Pumping tests, La Grange region, Western Australia

Groundwater Consulting Services

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1. INTRODUCTION

The Department of Agriculture and Food is in the final stages of the La Grange Agriculture Opportunities investigation into the suitability of land and water resources in the La Grange region, south and west of Broome, for irrigated agriculture. The La Grange region lies between the Roebuck Plains marine embayment to the north and the Mandora Marsh system to the south (Figure 1, Appendix A). Paul et al (2013) identified the need for good quality hydraulic data to enable informed decisions to be made in relation to expanding irrigated agriculture in the region.

There are a number of existing and historical irrigated agriculture projects in the region. The Department of Agriculture and Food project seeks to reduce the risk of expansion to irrigated agriculture by identifying areas that are most suitable for development.

As a part of this project Department of Agriculture and Food undertook a review of the knowledge gaps (Paul et al 2013) and then led a phased process of investigations to seek data to better understand the technical issues relating to development of irrigated agriculture. These included an inventory of over 300 existing bores, a regional airborne electromagnetic survey (aquifer geometry, quality, and saltwater interactions), detailed aquifer chemistry to assess water quality and an assessment of wetlands. In 2014 and 2015 the Department drilled a network of 49 monitoring bores at 24 sites to assess aquifer recharge, test the airborne electromagnetic survey to assist in construction of a groundwater model and enable baseline aquifer conditions to be determined. These bores were utilised to obtain aquifer hydraulic properties through pumping tests.

Groundwater Consulting Services was contracted to collate and analyse pumping test information from four sites in the study area. Two of the pumping tests were conducted by Groundwater Consulting Services and the remaining two pumping tests were conducted by Kimberley Water Pty Ltd under instruction from the Department of Agriculture and Food.

The major objective of the work was to provide aquifer hydraulic data to be used as input into a numerical model being developed by the Department of Agriculture and Food. A secondary objective was to provide irrigation water supply development advice for potential irrigation projects. The aquifer hydraulic data provided by this study supplements that sourced from other investigations in the region.

The Broome Sandstone in the La Grange region hosts the regionally extensive Broome Sandstone aquifer which supports most of the existing and future groundwater irrigation projects in the region, and is the subject of this work. Large-scale abstraction from the Broome Sandstone aquifer provides the Broome town water supply borefield and irrigation projects at Skuthorpe, Shamrock Gardens and Shelamar Station. Decommissioned irrigation projects using the resources of the Broome Sandstone aquifer occur at Bidyadanga and Nita Downs, but the groundwater resource was not a constraint. Irrigation of stock feed on Pardoo and Wallal Downs Stations west of the study area draws from the confined artesian Wallal aquifer, which is probably brackish beneath the La Grange area. Brackish artesian water
from the Wallal Sandstone aquifer was used for irrigation on Anna Plains in the 1970s but failed due to salinisation of the soils.

There are two active irrigated agriculture projects and a further three to four in various development or planning stages through the La Grange region. The region has been identified as a target for development of irrigated agriculture by the *Water for Food* initiative driven by the Department of Water.
The testing programme was designed to obtain:

- Approximate bore yield and drawdown characteristics
- Local aquifer parameters transmissivity and storativity
- Assessment of propagation of drawdown to the water table
- Representative water quality

The ability to achieve these objectives is controlled by the geological understanding, available monitoring bore network and the achievable pumping rate.

1.1 PREVIOUS WORK

Pumping tests have been completed in the Broome Sandstone aquifer to support applications for groundwater licences in the La Grange region at:

- Nita Downs Station (reference unavailable).
- Anna Plains Station (Groundwater Consulting Services 2009).
- Shelamar Station (Groundwater Consulting Services, 2011).
- Bidyadanga water supply (Rockwater, 2015).

A summary of the test parameters and hydraulic parameters interpreted from the pumping tests is provided in Table 1.1.
Table 1.1 Previous Work – Pumping Tests and Derived Hydraulic Parameters

<table>
<thead>
<tr>
<th>Location</th>
<th>Pumping Bore</th>
<th>Duration (hrs)</th>
<th>Discharge Rate (kL/day)</th>
<th>Response Bore</th>
<th>Transmissivity (m²/day)</th>
<th>Hydraulic conductivity (m/day)</th>
<th>Specific Yield (-)</th>
<th>Storativity (-)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anna Plains Station</td>
<td>PB1</td>
<td>19</td>
<td>3,620</td>
<td>Pumping</td>
<td>3,400</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>Groundwater Consulting Services (2009)</td>
</tr>
<tr>
<td>Shamrock Station</td>
<td>Various</td>
<td>48</td>
<td>3,890</td>
<td>Observation (small radius)</td>
<td>9,600</td>
<td>55</td>
<td>-</td>
<td>1.5 x 10⁻³</td>
<td>Groundwater Consulting Services (2010)</td>
</tr>
<tr>
<td>Shelamar Station</td>
<td>Bore 11, 12</td>
<td>24</td>
<td>8,655</td>
<td>Observation</td>
<td>2,800</td>
<td>14</td>
<td>0.05</td>
<td>5 x 10⁻⁴</td>
<td>Groundwater Consulting Services (2011)</td>
</tr>
<tr>
<td>Bidyadanga</td>
<td>B-1/15</td>
<td>24</td>
<td>730</td>
<td>Pumping</td>
<td>130</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rockwater (2015)</td>
</tr>
<tr>
<td>Shamrock Station</td>
<td>GH</td>
<td>46</td>
<td>3,845</td>
<td>Observation</td>
<td>3190</td>
<td>177 (16)*</td>
<td>-</td>
<td>-</td>
<td>WMC (1999)</td>
</tr>
</tbody>
</table>

Note: *-177m/day appears to be erroneously high. Based on aquifer thickness 190m and derived transmissivity of 3000m²/day, the hydraulic conductivity is 16m/day.
2. **PUMPING TEST SITES**

The Department of Agriculture and Food nominated four sites on Roebuck Plains, Shamrock, Frazier Downs and Nita Downs Stations as suitable for pumping tests (*Figure 1, Appendix A*).

Each site has a local network of monitoring bores to assess horizontal and vertical propagation of drawdown. The monitoring bore network was designed and installed by the Department of Agriculture and Food. Test site layouts are shown on *Figures 2a to 2d, Appendix A* and incorporate some existing bores.

2.1 **NOMENCLATURE**

Bore names were either derived from names in common usage for existing bores or from the Department of Agriculture and Food records for bores constructed by the Department of Agriculture and Food. The Department of Agriculture and Food bores are named as follows:

- prefixed by 15 or 16 for the year in which the bore was drilled
- then LAG for “La Grange”,
- followed by the site identification number (for example “08” for the site on Shamrock Station), and
- S, I or D representing screen intervals at an arbitrary shallow, intermediate or deep zone within the Broome Sandstone aquifer.

Bore names in common use were retained for existing bores, and matched to names provided by the Department of Agriculture and Food where possible.

The test sites are referred to in this report by the name of the station on which the pumping bore lies, presented in order of increasing distance from Broome.

2.2 **BORE DETAILS**

Available bore records for test pumping bores and observation bores are summarised in *Table 2.1*. The bore data were compiled from available records, cross-checked by measurements collected by Groundwater Consulting Services and represent collation of data from various sources.

Lithological logs and bore completion records as provided by the Department of Agriculture and Food are provided in *Appendix B*.

Photographs of the test pumping and observation bores at each site are provided in *Appendix C*. Photographs of the pumping tests conducted by Groundwater Consulting Services at Shamrock Station and Nita Downs Station are also provided.
Table 2.1  Pumping Test Programme Bore Details

<table>
<thead>
<tr>
<th>Test/Region</th>
<th>Bore</th>
<th>Pumping Test Purpose</th>
<th>Distance From Pumping Bore (m)</th>
<th>GPS Co-ordinates (m MGA94)</th>
<th>Reference Point (RP)</th>
<th>Survey Elevation</th>
<th>PVC Casing ID (mm)</th>
<th>Total Depth (mBRP)</th>
<th>Screen Interval (mBGL)</th>
<th>Water Level (mBRP)</th>
<th>Date and Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Easting</td>
<td>Northing</td>
<td></td>
<td></td>
<td>Ground (mAHED)</td>
<td>PVC Casing (mAHED)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roebuck Plains</td>
<td>15LAG02I</td>
<td>Pumping bore</td>
<td>0</td>
<td>4666501</td>
<td>8003354</td>
<td>TOC PVC</td>
<td>0.245</td>
<td>22.296</td>
<td>23.511</td>
<td>149</td>
<td>77.245</td>
</tr>
<tr>
<td></td>
<td>15LAG02S</td>
<td>Local observation</td>
<td>1</td>
<td>4666500</td>
<td>8003353</td>
<td>TOC PVC</td>
<td>0.77</td>
<td>23.215</td>
<td>23.952</td>
<td>50</td>
<td>14.57</td>
</tr>
<tr>
<td></td>
<td>16LAG02S</td>
<td>Local observation</td>
<td>6.5</td>
<td>466498</td>
<td>8003359</td>
<td>TOC PVC</td>
<td>0.715</td>
<td>50</td>
<td>30.715</td>
<td>27-30</td>
<td>8.75</td>
</tr>
<tr>
<td></td>
<td>16LAG02I</td>
<td>Local observation</td>
<td>23</td>
<td>466484</td>
<td>8003368</td>
<td>TOC PVC</td>
<td>0.58</td>
<td>98</td>
<td>78.58</td>
<td>72-78</td>
<td>8.69</td>
</tr>
<tr>
<td>Shamrock</td>
<td>PB1</td>
<td>Pumping bore</td>
<td>0</td>
<td>404457</td>
<td>7952880</td>
<td>Concrete*</td>
<td>0.20</td>
<td>250</td>
<td>153</td>
<td>95-153</td>
<td>42.00</td>
</tr>
<tr>
<td></td>
<td>15LAG008</td>
<td>Local observation</td>
<td>352</td>
<td>404772</td>
<td>7952723</td>
<td>TOC PVC</td>
<td>0.505</td>
<td>55.290</td>
<td>55.620</td>
<td>97</td>
<td>49.505</td>
</tr>
<tr>
<td></td>
<td>15LAG009</td>
<td>Local observation</td>
<td>355</td>
<td>404775</td>
<td>7952723</td>
<td>TOC PVC</td>
<td>0.605</td>
<td>55.906</td>
<td>102.605</td>
<td>96-102</td>
<td>43.18</td>
</tr>
<tr>
<td></td>
<td>Cookies old</td>
<td>Regional observation</td>
<td>2536</td>
<td>403315</td>
<td>7950616</td>
<td>TOC PVC</td>
<td>0.51</td>
<td>140</td>
<td>65</td>
<td>unknown</td>
<td>49.86</td>
</tr>
<tr>
<td></td>
<td>Thangoo #1</td>
<td>Regional observation</td>
<td>6761</td>
<td>403327</td>
<td>7959546</td>
<td>TOC PVC</td>
<td>0.45</td>
<td>150</td>
<td>72</td>
<td>unknown</td>
<td>30.65</td>
</tr>
<tr>
<td></td>
<td>La Grange #1</td>
<td>Regional observation</td>
<td>12315</td>
<td>393888</td>
<td>7946395</td>
<td>TOC PVC</td>
<td>0.25</td>
<td>140</td>
<td>12.85</td>
<td>unknown</td>
<td>12.85</td>
</tr>
<tr>
<td>Frazier Downs</td>
<td>15LAG026TP</td>
<td>Pumping bore</td>
<td>0</td>
<td>377768</td>
<td>7916620</td>
<td>TOC PVC</td>
<td>0.755</td>
<td>30.398</td>
<td>31.153</td>
<td>150</td>
<td>66.65</td>
</tr>
<tr>
<td></td>
<td>16LAG026S</td>
<td>Local observation</td>
<td>~7</td>
<td>377774</td>
<td>7916623</td>
<td>TOC PVC</td>
<td>0.41</td>
<td>50</td>
<td>23.84</td>
<td>20.84-23.84</td>
<td>16.29</td>
</tr>
<tr>
<td></td>
<td>15LAG026I</td>
<td>Local observation</td>
<td>~36</td>
<td>377804</td>
<td>7916831</td>
<td>TOC PVC</td>
<td>0.615</td>
<td>30.601</td>
<td>31.263</td>
<td>97</td>
<td>66.6</td>
</tr>
<tr>
<td>Nita Downs</td>
<td>PB1</td>
<td>Pumping bore</td>
<td>0</td>
<td>360304</td>
<td>7890481</td>
<td>TOC PVC</td>
<td>0.29</td>
<td>30.610</td>
<td>30.948</td>
<td>195</td>
<td>&gt;100</td>
</tr>
<tr>
<td></td>
<td>NW</td>
<td>Local observation</td>
<td>974</td>
<td>359707</td>
<td>7889711</td>
<td>TOC PVC</td>
<td>0.06</td>
<td>26.992</td>
<td>27.062</td>
<td>148</td>
<td>41.7</td>
</tr>
<tr>
<td></td>
<td>ME1</td>
<td>Local observation</td>
<td>983</td>
<td>360437</td>
<td>7889903</td>
<td>TOC PVC</td>
<td>0.12</td>
<td>29.099</td>
<td>29.191</td>
<td>148</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>Regional observation</td>
<td>1436</td>
<td>360332</td>
<td>7889045</td>
<td>TOC PVC</td>
<td>0.14</td>
<td>25.38</td>
<td>28.575</td>
<td>145</td>
<td>40.2</td>
</tr>
<tr>
<td></td>
<td>15LAG19S</td>
<td>Regional observation</td>
<td>2057</td>
<td>358032</td>
<td>7889955</td>
<td>TOC PVC</td>
<td>0.62</td>
<td>22.805</td>
<td>24.554</td>
<td>50</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>15LAG19I</td>
<td>Regional observation</td>
<td>2058</td>
<td>358032</td>
<td>7889984</td>
<td>TOC PVC</td>
<td>0.78</td>
<td>23.10</td>
<td>23.78</td>
<td>100</td>
<td>93</td>
</tr>
</tbody>
</table>

Notes: * airline reference point.
Distance from pumping bore measured using a tape for Roebuck Plains observation bores. Other distances calculated from GPS measurements.
GPS co-ordinates by Groundwater Consulting Services single handheld GPS for consistency between measurements.
Total depths from DAFWA data, based on tagged depths.
All water level measurements as recorded by Groundwater Consulting Services.
15LAG02s is hydraulically isolated from the Broome Sandstone aquifer.
2.3 BROOME SANDSTONE AQUIFER

The Broome Sandstone aquifer is regionally comprised of two layers; an upper deltaic facies with moderate permeability and a lower fluvial facies with higher permeability. The upper unit is suitable for bores with modest water requirements, but large scale commercial irrigation bores typically target the lower more permeable layer. The transition between the two commonly occurs at about 60m depth but has not been specifically reviewed in this study. Review of the lithological logs provided by DAFWA confirms a transition to more permeable materials with depth at about 50-70m, however drilling does not extend far enough to be certain of the transition depth in many cases.

Confined or partially confined conditions are likely to occur beneath the lowlying coastal plain where clayey materials overlie the aquifer. Confined aquifer responses were observed at Kilto (Groundwater Consulting Services 2012), in what has been reinterpreted since as a Palaeochannel aquifer, as well as at Roebuck Plains (ibid). The geometric relationships between the fine-grained coastal plain sediments and the Broome Sandstone have not been investigated in any detail.

DAFWA did not run geophysical logs during the drilling programme. CSIRO geophysically logged the saltwater interface bores and Department of Agriculture and Food planned to log the remainder of the bores. After logging at Site 2, the equipment failed and the programme was deferred. The lack of geophysical logs reduces the ability to meaningfully subdivide the aquifer.

The screen intervals of the intermediate bores at Roebuck Plains (15LAG02I And 16 LAG02I) are both within the higher permeability lower zone. The screen intervals of the intermediate bores at Frazier Downs (15LAG26I and 15LA26TP) are interpreted to extend into the top of the lower Broome Sandstone aquifer. The screen intervals for the production bores on Shamrock (PB1) and Nita Downs (PB1) extend through both the upper and lower intervals.
3. PROGRAMME SETUP

The characteristics and overall scope of the testing programme at each site is summarised in Table 3.1.

Pumping tests at Shamrock Station and Nita Downs Station were carried out by Groundwater Consulting Services. Pumping tests at Roebuck Plains Station and Frazier Downs Station were carried out by Kimberley Water under instruction from the Department of Agriculture and Food. The testing setup and measurement methods varied across the sites and are summarised in Table 3.2.

Groundwater levels were measured manually using an electronic water level meter or through dataloggers installed in selected bores. The installed dataloggers were a combination of vented and unvented units of two different brands owned by the Department of Agriculture and Food and Groundwater Consulting Services. Unvented dataloggers record water pressure and barometric pressure and barometric corrections were applied from barometric loggers operating at the site or up to 30 km distant (Section 4.2). Dataloggers suspended on fishing line by the Department of Agriculture and Food required arbitrary manual corrections to be applied, likely due to stretching or relaxing of the line during the process of retrieving the logger for downloading. An airline system was used to measure water levels in Shamrock PB1 as there was no access for a water level meter.

Flow rates were recorded at Shamrock Station using a new digital ultrasonic flowmeter and are considered to be accurate. The other pumping tests were based on a circular orifice weir and the installation was only observed directly by Groundwater Consulting Services at Nita Downs. The flow rate was determined by using the measured physical dimensions of the orifice weir and the water pressure in the manometer tube to calculate the flow rate (Driscoll, 1986).

Flow rates for the tests on Roebuck Plains and Frazier Downs Stations were determined by Kimberley Water using the same orifice weir arrangement and reported to Groundwater Consulting Services; however the installation details and manometer water pressure height data were not available. Groundwater Consulting Services notes that the calculated open flow rate for the pump at Nita Downs (15.9 L/s) was about 20 % less than the flow rate reported by Kimberley Water for the same pump. The water levels at Nita Downs and Frazier Downs are similar (about 19 mBGL) and it is suspected that the derived flow rates for the tests at Frazier Downs are over-reported. The shallower groundwater level at Roebuck Plains (about 9 mBGL) means that a higher flow could be obtained from the pump and this rate is more likely to be achievable, but is still poorly constrained. The flow rate advised by Kimberley Water was taken at face value.
### Table 3.1 Description of the Overall Programme – Testing and Responsibilities

<table>
<thead>
<tr>
<th>Station</th>
<th>Roebuck Plains</th>
<th>Shamrock</th>
<th>Frazier Downs</th>
<th>Nita Downs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended rigour</td>
<td>Low-moderate</td>
<td>High</td>
<td>Low-moderate</td>
<td>High</td>
</tr>
<tr>
<td>Reason for testing</td>
<td>Provide information to traditional owners on bore/aquifer capacity for development advice, add to regional database of hydraulic data</td>
<td>Partially driven by SAWA requirement for both bore performance data which was used to select scale for the first stage of development. Opportunity to use existing pump at high flow rate to get good hydraulic data and understand vertical propagation of drawdown. Note costs for this field work shared 50:50 SAWA/DAFWA</td>
<td>Provide information to traditional owners on bore/aquifer capacity for development advice, add to regional database of hydraulic data</td>
<td>Improve spatial coverage of hydraulic data. The Department of Agriculture and Food was advised that low anticipated pumping rate (limited by bore diameter) and distance to monitoring bores would compromise the value of the test.</td>
</tr>
<tr>
<td>Test equipment owner</td>
<td>Kimberley Water</td>
<td>SAWA</td>
<td>Kimberley Water</td>
<td>Kimberley Water</td>
</tr>
<tr>
<td>Test supervised/run/ data collection by</td>
<td>Kimberley Water</td>
<td>Groundwater Consulting Services</td>
<td>Kimberley Water</td>
<td>Groundwater Consulting Services</td>
</tr>
<tr>
<td>Flow rate robustness</td>
<td>Moderate (Orifice Weir - manometer heights not recorded)</td>
<td>High (Octave flowmeter)</td>
<td>Moderate (Orifice Weir – manometer heights not recorded)</td>
<td>Moderate to High (Orifice Weir - manometer heights were recorded)</td>
</tr>
<tr>
<td>Test programme</td>
<td>Test pumping bore 15LAG02I Step test (four 1-hour steps) 24-hour constant-discharge test at 1728 kL/day (20 L/s)</td>
<td>Test pumping bore PB1 Step test (four 1-hour steps) 48-hour constant-discharge test at 6765 kL/day (78 L/s)</td>
<td>Test pumping bore 15LAG26TP Step test (four 1-hour steps) 23-hour constant-discharge test at 1728 kL/day (20 L/s)</td>
<td>Test pumping bore PB1 No step test 24-hour constant-discharge test at 1374 kL/day (16 L/s)</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Good drawdown responses were obtained in the production aquifer and the top of the aquifer. Bore is relatively shallow and does not test the high permeability zone in the lower Broomie Sandstone. Monitoring bore was relatively close to the pumping bore and the volume of aquifer tested was not significant. Mounding of discharged water was observed in the water table bore.</td>
<td>Good drawdown responses were obtained in the production aquifer and water table. Production bores test the deeper high permeability zone in the aquifer. Monitoring bore was relatively distant to the pumping bore and the volume of aquifer tested was significant.</td>
<td>Good drawdown responses were obtained in the production aquifer and water table. Bore is relatively shallow and does not test the high permeability zone in the lower Broomie Sandstone. Monitoring bore was relatively close to the pumping bore and the volume of aquifer tested was not significant.</td>
<td>Flow rate was just sufficient to induce a response at the nearest observation bores. No monitoring bores were available to assess the response at the water table.</td>
</tr>
<tr>
<td>Item</td>
<td>Pumping Test Location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
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<tr>
<td>Test conducted by</td>
<td>Kimberley Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test pumping bore</td>
<td>15LAG026</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump details</td>
<td>Water was pumped using a Grundfos SP60-6 electric submersible pump installed on steel rising main and powered by a diesel generator. SAWA installed a 250 mm ID PVC-cased production bore screening the Broome Sandstone and installed a diesel engine-driven turbine pump for production purposes. The pump is a Pentair Everflow 200-GHH 8 stage turbine pump. A John Deere diesel engine mounted at the surface drives the pump through a rotating drive-shaft and right-angle gearbox. The pump was installed just prior to testing and there had been no irrigation on the property at the time of writing. Water was pumped using a Grundfos SP60-6 electric submersible pump installed on steel rising main and powered by a diesel generator. Production bore PB1 was drilled in the 1980s and is to be equipped with a pump for a proposed irrigation development. As the irrigation pump was not available in time for the testing programme, Kimberley Water was contracted by the Department of Agriculture and Food to install and operate a pump in the bore. A Grundfos SP60-6 was installed on a steel rising main and powered by a diesel generator.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rate measurement</td>
<td>Flow rates were determined using an orifice weir and controlled with a manual gate valve to maintain a predetermined flow rate represented by a water level in the manometer. The maximum flow rate for the pump was 20 L/s, however the manometer heights were not recorded. Flow rates were determined using an orifice weir and controlled with a manual gate valve. Water was discharged locally at the site of the pumping test. The maximum flow rate for the pump was 20 L/s, however the manometer heights were not recorded. The flow rate was measured using a circular orifice weir installed by Kimberley Water Pty Ltd. The weir had a diameter of 4&quot; and an orifice plate of 3&quot; was fitted. A clear manometer tube was used to measure the backpressure in the weir and to then calculate the flow rate.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge control</td>
<td>Water was discharged locally at the site of the pumping test. Water was discharged from the test was pumped into a trench ready for the irrigation pipework, and flowed away on the surface. Water was discharged locally at the site of the pumping test. Water was discharged locally at the site of the pumping test. Water was discharged locally at the site of the pumping test. Water discharged from the test was pumped into a trench ready for the irrigation pipework, and flowed away on the surface. Water was discharged locally at the site of the pumping test. Water was discharged locally at the site of the pumping test.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water level measurement –</td>
<td>Manual water level measurements only. Datalogger not installed.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test pumping bore</td>
<td>Kimberley Water re-installed the logger installed by Groundwater Consulting Services prior to the pumping test programme. The logger became hung up in the hole and was not submerged during the full pumping cycle for the step or constant discharge test. Kimberley Water maintained manual water level measurements throughout the test and recovery period. Datalogger data from Cookies Old are unusable. Kimberley Water measured pre-CDT water level in 15LAG026, 15LAG028 and in 16LAG028 only. Dataloggers installed in 15LAG025, 15LAG026 and 16LAG025. Kimberley Water measured pre-CDT water level in 15LAG026. Dataloggers were installed in 15LAG26TP, 15LAG26S and 15LAG26I. Manual measurements in observation bores 15LAG03S, 15LAG03I and Cookies Old were made throughout constant discharge test. Dataloggers installed in 15LAG03S, 15LAG03I, La Grange #1, Thargoo #1. Manual measurements in observation bore 15LAG026 throughout constant discharge test. Dataloggers installed in NW bore, Nita MB1, SE bore, 15LAG19S and 15LAG19I. No water samples were collected. Chemistry data were taken from an airlifted sample. The electrical conductivity of the discharged water was recorded periodically throughout the test. A water sample was collected at the end of the test and provided to the Department of Agriculture and Food. The electrical conductivity of the discharged water was recorded periodically throughout the test. A water sample was collected at the end of the test and provided to the Department of Agriculture and Food. Kimberley Water measured water levels in 15LAG026 and in 16LAG026 only. Dataloggers installed in 15LAG025, 16LAG02S and 16LAG026. Water quality sampling</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Groundwater Consulting Services and the Department of Agriculture and Food used synchronised time (www.nist.gov) to ensure that manual observations and datalogger measurements were synchronised. Kimberley Water used an iPhone which automatically synchronises with an unknown time server as the primary time reference. Time measurements are assumed to be sufficiently accurate.

Electrical conductivity was recorded by Groundwater Consulting Services using a field WTW electrical conductivity meter, recently calibrated. Laboratory analyses of water quality would take precedence over field-derived electrical conductivity. The recorded electrical conductivity indicates that groundwater salinity is not a constraint for irrigated agriculture and any errors are not significant. No trends were observed nor expected.
4. RESULTS AND ANALYSIS

4.1 BORE EFFICIENCY

The two key measures of the hydraulic performance of a bore are the specific capacity and the bore efficiency. The specific capacity of a bore represents the flow available for each unit of drawdown and high specific capacities are preferred to minimise pumping cost. The well efficiency reflects the ratio of the energy required to move water through the aquifer to the bore at a given flow rate, to the total energy required to move the water through the aquifer to the bore and through the screen into the casing. Decreasing efficiency means that elements of the bore design, construction or development are increasingly significant components of the drawdown induced during pumping, and therefore the operating costs of the bore.

In the case of these pumping tests, the hydraulic performance of the bore was not a constraint on the flow rate at which the constant discharge test could be run. All tests were run at the maximum capacity of the installed pump, which in turn was the maximum available given the casing diameter constraint. Note that a turbine pump has been operated in Nita Downs PB1 historically at an anecdotal flow rate of about 50L/s.

The specific capacities were relatively low (2.8L/s/m at Roebuck Plains and 1.7L/s/m at Frazier Downs) for the bores installed for testing purposes by Department of Agriculture and Food, presumably limited by the relatively short screen intervals. The specific capacities for the commercial irrigation bores were significantly higher (11.2L/s/m for Shamrock and 10.2L/s/m at Nita Downs) and reflect the improved bore performance achieved with longer screen intervals, likely assisted by being screened in the deeper, more permeable aquifer zone also.

The step test data were analysed (Appendix D) to provide a measure of the well efficiency. A summary of the bore hydraulic performance data is provided in Table 4.1 and a record of the pumping test rates and times is provided in Table 4.2.

The bore efficiencies at the higher flow rates ranged from 50% (Shamrock) to 60% (Roebuck Plains and Frazier Downs). The efficiency of the bore deteriorates with increasing pumping rate. Efficiency can be improved at the time of bore design and construction by placing longer lengths of stainless steel screen, which has a high open area, against more permeable sections of the aquifer. After completion, attention to proper bore development may improve the bore efficiency.

PB1 at Shamrock station has a relatively low efficiency despite a long screen interval. The bore produced dirty water on starting the pump and the bore may not have been developed properly. Despite the low efficiency, it does not contribute significantly to the overall pumping costs.
The moderate efficiency at Roebuck Plains and Frazier Downs probably reflects the use of short slotted PVC inlet zones which have limited capacity to transmit water. Changes to the bore design are appropriate for any future commercial irrigation bores.

Construction of bores with long intervals of stainless steel screens placed against permeable zones, properly developed, will maximise the bore efficiency and minimise pumping costs in the long term. A rule of thumb would be to allow at least 0.5m of screen against permeable aquifer material per L/s of design flow.

Increased expenditure on changes to the bore design or increased development effort is expected to improve the bore efficiency and to reduce pumping cost in the long term through reduced energy consumption. Whether the extra capital cost is offset by reduced operating costs needs to be assessed on a case by case basis and is not certain.

The small drawdown induced at Nita Downs indicates that bore efficiency is not an issue for concern, as improvements will not substantially affect pumping costs. The specific capacity, which compares the flow available per metre of drawdown directly affects operating costs and should be minimised through constructing bores with sufficient screen lengths placed against permeable aquifer materials.

### Table 4.1 Bore Hydraulic Performance Data

<table>
<thead>
<tr>
<th>Site</th>
<th>Bore</th>
<th>Peak Flow (L/s)</th>
<th>Drawdown (m)</th>
<th>Efficiency at Peak Flow (%)</th>
<th>Specific Capacity (L/s/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roebuck Plains</td>
<td>LAG02I</td>
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<td>7.23</td>
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</tr>
<tr>
<td>Shamrock</td>
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<td>7.02</td>
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<tr>
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<td>Nita Downs</td>
<td>PB1</td>
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<td>1.565</td>
<td>-</td>
<td>10.2</td>
</tr>
</tbody>
</table>
# Pumping Bore Drawdown Summary

<table>
<thead>
<tr>
<th>Station</th>
<th>Bore</th>
<th>Test</th>
<th>Start Date/Time</th>
<th>Stop Date/Time</th>
<th>Duration (min)</th>
<th>Flow Rate (L/s)</th>
<th>Flow Rate (kL/day)</th>
<th>Uncorrected Stage Drawdown (m)</th>
<th>Specific Capacity (L/s/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roebuck Plains</td>
<td>15LAG02I</td>
<td>Step Test</td>
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<td>28/04/2016 17:00</td>
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<td>518</td>
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</table>

**Note:** Uncorrected drawdown calculated by subtracting manual water level measurements from a single pre-test water level measurement.
4.2 GROUNDWATER HYDROGRAPHS

Unvented pressure dataloggers were operating in fifteen pumping, observation and regional bores that were accessed for the test. Barometric dataloggers were operating at the sites of bores Fly Flat #1, La Grange #1 and Nita Downs SE bore. Groundwater pressure is calculated by subtracting barometric pressure from the unvented datalogger data. Where the barometer is located at some distance from the datalogger installed in the bore, the station barometric pressure has been corrected for the difference in ground elevation between the two locations. There is no account of areal changes in barometric pressure between the barometer location and the bore and, if the bore has not been surveyed, an error is also introduced with the estimate of ground elevation. Vented pressure dataloggers were operated in four observation bores.

The reduced groundwater pressure data were converted to groundwater level data by adjusting the datalogger trace to manual depth to water measurements recorded by the Department of Agriculture and Food, Kimberley Water and Groundwater Consulting Services using an electronic water level indicator.

Hydrographs of groundwater level data from November 2015 are provided with barometric pressure and rainfall charts for each test site in Appendix E.

There is a paucity of manual water level measurements and the datalogger hydrographs provided could be improved if all the manual groundwater level measurements were incorporated, particularly the manual water level measurements recorded when the dataloggers were first installed.

In some instances, a datalogger was removed from a regional bore and re-deployed in an observation bore used in the testing programme. The datalogger was downloaded before being removed from the regional bore and these data are presented in Appendix F with a table of bore locations and construction details. Photographs of these bores are provided in Appendix C.

4.3 ANTECEDENT CONDITIONS

The analysis of pumping test drawdown using analytical methods assumes that pumping from the test production bore is the only influence on groundwater levels in the observation bores. In reality, there can be numerous external influences on groundwater levels in the observation bores including:

- rainfall
- seasonal trends
- barometric pressure
• regional pumping
• recovery from previous operation of the pump in the test production bore.

There was no rainfall during the pumping test period at Roebuck Station, Shelamar Station and Frazier Downs Station. There was heavy rainfall the night prior to the Nita Downs station pumping test which was recorded at the Bureau of Meteorology’s station at Bidyadanga and is reflected in the barometric pressure record at Nita Downs station (Appendix D-4).

The shallowest monitoring bore at Roebuck Plains station, 15LAG02S, is screened in a surficial water table aquitard. Groundwater levels in 15LAG02S respond to rainfall events and then recede (Appendix E-1). Groundwater levels in 15LAG02S rose by around 0.2m following rainfall at the end of January 2016.

The groundwater level monitoring record for observation bores 15LAG08S and 15LAG08I indicate that Shamrock PB1 was not operated prior to the pumping test (Figure 3b, Appendix A). The Department of Agriculture and Food’s observation bores at Nita Downs station, which were fitted with dataloggers prior to the testing programme, are too remote (>2km) from the irrigation bore to register any drawdown due to abstraction from Nita PB1. There was no other groundwater use at Nita Downs other than for stock and domestic requirements. Commercial irrigation bores operated at Shamrock Gardens during the testing programme. Broome Sandstone aquifer irrigation bores are in operation at the Shelamar horticultural lease but are too remote from the Roebuck Plains, Shamrock and Frazier Downs test sites to affect groundwater levels but will result in small, long-term drawdown impacts at Nita Downs station.

Regionally, groundwater levels in the Broome Sandstone aquifer show a small decline, generally around 0.05 m between November 2015 and May 2016 (Appendix E) following very low rainfall during the 2015/2016 wet season. For some bores, groundwater levels are rising and hydrographs for some of the regional bores (Appendix F) show other influences affecting groundwater levels. In both instances, it may be groundwater logger drift, stretch in fishing line used to suspend the loggers, or poor reduction of datalogger pressure to groundwater level as a result of insufficient manual water level measurements.

The primary influence on groundwater levels in Broome Sandstone aquifer bores over the pumping test period, other than pumping, is barometric pressure. Groundwater levels respond inversely to changes in barometric pressure. Groundwater levels in observation bores screened at deeper intervals in the Broome Sandstone aquifer show a more marked response to barometric fluctuation (Appendix E).

4.4 CALCULATION OF DRAWDOWN

Hydrographs over the pumping test period at each of the four test locations are provided on Figure 3a to 3d, Appendix A with charts of the pumping test flow rates and rainfall.
The groundwater levels in observation bores are not static prior to the pumping test. To calculate drawdown, groundwater levels for a remote bore that was unaffected by the pumping for the test, were used to provide an estimate of groundwater level variation in the test observation bores in the absence of pumping. All available remote monitoring bore data were reviewed to find the monitoring bore with the closest match in daily groundwater level fluctuations due to barometric pressure changes and seasonal trends in the pre-test period to the observation bore at each test site.

In most cases, the Nita Downs monitoring bore 15LAG19I was selected as the remote bore to be used to calculate the baseline groundwater level at the test observation bore. In the case of the Frazier Downs test, only monitoring data for Nita Downs station were available. The groundwater level data for the remote bore was shifted to match the pre-test groundwater levels in the test observation bore, in order to derive drawdown for the bore being assessed. In some instances a time lag was applied to improve the match. The derived pre-test relationship in groundwater levels between the remote bore and test observation bore was applied over the test period to provide a baseline hydrograph for the test observation bore as shown on Figure 3a to 3d, Appendix A.

Drawdown was calculated as the difference between the measured groundwater level and the estimated baseline (non-pumping) groundwater level in the observation bore. In most instances the datalogger water level data from the remote bore was interpolated to 15 minute intervals to match the frequency of the test datalogger data.

For the Shamrock station test, Frazier Downs bore 16LAG26S was used as a baseline for 15LAG08S as it provided the closest match to pre-test groundwater level fluctuations in 15LAG08S.

No remote bore provided a good match with the pre-test groundwater levels in intermediate bore 15LAG08I at Shamrock station. The closet match in daily fluctuations was the intermediate bore at Frazier Downs station, 15LAG26I, however over the longer monitoring record, the groundwater level in the bore is rising (Appendix E-3) while the long-term water level trend in 15LAG08I is relatively stable. The rise in groundwater levels in 15LAG26I is not evident in the hydrograph for 15LAG26TP and may be logger drift. Two baselines were used for 15LAG08I, one based on groundwater levels in 15LAG26I and one based on inverse barometric pressure (Figure 3c, Appendix A).

4.5 DRAWDOWN ANALYSIS

Drawdown curves from the start of the step test at the Roebuck Plains station, Shamrock station and Frazier Downs station test sites are shown on Figure 4, Appendix A.

At Roebuck Plains station, a surficial water table aquitard overlies the aquifer screened by the test pumping bore. Observation bore 15LAG02S is screened in the water table aquitard and groundwater levels rose by 1.8m over the course of the test due to recharge of the pumped water from the test pumping bore 15LAG02I which was disposed on the ground at the
borehead (Figure 3a, Appendix A). The groundwater level in the shallow observation bore 16LAG02S, which is screened beneath the aquitard in the Broome Sandstone aquifer, is not affected by the disposal of the pumping test discharge.

Within the Broome Sandstone aquifer, there is a lower transmissivity layer in which the shallow observation bores are screened that overlies a higher transmissivity layer in which the intermediate observation bores and the test pumping bores are screened.

The drawdown responses of the shallow and deep observation bores at the Roebuck Plains station test site differ to those at the Shamrock station and Frazier Downs station test sites.

For the Roebuck Plains station test, the drawdown in the shallow observation bore 16LAG02S, is a similar proportion of the drawdown in the intermediate observation bore 16LAG02I at the end of the step test and at the end of the constant-discharge test, with near complete groundwater level recovery at the end of each test.

In contrast, the drawdown response in the shallow observation bores at the end of the step tests at Shamrock and Frazier Downs stations is a small proportion of the drawdown observed in the intermediate bore at each station. Drawdown in the shallow observation bores continues after the end of the step test and groundwater level recovery after the step test is incomplete. Over the course of the constant-discharge test, the drawdown in the shallow observation bores increases and is a much larger proportion of the drawdown observed in the intermediate observation bores at the end of the constant-discharge test (Table 4.3 and Figure 4, Appendix A). The flattening of the drawdown response in 15LAG26I is a result of the rising groundwater level trend compared to the relatively steady groundwater level in 15LAG19I which was used to calculate the baseline for the drawdown calculation.

Aqtesolv 4.5, a standard industry software package, was used to analyse the observation bore drawdown. The step tests and constant-discharge tests, and following recovery periods, were analysed concurrently and partial penetration of bores into the aquifer was incorporated in the analyses. The analytical results are shown on Figure 4, Appendix A.

Based on the drawdown responses, the Roebuck Station test was analysed using the Theis solution for confined aquifer systems. The Shamrock station and Frazier Downs station tests were analysed using the Neuman solution for unconfined aquifers.

There are no analytical methods that accommodate multi-layer aquifer systems. Both solutions assume a single-layer aquifer system that is homogeneous and of infinite extent. Some anisotropy in the vertical plane is incorporated by adjusting the ratio of the vertical to horizontal hydraulic conductivity, but this is for a single aquifer layer. As a result, the match of the shallow observation bore drawdown response is generally poor for the Shamrock and Frazier Downs station tests (Figure 4, Appendix A).

The results provided in Table 4.3 are average hydraulic parameters for the Broome Sandstone aquifer which should be used as starting set of parameters for the numerical model that is being developed by the Department of Agriculture and Food. In reality, the transmissivity of the lower layer which is being pumped will be higher than the reported
average and the transmissivity of the layer screened by shallow observation bore will be lower.

It is possible that at the Roebuck Plains station test site, the upper, lower permeability layer is absent and that 15LAG02I and 16LAG02I are screened in a similar portion of the lower, higher permeability layer. Geophysical logs would be needed to confirm the local stratigraphy at Shamrock, Frazier Downs and Nita Downs stations.

The Nita Downs constant-discharge test has not been analysed. Although a very small drawdown (around 0.02m) is evident in the observation bores MB1 and NW bore (Figure 3d, Appendix A), which are around 980m from the pumping test bore Nita PB1, the aquifer has not been sufficiently stressed to generate a drawdown curve suitable for analysis. The low drawdown and rate of change of drawdown indicates a transmissive aquifer.
### Table 4.3  
**Average Broome Sandstone Aquifer Hydraulic Parameter Estimates**

<table>
<thead>
<tr>
<th>Test</th>
<th>Bore</th>
<th>Screen Interval (mBGL)</th>
<th>Distance From Pumping Bore (m)</th>
<th>Aquifer/ Aquitard</th>
<th>Observation Bore Corrected Drawdown (m)</th>
<th>Analysis method</th>
<th>Estimated total aquifer thickness (m)</th>
<th>Estimated transmissivity (m²/day)</th>
<th>Estimated hydraulic conductivity (m/day)</th>
<th>Specific Yield</th>
<th>Storativity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>End of step test</strong></td>
<td><strong>End of constant discharge test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Roebuck Plains</strong></td>
<td>15LAG02S</td>
<td>10.8-13.8</td>
<td>1</td>
<td>Water table aquitard</td>
<td>recharge</td>
<td>recharge</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>16LAG02S</td>
<td>27-30</td>
<td>0.5</td>
<td>Unpumped aquifer layer</td>
<td>0.32</td>
<td>0.42</td>
<td>Confined - Theis</td>
<td>100</td>
<td>2715</td>
<td>-</td>
<td>0.0038</td>
</tr>
<tr>
<td></td>
<td>15LAG02 (pumping bore)</td>
<td>70.92-76.92</td>
<td>23</td>
<td>Pumped aquifer layer</td>
<td>0.67</td>
<td>0.72</td>
<td>Unconfined - Neuman</td>
<td>176</td>
<td>2000</td>
<td>11</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>15LAG03</td>
<td>72-78</td>
<td>72</td>
<td>Unconfined - Neuman</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0018</td>
</tr>
<tr>
<td><strong>Shamrock</strong></td>
<td>15LAG08S</td>
<td>46-49</td>
<td>362</td>
<td>Unpumped aquifer layer</td>
<td>0.03</td>
<td>0.21</td>
<td>Unconfined - Neuman</td>
<td>174</td>
<td>1400</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>15LAG08I</td>
<td>95-153</td>
<td>365</td>
<td>Pumped aquifer layer</td>
<td>0.18</td>
<td>0.27</td>
<td>Unconfined - Neuman</td>
<td>174</td>
<td>1400</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Frazier Downs</strong></td>
<td>16LAG26S</td>
<td>21-24</td>
<td>~7</td>
<td>Unpumped aquifer layer</td>
<td>0.23</td>
<td>0.52</td>
<td>Unconfined - Neuman</td>
<td>174</td>
<td>1400</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>15LAG26TP (pumping bore)</td>
<td>54-60</td>
<td>0</td>
<td>Pumped aquifer layer</td>
<td>0.58</td>
<td>0.64</td>
<td>Unconfined - Neuman</td>
<td>174</td>
<td>1400</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>15LAG26I</td>
<td>54-66</td>
<td>~38</td>
<td>Pumped aquifer layer</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Nita Downs</strong></td>
<td>NW</td>
<td>unknown (41.77)</td>
<td></td>
<td>Shallow aquifer layer</td>
<td>~&lt;0.02</td>
<td>-</td>
<td>Not suitable for analysis</td>
<td>174</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>MB1</td>
<td>unknown (477)</td>
<td></td>
<td>Shallow aquifer layer</td>
<td>-</td>
<td>~&lt;0.02</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>PB1 (pumping bore)</td>
<td>33-123</td>
<td>0</td>
<td>Pumped aquifer layer</td>
<td>1.565</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Note:** Long screen in Nita Downs PB1 means contribution of water from upper and lower parts of the aquifer are not known. Monitoring bores are screened in the upper part of the aquifer. Most of the water is probably drawn from the lower part of the aquifer. Drawdown data for Nita Downs were not corrected due to the small magnitude and unsuitability for analysis.
4.6 GROUNDWATER QUALITY

Groundwater samples were collected at the end of the constant-discharge test from the test pumping bores on Shamrock Station, Frazier Downs and Nita Downs. The Department of Agriculture and Food submitted the samples to the ChemCentre laboratory for analysis of physicochemical parameters, major ions and metals. The water quality reported for Roebuck Plains is from an airlifted sample as a sample was not collected following the pumping test.

The laboratory records indicate the water quality is fresh, with salinity ranging from 230 to 520 mg/L total dissolved solids concentration. The pH ranges from 6.8 to 7.9 and is slightly alkaline.

All of the groundwater that was sampled is suitable for irrigation of a wide range of crops. Specific testing may be warranted for sensitive crops or unconventional irrigation systems if dissolved salts are be allowed to build up in the root zone.

The comprehensive analytical results are provided in the analytical report in Appendix G and Table 4.3 contains a summary of the major hydrochemical parameters and major ions.

4.7 DEVELOPMENT ADVICE

Development advice is provided in Appendices H and I for Roebuck Plains and Frazier Downs respectively. The advice is intended to provide basic information to help the lessees assess whether they would like to pursue an irrigation project, and to provide starting points for assessment of water resource capacity to support the project. Basic advice on water requirements and the scale of bore required for irrigation purposes is included.
<table>
<thead>
<tr>
<th>Station</th>
<th>Roebuck Plains</th>
<th>Shamrock</th>
<th>Frazier Downs</th>
<th>Nita Downs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore</td>
<td>15LAG02I</td>
<td>PB1</td>
<td>15LAG26TP</td>
<td>PB1</td>
</tr>
<tr>
<td>pH</td>
<td>6.8</td>
<td>7.4</td>
<td>7.2</td>
<td>7.9</td>
</tr>
<tr>
<td>Electrical conductivity (µS/cm)</td>
<td>412</td>
<td>456</td>
<td>581</td>
<td>937</td>
</tr>
<tr>
<td>TDS (calculation)</td>
<td>230</td>
<td>250</td>
<td>320</td>
<td>520</td>
</tr>
<tr>
<td>Sodium</td>
<td>46.4</td>
<td>62</td>
<td>83.3</td>
<td>130</td>
</tr>
<tr>
<td>Potassium</td>
<td>6.4</td>
<td>5.1</td>
<td>2.8</td>
<td>8.4</td>
</tr>
<tr>
<td>Calcium</td>
<td>8.4</td>
<td>12.2</td>
<td>6.7</td>
<td>30.1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>11.7</td>
<td>7.7</td>
<td>13.5</td>
<td>17.4</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Chloride</td>
<td>82</td>
<td>96</td>
<td>149</td>
<td>192</td>
</tr>
<tr>
<td>Sulphate</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>45</td>
</tr>
<tr>
<td>Nitrate/Nitrite Nitrogen</td>
<td>9.1</td>
<td>5.9</td>
<td>1.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>9.3</td>
<td>6.3</td>
<td>1.7</td>
<td>0.12</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>0.02</td>
<td>0.013</td>
<td>0.029</td>
<td>0.06</td>
</tr>
<tr>
<td>Hardness (as CaCO₃)</td>
<td>17</td>
<td>62</td>
<td>71</td>
<td>150</td>
</tr>
<tr>
<td>Alkalinity (as CaCO₃)</td>
<td>70</td>
<td>54</td>
<td>53</td>
<td>129</td>
</tr>
<tr>
<td>Sample comments</td>
<td>Airlift on completion</td>
<td>End of pumping test</td>
<td>End of pumping test</td>
<td>End of pumping test</td>
</tr>
</tbody>
</table>

Note: Concentrations reported as ppm (mg/L) unless otherwise stated.
5. MAJOR OUTCOMES

The pumping tests in this programme and records of previous work enable development of a reasonable understanding of the hydraulic properties of the Broome Sandstone aquifer on a regional basis, and with some information about vertical differences.

The Broome Sandstone aquifer broadly comprises a two-layer system with a higher permeability layer in the lower half of the aquifer overlain by a moderately permeable layer. The Department of Agriculture and Food also identifies a transition layer above the Jarlemai Siltstone but that zone was not a subject of this work.

Drawdown induced by pumping from the production zone propagates to the upper Broome Sandstone in all cases where suitable monitoring bores exist.

The aquifer is mostly unconfined but confined conditions were confirmed at Roebuck Plains and this means that drawdown induced in the deeper parts of the Broome Sandstone aquifer does not substantially propagate to the water table. On Shamrock Station and Frazier Downs Station, drawdown induced in the deeper part of the aquifer propagated to the water table. It is likely that drawdown propagates to the water table in most of the aquifer, but confined conditions are likely to exist under the fine-grained coastal plain sediments and therefore some protection of groundwater dependent ecosystems from drawdown is likely. Site specific investigations would be required to confirm this observation.

Wright (pers. comm., 2016) advised that the elevation of the wetlands on the fringe of the coastal plain effectively coincide with the water table elevation in the Broome Sandstone. This premise supports an argument that the ecological values are likely to be supported by groundwater levels in the Broome Sandstone aquifer.

The water table in low-lying areas nearer the marine embayments may be hosted in low permeability materials which have a significant potential to both store soil moisture and to impede downward movement of water which would otherwise be expected as a result of reduction in water levels due to pumping. It is therefore possible that areas of potential groundwater dependent ecosystems are not as sensitive to drawdown impacts as indicated by the evident propagation of drawdown to the top of the aquifer. The co-existence of vegetated wetlands or similar groundwater dependent ecosystems with both high traditional owner and ecological values and fine-grained soils means it may not be easy to discern the real sensitivity of these systems to drawdown in the Broome Sandstone aquifer. Site specific investigations would be required to assess the nature of the hydraulic support mechanisms to determine the level of dependence on the Broome Sandstone aquifer water levels.

The production zone in the Broome sandstone aquifer has a hydraulic conductivity ranging from 8 to 27m/day as an average for the overall thickness of the aquifer. There is likely to be a difference in the hydraulic conductivity of the aquifer between the lower and upper zones that will vary based on the lithology, and could range from a factor of five to several orders of magnitude. The upper Broome Sandstone aquifer probably has a hydraulic conductivity ranging between about 1 and 10m/day depending on local lithological characteristics. The
lower Broome Sandstone aquifer has a hydraulic conductivity ranging from about 10-30m/day. Higher permeability layers are expected in gravelly zones which may occupy smaller intervals vertically or spatially.

The storage coefficient ranges from 0.001 to 0.0038 and the specific yield is about 0.05.

The hydraulic data obtained in this programme supplements the body of hydraulic data available from other studies in the region. The major cause for inconsistency between sources of hydraulic data is the aquifer zone in which the bore is screened.

Analysis of the hydraulic properties was compromised by the lack of good geological knowledge of the aquifer, particularly the extent of layering in the aquifer, and screening of bores near the inferred boundary between the upper and lower parts of the aquifer. The derived aquifer properties are sensitive to the geological model used and should be confirmed during the numerical modelling phase of the project. The data do not enable derivation of reliable discrete hydraulic properties for the upper part of the aquifer due to the uncertainty in the geology.
6. RECOMMENDATIONS

The following recommendations are provided with reference to issues affecting the pumping test programme and future groundwater development in the region.

6.1 AQUIFER MANAGEMENT

- Groundwater numerical modelling should be guided by the hydraulic parameters obtained from the pumping test results. As there is uncertainty in curve matching methods, calibration of the model should focus on matching the observed responses. Bores where the screen intervals are not discretely observing a model layer and where the distances between the monitoring and production bores are smaller will be subject to higher uncertainty. The process should recognise that point data are available for a relatively small number of locations only.

- Management of impacts on groundwater dependent ecosystems will be the primary constraint on the scale and rate of groundwater development in the La Grange region. Additional detailed hydrogeological investigations are warranted near potentially groundwater dependent ecosystems in order to be certain of the understanding of how groundwater levels in the Broome Sandstone aquifer support the groundwater-supported values of the ecosystem. It is possible that a shallow perching layer limits the propagation of drawdown at such groundwater dependent ecosystems. There is not sufficient detailed hydrogeological data to be sure that drawdown impacts in the Broome Sandstone aquifer would negatively affect a groundwater dependent ecosystem supported by water above a perching layer. In the absence of detailed investigations, it should be conservatively assumed that drawdown propagating to a particular location propagates to the water table at that location.

Although site specific studies are expected to be required of individual proponents, improving the understanding of the regional system should fall as a responsibility of the Department of Water and is likely to be a suitable candidate for a Water for Food project. The importance of robust and rigorous technical evaluation of this issue to support groundwater-based developments in an aquifer which is flanked to the north and south by Ramsar-listed wetlands cannot be overstated.

- Efforts to obtain high quality pumping test data to improve our collective understanding of aquifer hydraulics should be promoted by the Department of Water through the normal hydrogeological investigation and assessment process. Key considerations are establishing screen intervals, monitoring bore screen intervals, distances from pumping to monitoring bores, flow rates and test duration. The objective should be to test the largest possible volume of aquifer and ensure that an analysable drawdown response is obtained. Other site or project specific
considerations are likely. Flowmeters should be used to provide more readily auditable flow rate measurements.

- Proponents should be required to demonstrate establishment of a baseline monitoring programme during early stages of project planning so that the framework for future groundwater impacts assessment is set early. This can be facilitated through the setting of technical expectations as part of the normal hydrogeological assessment process. This is a particularly important process as the aquifer is essentially undisturbed over most of its area, but is subject to potentially rapid expansion by a small number of large irrigation projects. There will be time when the level of understanding of the aquifer lags behind the industry demand for licensed allocations in a similar manner as the lag identified in the West Canning Basin.

### 6.2 PROJECT DEVELOPMENT

- Large scale irrigation projects should plan to install a water table monitoring bore within or near the production borefield, and another in a suitable location between the production borefield and any potential groundwater dependent ecosystems so that the magnitude of water level changes at the water table can be directly measured during project development and operations.

- Acknowledge that drawdown impacts induced in the production zone are likely to propagate to the water table, in the absence of site-specific investigations or monitoring data to the contrary.

- Opportunities to collect geophysical logs in bores should be taken especially where horizontal layering is likely to be an important consideration in vertical propagation of drawdown.

### 6.3 REGIONAL MONITORING

- As the Department of Agriculture and Food project winds up there is a need to maintain a reasonable level of regional groundwater monitoring coverage. This should be maintained by the Department of Water to provide water level data independent of that obtained by irrigation proponents or their consultants. The coverage should include bores located along and across the direction of regional flow, and pairs of shallow and deep bores. A rigorous review of the stratigraphic interval screened by each bore will be necessary to determine its value for ongoing monitoring. The need for maintenance of this regional network and monitoring programme to support ongoing numerical modelling and assessment of impacts on water level changes cannot be over-stated.
- A minimum measurement frequency of quarterly is recommended for water level measurements in monitoring bores as there is a need to minimise loss of data through logger failure, and correction of drift or other errors relies on repetitive measurements. The use of dataloggers supports but cannot replace the value of manual measurements.

- Dataloggers should be suspended on stainless steel cable (grade 316) or similar to limit the amount of stretch induced when the loggers are installed. Cheaper options such as fishing line are not considered suitable for collection of groundwater level data, as the highly transmissive aquifer means that changes in groundwater levels can be small and difficult to resolve from background water level variations. The small additional cost is rapidly offset by reduced data processing effort. Grade 304 (cheaper, lower grade) stainless steel cable has been rapidly corroded in bores in La Grange and is not recommended.

Groundwater Consulting Services will work through the recommendations with the Department of Agriculture and Food, Department of Water or other agencies to help optimise groundwater resource management in the region.
On behalf of Groundwater Consulting Services Pty Ltd,

Sam Burton
Director.
7. REFERENCES

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Groundwater Consulting Services, 2009

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Groundwater Consulting Services, 2011

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*H2 Hydrogeological Assessment – Kilto Station Horticultural Project, Lots 263 and 398 Waterbank, Western Australia*. Prepared for Yeeda Pastoral Company Pty Ltd. Project No. YPC002, February 2013.

Paul, R., George, R., and Gardiner, P, 2013

Rockwater, 2015
8. LIMITATIONS

Groundwater Consulting Services Pty Ltd has prepared this report for the Department of Agriculture and Food in accordance with generally accepted consulting practice. The specific conditions of the contract and subsequent communications have had a bearing on the depth and breadth of the project and on the confidence in the findings. When client constraints, whether express or implied, have limited the scope of work, a lower than normal confidence may occur.

The confidence in the ability of a groundwater resource to support a nominated withdrawal of groundwater is subject to spatial and temporal variations in the aquifers, climate and landuse that may not be known or predictable. Conservative assumptions will have been used wherever possible, however, estimates of bore yield or predicted impacts of pumping can be incorrect, especially where conditions on which predictions were made have been changed. Groundwater Consulting Services Pty Ltd's predictions are made on the basis that Groundwater Consulting Services Pty Ltd will be contracted to undertake regular reviews of operational data that may lead to groundwater availability or quality predictions being re-estimated.

Groundwater Consulting Services Pty Ltd does not provide advice on crop water requirements, irrigation schedules, irrigation system design and other non-groundwater related areas. Groundwater Consulting Services Pty Ltd's advice on bore placement and operation must be considered by the proponent with reference to expert advice from other disciplines.

The project for which Groundwater Consulting Services Pty Ltd was contracted was undertaken for the client and its consulting advisors, and for review by regulatory agencies. The report should not be used by other parties without the consent of Groundwater Consulting Services Pty Ltd due to the potential for misunderstandings to occur.
9. **APPENDICES**

Appendix A – Figures

Appendix B – Bore Completion Reports

Appendix C – Plates

Appendix D – Step Test Data and Analysis

Appendix E – Long Term Hydrographs

Appendix F – Other Regional Bore Data

Appendix G – Laboratory Analytical Reports

Appendix H – Groundwater Development Advice
               Roebuck Plains Station

Appendix I – Groundwater Development Advice
               Frazier Downs Station
Groundwater Development Advice
Roebuck Plains Station

This commentary is provided to help the lessee of Roebuck Plains Station to consider the viability of using the Broome Sandstone aquifer at the tested location (Site 2) to provide water supply for irrigated agriculture. The advice provided is general in nature extends beyond the site hydrogeology – suitable advice on production systems should be sought. Groundwater Consulting Services has attempted to err on the side of allowing enough water for a wide range of crops and production systems so that water is not a limiting factor. The advice provided below is general and a hydrogeologist should be consulted to provide project-specific advice.

The major issue to address is the minimum or preferred scale of development required to develop a financially self-supporting business unit, which has implications on the minimum required water supply. The water supply is considered in terms of an annual allocation for licensing purposes, as well as a peak instantaneous water demand, which provides design criteria for bores and pumping infrastructure.

In this region, groundwater quality is typically acceptable for irrigation but brackish to saline groundwater does occur near the coast and beneath the marine plain. Ensuring that the scale and proximity of a proposed project to known and inferred poor quality groundwater does not induce an unacceptable risk should be part of project planning but is outside the scope of this document. Analytical estimates of groundwater drawdown can help assess whether the expected drawdown from a water supply system are sufficient to destabilise zones of brackish water.

As a rule of thumb an irrigation water supply would need to be capable of supplying at least 1.4L/s per hectare to the active cropped area in hot conditions to achieve an irrigation rate of about 12mm/day. Thus a nominal 40ha centre pivot irrigator would need to be provided with 56L/s from a bore or bores. The total borefield and pivot area would need to consider the implications of pump or bore failure, and the total instantaneous system capacity should allow for loss of a bore whilst maintaining the minimum required water supply. The minimum requirement will depend on seasonal conditions, crop types and the area in active growth at any time.

A bore completed with 250mm nominal diameter casing can accommodate a 200mm nominal diameter turbine pump which can produce 56L/s. Larger diameters may be required for a submersible pump. In order to minimise the drawdown in the bore during pumping, the bore should be completed with stainless steel screens in the most productive part of the aquifer, which would be identified during test drilling. For planning purposes, a bore with minimum 42m of screens set between nominally 80 and 122m depth should be allowed for, noting that the base of the aquifer is estimated by Department of Agriculture and Food to be at about 127m depth at this location. The screen diameter could be reduced to nominal 200mm. It is likely that a properly constructed bore would have a yield of over 60L/s. Drawdowns during
pumping in the order of 5-15m can be expected. Note that drilling by DAFWA may not have intersected the best aquifer material and deeper test drilling is warranted.

The tested bore, 15LAG02I, is constructed with a casing diameter of about 149mm ID and flows are limited by the size of the pump that can be installed, to about 20L/s. The pumping test was conducted at 20L/s and a stable drawdown of about 7m was induced. With a starting water level of about 8m below ground, the expected pumping water level is about 16m below ground at this flow rate.

For a development comprising multiple centre pivot irrigators, it may be acceptable to plan for a single production bore for each pivot area, with interconnecting pipelines to enable water to be transferred between pivot areas if required. The need for interconnecting pipelines depends on the level of risk that can be borne by the project in the event of a bore or pump failure. Production of fodder crops which are of relatively low value and tolerant of periods with limited irrigation may not warrant the additional security offered by interconnecting pipelines.

There is a financial interplay between higher capital cost bores constructed to minimise interference drawdown to reduce long term operating costs, and lower cost bores with potentially higher long term operating costs.

Experience with bores screened in the Broome Sandstone aquifer indicate that interference drawdown between operating bores is unlikely to be an issue, especially if a centre-pivot irrigator layout provides for bore separations exceeding 500m. Production bores should not be placed closer than perhaps 100m apart unless necessary and in this case some allowance for additional drawdown should be made in the bore and pumping system design.

The Broome Sandstone contains zones of fine-grained unconsolidated sand which can bleed into screens over a long period of time exacerbating pump wear. A bore design which reflects the aquifer materials intersected during drilling of a test hole can minimise the potential for long term sand pumping.

The location of an irrigation project should maximise the distance from saline water, vertically and laterally, and minimise the total pumping lift. These two principles are in opposition, as saline groundwater typically occurs near and beneath the lowlying coastal zone and marine embayments. A hydrogeologist’s advice would be required to consider the optimum location and bore design to minimise project risk.

Predictions of water level impacts at any given distance and time, based on a pumping rate, can be determined conservatively from the testing work conducted by DAFWA. We expect that commercial scale irrigation bores would be screened at greater depths within the aquifer and that more permeable materials would be intersected. This means that drawdown impacts predicted using the aquifer hydraulic parameters obtained through the pumping test work will tend to overpredict the drawdown that would be observed at any location during production pumping. Improved predictions would be possible once a completed commercial-scale production bore has been installed.
The groundwater elevation map and the expected location and depth of saline groundwater which were deliverables from the La Grange DAFWA project can be used to design a reliable long term irrigation project.

Further evaluation of the viability of an irrigation project at Site 2 should focus on:

Development of a site hydrogeological cross-section including all available data such as:

- Cadastre and other land use considerations.
- Environmentally sensitive areas, if any.
- Ground elevation from digital elevation model.
- Groundwater table elevation from DAFWA model.
- Drilling data (bore screens, water levels, known salinity)
- Known geological conditions and identification of major aquifer zones.
- Inverted ground conductivity data from the airborne electromagnetic survey to advise on water quality changes expected laterally and vertically.
- Simulated drawdown based on an arbitrary pumping rate, in the lower and upper part of the aquifer.

The cross-section would enable relatively transparent assessment of the viability of the project, and would allow easy communication of the effects of design changes. It would clearly inform the need for any additional site investigation work required to support a hydrogeological assessment submitted to the Department of Water for licensing purposes.

It is likely that a monitoring bore would be required to be installed or identified in a suitable location and depth in order to measure impacts due to pumping on any identified receptors. This may involve a bore screened nearer the saline interface to observe drawdown and any water quality changes, or simply monitoring of water levels in a stock bore to ensure continuity of supply.
Appendix I

Groundwater Development Advice – Frazier Downs Station
Groundwater Development Advice  
Frazier Downs Plains Station

This commentary is provided to help the lessee of Frazier Downs Station to consider the viability of using the Broome Sandstone aquifer at the tested location (Site 26) to provide water supply for irrigated agriculture. The advice provided is general in nature extends beyond the site hydrogeology – suitable advice on production systems should be sought. Groundwater Consulting Services has attempted to err on the side of allowing enough water for a wide range of crops and production systems so that water is not a limiting factor. The advice provided below is general and a hydrogeologist should be consulted to provide project-specific advice.

The major issue to address is the minimum or preferred scale of development required to develop a financially self-supporting business unit, which has implications on the minimum required water supply. The water supply is considered in terms of an annual allocation for licensing purposes, as well as a peak instantaneous water demand, which provides design criteria for bores and pumping infrastructure.

In this region, groundwater quality is typically acceptable for irrigation but brackish to saline groundwater does occur near the coast and extends inland further under lowlying areas. Ensuring that the scale and proximity of a proposed project to known and inferred poor quality groundwater does not induce an unacceptable risk should be part of project planning but is outside the scope of this document. Analytical estimates of groundwater drawdown can help assess whether the expected drawdown from a water supply system are sufficient to destabilise zones of brackish water.

As a rule of thumb an irrigation water supply would need to be capable of supplying at least 1.4L/s per hectare to the active cropped area in hot conditions to achieve an irrigation rate of about 12mm/day. Thus a nominal 40ha centre pivot irrigator would need to be provided with 56L/s from a bore or bores. The total borefield and pivot area would need to consider the implications of pump or bore failure, and the total instantaneous system capacity should allow for loss of a bore whilst maintaining the minimum required water supply. The minimum requirement will depend on seasonal conditions, crop types and the area in active growth at any time.

A bore completed with 250mm nominal diameter casing can accommodate a 200mm nominal diameter turbine pump which can produce 56L/s. Larger diameters may be required for a submersible pump. In order to minimise the drawdown in the bore during pumping, the bore should be completed with stainless steel screens in the most productive part of the aquifer, which would be identified during test drilling. For planning purposes, a bore with minimum 42m of screens set between nominally 80 and 122m depth should be allowed for. The base of the aquifer is estimated by Department of Agriculture and Food to be at about 190m depth at this location, and longer screen intervals could be installed if justified by the materials intersected. The screen diameter could be reduced to nominal 200mm. It is likely that a properly constructed bore would have a yield of over 60L/s. Drawdowns during pumping in
the order of 5-15m can be expected. Note that drilling by DAFWA may not have intersected the best aquifer material and deeper test drilling is warranted.

The tested bore, 15LAG26TP, is constructed with a casing diameter of about 149mm ID and flows are limited by the size of the pump that can be installed, to about 20L/s. The pumping test was conducted at 20L/s and a stable drawdown of about 12m was induced. With a starting water level of about 17m below ground, the expected pumping water level is about 30m below ground at this flow rate.

For a development comprising multiple centre pivot irrigators, it may be acceptable to plan for a single production bore for each pivot area, with interconnecting pipelines to enable water to be transferred between pivot areas if required. The need for interconnecting pipelines depends on the level of risk that can be borne by the project in the event of a bore or pump failure. Production of fodder crops which are of relatively low value and tolerant of periods with limited irrigation may not warrant the additional security offered by interconnecting pipelines

There is a financial interplay between higher capital cost bores constructed to minimise interference drawdown to reduce long term operating costs, and lower cost bores with potentially higher long term operating costs.

Experience with bores screened in the Broome Sandstone aquifer indicate that interference drawdown between operating bores is unlikely to be an issue, especially if a centre-pivot irrigator layout provides for bore separations exceeding 500m. Production bores should not be placed closer than perhaps 100m apart unless necessary and in this case some allowance for additional drawdown should be made in the bore and pumping system design.

The Broome Sandstone contains zones of fine-grained unconsolidated sand which can bleed into screens over a long period of time exacerbating pump wear. A bore design which reflects the aquifer materials intersected during drilling of a test hole can minimise the potential for long term sand pumping.

The location of an irrigation project should maximise the distance from saline water, vertically and laterally, and minimise the total pumping lift. These two principles are in opposition, as saline groundwater typically occurs near and beneath the lowlying coastal zone. A hydrogeologist's advice would be required to consider the optimum location and bore design to minimise project risk.

Predictions of water level impacts at any given distance and time, based on a pumping rate, can be determined conservatively from the testing work conducted by DAFWA. We expect that commercial scale irrigation bores would be screened at greater depths within the aquifer and that more permeable materials would be intersected. This means that drawdown impacts predicted using the aquifer hydraulic parameters obtained through the pumping test work will tend to over-predict the drawdown that would be observed at any location during production pumping. Improved predictions would be possible once a completed commercial-scale production bore has been installed.
The groundwater elevation map and the expected location and depth of saline groundwater which were deliverables from the La Grange DAFWA project can be used to design a reliable long term irrigation project.

Further evaluation of the viability of an irrigation project at Site 26 should focus on:

Development of a site hydrogeological cross-section including all available data such as:

- Cadastre and other land use considerations
- Environmentally sensitive areas if any
- Ground elevation from digital elevation model
- Groundwater table elevation from DAFWA model
- Drilling data (bore screens, water levels, known salinity)
- Known geological conditions and identification of major aquifer zones
- Inverted ground conductivity data from the airborne electromagnetic survey to advise on water quality changes expected laterally and vertically
- Simulated drawdown based on an arbitrary pumping rate, in the lower and upper part of the aquifer.

The cross-section would enable relatively transparent assessment of the viability of the project, and would allow easy communication of the effects of design changes. It would clearly inform the need for any additional site investigation work required to support a hydrogeological assessment submitted to the Department of Water for licensing purposes.

It is likely that a monitoring bore would be required to be installed or identified in a suitable location and depth in order to measure impacts due to pumping on any identified receptors. This may involve a bore screened nearer the saline interface to observe drawdown and any water quality changes, or simply monitoring of water levels in a stock bore to ensure continuity of supply.
Appendix A

Figures
Figure 1

Department of Agriculture and Food
PUMPING TESTS
LA GRANGE REGION, WESTERN AUSTRALIA

BORE LOCATIONS

Legend
- Pumping Bore Location
- Monitoring Well Location
- Regional Monitoring Well Location

SCALE 1:600,000 at A3 (MGA)

Fly Flat #1

East Crab Creek

Goldwyn #1

Goldwyn #2

Thangoo #1

La Grange #1

Shamrock

FRAZIER

DOWNS

Shelamar

15LAG08I 15LAG08S

15LAG19I 15LAG19S

15LAG26TP 15LAG26I 15LAG26S

15LAG0802 15LAG0802s 15LAG02I 15LAG02S

15LAG03D

ANNA PLAINS

SHAMROCK STATION

Great Sandy Desert

Drawn: S. Banton
Date: 4 Jul 2016
Figure 2b

Department of Agriculture and Food
PUMPING TESTS
LA GRANGE REGION, WESTERN AUSTRALIA

SHAMROCK STATION - BORE LOCATIONS

AERIAL PHOTOGRAPH SOURCE: Microsoft Virtual Earth, flown August 2012.

Shamrock Gardens
Shamrock Homestead

INSET

See Inset for Detail

INSET

La Grange #1

Thangoo #1

Pumping Bore Location
Monitoring Well Location
Regional Monitoring Well Location

Drawn: S. Burton
Date: 4 Jul 2016

Legend

PB1
Yards
Cookies
Cookies old
Cookies abd

15LAG08I
15LAG08S

7 952 000mN
7 954 000mN
404 000mE
406 000mE

SCALE 1: 100 000 at A3 (MGA)

SCALE 1: 20 000 at A3 (MGA)
Legend:
- Station Boundary
- Cadastral Boundary
- Pumping Bore Location
- Monitoring Well Location

Department of Agriculture and Food
PUMPING TESTS
LA GRANGE REGION, WESTERN AUSTRALIA

NITA DOWNS - BORE LOCATIONS

Project No. DAFWA001

Drawn: S. Burton
Date: 4 Jul 2016
RAINFALL
Bidyadanga
no rainfall recorded

Flow Rate 15LAG02I
Test Pumping Bore

Groundwater Level
Test Pumping Bore - 15LAG02I
screen 70.9-76.9m
test period datalogger missing

15LAG02S
1m from 15LAG02I
screen 19-22m
showing mounding from recharge of pumped water from the test pumping bore

16LAG02S
6.5m from 15LAG02I
screen 27-30m

16LAG02I
23m from 15LAG02I
screen 72-78m

Logger water level
Manual water level
Estimated baseline water level
Appendix 3b
Department of Agriculture and Food
PUMPING TESTS
LA GRANGE REGION, WESTERN AUSTRALIA
Date: June 2016

PUMPING TEST HYDROGRAPHS - SHAMROCK STATION

RAINFALL
Bidyadanga

Flow Rate Shamrock PB1
Test Pumping Bore

Airline Pressure
Test Pumping Bore - PB1
screen inlet 95-153m

OBSERVATION BORE RESPONSES

15LAG08S bore
352m from PB1
screen 46-49m

15LAG08I
355m from PB1
screen 96-102m

Cookies Old
2536m from PB1
tagged depth 65m
Appendix 3c
Department of Agriculture and Food
PUMPING TESTS
LA GRANGE REGION, WESTERN AUSTRALIA
PUMPING TEST HYDROGRAPHS - FRAZIER DOWNS STATION

RAINFALL
Bidyadanga

Flow Rate 15LAG26TP
Test Pumping Bore

Groundwater Level
Test Pumping Bore - 15LAG26TP
screen 54-66m

OBSERVATION BORE RESPONSES

16LAG26S
6.5m from 15LAG26TP
screen 20.8-23.8m

15LAG26I
38m from 15LAG26TP
screen 54-66m
Appendix 3d

Department of Agriculture and Food

PUMPING TESTS

LA GRANGE REGION, WESTERN AUSTRALIA

Project No. DAFWA001

PUMPING TEST HYDROGRAPHS - NITA DOWNS STATION

Date: June 2016
ROEBUCK PLAINS STATION PUMPING TEST

Pumping Wells
15LAG 02i
Aquifer Model
Confined
Solution
Neuman

Parameters
T = 2000 m²/day
S = 0.0018
Sy = 0.05
Kz/Kr = 0.1

Discharge (m³/day)

Time (min)

Displacement (m)

SHAW ROCK STATION PUMPING TEST

Pumping Wells
Shamrock PB1
Aquifer Model
Unconfined
Solution
Neuman

Parameters
T = 2715 m²/day
S = 0.0038

Discharge (m³/day)

Time (min)

Displacement (m)

FRAZIER DOWNS STATION PUMPING TEST

Pumping Wells
20TP
Aquifer Model
Unconfined
Solution
Neuman

Parameters
T = 1400 m²/day
S = 0.0025
Sy = 0.05
Kz/Kr = 0.35

Discharge (m³/day)

Time (min)

Displacement (m)

---

Figure 4

DRAWDOWN ANALYSES

Department of Agriculture and Food
PUMPING TESTS
LA GRANGE, WESTERN AUSTRALIA

Project No. DAFW901

Date: June 2016
Appendix B

Bore Completion Reports
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Location QC: Real time kinematic GPS to AusPos base

Datum: GDA94  Zone: 51  AHD (m): 30.6  E (m): 377766  N (m): 7916619

Supervisor/s: Nicholas Wright  Project: La Grange  Start date: 15/12/2015

Drill site: 26  Bore name/s: 15LAG26TB1, 15LAG26I
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Information to be provided on completion of a non-artesian well

Information to be provided to the Department of Water under the Water Agencies (Powers) Act 1984 and Section 26E of the Rights in Water and Irrigation Act 1914 and Regulation 39 of the Rights in Water and Irrigation Regulations 2000

Please note:
- All information is to be written clearly and in block letters.
- If insufficient room please use a separate piece of paper.
- It is the responsibility of the person carrying out the works to fill out this form.

Part 1: Details of any licence granted for the work under the Rights in Water and Irrigation Act 1914 section 26D

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Part 2: Details of person carrying out the works

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<td>91924217</td>
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<td>Email</td>
<td><a href="mailto:dawid.davison@hotmail.com">dawid.davison@hotmail.com</a></td>
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Part 3: Location of well

A 26D licence will list the premises on which well construction is to occur.

If the physical address of the well is different from the property address listed on the licence, contact the Department of Water prior to the commencement of construction.

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Location plan – In the box below please sketch a plan showing position of well in relation to building, boundaries, road, nearest cross road and any additional information to assist in locating the well.

SAMPLE

In the box to the right, please sketch a plan showing:
- location of all wetlands / watercourses / wells / soakas (existing and proposed).
- shaded sections to indicate areas under development.
### Production casing detail

<table>
<thead>
<tr>
<th>Material</th>
<th>Nominal bore (mm)</th>
<th>Diameter O.D (mm)</th>
<th>Wall thickness (mm)</th>
<th>Depth From (m)</th>
<th>Depth To (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>2280mm</td>
<td>2280mm</td>
<td>20mm +0.85</td>
<td>95m</td>
<td>95m</td>
</tr>
</tbody>
</table>

### Screens/slots

<table>
<thead>
<tr>
<th>Screens/slot (type)</th>
<th>Diameter O.D (mm)</th>
<th>Aperture (mm)</th>
<th>Top of screen (m)</th>
<th>Bottom of screen (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>2280mm</td>
<td>95mm</td>
<td>95m</td>
<td>155m</td>
</tr>
</tbody>
</table>

### Gravel pack details

<table>
<thead>
<tr>
<th>Gravel size (mm)</th>
<th>From (m)</th>
<th>To (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6-3.2</td>
<td>153m</td>
<td>75m</td>
</tr>
</tbody>
</table>

### Annular fill

<table>
<thead>
<tr>
<th>Material type</th>
<th>From (m)</th>
<th>To (m)</th>
</tr>
</thead>
</table>

### Cementing detail

- Pressure cement grouted [ ]
- Tremmie [ ]

<table>
<thead>
<tr>
<th>Casing diameter (mm O.D)</th>
<th>Depth From (m)</th>
<th>Depth To (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2280mm</td>
<td>75m</td>
<td>0</td>
</tr>
</tbody>
</table>

Total depth drilled (from ground level): 155m

Geophysical log required as condition of licence: [ ] Yes [ ] No

Geophysical log taken? (attach log and contractor details): [ ] Yes [ ] No

<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Strata description (if insufficient room attach on separate page)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>19</td>
<td>Red sandstone.</td>
</tr>
<tr>
<td>19</td>
<td>26</td>
<td>Redan lighter in colour and very fine.</td>
</tr>
<tr>
<td>26</td>
<td>32</td>
<td>Hard with a little cobble rock.</td>
</tr>
<tr>
<td>32</td>
<td>40</td>
<td>Hard red and yellow sandstone.</td>
</tr>
<tr>
<td>40</td>
<td>48</td>
<td>White sandstone and chalk.</td>
</tr>
<tr>
<td>48</td>
<td>50</td>
<td>White sandstone and dark red and black pebbles.</td>
</tr>
<tr>
<td>50</td>
<td>55</td>
<td>Sandstone.</td>
</tr>
<tr>
<td>55</td>
<td>68</td>
<td>White sandstone, gravel, and chalk.</td>
</tr>
<tr>
<td>From (m)</td>
<td>To (m)</td>
<td>Strata description (If insufficient room attach on separate page)</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>68</td>
<td>75</td>
<td>medium to fine sand</td>
</tr>
<tr>
<td>75</td>
<td>88</td>
<td>medium to fine sand and aquifer</td>
</tr>
<tr>
<td>88</td>
<td>100</td>
<td>medium to fine sand and aquifer</td>
</tr>
<tr>
<td>100</td>
<td>127</td>
<td>medium to coarse sand and aquifer</td>
</tr>
<tr>
<td>127</td>
<td>155</td>
<td>coarse sand and aquifer</td>
</tr>
</tbody>
</table>
### Part 5: Particulars of well

<table>
<thead>
<tr>
<th>Well name / number</th>
<th>Drilling start</th>
<th>Drilling completion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>03/08/2015</strong></td>
<td><strong>12/09/2015</strong></td>
</tr>
</tbody>
</table>

- **Drilling start data** refers to the date drilling begins. Do not include set up date.

- **Drilling method used**
  - [ ] Rotary air
  - [ ] Cable tool
  - [ ] Auger
  - [x] Rotary mud
  - [ ] Sludge
  - [ ] Other (specify)

- **Drilling completion date** includes well development and testing.

- **Final status of well**
  - [x] Ready to operate
  - [ ] Decommissioned
  - [ ] Other (specify)

- **Purpose (use) of well**
  - [x] Production
  - [ ] Investigation
  - [ ] Monitoring
  - [ ] Other (specify)

### Part 6: Well development

- **Date (dd/mm/yy)**: **26/09/2015**
- **Duration of development**: 8 hours
- **Method**
  - [x] Airlift
  - [ ] Pump
  - [ ] Jetting
  - [x] Surging

- **Development pump rate** *(e.g. L/s, m³/day)*

### Part 7: Pump testing (if applicable)

- **Date start (dd/mm/yy)**
- **Date end (dd/mm/yy)**
- **Duration of test** 8 hours
- **Constant rate - pump rate (e.g. m³/day)**
- **Pump type (e.g. submersible)**

- **Water level prior to test (m)**

- **Measurements taken from**
  - [ ] top of casing (TOC)
  - [ ] ground level (GL)
  - [ ] other (specify)

- **Elevation of measurement reference point** *(if known)* *(metres AHD)*
  - [ ] GPS
  - [ ] Estimate
  - [ ] other (specify)

- **Final drawdown** *(m)*
- **Recommended supply** *(e.g. m³/day)*

### Comments...

### Part 8: Field samples

- **Collection method** *(e.g. pump test, airlift)*

- **Conductivity** *(e.g. mS/m)*
  - [ ] Temperature compensated
  - [ ] Temperature uncompensated
- **Water temperature at test**

### Comments...

### Part 9: Lab samples

- **Lab samples taken** *(Please attach)*
  - [ ] Yes
  - [ ] No

- **TDS (e.g. mg/l)**

Please submit samples separately to form if not received before the 1 month submission deadline.
Part 10: Water levels

<table>
<thead>
<tr>
<th>SWL (Static water level)</th>
<th>m</th>
<th>Water cut at</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements taken from

- [x] top of casing (TOC)
- [ ] ground level (GL)
- [ ] other (specify)

Date of reading (dd/mm/yyyy): 30/09/2015

Comments

Part 11: Declaration and signature

Capacity of person making declaration:

- [x] An individual who carried out the work
- [ ] An officer who is a director or secretary of a corporation that carried out the work.
- [ ] Other (describe)

David Brown

(name of person making declaration) declare that the information provided on this form is true and correct.

Important information

- All information must be completed on the form unless otherwise indicated as optional for example; provision of the drillers licence number and classification fields are not mandatory and can be left blank at the drillers discretion. Provision of non-mandatory details would greatly assist the department in completion of its data set.
- Failure to complete all mandatory details and to submit the form to the department is an offence under the Rights In Water and Irrigation Act 1914.
- Under section 26E and regulation 39 within 1 month of completion of the construction of or deepening of the well, the person carrying out the work for a 26D licence must submit this form.
- Non-artesian wells in proclaimed areas require a licence unless exempted under the Rights in Water and Irrigation Exemption (S26C) Order 2007.

Where and how to submit this form

This form can be submitted by fax, post or in person to the appropriate Department of Water regional office. For assistance in completing this form contact your regional office.

Kimberley Region
Kununurra Regional Office
27 Victoria Hwy
Kununurra WA 6743
Tel: 08 9166 4100
Fax: 08 9166 3174
PO Box 626
Kununurra WA 6743

Midwest Gascoyne Region
Geraldton Regional Office
94 Sanford Street
Geraldton WA 6531
Tel: 08 9955 7400
Fax: 08 9954 5983
PO Box 73
Geraldton WA 6531

Kwinana Peel Region
Mandurah Regional Office
107 Breakwater Parade
Mandurah WA 6210
Tel: 08 9550 4222
Fax: 08 9561 4500
PO Box 332
Mandurah WA 6210

South West Region
Bunbury Regional Office
36-39 McCombe Road
Bunbury WA 6230
Tel: 08 9726 4111
Fax: 08 9726 4100
PO Box 281
Bunbury WA 6231

Busselton
Busselton District Office
Suite 2, 72 Duchess Street
Busselton WA 6280
Tel: 08 9751 0188
Fax: 08 9754 4335
PO Box 269
Busselton WA 6280

South Coast Region
Albany Regional Office
5 Bevan Street
Albany WA 6330
Tel: 08 9842 5700
Fax: 08 9842 1204
PO Box 625
Albany WA 6331

Pillbara Region
Karratha Regional Office
Lot 4008 Cherratta Road
Karratha Industrial Estate
Karratha WA 6714
Tel: 08 9144 2000
Fax: 08 9144 2810
PO Box 263
Karratha WA 6714

Swan Avon Region
Victoria Park Regional Office
7 Ellam Street
Victoria Park WA 6100
Tel: 08 6250 8000
Fax: 08 6250 8050

Manjimup
Manjimup District Office
52 Bath Street
Manjimup WA 6258
Tel: 08 9771 8108
Fax: 08 9771 4435

Please retain a copy of this form for your records
Appendix C

Plates
La Grange #1 also known as Shamrock MRD bore (15 April 2016)

Airline equipment (18 April 2016)

Observation bores 15LAG08S and 15LAG08I (19 April 2016)

Shamrock Station Yards bore - no role in test programme (5 March 2016)

La Grange #1 also known as Shamrock MRD bore (15 April 2016)
PLATES - OTHER LA GRANGE REGION BORES
Appendix D

Step Test Data and Analysis
\[ s = BQ + CQ^2 \]  

(Rorabaugh's equation)

Where: 
- \( B \): Intercept with y axis (coefficient of aquifer loss or laminar flow)
- \( C \): Gradient (coefficient of turbulent flow loss or apparent well loss)
- \( s \): Drawdown in the borehole
- \( P \): Value determined using Rorabaugh's method of superposition

Components of Jacob's (1947) equation \( BQ \) and \( CQ^2 \) are termed the aquifer loss and apparent well loss respectively. They give an indication of the proportion of total drawdown caused by laminar and turbulent flow.

**Please note:**
1. In thin or fissured aquifers large components of well loss are due to high flow velocities in the aquifer rather than inefficient bore design. Therefore, the term "apparent well loss" is better than well loss.
2. In aquifers where the flow horizons are vertically anisotropic, changes in bore performance often relate to changes in the rest water level with respect to the primary aquifer horizons.

\[ E_w = \frac{BQ}{BQ + CQP} \times 100 \]

\( E_w \) or Well Efficiency represents the proportion of drawdown caused by laminar flow.

**From plot of \( s/Q \) v \( Q \) (trend line equation):**

- **Intercept (B):** 2.100E-03
- **Gradient (C):** 7.050E-07

**ANALYSIS TABLE**

<table>
<thead>
<tr>
<th>Step (60 minute duration)</th>
<th>Discharge (l/s)</th>
<th>Discharge (Q) (m³/d)</th>
<th>Measured Incremental Drawdown (metres)</th>
<th>Corrected Drawdown (metres)</th>
<th>Predicted Drawdown (metres)</th>
<th>s/Q</th>
<th>Apparent Efficiency (Ew) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0</td>
<td>518</td>
<td>1.24</td>
<td>1.24</td>
<td>1.28</td>
<td>0.0024</td>
<td>85.2</td>
</tr>
<tr>
<td>2</td>
<td>10.0</td>
<td>864</td>
<td>1.15</td>
<td>2.39</td>
<td>2.34</td>
<td>0.0028</td>
<td>77.5</td>
</tr>
<tr>
<td>3</td>
<td>16.0</td>
<td>1382</td>
<td>1.98</td>
<td>4.37</td>
<td>4.25</td>
<td>0.0032</td>
<td>68.3</td>
</tr>
<tr>
<td>4</td>
<td>20.0</td>
<td>1728</td>
<td>2.78</td>
<td>7.15</td>
<td>5.73</td>
<td>0.0041</td>
<td>63.3</td>
</tr>
</tbody>
</table>
\[ s_{wp} = BQ + CQ^2 \] (Rorabaugh's equation)

Where:
- \( B \) = Intercept with y axis (coefficient of aquifer loss or laminar flow)
- \( C \) = Gradient (coefficient of turbulent flow loss or apparent well loss)
- \( s \) = Drawdown in the borehole
- \( P \) = Value determined using Rorabaugh's method of superposition

Components of Jacob's (1947) equation \( BQ \) and \( CQ^2 \) are termed the aquifer loss and apparent well loss respectively. They give an indication of the proportion of total drawdown caused by laminar and turbulent flow.

**Please note:**
1. In thin or fissured aquifers large components of well loss are due to high flow velocities in the aquifer rather than inefficient bore design. Therefore, the term "apparent well loss" is better than well loss.
2. In aquifers where the flow horizons are vertically anisotropic, changes in bore performance often relate to changes in the rest water level with respect to the primary aquifer horizons.

\[ E_w = \frac{BQ}{BQ + CQ^2} \times 100 \]

\( E_w \) or Well Efficiency represents the proportion of drawdown caused by laminar flow.

---

**From plot of \( s/Q \) v \( Q \) (trend line equation):**

- Intercept (B) \( 8.150E-04 \)
- Gradient (C) \( 1.080E-07 \)

**ANALYSIS TABLE**

<table>
<thead>
<tr>
<th>Step (50 minute duration)</th>
<th>Discharge (l/s)</th>
<th>Discharge (m³/d)</th>
<th>Measured Incremental Drawdown (metres)</th>
<th>Corrected Drawdown (metres)</th>
<th>Predicted Drawdown (metres)</th>
<th>s/Q</th>
<th>Apparent Efficiency (Ew) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54.2</td>
<td>4683</td>
<td>4.405</td>
<td>4.41</td>
<td>6.18</td>
<td>0.0009</td>
<td>61.7</td>
</tr>
<tr>
<td>2</td>
<td>68.8</td>
<td>5944</td>
<td>1.335</td>
<td>5.74</td>
<td>8.66</td>
<td>0.0010</td>
<td>55.9</td>
</tr>
<tr>
<td>3</td>
<td>80.5</td>
<td>6955</td>
<td>1.215</td>
<td>6.96</td>
<td>10.89</td>
<td>0.0010</td>
<td>52.0</td>
</tr>
<tr>
<td>4</td>
<td>86.7</td>
<td>7491</td>
<td>0.575</td>
<td>7.53</td>
<td>12.17</td>
<td>0.0010</td>
<td>50.2</td>
</tr>
</tbody>
</table>
sw(n) = BQn + CQn

Where:
- B = Intercept with y axis (coefficient of aquifer loss or laminar flow)
- C = Gradient (coefficient of turbulent flow loss or apparent well loss)
- s = Drawdown in the borehole
- P = Value determined using Rorabaugh's method of superposition

Components of Jacob's (1947) equation BQ and CQ² are termed the aquifer loss and apparent well loss respectively. They give an indication of the proportion of total drawdown caused by laminar and turbulent flow.

Please note:
1. In thin or fissured aquifers large components of well loss are due to high flow velocities in the aquifer rather than inefficient bore design. Therefore, the term "apparent well loss" is better than well loss.
2. In aquifers where the flow horizons are vertically anisotropic, changes in bore performance often relate to changes in the rest water level with respect to the primary aquifer horizons.

Ew = \( \frac{BQ}{BQ + CQP} \times 100 \)

Ew or Well Efficiency represents the proportion of drawdown caused by laminar flow

\[ s_{WP} = BQ + CQ^n \] (Rorabaugh's equation)

Where:
- B = Intercept with y axis (coefficient of aquifer loss or laminar flow)
- C = Gradient (coefficient of turbulent flow loss or apparent well loss)
- s = Drawdown in the borehole
- P = Value determined using Rorabaugh's method of superposition

From plot of s/Q v Q (trend line equation):
- Intercept (B) 3.200E-03
- Gradient (C) 1.325E-06

**ANALYSIS TABLE**

<table>
<thead>
<tr>
<th>Step (60 minute duration)</th>
<th>Discharge (l/s)</th>
<th>Discharge (Q) (m³/d)</th>
<th>Measured Incremental Drawdown (metres)</th>
<th>Corrected Drawdown (metres)</th>
<th>Predicted Drawdown (metres)</th>
<th>s/Q</th>
<th>Apparent Efficiency (Ew) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0</td>
<td>518</td>
<td>1.925</td>
<td>1.93</td>
<td>2.01</td>
<td>0.0037</td>
<td>62.3</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
<td>907</td>
<td>1.975</td>
<td>3.90</td>
<td>3.99</td>
<td>0.0043</td>
<td>72.7</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>1339</td>
<td>2.83</td>
<td>6.73</td>
<td>6.66</td>
<td>0.0050</td>
<td>64.3</td>
</tr>
<tr>
<td>4</td>
<td>20.0</td>
<td>1728</td>
<td>5.13</td>
<td>11.86</td>
<td>9.49</td>
<td>0.0069</td>
<td>58.3</td>
</tr>
</tbody>
</table>
Appendix E

Long Term Hydrographs
Appendix F

Other Regional Bore Data
Table F-1  Regional Bore Details

<table>
<thead>
<tr>
<th>Bore</th>
<th>Purpose of visit</th>
<th>GPS Co-ordinates (m MGA94)</th>
<th>Reference Point (RP)</th>
<th>Survey Elevation (Ground (mAHD))</th>
<th>PVC Casing (mAGL)</th>
<th>Total Depth (mBRP)</th>
<th>Screen Interval (mBGL)</th>
<th>Water Level (mBRP)</th>
<th>Water Level Date and Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldwyn #1</td>
<td>Removed logger for use at Site 26 pumping test</td>
<td>415948 7971877</td>
<td>TOC PVC</td>
<td>0.4</td>
<td>34</td>
<td>140</td>
<td>unknown</td>
<td>unknown</td>
<td>23.86</td>
</tr>
<tr>
<td>Goldwyn #2</td>
<td>Removed logger for use at Site 26 pumping test</td>
<td>416600 7972830</td>
<td>TOC PVC</td>
<td>0.36</td>
<td>28</td>
<td>140</td>
<td>unknown</td>
<td>unknown</td>
<td>19.78</td>
</tr>
<tr>
<td>Maffia</td>
<td>Removed logger for use as a spare for pumping test</td>
<td>420164 7975804</td>
<td>TOC PVC</td>
<td>0.45</td>
<td>18</td>
<td>140</td>
<td>unknown</td>
<td>unknown</td>
<td>9.41</td>
</tr>
<tr>
<td>East Crab Creek</td>
<td>Regional monitoring bore for pumping tests at Site 2</td>
<td>458606 8007656</td>
<td>TOC PVC</td>
<td>0.545</td>
<td>15</td>
<td>145</td>
<td>unknown</td>
<td>unknown</td>
<td>3.34</td>
</tr>
<tr>
<td>1SLAG03D</td>
<td>Removed logger for use at Site 2 pumping test</td>
<td>452893 8002583</td>
<td>TOC PVC</td>
<td>0.635</td>
<td>68.66</td>
<td>69.495</td>
<td>102</td>
<td>128.2-140.2</td>
<td>48.48</td>
</tr>
<tr>
<td>1SLAG03S</td>
<td>Removed logger for use at Site 2 pumping test</td>
<td>452893 8002580</td>
<td>TOC PVC</td>
<td>0.68</td>
<td>68.9</td>
<td>69.58</td>
<td>102</td>
<td>50.8-53.8</td>
<td>48.48</td>
</tr>
<tr>
<td>Fly Flat #1</td>
<td>Barometer logger at this bore for Site 2 and 26</td>
<td>450754 7993251</td>
<td>TOC PVC</td>
<td>0.17</td>
<td>32</td>
<td>140</td>
<td>unknown</td>
<td>unknown</td>
<td>17.4</td>
</tr>
</tbody>
</table>
Appendix G

Laboratory Analytical Reports
Appendix H

Groundwater Development Advice – Roebuck Plains Station
Groundwater Development Advice
Roebuck Plains Station

This commentary is provided to help the lessee of Roebuck Plains Station to consider the viability of using the Broome Sandstone aquifer at the tested location (Site 2) to provide water supply for irrigated agriculture. The advice provided is general in nature extends beyond the site hydrogeology – suitable advice on production systems should be sought. Groundwater Consulting Services has attempted to err on the side of allowing enough water for a wide range of crops and production systems so that water is not a limiting factor. The advice provided below is general and a hydrogeologist should be consulted to provide project-specific advice.

The major issue to address is the minimum or preferred scale of development required to develop a financially self-supporting business unit, which has implications on the minimum required water supply. The water supply is considered in terms of an annual allocation for licensing purposes, as well as a peak instantaneous water demand, which provides design criteria for bores and pumping infrastructure.

In this region, groundwater quality is typically acceptable for irrigation but brackish to saline groundwater does occur near the coast and beneath the marine plain. Ensuring that the scale and proximity of a proposed project to known and inferred poor quality groundwater does not induce an unacceptable risk should be part of project planning but is outside the scope of this document. Analytical estimates of groundwater drawdown can help assess whether the expected drawdown from a water supply system are sufficient to destabilise zones of brackish water.

As a rule of thumb an irrigation water supply would need to be capable of supplying at least 1.4L/s per hectare to the active cropped area in hot conditions to achieve an irrigation rate of about 12mm/day. Thus a nominal 40ha centre pivot irrigator would need to be provided with 56L/s from a bore or bores. The total borefield and pivot area would need to consider the implications of pump or bore failure, and the total instantaneous system capacity should allow for loss of a bore whilst maintaining the minimum required water supply. The minimum requirement will depend on seasonal conditions, crop types and the area in active growth at any time.

A bore completed with 250mm nominal diameter casing can accommodate a 200mm nominal diameter turbine pump which can produce 56L/s. Larger diameters may be required for a submersible pump. In order to minimise the drawdown in the bore during pumping, the bore should be completed with stainless steel screens in the most productive part of the aquifer, which would be identified during test drilling. For planning purposes, a bore with minimum 42m of screens set between nominally 80 and 122m depth should be allowed for, noting that the base of the aquifer is estimated by Department of Agriculture and Food to be at about 127m depth at this location. The screen diameter could be reduced to nominal 200mm. It is likely that a properly constructed bore would have a yield of over 60L/s. Drawdowns during
pumping in the order of 5-15m can be expected. Note that drilling by DAFWA may not have intersected the best aquifer material and deeper test drilling is warranted.

The tested bore, 15LAG02I, is constructed with a casing diameter of about 149mm ID and flows are limited by the size of the pump that can be installed, to about 20L/s. The pumping test was conducted at 20L/s and a stable drawdown of about 7m was induced. With a starting water level of about 8m below ground, the expected pumping water level is about 16m below ground at this flow rate.

For a development comprising multiple centre pivot irrigators, it may be acceptable to plan for a single production bore for each pivot area, with interconnecting pipelines to enable water to be transferred between pivot areas if required. The need for interconnecting pipelines depends on the level of risk that can be borne by the project in the event of a bore or pump failure. Production of fodder crops which are of relatively low value and tolerant of periods with limited irrigation may not warrant the additional security offered by interconnecting pipelines.

There is a financial interplay between higher capital cost bores constructed to minimise interference drawdown to reduce long term operating costs, and lower cost bores with potentially higher long term operating costs.

Experience with bores screened in the Broome Sandstone aquifer indicate that interference drawdown between operating bores is unlikely to be an issue, especially if a centre-pivot irrigator layout provides for bore separations exceeding 500m. Production bores should not be placed closer than perhaps 100m apart unless necessary and in this case some allowance for additional drawdown should be made in the bore and pumping system design.

The Broome Sandstone contains zones of fine-grained unconsolidated sand which can bleed into screens over a long period of time exacerbating pump wear. A bore design which reflects the aquifer materials intersected during drilling of a test hole can minimise the potential for long term sand pumping.

The location of an irrigation project should maximise the distance from saline water, vertically and laterally, and minimise the total pumping lift. These two principles are in opposition, as saline groundwater typically occurs near and beneath the lowlying coastal zone and marine embayments. A hydrogeologist’s advice would be required to consider the optimum location and bore design to minimise project risk.

Predictions of water level impacts at any given distance and time, based on a pumping rate, can be determined conservatively from the testing work conducted by DAFWA. We expect that commercial scale irrigation bores would be screened at greater depths within the aquifer and that more permeable materials would be intersected. This means that drawdown impacts predicted using the aquifer hydraulic parameters obtained through the pumping test work will tend to overpredict the drawdown that would be observed at any location during production pumping. Improved predictions would be possible once a completed commercial-scale production bore has been installed.
The groundwater elevation map and the expected location and depth of saline groundwater which were deliverables from the La Grange DAFWA project can be used to design a reliable long term irrigation project.

Further evaluation of the viability of an irrigation project at Site 2 should focus on:

Development of a site hydrogeological cross-section including all available data such as:

- Cadastre and other land use considerations.
- Environmentally sensitive areas, if any.
- Ground elevation from digital elevation model.
- Groundwater table elevation from DAFWA model.
- Drilling data (bore screens, water levels, known salinity)
- Known geological conditions and identification of major aquifer zones.
- Inverted ground conductivity data from the airborne electromagnetic survey to advise on water quality changes expected laterally and vertically.
- Simulated drawdown based on an arbitrary pumping rate, in the lower and upper part of the aquifer.

The cross-section would enable relatively transparent assessment of the viability of the project, and would allow easy communication of the effects of design changes. It would clearly inform the need for any additional site investigation work required to support a hydrogeological assessment submitted to the Department of Water for licensing purposes.

It is likely that a monitoring bore would be required to be installed or identified in a suitable location and depth in order to measure impacts due to pumping on any identified receptors. This may involve a bore screened nearer the saline interface to observe drawdown and any water quality changes, or simply monitoring of water levels in a stock bore to ensure continuity of supply.
Appendix I

Groundwater Development Advice – Frazier Downs Station
Groundwater Development Advice
Frazier Downs Plains Station

This commentary is provided to help the lessee of Frazier Downs Station to consider the viability of using the Broome Sandstone aquifer at the tested location (Site 26) to provide water supply for irrigated agriculture. The advice provided is general in nature extends beyond the site hydrogeology – suitable advice on production systems should be sought. Groundwater Consulting Services has attempted to err on the side of allowing enough water for a wide range of crops and production systems so that water is not a limiting factor. The advice provided below is general and a hydrogeologist should be consulted to provide project-specific advice.

The major issue to address is the minimum or preferred scale of development required to develop a financially self-supporting business unit, which has implications on the minimum required water supply. The water supply is considered in terms of an annual allocation for licensing purposes, as well as a peak instantaneous water demand, which provides design criteria for bores and pumping infrastructure.

In this region, groundwater quality is typically acceptable for irrigation but brackish to saline groundwater does occur near the coast and extends inland further under lowlying areas. Ensuring that the scale and proximity of a proposed project to known and inferred poor quality groundwater does not induce an unacceptable risk should be part of project planning but is outside the scope of this document. Analytical estimates of groundwater drawdown can help assess whether the expected drawdown from a water supply system are sufficient to destabilise zones of brackish water.

As a rule of thumb an irrigation water supply would need to be capable of supplying at least 1.4L/s per hectare to the active cropped area in hot conditions to achieve an irrigation rate of about 12mm/day. Thus a nominal 40ha centre pivot irrigator would need to be provided with 56L/s from a bore or bores. The total borefield and pivot area would need to consider the implications of pump or bore failure, and the total instantaneous system capacity should allow for loss of a bore whilst maintaining the minimum required water supply. The minimum requirement will depend on seasonal conditions, crop types and the area in active growth at any time.

A bore completed with 250mm nominal diameter casing can accommodate a 200mm nominal diameter turbine pump which can produce 56L/s. Larger diameters may be required for a submersible pump. In order to minimise the drawdown in the bore during pumping, the bore should be completed with stainless steel screens in the most productive part of the aquifer, which would be identified during test drilling. For planning purposes, a bore with minimum 42m of screens set between nominally 80 and 122m depth should be allowed for. The base of the aquifer is estimated by Department of Agriculture and Food to be at about 190m depth at this location, and longer screen intervals could be installed if justified by the materials intersected. The screen diameter could be reduced to nominal 200mm. It is likely that a properly constructed bore would have a yield of over 60L/s. Drawdowns during pumping in
the order of 5-15m can be expected. Note that drilling by DAFWA may not have intersected the best aquifer material and deeper test drilling is warranted.

The tested bore, 15LAG26TP, is constructed with a casing diameter of about 149mm ID and flows are limited by the size of the pump that can be installed, to about 20L/s. The pumping test was conducted at 20L/s and a stable drawdown of about 12m was induced. With a starting water level of about 17m below ground, the expected pumping water level is about 30m below ground at this flow rate.

For a development comprising multiple centre pivot irrigators, it may be acceptable to plan for a single production bore for each pivot area, with interconnecting pipelines to enable water to be transferred between pivot areas if required. The need for interconnecting pipelines depends on the level of risk that can be borne by the project in the event of a bore or pump failure. Production of fodder crops which are of relatively low value and tolerant of periods with limited irrigation may not warrant the additional security offered by interconnecting pipelines.

There is a financial interplay between higher capital cost bores constructed to minimise interference drawdown to reduce long term operating costs, and lower cost bores with potentially higher long term operating costs.

Experience with bores screened in the Broome Sandstone aquifer indicate that interference drawdown between operating bores is unlikely to be an issue, especially if a centre-pivot irrigator layout provides for bore separations exceeding 500m. Production bores should not be placed closer than perhaps 100m apart unless necessary and in this case some allowance for additional drawdown should be made in the bore and pumping system design.

The Broome Sandstone contains zones of fine-grained unconsolidated sand which can bleed into screens over a long period of time exacerbating pump wear. A bore design which reflects the aquifer materials intersected during drilling of a test hole can minimise the potential for long term sand pumping.

The location of an irrigation project should maximise the distance from saline water, vertically and laterally, and minimise the total pumping lift. These two principles are in opposition, as saline groundwater typically occurs near and beneath the lowlying coastal zone. A hydrogeologist's advice would be required to consider the optimum location and bore design to minimise project risk.

Predictions of water level impacts at any given distance and time, based on a pumping rate, can be determined conservatively from the testing work conducted by DAFWA. We expect that commercial scale irrigation bores would be screened at greater depths within the aquifer and that more permeable materials would be intersected. This means that drawdown impacts predicted using the aquifer hydraulic parameters obtained through the pumping test work will tend to over-predict the drawdown that would be observed at any location during production pumping. Improved predictions would be possible once a completed commercial-scale production bore has been installed.
The groundwater elevation map and the expected location and depth of saline groundwater which were deliverables from the La Grange DAFWA project can be used to design a reliable long term irrigation project.

Further evaluation of the viability of an irrigation project at Site 26 should focus on:

Development of a site hydrogeological cross-section including all available data such as:

- Cadastre and other land use considerations
- Environmentally sensitive areas if any
- Ground elevation from digital elevation model
- Groundwater table elevation from DAFWA model
- Drilling data (bore screens, water levels, known salinity)
- Known geological conditions and identification of major aquifer zones
- Inverted ground conductivity data from the airborne electromagnetic survey to advise on water quality changes expected laterally and vertically
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The cross-section would enable relatively transparent assessment of the viability of the project, and would allow easy communication of the effects of design changes. It would clearly inform the need for any additional site investigation work required to support a hydrogeological assessment submitted to the Department of Water for licensing purposes.

It is likely that a monitoring bore would be required to be installed or identified in a suitable location and depth in order to measure impacts due to pumping on any identified receptors. This may involve a bore screened nearer the saline interface to observe drawdown and any water quality changes, or simply monitoring of water levels in a stock bore to ensure continuity of supply.