## WEST CANNING BASIN MODEL DESIGN REPORT

<table>
<thead>
<tr>
<th>Prepared for</th>
<th>Department of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Issue</td>
<td>1 May 2009</td>
</tr>
<tr>
<td>Our Reference</td>
<td>1033/B/021c</td>
</tr>
</tbody>
</table>
**WEST CANNING BASIN MODEL DESIGN REPORT**

<table>
<thead>
<tr>
<th>Prepared for</th>
<th>Department of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Issue</td>
<td>1 May 2009</td>
</tr>
<tr>
<td>Our Reference</td>
<td>1033/B/021c</td>
</tr>
</tbody>
</table>
WEST CANNING BASIN MODEL DESIGN REPORT

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Revision Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision a</td>
<td>6/03/2009</td>
<td>Draft</td>
</tr>
<tr>
<td>Revision b</td>
<td>11/03/2009</td>
<td>Final report for Department comment</td>
</tr>
<tr>
<td>Revision c</td>
<td>01/05/2009</td>
<td>Final report including agreed changes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Originator</strong></td>
<td>Kate Holder</td>
<td></td>
<td>01/05/09</td>
</tr>
<tr>
<td></td>
<td>Kathryn Rozlapa</td>
<td></td>
<td>01/05/09</td>
</tr>
<tr>
<td><strong>Reviewer</strong></td>
<td>Greg Sheppard</td>
<td></td>
<td>01/05/09</td>
</tr>
<tr>
<td></td>
<td>Graham Smith</td>
<td></td>
<td>01/05/09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issuing Office</td>
<td>Perth</td>
</tr>
</tbody>
</table>
CONTENTS

1 INTRODUCTION ...................................................................................................1
  1.1 Background ................................................................................................... 1
  1.2 Objectives of the Overall Study ................................................................. 1
  1.3 Scope of Work ............................................................................................ 1

2 EXISTING ENVIRONMENT ............................................................................5
  2.1 Climate ......................................................................................................... 5
  2.2 Geology ....................................................................................................... 5
    2.2.1 Regional Geological Structure ............................................................. 5
    2.2.2 Wallal Sandstone ................................................................................. 6
    2.2.3 Jarlemai Siltstone ................................................................................. 6
    2.2.4 Broome Sandstone .............................................................................. 6
  2.3 Hydrogeology ............................................................................................. 7
    2.3.1 Broome Sandstone .............................................................................. 7
    2.3.2 Wallal Sandstone ................................................................................. 7
    2.3.3 Springs ............................................................................................... 7

3 DATA REVIEW ..................................................................................................11
  3.1 GSWA Investigation (1979) ........................................................................ 11
  3.2 Petroleum Wells .......................................................................................... 11
  3.3 DoW Water Resources Information Catalogue .......................................... 11
  3.4 Moly Mines & BHP Billiton Investigations .................................................. 11
  3.5 Atlas Iron Investigations at Pardoo Station ................................................. 12

4 CONCEPTUAL HYDROGEOLOGY .................................................................19
  4.1 Introduction ................................................................................................ 19
  4.2 Broome Sandstone (Unconfined Aquifer) .................................................... 19
    4.2.1 Aquifer Properties ............................................................................. 19
    4.2.2 Recharge ........................................................................................... 19
    4.2.3 Groundwater Flow ............................................................................ 20
  4.3 Jarlemai Siltstone (Aquitard) ...................................................................... 20
  4.4 Wallal Sandstone (Confined Aquifer) ......................................................... 25
    4.4.1 Aquifer Properties ............................................................................. 25
    4.4.2 Recharge .......................................................................................... 26
    4.4.3 Groundwater Flow ............................................................................ 26
  4.5 Springs ........................................................................................................ 26
  4.6 Hydrochemistry .......................................................................................... 37
    4.6.1 Broome Sandstone ............................................................................. 37
4.6.2 Wallal Sandstone ............................................................... 37
4.6.3 Springs.............................................................................. 37
4.7 Conceptual Model .............................................................. 43

5 NUMERICAL MODEL ................................................................. 51
5.1 Code Selection................................................................. 51
5.2 Model Set Up................................................................. 51
5.3 Model Extent, Layering and Grid........................................... 51
5.4 Boundary Conditions....................................................... 53
5.5 Aquifer Parameters.......................................................... 54
5.6 Model Calibration ........................................................... 54

6 REFERENCE LIST...................................................................... 61

TABLES

Table 2.1: Summary of Climate Data.............................................. 5
Table 3.1: Summary of GSWA Drilling Investigation (Leech, 1979) ............... 13
Table 3.2: Summary of Petroleum Wells ........................................... 14
Table 3.3: Summary of Shay Gap Borefield & Spinifex Ridge Borefield.............. 15
Table 3.4: Summary of Pardoo Borefield Investigation .............................. 16
Table 4.1: Summary of Lithology at GSWA10A and Pardoo ....................... 25
Table 4.2: Summary of Field Water Quality Analysis (DoW, 2009) ............... 38
Table 4.3: Summary of Laboratory Water Quality Analysis (DoW, 2009) ....... 39
Table 5.1: Summary of Groundwater User Interface .................................. 52
Table 5.2: Layer Geometry ....................................................... 53
Table 5.3: Model Domain.......................................................... 53
Table 5.4: Initial Aquifer Parameter Estimates ...................................... 54
FIGURES

Figure 1.1: Location Plan ................................................................. 3
Figure 2.1: West Canning Basin Project Surface Geology ................. 9
Figure 3.1: West Canning Basin Bore Location Plan ....................... 17
Figure 4.1: Broome Sandstone Thickness ....................................... 21
Figure 4.2: Alluvium/Broome Sandstone Water Levels .................. 23
Figure 4.3: Jarlemai Siltstone Thickness ........................................ 27
Figure 4.4: Wallal Sandstone Unconfined & Artesian Boundaries .... 29
Figure 4.5: Wallal Sandstone Thickness .......................................... 31
Figure 4.6: Wallal Sandstone Hydraulic Conductivity Distribution .... 33
Figure 4.7: Wallal Sandstone Potentiometric Surface ...................... 35
Figure 4.8: Expanded Durov ........................................................... 41
Figure 4.9: Generalised Conceptual Hydrogeology ......................... 45
Figure 4.10: Generalised Conceptual Hydrogeology in the West of the Project Area 47
Figure 4.11: Section Location Plan .................................................. 49
Figure 5.1: Model Extent and Boundary Conditions (Broome Aquifer) 55
Figure 5.2: Model Extent and Boundary Conditions (Wallal Aquifer) 57
Figure 5.3: Schematic Boundary Conditions Set Up ....................... 59
INTRODUCTION

1.1 BACKGROUND
The onshore Canning Basin underlies an area of more than 530,000km² in the north of Western Australia. The western most part of the Canning Basin, the West Canning Basin, covers an area of around 9,400km² and comprises a substantial groundwater resource that is largely untapped. The majority of the Canning Basin is fairly remote, however, the proximity of the West Canning Basin to the town of Port Hedland and a number of existing and proposed mining operations means that the groundwater resource is coming under increasing demand for mine water supplies, public water supply and irrigation.

The West Canning Basin area for this Project is shown in Figure 1.1.

This project being undertaken by the Department of Water (DoW) is part funded by the Australian Government under its $12.9 billion Water for the Future plan. It will ensure water is available for continued growth of the mining industry, whilst allowing water for sustainable existence of environmental and cultural features. A regional scale numerical model of the West Canning Basin is one of the regional tools required by the DoW to support regional water management objectives. The overall scope of this Project is to develop a better understanding of the hydrogeology and groundwater resources of the West Canning Basin on a regional scale and to develop a numerical model that can be used by the DoW to assess potential impacts of future abstraction on groundwater resources.

1.2 OBJECTIVES OF THE OVERALL STUDY
The principal objectives of the overall West Canning Basin Modelling study, which will be undertaken in stages, are to:

▼ Improve understanding of the hydrogeology of the West Canning Basin.
▼ Refine basin boundaries and basin geometry over the Project area.
▼ Improve understanding of groundwater flow patterns.
▼ Assess groundwater-surface water interaction, particularly with regard to mound springs.
▼ Evaluate the impact of existing and proposed groundwater abstraction on groundwater storage across the basin.
▼ Evaluate the impact of climate change on the groundwater resources.

1.3 SCOPE OF WORK
The scope of work for this stage of the Project is to develop a conceptual model for the West Canning Basin.

This report presents and discusses the essential hydrogeological features of the West Canning Basin and represents a conceptual hydrogeological model. A preferred numerical modelling package is identified, and recommendations are given for model setup such as model domain, boundary conditions and layer configurations.

The report has been structured in the following order:

▼ Existing environment.
▼ Conceptual hydrogeology.
▼ Numerical model.
FIGURE 1.1
LOCATION PLAN

LEGEND
- Town

Project Area

Location: F:\Jobs\1033B\MapInfo\021c_fig1.1.WOR

aquatekra

FIGURE 1.1
LOCATION PLAN

AUTHOR: KMH
DRAWN: KMH
DATE: 5/03/2009
JOB NO: 1033B

LOCATION MAP

PROJECTION: GDA94

SCALE: 1:1,500,000
2 EXISTING ENVIRONMENT

2.1 CLIMATE

The West Canning Basin is located in the Pilbara district of Western Australia. The climate in the Pilbara district is classified as arid tropical, characterised by hot summers from October to April and mild winters from May to September. Evaporation rates are much larger than mean annual rainfall.

Rainfall in the Pilbara is highly variable and largely driven by cyclonic events and localised thunderstorms between December and March. Meteorological data is collected at Pardoo Station (station number 004028), located in the north west of the Project area, and Mandora Station (station number 004019), located in the north east of the Project area. Long-term mean annual rainfall at Pardoo station is 314.9mm, with an average of 16 rain days per year. Whilst the long-term mean annual rainfall at Mandora station is approximately 370.9mm, with an average of 19 rain days per year. Climate data for both stations is summarised in Table 2.1.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean Rainfall (mm)</th>
<th>Mean Maximum Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pardoo Station</td>
<td>Mandora Station</td>
</tr>
<tr>
<td>January</td>
<td>59.2</td>
<td>81.4</td>
</tr>
<tr>
<td>February</td>
<td>75.0</td>
<td>101.6</td>
</tr>
<tr>
<td>March</td>
<td>63.4</td>
<td>74.5</td>
</tr>
<tr>
<td>April</td>
<td>19.9</td>
<td>21</td>
</tr>
<tr>
<td>May</td>
<td>24.9</td>
<td>25.3</td>
</tr>
<tr>
<td>June</td>
<td>21.7</td>
<td>28.2</td>
</tr>
<tr>
<td>July</td>
<td>9.5</td>
<td>8.4</td>
</tr>
<tr>
<td>August</td>
<td>5.0</td>
<td>2.6</td>
</tr>
<tr>
<td>September</td>
<td>2.7</td>
<td>0.9</td>
</tr>
<tr>
<td>October</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>November</td>
<td>3.3</td>
<td>6.5</td>
</tr>
<tr>
<td>December</td>
<td>23.0</td>
<td>31.5</td>
</tr>
<tr>
<td>Annual Total</td>
<td>314.9</td>
<td>370.9</td>
</tr>
</tbody>
</table>

2.2 GEOLOGY

2.2.1 REGIONAL GEOLOGICAL STRUCTURE

As previously mentioned, the Canning Basin extends over 530,000km², of which approximately two-thirds is onshore. Sediments of the basin range in age from Ordovician (approximately 450 million years ago) to Quaternary, reaching a maximum cumulative thickness of over 8km. Deposition in the Canning Basin commenced in the early Ordovician, with a series of transgression and regression cycles and tectonic movement shaping the basin. The rifting and break-up between Australia and a former continental mass, resulted in a transgression from the northwest. Up to 700m of Early Jurassic to Early Cretaceous sediments are preserved onshore and up to 4000m offshore.
EXISTING ENVIRONMENT

The area included in this Project covers a small portion in the southwest of the Canning Basin and is confined to the western part of the Anketell Shelf. This includes the northwesterly trending Wallal Platform (to the west of the Willara Platform), which is a basement high in this area of the Canning Basin. Investigations by Leech (1979) discovered a steepening in the gradient of the bedrock floor in the northeast area of the West Canning Basin, suggesting that this structure may be an ancient fault scarp, or a hinge line with greater subsidence to the northeast.

During the Permian era, the glacigene Grant Formation, of Sakmarian age, was unconformably deposited on the Archaean basement rocks in the east of the West Canning Basin. This was followed by the deposition of the Dora Shale (Late Sakmarian or Early Artinskian), a continental sequence of claystone, siltstone and sandstone. At the end of the Permian, an interval of uplift occurred and sedimentation ceased (Leech, 1979).

During the Middle Jurassic, renewed subsidence resulted in marine transgression across the West Canning Basin. An unnamed claystone unit was deposited locally on Archaean basement. Further subsidence occurred during the Callovian, during which the Wallal Sandstone was deposited. This sandstone occurs over most of the Canning Basin as the basal unit of the Jurassic marine transgression, and was deposited unconformably on Archaean or Permian rocks. Further transgression during the Oxfordian resulted in the marine Jarlemai Silstone being disconformably deposited on the Wallal Sandstone in a relatively low energy environment (Leech, 1979).

During the Upper Jurassic and Early Cretaceous, the regressive Broome Sandstone was deposited in a non-marine high energy environment. Since the Early Cretaceous, uplift and erosion has taken place with only very minor deposition (Leech, 1979).

The stratigraphic units most relevant to this Project are the Wallal Sandstone, Jarlemai Siltstone and Broome Sandstone. These sediments generally thicken and deepen to the northeast. Brief descriptions of these units are provided below.

Figure 2.1 presents the geology in the West Canning Basin area.

2.2.2 WALLAL SANDSTONE

The Wallal Sandstone generally comprises very coarse to fine grained sands, which are beige to light grey in colour. Conglomerate is common towards the base of the formation, containing quartz, quartzite, jasper and other pebbles. A fine to medium grained sandstone and a medium to fine grained mudstone, consistent throughout the upper Wallal Sandstone has been correlated with the Alexander Formation. The Wallal Sandstone generally overlies the Pre-Cambrian basement, however in the northeast of the West Canning Basin, faulting has resulted in deeper basin development and the Wallal Sandstone is underlain by the Dora Shale and Grant Formation (Leech, 1979). The Wallal Sandstone is considered to be Jurassic in age and has a maximum recorded thickness of 420m in northeast of the West Canning Basin.

2.2.3 JARLEMAI SILTSTONE

The Jarlemai Siltstone comprises mainly black puggy clay and silt clay, which is light grey to black in colour. This unit is present throughout the West Canning Basin, except to the south where it pinches out. The Jarlemai Siltstone has a maximum recorded thickness of 200m in the West Canning Basin.

2.2.4 BROOME SANDSTONE

The Broome Sandstone is correlated as part of the Callawa Formation and outcrops as isolated mesas of cross-bedded sandstone and conglomerate. Conglomerate is common towards the base of the formation, containing quartz, quartzite, jasper and other pebbles. A fine to medium grained sandstone and a medium to fine grained mudstone, consistent throughout the upper Wallal Sandstone has been correlated with the Alexander Formation. The Broome Sandstone has a maximum thickness of 62m in the West Canning Basin. Clastic to the coast, the Broome Sandstone is overlain by the Bossut Formation, comprising limestone and sandstone. The Broome Sandstone is overlain by the Bossut Formation, comprising limestone and sandstone. The Broome Sandstone is overlain by the Bossut Formation, comprising limestone and sandstone.
2.3 HYDROGEOLOGY

The Project area is dominated by two main aquifer systems hosted in the largely unconfined Broome Sandstone and the confined Wallal Sandstone. These two aquifers are separated by the generally impermeable Jarlemai Siltstone.

2.3.1 BROOME SANDSTONE

The flow system in the Broome Sandstone is generally unconfined, with groundwater flow direction generally northwards toward the Indian Ocean. Groundwater recharge is mainly through direct percolation from rainfall or indirectly through the thin Tertiary or Quaternary sediments. Water levels are observed to fluctuate with heavy rainfall events. Groundwater discharge is to the Indian Ocean and by evapotranspiration in the low lying coastal area.

2.3.2 WALLAL SANDSTONE

The Alexander Formation and Wallal Sandstone are confined beneath the Jarlemai Siltstone over most of the West Canning Basin, with much of the aquifer demonstrating artesian heads of up to 30m above ground level toward the coast. Groundwater recharge occurs mainly in the south of the main Canning Basin where the Jarlemai Siltstone is absent and the unit is unconfined. A smaller component of recharge will also occur along the southern margin of the West Canning Basin where the Jarlemai Siltstone is also absent. Groundwater flow direction is west-northwesterly, indicating the importance of groundwater throughflow from the main Canning Basin. Groundwater discharge is likely to occur via vertical seepage to overlying units and through sub-marine springs at an unknown distance offshore.

2.3.3 SPRINGS

A number of springs (seepage areas) are present along the coast in the Project area. They have generally been excavated to provide water for stock and are not free-flowing. Discharge from these springs is via evapotranspiration and stock watering.

The source of these springs is currently unclear, however, they appear to be chemically closer to the Wallal Sandstone groundwater type than the unconfined Broome Sandstone. This is discussed further in Section 4.6.
3 DATA REVIEW

3.1 GSWA INVESTIGATION (1979)

A widespread hydrogeological investigation was conducted in the south-west area of the Canning Basin in the late 1970’s, providing comprehensive hydrogeological information regarding the Walal Sandstone, Jarlemai Siltstone and Broome Sandstone (Leech, 1979). A total of 47 boreholes were drilled during this investigation in order to define the stratigraphy and derive aquifer characteristics. Of these 47 boreholes drilled, 40 were cased for future use and monitoring purposes. It is not known if all these boreholes are still open. This investigation largely focussed on the western limits of the Canning Basin, with the most easterly drilling transect located near the Shay Gap borefield. The information in this report is largely based on the findings of this investigation. Table 3.1 provides a summary of the boreholes drilled, with locations displayed on Figure 3.1.

In addition to the above drilling programme, a large scale geophysical survey has been conducted on the West Canning Basin area (Rowston, 1976). This geophysical survey included seismic reflection and resistivity surveys and provides information regarding depths to basement and changes in basement lithology.

3.2 PETROLEUM WELLS

A number of wells have been drilled throughout the Canning Basin since the early 1920’s in search for hydrocarbon reserves (Apak, Sand Ca rsen, G, 1997). The majority of these wells were drilled in the northeast of the Canning Basin, with only a few located in the northeast of the West Canning Basin. Table 3.2 provides a summary of the petroleum wells drilled in the West Canning Basin area; locations are shown in Figure 3.1. These bores provide information regarding depths and thicknesses of stratigraphic sequence intercepted and assist in defining the basin geometry in the northeast area of West Canning Basin.

A single petroleum well, known as Pandanus, is located in the southeast of the West Canning Basin. This well was drilled to a depth of 214m, however, no lithological information has been found for this well and there is limited information available regarding stratigraphy.

3.3 DOW WATER RESOURCES INFORMATION CATALOGUE

A data search was conducted through the Department of Water’s (DoW) Water Resource Information (WIN) Catalogue for hydrogeological information, such as drilled depths, lithological logs, water levels and water quality data, in the Project area. This search returned a number of drill holes in the area around the De Grey River, Pardoo station, Shay Gap, and along the coast to Mandora. The location of these bores is presented Figure 3.1.

3.4 MOLY MINES & BHP BILLITON INVESTIGATIONS

BHP Billiton own and operate S hay Gap borefield located in the south of the Project area, approximately 165km east of Port Hedland (Figure 3.1). The borefield was established in 1993 to supply the former township of Shay Gap. The borefield currently supplies potable and raw water abstracted from the Walal Sandstone to BHPB’s Yarrie mine and camp. Shay Gap borefield comprises four non-artesian production bores (PB1, PB2, PB3 and PB4), and one centrally located observation bore (OB1).

In addition, Moly Mines have conducted hydrogeological investigations in the area approximately 10km east of the Shay Gap borefield, in order to locate a water supply for the proposed molybdenum-copper mine at S pinifex Ridge. Four exploration bores were drilled in the Moly Mines Project area and an additional two production bores were drilled and constructed to fully penetrate the Wallal Sandstone (Aquaterria, 2007).

Table 3.3 provides a summary of the BHPB Shay Gap bores and Mol y Mines S pinifex Ridge bores.
3.5 ATLAS IRON INVESTIGATIONS AT PARDOO STATION

Atlas Iron have conducted hydrogeological investigations in the Pardoo station area approximately 120km east of Port Hedland, in order to locate a water supply for their proposed magnetite project (Figure 3.1). The hydrogeological investigation included the installation of a trial production bore, two deep monitoring bores into the artesian Wallal Sandstone and one shallow monitoring bore in the unconfined Broome Sandstone (Aquaterra, 2009). The results of the hydrogeological investigation confirmed aquifer geometry and characteristics assessed by Leech (1979).

Table 3.4 summarises the Atlas Iron bores constructed in the vicinity of Pardoo station.
### Table 3.1: Summary of GSWA Drilling Investigation (Leech, 1979)

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Easting (MGA94)</th>
<th>Northing (MGA94)</th>
<th>Zone</th>
<th>Drilled Depth (m)</th>
<th>Elevation (mRL)</th>
<th>Top of Broome (mRL)</th>
<th>Top of Jarlemai (mRL)</th>
<th>Top of Wallal (mRL)</th>
<th>Base of Wallal (mRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>746658</td>
<td>7763314</td>
<td>50</td>
<td>83.2</td>
<td>19.66</td>
<td>NP</td>
<td>NP</td>
<td>19.66</td>
<td>-43.3</td>
</tr>
<tr>
<td>2D</td>
<td>752279</td>
<td>7767694</td>
<td>50</td>
<td>104</td>
<td>31.06</td>
<td>31.06</td>
<td>-1.9</td>
<td>-9.9</td>
<td>-71.9</td>
</tr>
<tr>
<td>3A</td>
<td>756729</td>
<td>7770638</td>
<td>50</td>
<td>103.4</td>
<td>19.17</td>
<td>19.17</td>
<td>-16.8</td>
<td>-35.8</td>
<td>-70.8</td>
</tr>
<tr>
<td>4A</td>
<td>763841</td>
<td>7775365</td>
<td>50</td>
<td>133.5</td>
<td>12.68</td>
<td>12.68</td>
<td>-26.3</td>
<td>-62.3</td>
<td>-104.3</td>
</tr>
<tr>
<td>5A</td>
<td>790479</td>
<td>7756603</td>
<td>50</td>
<td>43.5</td>
<td>64.71</td>
<td>64.71</td>
<td>52.7</td>
<td>38.7</td>
<td>24.7</td>
</tr>
<tr>
<td>6A</td>
<td>791229</td>
<td>7763730</td>
<td>50</td>
<td>78.5</td>
<td>48.27</td>
<td>48.27</td>
<td>18.3</td>
<td>3.3</td>
<td>-24.7</td>
</tr>
<tr>
<td>7A</td>
<td>791580</td>
<td>7770370</td>
<td>50</td>
<td>125</td>
<td>34.23</td>
<td>34.23</td>
<td>7.2</td>
<td>-22.8</td>
<td>-84.8</td>
</tr>
<tr>
<td>8A</td>
<td>791343</td>
<td>7777015</td>
<td>50</td>
<td>183</td>
<td>15.12</td>
<td>15.12</td>
<td>-14.9</td>
<td>-60.9</td>
<td>-142.9</td>
</tr>
<tr>
<td>9D</td>
<td>791463</td>
<td>7784721</td>
<td>50</td>
<td>224</td>
<td>7.08</td>
<td>7.08</td>
<td>-64.9</td>
<td>-113.9</td>
<td>-211.9</td>
</tr>
<tr>
<td>10A</td>
<td>780822</td>
<td>7771956</td>
<td>50</td>
<td>116.4</td>
<td>20.98</td>
<td>20.98</td>
<td>0 (sea level)</td>
<td>-20</td>
<td>-92.0</td>
</tr>
<tr>
<td>11A</td>
<td>771511</td>
<td>7772501</td>
<td>50</td>
<td>129.7</td>
<td>19.73</td>
<td>19.73</td>
<td>-16.3</td>
<td>-56.3</td>
<td>-77.3</td>
</tr>
<tr>
<td>12A</td>
<td>767281</td>
<td>7764827</td>
<td>50</td>
<td>45.7</td>
<td>32.17</td>
<td>32.17</td>
<td>-7.8</td>
<td>NP</td>
<td>-</td>
</tr>
<tr>
<td>13A</td>
<td>756724</td>
<td>7761795</td>
<td>50</td>
<td>69.7</td>
<td>46.1</td>
<td>46.1</td>
<td>-6.9</td>
<td>NP</td>
<td>-</td>
</tr>
<tr>
<td>14A</td>
<td>780421</td>
<td>7762976</td>
<td>50</td>
<td>77.1</td>
<td>53.7</td>
<td>53.7</td>
<td>43.7</td>
<td>17.7</td>
<td>-18.3</td>
</tr>
<tr>
<td>15A</td>
<td>807933</td>
<td>7761586</td>
<td>50</td>
<td>120.5</td>
<td>84.31</td>
<td>84.31</td>
<td>61.3</td>
<td>21.3</td>
<td>-29.7</td>
</tr>
<tr>
<td>16A</td>
<td>807985</td>
<td>7773501</td>
<td>50</td>
<td>184</td>
<td>41.98</td>
<td>41.98</td>
<td>-3</td>
<td>-49</td>
<td>-138.0</td>
</tr>
<tr>
<td>17A</td>
<td>809046</td>
<td>7784928</td>
<td>50</td>
<td>259</td>
<td>18.75</td>
<td>18.75</td>
<td>-54.3</td>
<td>-118.3</td>
<td>-234.3</td>
</tr>
<tr>
<td>18A</td>
<td>823148</td>
<td>7749194</td>
<td>50</td>
<td>126.5</td>
<td>157.64</td>
<td>157.64</td>
<td>119.6</td>
<td>104.6</td>
<td>35.6</td>
</tr>
<tr>
<td>19A</td>
<td>823213</td>
<td>7762253</td>
<td>50</td>
<td>176</td>
<td>105.92</td>
<td>105.92</td>
<td>54.9</td>
<td>26.9</td>
<td>-69.1</td>
</tr>
<tr>
<td>20A</td>
<td>823474</td>
<td>7770163</td>
<td>50</td>
<td>215</td>
<td>77.06</td>
<td>77.06</td>
<td>20.1</td>
<td>-30.9</td>
<td>-137.9</td>
</tr>
<tr>
<td>21A</td>
<td>823723</td>
<td>7778421</td>
<td>50</td>
<td>235</td>
<td>37.88</td>
<td>37.88</td>
<td>-5.1</td>
<td>-74.1</td>
<td>-189.1</td>
</tr>
</tbody>
</table>
# West Canning Basin Model Design Report

## Data Review

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Easting (MGA94)</th>
<th>Northing (MGA94)</th>
<th>Zone</th>
<th>Drilled Depth (m)</th>
<th>Elevation (mRL)</th>
<th>Top of Broome (mRL)</th>
<th>Top of Jarlemai (mRL)</th>
<th>Top of Wallal (mRL)</th>
<th>Base of Wallal (mRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22A</td>
<td>823918</td>
<td>7786784</td>
<td>50</td>
<td>344</td>
<td>11.08</td>
<td>11.08</td>
<td>-44.9</td>
<td>-113.9</td>
<td>-331.9</td>
</tr>
<tr>
<td>23A</td>
<td>836223</td>
<td>7768745</td>
<td>50</td>
<td>210</td>
<td>70.91</td>
<td>70.91</td>
<td>46.9</td>
<td>3.9</td>
<td>-100.1</td>
</tr>
<tr>
<td>24A</td>
<td>836488</td>
<td>7777527</td>
<td>50</td>
<td>267</td>
<td>43.77</td>
<td>43.77</td>
<td>2.8</td>
<td>-71.2</td>
<td>-222.2</td>
</tr>
<tr>
<td>25C</td>
<td>836954</td>
<td>7788139</td>
<td>50</td>
<td>696</td>
<td>16.21</td>
<td>16.21</td>
<td>-38.8</td>
<td>-133.8</td>
<td>-322.8</td>
</tr>
</tbody>
</table>

Note: NP=Not Present. – Indicates where no data available

## Table 3.2: Summary of Petroleum Wells

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Easting (MGA94)</th>
<th>Northing (MGA94)</th>
<th>Zone</th>
<th>Drilled Depth (m)</th>
<th>Elevation (mRL)</th>
<th>Top of Broome (mRL)</th>
<th>Top of Jarlemai (mRL)</th>
<th>Top of Wallal (mRL)</th>
<th>Base of Wallal (mRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samphire Marsh 1</td>
<td>309342</td>
<td>7840589</td>
<td>51</td>
<td>2031.2</td>
<td>4.9</td>
<td>-36</td>
<td>-165.1</td>
<td>-257</td>
<td>-683</td>
</tr>
<tr>
<td>BMR 04A Mandora</td>
<td>263269</td>
<td>7816079</td>
<td>51</td>
<td>679</td>
<td>9</td>
<td>-11</td>
<td>-106</td>
<td>-183</td>
<td>-540</td>
</tr>
<tr>
<td>Wallal Corehole 1</td>
<td>252137</td>
<td>7801963</td>
<td>51</td>
<td>309.1</td>
<td>24.5</td>
<td>12.3</td>
<td>-60.9</td>
<td>-189</td>
<td>-</td>
</tr>
<tr>
<td>Chirup 1</td>
<td>231471</td>
<td>7803245</td>
<td>51</td>
<td>762.6</td>
<td>3.1</td>
<td>-3.4</td>
<td>-136.3</td>
<td>-157</td>
<td>-496</td>
</tr>
<tr>
<td>Corbett 1</td>
<td>250328</td>
<td>7779231</td>
<td>51</td>
<td>800</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>77</td>
<td>-244</td>
</tr>
<tr>
<td>Pandanus</td>
<td>260382</td>
<td>7739597</td>
<td>51</td>
<td>214</td>
<td>210</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: – Indicates where no data available
Table 3.3: Summary of Shay Gap Borefield & Spinifex Ridge Borefield

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Easting (MGA94)</th>
<th>Northing (MGA94)</th>
<th>Zone</th>
<th>Drilled Depth (m)</th>
<th>Elevation (mRL)</th>
<th>Top of Broome (mRL)</th>
<th>Top of Jarlemai (mRL)</th>
<th>Top of Wallal (mRL)</th>
<th>Base of Wallal (mRL)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB1</td>
<td>216225</td>
<td>7748913</td>
<td>51</td>
<td>126</td>
<td>133</td>
<td>-</td>
<td>-</td>
<td>122</td>
<td>-</td>
<td>Shay Gap borefield</td>
</tr>
<tr>
<td>PB2</td>
<td>215246</td>
<td>7748959</td>
<td>51</td>
<td>126</td>
<td>133</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Shay Gap borefield</td>
</tr>
<tr>
<td>PB3</td>
<td>215824</td>
<td>7748003</td>
<td>51</td>
<td>115.8</td>
<td>137</td>
<td>-</td>
<td>-</td>
<td>133</td>
<td>-</td>
<td>Shay Gap borefield</td>
</tr>
<tr>
<td>OB1</td>
<td>215725</td>
<td>7748580</td>
<td>51</td>
<td>128</td>
<td>133</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Shay Gap borefield</td>
</tr>
<tr>
<td>PB4</td>
<td>215719</td>
<td>7749685</td>
<td>51</td>
<td>116.4</td>
<td>148</td>
<td>148</td>
<td>-</td>
<td>133</td>
<td>31</td>
<td>Shay Gap borefield</td>
</tr>
<tr>
<td>MMCA01E*</td>
<td>213731</td>
<td>7758337</td>
<td>51</td>
<td>174.5</td>
<td>105</td>
<td>105</td>
<td>86</td>
<td>62</td>
<td>-63</td>
<td>Spinifex Ridge</td>
</tr>
<tr>
<td>MMCA01P*</td>
<td>213753</td>
<td>7758335</td>
<td>51</td>
<td>140.4</td>
<td>105</td>
<td>105</td>
<td>86</td>
<td>62</td>
<td>-63</td>
<td>Spinifex Ridge</td>
</tr>
<tr>
<td>MMCA03E*</td>
<td>213847</td>
<td>7753667</td>
<td>51</td>
<td>146.1</td>
<td>125</td>
<td>125</td>
<td>115</td>
<td>89</td>
<td>-20</td>
<td>Spinifex Ridge</td>
</tr>
<tr>
<td>MMCA13E*</td>
<td>220725</td>
<td>7757936</td>
<td>51</td>
<td>186</td>
<td>127</td>
<td>127</td>
<td>90</td>
<td>66</td>
<td>-58</td>
<td>Spinifex Ridge</td>
</tr>
<tr>
<td>MMCA13P*</td>
<td>220724</td>
<td>7757947</td>
<td>51</td>
<td>175</td>
<td>127</td>
<td>127</td>
<td>86</td>
<td>68</td>
<td>-</td>
<td>Spinifex Ridge</td>
</tr>
<tr>
<td>MMCA16E*</td>
<td>213675</td>
<td>7748337</td>
<td>51</td>
<td>120</td>
<td>162</td>
<td>162</td>
<td>NP</td>
<td>104</td>
<td>44</td>
<td>Spinifex Ridge</td>
</tr>
</tbody>
</table>

Note: NP=Not Present.
- Indicates where no data available
* Data provided by Moly Mines Pty Ltd
Table 3.4: Summary of Pardoo Borefield Investigation

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Easting (MGA94)</th>
<th>Northing (MGA94)</th>
<th>Zone</th>
<th>Drilled Depth (m)</th>
<th>Elevation (mRL)*</th>
<th>Top of Broome (mRL)</th>
<th>Top of Jarlemai (mRL)</th>
<th>Top of Wallal (mRL)</th>
<th>Base of Wallal (mRL)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB1</td>
<td>781859</td>
<td>7771817</td>
<td>51</td>
<td>101</td>
<td>26</td>
<td>21</td>
<td>2</td>
<td>-17</td>
<td>-72</td>
<td>Production Bore</td>
</tr>
<tr>
<td>MB1</td>
<td>781852</td>
<td>7771812</td>
<td>51</td>
<td>28</td>
<td>26</td>
<td>20</td>
<td>2</td>
<td>Not Encountered</td>
<td>Not Encountered</td>
<td>Shallow Monitoring Bore</td>
</tr>
<tr>
<td>MB2</td>
<td>781876</td>
<td>7771832</td>
<td>51</td>
<td>102</td>
<td>26</td>
<td>21</td>
<td>0</td>
<td>-16</td>
<td>-72</td>
<td>Deep Monitoring Bore</td>
</tr>
<tr>
<td>MB3</td>
<td>783011</td>
<td>7773626</td>
<td>51</td>
<td>116</td>
<td>23</td>
<td>18</td>
<td>-11</td>
<td>-27</td>
<td>-91</td>
<td>Deep Monitoring Bore</td>
</tr>
</tbody>
</table>

* Approximate elevation

Data provided by Atlas Iron Ltd
FIGURE 3.1
Bore Location Plan

Legend

- Atlas Iron Bores
- GSWA Bores
- Petroleum Wells
- DoW WIN Database Bores
- Moly Mines Spinifex Ridge Bores

- Project Area
- BHPB Shay Gap Borefield
- Moly Mines Spinifex Ridge
- Atlas Iron Pardoo Bores

Location: F:\Jobs\1033B\MapInfo\021c_Fig3.1.WOR
4 CONCEPTUAL HYDROGEOLOGY

4.1 INTRODUCTION
The conceptual hydrogeology of the West Canning Basin is based on the integration of all available information. The conceptual hydrogeology was largely based on the results of the 1979 investigations conducted by Leech for the Geological Survey of Western Australia (GSWA), and was refined and confirmed by other information available. The area to the west of the De Grey River was included in the Project area with information regarding lithologies and water levels based on limited information available from the DOW WIN database and geophysical interpretations made by Rowston (1976). It is acknowledged that significant uncertainty exists in this area.

The conceptual hydrogeology described in this report represents a simplified understanding of the behaviour and dynamics of the aquifer systems and provides the technical foundation for the numerical model design and framework. Aquifer parameter estimates have been provided for the aquifers and aquitard, however these parameters are initial estimates and will be refined during calibration of the numerical model.

As previously mentioned, the West Canning Basin contains two main aquifer systems: the unconfined Broome Sandstone aquifer and the deeper, largely confined and artesian Wallal Sandstone aquifer (which includes the Alexander Formation). These two aquifers are separated by the generally impermeable Jarlemai Siltstone.

4.2 BROOME SANDSTONE (UNCONFINED AQUIFER)

4.2.1 AQUIFER PROPERTIES
The unconfined Broome Sandstone is present over the West Canning Basin ranging in thickness from 10m in the south to 130m in the northeast of the basin. Figure 4.1 presents the inferred thickness of the Broome Sandstone over the Project area.

Hydraulic tests were conducted on five bores completed in the Broome Sandstone during the 1979 investigations (Leech, 1979). Measured hydraulic conductivities ranged between 3 and 15m/day, and averaged 7.5m/day. Specific yield values for the Broome Sandstone have not been calculated, however a specific yield between 10% and 30% has been estimated (Leech, 1979).

A hydraulic conductivity of 7.5m/day has been adopted for the Broome Sandstone for this Project, based on the findings of Leech (1979). An initial specific yield value of 15% has been adopted for this Project, and is based on values typical for sediments such as the Broome Sandstone.

The Broome Sandstone is overlain by recent superficial sediments, such as alluvium, eolian deposits and sand dunes, across the basin approximately 5m thick. In the west of the Project area, around the De Grey River, alluvium associated with the De Grey River reaches thicknesses up to 80m. The Broome Sandstone appears to pinch out in places to the west near the De Grey River, where it is thought to have been eroded by the palaeo De Grey River. Due to lack of information in the area west of the De Grey River, and for the purposes of the model, it has been inferred that the Broome Sandstone thins out with limited variation in thickness and depth.

Where superficial sediments overlie the Broome Sandstone, these units have been ascribed a similar specific yield (15%) and a hydraulic conductivity of 1m/day. These parameter values are based on our experience and knowledge in the area and typical values for such sediments. However, over the major part of the Project area, the superficial sediments are expected to be largely unsaturated with the exception of the De Grey River area.

4.2.2 RECHARGE
Recharge to the Broome Sandstone is by direct percolation of rainfall (or indirectly through overlying sediments). Observations have shown that the water table fluctuates seasonally, rising after sustained intense rainfall events (i.e. tropical cyclones) and declining during periods of reduced rainfall.
Rates of recharge to the unconfined Broome Sandstone aquifer were estimated by Leech (1979) as 6% of rainfall. This recharge calculation was based on an assumed porosity of 30% (based on typical porosity values for similar sediments) and changes in water levels following a large rainfall event (such as a cyclone). While we feel that a value of 6% may be applicable to high intensity rainfall events, when applied to average rainfall this number is likely to be significantly lower. We feel that a value of 3% may be more realistic, however, the rainfall recharge rate will be refined during calibration of the numerical model.

Groundwater throughflow has been estimated by Leech (1979) to be approximately 20x10^6 m^3/yr (20GL/yr), based on a hydraulic conductivity of 7.5m/day.

### 4.2.3 GROUNDWATER FLOW

There is limited current information available regarding depths to water in the Broome Sandstone. However, based on the information available (five GSWA bores) and work done by Leech (1979), it is apparent that groundwater flow in the unconfined Broome Sandstone is generally in a northerly direction, with groundwater discharge to the ocean. In addition to groundwater discharge to the ocean, potential exists for groundwater discharge through seepage and evapotranspiration along the coastal strip where depths to water are less than 3m.

In the western corner of the West Canning Basin, groundwater flow direction becomes north to north-westerly toward the De Grey River alluvium.

The Broome Sandstone is unsaturated in the south of the basin, where the base of the Broome Sandstone is elevated.

Figure 4.2 presents water table contours of the unconfined Broome Sandstone and alluvium aquifer across the West Canning Basin.

### 4.3 JARLEMAI SILTSTONE (AQUITARD)

The Jarlemai Siltstone is present over most of the West Canning Basin, however the unit shallows and thins to the south, eventually pinching out towards the southern basin boundary. The Jarlemai Siltstone reaches a thickness of up to 200m in the northeastern area of the basin. Figure 4.3 presents the inferred extent and thickness of the Jarlemai Siltstone across the West Canning Basin.

The Jarlemai Siltstone appears to pinch out in places to the west near the De Grey River, where it is thought to have been eroded by recent alluvium. Due to lack of information in the area west of the De Grey River, and for the purposes of the model, it has been inferred that the Jarlemai Siltstone flattens out with limited variation in thickness and depth (Figure 4.3).

This unit separates the flow systems of the underlying confined Wallal Sandstone from the overlying unconfined Broome Sandstone. Given that groundwater movement in each aquifer is separate and differs markedly in direction and that there exists up to 30 m head difference between the units, the Jarlemai Siltstone is considered a significant aquitard. Therefore, a horizontal hydraulic conductivity of 1x10^-3 m/day and a vertical hydraulic conductivity of 1x10^-4 m/day have been adopted for this aquitard unit. The unconfined specific yield of the Jarlemai Siltstone has been estimated at 3.5%, based on the observed clayey nature of the unit.
FIGURE 4.1
Broome Sandstone Thickness (m)

Legend

- Broome Sandstone Approximate Thickness (m)
- Project Area
- Bore Location Broome Sandstone Thickness (m)

Location: F:\Jobs\1033\MapInfo\021c_fig4.1.WOR
FIGURE 4.2
Alluvium/Broome Sandstone
Water Levels

Legend
- GSWA Bores
- Broome Water Levels (mRL)
- DoW WIN Database
- Water Levels (mRL)
- Alluvium/Broome Water Level Contours (mRL)
- Project Area
- Groundwater Flow Direction

Location: F:\Jobs\1033B\MapInfo\021c_fig4.2.WOR
4.4 WALLAL SANDSTONE (CONFINED AQUIFER)

4.4.1 AQUIFER PROPERTIES

The Wallal Sandstone is an extensive unit and is present over the entire West Canning Basin. It is confined by the Jarl emai Siltstone across most of the basin, except in the south where the base of the Jarl emai Siltstone rises above water table, and at the southern basin boundary where the Jarl emai Siltstone is absent and the Wallal Sandstone is in direct contact with the unsaturated Broome Sandstone.

As previously mentioned, the Wallal Sandstone can be divided into an upper finer grained unit (Alexander Formation) and a coarser, more permeable lower unit. Available data suggests that Leech (1979) included the Alexander Formation within the Wallal Sandstone unit. Table 4.1 shows a comparison between unit depths and thicknesses at GSWA bore 10A (logged by Leech (1979)) and the nearby production bore drilled at Pardoo station (Aquaterra, 2009). Available lithological data from petroleum wells drilled within the Project area differentiates between the Alexander Formation and the lower Wallal Sandstone. There are no known aquifer parameters established for the Alexander Formation. Review of available data suggests that the Alexander Formation is generally one-third to one-quarter of the overall Wallal Sandstone thickness across the basin. For the purposes of this Project, the Alexander Formation is represented as part of the Wallal aquifer and has been assigned the same initial aquifer parameters as the overall Wallal aquifer, which are discussed further below.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit Depths (mRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GSWA10A</td>
</tr>
<tr>
<td>Broome Sandstone</td>
<td>21</td>
</tr>
<tr>
<td>Jarlemai Siltstone</td>
<td>0</td>
</tr>
<tr>
<td>Alexander Formation</td>
<td>-17</td>
</tr>
<tr>
<td>Wallal Sandstone</td>
<td>-20</td>
</tr>
</tbody>
</table>

The Wallal aquifer is artesian along the coastal plain where the measured potentiometric surface reaches up to 30m above sea level. Figure 4.4 shows where the Wallal Sandstone is unconfined and where the aquifer becomes artesian.

The Wallal Sandstone ranges in thickness from 14 m to 355m in the study area. Figure 4.5 presents the inferred thickness of the Wallal Sandstone over the Project area.

In addition, the Wallal Sandstone appears to pinch out, along with the Broome Sandstone and Jarlemai Siltstone, in places to the west near the De Grey River, where it is thought that these units have been eroded out by recent alluvium. Due to lack of information in the area west of the De Grey River, and for the purposes of the model, it has been inferred that the Wallal Sandstone flattens out with limited variation in thickness and depth (Figure 4.5).

Hydraulic tests were conducted on 18 sub-artesian and artesian bores completed in the Wallal Sandstone during the 1979 investigation (Leech, 1979). The resulting test pumping data was matched with leaky artesian type curves. Measured hydraulic conductivities range from 1m/day to 138m/day (Leech, 1979), however bore construction of the GSWA bores did not screen the entire length of the Wallal Sandstone aquifer and typically only represented an average of 18m sections of the aquifer. Therefore, these calculated mean hydraulic conductivity values may not be representative of the entire Wallal Sandstone unit. More recent investigations by Moly Mines and Atlas Iron calculated hydraulic conductivity values around 40-4 5m/day (Aquaterra, 2007) and 20-60m/day (Aquaterra, 2009), respectively. A uniform hydraulic conductivity of 20m/day was adopted by Leech (1979) and is considered appropriate as an initial estimate.
The areal distribution of hydraulic conductivity for the Wallal Sandstone in the Project area suggests a decreasing trend in a westerly direction and a slight decreasing trend in a northerly direction toward the ocean (Figure 4.6). This decreasing trend is in line with our understanding of the Wallal Sandstone, which was deposited in a fluvial environment in the Canning Basin.

A confined storage coefficient of $5 \times 10^{-4}$ has been adopted for the Wallal Sandstone aquifer, based on analysis by Leech (1979), Moly Mines (Aquaterra, 2007) and Atlas Iron (Aquaterra, 2009). Where the Wallal is unconfined, a specific yield of 20% has been applied, consistent with typical values for clean sand/gravel aquifers.

4.4.2 RECHARGE

The dominant source of recharge to the Wallal Sandstone in the study area is via throughflow from outside the model area. A small percentage of recharge will also be derived from infiltration of rainfall during intense events along the southern margin of the basin, where the Jarlemai Siltstone is absent and the Wallal Sandstone is unconfined (Figure 4.4). This rainfall recharge value will be applied consistent with the Broome Sandstone recharge value, in calibration of the numerical model.

Groundwater throughflow at the eastern margin of the West Canning Basin has been estimated by Leech (1979) to be approximately $21 \times 10^6$ m$^3$/yr (21GL/yr), based on a hydraulic conductivity of 20m/day.

4.4.3 GROUNDWATER FLOW

Groundwater flow direction in the Wallal Sandstone in the larger Canning Basin is in a general northerly direction (Leech, 1979). Whereas, groundwater flow in the Project area is in a general west-northwesterly direction, due to the radial distribution of the flow from the larger basin. Figure 4.7 presents the potentiometric surface of the Wallal Sandstone across the Project area. Groundwater discharge from the Wallal Sandstone occurs offshore along preferential flow paths associated with faulting and/or by upward leakage, given the pressure differential between the Wallal Sandstone and the Broome Sandstone.

The hydraulic gradient in the Wallal Sandstone is relatively uniform across the study area, despite possible reductions in hydraulic conductivity towards the west (Figure 4.6 and 4.7). This indicates potential for groundwater loss from the Wallal aquifer through upward leakage in the west of the Project area.

4.5 SPRINGS

It has been suggested that the springs present along the coast in the Project area are sourced from minor upward leakage from the Wallal Sandstone. However, one of the springs, Myadee Spring, has been dry for some years whilst artesian heads in the Wallal Sandstone in this area are around 10m above ground level.

It is understood that the DoW will be collecting water samples from a number of springs and shallow bores located along the coast in the West Canning Basin in May 2009. These water samples will be analysed for major ions, trace metals and Carbon-14 dating. This data will assist in determining the source of the springs, but will not be available for inclusion in the Project as currently defined.

These springs are not thought to comprise a significant part of the overall water balance of the West Canning Basin and the origin of the water is not yet known with any degree of certainty. The springs and their mechanism of discharge will be represented by evapotranspiration (ET) from the Broome aquifer, or superficial sediments, in the numerical model developed within the scope of this Project.
FIGURE 4.4
Wallal Sandstone Unconfined & Artesian Heads Boundary

Legend
- Project Area
- Wallal Sandstone Unconfined Area
- Wallal Sandstone Artesian Boundary
- GSWA Bores Water Level (mRL)

Location: F:\Jobs\1033B\MapInfo\021c_fig4.4.WOR
FIGURE 4.5
Wallal Sandstone Thickness (m)

Legend
- Bores
- Wallal Sandstone Approximate Thickness (m)
- Faults
- Project Area

Location: F:\Jobs\1033\MapInfo\021c_fig.4.5.WOR

PROJECTION: MGA94
SCALE: 1:1,000,000
DATE: 6 March 2009
AUTHOR: KMH
DRAWN: SHC
REPORT NO: 021
JOB NO: 1033B
REVISON: c
FIGURE 4.6
Wallal Sandstone
Hydraulic Conductivity Distribution

LEGEND

- Bores
  (Hydraulic Conductivity, K (m/day))

- Project Area

LOCATION MAP

AUTHOR: KMH
DRAWN: KMH
DATE: 9/03/09
JOB NO: 1033B
REPORT NO: 021
REVISION: c
SCALE: 1:900,000
PROJECTION: MGA94 (Z50/51)
FIGURE 4.7
Wallal Sandstone Potentiometric Surface

Legend
- Wallal Sandstone
- Water Level Contours (mRL)
- Project Area
- Groundwater Flow Direction
- Wallal Sandstone Unconfined Area
- Wallal Sandstone Artesian Head Boundary

Location: F:\Jobs\1033B\MapInfo\021c_fig4.7.WOR
4.6 HYDROCHEMISTRY

4.6.1 BROOME SANDSTONE

Investigations by Leech (1979) indicate that groundwater salinity in the Broome Sandstone and other unconfined aquifers in the Project area range from 380mg/L total dissolved solids (TDS) in the east to over 10,000mg/L TDS in the west of the Project area. Elevated groundwater salinities in the west of the study area are thought to be due to evapotranspiration in low lying coastal areas, where the depth to water is less than 5m below ground level. Spatial distribution of groundwater salinity in the Broome Sandstone was presented by Leech (1979) and is provided in Appendix A.

Figure 4.8 is an expanded Durov diagram showing groundwater in the Broome Sandstone to be chloride and sodium dominant, indicative of mature groundwater or evapotranspiration processes.

4.6.2 WALLAL SANDSTONE

Groundwater salinity values in the confined Wallal Sandstone aquifer were measured during the 1979 investigation by Leech and range from around 250mg/L TDS in the east to approximately 2,000mg/L TDS in the west of the Project area. Two particularly high concentrations are reported (5,500mg/L and 13,700mg/L). It is not clear if these elevated salinities are associated with the Wallal aquifer. Given the large hydraulic heads in the Wallal aquifer at the coast, the increase in groundwater salinity in the west of the Project area is unlikely to be due to saline intrusion. Rather, it may be due to mixing or intrusion of higher salinity water associated with basement or structural changes at the western boundary of the basin. The aerial distribution of groundwater salinity in the Wallal Sandstone was presented by Leech (1979) and is provided in Appendix A.

The DoW collected a number of water samples from selected GSWA bores in the north of the West Canning Basin in December 2008. These water samples were analysed for major ions, trace metals and Carbon-14 dating (refer Table 4.2 and 4.3).

Figure 4.8 is an expanded Durov diagram, showing groundwater in the Wallal Sandstone to vary from sulphate dominant and sodium dominant, which is indicative of mixing influences, to chloride and sodium dominant, indicative of “end point” or mature groundwater. This is to be expected given the distance of the sample points from the recharge area for the Wallal Sandstone.

4.6.3 SPRINGS

Salinities of the springs ranged from 1,000mg/L to 3,200mg/L TDS, however these higher salinities may be due to localised salt concentration from evapotranspiration.

Concentrations of nitrate and bicarbonate, common indicators of recent recharge to groundwater, are low in the spring water analysed and more consistent with Wallal groundwater than that from the Broome Sandstone. However, concentrations of calcium and magnesium in the spring water are more similar to the shallow groundwater sample than to the samples from the Wallal aquifer.
Table 4.2: Summary of Field Water Quality Analysis (DoW, 2009)

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Sample Date</th>
<th>Temp (°C)</th>
<th>Electrical Conductivity (mS/cm)</th>
<th>Dissolved Oxygen (mg/L)</th>
<th>pH</th>
<th>DO % Sat</th>
<th>Redox Potential (ORP) (mV)</th>
<th>Titration (100mL Drops 1.6N H₂SO₄)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB1</td>
<td>2/12/08</td>
<td>33.47</td>
<td>0.600</td>
<td>6.71</td>
<td>6.46</td>
<td>94.7</td>
<td>180</td>
<td>83</td>
<td>C14 sample not filtered rest filtered via syringe</td>
</tr>
<tr>
<td>PB3</td>
<td>2/12/08</td>
<td>33.58</td>
<td>0.359</td>
<td>6.54</td>
<td>6.19</td>
<td>91.7</td>
<td>193</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>WCB22</td>
<td>3/12/08</td>
<td>32.90</td>
<td>1.020</td>
<td>0.77</td>
<td>6.39</td>
<td>11.2</td>
<td>-24</td>
<td>171</td>
<td></td>
</tr>
<tr>
<td>WCB17</td>
<td>3/12/08</td>
<td>34.21</td>
<td>0.801</td>
<td>0.43</td>
<td>6.52</td>
<td>5.5</td>
<td>18</td>
<td>203</td>
<td></td>
</tr>
<tr>
<td>WCB9</td>
<td>3/12/08</td>
<td>32.49</td>
<td>1.670</td>
<td>0.21</td>
<td>6.23</td>
<td>2.9</td>
<td>-5</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>WCB8</td>
<td>3/12/08</td>
<td>32.81</td>
<td>1.700</td>
<td>0.68</td>
<td>6.27</td>
<td>9.4</td>
<td>-130</td>
<td>126</td>
<td>Data logger in bore</td>
</tr>
<tr>
<td>WCB4</td>
<td>4/12/08</td>
<td>32.41</td>
<td>3.040</td>
<td>1.18</td>
<td>6.17</td>
<td>14.3</td>
<td>101</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>WCB10</td>
<td>4/12/08</td>
<td>31.90</td>
<td>2.000</td>
<td>0.34</td>
<td>6.32</td>
<td>4.4</td>
<td>76</td>
<td>63</td>
<td>C14 sample not filtered rest filtered via syringe as bore flow pressure is too low for online filter to be used:</td>
</tr>
</tbody>
</table>
### Table 4.3: Summary of Laboratory Water Quality Analysis (DoW, 2009).

<table>
<thead>
<tr>
<th>Analyte</th>
<th>LOR</th>
<th>Units</th>
<th>PB1</th>
<th>PB3</th>
<th>WCB22</th>
<th>WCB17</th>
<th>WCB17</th>
<th>WCB9</th>
<th>WCB8</th>
<th>WCB4</th>
<th>WCB10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
</tr>
<tr>
<td><strong>Date Collected</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>mg/L</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>-</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Barium</td>
<td>mg/L</td>
<td>0.11</td>
<td>0.097</td>
<td>0.035</td>
<td>0.034</td>
<td>-</td>
<td>0.082</td>
<td>0.04</td>
<td>0.046</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Boron</td>
<td>mg/L</td>
<td>0.11</td>
<td>0.1</td>
<td>0.15</td>
<td>0.24</td>
<td>-</td>
<td>0.13</td>
<td>0.17</td>
<td>0.17</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>mg/L</td>
<td>0.002</td>
<td>0.003</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Cobalt</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Copper</td>
<td>mg/L</td>
<td>0.001</td>
<td>0.006</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Lead</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>0.002</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lithium</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.021</td>
<td>0.006</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.019</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.002</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nickel</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>-</td>
<td>0.005</td>
<td>0.004</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Strontium</td>
<td>mg/L</td>
<td>0.29</td>
<td>0.21</td>
<td>0.36</td>
<td>0.24</td>
<td>-</td>
<td>0.72</td>
<td>0.68</td>
<td>1.2</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>Thorium</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Titanium</td>
<td>mg/L</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Uranium</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Vanadium</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg/L</td>
<td>0.025</td>
<td>0.092</td>
<td>0.037</td>
<td>0.11</td>
<td>-</td>
<td>0.046</td>
<td>0.054</td>
<td>0.037</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Bromide</td>
<td>mg/L</td>
<td>&lt;0.01</td>
<td>0.45</td>
<td>0.24</td>
<td>0.75</td>
<td>0.58</td>
<td>0.61</td>
<td>0.96</td>
<td>1.6</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Calcium - Filterable</td>
<td>mg/L</td>
<td>&lt;1</td>
<td>21</td>
<td>15</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>64</td>
<td>61</td>
<td>86</td>
<td>68</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>&lt;10</td>
<td>110</td>
<td>60</td>
<td>170</td>
<td>140</td>
<td>140</td>
<td>450</td>
<td>380</td>
<td>760</td>
<td>500</td>
</tr>
<tr>
<td>Analyte</td>
<td>LOR</td>
<td>Units</td>
<td>PB1</td>
<td>PB3</td>
<td>WCB22</td>
<td>WCB17</td>
<td>WCB17</td>
<td>WCB9</td>
<td>WCB8</td>
<td>WCB4</td>
<td>WCB10</td>
</tr>
<tr>
<td>------------------</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Date Collected</td>
<td></td>
<td></td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
<td>2-Dec-08</td>
</tr>
<tr>
<td>Fluoride</td>
<td>&lt;0.05</td>
<td>mg/L</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Iodide</td>
<td>&lt;0.05</td>
<td>mg/L</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>0.24</td>
<td>0.23</td>
<td>0.23</td>
<td>0.08</td>
<td>0.19</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>Magnesium - Filterable</td>
<td>&lt;1</td>
<td>mg/L</td>
<td>14</td>
<td>9</td>
<td>14</td>
<td>11</td>
<td>11</td>
<td>32</td>
<td>31</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>Nitrate as NO3-N (Calc)</td>
<td>&lt;0.010</td>
<td>mg/L</td>
<td>5.7</td>
<td>1.7</td>
<td>0.037</td>
<td>&lt;0.010</td>
<td>&lt;0.010</td>
<td>&lt;0.010</td>
<td>&lt;0.010</td>
<td>&lt;0.010</td>
<td>0.01</td>
</tr>
<tr>
<td>FRP as P</td>
<td>&lt;0.005</td>
<td>mg/L</td>
<td>0.006</td>
<td>0.009</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Potassium - Filterable</td>
<td>&lt;1</td>
<td>mg/L</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Silica as SiO2</td>
<td>&lt;0.002</td>
<td>mg/L</td>
<td>61</td>
<td>58</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>14</td>
<td>17</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Sodium - Filterable</td>
<td>&lt;10</td>
<td>mg/L</td>
<td>70</td>
<td>40</td>
<td>160</td>
<td>150</td>
<td>150</td>
<td>210</td>
<td>230</td>
<td>430</td>
<td>270</td>
</tr>
<tr>
<td>Sulfate</td>
<td>&lt;5</td>
<td>mg/L</td>
<td>15</td>
<td>&lt;5</td>
<td>92</td>
<td>73</td>
<td>72</td>
<td>77</td>
<td>160</td>
<td>230</td>
<td>140</td>
</tr>
<tr>
<td>Iron - Filterable</td>
<td>&lt;0.005</td>
<td>mg/L</td>
<td>0.007</td>
<td>&lt;0.005</td>
<td>1.8</td>
<td>0.15</td>
<td>0.16</td>
<td>0.87</td>
<td>0.012</td>
<td>0.2</td>
<td>0.033</td>
</tr>
<tr>
<td>Manganese - Filterable</td>
<td>&lt;0.001</td>
<td>mg/L</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.019</td>
<td>0.006</td>
<td>0.006</td>
<td>0.017</td>
<td>&lt;0.001</td>
<td>0.071</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Figure 4.8

**Expanded Durov Diagram**

Date: 11/03/09

Project: West Canning Basin

Description: Conceptual Hydro

Project No: 1033B

Client: Department of Water

---

**WATER TYPE SUB-FIELDS**

1. \( \text{HCO}_3^- \) and \( \text{Ca}^{2+} \) dominant (frequently indicates recharging waters)
2. \( \text{HCO}_3^- \) dominant and \( \text{Mg}^{2+} \) dominant or cations indiscriminant
3. \( \text{HCO}_3^- \) and \( \text{Na}^+ \) dominant (ion exchanged waters)
4. \( \text{SO}_4^{2-} \) dominant or anions indiscriminant and \( \text{Ca}^{2+} \) dominant (recharge/mixed water)
5. No dominant anion or cation (dissolution/mixing)
6. \( \text{SO}_4^{2-} \) dominant or anions indiscriminant and \( \text{Na}^+ \) dominant (mixing influences)
7. \( \text{Cl}^- \) and \( \text{Ca}^{2+} \) dominant (cement pollution or reverse ion exchange of NaCl waters)
8. \( \text{Cl}^- \) dominant and no dominant cation (reverse ion exchange of NaCl waters)
9. \( \text{Cl}^- \) and \( \text{Na}^+ \) dominant (end point water)
4.7 CONCEPTUAL MODEL

The conceptual hydrogeology as described in the preceding sections has been summarised and presented in Figure 4.9 and Figure 4.10. Figure 4.9 represents our understanding of the hydrogeology in the north-south direction across the middle of the basin, whilst Figure 4.10 represents our understanding of the hydrogeology in the western area, near the De Grey River, in an east-west direction. The general location of these sections is shown in Figure 4.11.

The south-western margin of the Project area has been assigned approximately 20km west of the De Grey River. There is limited information available regarding the stratigraphy in the area around the De Grey River, and, as mentioned, information available suggests that the Broome Sandstone has been eroded out in places by the palaeo De Grey River, and that there exists hydraulic connection between the Broome Sandstone and the De Grey River alluvials. The extent of the Broome Sandstone, Jarlemai Siltstone and Wallal Sandstone in this area has been estimated based on available information and knowledge in the area.

Following the data review, it is apparent there has been limited hydrogeological or mineral exploration in the southeast area of the West Canning Basin. A petroleum bore, Pandanus, was drilled to 214m in the southeast area of the West Canning Basin, however lithological and hydrogeological information could not be found for this bore. As there is no further information available in this area, we have inferred stratigraphic depths, etc based on the remaining information available. In addition, the elevation of the inflow boundary for the Wallal Sandstone in this area of the basin will be assigned during the calibration of the model, which will, in turn, confirm recharge to the Wallal Sandstone via throughflow from outside the model area.

There are a number of faults within the Project area that are thought to be present within the basement rock (Figure 2.1 and 4.5). There is no indication, from the available data set, that these faults influence the hydrogeology of the Wallal Sandstone, Jarlemai Siltstone or Broome Sandstone. In addition, there does not appear to be any correlation between these faults and observed piezometry (Figure 4.7).
GENERALISED CONCEPTUAL HYDROGEOLOGY

FIGURE 4.9

South North

Rainfall Recharge

Leakage

Wallal WL

Granite, Dora Formation and Grant Formation are not anticipated to have any interaction with the Wallal aquifer

NOT TO SCALE
GENERALISED CONCEPTUAL HYDROGEOLOGY IN THE WEST OF THE PROJECT AREA

FIGURE 4.10

-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 5,000 10,000 15,000 20,000 25,000 30,000

Chainage (m)

mAHD

West

East

A

De Grey no 4

De Grey no 2

De Grey no 1

Wallal Water Level

GSWA4A

A’

Broome Sandstone

Alluvium

Jarlemai Siltstone

Alexander Formation

Unconfined Water Level

Leakage

Wallal Sandstone

Basement

De Grey no 1

De Grey no 2

De Grey no 4

GSWA4A

West

East

mAHD

Chainage (m)
5 NUMERICAL MODEL

5.1 CODE SELECTION

Modflow (McDonald and Harbaugh, 1998) is one of the industry leading groundwater modelling codes and is proposed as the computational/numerical code for simulating the West Canning Basin. The requirement to develop a Modflow model has already been agreed with DoW staff. Modflow is well suited to the nature of the aquifer units of the West Canning area (gently sloping geometry and predominantly isotropic aquifer hydraulic conductivity) and we believe that a standard version of Modflow will be adequate to simulate the essential hydrogeological features of the system. A Modflow variant such as Modflow Surfact (Hydrogeologic, 1996), which allows for a more rigorous treatment of the unsaturated zone hydraulics should not be required for this work, nor for any model updates in the future.

We understand that it is the preference of the DoW for the West Canning groundwater model to be delivered in the Visual Modflow Graphical User Interface (GUI). Discussions with DoW staff have outlined the reasons for the preference. While Visual Modflow does have a range of useful and proven features, there is also some justification for the use of another well documented and supported GUI, Groundwater Vistas. A summary of the benefits and potential disadvantages of both of these GUIs is summarised in Table 5.1. Most of the benefits and disadvantages outlined are relevant to this project. The only issues which are not relevant are related to limitations associated with Visual Modflow and the interface to Modflow Surfact.

It is our intention to develop, calibrate, use the model for predictions and deliver it to the DoW in a single GUI. We recommend the use of Groundwater Vistas for the range of features outlined above. We do, however, understand that the DoW have in-house expertise and a preference in Visual Modflow and the model can be developed in this GUI, if required.

While a number of issues are outlined in Table 5.1, the main issue that suggests that Groundwater Vistas would be the preferred GUI is the simulation of evapotranspiration. Groundwater Vistas allows evapotranspiration from any model layer (not just layer 1) and also allows the evapotranspiration surface to be set at any elevation (Visual Modflow constrains this value to ground surface). This issue is particularly relevant to the simulation of the springs, shallow water tables and constrained groundwater pumping using the ET package as outlined in Section 5.4.

5.2 MODEL SET UP

The model will include features to simulate:

- Hydrogeological features of the aquifer system.
- Rainfall recharge to the aquifer.
- Groundwater inflow to and outflow from the modelled area.
- Groundwater pumping from the Broome Sandstone and Wallal Sandstone aquifer.

5.3 MODEL EXTENT, LAYERING AND GRID

The model will be developed with five layers to include two layers for the Wallal Sandstone (to enable assessment of sensitivity relating to the Alexander Formation), Jarlemai Siltstone, Broome Sandstone and the surficial sediments (Table 5.2). The model and all associated data will be plotted using the GDA94 Zone 51 coordinate system. Coordinates of the proposed rectangular model domain (four corner points) are detailed in Table 5.3. Extents of individual aquifer units may be smaller than this maximum extent.

A grid size of 500 metres is proposed for the majority of the model grid that is used to simulate the main land areas of the aquifer units of interest. The off shore or ocean area (as outlined in Section 5.4 below) will include larger model cells, up to a maximum size of 1000 metres. This results in a total of approximately 966,720 cells over the five model layers. Recent experience indicates that model run times should not be problematic with this model dimensionality. There may be some scope to reduce the uniform grid size locally to 250 metres, if required.
### Table 5.1: Summary of Groundwater User Interface

<table>
<thead>
<tr>
<th>GUI</th>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual Modflow</strong></td>
<td>Well supported and documented with ongoing development</td>
<td>Evapotranspiration (ET) must be specified from the top grid layer and the ET surface must be equal to topography. ET function cannot be used to constrain pumping. Must use Modflow Surfact Fracture Well package to constrain pumping relative to a water level</td>
</tr>
<tr>
<td></td>
<td>Ease of use. In-house expertise in DoW</td>
<td>Some limitations associated with Modflow Surfact models</td>
</tr>
<tr>
<td></td>
<td>Excellent result and output viewing capabilities</td>
<td>Cell re-wetting uses global rather than spatially-varying cell by cell parameters</td>
</tr>
<tr>
<td></td>
<td>Good interface with GIS shape files</td>
<td>No matrix arithmetic capabilities</td>
</tr>
<tr>
<td></td>
<td>Automatic stress period setup created from time series data, however some caution is required</td>
<td>Water budgets not easily tabulated per stress period. Must look at time series differences to assess water balance components.</td>
</tr>
<tr>
<td></td>
<td>Groundwater pumping can be placed over multiple layers based on screened intervals and a weighting equation. Time series pumping easily imported</td>
<td>Limited capability in inputting Modflow input files (eg bas.dat, bcf.dat etc)</td>
</tr>
<tr>
<td><strong>Groundwater Vistas</strong></td>
<td>Well supported and documented with ongoing development including personal service from developers. Blog updated by developers ([<a href="http://groundwater">http://groundwater</a> models.blogspot.com/](<a href="http://groundwater">http://groundwater</a> models.blogspot.com/))</td>
<td>Some specific skills required to use. Skills not currently available in-house at DoW</td>
</tr>
<tr>
<td></td>
<td>Evapotranspiration (ET) can be specific from any layer and ET surface can be user specified. ET function can then be used to assign constrained groundwater pumping in standard Modflow</td>
<td>Some ambiguity in hydrograph and mass balance views for large models</td>
</tr>
<tr>
<td></td>
<td>Excellent result and output viewing capabilities. Uses only one file to store all model related data. Spatially-varying cell re-wetting.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supports most GIS file types. Basic matrix arithmetic capabilities (useful for efficient data processing).</td>
<td>Groundwater pumping can be placed over multiple layers based on screened intervals and a weighting equation</td>
</tr>
<tr>
<td></td>
<td>Easy import and/or interpolation of data via text files</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.2: Layer Geometry

<table>
<thead>
<tr>
<th>Layer</th>
<th>Hydrogeological Unit</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surficial Sediments</td>
<td>Top of layer to follow surface topography. Base of layer assigned consistent with GSWA data for base of alluvium. Thickness estimated to be between 2 and 10 metres</td>
</tr>
<tr>
<td>2</td>
<td>Broome Sandstone (Aquifer)</td>
<td>Base of layer will be assigned consistent with GSWA and other data available for base of Broome Sandstone. Thickness estimated to be between 10 and 130 metres</td>
</tr>
<tr>
<td>3</td>
<td>Jarlemai Siltstone (Aquitard)</td>
<td>Base of layer will be assigned consistent with GSWA data for base of Jarlemai. Thickness varies between 10 and 120 metres.</td>
</tr>
<tr>
<td>4 and 5</td>
<td>Wallal Sandstone (Aquifer)</td>
<td>Base of the Wallal will be assigned consistent with GSWA data for base of Wallal. Thickness layer of layer 4 (Alexander formation) will be set at approximately one-third the overall Wallal Sandstone thickness. Total thickness of Wallal (i.e., layers 4 and 5) varies between 20 and 370 metres.</td>
</tr>
</tbody>
</table>

Table 5.3: Model Domain

<table>
<thead>
<tr>
<th>Grid Position</th>
<th>Easting*</th>
<th>Northing*</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East</td>
<td>279000</td>
<td>7961470</td>
</tr>
<tr>
<td>North West</td>
<td>51000</td>
<td>7961470</td>
</tr>
<tr>
<td>South West</td>
<td>51000</td>
<td>7706210</td>
</tr>
<tr>
<td>South East</td>
<td>279000</td>
<td>7706210</td>
</tr>
</tbody>
</table>

* GDA94 Zone 51 (as project area crosses zones 50 and 51)

5.4 BOUNDARY CONDITIONS

A groundwater inflow boundary will be assigned at the upstream boundary of the Wallal Sandstone aquifer. The location of the coastal or downstream boundaries is shown schematically in Figure 5.1 and 5.2. The northern boundary of the model will be set a distance of approximately 9 km from the coastline in the west, to approximately 120 km from the coastline in the east of the project area. This approach will allow the coastal outflow, or downstream model boundary to be simulated in such a way that the boundary location will not overly constrain model results. For example, if a proposed borefield in the Wallal Sandstone is simulated close to the coast, the model boundary is sufficiently far away that it will not result in underestimation of the impact of long-term pumping.

The proposed setup of the coastal boundary condition is shown schematically in section in Figure 5.3. The ocean will be simulated in layer 1 using the River Package in MODFLOW. The base of the “river” cells will be set consistent with available sea flow bathymetry data with the “head” in the river set consistent with mean sea level. The elevations of the ocean boundary (to be incorporated in the River package) will be set consistent with available monitoring data and consistent with information provided by Turner and Coates on how ocean boundaries should be specified (Turner et al., 1996). The underlying layers will be assigned a no flow condition at their northern limit as it is assumed that all groundwater outflow will ultimately be to the ocean, driven by the difference between the discharging freshwater and the more saline sea water. This arrangement will not account for the density driven processes but will provide a sufficient approximation to the inferred groundwater outflow process. It will also allow for an early assessment of the potential for saline intrusion via the reversal of flow directions at this model boundary.

Rainfall recharge will be assigned consistent with analytical estimates to the saturated surficial sediments and unconfined areas of the Broome and Wallal aquifers.
Evapotranspiration from shallow water tables and/or springs will be simulated using the Evapotranspiration (ET) package in Modflow. The evaporative feature may need to be included in both layer 1 and/or layer 2, depending on the saturated thickness of the surficial sediments and the Bronge Sandstone. If Visual Modflow is used, it may be difficult to simulate this evaporative flux using the ET package and it may be necessary to use the drain package (DRN) in Modflow.

Groundwater pumping will be simulated by the pumping wells (WEL package in Modflow) or if Groundwater Vista is adopted as the GUI, via the ET package in Modflow, which allows minimum water levels or constrained pumping to be applied.

### 5.5 AQUIFER PARAMETERS

Aquifer parameter values will be refined during model calibration, however initial estimates based on available data are presented in Table 5.4.

<table>
<thead>
<tr>
<th>Aquifer/Aquitard Unit</th>
<th>Horizontal Hydraulic Conductivity (m/d)</th>
<th>Vertical Hydraulic Conductivity (m/d)</th>
<th>Confined Storage Coefficient</th>
<th>Specific Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial Sediments</td>
<td>1</td>
<td>0.1</td>
<td>NA</td>
<td>0.15</td>
</tr>
<tr>
<td>Broome Sandstone</td>
<td>7.5</td>
<td>0.75</td>
<td>5x10^-4</td>
<td>0.15</td>
</tr>
<tr>
<td>Jarlemai Siltstone</td>
<td>0.001</td>
<td>0.0001</td>
<td>5x10^-4</td>
<td>0.035</td>
</tr>
<tr>
<td>Alexander Formation</td>
<td>20</td>
<td>2</td>
<td>5x10^-4</td>
<td>0.2</td>
</tr>
<tr>
<td>Wallal Sandstone</td>
<td>20</td>
<td>2</td>
<td>5x10^-4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

### 5.6 MODEL CALIBRATION

The model will be calibrated in steady state ("long term average") mode to measured (assumed steady) water levels. Calibration will be assessed by quantifying the Scaled Root Mean Squared (SRMS) of measured versus modelled groundwater levels. In accordance with best practice modelling guidelines (MDBC, 2001), a SRMS value of less than 5% will be targeted, but model calibration performance may be limited by data availability. Plots of modelled groundwater contours will be presented overlaid with measured spot heights, along with scatter plots of measured and modelled hydraulic heads.

The following data are available for transient model calibration:

- [Data associated with the operation of the BHPBIO Shay Gap borefield.](#)
- [Groundwater level monitoring data at GSWA 20C.](#)

This data does not show any significant piezometric level changes over time. Therefore, the data can be used to provide a lower limit on aquifer storage values.

The available C14 data will be used to test if the model, prior to the inclusion of any additional borefield pumping (other than Shay Gap), is able to replicate groundwater travel times inferred from the data. It is assumed that the data currently available will be incorporated and that any data that becomes available in the future will be used as part of further model calibration and development under an extended work programme.

As required, all other modelling activities will be completed in accordance with best practice modelling guidelines (MDBC). If this is not achievable, the implications will be discussed with DoW staff as soon as possible to identify impacts on the project and an implementable solution.
FIGURE 5.1
Model Extent and Boundary Conditions
(Broome Aquifer)

LEGEND
- Model Boundary
- No Flow Boundary

LOCATION MAP

AUTHOR: AP
DRAWN: AN
DATE: 05/03/09
JOB NO: 1033B
REPORT NO: 021
REVISION: ...
SCALE: 1:900,000
PROJECTION: MGA94
FIGURE 5.2
Model Extent and Boundary Conditions (Wallal Aquifer)

Legend:
- Model Boundary
- Notional Fixed Head
- Inflow Boundary
- No Flow Boundary

SCALE: 1:1,500,000
DATE: 05/03/09
JOB NO: 1033B
REPORT NO: 021
REVISION: ...
SCALE: 1:1,500,000
PROJECTION: MGA94

LOCATION MAP
SCHEMATIC BOUNDARY CONDITIONS SET-UP

Fig 5.3

Evapotranspiration

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5

River Boundary Conditions

No Flow Boundary Layers 2 to 5

Base of Model

Alluvials
Broome Sandstone
Jarlemai Silstone
Alexander Formation
Wallal Sandstone

Coastline

NOT TO SCALE
6  REFERENCE LIST


