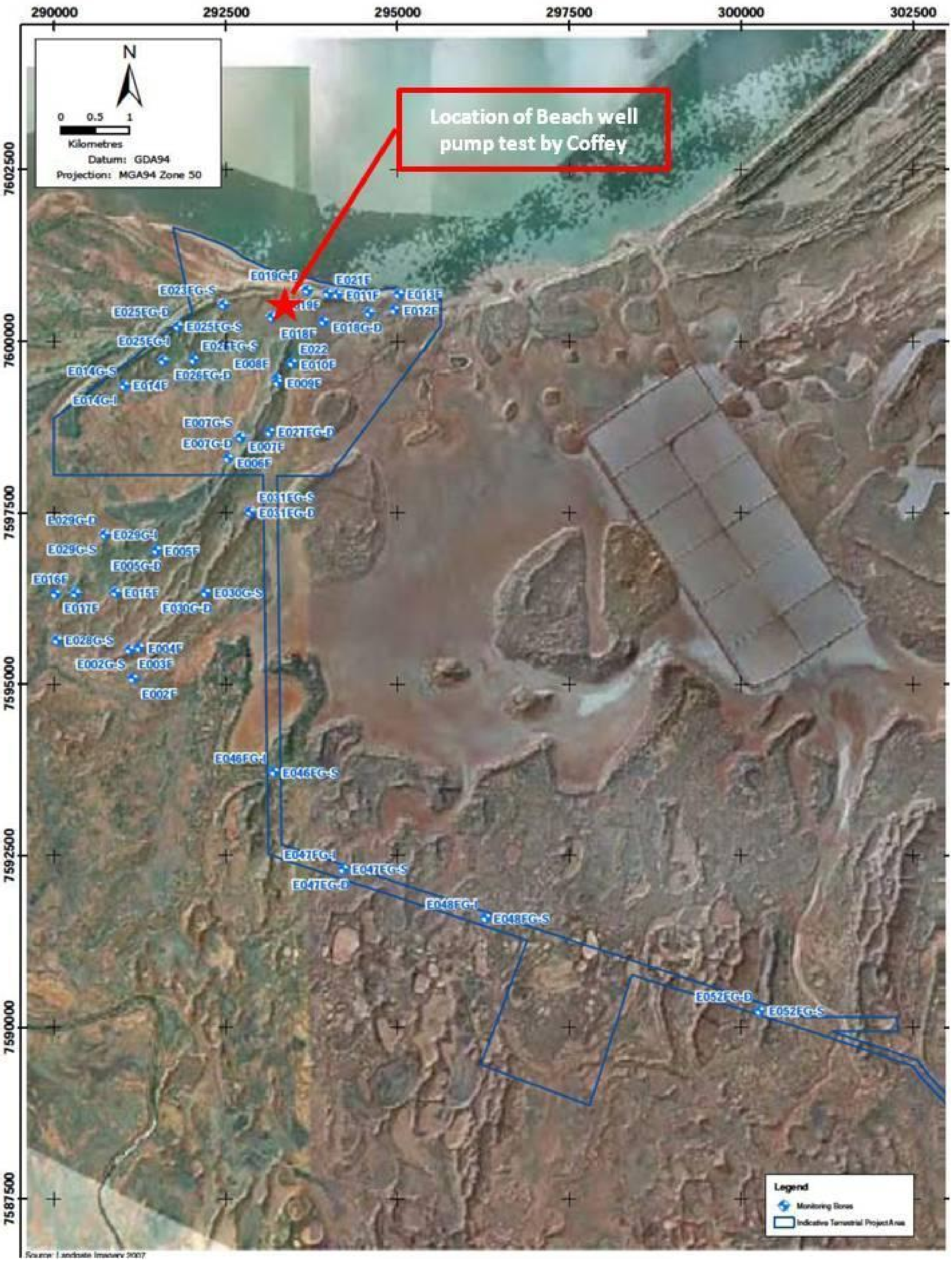

Figure 10 Bore Locations in Wheatstone LNG Project Area (after URS, 2010)

3.5.2 Geology

Quaternary superficial and alluvial sediments of the coastal plain overlie Tertiary and/or Cretaceous siltstone and claystone successions. The coastal plain alluvium consists of silty and sandy claystone, minor limestone and thin interbeds of calcarenite, calcilutite and calcisiltite. Sandy palaeochannel deposits, associated with the Ashburton River Delta are also present. These successions are poorly consolidated. The coastal alluvium is overlain by a cover of aeolian calcareous sands that forms small dunes (URS, 2009a).

Rockwater reported aeolian deposits and alluvium were intersected, consisting of dunal sands, clay, sand and gravel in varying proportions, to depths ranging up to 39 m. Beneath the superficial formations is Tertiary limestone and sandstone (Trealla Limestone), with a variable thickness of 60 m (URS, 2010).

3.5.3 Hydrogeology

Groundwater typically occurs in each of the alluvial successions formed by the Quaternary and Tertiary sediments, with groundwater levels typically less than 10 mbgl in inland areas and within a few metres of ground surface near the coast.

Airlift yields within the Quaternary sediments drilled by Rockwater ranged from 10 kL/day to 260 kL/day, whilst salinities recorded in the Quarternary sediments ranged between about 32,000 – 74,000 mg/L TDS. Only one drillhole (10/09) was drilled by Rockwater into the underlying Tertiary Trealla Limestone; this bore recorded a maximum airlift yield of 170 kL/day and a final salinity of about 35,000 mg/L. The Rockwater programme did not involve any pumping tests, which provide more reliable estimates of bore yields than airlifting.

Rockwater (2009) state that "*Only small to moderate groundwater supplies are indicated to be available from the coastal sand/calcarenite/gravel aquifer, although yields from production bores would be somewhat higher than from 144 mm-diameter air-core drillholes. Also, the water is commonly more saline than seawater and the salinity could increase with pumping if water is drawn in from beneath the swale to the east. This would be countered by inflows of seawater from the ocean*".

URS (2010) concluded the following hydrogeology aspects of the Wheatstone LNG project area:

- *A shallow water table, predominantly saline to hypersaline*.
- *The area predominantly represents a groundwater discharge zone associated with* (deeper) *regional Carnarvon Basin successions, although local exceptions occur seasonally, when the* (surficial*) dunal terrain intercepts and transmits rainfall recharge.*
- Has the following typical vertical profile with regard to hydrostratigraphy, transmissivity and salinity:
  - *Shallow dunal sands; 3m thick; transmissivity 10 – 30 m^2/day, salinity 20,000 – 120,000 mg/L TDS;*
  - *Ashburton River Delta alluvium; 20 m thick; transmissivity about 10 m^2/day, 50,000 – 150,000 mg/L TDS*
  - *Ashburton River Delta clays; 5 m thick; transmissivity 2 m^2/day; and*
  - *Trealla Limestone; 10 m thick; transmissivity 2 m^2/day, salinity of 156,000 to 200,000 mg/L TDS.*
- *Local groundwater flow is influenced by topography and also density effects*.
- *Dissolved metal concentrations in many of the installed monitoring bores are above marine ANZECC Guidelines, the comparatively high levels are commensurate with the accumulation of salt in the local groundwater environment and the high groundwater salinity*.

Coffey (2010) installed several monitoring bores and one test production bore within about 250 to 400 m of the shoreline in the Wheatstone LNG project area in 2009 (Figure 10) as part of testing the concept of 'beach wells' as an alternative seawater intake mechanism for seawater desalination. The test production bore (BH504a) was screened across 10 m of sands and clays from 5.5 – 15.5 mbgl, effectively within the hydrostratigraphy defined by URS (2010) as Ashburton River Delta Alluvium. Based on the bore construction, this investigation, which was presumably done as a test of the beach well concept, does not reconcile with, or adequately test, the concept of beach well supply option as discussed by URS (2009 a,b). This discrepancy is discussed in more detail below in Section 3.5.5.

Bore 504a underwent a 2-step step-drawdown test and a 24 hour constant rate test (at 432 kL/day) in September 2009 and included collection of water samples and subsequent chemical analyses. The testing by Coffey (2010) concluded:

- *Groundwater salinity is strongly stratified; being about 30,000 mg/L TDS in the upper six metres of the aquifer and then increasing rapidly to over 100,000 mg/L near the base of the screened interval.* The salinity of abstracted water during the test was typically about 60,000 mg/L, indicating a mixing of the relatively shallow and deeper groundwater.
- *The test period was not of sufficient duration to detect seawater intrusion into the aquifer.*

- *The average hydraulic conductivity of the tested hydrostratigraphy is 3 to 4 m/day.*
- *The presence of shallow hypersaline aquifers in the nearby vicinity suggests that long term abstraction from a well field may draw in hypersaline water*.

Consideration of the various data suggests that bore BH504A may be located in area with slightly more transmissive shallow sediments than other sites and that the pumping rate of 432 kL/day (5 L/sec) was probably not sustainable.

A better analogue for testing of the shallow beach well concept may be from a test production bore constructed only within the shallow dunal sands (E022), located about 800 m south of the bore tested by Coffey. This bore was test-pumped by URS for 48 hours in September 2009, at a rate of 87 kL/day and produced 2.6 m of drawdown in the pumped bore at the end of the test. Water salinity throughout the test was typically about 87,000 mg/L TDS.

The investigations by Rockwater (2009), URS (2010) and Coffey (2010) indicate that the Quaternary sediments and groundwater systems are relatively complex and variable. The work to date suggests the distribution and nature of the underlying Tertiary Trealla Limestone aquifer may not be as complex but still involves significant variability.

3.5.4 DoW Allocation Status and Other Groundwater Users

The Coastal Plain sediments aquifer lies within the Ashburton subarea of the Pilbara groundwater area. At present, an allocation limit has not been set for the Coastal Plain sediments. Assessment of the DoW WIN database sites suggests there are no current users of the Coastal Plain sediments aquifer.

3.5.5 Previously Reported Water Supply Options within the Coastal Plain Sediments

It is important to understand that groundwater and seawater could potentially be abstracted from coastal plain sediments in varying proportions depending on the location, depth and design of abstraction infrastructure. In the context of water supplies for the Wheatstone LNG project, this has been recognised in the various water supply studies completed to date by URS, Bechtel and Coffey. The concept of near-shore beach wells as a potential water source option has been specifically raised by the Chevron Wheatstone Social Infrastructure team.

This section provides a brief discussion and reconciliation of the URS, Bechtel and Coffey work, as it is apparent there are potential inconsistencies and a lack of clarity between the definitions and assessments of shallow beach wells as a supply option.

The 2009 Bechtel study, which considered a freshwater demand of 0.67 ML/day for use in LNG processing, concluded that shallow beach wells were the preferred option for seawater intake to minimize environmental impacts and impingement of marine life. Based on a desktop study of presumably other sites, Bechtel concluded that shallow vertical beach wells could abstract up to 4.8 ML/day and one radial well could abstract up to 24 ML/day. AECOM considers these nominated abstraction rates to be applicable only to the simple hydrogeological setting where an extensive and continuous (laterally and vertically) distribution of sand exists beneath the shoreline and adjacent inland areas. This is not the case in the Wheatstone project area based on URS studies (2010), which have shown the existence of fine grained clayey sediments at shallow depths and that the hydraulic connection of seawater to potential abstraction points just inland of the shoreline may be limited (and that hypersaline groundwater would be preferentially abstracted instead).Bechtel clarified their conclusions and recommendations by stating that if the geotechnical test shows that the formation is not suitable or transmissivity is too low, then an open seawater intake should be used.

Presumably on the basis of the 2009 Bechtel work, URS was asked by Chevron to comment on the likely amounts of groundwater that could be sourced from beach wells, an assessment of the number and location of wells and any potential regulatory and permitting issues. URS (2009b) concluded that ‘beach well’ abstraction from the shallow dunal sand, seawater interface:

- Would involve numerous low-yielding bores given the low transmissivity of shallow sediments near the seawater interface (potentially up to 184 wells to abstract a total of 1.59 ML/day.
- Could potentially be alternatively undertaken by installation of a shallow trench of the order of 1,000 m long.
- May not reliably intercept seawater but instead predominantly intercept saline to hypersaline groundwater.

URS (2009b) indicated that higher yields could be obtained at lower costs from the deeper alluvium and/or Trealla Limestone formations compared to the uppermost watertable / seawater interface setting.

The bore installed and tested by Coffey does not represent the generic beach well concept as described or implied by Bechtel (2009), or as evaluated by URS (2009b). Instead it represents an abstraction regime from the shallow water table setting and also the deeper alluvium. Based on the Coffey test-pumping it is likely that most bores installed into the deeper alluvium would only be capable of abstraction rates of the order of 90 – 270 kL/day and that abstraction from such a setting would produce groundwater salinities significantly in excess of seawater (of the order of 50,000 – 75,000 mg/L TDS).

3.6 Robe River Alluvium

The Robe River alluvium of the Ashburton Plain lies about 80 km east of Onslow, see Figure 1.

3.6.1 Previous Investigations

Commander, 1994 reported previsions investigations by Broken Hill Proprietary Company (BHP) and the State Energy Commission.

In 1965, BHP drilled 19 exploratory water bores in the area. Investigations intersected a maximum thickness of 18 m of saturated alluvium. Bore yields ranged up to 1000 kL/day, groundwater salinity was between 900 mg/L and 1400 mg/L TDS.

In 1982, the SEC drilled two bores into the Robe River alluvium to provide water for hydrostatic testing of the Dampier-Perth natural gas pipeline. Bores yielded 1000 kL/day; groundwater salinity was about 500 mg/L.

In 1983, the Geological Survey of Western Australia carried out an exploratory drilling and test pumping program of the Robe River alluvium, during an assessment of groundwater supplies for towns along the Pilbara coast (Commander, 1994). Twenty-two sites were investigated to delineate the extent of the aquifer. Exploration of the alluvium ranged between 18.5 m to 66 m deep. Pumping tests included a six stage step-drawdown test followed by an eight hour constant rate test. Constant test rates between 980 kL/day and 1,340 kL/day were used. During the investigation, groundwater levels were monitored at intervals between 2 weeks and 3 months; depending on the flow stage of the river. It was concluded that the alluvial gravels underlying and adjacent to the Robe River are a significant source of fresh groundwater in the region, and that the resource is sufficiently large to supply a town or support irrigated agriculture.

SKM modelled the alluvial aquifer of the Lower Robe Alluvium using a FEFLOW finite element model. The model was calibrated by matching predicted data with observed data through 1984 to 2008. It was regarded that the evapotranspiration flux in the model was considered an indicator of the water availability to groundwater dependent vegetation. Impacts were estimated for a range of groundwater extraction rates from 5 GL/yr to 12 GL/yr. Modelled drawdown as a result of the different extraction rates resulted in a consequent reduction in evapotranspiration between 4 GL/yr and 8 GL/yr. The reduction in evapotranspiration represents a 6% to 11% reduction in groundwater available for groundwater dependent ecosystems.

The model predicted that extraction within the modelled range is unlikely to expand a drawdown cone to the coast and cause further salt water intrusion.

Sensitivity analysis suggested that model predictions were considered relatively uncertain.

3.6.2 Geology

The investigation area lies mainly within the Phanerozoic Carnarvon Basin but also extends to the Precambrian Ashburton Basin. The Carnarvon basin, formed on the western margin of the Pilbara Craton, contains relatively unconsolidated, gently dipping Cretaceous sediments.

Overlying the Cretaceous and Proterozoic rocks are Tertiary and Quaternary sediments.

The Trealla Limestone, which extends over much of the coastal plain, lies un-conformably over pisolitic limonite or Cretaceous sediments. The formation ranges from a fine crystalline limestone to a pale, cream and yellow clay, often with a greenish tinge. The maximum thickness encountered during investigations at the Robe River was 17m. The Trealla Limestone is un-conformably overlain by the Quaternary alluvium.

Flood deposits of the Robe River, up to 30m thick cover the coastal plain and form a delta at the mouth of the river (Commander, 1994). The sediments are mainly predominantly over-bank deposits of clay and silt. Gravel bed-load deposits outcrop in the river bed, and occur in the subsurface within 3 km of the river, where they are concealed by over-bank deposits.

The gravel beds consisted of rounded tabular pebbled of banded chert and jaspilite, up to 100 mm diameter and 50 mm thick, with rounded pebbles of basalt and quartz. The gravel is generally loose, with some surface cementation observed near semi-permanent river pools (Commander, 1994).

The gravel bed appears thickest closest to the North West coastal highway, thinning laterally, away from the river and also progressively downstream. The gravel bed is interbedded with clay (Commander, 1994). The clay and silt are generally reddish brown, indurated, and contain local thin layers of fine pebbles and grains of jaspilite and basalt (Commander, 1994). Pisolitic ironstone, probably derived from the Robe Pisolite is present at the base of the gravel sequence in the absence of the Trealla Limestone (Commander, 1994). Within the alluvium, widespread calcretion has occurred close to and up to 5 m below the water table. Gravel deposits are generally unaffected (Commander, 1994).

3.6.3 Hydrogeology

The gravel of the Robe River alluvium forms a major aquifer, and is thickest and deepest adjacent to the Robe River, grading laterally into floodplain silts and clays, which have a very much lower transmissivity (Commander, 1994). Figure 10 shows the area previously investigated.

The investigated area of the Robe River alluvium showed a maximum of 13 m of saturated gravels, thinning to less than 4 m downstream. The gravel is exposed only in the river bed, elsewhere it is covered by between 2 m and 5 m of overbank silt (Commander, 1994).

The alluvium overlies relatively impermeably Tertiary, Cretaceous and Proterozoic rocks. In the Robe River area, the Trealla Limestone is mostly clayey and impermeable, however fissured limestone was found within the investigated area. The permeability of the Robe Pisolite is low in the Robe River area.

The watertable is generally between 5 m and 9 m below ground and slopes away from the river, depending on the time elapsed since it last flowed.

Recharge occurs through direct infiltration through the river bed during periods of flow. The quantity of recharge depends of the frequency, size and duration of the flows. URS (2008) estimated recharge at 10 GL/yr. The floodplain silts are likely recharged mainly by local rainfall and runoff. Groundwater flows downstream discharges through transpiration from thick vegetation occupying the river bed. Evaporation of groundwater through the unsaturated zone also occurs in this area. It is expected that leakage from the Robe River alluvium to the underlying units is likely to be very small.

Groundwater in the alluvial gravels flows in a general northwest direction, in line with the river. During periods of flow, a groundwater mound builds up beneath the river bed, as recharge occurs, and lateral flow increases away from the river. Commander (1994) reported an average horizontal hydraulic conductivity of 25 m/day.

Groundwater of the Robe River alluvium is of a low salinity. Near the river salinity is generally below 500 mg/L, ranging to about 1300 mg/L at the margins of the gravel beds. Salinity of the resources is related to the salinity of the recharge water from the river, and increases laterally dur to mixing with higher salinity water from the floodplain deposits.

Salinity generally decreases with depth below the water table. This is believed to be associated with evapotranspiration.

Commander states that the area considered most suitable for development is a 2 km wide by 7 km long area extending along the river about 10 km north west of where the North West Coastal Highway crosses the Robe River. Saturated thickness in this area was at least 5 m and the salinity range was 450-750 mg/L at the time of investigations.

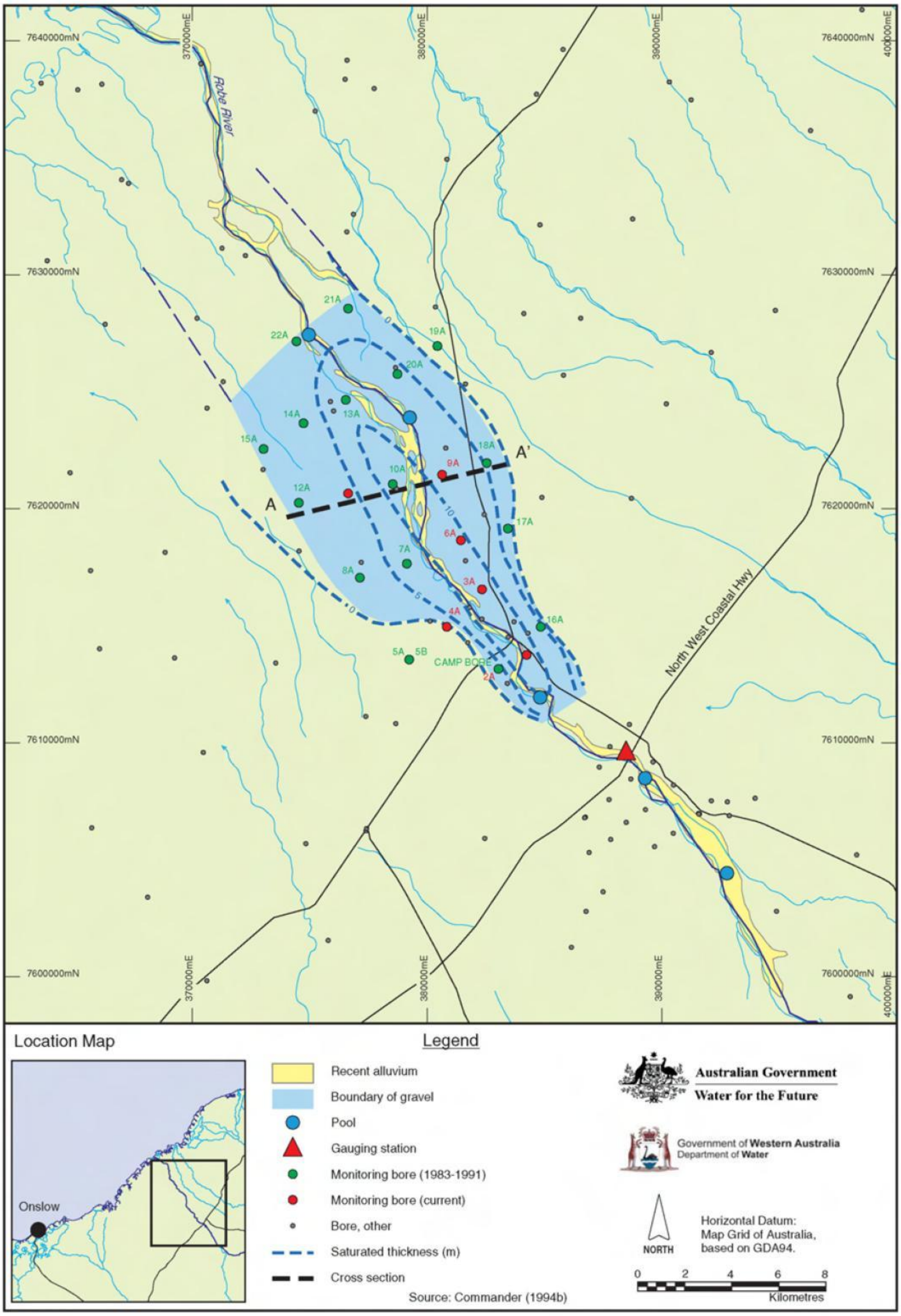

Figure 11 Lower Robe River (after Haig, 2009)

Bore yields demonstrated were between 1000-1300 kL/day, however in some locations, potential yield was projected to be 3000 kL/day.

Aquifer yield is dictated by recharge from Robe River flow. Recharge volume depends on the duration of flow and storage level in the aquifer. Estimated recharge (based on the decline in storage over a year of no river flow) and the limitation of river flow suggest that 10 GL is a reasonable upper limit for annual abstraction. Estimated groundwater in storage, 70 GL, could be utilized in periods of below average runoff.

3.6.4 DoW Allocation Status and Other Groundwater Users

The Robe River alluvial aquifer lies within the Ashburton subarea of the Pilbara groundwater area. Currently no allocation limit has been set for the Robe River. However, the Robe River has been targeted by the DoW as a resource that requires allocation. An allocation plan for the Pilbara area, due for public comment May 2012, will include DoW’s allocation limit on the Rove River alluvial aquifer.

An inspection of the WIN database suggests that there are currently small scale private users of the Robe River alluvial aquifer.

3.7 Summary of Water Sources

Summary information on each of the identified water sources are provided in Table 4.

Table 4 Water Sources – Summary Information

Aspect	Groundwater Source							
	Birdrong Aquifer – Onslow	Birdrong Aquifer – Upper Cane River	Coastal Plain Sediments –Dunal Sands Beach Wells	Coastal Plain Sediments – Alluvium	Coastal Plain Sediments – Trealla Limestone	Cane River Alluvial Aquifer	Ashburton River Alluvial Aquifer	Lower Robe River Alluvial Aquifer
Approximate Distance from Onslow	Beneath project area	50 – 60 km SE	Beneath project area	Beneath project area	Beneath project area	30 – 50 km E, SE	70 – 90 km S	80 – 90 km E, NE
Potential or Known Depth to top of Aquifer (m)	~ 500	20 - 30	< 5	5 – 10	25 – 40	5 - 15	10 - 25	5 - 10
Potential or Known Thickness of Aquifer (m)	~ 17 - 34	~ 30	< 5	20 – 30	10 – 30	10 - 15	10 - 20	5 - 15
Aquifer type	Confined	Unconfined – semi-confined	Unconfined	Unconfined – semi-confined	Confined – semi-confined	Unconfined	Unconfined – semi-confined	Unconfined
Potential or Known Aquifer Transmissivity (m^2/day)	20 - 200	Not known	10 – 30	20 – 30	10 – 30	20 – 200	20 - 200	50 - 300
Current Groundwater Levels (mbgl)	uncertain, potentially artesian; -10 to 10	10 - 30	< 5	5 – 10	5 – 10	5 - 15	10 - 25	5 - 10
Typical or Potential Groundwater Salinity (mg/L TDS)	6,000 – 20,000	300 – 3,500	25,000 – 75,000	35,000 – 125,000	75,000 – 150,000	300 – 1,700	2,000 – 8,000	500 – 1,300
Potential Individual Bore Yields (ML/day)	1 - 4	0.15 – 0.3	0.017 – 0.17	0.08 – 0.35	0.08 – 0.35	0.15 – 0.5	0.1 – 0.5	0.75 – 1.5
Assumed source demand for 2 ML/day system (ML/day)	3.33	2	6.66	> 6.66	>>6.66	2	3.33	2
Assumed source demand for 4 ML/day system (ML/day)	6.66	4	13.3	> 13.3xx	>>13.3	4	6.66	4
Current DoW Allocation Limit (ML/year)	300	300	1,650,000	1,650,000	1,650,000	1,000	not set	Not set (due in mid-2012)
Current Licensed and Reserved Allocations (ML/year)	270	270	1,294,000	1,294,000	1,294,000	900	n/a	n/a

Notes 1. ML = megalitre, GL = Gigalitres

4.0 Alternative Water Source Reliability Assessment

4.1 Criteria

At a meeting between Chevron and AECOM on 8 March 2012, an approach to assessing the various water sources identified by this study was developed for determining which sources should be further assessed as potential supply alternatives to the current base case of seawater desalination.

Initially, the assessment of the identified water sources is to be based on criteria that define the 'reliability' of the sources as options in terms of the:

- Extent to which the physical characteristics of the source are known and suitable for the requirements of the project.
- The potential environmental and regulatory issues likely to be associated with each source and the probability of securing a licensed water allocation from the Department of Water.
- Long term viability and sustainability of the source. The definition of long-term has been taken from current Water Corporation design standards for potable water supply systems, which range between 50 – 100 years depending on the system component.

Application of the above reliability criteria will form a 'first filter' intended to remove any unsuitable options from any further consideration. Subsequent to this filtering, remaining options will be assessed against other criteria that will comprise:

- Time and cost criteria for securing and developing each water source option.
- Capital and operating cost-benefit analyses of each option in comparison to the base case sea water desalination system.
- Water quality and water conditioning criteria for the water treatment and supply system (these are yet to be fully defined).

This report only considers the first filter stage involving reliability criteria and does so for both the base case potable water supply system capacity of 2 ML/day and the potential longer-term capacity requirement of 4 ML/day.

Application of the reliability criteria is complicated by the variable levels of uncertainty associated with the current understanding of the different sources. Consequently, qualitative definitions of uncertainty have been applied to each reliability criteria, these are provided in Table 5.

An important aspect of the reliability assessment are the potential volumes of feed water to a desalination system for brackish and saline water. Assumed recoveries and resultant feed water rates are provided in Table 6.

4.2 Results

The assignment of the reliability criteria and uncertainty levels are provided in Table 7 for the 2 ML/day potable supply system and Table 8 for the 4 ML/day system.

Table 5 Uncertainty Definitions

Uncertainty Level	Reliability Criteria	Definition
Very High	Physical presence	No project area or regional field-based investigations completed
	Water Licence	n/a
	Long-term viability	n/a
High	Physical presence	No project area field-based investigations completed, but some relevant regional investigations completed and/or indirect data available
	Water Licence	Water source not recognised within current allocation system and/or significant potential for adverse impacts on existing environmental water values or other users
	Long-term viability	Assigned to a source that is poorly defined or understood, notably in terms of recharge mechanisms and details
Moderate	Physical presence	Limited field investigations of project area completed, supported by relevant regional investigations and/or indirect data
	Water Licence	Water source not recognised within current allocation system and/or potential for adverse impacts on existing environmental water values or other users
	Long-term viability	Assigned to a source that is reasonably well understood
Low	Physical presence	Significant field-based investigations completed in project area and regional area
	Water Licence	Water source recognised within current allocation system and/or no or limited potential for adverse impacts on existing environmental water values or other users
	Long-term viability	Assigned for a source that is well understood, notably recharge sources and mechanisms
Very Low	Physical presence	Extensive field-based investigations completed in project area
	Water Licence	n/a
	Long-term viability	n/a

Table 6 Assumptions for feed water to desalination system

Item	Unit	Brackish	Saline
Salinity	mg/L	2,000 – 20,000	20,000 – 40,000
Assumed net recovery efficiency	%	60	30
Average feed water rate required for 2 ML/day system	L/sec	38.5	77.2
	ML/day	3.33	6.66
	GL/year	1.22	2.43
Average feed water rate required for 4 ML/day system	L/sec	77.2	154.2
	ML/day	6.66	13.33
	GL/year	2.43	4.87

Table 7 Water Source Reliability Assessment – 2 ML/day Potable Supply System,

Factor	Seawater Desalination Base Case	Potential Alternative Water Source							
		Birdrong Aquifer – Onslow	Birdrong Aquifer – Upper Cane River	Coastal Plain Sediments – Dunal Sands Beach Wells	Coastal Plain Sediments – Alluvium	Coastal Plain Sediments – Trealla Limestone	Cane River Alluvial Aquifer	Ashburton River Alluvial Aquifer	Lower Robe River Alluvial Aquifer
Summary Source Information									
Potential or known salinity of source (mg/L TDS)	~35,000	6,000 – 20,000	300 – 3,500	25,000 – 75,000	35,000 – 125,000	75,000 – 150,000	300 – 1,700	2,000 – 8,000	500 – 1,300
Potential Source Volumes required (GL/year)[1]	2.43	~ 1.22	0.73	>2.43	>2.43	>>2.43	0.73	~1.22	0.73
Physical Characteristics Criteria									
Is source well defined ?	yes	no	no	yes	Yes	no	yes	no	yes
Probability of adequate source yields	certain	moderate - high	low - moderate	moderate - high	moderate - high	moderate - high	low – moderate	moderate	v. high
Salinity compared to seawater base case	n/a same	favourable, potentially 2 to 3 times lower	very favourable, fresh to brackish resource	Similar to seawater, but significant proportions unfavourable, potentially up to 2 times higher than seawater	unfavourable, potentially up to 3 times higher than seawater	unfavourable, potentially up to 3 – 4 times higher than seawater	very favourable, fresh to brackish resource	favourable, fresh to brackish resource	very favourable, fresh to brackish resource
Potential number of bores to meet required volumes	n/a	1 – 2	7 - 15	50 - 200	25 - 100	40 - 150	5 - 15	10 - 30	3 - 5
Overall uncertainty level	v. low	moderate - high	low - moderate	low	low	low - moderate	low	moderate - high	low
Water Licensing Criteria									
Source included in current DoW allocation system?	n/a	yes	uncertain	yes	yes	uncertain	yes	no	yes (in mid-2012)
Sufficient available allocations exist to meet potential source volumes required?	n/a	no	n/a	no	no	n/a	no	n/a	yes
Probability of securing required 5C Licence from DoW	n/a	high	low	moderate	moderate - high	high	v. low	moderate - high	high
Overall uncertainty level	n/a	moderate	low	moderate	moderate	low	low	low	low
Long-term Viability Criteria									
Potential for significant declines to source water levels and yields	nil	low - moderate	moderate	low	low	low	moderate	low	low
Potential for adverse changes to water salinity and quality	nil	low - moderate	low	low	low	low	moderate	low - moderate	low
Overall uncertainty level	n/a	high	high	low -moderate	low-moderate	moderate	low	moderate	low

Notes 1. GL = Gigalitres

Table 8 Water Source Reliability Assessment – 4 ML/day Potable Supply System

Factor	Seawater Desalination Base Case	Potential Alternative Water Source							
		Birdrong Aquifer – Onslow	Birdrong Aquifer – Upper Cane River	Coastal Plain Sediments – Beach Wells	Coastal Plain Sediments – Alluvium	Coastal Plain Sediments – Trealla Limestone	Cane River Alluvial Aquifer	Ashburton River Alluvial Aquifer	Lower Robe River Alluvial Aquifer
Summary Source Information									
Salinity of Source (mg/L TDS)	~35,000	6,000 – 20,000	300 – 3,500	40,000 – 70,000	50,000 – 75,000	> 75,000	300 – 1,700	2,000 – 8,000	500 – 1,300
Potential Source Volumes required (GL/year)[1]	***4.87***[2]	***~ 2.43***	***1.46***	***>4.87***	***>4.87***	***>>4.87***	***1.46***	***~2.43***	***1.46***
Physical Characteristics Criteria									
Is source well defined ?	yes	no	no	yes	yes	no	yes	no	yes
Probability of adequate source yields	certain	***moderate***	***low***	moderate - high	moderate - high	moderate - high	low – moderate	moderate	v. high
Salinity compared to seawater base case	n/a same	favourable, potentially 2 to 3 times lower	very favourable, fresh to brackish resource	unfavourable, potentially up to 2 times higher than seawater	unfavourable, potentially up to 2 times higher than seawater	unfavourable, potentially up to 3 – 4 times higher than seawater	very favourable, fresh to brackish resource	favourable, fresh to brackish resource	very favourable, fresh to brackish resource
Potential number of bores to meet required volumes	n/a	***2 – 5***	***15 - 30***	***100 - 400***	***50 - 200***	***80 - 300***	***10 - 30***	***20 - 60***	***6 - 10***
Overall uncertainty level	v. low	moderate - high	low - moderate	low	low	low - moderate	low	moderate - high	low
Water Licensing Criteria									
Source included in current DoW allocation system?	n/a	yes	uncertain	yes	yes	uncertain	yes	no	yes (in mid-2012)
Sufficient available allocations exist to meet potential source volumes required?	n/a	no	n/a	no	no	n/a	no	n/a	yes
Probability of securing required 5C Licence from DoW	n/a	***moderate***	low	moderate	moderate - high	high	v. low	moderate - high	high
Overall uncertainty level	n/a	moderate	low	moderate	moderate	low	low	low	low
Long-term Viability Criteria									
Potential for significant declines to source water levels and yields	nil	***moderate***	***moderate - high***	low	low	low	***high***	***low - moderate***	low
Potential for adverse changes to water salinity and quality	nil	***moderate***	***low - moderate***	low	low	low	***high***	***moderate - high***	***low - moderate***
Overall uncertainty level	n/a	high	high	low - moderate	low - moderate	***moderate - high***	low	moderate	***low - moderate***

Notes
1. GL = Giga-litre
2. Values in italics represent changes from the 2 ML/day assessment

4.2.1 2 ML/day Potable Supply Assessment

On the basis of potential source yields and/or water salinity, five of the eight sources are not considered adequate to be considered as reliable supply options (Birdrong – Upper Cane River, Coastal Plain Sediments – Dunal Sands Beach Wells, Coastal Plain Sediments – Alluvium, Coastal Plain Sediments – Trealla Limestone and Cane River Alluvium.

Of these five sources, the Cane River Alluvium is also not considered to be unreliable in terms of both licensing and long-term viability criteria. The Birdrong – Upper Cane River source is considered to be unreliable in terms of the potential to licence the required supply.

The aquifer sources that have a strong connection to recharge from river systems (the Ashburton River alluvium, Cane River Birdrong and alluvium and Lower Robe River sources) have the greatest potential to be affected by any long-term declines to rainfall and runoff. Climate change predictions by CSIRO (2007) indicate that the probability for lower rainfall in the Onslow region by 2070 (under high or low carbon emission scenarios) is higher than the probability of increased rainfall (Figure 12). However, in more absolute terms, the predicted probability of annual rainfall declines in the Onslow region only exceeds 50% for the 2070 high emissions case for a rainfall decrease of the order of 10 – 20%. These predictions suggest that annual rainfall is not likely change significantly in the Onslow region by 2070 compared to 1990.

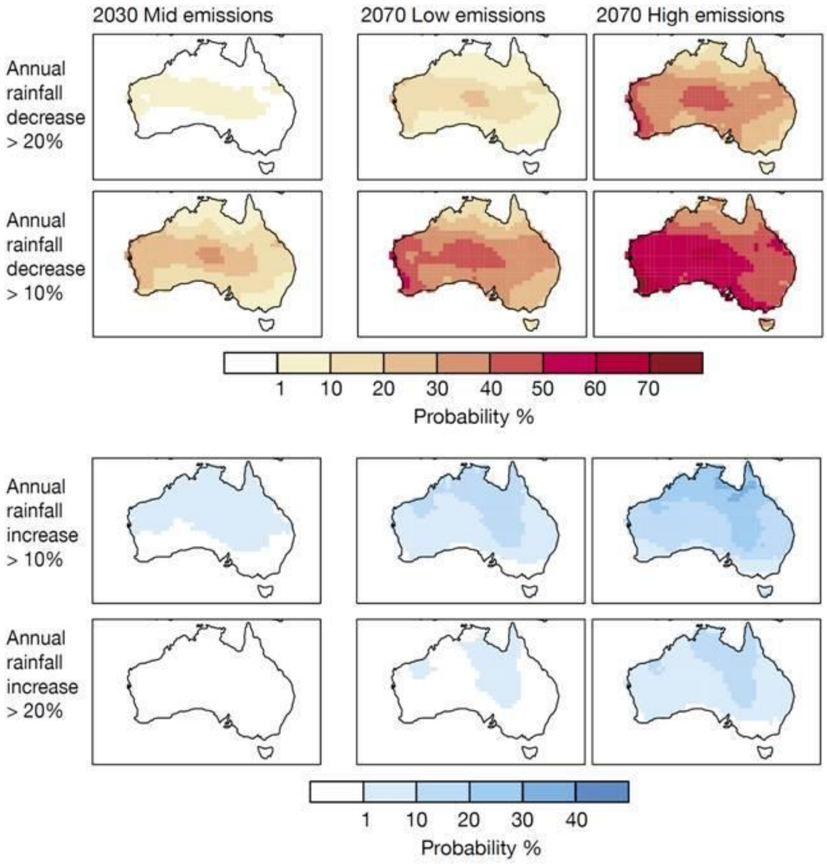

Figure 12 Probability (%) of Annual Rainfall Change Relative to 1990 (after CSIRO, 2007)

The Birdrong Aquifer in the Onslow area, the Ashburton River alluvium and Lower Robe River alluvium sources are considered to have sufficient reliability criteria to warrant further assessment as supply options. However, in terms of uncertainty associated with the assigned reliability factors, the Birdrong source has high levels of uncertainty, whilst the Ashburton River alluvium source is considered to have less, but still significant uncertainty associated with it. The Lower Robe River source has the least amount of uncertainty of the three sources and consequently is considered the highest ranked source in terms of reliability.

It is important to note that the sources have been assessed as singular ‘stand-alone’ supply options. Assessment of the combination of two or more sources as a supply option should potentially be considered, perhaps moreso for the longer-term 4ML/day supply scenario.

4.2.2 4 ML/day Potable Supply Assessment

Adjustment of the various reliability criteria to the higher demand scenario of a 4 ML/day potable water system does not effectively change the results from the 2 ML/day base case assessment. The same five sources as above are not considered suitable in terms of source yields and/or salinity.

The greater abstraction rates required potentially diminishes the reliability rating of the Birdrong and Ashburton River alluvium sources, however, this is influenced to a large degree by the relatively high uncertainties associated with these two sources compared to the Lower Robe River alluvium source.

5.0 Recommendations

Based on the approach to further assessment developed on 8 March 2012, we recommend that the Birdrong, Ashburton River alluvium and Lower Robe River alluvium sources be considered further as potential alternative options for the new Onslow water supply by:

- Estimating the various tasks, time and costs likely to be involved with investigation and development of each source to the point where water licences, land tenure/access and other regulatory approvals can be secured.
- Undertaking a Class 1 capital and operating cost-benefit analyses (+50% / -30%) for each source option.
- Define and apply water quality and water conditioning criteria for the water treatment and supply system to each source option.
- Comparing the results of the above tasks to the base case seawater desalination system to assess whether any of the three source options warrant further detailed assessment as alternative water supply options.

6.0 References

Bechtel, 2009, *Wheatstone Downstream Project – Study Report for Water Supply and Treatment 4.3 MTPA BOD Update CTR-51E.* Unpublished report prepared by Bechtel for Chevron Australia Pty Ltd, November 2009, Chevron document reference WS1-0000-HES-RPT-BEC-000-00007-000-1.

Bechtel, 2009, *Wheatstone Project LNG Plant – Water Study Report for Plant Operation.* Unpublished report prepared by Bechtel for Chevron Australia Pty Ltd, June 2010, Chevron document reference WS1-0000-HES-RPT-BEC-000-00013-000-0.

Commander, D P 1994 *Hydrogeology of the Robe River alluvium, Ashburton Plain, Carnarvon Basin,* Western Australian Geological Survey, Report 37 Professional Papers, pp. 75-100, Western Australia.

Crostella, A Lasky R P, Blundell K A, Yasin A R and Ghori, K A R 2000, *Petroleum Geology of the Peedamullah Shelf and Onslow Terrace, Northern Carnarvon Basin, Western Australia*, Western Australia Geological Survey, Report 73, Perth.

DoW, 2011 *Carnarvon Artesian Basin water management plan: Evaluation statement 2009 – 2011,* Department of Water online publication, accessed 16 February 2011.

Haig, 2009 *The Pilbara Coast Water Study ,*Hydrogeological Record Series, Report no. HG34, Department of Water, Western Australia.

Hocking, R M Morris, H T Van De Graff, W J E 1987 *Geology of the Carnarvon Basin Western Australia*, Western Australia Geological Survey, Bulletin 133, Perth.

Rockwater, 2009 *Onslow Town Water Supply: Results of Exploratory Drilling and Testing for Additional Water Sources,* Unpublished report prepared for Water Corporation, Western Australia.

SKM, 2010 *Lower Robe Groundwater Model,* Unpublished report prepared for Government of Western Australia, Department of Water, Tatura, Victoria.

URS, 2008 *Development of an Integrated Water Resource Planning Tool for the Pilbara Region* Unpublished report prepared for Government of Western Australia, Department of Water, Perth.

URS, 2009(a) *Water Source Option Assessment for Wheatstone Project,* Unpublished report prepared for Chevron Australia Pty Ltd, Chevron document reference WS0-0000-DES-RPT-URS-000-00015-000.

URS, 2009(b) *Wheatstone – Beach Wells as preferred water supply,* Memorandum prepared for Chevron Australia Pty Ltd, part of Chevron document WS1-0000-HES-MOM-BEC-000-00106-0.

URS, 2010 *Wheatstone Project Groundwater Studies,* Unpublished report prepared for Chevron Australia Pty Ltd, Western Australia.

- Changemarks (1

No changemarks applied