Water management plan for the Shire of Woodanilling

Mark Pridham

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Water Management Plan for the Shire of Woodanilling

Mark Pridham

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RESOURCE MANAGEMENT TECHNICAL REPORT 356
Water Management Plan
for the Shire of Woodanilling

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Rural Towns - Liquid Assets
Summary

Woodanilling requires a water management plan that will identify opportunities for groundwater and surface water resource development, primarily for townsite irrigation; to manage salinity and waterlogging; and identify socio-economic opportunities associated with water resources.

A workshop in June 2005 identified priorities as providing secure water supply by improving the structural integrity of the town dam, particularly its back wall; to prevent possible seepage and subsidence; to improve overflow structure and enhancing run-off from the catchment.

Shallow groundwater contains 6,800 to 27,200 mg/L of salt (1000-4000 mS/m). Samples from the shallow bore at town centre showed low microbiological levels, probably from septic tanks. Salinity risk is confined to the lower western slopes, roughly following the railway line. Damage is estimated at $4000/year and the project NPV cost over 20 years is $42,600 if a ‘do-nothing’ option is adopted.

Woodanilling receives 25.7 ML/year from the regional water supply scheme of which about 46% is used outside, mostly for lawns and gardens. Using rainwater tanks for residential outdoor use and toilet flushing was modelled to investigate effectiveness at conserving water. Tanks would reduce scheme water consumption by 13% or 3.4 ML/year but have minimal impact on stormwater run-off. Alternative supplies include the dam to the south of town with a capacity of 40 ML. Yield is currently unreliable and little or no flow was received in the first two years following construction.

Stormwater run-off is a large potential water resource. About 243 ML/year is generated within the gazetted boundary and about 27.9 ML/year within the current township. Water for parks and oval irrigation is sourced from regional scheme water and local stormwater. Up to 5 ML/year is supplied by local dams, the remainder from scheme water costing up to $11,000/year, equivalent to 8-9 ML/year (based on current prices).

Investigations suggested three options:

1: Upgrade the town dam and catchment to increase run-off reliability to supply irrigation demand

2a: Collect surface run-off via a new sump, and pump it to the **town dam** for irrigation

2b: Collect surface run-off via a new sump, and pump it to a **new dam** for irrigation

3: Collect subsurface run-off via a drainage system then use for irrigation or discharge into the creek (discarded due to expense and soil types, while recognising it would require further investigation).

The dam has an average annual yield of 4.8 ML, based on the last 10 years of rainfall. This represents 34% of current water demand of 14 ML/year. The maximum yield was 14.4 ML/year, with none in one year. This suggests that the catchment is unreliable as it is mostly farmland (99 ha) with a high rainfall threshold (25 mm) plus a small roaded catchment (1 ha) with low threshold (8 mm). Roaded catchment of 25 ha would meet existing demand, assuming the farmland catchment was retained.

The average surface run-off that could be collected from the townsite is 24 ML/year. When combined with town dam supplies this would meet current demand with an average 13 ML of excess water.

Location of a new dam is assumed to be south of the golf course. The size required is 25 ML assuming dimensions of 40 x 40 x 6 m at a 1:3 side slope. The average yield would be enough to supply the existing demand of 14 ML/year with an excess of 5.5 ML/year. Total yield is less than that from collecting surface run-off and augmentation of the town dam.

Two sets of costings were used during the study, KBR commercial rates and lower DAWA/Shire rates.
The cost of scheme water provided by the Integrated Water Supply System to vacant non-residential land is assumed to be $1.20/kL. Current costs of water from the town dam are estimated at $1.61/kL. Water from Option 1 would cost $2.44/kL (KBR commercial rates) or $1.38 (DAWA/Shire rates). Option 2a would cost $2.08 and 58c/kL respectively while Option 2b is estimated to cost $5.44 and $1.82/kL.

Thus, water provided by Options 1, 2a or 2b would need to be sold above the estimated scheme water price if it was produced by processes that incur KBR commercial rates. However, when DAWA/Shire rates were used in analysis for Option 2a and possibly Option 1 the break-even price was below the average scheme water price.

Due to the sensitivity of this outcome to relatively small changes, decision-makers may wish to consider the potential of Option 1 more thoroughly. Option 2 provides additional benefits of up to $4,018 per year resulting from a reduction in risk of salinity and water damage to infrastructure such as buildings and roads. As expected, the break-even water price for Option 2a (calculated using DAWA/Shire rates) would be a little more attractive when infrastructure damage reduction is considered, while other scenarios would still have break-even water prices above the average scheme water price.

Excess water would be beneficial in terms of providing an ‘insurance measure’ for exceptionally dry years. Uses for the excess water may include application in industry or beautifying the town. However, if the value placed on this water is below the break-even price then any water production enterprise would make a loss or be subsidised by the supplier.

Overall, it would appear convincingly that Option 2a (analysed using DAWA/Shire rates) is the management option that produces the greatest net benefits. The break-even price of water calculated in Option 1 (based on DAWA/Shire rates) could be potentially competitive with scheme water.

There is potential to re-use treated wastewater (about 14.9 ML/year), however a collection system would need to be put in place first, as Woodanilling is currently on septic systems.
# Contents

1 INTRODUCTION
1.1 Background ................................................................. 1-1
1.2 Water management objectives ........................................ 1-1
1.3 Purpose of water management plan ................................. 1-2

2 CURRENT TOWN STATUS
2.1 Scientific studies and investigations ................................. 2-5
2.2 Salinity risk assessment .................................................. 2-5
2.3 Urban water ............................................................... 2-7
2.4 Town water resources .................................................... 2-8
2.5 Socio-economic factors .................................................. 2-8

3 WATER MANAGEMENT OPTIONS
3.1 Options identified ....................................................... 3-122
3.2 Options for further investigation .................................... 3-122

4 ENGINEERING ANALYSIS OF WATER MANAGEMENT OPTIONS
4.1 Option 1 – Existing town dam ......................................... 4-13
4.2 Option 2a – Town run-off to existing dam ....................... 4-14
4.3 Option 2b – Town run-off to new dam .............................. 4-17
4.4 Summary of all options ................................................ 4-19

5 COST-BENEFIT ANALYSIS
5.1 Introduction .............................................................. 5-23
5.2 Application ............................................................... 5-23
5.3 Results and conclusions ............................................... 5-23

6 CONCLUSION ............................................................... 6-26

7 REFERENCES ............................................................... 7-27
APPENDICES
A - Socio-economics notes
B - Shire meeting notes
C - Surface water
D - Geophysics summary
E - Groundwater Report
F - Assessment of Infrastructure Damage caused by Salinity
G - Water Quality
H - Water Balance Study
I - Methodology for Assessment of Options
J - Engineering Analysis
K - Cost-benefit analysis for water management incorporating data from KBR, DAWA and Shire
L - Hydrogeological modelling
M - H₂O beef

ILLUSTRATIONS
1.1 Woodanilling locality map ................................................................. 1-3
1.2 Woodanilling townsite and key water management features ......................... 1-4
2.1 Contour map of shallow groundwater depth at Woodanilling .......................... 2-9
2.2 Salinity risk mapping at Woodanilling ..................................................... 2-10
2.3 Salinity risk mapping from break of slope surface water process .................. 2-11
4.1 Schematic for Option 1 - Existing town dam to oval ................................. 4-20
4.2 Schematic for Option 2a - Town surface run-off and to existing dam ............. 4-21
4.3 Schematic for Option 2b - town surface run-off to new dam ....................... 4-22

TABLES
2.1 Estimated infrastructure damage due to shallow watertable and salinity .......... 2-6
2.2 Urban water balance for Woodanilling .................................................... 2-7
2.3 Water demand for irrigation on parks and gardens (Source: DAWA) .............. 2-8
4.1 Capital requirements and costs, and operation and maintenance costs for Option 1 . 4-15
4.2 Capital requirements and costs, and operation and maintenance costs for Option 2a . 4-16
4.3 Capital requirements and costs, and operation and maintenance costs for Option 2b . 4-18
4.4 Water yield for all options including what is currently supplied by the dam in existing state 4-19
4.5 Cost for all options ............................................................................... 4-19
5.1 Break-even price for water produced from the dam in its current state and for each Option, using either KBR commercial or DAWA/Shire rates and base case assumptions ............ 5-23
5.2 Capital and opportunity cost of investment per kilolitre of product water produced from dam in current state, and for each Option, using either KBR commercial or DAWA/Shire rates, and operating and maintenance costs ............................................. 5-25
1 Introduction

1.1 BACKGROUND
This project aims to devise solutions for potential and existing townsite salinity problems as well as developing new locally-based water resources, for 16 participating rural towns. New research and existing knowledge will be used to identify water management options and construct townsite Water Management Plans (WMPs) that focus on improved and integrated water management strategies.

The Department of Agriculture (DAWA), with project partners which include CSIRO, CRC LEME, UWA Agricultural Resource Economics, UWA Centre for Water Research, the WA Chemistry Centre and Wheatbelt Enterprise Technologies, is responsible.

The project is funded by the Western Australian Government, 16 Local Government Authorities and the National Action Plan for Salinity and Water Quality (NAP). Other major stakeholders are the Avon Catchment Council (ACC), the Northern Agricultural Catchment Council (NACC), the South West Catchment Council (SWCC) and the South Coast Regional Initiative Planning Team (SCRIPT).

Woodanilling is about 252 km south-east of Perth (Figures 1.1 and 1.2) and has a population of 110 residents. The Shire has been involved in the Rural Towns Program since 2001.

1.2 WATER MANAGEMENT OBJECTIVES
The objective for Woodanilling is to devise a water management plan that will:

- identify opportunities for groundwater and surface water resource development, primarily for townsite irrigation;
- manage salinity and waterlogging; and
- identify socio-economic opportunities associated with water resources.

A workshop was held with the Shire and Project Planning Team in June 2005 to identify priorities which were used to guide this Water Management Plan. A summary of outcomes is in Appendix B. The priorities and issues identified were:

1. Providing a secure water supply from the existing town dam by:
   - Improving the structural integrity of the dam, particularly its back wall, to prevent possible seepage and subsidence, and improve overflow structure; and
   - Enhancing run-off from the catchment;

2. Quantifying the cost-benefit of feasible stormwater management options;

3. Investigating possible contamination of groundwater from septic systems and taking appropriate action.
1.3 PURPOSE OF WATER MANAGEMENT PLAN

The proposed water management plan for Woodanilling is based on:

1. A summary of technical reports on:
   - Woodanilling geophysics
   - Urban water balance study
   - Methodology for assessment of water management options
   - Groundwater quality
   - Groundwater levels and associated impacts on salinity and infrastructure
   - Evaluation of costs associated with infrastructure damage caused by salinity
   - A brief socio-economic report;

2. Recommended water management options for managing salinity and developing new water supplies;

3. Preliminary engineering design of water management options;

4. Cost-benefit analysis for the recommended water management options; and

5. Recommended priority water management options.
Figure 1.1: Woodanilling locality map
Figure 1.2: Woodanilling townsite and key water management features
2 Current Town Status

2.1 SCIENTIFIC STUDIES AND INVESTIGATIONS

The following studies identified the current water management status at Woodanilling and recommended:

- An assessment of the risks of salinity and waterlogging due to surface run-off, and description of existing and potential water resources (Appendix C);
- Geophysical investigation of underlying geology, particularly the basement rocks and regolith material that lie between the bedrock and ground surface, which is important in understanding the hydrogeology, salinity risks and its management (Appendix D);
- Groundwater investigation to assess salinity risk from rising watertable, and to determine the feasibility of dewatering to lower the watertable for salinity management (Appendix E);
- Cost of damage to infrastructure caused by salinity and waterlogging (Appendix F);
- Investigation of possible use of additional water resources generated from management options;
- Groundwater quality investigations to determine constraints for local water supply from groundwater sources, both directly (brackish) or after water treatment (desalination). If dewatering is feasible, determine the appropriate level of treatment (e.g. reverse osmosis, desalination, nanofiltration or evaporative desalination), assess the potential for bulk mineral harvesting from saline water and disposal (Appendix G);
- Assess groundwater quality and its spatial and temporal distribution and variation which could provide key information on groundwater and surface water interactions, and interconnection within groundwater systems when integrated with hydrogeology, groundwater modelling, geophysics and surface hydrology (Appendix G); and
- Urban water balance to identify existing water usage in town and volumes of other sources of water within town which can be developed (Appendix H).

The outcomes of these investigations are summarised below as the current status of Woodanilling. For more information refer to relevant appendices.

2.2 SALINITY RISK ASSESSMENT

A telephone survey (Appendix A) indicated that residents do not consider salinity a problem in the townsite, except near the Name Creek.

Investigations revealed that during winter, when the groundwater level is at its highest, the depth for most of the townsite is greater than 1.8 m, except for the low-lying western part of town (Figure 2.1). A depth of 1.8 m is considered the maximum from which groundwater can be expected to passively discharge to the land surface as a result of evaporation during summer. Therefore, salinity risk has been mapped as very low to low, moving from east to west across the townsite (Figure 2.2).

Seasonal monitoring of groundwater shows a weakly upward hydraulic gradient delivering water along the valley floor, or low-lying western area of the townsite. This is likely to be caused by regional groundwater systems associated with a paleochannel which coincides with the Name Creek valley. However the deeper groundwater is isolated from shallow systems by a 30 m clay layer and so unlikely to contribute to the shallow bore. As a result shallow groundwater in the west of the town is
defined by low surface gradient and local recharge in a form of infiltration of rainwater or stormwater accumulation on the surface.

The surface water process attributed to waterlogging/inundation is often associated with the break of slope or soil profile changes from permeable to less permeable thus discharging at the soil interface. Assessment of LandMonitor data and soil-landscape units showed that Woodanilling is located on a mid to low hillslope recharge-discharge zone. A break of slope is present at the western edge of town (Figure 2.3). This is confirmed by gravity data from the geophysics investigation which identified a large fault. Thus, the area downstream of the break of slope is prone to waterlogging from subsurface discharge and seepage, and hence salinity from surface water processes. Anecdotal evidence of the seepage coincides with the Public Bar in town. Furthermore, it was identified that this seepage also causes problems for septic tank drainage.

The prospect of salinity management through pumping is poor, due to the low aquifer yield (<0.2 L/s per bore). Salinity control would be more effective through surface water management particularly in alleviating the waterlogging/inundation.

Shallow groundwater has salinity between 6,800 and 27,200 mg/L (1000-4000 mS/m). Samples from the shallow bore at the centre of town showed low microbiological (E. coli and total coliforms) levels, probably from septic tanks.

The geophysics investigation showed a basement depression at the valley to the west of the townsite. The depth to basement is 45 m, and groundwater is increasing from saline to hyper-saline with depth.

### 2.2.1 Infrastructure damage through salinity

The cost of damage caused by salinity was based on integrated analysis of soil saturation 1 m below ground level (Figure 2.2), and individual infrastructure damage associated with spatially defined salinity risk. Assessment was confined to parts areas containing observation bores. The methodology details are given in Appendix F.

Salinity risk for Woodanilling is confined to the lower western slopes of the townsite, roughly following the railway line. The estimated damage cost for different land use zones as described in the town planning scheme is $4000/year and the project NPV (net present value) cost over the next 20 years is $42,600 if the 'do-nothing' option is adopted. This information is also shown in Table 2.1.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Damage cost in Year 1 ($)</th>
<th>Projected NPV over 20 years (@ 7%) ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>55</td>
<td>583</td>
</tr>
<tr>
<td>Industrial</td>
<td>76</td>
<td>805</td>
</tr>
<tr>
<td>Local rural</td>
<td>133</td>
<td>1,409</td>
</tr>
<tr>
<td>Public purposes</td>
<td>79</td>
<td>837</td>
</tr>
<tr>
<td>Railway</td>
<td>1,967</td>
<td>20,838</td>
</tr>
<tr>
<td>Recreation</td>
<td>940</td>
<td>9,958</td>
</tr>
<tr>
<td>Residential</td>
<td>598</td>
<td>6,335</td>
</tr>
<tr>
<td>Roads</td>
<td>167</td>
<td>1,769</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,018</strong></td>
<td><strong>42,567</strong></td>
</tr>
</tbody>
</table>
2.3 URBAN WATER

2.3.1 Urban water balance

The urban water balance for Woodanilling was determined by analysis of several key components, namely:

- existing scheme water consumption provided by the Water Corporation and billing records;
- townsite wastewater generation; and
- modelled stormwater run-off from assumptions about the surface run-off characteristics using AQUACYCLE.

The urban water balance based upon the last 50 years of meteorological data, and recent scheme water consumption records from the Water Corporation are summarised in Table 2.2. Further explanations of the derivation these figures are provided in Appendix H.

Table 2.2: Urban water balance for Woodanilling

<table>
<thead>
<tr>
<th>Items</th>
<th>Indoor use (ML/year)</th>
<th>Outdoor use (ML/year)</th>
<th>Total (ML/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total scheme water use</td>
<td>13.8</td>
<td>11.9</td>
<td>25.7</td>
</tr>
<tr>
<td>Scheme water - residential</td>
<td>7.52</td>
<td>6.98</td>
<td>14.5</td>
</tr>
<tr>
<td>Scheme water - commercial</td>
<td>1.53</td>
<td>1.47</td>
<td>3.0</td>
</tr>
<tr>
<td>Scheme water - industry</td>
<td>1.50</td>
<td>1.50</td>
<td>3.0</td>
</tr>
<tr>
<td>Scheme water - other</td>
<td>3.23</td>
<td>1.92</td>
<td>5.15</td>
</tr>
<tr>
<td>Wastewater</td>
<td></td>
<td></td>
<td>14.9</td>
</tr>
<tr>
<td>Modelled stormwater run-off</td>
<td></td>
<td></td>
<td>243 (27.9)</td>
</tr>
</tbody>
</table>

The current supply to Woodanilling from the regional water supply scheme is 25.7 ML/year. As shown in Table 2.2 about 46% of the total usage is used outside, mostly for lawns and gardens.

A large potential water resource for the town is stormwater run-off. About 243 ML/year is generated within the gazetted boundary and about 27.9 ML/year within the current township, which covers less than 10% of the gazetted area. The other potential resource is treated wastewater. The model estimated that approximately 14.9 ML/year could be collected and reused. It is important to note that this wastewater quantity is a result of a modelling exercise, as Woodanilling is currently on a septic tank system.

2.3.2 Water demand for irrigation on community open spaces

Water for parks and oval irrigation (see Table 2.3) is sourced from regional scheme water and local stormwater. It is reported that up to 5 ML/year for irrigation is supplied by local dam catchments. The remainder is from scheme water, reportedly costing up to $11,000/year. This expenditure is equivalent to 8-9 ML/year (based on current prices).

Some scheme water used for irrigating parks and ovals is accounted for in the urban water balance in Table 2.2 as outdoor use of ‘Scheme water - other’.
Table 2.3 - Water demand for irrigation on parks and gardens (Source: DAWA)

<table>
<thead>
<tr>
<th>Location of demand</th>
<th>Area (hectares)</th>
<th>Watering depth (mm/week)</th>
<th>Frequency per week</th>
<th>Watering months per year</th>
<th>Annual volume (ML/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oval</td>
<td>2.0</td>
<td>18</td>
<td>7</td>
<td>8 (Sep-Apr)</td>
<td>11.5</td>
</tr>
<tr>
<td>Park</td>
<td>0.5</td>
<td>18</td>
<td>7</td>
<td>8 (Sep-Apr)</td>
<td>2.9</td>
</tr>
<tr>
<td>Total</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td>14.4</td>
</tr>
</tbody>
</table>

The Shire of Woodanilling also indicated that if more water was available it could be used for beautification of the townsite.

2.3.3 Rainwater tanks

Using rainwater tanks to substitute for residential outdoor use and toilet flushing was modelled to investigate effectiveness at conserving scheme water. It was found that rainwater tanks would reduce scheme water consumption by 13% or 3.4 ML/year.

Due to a small proportion of roof area, rainwater tanks would have minimal impact on stormwater run-off, reducing it by 1.3% or 3.3 ML/year on average (see Appendix H).

2.4 TOWN WATER RESOURCES

Existing water harvesting facilities include the town dam to the south of town with a capacity of 40 ML and run-off from a roaded catchment of 1 hectare and a farmland catchment of 99 ha. Currently, water is being pumped out of the dam to the oval tanks (44 kL capacity) for irrigation. Yield is reported to be 5 ML/year. However, according to the Shire, dam yield is unreliable and little or no flow was received in the first two years following construction.

2.5 SOCIO-ECONOMIC FACTORS

In a telephone survey (Appendix A), water resources were identified as the biggest problem, particularly improving run-off from roaded catchments, capturing surface water and use of rainwater tanks.

The Shire would also like access to more water for beautification to attract more people to the town. Furthermore, should there be excess water, they would develop more water-based industries, with aquaculture and salt-tolerant plants preferred, followed by nurseries and viticulture/olives.
Figure 2.1: Contour map of shallow groundwater depth at Woodanilling
Figure 2.2: Salinity risk mapping for Woodanilling
Figure 2.3: Salinity risk mapping from break of slope surface water process
3 Water Management Options

Water management options were formulated following investigation of current practices, and discussions between the planning team and Shire representatives.

Water management options are outlined below. These address resources, salinity and socio-economic development objectives. Refer to Figure 1.2 for location of key features.

3.1 OPTIONS IDENTIFIED

3.1.1 Option 1: Town dam
Upgrade the existing town dam including the overflow structure and roaded catchment to increase run-off reliability and performance. This would supply sufficient water for current and future needs.

3.1.2 Option 2: Town surface run-off and drainage works
Surface water run-off from the townsite could be harvested and stored to irrigate parks and ovals. Some upgrades of the main drainage structures would be required. This would allow more development and alleviate townsite salinity and waterlogging.

3.1.3 Option 3: Town subsurface run-off
Subsurface run-off could be collected via a subsurface drainage system, then used for irrigation or discharged into the creek. This was discarded due to expense and nature of soils.

3.2 OPTIONS FOR FURTHER INVESTIGATION

Only Options 1 and 2 have been considered as they are major priorities, and have the highest potential to meet objectives. The process of option selection involved discussions with the Shire and all stakeholders. The method for assessment, and selection of recommended option informally adopted the method outlined in Appendix I.

Option 3 was considered a second order priority. While recognised, it would require further investigation. Problems which still need to be resolved include: potential contamination of subsurface run-off through leaching of septic tanks; low level of microbiological contamination; consultation with the Water Corporation for reuse of treated wastewater, and assessing the quality and treatment required by the Department of Health for reuse on parks and ovals.
4 Engineering analysis of water management options

Kellogg Brown and Root Pty Ltd (KBR) were commissioned to undertake preliminary engineering analysis of the options identified for water management. The options and sub-options (based on engineering alternatives) analysed are:

- Option 1: Upgrade the town dam and catchment to increase run-off reliability to supply irrigation demand;
- Option 2a: Collect surface run-off via a new sump, and pump it to the town dam for irrigation; and
- Option 2b: Collect surface run-off via a new sump, and pump it to a new dam for irrigation.

The engineering analysis included estimation of potential water yield from each option, capital requirements, operation and maintenance cost. More information is in Appendix I.

The analysis is preliminary, based upon limited site-specific data supplied. Accordingly, further design would have to be undertaken prior to implementation of any options.

4.1 OPTION 1 – EXISTING TOWN DAM

4.1.1 Description of option

Water for irrigation at the oval and park is supplied by the town dam, which has a capacity of 40 ML. The dam is fed by a roaded catchment and run-off from nearby farmland with areas of 1 and 99 ha, respectively. An existing pipe and pump supply water to the demand points. The inlet, outlet and overflow structures require upgrade to ensure structural integrity and performance (see Figure 4.1).

4.1.2 Water yield

The dam has an average annual yield of 4.8 ML based on the last 10 years of rainfall. This corresponds to the yield reported by the Shire. The annual average yield represents 34% of current water demand of 14 ML/year. The annual yield is also less than the 40 ML capacity of the existing town dam.

The maximum yield from the dam was 14.4 ML/year over 10 years, with no yield on one occasion. This suggests that the total catchment is unreliable as it consists mostly of farmland (99 ha) with high threshold (25 mm) and small roaed catchment (1 ha) with low threshold (8 mm). The farmland catchment produces very high volume of run-off, however, this is sporadic as it has a high threshold.

To improve reliability, analysis into increasing the area of roaed catchment was undertaken. It was found that roaed catchment of 25 ha would be adequate to meet the existing demand of 14 ML/year, assuming that the 99 ha of natural farmland catchment was retained.
4.1.3 Capital requirements and costs

Existing pipe and pump

The existing water supply scheme from the town dam to the oval consists of a 90 mm pipe and pump. Peak demand for irrigation is 6 L/s based on the current watering regime. It has been assumed that pipe and pump are still in good working condition, and require no further upgrade.

Existing town dam structure

It has been reported that the town dam has several structural problems, including a crack in the back wall and overflow structure at poor integrity. Allowance will be made in the cost estimate for upgrades of the dam to restore it.

Capital requirements and costs

The capital requirements and costs for this option are shown in Table 4.1. The estimates on capital requirements are provided at KBR commercial rates and DAWA/Shire rates. The assumptions and cost details are supplied in Appendix J. Costs may be further refined at the detailed engineering design stage.

4.2 OPTION 2A – TOWN RUN-OFF TO EXISTING DAM

4.2.1 Description of option

Surface run-off is to be collected at a new sump and pumped to the dam for storage before irrigation of parks and ovals. Advice indicates that some upgrades of the drainage system would be required including a new channel along Yairabin Street and the existing main drain along Burt Road.

The main drain discharges at the northern end of town into a natural creek. As such, it was determined that the best location for the new sump was along Burt Road at its intersection with Yairabin Street to follow this existing drainage arrangement.

The requirements for this option are:

- Construction of the new sump;
- Sizing of upgrades of all drainage features;
- Determine volume of surface run-off which can be captured; and
- Yield analysis for the existing town dam with the augmentation of town surface run-off.

All features discussed in each sub-option are shown in Figure 4.2.
Table 4.1: Capital requirements and costs, and operation and maintenance costs for Option 1

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase size of town dam roaded catchment</td>
<td>Additional 24 hectares</td>
<td>144,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td></td>
<td>5,300</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td></td>
<td>4,283</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td></td>
<td>9,570</td>
<td>2,950</td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location e.g. transportation as costs are based on metro rates</td>
<td>32,631</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub-total capital costs</strong></td>
<td></td>
<td>195,784</td>
<td>123,950</td>
</tr>
<tr>
<td>Additional project costs</td>
<td></td>
<td>86,145</td>
<td>-</td>
</tr>
<tr>
<td>General contractors’ prelims (20%)</td>
<td>For mobilisation/demobilisation, site set-up, clean-up etc</td>
<td>39,159</td>
<td>-</td>
</tr>
<tr>
<td>EPCM fees (@10% of cost)</td>
<td>Engineering, Procurement, Construction and Management fees</td>
<td>23,494</td>
<td>-</td>
</tr>
<tr>
<td>Contingency (@10% of cost)</td>
<td></td>
<td>23,494</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub-total for additional project costs</strong></td>
<td></td>
<td>86,145</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total for capital investment</strong></td>
<td></td>
<td>281,929</td>
<td>123,950</td>
</tr>
</tbody>
</table>

4.2.2 Water yield

Based on the last 10 years’ of rainfall the average annual surface run-off that can be collected from the townsit is 24 ML/year. This is consistent with the previous estimate of 27.9 ML/year (Appendix H).

Town surface run-off when combined with yield from the town dam catchment produces an average annual yield in excess of required 14 ML/year, which would meet current demand.

The dam has adequate capacity with a likely average annual yield of 27 ML/year, assuming that all water available in the dam is withdrawn.

Thus, after satisfying the existing demand of 14 ML/year, there is an average of 13 ML/year of excess water from the dam.

4.2.3 Capital requirements and costs

The capital requirements and costs based on this option are shown in Table 4.2. The cost estimates on capital requirements are provided for KBR commercial rates and DAWA/Shire rates. The
assumptions and cost details for these rates are supplied in Appendix J. Costs may change at the
detailed engineering design stage.

As with Option 1, allowance for upgrades of inlet, outlet and overflow structures at the existing town
dam has been made, as the dam is currently not in good structural condition.

Table 4.2: Capital requirements and costs, and operation and maintenance costs for Option 2a

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($ 20%+30%)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td></td>
<td>5,300</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td></td>
<td>4,283</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td></td>
<td>9,570</td>
<td>2,960</td>
</tr>
<tr>
<td>Upgrade drainage channel along Burt Road for 1:10year peak flow</td>
<td>362 m long, 2 m bottom width, 1:4 side slope, 1 m deep</td>
<td>48,500</td>
<td>900</td>
</tr>
<tr>
<td>Install new drainage channel along Yairabin Street for 1:10year peak flow</td>
<td>535 m long, 2 m bottom width, 1:4 side slope, 1 m deep</td>
<td>88,500</td>
<td>14,124</td>
</tr>
<tr>
<td>New sump</td>
<td>40 m×20 m×2.5 m fully lined</td>
<td>76,040</td>
<td>5,400</td>
</tr>
<tr>
<td>Pump from new sump to existing town dam</td>
<td>1× 4 L/s @ 70 m head</td>
<td>35,420</td>
<td>33,080</td>
</tr>
<tr>
<td>Pipe to connect from new sump to existing dam</td>
<td>Extra 100 m of 90 mm PVC</td>
<td>11,050</td>
<td>7,190</td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location factor eg transportation etc as costs are based on metro rates</td>
<td>56,333</td>
<td>-</td>
</tr>
</tbody>
</table>

Sub-total for capital costs 334,996 64,654

Additional project costs

| General contractors prelims (20%)                  | For mobilisation/demobilisation, site set-up, site clean-up etc       | 67,599                          |
| EPCM fees (@10% of cost)                           | Engineering, Procurement, Construction and Management fees             | 40,560                          |
| Contingency (@10% of cost)                         |                                                                        | 40,560                          |

Sub-total for additional project costs 148,719

Total for capital investment 483,715 64,654

Operation and Maintenance Details Cost ($/year)

| Operation of pump from existing town dam to oval  | 4 hrs/day, 7 days/week, 8 months/year of 10 kW pump and $0.17/kWh    | 1,523                           |
| Operation of pumps from new sump to existing town dam | more intensive during winter, 4 hrs/session, Nominal operations = 3 times/week, 8 months/year of 10 kW pump and $0.17/kWh | 653                             |
| Maintenance personnel & repairs                   | $80/hr 2 hrs/week 7 months/year                                      | 4,480                           |

Total for operation and maintenance 6,656
4.3  OPTION 2B – TOWN RUN-OFF TO NEW DAM

4.3.1  Description of option

This is similar to Option 2a except the surface run-off is to be stored at a new dam instead of the existing dam. Upgrades of the existing drainage system would still be required.

The location of this new dam is assumed to be south of the golf course (see Figure 4.3).

4.3.2  Water yield

As with Option 2a, the average annual town surface run-off was estimated to be 24 ML/year. The size of the new dam required to capture all this run-off is 25 ML assuming dimensions of 40 x 40 x 6 m at a 1:3 side slope.

Based on the last 10 years’ rainfall record, the annual average yield from the new dam would be enough to supply the existing demand of 14 ML/year. A total of 19.5 ML/year could be drawn, satisfying the existing demand of 14 ML/year, with an excess of 5.5 ML/year.

Total yield from Option 2b is less than 2a, as augmentation from the town dam is not included.

4.3.3  Capital requirements and costs

The capital requirements and costs are shown in Table 4.3. The assumptions and cost details are supplied in Appendix J.

Costs may change at the detailed engineering design stage.
Table 4.3: Capital requirements and costs, and operation and maintenance costs for Option 2b

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20%+30%</td>
<td></td>
</tr>
<tr>
<td>Upgrade drainage channel along Burt Road for 1:10 year peak flow</td>
<td>362 m long, 2 m bottom width, 1:4 side slope, 1.5 m deep</td>
<td>48,500</td>
<td>900</td>
</tr>
<tr>
<td>Install new drainage channel along Yairabin Street for 1:10 year peak flow</td>
<td>535 m long, 2 m bottom width, 1:4 side slope, 1.5 m deep</td>
<td>80,500</td>
<td>14,124</td>
</tr>
<tr>
<td>New sump</td>
<td>40 m×20 m×2.5 m fully lined</td>
<td>79,040</td>
<td>5,400</td>
</tr>
<tr>
<td>Pump from new sump to new dam</td>
<td>1× 4 L/s @ 34 m head</td>
<td>35,420</td>
<td>31,880</td>
</tr>
<tr>
<td>Pipe to connect from new sump to new dam</td>
<td>750 m of 90 mm PVC</td>
<td>53,950</td>
<td>28,250</td>
</tr>
<tr>
<td>New dam</td>
<td>25 ML capacity 40 m×40 m×6 m with 1:3 side slope</td>
<td>200,560</td>
<td>136,850</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with liner</td>
<td>without liner</td>
</tr>
<tr>
<td>Reticulation line from new dam to oval</td>
<td>500 m of 90 mm PVC with 10 m head</td>
<td>37,450</td>
<td>20,150</td>
</tr>
<tr>
<td>Pump from new dam to oval</td>
<td>6 L/s @ 10 m head</td>
<td>35,420</td>
<td>27,380</td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location factor e.g. transportation as costs are based on metro rates</td>
<td>114,168</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-total for capital costs</strong></td>
<td></td>
<td><strong>685,008</strong></td>
<td><strong>264,934</strong></td>
</tr>
<tr>
<td></td>
<td>with liner</td>
<td>with liner</td>
<td>with liner</td>
</tr>
<tr>
<td></td>
<td>200,984</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional project costs

<table>
<thead>
<tr>
<th>Details</th>
<th>Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General contractors prelims (20%)</td>
<td>For mobilisation/demobilisation, site set-up, clean-up etc</td>
</tr>
<tr>
<td>EPCM fees (@10% of cost)</td>
<td>Engineering, Procurement, Construction and Management fees</td>
</tr>
<tr>
<td>Contingency (@10% of cost)</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-total for additional project costs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total for capital investment</strong></td>
<td></td>
</tr>
<tr>
<td>with liner</td>
<td>with liner</td>
</tr>
<tr>
<td>200,984</td>
<td>264,934</td>
</tr>
</tbody>
</table>

Operation and Maintenance

<table>
<thead>
<tr>
<th>Details</th>
<th>Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation of pump from existing town dam to oval</td>
<td>4 hrs/day, 7 days/week, 8 months/year of 10 kW pump and $0.17/kWh</td>
</tr>
<tr>
<td>Operation of pumps from new sump to existing town dam</td>
<td>more intensive during winter months, 4 hrs/session, Nominal operations = 3 times/week, 8 months/year of 10 kW pump and $0.17/kWh</td>
</tr>
<tr>
<td>Maintenance personnel &amp; repairs</td>
<td>$80/hr 2 hrs/week 7 months/year</td>
</tr>
<tr>
<td><strong>Total for operation and maintenance</strong></td>
<td></td>
</tr>
</tbody>
</table>
4.5 SUMMARY OF ALL OPTIONS

Woodanilling requires 14.4 ML/year. Water yield for all options is summarised in Table 4.4.

Table 4.4: Water yield for all options including current supply by dam in its existing state

<table>
<thead>
<tr>
<th>Option</th>
<th>Average annual water yield (ML/year)</th>
<th>% of demand (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>4.8</td>
<td>34</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>99</td>
</tr>
<tr>
<td>2a</td>
<td>26.7¹</td>
<td>134</td>
</tr>
<tr>
<td>2b</td>
<td>18.9²</td>
<td>134</td>
</tr>
</tbody>
</table>

¹. Yield combines run-off of 24.22 ML/year town surface and 4.8 ML/year from existing town dam with 2.32 ML unavailable for use.
². Yield combines run-off of 24.22 ML/year town surface with 5.32 ML unavailable for use.

The capital, operation and maintenance costs for all options are summarised in Table 4.5.

Table 4.5: Cost for all options

| Option | KBR Commercial Rates ($) (Including location allowance) (-20%+30%) | Additional Cost ($) (-20%+30%) | TOTAL KBR Commercial Rates¹ Capital Investment Costs ($) (-20%+30%) | TOTAL DAWA/Shire Rates¹ Capital Investment Costs ($) | O & M Cost ($)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>195,784</td>
<td>86,145</td>
<td>281,929</td>
<td>123,960</td>
<td>6,003</td>
</tr>
<tr>
<td>2a</td>
<td>333,996</td>
<td>148,719</td>
<td>486,714</td>
<td>64,654</td>
<td>6,656</td>
</tr>
<tr>
<td>2b</td>
<td>685,008</td>
<td>301,404</td>
<td>986,412 with liner</td>
<td>264,934 with liner</td>
<td>6,656</td>
</tr>
</tbody>
</table>

¹. See Capital Investment and Costs for calculation methodology and assumptions.
Figure 4.1: Schematic for Option 1 - existing town dam to oval
Figure 4.2: Schematic for Option 2a - town surface run-off and to existing dam
Figure 4.3: Schematic for Option 2b - town surface run-off to new dam
5 Cost-benefit Analysis

5.1 INTRODUCTION

Costs and benefits arising from the proposed water management options and the current use of the existing town dam were analysed. Because there is no market price for locally-produced water, instead of documenting net benefits, the results are expressed in terms of the break-even water price needed so that total costs equal total benefits (Appendix K).

5.2 APPLICATION

General base case assumptions that pertain to each of the options include surface water harvested in Woodanilling in its current state, would be fit for irrigation only. It is also assumed that if necessary scheme water will supplement the water available from the dam (dependent on the selected water management option as outlined below) and all 14.4 ML that is assumed to be required annually will be used (despite the rainfall in any particular year). Based on Water Corporation (2005) data, the cost of scheme water provided by the Integrated Water Supply System to vacant non-residential land is assumed to be $1.20/kL. This cost-benefit analysis has been done over a 20 year period with a 7% discount rate. This discount rate is slightly higher than current bank interest so that long-term risk of an interest rate increase can be factored into the analysis. However, the rate is dropped to 4% in a sensitivity analysis to determine if the discount rate has a bearing on the overall outcome. In other sensitivity analyses the costs are varied up by 30% and down by 20% and the quantity of water produced by any of the options is increased and decreased by 10%. If the overall results do not change when these analyses are imposed then they can be considered to be robust.

For water produced by the dam in its current state, it is assumed that operating and maintenance costs are the same as for Option 1 (based on DAWA/Shire rates) and that there is a capital contingency of $5,000 in year 1. In addition, for each option all pumps are replaced in year 11. For the current option the cost of the pump is equivalent to that in Option 1 (based on DAWA/Shire rates).

Details of the complete schedule of costs are in the previous section. It is assumed that 95% of capital costs will be funded up front in the form of a grant and/or other funding, while the remaining costs are annualised over 20 years.

5.3 RESULTS AND CONCLUSIONS

A summary of the price of water required for an option to break-even given the base case assumptions described above is in Table 5.1.

Table 5.1. Break-even price for water produced from the dam in its current state and as described for each Option, using either KBR commercial or DAWA/Shire rates and base case assumptions

<table>
<thead>
<tr>
<th>Option</th>
<th>Water price ($/kL) based on</th>
<th>KBR commercial rates</th>
<th>DAWA/Shire rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>-</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.44</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>2.08</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>2b (with liner)</td>
<td>5.44</td>
<td>1.82</td>
<td></td>
</tr>
</tbody>
</table>
Acknowledging the base case assumptions, use of the town dam to produce water as done currently, costs more than the estimated average price of scheme water. Water provided by the means stated in Options 1, 2a or 2b would need to be sold above the estimated scheme water price if it was produced by the processes that incur KBR commercial rates. However, when DAWA/Shire rates were used in analyses for Option 2a and possibly Option 1 the break-even price was below the average scheme water price. For this option, changing the base case values to increase the product water by just 15% or reduce costs by around 12% in a sensitivity analysis would bring the cost of water in line with scheme water. Therefore, due to the sensitivity of this outcome to relatively small changes in the parameters, decision makers may wish to consider the potential of Option 1 more thoroughly. For all options, decreasing the discount rate to 4% from the base of 7% did not change the overall outcome.

Option 2 provides additional benefits of up to $4,018 per year resulting from a reduction in risk of salinity and water damage to infrastructure such as buildings and roads. However, even if it was assumed that the total benefit from reduced damage could be achieved, it would not change the overall outcome as presented in Table 5.1. That is, the number of options having a break-even water price under the average price of scheme water would remain the same. As expected the break-even water price for Option 2a (calculated using DAWA/Shire rates) would be a little more attractive when infrastructure damage reduction is considered ($0.43/kL), while the other scenarios for Option 2 would still have break-even water prices above the average scheme water price.

It is assumed in the base case analysis that all of the water produced in Options 1 and 2a results from improvements to the dam, and if these alterations were not done the existing dam in its current state would yield nothing. Alternatively, if the costs for Options 1 and 2a are linked specifically to additional water produced over and above that currently generated by the dam in its existing state (4.8 ML), then the break-even water price for each option would increase. However, the general outcome for each option would not alter from the base case analysis stated above. Option 2a (calculated using DAWA/Shire rates) would still be a better option than simply using scheme water while the other options would produce water above the average scheme water price.

While total costs are included in the analysis, the break-even water price can be divided into annual operating costs per kilolitre of water produced, and the combined capital and opportunity cost of investment per kilolitre of product water for each option (Table 5.2). Note that commercial costs and the DAWA/Shire estimation for operating and maintenance were assumed to be the same.
Table 5.2. Capital and opportunity cost of investment per kilolitre of product for water produced from the dam in its current state, and for each Option, using either KBR commercial or DAWA/Shire rates, and operating and maintenance costs

<table>
<thead>
<tr>
<th>Option</th>
<th>Capital and opportunity cost of investment based on KBR commercial rates</th>
<th>Capital and opportunity cost of investment based on DAWA/Shire rates</th>
<th>Operating and maintenance cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>-</td>
<td>0.35</td>
<td>1.25</td>
</tr>
<tr>
<td>1</td>
<td>2.01</td>
<td>0.95</td>
<td>0.43</td>
</tr>
<tr>
<td>2a</td>
<td>1.83</td>
<td>0.33</td>
<td>0.25</td>
</tr>
<tr>
<td>2b (with liner)</td>
<td>5.09</td>
<td>1.46</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Excess water that is expected to be produced over and above the current estimated demand for Woodanilling for Options 2a and 2b, as described in Section 4.4, would be beneficial in terms of providing an ‘insurance measure’ for exceptionally dry years. Alternatively, if it is deemed viable, uses for the excess irrigation water may include application in industry (see Appendix M) or beautifying the town. However, if the value placed on this water is below the break-even price as calculated in Table 5.1 then the ‘water production enterprise’ would make a loss or in other words be subsidised by the supplier. Hence town decision makers should be mindful of how best to consider this excess water.

Overall it would appear convincingly that Option 2a (analysed using DAWA/Shire rates) is the water management option that produces the greatest net benefits for Woodanilling (Table 5.1). It should also be noted that this Option also accounts for benefits arising from a reduction in salinity and water damage to townsite infrastructure.

The break-even price of water calculated in Option 1 (based on DAWA/Shire rates) could be potentially competitive with scheme water. This may occur if

- the base cost is at least 12% lower than the total value of capital and operating costs for this option as reported in Table 4.5
- water production is 15% above the estimated base value
- there are additional unquantifiable benefits.

In any case this option is less economically viable that Option 2a (calculated using DAWA/Shire rates). All other options are unlikely to be viable given the assumptions and data used in this study.
6 Conclusion

As part of the Rural Towns - Liquid Assets project, DAWA and other stakeholders have undertaken scientific investigations, and in consultation with the Shire of Woodanilling have devised solutions for water management.

The objectives of water management at Woodanilling are:

- To provide water resources development; for salinity management; and
- identify socio-economic opportunities associated with water resources.

This Water Management Plan synthesises outcomes from all scientific investigations and reports, and presents the recommended water management options.

The outcomes of scientific investigations suggest that:

- Salinity risk for most of the town is low, except at the western edge. There is little anecdotal evidence of salinity;
- Waterlogging is reported due to discharges of subsurface run-off at the break of slope and stormwater accumulation, which coincides with the western edge of town;
- Salinity management should focus on surface water processes; abstraction of groundwater is not feasible;
- Total scheme water consumption is 25.7 ML/year, supplied by the local Water Corporation dam. There is potential to reuse treated wastewater (about 14.9 ML/year), however a collection system would need to be put in place first, as Woodanilling is currently on septic systems. The modelled surface run-off which could be captured off the townsite is 27.9 ML/year;
- Current demand for irrigation on parks and ovals is about 14.4 ML/year. Of this 4.8 ML/year is reported to be supplied by the existing town dam and catchment plus 8-9 ML/year as scheme water when the dam is dry.

Recommended water management options outlined below are a result of the above scientific outcomes and in consultation with the Shire of Woodanilling:

- Option 1: Upgrade the existing town dam and catchment to improve reliability of run-off to supply irrigation demand;
- Option 2a: Collect surface run-off from town via a new sump, and pump it to the existing town dam to supply irrigation demand;
- Option 2b: Collect surface run-off from town via a new sump, and pump it to a new dam to supply irrigation demand.

Preliminary engineering analyses were undertaken to quantify water yield for each option and associated capital requirements and costs, as well as operation and maintenance costs. Two sets of costings are provided. One, termed ‘KBR commercial rates’, includes comprehensive costs based on the assumption that the project would be completely out-sourced and use materials of the highest quality. The alternative costings are termed ‘DAWA/Shire rates’ and based on work conducted by local operators using adequate materials. It is important to note that further engineering analysis would be required prior to implementation of any of these options.
The annual water yield from the current dam in its existing state is estimated to be 4.8 ML. With additional catchment and other improvements as documented for Option 1, water yield would increase to 14 ML per year. These same improvements plus capturing surface water from within the town site as suggested in Option 2a would see annual water yield increase to 26.7 ML. With a new dam and capture of surface water from within the town site, as suggested in Option 2b, annual water yield from this system would total 18.9 ML.

Cost-benefit analyses were completed for the existing dam in its current state and for Options 1, 2a and 2b using KBR commercial rates and DAWA/Shire rates. They indicate that Option 2a (using DAWA/Shire rates) is the option that produces the greatest net benefits for Woodanilling. These benefits also include the return expected from a reduction in salinity (albeit small) and water damage to infrastructure. All other options, except Option 1 under particular circumstances, are unlikely to be viable given the assumptions and data used in this study.

7 References

APPENDIX A

Preliminary Community Profile for the Shire of Woodanilling

An investigation into the demographic environment and community perspectives

Joanne Willers
CSIRO Land and Water
The University of Western Australia
February 2005
Contents
Summary………………………………………………………………………………………………………………..A3
1 Introduction…………………………………………………………………………………………………………..A4
2 Demographic Trends & Indicators…………………………………………………………………………………A5
   2.1 Population……………………………………………………………………………………………………...A5
   2.2 Employment…………………………………………………………………………………………………..A8
   2.3 Industry………………………………………………………………………………………………………..A11
   2.4 Finance………………………………………………………………………………………………………..A13
3 Climate………………………………………………………………………………………………………………A14
4 Geology………………………………………………………………………………………………………………A15
5 Water prices…………………………………………………………………………………………………………A17
6 Public utilities………………………………………………………………………………………………………..A18
7 Post-survey review…………………………………………………………………………………………………A20
8 Conclusions & recommendations…………………………………………………………………………………A23
9 List of additional information…………………………………………………………………………………...A24
10 References…………………………………………………………………………………………………………A25

APPENDIX A: WOODANILLING COMMUNITY PROFILE

Summary

The Woodanilling townsite is 252 km south of Perth and only 25 km from Katanning and 30 km from Wagin. The Shire is predominantly a sheep and grain producing area; these activities remain the economic mainstay of the region. The localities within the Shire of Woodanilling include Beaufort River, Boyerine, Cartmeticup, Boscabel, Congee, Kenmare and Westwood. Woodanilling townsite comprises residential, light industrial and recreational land. The town income is predominantly from servicing the surrounding agricultural area (Whitfield 2001). In June 2002 Woodanilling had a population of 390 people. The Shire exhibits the typical characteristics of a traditional Western Australian rural town.

Scheme water is supplied to Woodanilling via a comprehensive water scheme from the Harris River Dam. It was determined via questionnaires completed by a number of residents that the quality of scheme water is good overall but may vary seasonally. Given that agriculture is the predominant industry in the town and is the highest contributor to the economy in the region, water is often the defining resource that determines the profitability of the industry. The demographic profile (population, employment, income, occupation) of the town will often fluctuate depending on the success of the agricultural industry and so for farmers to remain sustainable it is vital to ensure quality resources for the future. The surveys carried out in Woodanilling revealed that no one is more aware of this crisis than the farmers themselves. Many farmers have detailed water management plans. It is important to utilize this local knowledge and possibly adopt some of these ideas into the water management plan derived within the project in order to ensure the future sustainability of water in Woodanilling. It was also established that the water crisis was not felt so severely by those who had access to scheme water. They were not affected by lack of supply and rarely affected by poor quality water.

Urban salinity has a significant economic impact on 38 rural towns in Western Australia. The Salinity Investment Framework (SIF) predicts that damage within those towns will be more than $55 million over the next 30 years. With increasing water restrictions, economic and social development is also being stifled by declining water supplies. Salinity management based solely on water abstraction isn’t cost effective. However, an integrated approach incorporating salinity management with new industries (based on local water production) may be viable and produce multiple benefits. As a part of this project people’s perceptions and concerns relating to townsite salinity were investigated. Most residents who participated believed there was no problem with salinity in the townsite. Those who said there was a salt problem in the town mentioned that they could not visually see any problems but had been told by someone that there was salt in the water. Quite a different response was presented from farmers who were interviewed. Most farmers thought there were salinity problems in the town and were also aware of the rising groundwater problems.

It was interesting to note that although on the Woodanilling Shire website there was issue regarding the power problems in the town, this was rarely raised by residents in the surveys. All three towns CEOs mentioned they were not partaking in any initiatives to secure private power supplies and there was no great interest in large scale use of oil mallees for biofuel from residents.

Other important issues such as the possibility of recycled water consumption, Waterwise gardening, water management and water related industries were also assessed.

As a result of this preliminary investigation a set of recommendations was derived that will aid in the successful completion of the project for all parties involved. These recommendations are: Determine each town’s expectations for RT-LA, revisit Woodanilling and conduct a more thorough investigation with a larger sample, increase community education and communication among stakeholders, and further investigation into new water-related industries.
1 Introduction

The Woodanilling townsite is located approximately 252 km south of Perth and only 25 km from Katanning and 30 kilometres from Wagin (Shire of Woodanilling 2004). Woodanilling was named after a spring in the Boyerine Creek 1 kilometre south of the townsite. Europeans first explored the district in 1830-31. Following this, the construction of the Perth/Albany road in the early 1850s brought the grazing lands in this region to the attention of many pastoralists (Shire of Woodanilling 2004). Around this time (1906) the shire began to flourish and a population of around 800 people were present and Woodanilling boasted a number of businesses including a blacksmith, wheelwright, five general stores, post office, banks, hotel, hospital, school, bakery, church, barbers, boarding house, saddlery shop, railway station and the first trotting track outside the Perth metropolitan area (Shire of Woodanilling 2004). By 1984 the Shire’s population had diminished substantially to around 470 mainly due to rural depopulation issues facing the entire wheatbelt (Shire of Woodanilling 2004). Today, the decline in the population continues and current Shire statistics are outlined below.

Distance from Perth (km) 252
Area (sq km) 1126
Length of Sealed Roads (km) 107.6
Length of Unsealed Roads (km) 413.6
Population 409
Total Revenue 1,022,871
Number of Dwellings 160
Number of Rate Assessments 329
Shire Employees 11

(Shire of Woodanilling 2004)

The Shire is predominantly a sheep and grain producing area; these activities remain the economic mainstay of the region. The localities within the Shire include Beaufort River, Boyerine, Cartmeticup, Boscabel, Congee, Kenmare and Westwood (Shire of Woodanilling 2004). Woodanilling townsite comprises of residential, light industrial and recreational land use. The town income is predominantly from servicing the surrounding agricultural area (Whitfield 2001).

Despite a declining rural population the Shire of Woodanilling caters well for the local community and provides an abundance of recreational and sporting activities that contribute to the thriving social nature of the town. The Shire has a cricket club, badminton, tennis, hockey, golf, indoor bowls, darts, pool, equestrian facilities and basketball courts. As well as the vast array of sporting activities, Woodanilling also has a number of recreational areas that are promoted as tourist attractions such as the Queerearrup Lake popular for skiing and barbequing, Martup Pool (bush walking, picnic area), King Rock (bush walking, wildflowers, nature reserve) and the Wingedyne Nature Reserve for bird watching (Shire of Woodanilling 2004).

Community organisations include a Baptist church, town improvement committee, playgroup, P&C Association, volunteer bushfire brigades, CWA, LCDC, library and a family dance group (Shire of Woodanilling 2004).

Woodanilling has one school in its district, the Primary School that caters for kindy to year 4. It is serviced by a school bus to Katanning, which has three primary schools, one Senior High School, two pre-primary schools, one residential hostel and a TAFE Centre (Shire of Woodanilling 2004). School
bus routes also cater for students attending schools at Wagin or Kojonup. The close proximity of both Katanning and Wagin makes travel to schools easy, especially with the bus service.

The Shire also features a caravan park, tavern and general store that are able to accommodate tourists. Council buildings include the Town Hall, CWA Hall, Library, Caravan Park and the Recreation Complex, which are available for all community requirements.

2 Demographic Trends and Indicators

2.1 Population

The population of Woodanilling was 382 in August 2001 (209 males, 173 females). This represents an increase of 7.9% since the 1996 census and a decrease of 2.3% since 1991 (Table 1).

Table A2.1. Census Population Counts - Woodanilling

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>209</td>
<td>179</td>
<td>204</td>
<td>2.5%</td>
</tr>
<tr>
<td>Female</td>
<td>173</td>
<td>175</td>
<td>187</td>
<td>-7.5%</td>
</tr>
<tr>
<td>Total</td>
<td>382</td>
<td>354</td>
<td>391</td>
<td>-2.3%</td>
</tr>
</tbody>
</table>

Note: Overseas visitors are included in these counts (ABS (515059380) 2004)

Furthermore, at June 2002 Woodanilling had a population of 390. According to the Australian Bureau of Statistics this represented a decline of 1.0% from the previous year. Over the same period, the population of regional Western Australia grew by 1.1% and the State’s population by 1.4%, as can be seen in Figure A2.1a (Department of Local Government and Regional Development, Government of Western Australia (b) 2003).

In June 2002 the population of the Shire made up 0.1% of the people living in regional WA and 0.02% of the entire State population (Department of Local Government and Regional Development, Government of Western Australia (b) 2003). The median age of people living in Woodanilling in 2001
was 35 years. This increased from 31 in 1996 and 29 in 1991. These statistics are similar to many towns in the wheatbelt which are also experiencing an ageing population (Figure 1b).

![Total Population Ages in Woodanilling](image)

Figure A2.1b. Population ages over three census years, Shire of Woodanilling

There is a lack of 15-19 year olds (Figure A2.1b). It is possible there could be a lack in the age category as this is a time when children may start to leave home to seek further education or employment. In 2001 there also seemed to be a significant increase in the number of 35-39 year-olds compared to the previous census counts. Figure A2.1b also shows that in 1996 there was a decline in population in most age categories in comparison with 2001 and 1991.

![Age Sex Ratio](image)

Figure A2.1c. A comparison of age versus sex in Woodanilling (Anon 2004)

Figure A2.1c shows the predominant age group in Woodanilling to be 0-9 years. There are very few people above 70.

In 2001 88.4% of people were Australian born according to the Australian Bureau of Statistics. Of those born overseas, the three main countries of birth included the UK (4.2%), New Zealand (1.6%) and Canada (0.8%). In the previous two censuses, Italy and Mauritius also featured in these top three
APPENDIX A: WOODANILLING COMMUNITY PROFILE

In the 2001 census, the three most common ancestries identified included English (50.8%), Australian (42.6%) and Irish (9.5%).

Figure 1e indicates the dominant religion is Anglican, followed by no religion, Catholic and Baptist. The high affiliation with the Baptist religion may be associated with the church in the Woodanilling townsite.

![Birthplace of Woodanilling Population (Excluding Australia)](image)

*Figure A2.1d. Birthplace of Woodanilling residents, excluding Australia*

![Religious Affiliation of Woodanilling](image)

*Figure A2.1e. Religious affiliation in Woodanilling (Census 2001)*
2.2 Employment

Total employment in the Shire of Woodanilling in June 2003 was 246 people. This represented an increase of 1.2% from the previous quarter as can be seen in Figure A2.2a. Comparing the June 2003 quarter with the same quarter from the previous year, employment decreased by 8.2%. In contrast, employment increased by 1.5% for regional WA and 1.9% for the State as a whole (Department of Local Government and Regional Development (b) 2003).

![Employment [Quarterly]](image)

*Figure A2.2a. Quarterly employment statistics for the shire of Woodanilling*

In the June 2003 quarter there were four unemployed people in the Shire, compared with two in the previous quarter and four the quarter before that. The unemployment rate for the Shire in the June 2003 quarter was 1.6% (Figure 2b). This unemployment rate compares to 5.6% for regional Western Australia and 5.9% for the State in that same quarter (Department of Local Government and Regional Development, Government of Western Australia (b) 2003). Although these statistics look positive when comparing them to unemployment at a regional and State level, it has been suggested that the figures may be inaccurate. The Wheatbelt Area Consultative Committee believes that these figures do not give a true picture of the unemployment status of particular regions due to the fact that people (particularly young people) are being forced to leave their small communities when they become unemployed to find work in the larger centres (Bothams 1998). The process of rural depopulation due to lack of employment opportunities is not accounted for in the unemployment status of rural towns and may therefore be highly underestimated. Hidden unemployment statistics are a significant regional issue that needs to be reassessed before making any assumptions about the status of a rural town. For this reason, although Figure 2b provides a good approximation of what may be occurring in Woodanilling in terms of unemployment, it is likely to be highly under-estimated.
Figure A2.2b. Quarterly unemployment statistics for Shire of Woodanilling

Figure A2.2c shows a significant drop in unemployment in 1996 compared to the other two census years.

In all regions of the wheatbelt including Woodanilling, part-time employment is growing while the number of full time positions is declining. A recurring trend shows the number of females increasing as a proportion of the work force. The proportion of women in part-time work is close to twice that of men. Almost half of the female population in the workforce work part-time, while the great majority of men work full time (Bothams 1998). Another reason why employment statistics are so difficult to accurately determine in agricultural areas is the high level of seasonal employment that comes with traditional farming. However, general trends do indicate that Woodanilling is following the path of many country towns and experiencing growing numbers of part-time positions, especially to females (Figure A2.2d).

Figure A2.2c. People unemployed in Woodanilling over three census counts

The Australian Bureau of Statistics stated that of the total number of employed people in Woodanilling for census 2001, 68.9% were working full time, while 24.4% were part-time (ABS (515059380), 2004).
2.3 Industry

Much the same as the remainder of the wheatbelt, agriculture continues to employ most people in Woodanilling. In 2000/01 total agricultural production was valued at $19.9 million, an increase of 11.1% from the previous year. However, statewide, the industry experienced a decline of 7.7%, suggesting a positive outlook. Statistics relating to the agricultural production over a nine year period can be seen in Figure A2.3a. This shows a huge increase in agricultural production between 1997 and 1999. Prior to this increase, the trend indicates a steady decline in growth of agricultural production in Woodanilling between 1994 and 1996.

According to the ABS the Shire of Woodanilling contributes 0.5% of the State’s total agricultural production by value.

![Agricultural Production [Annual]](image)

*Figure A2.3a. Annual agricultural production for Shire of Woodanilling*
Aside from the agricultural industry, other industries are still significant contributors to Woodanilling’s economy. Such industries are outlined in Figure A2.3b.

The most significant findings from these statistics relate to the huge decrease in retail trade, communication services, finance and insurance since the 1991 census. These decreases could be correlated to the decline in population and hence the reduced need for these services. Since 1991 Woodanilling has seen a steady increase in education workers. It is likely that the increase in the number of people employed in the education industry is due to the predominant age group of the population being 0-9 years (Figure A2.1c). An increasing number of people in the Shire of this age would inevitably lead to the need for more education staff. Also, in between the 1991 and 1996 census there was a large increase in the amount of people employed in the manufacturing industry. These figures could potentially relate to the growing need for farmers to diversify in order to remain sustainable and perhaps they are now beginning to move in to manufacturing their own produce. With respect to the property and business service industry there was a significant increase in the number of people employed between 1996 (1.6%) and 2001 (6.3%) (ABS (515059380) 2004). When comparing Woodanilling to another wheatbelt town such as Lake Grace, the statistics for employment are vastly different. Lake Grace has more diverse industries with relatively even employment statistics across most fields (due to larger population). On the other hand, Woodanilling’s industries are highly variable in terms of the number of people they employ from year to year as seen in Figure A2.3b.

![Industry in Woodanilling - Excluding Agriculture](image-url)

*Figure A2.3b. Industries of employment in Shire of Woodanilling*
In 2001 47.8% of people in the Shire were employed as managers and administrators (Figure A2.3c), a steady decrease from 57.6% in the 1991 census (ABS (515059380) 2004). With relation to the other categories this occupation employed by far the most people. This can be explained by the fact that both farmers and land managers fall under this section and thus occupy a great deal of the agricultural sector. This decline could again be attributed to rural depopulation possibly caused by farm amalgamation. Figure A2.3c shows far more males as managers and administrators than females.

There are more than twice as many female professionals in Woodanilling as males; 7.0% of people were employed as tradespersons in 2001. The number of tradespersons has continued to rise since the 1991 census when there was only 3.4% (ABS (515059380) 2004).

### 2.4 Finance

The average income for all individual taxpayers in the Shire of Woodanilling for 1999/00 was $25,910, which represents a decrease of 12.4% from 1998/99 when it was $29,566 (Figure A2.4a). This compares to the average taxable income in 1999/00 for all individual taxpayers in regional WA of $33,958 and $35,406 statewide (Department of Local Government and Regional Development, Government of Western Australia (b) 2003). Although Woodanilling’s average taxable income falls far below those at a regional or State level it would be inaccurate to make these comparisons due to the tax implications that apply to farmers in terms of significant deductions.
Figure A2.4a. Annual average taxable income over five years, Shire of Woodanilling

Figure A2.4b shows that the highest percentage of people in Woodanilling had a household income between $15,000-26,000 and $26,000-36,000. Approximately 60% of people fall in these two income brackets. Figure A2.4b shows that there is no household income exceeds $78,000.

Figure A2.4b. Annual household income, Shire of Woodanilling

(Anon 2004)
3. Climate

The climate is typical of the wheatbelt and described as Mediterranean. Essentially, it is characterised by cool moist winters and warm to hot, dry summers (Whitfield 2001). Most rainfall is received between May and August. However, summer thunderstorms often provide local rainfall (Whitfield 2001). Long-term average annual rainfall for Woodanilling for 1916 to 1999 was 464 mm. The 10 year average indicates a below-average rainfall trend since the mid-1970s (Whitfield 2001). A set of annual Katanning climate details is presented below. This is derived from the Bureau of Meteorology and is a set of long-term averages. This data is used as a comparison for Woodanilling as there are no raw data directly relating to the Shire of Woodanilling from the Bureau of Meteorology.

Table A3.1. Katanning climate averages, Bureau of Meteorology

<table>
<thead>
<tr>
<th>Mean Daily Max Temp (deg C)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.3</td>
<td>29.5</td>
<td>26.8</td>
<td>22.8</td>
<td>18.4</td>
<td>15.5</td>
<td>14.5</td>
<td>15.4</td>
<td>17.7</td>
<td>20.7</td>
<td>25.1</td>
<td>28.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Daily Min Temp (Deg C)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13.6</td>
<td>13.7</td>
<td>12.6</td>
<td>10.3</td>
<td>7.9</td>
<td>6.5</td>
<td>5.4</td>
<td>5.5</td>
<td>6.4</td>
<td>7.6</td>
<td>10</td>
<td>12.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Rainfall (mm)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13.3</td>
<td>16.2</td>
<td>22.5</td>
<td>30.2</td>
<td>60.5</td>
<td>77.2</td>
<td>76.2</td>
<td>63.6</td>
<td>47</td>
<td>35.7</td>
<td>21.5</td>
<td>16.3</td>
</tr>
</tbody>
</table>

(Bureau of Meteorology 2004)

Estimated annual class A pan evaporation for Woodanilling and Wagin is 1700 mm (De Silva et al. 2000).

4. Geology

“Woodanilling is situated in the middle of the fifth order Boyerine Creek catchment of the Blackwood River Basin” (Whitfield 2001). Granitoid rocks that contain small mafic and ultramafic remnants of dolerite and diorite underlie the catchment area. The granitoid is medium and course grained biotite granite and adamellite (Whitfield, 2001). Most of the townsie is situated on colluvium and alluvium and consists of silt, sand and gravel (Whitfield, 2001). The deposits on the slopes overlie laterite profiles of mottled and pallid, light to medium textured clays over course grained partly weathered granite, over a fresh layer of granitic bedrock (Whitfield 2001). The dolerite dykes situated in the westerly to north westerly areas of the catchment can often act as geological barriers to groundwater movement and form potentially susceptible sites for the development of groundwater salinisation to occur (De Silva et al. 2000). Specific to this management zone, at low elevations (<280 m AHD), the depth to water level ranges from 0.1 to 20 m with salinities of 100 to 46,000 mg/L. In the upper landscape (>330 m ADH), depth to water level is between 0.6 and 24 m with salinities from 90 to 10,000 mg/L (De Silva et al. 2000). It is suggested that groundwater salinity generally tends to increase in a downslope direction.

4.1 Source of groundwater

The main sources of groundwater below Woodanilling townsite include recharge and groundwater inflow from systems below the valley floor of the Boyerine Creek (Whitfield 2001). The water levels
were greater than 4 m deep below most of the Woodanilling townsite. However, there is a shallow area, less than 2 m deep at two sites along Burt Road (Whitfield 2001). Recharge within the town is substantial and can be the cause of many groundwater problems and enhanced saline environments. The implications of these issues can be seen in the figures below.

4.2 Groundwater management

A set of recommendations have been derived by the Rural Towns Program that outline options for reducing townsite recharge and hence the risk of salinity. Some of the management plans include water conservation options, the use of sewers not septic tanks, eliminate leaks from water pipes, rain water management, efficient water use methods and water harvesting and recycling (Whitfield 2001). Each option provides opportunities to reduce the recharge occurring within the townsite. Some of these management options would also have additional flow-on benefits to the Shire of Woodanilling.
5. Water prices

5.1 Rates and Charges – Country Commercial

Commercial properties are subject to a service charge and usage charges. The service charge is based on the metered water service serving the property. In 2004/05 the service charges were:

<table>
<thead>
<tr>
<th>Meter Size</th>
<th>Charge (2004/05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 mm &amp; 20 mm meter</td>
<td>$452.00</td>
</tr>
<tr>
<td>25 mm meter</td>
<td>$706.30</td>
</tr>
<tr>
<td>30 mm meter</td>
<td>$1,017.00</td>
</tr>
<tr>
<td>35 mm, 38 mm &amp; 40 mm meter</td>
<td>$1,808.00</td>
</tr>
<tr>
<td>50 mm meter</td>
<td>$2,825.00</td>
</tr>
<tr>
<td>70 mm, 75 mm &amp; 80 mm meter</td>
<td>$7,232.00</td>
</tr>
<tr>
<td>100 mm meter</td>
<td>$11,300.00</td>
</tr>
<tr>
<td>140 mm &amp; 150 mm meter</td>
<td>$25,425.00</td>
</tr>
</tbody>
</table>

In terms of usage charges the area in which you live is allocated by the Water Corporation to one of five classes on the basis of the cost of supplying water to that area. Woodanilling is allocated to class 3 and the tariffs for 2004/05 are outlined below.

Woodanilling

<table>
<thead>
<tr>
<th>Usage (kL)</th>
<th>Class 3 c/kl</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-300 kL</td>
<td>120.9</td>
</tr>
<tr>
<td>Over 300 kL</td>
<td>218.8</td>
</tr>
</tbody>
</table>

(Water Corporation (a) 2004)

5.2 Rates and Charges – Country Residential

Each residential property is subject to a service charge and usage charges. The Water Corporation issues an annual service charge for each property and in 2004/05 was $149 for each residential unit. Water usage charges are billed on a four monthly basis and increase with use to encourage the efficient use of water. As with commercial properties the area in which you live is allocated to one of five classes on the basis of the cost of providing water to that area. The Water Corporation allocates Woodanilling to class 3 and the usage charges are outlined below.

Woodanilling

<table>
<thead>
<tr>
<th>Usage (KL per year)</th>
<th>Class 4 c/kl</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 150 kl</td>
<td>41.6</td>
</tr>
<tr>
<td>Next 200 kl (350)</td>
<td>67.4</td>
</tr>
<tr>
<td>Next 100 kl (450)</td>
<td>85.7</td>
</tr>
<tr>
<td>Next 100 kl (550)</td>
<td>121.6</td>
</tr>
<tr>
<td>Next 200 kl (750)</td>
<td>144.2</td>
</tr>
<tr>
<td>Next 400 kl (1150)</td>
<td>230.6</td>
</tr>
<tr>
<td>Next 400 kl (1550)</td>
<td>349.7</td>
</tr>
<tr>
<td>Next 400 kl (1950)</td>
<td>461.2</td>
</tr>
<tr>
<td>Over 1950 kl</td>
<td>556.6</td>
</tr>
</tbody>
</table>

(Water Corporation (b) 2004)
6. Public Utilities

6.1 Water

The scheme water is supplied to Woodanilling via a comprehensive water scheme from the Harris River Dam. Quality is said to be good. However, supply needs would have to be discussed with the relevant authority if a large supply is needed. Scheme water prices in Woodanilling are less than those in Lake Grace as the Shire is allocated as a class 3 region.

6.2 Gas

Bottled gas is available from the Woodanilling store.

6.3 Waste

Woodanilling has a general refuse site and household refuse is collected every Tuesday morning. The main rubbish disposal site is situated in the western side of the townsite on Orchard Road and is restricted to residents use only. The town also offers a small drop off recycling service. The Woodanilling council has also recently installed a waste oils recycling area and green waste area (Shire of Woodanilling 2004)

6.4 Electricity

The Muja Power Station supplies Woodanilling's power. A relevant article posted on the Shire of Woodanilling’s website is outlined below.

“Council will be undertaking discussions with the state government and Western Power regarding the lack of power and/ or interrupted power supply to our district. If you have any problems with your power please report it to Pam at the shire on 9823 1506” (Shire of Woodanilling 2004).

This local problem could be interesting to look at in regards to oil mallees. Woodanilling played a role in the Western Oil Mallee Project conducted by Murdoch University. Oil mallees are widely known for their ability to combat dryland salinity due to their salt tolerance and deep roots, making them effective in lowering groundwater levels and possibly creating sustainable agriculture and rural industry development (Barton 2004). In conjunction with these environmental benefits, mallee trees have the ability to generate renewable electricity as well as activated carbon and eucalyptus oil. Yielding three products from one plant will ensure the operation remains economically viable (Chegwidden 2003).

6.5 Wagin/Woodanilling Landcare Zone

Woodanilling is part of the Wagin/Woodanilling Landcare Zone (Woodanilling Landcare project manager: Ms Sally Thomson – ph 9823 1506). Sally can be used as a contact for the surrounding agricultural community to assist with all landcare and agricultural issues. A list of common services is accessible on the website at: http://www.woodanilling.wa.gov.au/agriculture/community_landcare

An extensive range of landcare information specific to Woodanilling is available on this website. Some of the issues include groundwater monitoring, town revegetation projects, waterwise, saltwise gardening information and resource sharing of administrative personal between the Shire of Woodanilling and Broomehill. This in particular could be looked at in terms of possible industrial ventures arising from the Rural Towns - Liquid Assets project that could be beneficial to both towns. If there is already talk about resource sharing between the two towns it is likely that relations between the two communities are positive and willingness to explore new opportunities to ensure their towns sustainability may be looked upon favorably.

A list of major construction works that are taking place in the town are also displayed in the shire website. This may be useful to gain some understanding of the possible problems caused by salinity.
The Woodanilling Land Conservation District Committee is also responsible for running the waterway protection project in the Shire of Woodanilling in 2002-03. The total funding for this project equates to $69,051. The project aims to improve water quality and lower water tables in the shire of Woodanilling. It mainly involves fencing off waterways to prevent stock access and revegetation to lower water tables. Seepage interceptor banks and erosion/runoff grade banks were constructed to run fresh water away from saline water and into dams, thereby preserving fresh water supplies (Anon (3) 2004). The total length of waterway protected totalled 7 km and up to 210 ha will be protected from waterlogging. Furthermore, approximately 125 mL of water will be harvested per year into dams (Anon (3) 2003).

In terms of public education with respect to water and related issues, Woodanilling Primary School has received the seal of approval from the Water Corporation. Woodanilling Primary School participated in the Water Corporations Waterwise Schools Program that entailed schools conducting water-related activities in the classroom. The aim of the program is to educate students of the value of water as a precious resource and to realize how easy it is to save water by making simple changes to the way we do things (Water Corporation (b) 2004).
7. Post-survey review

A survey was constructed and designed to gather information from key recognized groups in the Woodanilling Shire and aimed to gain an understanding of what issues are seen as important by the local community, and of hopes and concerns for the future of the town. Individual questionnaires were designed for members of the residential and industrial population and a set of questions were allocated to the CEO of each town.

It is important to note that there was only a very small sample of the population surveyed and so the opinions described are not necessarily representative of the entire Shire’s population. It is also essential to understand that the findings documented below are in fact people’s opinions rather than facts and so some findings may be variations from the facts depending on people’s perceptions. In this section the key findings from the questionnaires completed in Woodanilling will be summarized.

When reviewing the questionnaire, its structure and its effectiveness it was clear that the question that posed the most problems to the majority of participants was the biodiversity question. The majority of participants either had to ask what the word meant or assumed that biodiversity related to diversity of businesses in the Shire. Those who I explained the meaning of the word biodiversity to mostly said that it was important to their town and that water management strategies were affecting the state of biodiversity in Woodanilling. However, I expect that this was a common response due to the fact that they were still unsure of what the word meant and felt this was the right answer to give rather than what they actually believed. For those who believed biodiversity related to the diversity of businesses in an area, most participants felt quite strongly about the importance of diversifying businesses in country areas and believed that water management strategies would effect this prospect. After conducting this survey it is clear that biodiversity is not a major issue in the Woodanilling Shire as little people actually know what it refers to and those who did believed it was unfortunately not profitable to protect biodiversity and therefore not feasible.

In many surveys discussion of water supply in Woodanilling relating to quality and quantity was quite a topical conversation. The majority of residents interviewed who lived in town generally had no issues with supply of water. Most of them had scheme water and supplemented this with rainwater in which they used to reduce their reliance on scheme water. From residents living in town some mentioned that their scheme water had never run out when they turned the tap on so they assumed supply was not an issue. Most said the quality of rainwater was fantastic and was used for drinking and all household purposes. In terms of scheme water peoples responses varied in terms of quality. However, most people said the quality of the scheme water was good but often included in their response that they had a filter on their scheme water going to the house. The comment also arose quite often that the quality of scheme water varied seasonally. Shire residents often related this to the fact that in summer the dams are low and so the salt and chemicals are more concentrated than in winter. For this reason summer time seemed to be the time when residents were most unhappy with the quality of their scheme water, but again this varies from person to person.

An important issue that the surveys revealed was that there was more concern regarding water supply and quality from the residents living on farms outside of the town compared to those living on residential blocks in the town. Many of these people surveyed did not have access to scheme water and so did display concern for their future water supplies and the sustainability of their farms. Most were more apprehensive towards future supply of water rather than quality however quality was still a major issue. It was clear when speaking to people on farms that there was a divide between two types of people and their opinions relating to water in Woodanilling. These two groups included those who had secured private water sources on their properties and those who did not either because the quality of water under their property was too saline or the water just wasn’t there. There was a definite split of opinion relating to water between these two groups. Those who had private water sources on their property of sufficient quality were not so concerned about the future of water supplies in Woodanilling. Many of the questions relating to water they were not able to answer or believed there was no problem and stated that they had never really had to consider issues like that because they have never been in a situation where quality water was lacking and probably never will be. On the other hand, those who were unable to secure private water sources or had private water sources that were very poor in quality showed more concern about the future especially in relation to sustainability. Those who had an abundance of water on their property also mentioned on numerous occasions how
they believe that what ever water is on the property that they own, they should be entitled to and
shouldn’t have to share with other people. I got the impression that rather than the future of water
supplies in Woodanilling, this was the major concern of these people that this project was not going to
aim to take their water away from them and share it between others.

When participants were asked what they would like to see any excess water being used on in the
Shire there was once again quite a divide between those who lived in the town and those who lived on
farms. Almost 100% of participants (residents, farmers and industry people) stated they would like to
see the water used for town beautification purposes. For some the reasoning behind this was purely
for personal satisfaction and lifestyle concerns, while others related better parks and gardens to
attracting more people to the town and an improved standard of living which would in turn benefit
Woodanilling. Although this response was common across town’s people, farmers and industry, the
farmers also made it clear that as well as town beautification they would like to see any excess water
stored for the future to aid in drought proofing farms. This was a very common response across most
farmers who thought storing the water in dams or other storage facilities would be a good idea
considering the future implications to the Shire relating to lack of water. Finally, there was some
suggestion that excess water may be used to make better use of the salt lakes for recreational
purposes and water sports. This suggestion was not mentioned as regularly as the other two major
uses for water but is important to recognize there are concerns in the community for this type of
initiative and the flow on benefits it may attract.

Respondents were also asked if they recycle any water within their household or business. The
responses from this question could be split into three categories, residential, industry and farmers.
Most residential people surveyed in Woodanilling stated they did recycle some of their grey water onto
the garden however none of them had a wastewater treatment or recycling device installed in their
home. When specific businesses were surveyed very few said they recycled water within the business
unless the productivity of their industry directly depended on water (farmers), examples of such
businesses include the hotel and local supermarket. At the other end of the scale farmers that were
interviewed seemed to be quite self sufficient when it comes to recycling water. Many had specific
management plans when it came to water harvesting and recycling of their water. Although the
majority of farmers were quite concerned with recycling water very few of them said they had actual
wastewater treatment facilities installed on their farms. Most mentioned that this would be highly
desirable for them to have and most made specific reference to desalination facilities but said that the
costs are too high for such systems and a substantial amount of funding would be necessary to make
this a viable option for their businesses.

The concept of the waterwise gardening initiative was introduced to those participating in the
residential questionnaire. Most respondents stated that they were aware of this initiative and
understood the reasoning behind planting plants that were better suited to drier conditions. The
majority of participants had adopted these plants as a part of their household gardens and mentioned
that every time one of their old plants died they would make sure they chose a waterwise plant to
replace it. Most did not have a whole garden made up of these plants but said that a substantial
portion of there gardens was made up of natives. Although a significant portion of the residents
interviewed were supportive of the waterwise garden initiative there was still the occasional person
who felt quite strongly about maintaining their traditional English garden and would not be adopting
any of these native plants.

Participants were also questioned about their willingness to drink recycled water. Again there was a
split in responses between people living in the town and farmers. The majority of people surveyed on
farms all had no problems with the thought of drinking recycled water. There was little questioning
about this concept, most just agreed straight away and made comments such as, when you know
what it’s like to have a lack of water you will drink anything and that many of them already drink from
their dams, which are not very clean. Most people in town also agreed that they would drink recycled
water. However, just about all of the people interviewed from the town in Woodanilling who said yes
were very apprehensive and mentioned that they would have to be assured it was safe and that there
was no decline in quality. One woman entertained the concept that perhaps she wasn’t to keen on
drinking recycled water just because the word ‘recycled’ sounds dirty. In my opinion it sounded like
many of the participants surveyed from the town said yes to this question because they thought that
was the right answer that I wanted to here, but did not really mean it. This problem is often
encountered in surveys similar to this one in which people can say they are going to do certain things,
but the question often is whether they are actually going to do them or not? Using willingness to pay (WTP) questions can usually counteract this problem. However, in this questionnaire the WTP question may not have been as effective as expected. This question could only be asked if people said no to drinking recycled water, but in most cases people said yes and may not have necessarily meant it and so the question was rarely used in the surveys. For future research I think these questions must be reviewed due to the fact that there was some confusion over the lack of specific details as to what type of recycled water they would be drinking. An answer to this question was highly dependent on people’s interpretation of the question. Some people interpreted it as drinking recycled sewerage water and there were very little people who said yes to drink this. Whereas others interpreted it as drinking recycled saline water and so were more inclined to answer yes to the question.

All people who participated in the survey were asked if they had any ideas for innovative water management and new water related industries. Some of the responses to innovative water management ideas are outlined as follows: managing eroded catchments to improve water resources and runoff, desalination was mentioned quite regularly as being highly beneficial but too expensive at the moment, pumping of underground water and feeding it to farmers, capturing surface water runoff from hard surfaces in the town, installing more rain water tanks in homes, groundwater that doesn’t get used and goes to waste and the promotion of water reuse in the town as this is not being done very effectively at the moment. The main response to this question was centered around the concept of water harvesting and was mentioned in many different forms. In terms of new water-related industries, suggestions included, aquaculture (trout/yabbie farming), which was the most popular of responses, nurseries, viticulture/olives (some people in the community are already interested in expanding this industry), solar technology and reusable energy and growing and hydroponics industries.

After this question the participants were given a list of water related industries and asked to identify whether or not they would like them introduced into the Shire. Most people were happy for any industry to open up because this would bring more people to Woodanilling and expand the Shire. However, there were some industries that were preferred more than others. A common response that seemed to come up with many respondents when suggesting some industries, was that the extreme temperatures and lack of rainfall wouldn’t permit many to be viable business options and so they would not like them to be opened up in Woodanilling. As mentioned, most people were happy to introduce any new industries that would bring people and money into the Shire but there were some common concerns about certain industries that did arise. It is important to remember that because such a small amount of the Shire’s population was interviewed we cannot take these concerns to be a representation of the entire population. Such concerns included the fact that wineries, floriculture, horticulture and tree farms may be affected from the chemicals from the farms and are often not compatible with broad acre farming techniques and chemicals. It was also suggested by one person that from a marketing point of view it might not be the right region for wineries and vineyards. Only 1 or 2 scattered wineries are not enough for it to become a tourism attraction. There is lots of competition in this industry which is reflected on profitability and their needs to be a large skill base for this type of thing that does currently not exist in Woodanilling. It was pointed out that some people in the Shire have put in some pine plantations and sandalwood. One person felt there may be some danger in expanding tree farms with people deciding to put trees on the whole farm and families move to the coast. This will then increase rural depopulation and this will have social implications. However, if this process was combined with traditional farming as a part of the diversifications of farms this can only bring positive benefits. This could also aid in making farms drought tolerant and relying on the trees as a source of income in the bad years. Farmers often had a common response to the notion of expanding tree farms in the area. Many believed that by introducing more tree farms this would degrade good farming land. This comment was only prevalent among farmers. In terms of expanding the town’s recreational facilities many people were against this, as they believed Woodanilling already has good recreational facilities, they just need to be maintained. Most people reacted positively to the introduction of intensive animal industries but a few people mentioned that they would not be happy if they were close to the townsite. The expansion of eco-tourism in Woodanilling was quite divided in terms of people’s opinions. The suggestion of focusing on agricultural tourism rather than natural heritage was made and it was felt that this might be more suitable to the area. The introduction of salt tolerant plant industries was the most encouraged industry by all participants, followed by aquaculture. One comment was made regarding inland salt water aquaculture that the advantages of having it in the Wheatbelt rather than on the highly populated coastal areas was that there was less backlash from environmentalists so competition might not be such an issue.
Most people interviewed in Woodanilling agreed that an increase of population could be supported as long as the increase was gradual rather than a large sudden influx. It was regularly mentioned that the amount of housing would need to increase in order for this to be possible but the land is available to be built on. With reference to transport it was also mentioned that the roads around Woodanilling are of a very high standard in comparison to those in the South West. Woodanilling has access to the Great Southern Highway, Albany Highway and the railway line. There is also a port in Albany that is relatively close.

Finally, all participants were asked if they see salinity as a problem in the town. Most residents from the town who participated believed there was no problem with salinity in the townsite. Those who said there was a salt problem in the town mentioned that they could not visually see any problems but had been told by someone that there was salt in the water. Quite a different response was presented from farmers who were interviewed. Most farmers thought there were salinity problems in the town and were also aware of the rising groundwater problems in the town. Other people who believed salinity was a major problem in the townsite were those who lived close to the creek that runs through Woodanilling. This creek is renowned for its high salt content. Those who lived close to this creek associated problems in the creek with problems in the town and were quite concerned.

In terms of specific findings it was discovered that the Woodanilling Primary School had increased its numbers from 12 to 30 children over the past three years. This may reflect the increasingly large number of younger people in the community aged between 25 and 40, which was presented in the demographics section of the report. This would without doubt contribute to the social nature and vibrancy of the community and it is my opinion that this is definitely evident throughout the Shire.

When interviewing various people throughout Woodanilling it became overwhelming the amount of people who wanted to add comments at the end of the survey regarding how happy they were to live in the town and how it was such a great place to live. This type of response was non-existent when speaking to people in the other towns. I also had a similar response when talking to someone in Yealering. There was a definite community vibrancy associated with these two small rural towns and so there may be some advantages that come with this such as ease of education and willingness to adapt to change, which is often a large hurdle for country towns.

Community vibrancy was also evident when asking Sally Thomson (Landcare officer) about community initiatives to keep people in the Shire. The other two towns had mentioned little in the way of initiatives to combat rural depopulation however Woodanilling was the opposite. At a local level it was mentioned that there are always events that are developed to instill a sense of community and show where the town has come from and where they are headed. Although these are not large scale events they enable the community to come together and unite. The town has promoted local events such as the 100 year reunion for establishment of school, creating there own number plates and local government banners to hang up in St Georges Terrace. The Shire’s long-term vision was stated as to ‘maintain a connected vibrant community that is affordable and comfortable’. Woodanilling also has a Tidy Towns Committee; they do little projects rather than have a strategic direction. This committee offers residents the potential to direct their interests into actions in the community.

With respect to tourism the major focus for Woodanilling is to continue to promote themselves as being a part of the Hidden Treasures of the Great Southern project. This is essentially rural agricultural tourism. Indirectly the project is related to water because it is related to diversification and finding a niche industry. Sally mentioned that water would help create this diversification.
8. Conclusions & recommendations

After completing the desktop study for Woodanilling it was evident that the Shire’s demographic profile was consistent with that of a traditional Western Australian rural town. Population is steadily declining and much of the community and local businesses are dependent on the success of the surrounding agricultural industry. After conducting surveys in the town it became evident that residents were keen to diversify and reduce their reliance on the success of the agricultural industry. This was reflected in the survey when participants responded positively to the suggestion of the introduction of a number of water related industries to the Shire. It was generally felt that the introduction of any industry would bring positive flow on benefits to the Shire’s economic state. Woodanilling in particular, due to its small population, is susceptible to rural depopulation and so it was discovered that many community members are keen to take actions that will ensure the Shire remains sustainable. The questionnaires revealed that water was a prominent concern in the Shire. However there was a clear divide between those people who received scheme water (majority of the town and some farms) and those who had to secure their own water source. It was clear that the later were more proactive in their outlook towards water management strategies and had some good suggestions relating to facing the problems associated with future water supplies. In Woodanilling it was clear that salinity was not a major issue in the townsite. Although it was affecting the profitability of the agricultural industry it was perceived that the state of the townsite itself was not under threat. After considering all of the information gathered from the desktop study and the perceptions gathered from the surveys, a set of recommendations for the Shire of Woodanilling is outlined below:

1. Revisit Woodanilling:

   It is suggested that a deeper study is done on Woodanilling to gain a more accurate picture of people’s expectations and perceptions regarding water in the Shire. It is proposed that a greater number of people be surveyed to ensure an even spread of the population when collating data. Consideration should also be taken into designing questions that are more suited to statistical analysis if time permits.

2. Determine each town’s expectations for the RT-LA project:

   It is of vital importance to ensure project team members are aware of the expectations of the council and community in relations to the outcomes they expect the project to deliver. We need to be conscious of these expectations to ensure each town is going to be happy with the final outcome.

3. Community education and communication:

   More communication is required in regards to the actual project objectives and aims. Many participants from the survey who were aware of the RT-LA project made mention of the fact that water was going to be pumped from under the townsite and that this water should be used to start more industries. I think it is important to make people aware that this is only a possibility and that not all towns will be pumping groundwater. Education is also required to inform people of the differences between rising groundwater problems and salt being in the water.

4. Further investigation into new water-related industries:

   More research needs to be done into the viability and sustainability of many water-related industries. There is no point suggesting particular industries to residents if we are unsure as to whether they would work in the Shire.
9. List of additional documents

#1 – Methodology for telephone interviews

#2 – Protocol for phone survey

#3 – Final copy of the Woodanilling questionnaire

#4 – Information that was not determined in this preliminary study

#5 – Woodanilling Shire Contacts

#6 – Completed Woodanilling CEO questions

#7 – Completed Woodanilling residential questions

#8 – Completed Woodanilling industrial questions

#9 – Appointment table

Some of the documents listed above are confidential, so if required, contact Dr Jo Pluske at the University of Western Australia.
10. References


3. Department of Local Government and Regional Development, Government of Western Australia (b) (2003), Regional Trends and Indicators, Shire of Woodanilling [online][Available at:] http://www.dlgrd.wa.gov.au/statisticInfo/regionTrendsIndicators.asp


APPENDIX B

WORKSHOP OUTCOMES, WOODANILLING SHIRE - 30/6/2005

PRIORITIES AND PREFERENCES:

1. Provide a secure water supply in the town dam including an adequate reserve (Target = dam is 50% full by each autumn).

2. Produce a Benefit-Cost Analysis (BCA), of various feasible stormwater management options utilising sump/pump technology. Road and roadside drainage strategies are to be incorporated in these management options.

ISSUES:

- Value for money - $15,000 of on-ground work out of a total $117,000 in investigations was questioned by the Shire. Total on-ground work expenditure is more likely to be between $15,000 and $30,000 (M. Pridham).
- If technically feasible, the proposed town dam overflow, waterway and eastern outlet scheme is to be given priority.
- Currently the provisions made for safe overflow are inadequate, particularly if another 100 mm overnight rainfall was experienced on a full dam.
- T. Cattlin and KBR to check levels, soils, ground cover parameters, and to calculate new versus existing culvert design specifications.
- Dam and catchment dynamics to be monitored in the medium term by DAWA as part of the performance evaluation.
- Existing catchment improvements feature a diversion bank to direct additional natural catchment into the dam. As it is not possible to return the diverted portion of runoff after it overflows the dam to a point where it would have normally left the property boundary, this arrangement discharges extra water onto neighbouring properties. This scheme could constitute an illegal diversion.
- A severe crack in the back wall of the dam developed after the first fill in early 2005. Even though the crack has largely closed up, subsidence and seepage through the back wall is still a possibility and will be monitored by DAWA.
- Although it filled and overflowed in 2005, the dam received little or no inflow for the first two years following construction. The reliability of this dam has to be improved dramatically in order to achieve the objective stated above.
- Economics of stormwater/seepage proposals for the townsite will determine if they provide a viable alternative water supply scheme. Ideally, they should produce some waterlogging control benefits as well.
- A new Rural Residential (2 ha) subdivision is proposed for north of town and around the golf course.
- Saline groundwater from around the town may provide future supplies if desalinated. However, high salt concentrations (>30,000 mg/L), are likely to rule it out as an option.
- Small traces of bacteria were found in one groundwater sample collected in late 2004. Possibly due to contamination from septic systems, this needs to be verified with further sampling.
• Modelled stormwater yields greatly exceed current demand. However, the modelled figures don’t fit with observations and intuition.
• There are potential flooding and salinity problems in the Jam Hill rural residential subdivision in the NW area of the townsite.

SUMMARY OF RT-LA MEETING WITH WOODANILLING SHIRE, 16 November 2005
(Mark Pridham notes)

Present: Russell Thomson (Shire Pres), Wayne Cooper (Works Manager), Cr. Trevor Young, Cr. Dale Douglas, Sally Thomson (CLC), Greg Dunn, Jeff Turner (RT-LA, CSIRO), Travis Cattlin (RT-LA, DAWA), Mark Pridham (RT-LA, DAWA).

Proposed Works

The Shire was most concerned about the lack of a safe overflow and seepage losses from the sportsground dam.

1. Modifications to the inflow and provision of a safe overflow system were priorities

ACTION: RT-LA project to provide two design options (east into Wise’s paddock and west into Garstone’s paddock) before December 23rd 2005.

ACTION: The Shire to organise and lead the discussions at meetings with the two landholders where the waterway/overflow options will be presented. Benefits to the landholders, including additional water supplies and waterlogging control, were to be pointed out.

2. Townsite waterlogging control and stormwater harvesting scheme

To be achieved with drainage improvements:
• Yairabin Street drain only required if additional water was to be harvested from that part of town flowing west and south. It was stated by the Shire that this additional water would not be required.
• The Burt Road drainage upgrade was needed.
• The collection sump was still needed but due to the shallow saline watertable, there were difficulties in locating it adjacent to the main creekline. Two possible locations for the sump were discussed.

ACTION: The Shire to re-examine sump location. RT-LA team to assist with technical innovations e.g. using a membrane to line the sump.

3. Waste water

The option for collection of waste water from leach drains was raised.

ACTION: J. Turner to provide some figures and possibilities for waste water utilisation.

WATER BALANCE

DEMAND
14.4 ML/yr was currently used on the sportsground. This was inadequate.
For maximum efficiency, 16.1 ML / yr is needed (18 mm per week for 7 months, irrigating 2.5 ha)
16.1 ML/yr
SUPPLY
Sports dam (modelled, previous 10 years): 4.8 ML/yr

DEFICIENCY: 11.3 ML/yr

Some examples were shown of how DAMCAT could be used for optimising dams and catchment areas and for using various combinations of dam size and roaded catchment were shown.

ACTION:
T. Cattlin to provide some DAMCAT simulations for the sports dam.

Costs

Costs provided in the consultant’s draft WMP were unacceptable. For example, Option 2a was quoted as $343,000 and Option 2b as $674,000.

The meeting agreed on what realistic costs might apply. Revised costs were transcribed directly into a version of the WMP.

Summary of revised costs

**Priority 1**
Upgrade town dam and 5 ha of catchment: $99,000 (giving an 80% reliability factor)
Plus land purchase.

OR
Upgrade town dam and 15 ha catchment: $127,000 (giving an 94% reliability factor)
Plus land purchase.

Annual operating and maintenance $6,000

**Priority 2**
Sump and pump to existing dam: $55,850
Annual operating and maintenance $10,000

This scheme provides an additional 27 ML/yr (4 ML dam + 23 ML town run-off).

**Priority 3**
Sump and pump to new dam: $100,700
Annual operating and maintenance: $ 6,650
Appendix C

Surface Water

Travis Cattlin and Craig Turton
Department of Agriculture

July 2005
1. Introduction

This report covers surface water and the associated processes. It describes any surface water problems (causes) and their associated management (treatment). Water management priorities and objectives introduced under the project are designed to investigate townsite salinity, develop water resources for sustainable water use throughout town and promote new water use options. The study area encompasses the townsite and the catchment area above and below town. A drilling project conducted throughout the town landscape under the Rural Town 1 and 2 project banner previously defined the groundwater status, salinity risk, groundwater modelling, flood risk analysis and introduced an ongoing monitoring program. This report will introduce surface water assessment and management to support an entire town water balance and ultimately a town water resources management plan.

2. Background

Woodanilling Shire has been involved in the Rural Towns Program since 2001. This report focuses on surface water processes and interactions (research) that will identify salinity management options and develop sustainable water resources (management).

Woodanilling is located approximately 230 km south-east of Perth and 25 km north of Katanning. It has a population of 110 residents.

3. Surface Water Processes (Research)

Surface water processes encompass two aspects: run-off and subsurface flow component. Run-off is derived from soil infiltration excess or soil saturation excess. Once rainfall falls upon the soil surface a proportion is infiltrated into the soil and the remainder is attributed to run-off. Run-off can distribute across the landscape from metres to tens of metres. Once run-off enters valley landscapes it becomes stream flow.

Subsurface flow is the portion of rainfall that infiltrated into the soil profile. If the soil profile has sufficient conductivity (porosity) and connectivity (permeability) that is water can move through the soil, and slope water will move downslope until a change in soil type or characteristic occurs. This is usually associated with the break of slope where the conductive topsoil is removed and a less conductive soil emerges (Figure B3.1). At this point water will seep causing some form of land degradation (waterlogging or salinity).
Run-off and stream flow can degrade the landscape if redistribution is not sufficiently controlled and any excess removed safely. Overland flow can become saline through two processes: accumulation of salt by passing over degraded saline soils or once inundated the water infiltrates into the soil and under capillary and evaporative pressure exfiltrates causing the remobilisation of salt towards the ground surface. Over time the soil and water resources become increasingly more saline.

Woodanilling has both surface and subsurface run-off processes to manage. The reason for this will be explained in the next section of this report.

### 3.1 Catchment analysis

Woodanilling is located in the medium rainfall district with average rainfall of 450 mm. The townsite is located on the upper to mid-slopes in the upper tributary valley of the Boyerine Creek. Boyerine Creek discharges into the Norring Lakes of the Coblinine River system. In essence this is where most of the discharge would remain. However, flow continues downstream into the Beaufort River to the Arthur River and finally into the Blackwood River. This landscape location dictates the surface water process.
3.1.1 Landform

Woodanilling townsite is located on the mid to lower slopes. The geomorphic features are gradational and both eroded and aggraded (McDonald 1984). This means the surface has the most opportunity to erode and deposit under run-off conditions. This gradational feature is exaggerated by the presence of impervious surfaces around town. Impervious surfaces are any hard surfaces that will generate run-off in low rainfall volumes include surfaces like roads, curbing and roof tops. With the landscape having gently inclined slopes (1°-2° or 1-3%, Figures 2 and 3) water generation is rapid and erosive velocities produced causing eroded surfaces. These factors require management to limit erosive potential.

Subsurface flow potential exists due to the combination of slope and valley interaction converging on a soil type change. Topographic process and soil type does move water through the profile to cause damage. Management of this process is important particularly for sewerage disposal (leach drains ineffective due to waterlogging).

![Figure C3.2. Slope showing gentle slopes and flat valleys](image-url)
Figure C3.3. 2 m contours showing defining landform descriptions

Figure C3.4. Topography with spot heights
The surrounding catchment landforms (Figure C3.3) are inclined to gently inclined slopes that have erosional surfaces. Streams are of a tributary form with convergent behaviour (McDonald 1984). That is the streams have incised and hilly landform that converge to form a dendritic or tree like pattern. Water discharge from these landforms is efficient because there is slope and tributary form. The stream channels are erosional to alluvial with a shallow cross section. They are shallow and wide with evidence of erosion and deposition. This evidence suggests the landscape requires a velocity control in management as with the townsite. Soils attributed to these landform descriptors will be described in the section.

3.1.2 Soil-landscapes

The soil-landscape mapping produced by the Department of Agriculture at a scale of 1:100,000 was completed in 1995. These soil-landscape units are shown in Figure C3.5 and described in Table C3.2. Table C3.2 comprises units that are encountered within the catchment above the townsite. Management options throughout the catchment would aim at securing sites for new dams if they were required. Clays at depth greater than the soil-landscape unit description would be defined through dam siting drilling practices.

The soil-landscape units from ridge to ridge within the townscape have been mentioned above but play a role in describing the hydrological process. The soils on the valleys comprise deep grey sandy duplex grading upslope to grey sandy duplexes to gravelly soils at the ridge. These configurations tend toward subsurface seepage with run-off as a secondary process, although the run-off volumes would be much greater than seepage volumes. Run-off is therefore as important a management option as seepage control.

<table>
<thead>
<tr>
<th>MAPPING UNIT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>257Be_1</td>
<td>Broad flats (1.5-6 km wide) along the Beaufort and Hillman Rivers with grey deep and shallow duplex soils (mainly with mottled, grey sodic subsoils) and areas of saline wet soils and alkaline grey shallow sandy duplex common.</td>
</tr>
<tr>
<td>257Ca_1</td>
<td>Gravelly soils capping hill crests and upper slopes in the Carrolup system.</td>
</tr>
<tr>
<td>257Ca_1s</td>
<td>Areas of pale deep sands on upper slopes associated with gravels in the Carrolup system.</td>
</tr>
<tr>
<td>257Ca_2</td>
<td>Grey sandy duplex soils on slopes, hill crests and less commonly minor drainage lines, within the Carrolup system.</td>
</tr>
<tr>
<td>257Ca_3</td>
<td>Low hills and rises in the Carrolup system with sandy and loamy soils formed on shallow weathered granite and dolerite and small areas of rock outcrop.</td>
</tr>
<tr>
<td>257Ca_4</td>
<td>Grey sandy duplex soils and some sandy gravels located on footslopes and lower slopes within the Carrolup system.</td>
</tr>
<tr>
<td>257Ca_5</td>
<td>Drainage lines and valley flats which are 100-300 m wide with mainly saline wet soils. Also includes some lower slopes.</td>
</tr>
<tr>
<td>257Ca_6</td>
<td>Broad valley flats and narrow alluvial plains, Carlecatup and Gordon Rivers. The flats are 300 to 1500 m wide. Soils are mainly grey deep and shallow sandy duplex soils. Brown deep sands occur in small dunes along the river.</td>
</tr>
<tr>
<td>257Ca_7</td>
<td>Dunes along the Carlecatup and Gordon Rivers with mainly brown deep sands derived from wind blown river deposits.</td>
</tr>
<tr>
<td>MAPPING UNIT</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>257De_2</td>
<td>Hillslopes and hillcrests with mainly grey deep sandy duplex soils and significant areas of grey shallow sandy duplex and moderately deep sandy gravels.</td>
</tr>
<tr>
<td>257De_4</td>
<td>Grey deep sandy duplex soils on foot slopes and lower slopes.</td>
</tr>
<tr>
<td>257De_8</td>
<td>Rocky rises and low hills, with deep sandy duplex soils capped with duplex sandy gravels.</td>
</tr>
<tr>
<td>257No_1</td>
<td>Broad valley flats bordering the lakes, with the Norring system. Soils are mainly grey loams with calcareous subsoils at depth with alkaline grey shallow sandy duplexes and saline wet soils.</td>
</tr>
<tr>
<td>257No_2</td>
<td>Saline broad valley flats with mainly saline loams and clays bordering and between lakes in the Norring system.</td>
</tr>
<tr>
<td>257No_3</td>
<td>Salt lakes and swamps in the Norring system and adjacent areas of saline flats and small lunettes and dunes.</td>
</tr>
<tr>
<td>257No_4</td>
<td>Gently undulating lunettes and dunes adjacent to the lakes and swamps of the Norring system, generally on the eastern and south-eastern sides.</td>
</tr>
<tr>
<td>257No_5</td>
<td>Sand plain east of the lakes of Norring system with grey deep sandy duplex soils and pale deep sands.</td>
</tr>
<tr>
<td>257No_5s</td>
<td>Small areas of deeper sands on the sand plain subsystem within the Norring system. Mainly bleached/pale deep sands or grey deep sandy duplex soils.</td>
</tr>
<tr>
<td>259Ek_1</td>
<td>Gravelly crests and mid to upper slopes. Mainly deep sandy gravels and shallow gravels with minor areas of duplex sandy gravels, loamy gravels and gravelly pale deep sands.</td>
</tr>
<tr>
<td>259Ek_2</td>
<td>Lower to upper slopes and broad hill crests with grey shallow and deep sandy duplex soils, alkaline grey shallow sandy duplex soils and duplex sandy gravels.</td>
</tr>
</tbody>
</table>

*Figure C3.5. Soil-landscape mapping units*
3.2 Hydrological assessment

The hydrological process, as described in earlier sections, depends largely on topographic slope and soil type (infiltration process). This assumption can describe sufficiently how water distributes across the landscape, where the water discharges, where run-off is derived and how, where recharge potential exists and what are the salinisation consequence and process. Each of these questions will be addressed in the following sections.

3.2.1 Water redistribution

Considering the upper landscape position of the greater Woodanilling townsite a large proportion of the run-off water will be derived from the impervious surfaces throughout town. Water will accumulate in the curbing or table drains and discharge downslope toward the railway line. Water is collected in a small ditch, conveyed northward and discharged behind the CBH installation. The water that can be conveyed (without being infiltrated or inundated due to poor drainage) through the sheoak woodland, makes its way into the Boyerine Creek.

Subsurface water discharge anecdotally seeps at the break of slope which coincides with the Public Bar and Burt Road (Figure C3.6). This water infiltrates into the sandy and gravelly soils in the upper landscape and is topographically driven downslope (Figure C3.1). This water causes issues with the septic tank drainage and eventually waterlogging and is some cases salinity.

Figure C3.6. Break of slope defined from anecdotal and contour interval
3.2.2 Recharge process

Recharge processes are synonymous with infiltration and water distribution. Woodanilling has soils prone to high infiltration therefore have a probability of deeper percolation of water and recharge, although this may not be the case if the underlying clays are impervious and the watertable is greater than 10 m deep (this is the case in Woodanilling the watertable is varying from 1 m in the valley complex to greater than 11 m in the upper landscape).

The water distribution process dictates where recharge occurs. If the water is inundating areas or flooding areas in-situ recharge is occurring. At the seepage face water is saturation the profile and deep percolation is adding water to the groundwater system although not enough at Woodanilling to cause a groundwater or salinity problem.

Hydrographs trends of the watertable have identical inflection points for both deep and shallow bores. The fluctuations in water level seasonally reflect rainfall patterns and longer term trends are flat suggesting the system is at or close to equilibrium. Therefore fluctuations result from vertical movement of water rather than horizontal pressure changes (flows). This supports the recharge and degradation processes mentioned above.

Fluctuations in watertable level below or around the break of slope are large compared to drier landscapes east of Woodanilling. This could be attributed to seepage water, stormwater discharge and rainfall volumes.

3.2.3 Salinity risk assessment

This report will cover the salinity risk only from run-off and seepage process not groundwater rise impacts. Again salinity risk is driven by hydrological process as described above. Water redistribution and eventual inundation onto soils prone to salinity risk will degrade the landscape.

Land Monitor data presented in Figure C3.7 represent areas of the landscape at risk to salinity development. The red, orange and yellow colourings indicate areas where degradation is in existence. The purple/blue colouring represents a degradation risk and clearly maps the valley floor and outlines the areas where soils are at risk to salinisation.
Figure C3.7. Land Monitor salinity risk mapping

Soil-landscape units that have been mapped as having a low risk to salinisation are presented in Figure C3.8. Conversely soils that have been mapped as having a high risk of salinisation are shown in Figure C3.9. The soils in Figure C3.8 are clearly above the break of slope and into the upper reaches of the catchment. Salinisation of these soils will rarely occur under uninterrupted surface water movement.
Figure C3.8. Soil-landscapes mapped as low risk of salinisation
Figure C3.9. Soil-landscapes mapped as having high risk of salinisation

Water distribution throughout the town and catchment if not managed and allowed to inundate particularly on areas below the break of slope have the ability to degrade the landscape. Management of salinity is paramount in delivering surface water effectively into the main Boyerine Creek for safe disposal. If Boyerine Creek has poor drainage then this also requires attention. The development of fresh to brackish water resources will be achieved above the break of slope and saline below. For the purpose of the next section water resources will be developed for irrigation therefore will be of a fresh water quality.
4 Water Management Plan (Management)

The research sections have given a sound insight into where to find suitable fresh water resources and manage salinity. This section outlines the currently available resources, evaluates their effectiveness and describes appropriate resource and salinity management options.

4.1 Town water resources

This section describes the existing water resources for townsite irrigation.

4.1.1 Current water storages

Woodanilling’s currently available water resources for irrigation are:
- Sports oval – 40,000 cubic metres
- Sports oval tanks – 44,000 litres.

4.1.2 Storage and deficiencies

The engineering project team formed through consultants Kellogg, Brown and Root Pty Ltd (KBR) will formulate the reliability of the sports oval dam and evaluate the management options described in the next section.

Water Corporation data shown in Table C4.1 indicates the deficiencies that have been recorded in the townsite.

Table C4.1. Water Corporation demand estimates for Woodanilling

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>Total Consumption Requested Period (kL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003</td>
</tr>
<tr>
<td>RESIDENTIAL</td>
<td>16,544</td>
</tr>
<tr>
<td>COMMERCIAL</td>
<td>5,250</td>
</tr>
<tr>
<td>OTHER</td>
<td>1,571</td>
</tr>
<tr>
<td>FARMLAND</td>
<td>454</td>
</tr>
<tr>
<td>VACANT LAND</td>
<td>418</td>
</tr>
</tbody>
</table>

This indicates that up to 2,000 kL is being used for townsite irrigation. This would be added to the stored water volume in the dam that will act as the demand estimate. The data used in this case is from the ‘other’ and ‘vacant land’ categories.

4.2 Water resource development

Water resources require development because the Shire is using Water Corporation scheme water to irrigate sporting facilities, parks and gardens. The aim of this project is to make irrigation water sustainable and develop water resources for new industries. The following options will develop this sustainable irrigation scenario.
4.2.1 Sports Dam

This is the primary water supply dam for irrigation of the town’s ovals and parklands. KBR will conduct a storage, demand and deficiency quantification to examine what needs to be explored to make the dam reliable. If the dam has about 6 m of water at the end of spring, it will last the summer irrigation period. The parameters used are:

- 30,000 cubic metres
- 18-22 mm per week summer (September–May)
- 2 hectares
- sprinkler timing needs quantification for pump and pipe specifications
- cost per annum $11,000 or 8000–9000 m³.

Once the demand storage and deficiency scenario is analysed the management options will be better quantified. They could be a combination of:

- Enlarge roaded catchment
- Enlarge dam
- Threshold treatment of roaded catchment
  - maintain surface
  - add treatment such as polymer sealant
- Dam and catchment are fine

The water supply dam primarily for irrigating the sports oval experienced (May 2005) a large volume and short duration storm that produced large volumes of run-off. Due to some design faults the dam filled above critical spill levels resulting in:

- A spillway dug to empty dam below a design freeboard
- The dozer built bank breached to again drain dam to below a designed freeboard
- Large and deep cracks appeared in the back wall suggesting the structure is unstable
- Seepage at the toe of the back wall suggesting saturation and poor wall design.

These faults that caused the design to begin to fail should be corrected before any catchment improvement work to increase the reliability and overflow works begin. The catchment improvement works consist of and are dependent on KBR simulations for storage and demand.

- Increase the size of the existing roaded catchment
- Construct another roaded catchment to increase surface area
- Construct an overflow structure to safely discharge water into the natural waterway systems (Figure C4.2)
- Reduce the size of the dozer-built bank
- Reverse the gradient on the dozer built bank to discharge water into the small farm dams (Figure C4.3).
Figure C4.1. Schematic of sports dam structures and dimensions
Option 1: Overflow waterway down existing depression

Option 2: Cross slope waterway into farm dam and waterway constructed into existing depression.

Figure C4.2. Dam overflow options
4.2.2 Construct new dam

Build a new dam in the area, if dam site testing is successful, outlined in Figure C4.4. This dam would be supplied through townsite stormwater harvesting or, if not reliable, a roaded catchment. The storage size would depend on the engineering specification provided by KBR.
4.2.3 Harvest stormwater in sump and pump

Harvest stormwater into a lined impermeable sump and pump into the new dam or new tanks (Figure C4.4). Any overflow will enter the Boyerine Creek system. Size and design will be supplied by KBR.

4.2.4 Harvest seepage water in sump and pump from option 4.2.3

Depending on the water quality harvest seepage water into the sump and pump to the new dam or new tanks. If the water quality is poor convey the water into Boyerine Creek. This option for disposal will be covered in the salinity management section.

Install two large storage tanks

Install large tanks above existing tanks to improve irrigation storage (Figure C4.4). The size will be determined by KBR.
4.3 **Salinity management**

The second management options are to prevent damage caused by salinity. These options will manage the causal process to abate symptoms.

4.3.1 **Surface water management to remove excess water**

Install subsurface drainage systems above the break of slope with the following scenarios:
1. Herring bone design from top to bottom
2. Two or three strategic subsurface water drains
3. One large break of slope subsurface water drain.

These options would connect into a main conveyance structure for storage (4.2.4) or disposal.

4.3.2 **Waterwise initiatives – tanks, natives, watering regimes**

Waterwise initiatives are a spin-off from the Rural Towns Program and brochures are available to explain details.

4.3.3 **Stormwater management – overflow into curbing, grates etc**

Considering most of the water generated throughout the town catchment is from impervious surfaces run-off will be termed stormwater management. Construct curbing, table drains or grate systems to control stormwater run-off. Run-off should be directed into the Boyerine Creek or the sump and pump option for reuse. Inundation of run-off water below the break of slope will cause in-situ recharge conditions allowing the opportunity for groundwater rise and salinity. Existing stormwater drainage has been undertaken by the shire although the small drain below the break of slope requires redesign (Figure C4.5).

4.3.4 **Boyerine Creek management**

Boyerine Creek drains all water away from the Woodanilling townsite. If the waterway is not well defined and there are backwater effects the channel requires definition. This definition will improve the hydraulic efficiency and contain 1:10 year run-off flows within the channel. This will improve overall flow continuity and is possibly a longer term management option (5-10 years).
5. Conclusions

The Shire of Woodanilling has been very forthcoming in the decision-making process as to what water resource options will benefit the community from a practical and economically viable viewpoint. Water resources used for irrigation of the town parks and recreation ovals are depleted in most average rainfall summers. This tendency toward depletion signifies a reliance on the reticulated water supply. It is imperative to prioritise actions that will develop sustainable water resources. The priority list is:

Town sports dam – construct overflow structure
- Construct a new graded bank to increase reliability
- Construct an overflow for existing dam and new dam
- Monitor dam batter wall for future failure and leakage.

Sump and Pump operation – Construct a sump and pump operation
- Construct new dam to store new resource.
- Salinity and flooding response – this is a low priority for the Shire and community but a subsurface drainage system designed to intercept subsoil moisture and discharged into the Boyerine Creek.

These initiatives will be above the proposed project budget and funding will need to be sought from other sources.
Appendix D

Woodanilling Geophysics Report

Brett Harris and Paul Wilkes
CRC LEME

7 July 2005

SUMMARY........................................................................................................ ................................... D2
1 INTRODUCTION AND BACKGROUND................................................................................. D2
2 OBJECTIVES...........................................................................................................................D2
3 CRITERIA FOR ACHIEVING OBJECTIVES...........................................................................D2
4 APPLICATION OF TEM AND GRAVITY METHODS............................................................. D2
5 PRESENTATION AND INTERPRETATION OF DATA...........................................................D3
  5.1 Locality and data............................................................................................................... D3
  5.2 Gravity images.................................................................................................................. .... D3
  5.3 TEM images...................................................................................................................... .... D6
  5.4 Composite interpretation................................................................................................. .... D10
6 MAJOR FINDINGS................................................................................................................D14
7 REFERENCES:......................................................................................................................D12

Attachment 1: Contour maps of Bouguer gravity and digital elevation data for Woodanilling ....... D12
Summary
Non-invasive small scale time domain electromagnetic (TEM) and gravity surveys were completed at Woodanilling. The objectives were to determine basement geometry and solute distribution along specifically located transects beneath and close to the town.

A major inset valley was located with the TEM method 500 m west of the townsite. The inset valley is not more than 45 m deep. Solute concentration in the valley increases with depth to be saline to hypersaline water in its base. A large fault structure is identified in gravity data and coincides with break of slope several hundred metres to the east. The location of the inset valleys, several possible basement lows and a major structure are provided in a series of images.

1 Introduction and background
It is important to understand the underlying geology of rural towns and especially the geometry of the underlying basement rocks and the regolith material that lies between bedrock and ground surface. This information is also important in understanding the hydrogeology of the towns.

Geophysics has been used to provide information on the underlying geology. Geophysical methods used were gravity and time domain electromagnetics as these are convenient to do in an urban environment and provide complementary information. Further detail on the application of these methods at Woodanilling is provided in Section 4.

2 Objectives
There were three primary objectives for the geophysical work at Woodanilling:
1. To determine the interface geometry between crystalline basement rock (hard rock) and overlying sediments
2. To locate and delineate any ancient inset valley west of the townsite
3. To establish the basic solute distribution on a specific transect near Woodanilling
4. To identify any major structures near to Woodanilling townsite.
This information is required to assess quality and potential yields of any subsurface water resources.

3 Criteria for achieving objectives
The criteria for meeting the above objectives were that the geophysical surveys should be rapid, low cost and non-invasive.

To achieve this, an east-west gravity profile and TEM profile were completed. The gravity method was used to rapidly determine gross basement geometry and the TEM method was used to determine solute distribution (salinity), the location of the main inset valley and general basement geometry.

4 Application of TEM and gravity methods
The gravity method measures variations in gravity due to density contrasts in the earth and using high accuracy (about 1 part in 100 million) we can map detail in the underlying geology. The strength of the earth’s gravity field is approximately 980,000 mgals. A gal is an acceleration of 1 cm/sec/sec. Bouguer gravity is the name given to measurements after correction for all non-geological components of the field.

Gravity measurements are made with accurate GPS survey to accuracy better than 5 cm in easting, northing and height above sea level. The resulting digital elevation data is useful in its own right and adds to the known survey data in the towns.

Haines Surveys measured 121 gravity stations in October 2004 under contract to CRC LEME. The stations were on an east-west line with 25 m spacing. Each measurement takes about 3 minutes. Further detail on the logistics and survey operations are available in the Haines Surveys report listed in the References. Contour maps of Bouguer gravity and digital elevation data are included in Attachment 1.
The electromagnetic method maps the variations in electrical conductivity of the rocks and sediments being investigated. In the time domain method (TEM) used in Woodanilling, a 30 x 30 metre loop was laid out on the ground and a pulsed current transmitted at a frequency of 8 Hz into the loop. This produces a magnetic field which induces secondary magnetic fields in the earth. The rate of decay of these secondary fields is dependent on ground conductivity. These fields are measured in the time between current pulses by a sensitive receiver usually positioned in the centre of the transmitter loop. Further detail on both the gravity and electromagnetic methods is provided in Wilkes (2005). The electromagnetic measurements at Woodanilling were made by Brett Harris and students from Curtin University Department of Exploration Geophysics.

5 Presentation and interpretation of data
A series of pictures shows how significant aspects of the hydrogeology (i.e. basement topography and solute distribution) are inferred from the geophysical data acquired.

5.1 Locality and data
Woodanilling is situated close to surface drainage. Figure D5.1 shows drill hole locations, TEM sounding locations and gravity stations.

![Figure D5.1. Location of gravity (green dots), TEM measurements (purple dots) and drill holes (light blue dots)](image)

5.2 Gravity images
The Bouguer gravity information acquired at Woodanilling has been imaged and is shown in Figure D5.2. The relative gravity lows within the bounds of the major surface drainage it likely to coincided the main inset valley (i.e. sediment-filled depression in crystalline basement). The axis of this low is marked in black on the image. The gravity also strongly suggests that the inset valley is asymmetric with it cutting edge on the west side of main inset valley (i.e. palaeochannel).

It should be stated that significant variations in density within basement also affect the Bouguer gravity image. The gravity lows outside the main drainage may be related to variations in basement rock type or other sediment or saprolite filled depressions in crystalline basement. However in general the most significant variation in density is expected to be between weakly/unconsolidated sediment and crystalline basement.
Figure D5.2. Bouguer gravity image. Colour bar is Bouguer gravity in mgals. The orientation of the Bouguer gravity low is identified as being related to the main inset valley marked in black. Note its asymmetry. The Bouguer gravity highs (basement highs) are seen as red and the approximate location of a major structure is marked in pink.
Figure D5.3. 3D topographic image with Bouguer gravity overlay. Colour bar is Bouguer gravity in mgals. Orientation of Bouguer gravity low is related to the main inset valley, marked in black. The orientation of a major structure or lithological contact is marked in red.
5.3 TEM images

TEM data was acquired along a transect to the west of Woodanilling. The data were converted to apparent conductivity and displayed in the sequence of images in Figures 5, 6 and 7. Each image shows data from successively later delay time channels and each channel contains information about solute concentration and rock type at successively greater depths.
Figure D5.5. Channel 6 (delay time = 0.194 ms) TEM apparent conductivities. Colour bar is shown units of mS/m. Note the red zone apparent conductivities are greater than 350 mS/m and expected to represent salinities between 10,000 and 2000 mg/L at 20-30 m below ground level.
Figure D5.6. Channel 6 (delay time= 0.194 msecs) TEM apparent conductivities. Colour bar is shown in mS/m. Note the red zone apparent conductivities are greater than 350 mS/m and expected to represent salinities between 10,000 and 2,000 mg/L at depths of 20-30 m below ground level.
Figure D5.7. Channel 10 (delay time = 0.437 msecs) TEM apparent conductivities. Colour bar is shown in units of mS/m. Note the red zone apparent conductivities are greater than 450 mS/m and expected to represent salinities greater than 20,000 mg/L about 40 m below ground level.
5.4 Composite interpretation

TEM apparent conductivity (channel 10) and Bouguer gravity data illustrated the generalised orientation and axis for the main inset valley 500 metres to the west of Woodanilling. In particular the major inset valley to the west is well located by the TEM data. The apparent conductivity at approximately the depth of the inset valley is more than 350 mS/m. It is expected that true conductivities at the base of the inset valley will be closer to 500 mS/m and that solute concentration in the inset valley will be substantially greater than 20,000 mg/L.

5.5 Major findings

The major findings for the geophysical surveys are provided below:

- The gravity method clearly delineated a basement depression that is highly likely to coincide with the major inset valley to the west the townsite. Maximum valley depth is expected to be less than 45 m.
- The TEM method clearly locates the major subsurface inset valley ('paleochannel') approximately 500 m west of the Woodanilling townsite.
- The TEM method indicates that solute concentration in the major inset valley increases shapely with depth. Apparent conductivity increased from 200 mS/m within 20 m of the surface to more than 350 mS/m in the base of the channel. True conductivities in the base of
the major subsurface channel are expected to be of the order 500 mS/m and salinity in the base of the ancient drainage system is expected to be substantially greater than 20,000 mg/L.

A series of images has been provided to illustrate the major findings.

In summary, gravity and TEM methods were successfully used to rapidly determine basement geometry and determine solute distribution with depth beneath and close to Woodanilling.

8 References


Attachment D1: Contour maps of Bouguer gravity and digital elevation data for Woodanilling
APPENDIX E

Groundwater levels and associated impacts on salinity and infrastructure

Peter de Broekert, Department of Agriculture, Perth

8 July 2005

Objectives

This report aims to present an overview of groundwater levels beneath Woodanilling, identify trends, and briefly assess the extent (if any) to which townsite infrastructure is being adversely affected by shallow watertables and the attendant development of secondary salinity. This information is principally required to help determine whether groundwater abstraction techniques, such as pumping or shallow subsurface drainage, are required to lower watertables, and if feasible (i.e. hydrogeological conditions permitting), whether they should be promoted as options within the Water Management Plan for Woodanilling.

Groundwater levels and temporal trends

A contour map of the depth to watertable beneath Woodanilling for the late winter (24/08/04) is presented in Figure E1. It is clear from the contours that even for this time of year, when the water levels are at their highest, all except the low-lying, westernmost part of town has a depth to water in excess of 1.5 m, being the approximate maximum depth from which groundwater can be expected to passively discharge to the land surface as a result of evaporation during the summer. The risk of salinity development for most of the town is therefore currently very low. That this is likely to continue is indicated by hydrographs of bores situated on the lower and middle slopes, which over the period of measurement showed no net rise or fall in the position of the watertable (Figure 2). An increase in watertable elevation of up to 1 m occurs during the winter owing to the direct infiltration of rainfall and possibly leakage from perched water held in shallow subsurface sandy and gravelly horizons, but this is balanced by a phase of discharge of similar magnitude during summer. Weak downward hydraulic gradients measured between adjacent deep and shallow bores (e.g. 00BY02D&M and 00BY11D&I in Figure E2) indicate that groundwater discharge partly occurs as saturated flow towards the valley floor, though vertical loss to the land surface via evaporation and evapotranspiration is likely to be more dominant.

Hydrographs of bores situated along the valley floor (Figure E3) exhibit a similar seasonal response to those beneath the lower to middle slopes (Figure E2), except in this case the hydraulic gradients are weakly upward resulting from the discharge of groundwater sourced from beneath the valley sides. Most of the water delivered to watertable along the valley floor, is again likely to be sourced directly from above, though in this case seepage of perched water at the break of slope and surface flooding are likely to be equal if not greater sources of recharge than rainfall.
Groundwater salinity

The electrical conductivity (salinity) of shallow groundwater at Woodanilling varies between 1,000 and 3,000 mS/m and shows no clear correlation with landscape position (Figure E4). As with the water levels, there is also no clear trend of increasing or decreasing salinity with time, although the shallow groundwater in some bores situated along the valley floor (see 00BY10M in Figure E4) becomes markedly fresher in the winter, providing further evidence that most of the recharge is locally sourced from rainfall, seepage of perched water and/or surface run-off (flooding).
Figure E2. Monthly rainfall for Woodanilling, and groundwater levels for deep (D) and shallow (M, I) bores situated over lower to middle valley side-slope landscape positions in the central to eastern part of town. See Figure E1 for bore locations.

Figure E3. Monthly rainfall for Woodanilling, and groundwater levels for deep (D) and shallow (M) bores situated over the valley floor in the far west of town. See Figure E1 for bore locations.
Infrastructure damage arising from shallow watertables

There are no known reports of damage to infrastructure arising from shallow groundwater tables at Woodanilling, which is not surprising given the high depth to water beneath most of the town. Perched water developed during the winter in shallow subsurface coarse-grained materials appears to result in localised waterlogging and blockage of leach drains carrying the overflow from septic tanks, but this is largely unrelated to the deep groundwater system. Of the two groundwater systems, it is therefore the shallow perched system which principally requires management in order to reduce damage to townsite infrastructure. An added benefit of managing the surface and shallow subsurface (perched) water would be to decrease recharge to the deeper groundwater system.

Prospects for groundwater abstraction

Water yields from the bores drilled to fresh bedrock at Woodanilling are very low (<0.2 L/s), indicating that the prospects for lowering watertables by groundwater pumping, should this be required, are poor. The use of shallow subsurface drains to manage perched water has not been investigated, but should be promoted as an option for waterlogging and salinity control within the Water Management Plan for the town.
APPENDIX F

EVALUATION OF COST ASSOCIATED WITH TOWNSITE INFRASTRUCTURE DAMAGE CAUSED BY SALINITY

Olga Barron and Trevor Smales

WATER FOR A HEALTHY COUNTRY
National Research Flagship

October 2005
1 Salinity risk

Evaluation of the salinity risk towards the infrastructure damage was based on the long-term average groundwater level for the shallow observation bores. The level of risk was estimated in accordance with soil saturation level at the 1m depth below the ground level. The extent of the salinity risk map is confined by the extent of the observation bores in each town, hence the salinity risk maps only cover a portion of each town.

2 Infrastructure damage cost

Infrastructure damage costs are calculated based on the simultaneous analysis of the salinity risk and infrastructure type within each land parcel land use, where surface types, area and structures have been identified. The average salinity risk of each land parcel is calculated, and using an algorithm adapted from the USEAP model, damage can be calculated (Table F2.1).

USEAP divides the town infrastructure into five key groups: residential housing, commercial/offices, public open space, ovals/playing fields and roads. Roads are classified as either sealed or gravel. Each category has an assigned annual damage cost, derived from the USEAP value assuming a 100% impact. This damage is then moderated based upon estimated degree of soil saturation, so that damage falls as soil saturation falls.

<table>
<thead>
<tr>
<th>Name</th>
<th>Quantity</th>
<th>Cost $</th>
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</thead>
<tbody>
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<td>/household</td>
<td>563</td>
</tr>
<tr>
<td>Commercial Building</td>
<td>/1000 sqm</td>
<td>663</td>
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<tr>
<td>Oval</td>
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<td>1900</td>
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<td>Open Space</td>
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<td>685</td>
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<td>Sealed Road</td>
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<td>400</td>
</tr>
<tr>
<td>Unsealed Road</td>
<td>/1000 m</td>
<td>200</td>
</tr>
</tbody>
</table>

It is important to note that the damage costs are only an indication, and that the only part of the gazetted townsite was considered. The water level is assumed to be at equilibrium currently. If the intention is to identify the impact of changes in management, then an assessment of only those areas which may feasibly be impacted by that management need to be considered. It is important to note that these are the estimates of current damage within the area, and as such are the MAXIMUM cost reduction that could be achieved if management options were introduced that completely ameliorated the problem. It is almost certainly the case that such total amelioration options will not be economic to achieve, and such options are not considered in the water management plans. However, these values give an indication of the overall size of the infrastructure damage problem within these towns. The details of the proposed methodology are given in ‘A Systems Approach to Rural Town Water Management’ (Water for Healthy Country 2006).
3 Woodanilling

Salinity risk for Woodanilling is confined to the lower western slopes of the townsite, roughly following the line of the railway. The overall salinity risk is small peaking in the medium category and shown in Figure F4.1. The estimated damage cost for the different land use zones as described in the town planning scheme is given in Table F3.1 as an annual damage cost ($4K) and projected NPV cost over next 20 years within do-nothing scenario ($42K).

Table F3.1. Woodanilling estimated damage cost

<table>
<thead>
<tr>
<th>Name</th>
<th>COST Year 1 $</th>
<th>Projected NPV (@ 7%) over 20 years $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>55</td>
<td>583</td>
</tr>
<tr>
<td>Industrial</td>
<td>76</td>
<td>805</td>
</tr>
<tr>
<td>Local rural</td>
<td>133</td>
<td>1,409</td>
</tr>
<tr>
<td>Public purposes</td>
<td>79</td>
<td>837</td>
</tr>
<tr>
<td>Railway</td>
<td>1,967</td>
<td>20,838</td>
</tr>
<tr>
<td>Recreation</td>
<td>940</td>
<td>9,958</td>
</tr>
<tr>
<td>Residential</td>
<td>598</td>
<td>6,335</td>
</tr>
<tr>
<td>Roads</td>
<td>167</td>
<td>1,769</td>
</tr>
<tr>
<td>Total</td>
<td>4,018</td>
<td>42,567</td>
</tr>
</tbody>
</table>
Figure F4.1. Woodanilling salinity risk map
APPENDIX G

Woodanilling water quality

Jeff Turner
Water for a Healthy Country Flagship, CSIRO

1 Project approach and methodology

Ground and surface water quality, such as parameters including gross salinity level (electrical conductivity), major ion composition, trace element composition, organic compound composition and total organic carbon, and pathogen (bacterial) status are key determinants for assessment and decision making in several aspects of water resources management of the project. Determination of water quality parameters is necessary as a basis for feasibility assessment of options for townsite water management. These include water treatment options (e.g. reverse osmosis desalination, nanofiltration, evaporative desalination), the suitability of treated water as either potable water supply or as potable substitute water, assessment of bulk mineral harvesting potential from saline water, water disposal options, long term implications of de-watering or drainage to control waterlogging and townsite salinisation, water quality assessment for new industries and downstream water users such as livestock, intensive horticulture, aquaculture and townsite irrigation. In addition to these water management issues, groundwater quality and its spatial and temporal distribution and variation provides key information on groundwater surface water interaction and interconnection within groundwater systems when integrated with hydrogeology, groundwater modelling, geophysics and surface hydrology. For example, when integrated with groundwater modelling of townsite dewatering scenarios, knowledge of the spatial distribution of groundwater salinity has enabled long term predictions of the volume and salinity of recovered groundwater. Such information is critical to the development of long term water treatment and water re-use scenarios and the identification of downstream uses of the recovered groundwater.

For rural town groundwater, the methodologies developed and employed have included:

1. Spatial and temporal monitoring and interpretation of deep, intermediate and shallow water quality parameters in a network of observation bores within each townsite. Temporal monitoring was undertaken bi-annually from 2001 to 2004 allowing temporal trends in key water quality parameters to be determined and assessment of whether the salinity trends in groundwater are degrading, improving, or remaining constant. Indicators of the extent of groundwater mixing, surface water-groundwater interaction and recharge to groundwater within townsites were developed from analysis of the spatial and temporal data.

2. Integration of the spatial distribution of groundwater quality with subsurface basement topography determined by seismic geophysics. Such integration enables more robust and reliable long-term predictions of groundwater recovery volumes and salinity. Development of the necessary data integration and software processing capacity to merge subsurface geophysical interpretation with spatial groundwater quality has been an important methodological development.
3. Spatial characterisation of major and trace ion compositions, organics and microbiological status was carried out to assess the potable or substitute potable suitability of groundwater, predict the long term characteristics of recovered groundwater and define the parameters of its desalination by RO and related technologies, estimate the recovery potential of bulk mineral salts from recovered groundwater.

4. Establishment of salt and water mass balances of groundwater will provide base data for a) economic analysis of groundwater pumping and water treatment as a potential source of new, useable water resources as a by-product of shallow watertable waterlogging alleviation and b) facilitate comparison between recovered groundwater volumes, water quality, recovery and treatment cost in comparison to available or harvestable surface water volumes and quality.

For surface water, very little or no prior information was available and due to low or zero flow in summer 2004-05, new data could not be collected. Reconnaissance electrical conductivity (salinity) in townsit run-off is being measured.

Expected outcomes from these methodologies were the interpretation of groundwater-surface water interaction, especially evidence for whether groundwater recharge occurs within the townsites and, on this basis, determining whether management of townsites surface water will be effective in alleviating waterlogging and salinisation due to shallow watertables. Conversely, it is important to determine whether townsite groundwater management (pumping, drainage) will be effective in long-term alleviation of waterlogging, or whether seasonal surface water recharge will rapidly overturn any benefits achieved by groundwater management. Overall, the methodologies provide information that form the basis for hydrologically and socio-economically sound decision making in relation to the alleviation of salinisation and waterlogging in rural towns.

**Data collected and results**

Groundwater quality data from Woodanilling was collected for multiple purposes including:

i) Spatial and temporal monitoring and hydrological interpretation of deep, intermediate and shallow water quality parameters in a network of observation bores. Interpretation of this data in the context of hydrological processes (e.g. recharge, groundwater sources) in the context of developing townsites water management plans is at the forefront of the purpose for this data.

ii) Determination of the potable or potable substitute potential of treated groundwater by characterisation of major and trace ion compositions, organics and microbiological status

iii) Determination of desalination potential, in particular variants of RO technologies, for water treatment, downstream water uses and bulk mineral recovery.

In the context of the overall Water Management Plan for Woodanilling, where it was concluded that groundwater recovery was not a viable water management option, the emphasis in this report and the importance of the application of water quality interpretations will be on point (i) above. Nevertheless, reporting of the details of the extensive groundwater quality data sets collated, collected and analysed is provided in this report.

**Spatial distribution and temporal trends in salinity**

Figures G1 and G2 show the spatial distribution of EC in deep groundwater overlain on DEM, topographic contour and cadastral information for Woodanilling. The spatial trend of lower to higher EC can be seen to follow decreasing topographic elevation and as such is consistent with the frequently observed occurrence of higher salinity in topographically low parts of the landscape. This indicates that townsites is situated in the lower region of a classic hillslope recharge-discharge zone. The location of the south-western margin of the townsites in the higher groundwater salinity zone is clearly indicated. Figure G3 shows the spatial distribution of pH in deep groundwater overlain on DEM, topographic contour and cadastral information for Woodanilling demonstrating the circum-neutral pH condition in Woodanilling groundwater. Figure G4 shows trends in groundwater EC during
the period 2002 to 2004 indicating the range of salinity from about 1,000 to 4,000 mS/m, and that groundwater salinities follow a steady trend over time. Figures G5 & G6 show Schoeller and Piper plots respectively of the major ion composition of groundwater sampled in late 2004 (Table G1). Shallow groundwaters are generally less saline than deeper groundwater, indicating the rainfall/run-off-infiltration process occurs across the townsite. This points to surface water management being a key factor in managing groundwater in the townsite.

Trace elements

Figures G7-15 show various trace element concentrations in groundwater for Nyabing (and for comparison, three other rural townsites). The data are from Table G1 and each caption shows the Australian Drinking Water Guideline (ADWG) for the corresponding element. The ADWG is presented as a reference only and does not imply an intention that the groundwater could be used as potable supply as its gross salinity alone is well above the ADWG. Woodanilling groundwater does not present any unusually high trace element concentrations.

Organics and pathogens

Table G1 shows a suite of organic compounds measured to determine whether Woodanilling groundwater demonstrated any significant organic contamination from urban sources. The reconnaissance analysis yields no evidence of organic compound contamination. Pathogen counts indicate three groundwater samples showing low level microbiological occurrence and is considered a result of septic tank system operation at Nyabing. The occurrence of _E. coli_ and total coliform counts in bore 00BY11D is noted and is of some concern.

Groundwater use options: salt production potential of saline groundwater and reverse osmosis

Salt harvesting was investigated as a possible use for Woodanilling groundwater. However, because it was concluded from related work described in this report conducted in parallel with analysis of salt recovery, that groundwater recovery was not a viable water management option, the results for salt harvesting are presented only for completion. Similarly RO treatment of recovered groundwater is not a viable option because groundwater recovery is not proposed.
Figure G1. Spatial distribution of salinity (EC as mS/m) in deep groundwater at Woodanilling townsite.
Figure G2. Spatial distribution of salinity (EC as mS/m) in intermediate groundwater at Woodanilling townsite.
Figure G3. Spatial distribution of pH in deep groundwater at Woodanilling townsite
Figure G4. Temporal variation in groundwater salinity in Woodanilling townsite

Figure G5. Major ion concentrations in Woodanilling groundwater (from Table G1)
Figure G6. Major ion distribution in Woodanilling groundwater
Figure G7. ADWG Guideline Al <0.2 mg/L, As <0.007 mg/L
Figure G8. ADWG Guideline Sb <0.003 mg/L, Ba 0.7 mg/L
Figure G9. ADWG Guideline Be: no guideline figure available, As <0.05 mg/L
Figure G10. ADWG Guideline Cu <2.0 mg/L, F <1.5 mg/L
Figure G11. ADWG Guideline Fe <0.3 mg/L, Pb <0.01 mg/L
Figure G12. ADWG Guideline Mn <0.5 mg/L, Hg <0.001 mg/L
Figure G13. ADWG Guideline Ni <0.02 mg/L, NO₃ <50 mg/L
Figure G14. ADWG Guideline P: no guideline available, Se <0.01 mg/L
Figure G15. ADWG Guideline Sr: no guideline available for non-radioactive Sr, Zn no health-based guideline is set for zinc
## Table G1. Trace elements, organics and pathogens measured in Woodanilling groundwater

<table>
<thead>
<tr>
<th>Woodanilling</th>
<th>Woodanilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client ID</td>
<td>00BY01D</td>
</tr>
<tr>
<td>Sample Date</td>
<td>29/11/2004</td>
</tr>
</tbody>
</table>

### Field Temp
- C: 18

### Field pH
- 6.87

### Field EC mS/cm
- mS/cm: 24.7

### DO
- mg/L: N/A

### Field Temp
- C

### Field pH
- 6.87

### Field EC mS/cm
- mS/cm: 24.7

### DO
- mg/L: N/A

### Trace Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Al</td>
<td>0.006</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>320</td>
</tr>
<tr>
<td>As</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ba</td>
<td>0.043</td>
</tr>
<tr>
<td>Be</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CO3</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Ca</td>
<td>206</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Cl</td>
<td>10000</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>ECond</td>
<td>2480</td>
</tr>
<tr>
<td>F</td>
<td>0.7</td>
</tr>
<tr>
<td>Fe</td>
<td>0.012</td>
</tr>
<tr>
<td>HCO3</td>
<td>390</td>
</tr>
<tr>
<td>Hg</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>K</td>
<td>41.6</td>
</tr>
<tr>
<td>Mg</td>
<td>679</td>
</tr>
<tr>
<td>Mn</td>
<td>10.5</td>
</tr>
<tr>
<td>N_NO2</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>N_NO3</td>
<td>0.01</td>
</tr>
<tr>
<td>Na</td>
<td>4990</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P_SR</td>
<td>0.01</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.0025</td>
</tr>
<tr>
<td>S</td>
<td>320</td>
</tr>
<tr>
<td>Sb</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Se</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SO4</td>
<td>861</td>
</tr>
<tr>
<td>SiO2</td>
<td>67</td>
</tr>
<tr>
<td>Solid_suspended</td>
<td>3</td>
</tr>
<tr>
<td>Sr</td>
<td>3.2</td>
</tr>
<tr>
<td>TDS_180C</td>
<td>17000</td>
</tr>
<tr>
<td>Zn</td>
<td>0.029</td>
</tr>
</tbody>
</table>

### Pathogens

- Total Coliforms: average cells /100 mL: 4.6
- Shigella sonnei: 1.2
- Escherichia coli: 0.2

### Organics

<table>
<thead>
<tr>
<th>Organic</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>toluene</td>
<td>&lt;10</td>
</tr>
<tr>
<td>ethylbenzene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>m&amp;p-xylene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>o-xylene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,2,3-trimethylbenzene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,2,4-trimethylbenzene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,3,5-trimethylbenzene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>2-methylnaphthalene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1-methylnaphthalene</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,2-DMN</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,3/1,7-DMN</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1,6-DMN</td>
<td>&lt;1</td>
</tr>
<tr>
<td>2,3/1,4/1,5-DMN</td>
<td>&lt;1</td>
</tr>
<tr>
<td>2,6/2,7-DMN</td>
<td>&lt;1</td>
</tr>
<tr>
<td>phenol</td>
<td>&lt;5</td>
</tr>
<tr>
<td>m&amp;p-cresol</td>
<td>&lt;5</td>
</tr>
<tr>
<td>o-cresol</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

### Sample Notes

- 00BY01D: 00BY01M 00BY02D 00BY06D 00BY10D 00BY11D
- 00BY06D (Dup 5)
- 00BY01D: 00BY02D 00BY06D 00BY10D 00BY11D
- 00BY06D: 00BY06D (Dup 5)
Saline waters, when evaporated, lead to the precipitation of some constituents. In general different minerals precipitate at different saturation points. This allows separation of valuable from low value salts. In commercial operations the valuable salt (e.g. halite) is recovered by transferring the saturated brine to another pond. Thermochemical modelling can predict the quantity of salt (sodium chloride) and bitterns to be produced from saline waters. The modelling work, by and large simulating commercial solar pond operations, involves calculations for producing gypsum, halite of saleable quality and quantity.

Sodium chloride and bittern potential of saline groundwater was investigated for Woodanilling having the chemical composition (comprising Na, Cl, Mg, SO\textsubscript{4}, Ca, K, alkalinity, pH and SG) shown in Tables G1 and G2.

Table G2. Chemical composition of saline waters (mg/L) modelled in this study

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample No</th>
<th>Na</th>
<th>Cl</th>
<th>Ca</th>
<th>Mg</th>
<th>SO\textsubscript{4}</th>
<th>K</th>
<th>HCO\textsubscript{3}</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodanilling</td>
<td>00BY10D</td>
<td>4540</td>
<td>10000</td>
<td>222</td>
<td>586</td>
<td>963</td>
<td>326</td>
<td>381</td>
<td>6.5</td>
</tr>
<tr>
<td>Woodanilling</td>
<td>00BY06D</td>
<td>2830</td>
<td>4900</td>
<td>37.1</td>
<td>318</td>
<td>504</td>
<td>31</td>
<td>362</td>
<td>6.7</td>
</tr>
<tr>
<td>Woodanilling</td>
<td>00BY01M</td>
<td>5160</td>
<td>9500</td>
<td>169</td>
<td>593</td>
<td>851</td>
<td>40.8</td>
<td>427</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The modelling was done for the system Na-K-Mg-Ca-H-Cl-SO\textsubscript{4}-OH-HCO\textsubscript{3}-CO\textsubscript{3}-CO\textsubscript{2}-H\textsubscript{2}O at 25°C.

The calculations performed by the program track the reaction path taken by the sample at 25°C as it evaporates to dryness by the stepwise removal of 996 g of H\textsubscript{2}O/L of water. By removing the 996 g of water, all the initial water is removed as the remaining 4 g are consumed by the formation of hydrated minerals.

The model provides indicative results only as it assumes 100% efficiency in precipitation and recovery. The modelling does not take into account kinetic effects such as caused by day-night temperature changes that may affect the crystallisation path significantly. The program assumes progressive evaporation of the saline water to dryness. Also note that the modelling work does not provide information on the fate of trace elements (e.g. heavy metals) in the salt products.

In the results presented, the Woodanilling sample was modelled by bringing (modelling) the saline water to complete dryness. The minerals predicted to precipitate under such a scenario and their tonnages are shown in Table G3. Table G4 shows the theoretical amount of gypsum/anhydrite, halite and bittern to be produced at a specific gravity of point of 1.25. This SG point is commonly used as point of salt harvesting in commercial operations.

Table G3. Predicted total mineral tonnages to be precipitated from Woodanilling groundwater as a result of evaporation to complete dryness of 1 megalitre of water

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>00BY10D</td>
<td>0.347</td>
<td>0.502</td>
<td>0.000</td>
<td>0.091</td>
<td>11.48</td>
<td>0.017</td>
<td>0.360</td>
<td>0.551</td>
<td>0.002</td>
<td>0.009</td>
<td>0.182</td>
<td>0.073</td>
</tr>
<tr>
<td>00BY06D</td>
<td>0.086</td>
<td>0.017</td>
<td>0.124</td>
<td>0.026</td>
<td>6.60</td>
<td>0.047</td>
<td>0.142</td>
<td>0.047</td>
<td>0.142</td>
<td>0.142</td>
<td>0.142</td>
<td>0.142</td>
</tr>
<tr>
<td>00BY01M</td>
<td>0.392</td>
<td>0.222</td>
<td>0.001</td>
<td>0.093</td>
<td>13.04</td>
<td>0.030</td>
<td>0.404</td>
<td>0.390</td>
<td>0.035</td>
<td>0.243</td>
<td>0.243</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Tables G3 and G4 show that the amount of halite and bittern to be precipitated depends on the total salinity. The predicted amount of halite is between 6 and 12 tonnes. However, in commercial operations the actual production will be 50 to 70% of the values shown in Table G4. The difference is due to losses during production, washing and stockpiling.
Table G4. Theoretical amount of gypsum/anhydrite, halite and bittern to be produced at a specific gravity point of 1.25

<table>
<thead>
<tr>
<th>Gypsum+Anhydrite (t)</th>
<th>Tonnage of good quality halite to be harvested at SG = 1.25</th>
<th>% Volume of Remaining Water (bittern)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00BY10D</td>
<td>0.58</td>
<td>10</td>
</tr>
<tr>
<td>00BY06D</td>
<td>0.04</td>
<td>6</td>
</tr>
<tr>
<td>00BY01M</td>
<td>0.30</td>
<td>12</td>
</tr>
</tbody>
</table>

Model verification was established by examining the mineral phases precipitated as a result of evaporation of Nyabing groundwater to dryness as determined by powder XRD technique.

This data verifies the presence of mainly halite and small amounts of impurity minerals. Not all the minerals listed in Table G2 appear in the XRD patterns due to their low abundance levels.

Salt harvesting potential was investigated by evaporating a groundwater sample (Table G5) to an SG of about 1.19–1.20 to precipitate gypsum, anhydrite, dolomite and magnesite.

Table G5. Amount of common salt harvestable from 1 litre of saline groundwater from Woodanilling

<table>
<thead>
<tr>
<th>Sample</th>
<th>Weight of Unwashed Product Halite (g)</th>
<th>Weight of washed Product (60% recovery) Halite (g)</th>
<th>Possible annual tonnage at groundwater recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>00BY01M - Woodanilling</td>
<td>6.0 (13.0) - 46%</td>
<td>3.6</td>
<td>Not applicable for Nyabing</td>
</tr>
</tbody>
</table>

Note that in Table G5 the numbers in parenthesis show theoretical amounts. Recoveries (in per cent) are within commercial limits.

The filtrate was then further evaporated at room temperature to a SG of about 1.25, filtered and washed with small amount of water. Halite recovered was dried at 110°C overnight and weighed. Small sub-samples were collected and submitted for chemical analysis.
The Water for a Healthy Country Flagship is a national research partnership between CSIRO, state and federal governments, private and public industry and other research providers.
SUMMARY

The township of Woodanilling is subject to problems of scarce water and urban salinity. The purpose of this study is to complete a water balance of the township. The results will enable more informed decisions to be made about how to address water scarcity and urban salinity.

Water balance modelling allows us to understand where water is being distributed within a township over time. The volume of stormwater run-off, wastewater discharge and scheme water consumption is calculated each day for the period of the study, which in this case is 1950–2003. Calculating water flows for each day allows us to understand the variation in water flows and the reliability of water supplies (both proposed and existing).

The water balance was calculated using end use data supplied by the Water Corporation of Western Australia and making a series of assumptions. The wastewater and water demand figures are accurate as they are based primarily on Water Corporation data. The stormwater figures are not as accurate because they rely on engineering judgement only and have not been calibrated to any real data.

Rainwater tanks are specifically investigated in this study to determine their effectiveness in supplying residential areas. Each house was modelled with rainwater tanks ranging from 10 to 40 kL, depending on expected demand, roof size and rainfall. The demand placed upon the tanks was for toilet flushing and garden irrigation. The study found that rainwater tanks would not be able to meet this demand and would only succeed in reducing total scheme water consumption by 13.1%. Stormwater run-off in the study area would be reduced by 1.3%.

If significant water management improvements are to be achieved, measures other than rainwater tanks need to be considered. End use demand management could achieve a significant reduction in scheme water consumption and wastewater discharge because end use is very high by Western Australian standards. Woodanilling residential end use is estimated to be 138.7 kL/capita/year which compares to the Western Australian average for 2000-01 of 132 kL/cap/year (ABS 2004) and the Perth average for single residential houses of 136 kL/cap/year (Loh & Coghlan 2003). Other management options such as stormwater collection and use, groundwater extraction and use, greywater use and reclaimed water use could also be considered however further modelling is required to determine how effective and feasible they would be.
CONTENTS

1. INTRODUCTION..................................................................................................................................... H4
2. INPUT DATA.......................................................................................................................................... H5
   2.1 END USE DATA.................................................................................................................................. H5
   2.2 TOPOGRAPHY DATA....................................................................................................................... H10
   2.3 CLIMATE DATA............................................................................................................................. H11
   2.4 STORMWATER RUN-OFF............................................................................................................... H11
3. WATER BALANCE............................................................................................................................... H13
   3.1 MODELLING APPROACH................................................................................................................ H13
   3.2 CALIBRATION OF GARDEN IRRIGATION..................................................................................... H14
   3.3 RESULTS....................................................................................................................................... H15
4. DISCUSSION.......................................................................................................................................... H22
   4.1 RAINWATER TANK....................................................................................................................... H22
5. CONCLUSION........................................................................................................................................ H27
REFERENCES......................................................................................................................................... H29
1. **INTRODUCTION**

Water balance modelling enables us to understand where water is being distributed within a township. It considers the volume of water being imported into the township, the volume of stormwater run-off and the volume of wastewater discharge. All water balance calculations have been calculated on a daily time step which means the model can reflect seasonal factors such as rainfall and evaporation which influence (among others) irrigation demand and stormwater run-off.

Water balance modelling also allows us to compare water management options. In the case of these Woodanilling, possible water management options include rainwater tanks, end-use demand management, groundwater extraction and use, stormwater re-use, wastewater re-use and grey water re-use. Water balance modelling will be able to determine how much imported water, wastewater discharge and stormwater run-off would vary for different options and the estimated required size of water storages (such as rainwater tanks, grey water tanks, stormwater storages, groundwater storages and treated wastewater storages).

This report analyses the base case, or the existing water balance of Woodanilling and compares it to a scenario where every house uses a rainwater tank for garden irrigation and toilet flushing.
2 **INPUT DATA**

2.1 **End Use Data**

End use data were supplied by the Water Corporation of Western Australia. The data were annual figures (for 2003 and 2004) with splits between land use types of ‘residential’, ‘commercial’, ‘industrial’ and ‘other’. The data were for use of ‘scheme water’ only (i.e. there was no data on alternative uses such as rainwater tanks, recycled water, bore water etc.). ‘Scheme water’ refers to water that is supplied by the Water Corporation.

Monthly scheme water end use data were supplied for Dowerin, Merredin, Katanning and Wongan Hills between July 2000 and January 2005. This is very useful as it demonstrates the seasonal variation in end use. The percentage breakdown of consumption between ‘commercial’, ‘industrial’, ‘residential’ and ‘other’ land use zones and the number of customers for each land use zone was also provided allowing us to calculate average unit consumption data for each land use zone.

An important assumption has been made when calculating water use for land use zones, namely: percentage breakdown of use between land use zones is constant for each month of the year. This assumption was made because no information on end use breakdowns between land use zones was available for individual months.

The weighted average from Dowerin, Merredin, Katanning and Wongan Hills for end use in residential areas is shown in. The end use data were ‘weighted’ based on population data from ABS (2005) shown in Table H2. These data allow us to estimate the variation in water use between each month, or the volume of irrigation that is used each month of the year. This estimated variation in irrigation is assumed to be similar to Woodanilling.

To estimate the percentage of consumption that was garden use, it was assumed that during the wettest month of the year there is no garden irrigation. This month is August and the residential consumption represents indoor consumption. This assumption means that indoor use is 228 L/cap/day and outdoor consumption is 499 L/unit/day. This compares to 155 L/cap/day and 707 L/unit/day for single houses in the Perth Domestic Water Use Study (Loh & Coghlan 2003) and 181 L/cap/day and 434 L/unit/day for all houses in WA (ABS 2004). The proportion of scheme water used for garden irrigation is estimated at 48%, which compares to the WA average of 50% (ABS 2004) and Perth single houses average of 54% (Loh & Coghlan 2003).

The indoor end use breakdown was based on typical Perth values for single houses (Loh & Coghlan 2003) of 33% bath & shower, 27% washing machine, 21% toilet, 16% tap and 3% other. Assumptions about distribution of ‘tap’ and ‘other’ were made to develop the indoor end use breakdown as shown in Table H3.

The breakdown between indoor and outdoor use in commercial areas was calculated in the same way as for residential areas; i.e. we have assumed that in the month with the lowest end use volume there was also no garden watering. The end use value for this month therefore represents the indoor end use volume. As can be seen in Table H1, this month is August. Irrigation is therefore estimated to account for 49% of water usage in commercial areas.

The volume of irrigation for industrial areas was calculated in the same way as commercial and residential areas as described above. Based on the data in Table H5, the volume of water used for irrigation in industrial areas is estimated as 50%.

Table H5
### Table H1: Weighted average monthly residential consumption

<table>
<thead>
<tr>
<th>Month</th>
<th>Residential Consumption (ML/month)</th>
<th>Residential Consumption per Unit (kL/Unit/month)</th>
<th>Residential Garden Consumption (kL/Unit/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>165</td>
<td>50</td>
<td>34</td>
</tr>
<tr>
<td>Feb</td>
<td>151</td>
<td>46</td>
<td>31</td>
</tr>
<tr>
<td>Mar</td>
<td>153</td>
<td>46</td>
<td>30</td>
</tr>
<tr>
<td>Apr</td>
<td>119</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>May</td>
<td>85</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Jun</td>
<td>59</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Jul</td>
<td>57</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Aug</td>
<td>54</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>55</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Oct</td>
<td>88</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>Nov</td>
<td>114</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>Dec</td>
<td>134</td>
<td>41</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>1,235</td>
<td>374</td>
<td>181</td>
</tr>
</tbody>
</table>

### Table H2: Population of townships (ABS 2005)

<table>
<thead>
<tr>
<th>Township</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodanilling</td>
<td>*127</td>
</tr>
<tr>
<td>Wongan Hills</td>
<td>783</td>
</tr>
<tr>
<td>Dowerin</td>
<td>358</td>
</tr>
<tr>
<td>Merredin</td>
<td>2,807</td>
</tr>
<tr>
<td>Katanning</td>
<td>3,685</td>
</tr>
</tbody>
</table>

* Figure based on average per dwelling for district as no specific information available for township.

### Table H3: Estimated Residential Indoor End Use Breakdown

<table>
<thead>
<tr>
<th>End use</th>
<th>Percentage Indoor Use</th>
<th>L/capita/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td>Laundry</td>
<td>32</td>
<td>73</td>
</tr>
<tr>
<td>Bathroom</td>
<td>38</td>
<td>87</td>
</tr>
<tr>
<td>Kitchen</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>228</td>
</tr>
</tbody>
</table>
Table H4: Weighted average commercial end use volumes each month

<table>
<thead>
<tr>
<th>Month</th>
<th>Commercial Total Consumption (ML/month)</th>
<th>Commercial Consumption (kL/Unit/month)</th>
<th>Commercial Garden Consumption (kL/Unit/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>34</td>
<td>64</td>
<td>43</td>
</tr>
<tr>
<td>Feb</td>
<td>33</td>
<td>63</td>
<td>43</td>
</tr>
<tr>
<td>Mar</td>
<td>30</td>
<td>57</td>
<td>36</td>
</tr>
<tr>
<td>Apr</td>
<td>25</td>
<td>47</td>
<td>26</td>
</tr>
<tr>
<td>May</td>
<td>17</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td>Jun</td>
<td>12</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>Jul</td>
<td>11</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Aug</td>
<td>11</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>12</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Oct</td>
<td>18</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>Nov</td>
<td>25</td>
<td>47</td>
<td>27</td>
</tr>
<tr>
<td>Dec</td>
<td>28</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>257</td>
<td>488</td>
<td>238</td>
</tr>
</tbody>
</table>

Table H5: Weighted average industrial end use volumes each month

<table>
<thead>
<tr>
<th>Month</th>
<th>Total Industrial Consumption (ML/month)</th>
<th>Industrial Consumption (kL/Unit/month)</th>
<th>Industrial Garden Consumption (kL/Unit/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>44</td>
<td>6342</td>
<td>4354</td>
</tr>
<tr>
<td>Feb</td>
<td>47</td>
<td>6654</td>
<td>4665</td>
</tr>
<tr>
<td>Mar</td>
<td>43</td>
<td>6193</td>
<td>4204</td>
</tr>
<tr>
<td>Apr</td>
<td>35</td>
<td>4988</td>
<td>2999</td>
</tr>
<tr>
<td>May</td>
<td>23</td>
<td>3279</td>
<td>1291</td>
</tr>
<tr>
<td>Jun</td>
<td>17</td>
<td>2414</td>
<td>425</td>
</tr>
<tr>
<td>Jul</td>
<td>15</td>
<td>2156</td>
<td>168</td>
</tr>
<tr>
<td>Aug</td>
<td>14</td>
<td>1988</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>16</td>
<td>2245</td>
<td>256</td>
</tr>
<tr>
<td>Oct</td>
<td>20</td>
<td>2854</td>
<td>865</td>
</tr>
<tr>
<td>Nov</td>
<td>27</td>
<td>3846</td>
<td>1857</td>
</tr>
<tr>
<td>Dec</td>
<td>33</td>
<td>4669</td>
<td>2680</td>
</tr>
<tr>
<td>Total</td>
<td>333</td>
<td>47,626</td>
<td>23,765</td>
</tr>
</tbody>
</table>
Community area irrigation was assumed to comprise 90% of total community use. “Community areas” refer to land uses such as parks, gardens, sports ovals, schools and community halls. Whilst the assumption regarding irrigation volume is somewhat crude, it should be remembered that community areas usually only comprise <10% of total water usage and that there is no high quality data available on seasonal variation.

End use data to be used for modelling Woodanilling’s water balance are shown in Table H6. The data are based on annual end use data for ‘residential’, ‘commercial’, ‘vacant land’, ‘farmland’ and ‘other’ land use zones (supplied by the Water Corporation of WA) for Woodanilling. To reconcile this data with the topography data in Section 2.2, ‘residential’ end use data was assigned to ‘residential’ areas, ‘other’ end use data was assigned to ‘community’ areas, ‘vacant land’ and ‘farmland’ end use data was assigned to ‘rural’ areas and ‘commercial’ end use data was split between ‘commercial’ and ‘industrial’ areas. The breakdown between irrigation and indoor use was calculated using the assumptions detailed above. The monthly variation in irrigation was taken into account using the assumptions detailed above (also see Section 3.2 for more details).

Table H6: Scheme water end use for Woodanilling neighbourhoods

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Pop</th>
<th>Dwellings /unit</th>
<th>People per unit</th>
<th>Total Use (kL/year)</th>
<th>Total Use (kL/unit/year)</th>
<th>Garden Use (kL/unit/year)</th>
<th>Total Garden Use (kL/year)</th>
<th>Total Indoor Use (kL/unit/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Small</td>
<td>13</td>
<td>6</td>
<td>2.17</td>
<td>1797</td>
<td>300</td>
<td>119</td>
<td>712</td>
<td>181</td>
</tr>
<tr>
<td>Residential Medium</td>
<td>16</td>
<td>7</td>
<td>2.29</td>
<td>2212</td>
<td>316</td>
<td>125</td>
<td>877</td>
<td>191</td>
</tr>
<tr>
<td>Residential Large</td>
<td>52</td>
<td>21</td>
<td>2.48</td>
<td>7188</td>
<td>342</td>
<td>136</td>
<td>2849</td>
<td>207</td>
</tr>
<tr>
<td>Semi-rural</td>
<td>46</td>
<td>17</td>
<td>2.71</td>
<td>6359</td>
<td>374</td>
<td>148</td>
<td>2521</td>
<td>226</td>
</tr>
<tr>
<td><strong>Total Residential</strong></td>
<td>127</td>
<td>51</td>
<td><strong>2.49</strong></td>
<td><strong>17,556</strong></td>
<td><strong>344</strong></td>
<td><strong>136</strong></td>
<td><strong>6959</strong></td>
<td><strong>208</strong></td>
</tr>
<tr>
<td>Rural (no dwelling)</td>
<td>138</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>25,670</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The numbers in Table H6 shown in italics are assumed and not based on citable data.
Total consumption = 26 megalitres per year

Figure H1: Scheme water end use breakdown for Woodanilling
2.2 Topography Data

The topography data were supplied by CSIRO Land & Water using town planning zone classification information. This data can be sourced from the GIS information on ftp://rtcsiro@spatial.agric.wa.gov.au/rural_towns/BaseData/ for those with access.

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Population</th>
<th>Dwellings/Units</th>
<th>People per unit</th>
<th>Average Block Size (m²)</th>
<th>Average Roof Area (m²)</th>
<th>Average Paved Area (m²)</th>
<th>Average Garden &amp; Lawn Area (m²)</th>
<th>Total Block Size (ha)</th>
<th>Total Open Space (ha)</th>
<th>Road Area (ha)</th>
<th>Total (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Small</td>
<td>13</td>
<td>6</td>
<td>2.17</td>
<td>4751</td>
<td>98</td>
<td>17</td>
<td>4,636</td>
<td>2.85</td>
<td>2.29</td>
<td>0.33</td>
<td>5.47</td>
</tr>
<tr>
<td>Residential Medium</td>
<td>16</td>
<td>7</td>
<td>2.29</td>
<td>1,999</td>
<td>212</td>
<td>38</td>
<td>1,749</td>
<td>1.40</td>
<td>1.12</td>
<td>0.16</td>
<td>2.68</td>
</tr>
<tr>
<td>Residential Large</td>
<td>52</td>
<td>21</td>
<td>2.48</td>
<td>4,590</td>
<td>316</td>
<td>57</td>
<td>4,217</td>
<td>9.64</td>
<td>7.74</td>
<td>1.12</td>
<td>18.50</td>
</tr>
<tr>
<td>Semi-rural</td>
<td>46</td>
<td>17</td>
<td>2.71</td>
<td>16,427</td>
<td>180</td>
<td>93</td>
<td>16,154</td>
<td>27.93</td>
<td>22.42</td>
<td>3.25</td>
<td>53.60</td>
</tr>
<tr>
<td>Total Residential</td>
<td>127</td>
<td>51</td>
<td>2.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41.81</td>
<td>33.57</td>
<td>4.87</td>
<td>80.25</td>
</tr>
<tr>
<td>Rural (no dwelling)</td>
<td>138</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25,873</td>
<td>357.05</td>
<td>286.66</td>
<td>685.26</td>
</tr>
<tr>
<td>Industrial</td>
<td>4</td>
<td></td>
<td></td>
<td>8,564</td>
<td>188</td>
<td>188</td>
<td>8188</td>
<td>3.43</td>
<td>2.75</td>
<td>0.40</td>
<td>6.57</td>
</tr>
<tr>
<td>Commercial</td>
<td>4</td>
<td></td>
<td></td>
<td>2,367</td>
<td>208</td>
<td>208</td>
<td>1951</td>
<td>0.95</td>
<td>0.76</td>
<td>0.11</td>
<td>1.82</td>
</tr>
<tr>
<td>Community</td>
<td>11</td>
<td></td>
<td></td>
<td>7,113</td>
<td>718.5</td>
<td>718.5</td>
<td>5676</td>
<td>7.82</td>
<td>6.28</td>
<td>0.91</td>
<td>15.02</td>
</tr>
<tr>
<td>Total</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>411.06</td>
<td>330.02</td>
<td>47.84</td>
<td>788.92</td>
</tr>
</tbody>
</table>

Numbers shown in italics are assumed and not based on citable data
2.3 Climate Data

The climate data have been sourced from the Bureau of Meteorology and are available from: ftp://rtcsiro@spatial.agric.wa.gov.au/rural_towns/BaseData/ for those with access. The data use a daily time-step. Figure H2 shows the annual Class A pan evaporation and rainfall for Woodanilling over the period of the dataset (1950–2003).

It should be noted that daily evaporation data 1950–1969 is based on average daily values from the remainder of the dataset. No Class A pan evaporation data was available prior to 1969. Using average daily values pre 1969 period allows us to use a longer rainfall data set which will help improve the reliability of the results. The average data included seasonal variation as each calendar day was given the average for that calendar day between 1970 and 2003 (e.g. the evaporation for 6 November 1955 is equal to the average evaporation for 6 November between 1970 and 2003).

![Figure H2: Rainfall and Evaporation for Woodanilling](image)

Figure H3 and Figure H4 show the average monthly rainfall and evaporation for the dataset (1950–2003). Note that rainfall and evaporation are both very seasonal, with the wet months May to August having the most rainfall and least evaporation.

2.4 Stormwater Run-off

It is very important to understand that no stormwater run-off data was available to calibrate the model. Ideally, volumetric run-off coefficients would have been available (i.e. the volume of stormwater run-off divided by the volume of rainfall) for each surface type in the study area. This would have allowed us to adjust variables in the model such as “percentage effective area”, “initial loss” and “soil depth capacity” to calibrate the stormwater run-off with recorded results. The lack of stormwater run-off calibration means that the values seen in the results section can only be considered as indicative and should not be relied upon for design and treated with caution for decision making.
Figure H3: Average monthly rainfall

Figure H4: Average monthly evaporation
3 WATER BALANCE

3.1 Modelling approach

A water balance computer model ‘AQUACYCLE’ (Mitchell 2000) has been used to analyse the water balance outcomes for the various water servicing options considered for the area.

Aquacycle integrates potable water supply, wastewater reticulation and stormwater flows into a single framework, and thus provides a holistic view of the urban water system in terms of the total water management. It uses a daily time step and represents an urban area in a quasi-distributed manner. Climate, land use and water servicing options associated with infrastructure required are the inputs into Aquacycle. It is able to account for:

- A variety of land use types; residential, industrial, commercial, parks and public open spaces
- Different conventional water infrastructure designs such as combined sewers, septic tanks, separate stormwater systems, and groundwater bores
- Local climatic conditions.

Aquacycle has three nested spatial scales to describe the components of an urban area. The unit block (single allotment) represents a building and associated paved and pervious areas such as paths, driveways and gardens. The proportion of these areas are specified by the user, allowing a range of allotment types such as flats, commercial premises and industry to be represented as well as detached dwellings. The neighbourhood (cluster) comprises of a number of identical unit blocks as well as roads and public open space. The catchment represents the grouping of one or more clusters that may or may not have the same land use. The order in which stormwater and wastewater flows from one cluster to another can be specified by the user, providing the ability to represent how they actually flow through a catchment.

The different spatial scales allow a variety of different water infrastructure to be modelled, for example:

- At allotment scale – water usage efficiency, rain tanks, greywater collection and sub-surface irrigation, on-site wastewater collection, treatment and reuse.
- At neighbourhood scale – open space irrigation efficiency, aquifer storage and recovery, stormwater collection, treatment and use, and local wastewater collection, treatment and use.
- At catchment/estate scale - stormwater collection, treatment and use, and wastewater collection, treatment and use.

Assumptions used in modelling representation

The following assumptions have been made for the water balance of the development site:

- The geology has been considered constant throughout the area. This simplifies the data input requirements and allows the analysis of simulation results to focus on land use impacts alone, discounting impacts due to geological variations.
- 3% of stormwater infiltrates into the wastewater reticulation system.
- Indoor water use is constant throughout the year. There is no day-to-day and household-to-household variation considered.
- Garden irrigation was based on soil moisture content. Irrigation was performed when the soil moisture fell below a certain level. The level was calibrated based on the end use data shown in Table H6.

The calibration parameters used in the water balance modelling are given Table H8.
### Table H8: Aquacycle Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of pervious soil store 1 (%)</td>
<td>50</td>
</tr>
<tr>
<td>Capacity of soil store 1 (mm)</td>
<td>50</td>
</tr>
<tr>
<td>Capacity of soil store 2 (mm)</td>
<td>120</td>
</tr>
<tr>
<td>Roof area maximum initial loss (mm)</td>
<td>1</td>
</tr>
<tr>
<td>Effective roof area %</td>
<td>95</td>
</tr>
<tr>
<td>Paved area maximum initial loss (mm)</td>
<td>1.5</td>
</tr>
<tr>
<td>Effective paved area %</td>
<td>10</td>
</tr>
<tr>
<td>Road area maximum initial loss (mm)</td>
<td>1</td>
</tr>
<tr>
<td>Effective road area %</td>
<td>20</td>
</tr>
<tr>
<td>Base flow index</td>
<td>0.1</td>
</tr>
<tr>
<td>Base flow recession constant</td>
<td>0</td>
</tr>
<tr>
<td>Infiltration index</td>
<td>0</td>
</tr>
<tr>
<td>Infiltration store recession constant</td>
<td>0</td>
</tr>
<tr>
<td>% surface run-off as inflow</td>
<td>3</td>
</tr>
<tr>
<td>Garden trigger to irrigate</td>
<td>0.05–0.60</td>
</tr>
<tr>
<td>POS trigger to irrigate</td>
<td>0</td>
</tr>
<tr>
<td>Rainwater tank first flush</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3.2 Calibration of Garden Irrigation

Garden water use is not constant throughout the year. The data shown in Table H3,
Table H4 and Table H5 reflect this. Figure H5 shows the estimated garden irrigation data (estimated using the assumptions in Section 0) and the modelled garden irrigation for the “residential small” neighbourhood. The other neighbourhoods have a similar relationship between estimated and modelled irrigation. Due to the nature of the Aquacycle model it is not possible to exactly recreate the original data however, as can be seen in Figure H5, the two datasets are very close.

![Figure H5: Comparison of modelled and supplied garden irrigation data for “residential small”](image)

### 3.3 Results

#### 3.3.1 Base Case

As seen in Figure H6, wastewater discharge and imported water volume is fairly constant from year to year for the Woodanilling base case, hovering around 16 ML and 29 ML respectively. Imported water varies from a peak of 29 ML in 1972 to a trough of 22 ML in 1971. The variation in imported water volumes is caused by the amount of rainfall and evaporation which influences the amount of garden irrigation. The wastewater discharge is influenced by stormwater run-off, as it is assumed 3% of surface run-off infiltrates into the wastewater sewerage. Stormwater run-off is highly variable because it is heavily dependant on rainfall, varying from 22 ML in 1979 to 1221 ML in 1964.

As seen in Table H9, the average annual scheme water use, wastewater discharge and stormwater run-off is 25.7 ML per year, 14.9 ML per year and 242.9 ML per year respectively. The high stormwater run-off is due to the large rural area included in the study area. The rural area contributes 203.8 ML per year on average to stormwater run-off.

Stormwater run-off from the Woodanilling study area totals 243 ML/yr on average and this is largely from pervious areas (due to the large rural area included in the study). Run-off from the pervious areas is largely confined to the wettest months, June through to August, which make up over 75% of run-off. Run-off from residential roofs totals only 3.9 ML/yr due to the small number of houses (51).
Table H10 shows the breakdown in water consumption between indoor and outdoor use for different land use zones. Note that the total annual figure has been calibrated to Woodanilling end use data, the breakdown between zones has been calibrated to Woodanilling and the proportion of water used indoors and outdoors has been based on averages from monthly data from Katanning, Wongan Hills, Dowerin and Merredin.

Figure H6: Imported water consumption, stormwater run-off and wastewater discharge over time for Woodanilling base case

Table H9: Average yearly scheme water use, wastewater discharge and stormwater run-off for Woodanilling base case

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Scheme Water Use (ML/yr)</th>
<th>Wastewater Discharge (ML/yr)</th>
<th>Stormwater Run-off (ML/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Small</td>
<td>1.8</td>
<td>1.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Residential Medium</td>
<td>2.2</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Residential Large</td>
<td>7.2</td>
<td>4.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Semi-rural</td>
<td>6.4</td>
<td>4.3</td>
<td>17.0</td>
</tr>
<tr>
<td>Rural (no dwelling)</td>
<td>0.5</td>
<td>0.0</td>
<td>203.8</td>
</tr>
<tr>
<td>Industrial</td>
<td>3.0</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.0</td>
<td>1.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Community</td>
<td>1.5</td>
<td>0.4</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25.7</strong></td>
<td><strong>14.9</strong></td>
<td><strong>242.9</strong></td>
</tr>
</tbody>
</table>

Stormwater run-off from the Woodanilling study area totals 243 ML/yr on average and this is largely from pervious areas (due to the large rural area included in the study). Run-off from the pervious areas
is largely confined to the wettest months, June through to August, which make up over 75% of run-off. Run-off from residential roofs totals only 3.9 ML/yr due to the small number of houses (51).
### Table H10: Summary of end use for Woodanilling

<table>
<thead>
<tr>
<th>Month</th>
<th>Indoor Use (ML)</th>
<th>Outdoor Use (ML)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residential</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toilet</td>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Feb</td>
<td>0.17</td>
<td>0.65</td>
<td>1.07</td>
</tr>
<tr>
<td>Mar</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Apr</td>
<td>0.18</td>
<td>0.69</td>
<td>1.14</td>
</tr>
<tr>
<td>May</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Jun</td>
<td>0.18</td>
<td>0.69</td>
<td>1.14</td>
</tr>
<tr>
<td>Jul</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Aug</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Sep</td>
<td>0.18</td>
<td>0.69</td>
<td>1.14</td>
</tr>
<tr>
<td>Oct</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Nov</td>
<td>0.18</td>
<td>0.69</td>
<td>1.14</td>
</tr>
<tr>
<td>Dec</td>
<td>0.19</td>
<td>0.71</td>
<td>1.18</td>
</tr>
<tr>
<td>Total</td>
<td>2.23</td>
<td>8.40</td>
<td>13.87</td>
</tr>
</tbody>
</table>

### Table H11: Average monthly stormwater run-off and wastewater generation for Woodanilling base case

<table>
<thead>
<tr>
<th>Month</th>
<th>Wastewater generation (ML/y)</th>
<th>Total</th>
<th>Total Impervious</th>
<th>Residential Roofs</th>
<th>Other Impervious (roads, paved areas)</th>
<th>Total Pervious</th>
<th>Garden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.2</td>
<td>11.8</td>
<td>1.2</td>
<td>0.1</td>
<td>1.1</td>
<td>10.6</td>
<td>0.0048</td>
</tr>
<tr>
<td>Feb</td>
<td>1.1</td>
<td>10.2</td>
<td>1.8</td>
<td>0.2</td>
<td>1.6</td>
<td>8.4</td>
<td>0.0032</td>
</tr>
<tr>
<td>Mar</td>
<td>1.2</td>
<td>4.9</td>
<td>1.6</td>
<td>0.2</td>
<td>1.5</td>
<td>3.2</td>
<td>0.0000</td>
</tr>
<tr>
<td>Apr</td>
<td>1.2</td>
<td>3.1</td>
<td>2.5</td>
<td>0.2</td>
<td>2.3</td>
<td>0.6</td>
<td>0.0000</td>
</tr>
<tr>
<td>May</td>
<td>1.2</td>
<td>10.9</td>
<td>5.3</td>
<td>0.5</td>
<td>4.8</td>
<td>5.6</td>
<td>0.0001</td>
</tr>
<tr>
<td>Jun</td>
<td>1.4</td>
<td>47.8</td>
<td>7.1</td>
<td>0.7</td>
<td>6.4</td>
<td>40.7</td>
<td>0.0075</td>
</tr>
<tr>
<td>Jul</td>
<td>1.5</td>
<td>81.9</td>
<td>6.5</td>
<td>0.6</td>
<td>5.9</td>
<td>75.4</td>
<td>0.0326</td>
</tr>
<tr>
<td>Aug</td>
<td>1.4</td>
<td>52.7</td>
<td>5.4</td>
<td>0.5</td>
<td>4.9</td>
<td>47.3</td>
<td>0.0293</td>
</tr>
<tr>
<td>Sep</td>
<td>1.2</td>
<td>11.2</td>
<td>3.9</td>
<td>0.4</td>
<td>3.5</td>
<td>7.4</td>
<td>0.0048</td>
</tr>
<tr>
<td>Oct</td>
<td>1.2</td>
<td>2.6</td>
<td>2.5</td>
<td>0.2</td>
<td>2.3</td>
<td>0.1</td>
<td>0.0000</td>
</tr>
<tr>
<td>Nov</td>
<td>1.2</td>
<td>2.8</td>
<td>2.2</td>
<td>0.2</td>
<td>2.0</td>
<td>0.6</td>
<td>0.0000</td>
</tr>
<tr>
<td>Dec</td>
<td>1.2</td>
<td>3.1</td>
<td>1.3</td>
<td>0.1</td>
<td>1.2</td>
<td>1.8</td>
<td>0.0003</td>
</tr>
<tr>
<td>Total</td>
<td>14.9</td>
<td>242.9</td>
<td>41.2</td>
<td>3.9</td>
<td>37.3</td>
<td>201.7</td>
<td>0.0827</td>
</tr>
</tbody>
</table>
3.3.2 Scenario 2: Rainwater Tanks

Scenario 2 is an investigation into the effectiveness of rainwater tanks in reducing scheme water use and stormwater run-off. The size of rainwater tanks to be used was based on the volumetric efficiency curves shown in Figure H7.

Based on Figure H7, rainwater tanks of 10, 25, 40 and 20 kL have been adopted for residential small, residential medium, residential large and semi-rural properties. This is seen as a compromise between available space, cost and maximising volumetric efficiency. A tank of 40 kL may be considered too expensive for residential houses however this size has been modelled so the maximum impact of rainwater tanks can be ascertained.

Figure H8 shows that scheme water consumption varies over the modelling period from a peak of 26 ML in 1954 to 18 ML in 1971. This is a reduction in peak of 3 ML from the base case. Stormwater run-off varied from 20 ML in 1979 to 1218 ML in 1964.

Adoption of rainwater tanks in Woodanilling would mean approximately 3.4 ML of rainwater and 22.4 ML of scheme water consumed on average each year.
Figure H8: Imported water consumption, stormwater run-off and wastewater discharge over time for Woodanilling scenario 2

Table H12: Average yearly scheme water use, rainwater tank use, wastewater discharge and stormwater run-off for Woodanilling Scenario 2

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Scheme Water Use (ML/yr)</th>
<th>Rainwater Tank Use (ML/yr)</th>
<th>Wastewater Discharge (ML/yr)</th>
<th>Stormwater Run-off (ML/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Small</td>
<td>1.6</td>
<td>0.2</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Residential Medium</td>
<td>1.8</td>
<td>0.4</td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Residential Large</td>
<td>5.4</td>
<td>1.8</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Semi-rural</td>
<td>5.5</td>
<td>0.9</td>
<td>4.2</td>
<td>16.2</td>
</tr>
<tr>
<td>Rural (no dwelling)</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>203.8</td>
</tr>
<tr>
<td>Industrial</td>
<td>3.0</td>
<td>0.0</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.0</td>
<td>0.0</td>
<td>1.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Community</td>
<td>1.5</td>
<td>0.0</td>
<td>0.4</td>
<td>7.9</td>
</tr>
<tr>
<td>Total</td>
<td><strong>22.4</strong></td>
<td><strong>3.4</strong></td>
<td><strong>14.8</strong></td>
<td><strong>239.7</strong></td>
</tr>
</tbody>
</table>

Rainwater tanks would have very little impact on the stormwater run-off from Woodanilling as the vast majority of run-off comes from pervious areas. Residential roofs make up only a small portion of total stormwater run-off (see
Table H13).
Table H13: Average monthly stormwater run-off and wastewater generation for scenario 2

<table>
<thead>
<tr>
<th>Month</th>
<th>Wastewater generation (ML/y)</th>
<th></th>
<th>Stormwater Run-off (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tot.</td>
<td>Impervious</td>
<td>Residential Roofs</td>
</tr>
<tr>
<td>Jan</td>
<td>1.2</td>
<td>11.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Feb</td>
<td>1.1</td>
<td>10.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Mar</td>
<td>1.2</td>
<td>4.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Apr</td>
<td>1.1</td>
<td>2.9</td>
<td>2.3</td>
</tr>
<tr>
<td>May</td>
<td>1.2</td>
<td>10.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Jun</td>
<td>1.3</td>
<td>47.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Jul</td>
<td>1.5</td>
<td>81.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Aug</td>
<td>1.4</td>
<td>52.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Sep</td>
<td>1.2</td>
<td>11.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Oct</td>
<td>1.2</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Nov</td>
<td>1.1</td>
<td>2.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Dec</td>
<td>1.2</td>
<td>3.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Total</td>
<td>14.8</td>
<td>239.6</td>
<td>38.0</td>
</tr>
</tbody>
</table>

3.3.3 Comparison

Rainwater tanks have the capacity to reduce scheme water consumption by an average of 3.4 ML/year which equates to 13% (see Table H14 and
Table H15). The impact of rainwater tanks on stormwater run-off is minimal, reducing run-off by 3.3 ML or 1.3% on average per year. This is because the vast majority of stormwater run-off does not come from residential roofs.

**Table H14: Comparison of base case with scenario 2 for Woodanilling**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Imported Water Usage (ML/yr)</th>
<th>Wastewater Discharge (ML/yr)</th>
<th>Stormwater Run-off (ML/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>25.7</td>
<td>14.9</td>
<td>242.9</td>
</tr>
<tr>
<td>Rainwater Tanks</td>
<td>22.4</td>
<td>14.8</td>
<td>239.7</td>
</tr>
<tr>
<td>Saving</td>
<td>3.4</td>
<td>0.1</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Table H15: Percentage difference between base case and scenario 2

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Imported Water Usage (ML/yr)</th>
<th>Wastewater Discharge (ML/yr)</th>
<th>Stormwater Run-off (ML/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Small</td>
<td>10.3</td>
<td>0.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Residential Medium</td>
<td>19.4</td>
<td>0.9</td>
<td>31.6</td>
</tr>
<tr>
<td>Residential Large</td>
<td>25.5</td>
<td>1.2</td>
<td>22.8</td>
</tr>
<tr>
<td>Semi-rural</td>
<td>14.3</td>
<td>0.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Rural (no dwelling)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Community</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>13.1</td>
<td>0.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Figure H9 shows the variation in scheme water usage for each scenario over the modelling period. The base case reduces peak imported water usage from 29 ML in 1972 to 26 ML in 1954.

Figure H9: Imported water comparison for Woodanilling scenarios
4 DISCUSSION

4.1 Rainwater Tanks

Analysis of the results in Section 3.3 and the end use figures in Section 0 leads to a number of conclusions:

- Rainwater tanks have only a minor impact in reducing scheme water use, ranging from 10.3% for ‘small’ houses to 25.5% for ‘large’ houses.
- Rainwater tanks have only a minor impact in reducing stormwater run-off volumes. Whilst tanks are effective in capturing most roof run-off, this only makes up a small portion of total run-off.
- Very large rainwater tanks are required to achieve reasonable volumetric efficiencies due to the infrequent and highly seasonal rainfall. Rainwater tanks ranging from 10 to 40 kL were chosen to achieve volumetric efficiencies ranging from ~20% to ~50%. If there was no limitation on the size of rainwater tanks, the maximum volumetric efficiencies that could be achieved range from ~21% to ~60% depending on roof size and demand placed on the tank.

4.1.1 Rainwater tanks for irrigation only

Rainwater tanks in the Scenario 2 water balances were used for toilet flushing and irrigation rather than irrigation only despite the cheaper plumbing costs for supplying irrigation only. This is because irrigation is a highly seasonal demand with low demand during the wet winter months and very high demand during dry summer months. If rainwater tanks supplied irrigation only they would fail to meet demand in summer and would be of limited use in winter because there would be reduced demand. Much of the roof run-off would overflow from the rainwater tanks during winter months. Using rainwater tanks for toilet flushing, which has a constant demand, allows the rainwater tank to become more useful during the winter months because it can reduce demand on imported water and at the same time reduce roof run-off.

Table H16 shows a comparison of rainwater tanks supplying irrigation with rainwater tanks supplying irrigation and toilet flushing. The rainwater tank volumes are kept constant for each scenario and are the same volumes used in Scenario 2 (see Section 3.3). As expected, the saving in scheme water is higher when toilets are connected to the rainwater tanks as is the reduction in roof run-off.

It should be noted that the high irrigation demand mitigates the difference between the effectiveness of the two options. If irrigation demand was reduced, the difference between supplying ‘toilet and irrigation’ and ‘irrigation only’ would be increased (both for roof run-off and rainwater consumption).

Table H16: Comparison of rainwater tanks used for irrigation with irrigation and toilet flushing

<table>
<thead>
<tr>
<th></th>
<th>Irrigation</th>
<th>Irrigation and toilet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential roof run-off generation (ML/yr)</td>
<td>3.94</td>
<td>2.65</td>
</tr>
<tr>
<td>Raintank water use (ML/yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheme water supply saving (%)</td>
<td>Irrigation</td>
<td>10.3%</td>
</tr>
<tr>
<td>Scheme water supply saving (%)</td>
<td>Irrigation and toilet</td>
<td>13.1%</td>
</tr>
<tr>
<td>Residential roof run-off reduction (%)</td>
<td>Irrigation</td>
<td>67.2%</td>
</tr>
<tr>
<td>Residential roof run-off reduction (%)</td>
<td>Irrigation and toilet</td>
<td>85.4%</td>
</tr>
</tbody>
</table>
4.1.2 Outdoor Water Use

Outdoor water use in Woodanilling is estimated to be 55 kL/capita/month (Table H17). This compares to the Western Australian average for 2000-01 of 66 kL/capita/year (ABS 2004) and the Perth single residential average of 77 kL/capita/year (Loh & Coghlan 2003). The reasons for discrepancies are plentiful and may include climate, cultural factors (e.g. socially acceptable garden type), land block size, population density, soil type and existing alternative water sources for irrigation.

Seasonal variation in residential outdoor water use ranges from 12 kL in July to 1103 kL in January (see Table H17). The extreme variation in irrigation consumption is a direct result of the extremely seasonal climate (see Figure H3 and Figure H4).

Table H17: Outdoor water use (residential) summary

<table>
<thead>
<tr>
<th>Month</th>
<th>Total (kL/month)</th>
<th>Per Capita (kL/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1103</td>
<td>8.7</td>
</tr>
<tr>
<td>Feb</td>
<td>923</td>
<td>7.3</td>
</tr>
<tr>
<td>Mar</td>
<td>1035</td>
<td>8.2</td>
</tr>
<tr>
<td>Apr</td>
<td>740</td>
<td>5.8</td>
</tr>
<tr>
<td>May</td>
<td>451</td>
<td>3.5</td>
</tr>
<tr>
<td>Jun</td>
<td>69</td>
<td>0.5</td>
</tr>
<tr>
<td>Jul</td>
<td>12</td>
<td>0.1</td>
</tr>
<tr>
<td>Aug</td>
<td>15</td>
<td>0.1</td>
</tr>
<tr>
<td>Sep</td>
<td>175</td>
<td>1.4</td>
</tr>
<tr>
<td>Oct</td>
<td>588</td>
<td>4.6</td>
</tr>
<tr>
<td>Nov</td>
<td>818</td>
<td>6.4</td>
</tr>
<tr>
<td>Dec</td>
<td>1053</td>
<td>8.3</td>
</tr>
<tr>
<td>Total</td>
<td>6981</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Outdoor water use in the non-residential areas was estimated to vary from 48 kL in July to 1,298 kL in January.
4.1.3 End use demand management

End use demand management is a very effective way of reducing water consumption. End use demand management could be in the form of structural changes, such as water efficient showerheads, revised garden landscaping or water efficient washing machines; or in the form of non-structural changes, such as educating consumers to reduce consumption. A study of the impact of structural end use demand management in Canberra (Diaper et al. 2003) reported annual water savings that can be achieved from water efficient appliances as:

- Water efficient dishwashers - save 0.6 kilolitres per year per household
- Water efficient showerheads - save 26 kilolitres per year per household
- Dual flush toilets - save 18 kilolitres per year per household
- Water efficient washing machines - save 10 kilolitres per year per household

This amounts to 55 kL of water per house annually that can be saved with adoption of water efficient appliances and does not include improved garden irrigation practices or non-structural demand management.

The saving of 55 kL per house per year for Canberra is not directly transferable to Woodanilling however it can be safely assumed that significant savings can be made. Estimated indoor end use for Woodanilling (228 L/cap/day) is well above the state average of 181 L/cap/day (ABS 2004) and the Perth average for single residential homes of 155 L/cap/day (Loh & Coghlan 2003). If scheme water use for Woodanilling is to be reduced, end use demand management should be considered as a means of achieving this.

4.1.4 Reclaimed water and stormwater collection and use

Stormwater collection and use, and reclaimed water collection and use, should both be considered to supplement scheme water. The annual stormwater run-off figures are high enough to warrant further analysis, however the infrequent and seasonal nature of rainfall would require a large storage. The storage volume could be minimised if Aquifer Storage and Recovery (ASR) is possible because this...
would minimise the evaporation from the storage. It should also be noted that the annual stormwater
run-off figures include areas beyond the immediate township and it may not be practical to collect all of
the stormwater run-off. Stormwater collection and use for toilet flushing and irrigation has the potential
to reduce scheme water consumption by roughly 35% to 50% however these figures would need to be
confirmed by more detailed analysis.

Reclaimed water use (say for toilet flushing and irrigation) should also be considered. Reclaimed water
use has the benefit over stormwater collection and use in that the supply is constant and not subject to
seasonal variation. This means the size of the reclaimed water storage will be significantly less than
stormwater storage with the same volumetric efficiency. Reclaimed water use for toilet flushing and
irrigation has the potential to reduce scheme water consumption by roughly 40% (further detailed
analysis would be required to confidently predict this figure).

4.1.5 Plumbing costs

It is difficult to exactly estimate the cost of rainwater tanks as the cost will vary from one place to
another. The information in this section has been collected from suppliers, websites and past studies.
The cost of the rainwater tanks from some manufacturers is listed in Table H20. The prices are
indicative for estimation purposes only.

In addition to cost of the rainwater tanks there are a number of other items to be considered for costing
such as transportation, installation, additional plumbing, first flush devices, maintenance and insect
proof screening. Some of these costs have been estimated by Grant et al. 2003 and shown in Table
H19. This should only be considered as indicative because installation costs are site specific.

Based on Table H19 and HTable H20 the total cost of a 20 kL tank should be around $3,195 as shown in
Table H21.

<table>
<thead>
<tr>
<th>Table H19: Rainwater tank installation and pump costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Pipes and fittings</td>
</tr>
<tr>
<td>Plumber charges</td>
</tr>
<tr>
<td>Pump</td>
</tr>
<tr>
<td>Electrician</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table H20: Cost of rainwater tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank capacity</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Litres</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1,000</td>
</tr>
<tr>
<td>1,300</td>
</tr>
<tr>
<td>1,500</td>
</tr>
<tr>
<td>2,000</td>
</tr>
<tr>
<td>2,250</td>
</tr>
<tr>
<td>3,000</td>
</tr>
<tr>
<td>3,300</td>
</tr>
<tr>
<td>3,600</td>
</tr>
</tbody>
</table>
### Table H21: Total cost of 20 kilolitre rainwater tank

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 kL Tank</td>
<td>2,375</td>
</tr>
<tr>
<td>Delivery</td>
<td>100</td>
</tr>
<tr>
<td>Installation</td>
<td>720</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,195</strong></td>
</tr>
</tbody>
</table>
5 CONCLUSION

Residential water consumption in Woodanilling, 139 kL/capita/year, is high by Western Australian standards of 132 kL/capita/year (ABS 2004) for 2000-2001 and the Perth average for single residential households of 136 kL/capita/year (Loh & Coghlan 2003).

Estimated stormwater run-off from the study area (Table H22) is significant, exceeding the total scheme water use on an average annual basis. This does not necessarily mean stormwater collection and use is a suitable water management option. The numbers in Table H22 are average annual and do not reflect the highly seasonal and infrequent nature of stormwater run-off. They are also for large areas beyond the immediate township which may be impractical for collecting run-off. It should also be remembered that the stormwater numbers are not calibrated to real data and are estimates based on a series of assumptions.

Wastewater discharge from the study area (Table H22) is also significant and wastewater treatment and re-use could also be considered. Values in Table H22 are more reliable than the stormwater numbers because they are based on data provided by the Water Corporation. The average annual wastewater discharge is lower than the stormwater discharge however this does not necessarily mean stormwater collection and use is a preferable option to wastewater treatment and re-use. Wastewater is constant which means the reliability of its re-use is higher than stormwater use for the same sized storages.

<table>
<thead>
<tr>
<th>Table H22: Water balance summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
</tr>
<tr>
<td>Climate (mm/year)</td>
</tr>
<tr>
<td>Rainfall</td>
</tr>
<tr>
<td>Evaporation</td>
</tr>
<tr>
<td>Water Supply (ML/y)</td>
</tr>
<tr>
<td>Indoor</td>
</tr>
<tr>
<td>Outdoor</td>
</tr>
<tr>
<td>Water Supply (kL/cap/y)</td>
</tr>
<tr>
<td>Indoor</td>
</tr>
<tr>
<td>Outdoor</td>
</tr>
<tr>
<td>Residential Water Supply (kL/cap/y)</td>
</tr>
<tr>
<td>Indoor</td>
</tr>
<tr>
<td>Outdoor</td>
</tr>
<tr>
<td>Wastewater</td>
</tr>
<tr>
<td>(kL/cap/y)</td>
</tr>
<tr>
<td>Stormwater Run-off</td>
</tr>
<tr>
<td>(kL/cap/y)</td>
</tr>
</tbody>
</table>

Rainwater tanks will only reduce scheme water consumption by 13.1% and stormwater run-off by 1.3%. Rainwater tanks are very good at intercepting roof run-off however this only makes up a small portion of total stormwater run-off. Even though roof run-off is reduced by 85.4%, stormwater run-off is reduced by only 1.3% (see Table H23).
Table H23: Rainwater tank summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential roof run-off generation (ML/yr)</td>
<td>3.94</td>
</tr>
<tr>
<td>Raintank water use* (ML/yr)</td>
<td>3.37</td>
</tr>
<tr>
<td>Scheme water supply saving (%)</td>
<td>13.1%</td>
</tr>
<tr>
<td>Residential roof run-off reduction (%)</td>
<td>85.4%</td>
</tr>
<tr>
<td>Stormwater run-off reduction for study area (%)</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

*This is equal to roof run-off reduction (ML/yr)

To achieve significant improvements in water management, i.e. to achieve a reduction in scheme water consumption, wastewater discharge and stormwater run-off, measures beyond rainwater tanks need to be considered. Other management options such as end use demand management, stormwater collection and use, groundwater extraction and use, greywater use and treated water use need to be considered if greater reductions in scheme water consumption, wastewater discharge and stormwater run-off are to be achieved.
REFERENCES


APPENDIX I: METHODOLOGY

CONTENTS

1. INTRODUCTION ............................................................................................................ I3
2. EXPERT SYSTEMS AND THEIR APPLICATIONS ................................................................. I4
3. FRAMEWORK FOR PRIORITISATION OF THE WATER MANAGEMENT OPTIONS............... I6
   3.1 Question 1: Is salinity a significant problem in the town? ........................................ I8
   3.2 Question 2: How is salinity best managed?.............................................................. I10
   3.3 Question 3: Is there significant demand for new water supply? ..................... I13
   3.4 Identifying the scope for the Water Management Plan and ranking the water management options ............................................................................................................. I16
4. CONCLUSIONS ........................................................................................................... I19
5. REFERENCES .............................................................................................................. I20

ATTACHMENT I1. WATER MANAGEMENT OPTIONS FOR WOODANILLING ......................... I22
1. INTRODUCTION

Current water management practice and townsite salinity issues in the Rural Towns - Liquid Assets towns have certain similarities which are associated with their water supply, geological and geographical characteristics of the townsite catchments and history of development. Commonly, all towns experience certain damage to the local infrastructure due to the corrosive effects of saline soil and groundwater. There is also a concern related to fresh water availability, its quality and costs associated with water delivery to the towns.

Variations in townsite characteristics influence the town-specific water management issues and priorities.

Urban salinity and waterlogging may be related to the regional processes (such as rising regional groundwater levels or regular flooding), localised processes (such as enhanced infiltration as a result of water use in the towns or stormwater ponding in landscape depressions and upstream from local infrastructure such as roads) or both. Accordingly, water management options or their combination will be different in each case. For instance, in a case of a rising regional groundwater levels, stormwater management may provide only a limited capacity to control salinity in the towns, and groundwater abstraction may become an important component of the water management plan. On the other hand, stormwater management may be adequate when salinity is caused by localised surface water accumulation.

It is important to note that the social survey, undertaken during 2004-05, indicated that local communities often do not consider townsite salinity as a pressing issue for their towns. Wall rendering is often used to protect local buildings, regular road repairs cover the damage caused by waterlogging, and overall salinity becomes a background feature of townsite life which often remains unnoticed.

Similarly, issues related to water supply were not identified by the towns’ residents as serious. Most of the towns included in the project have no restrictions on water use. However, the local shires are concerned with the cost of irrigation of recreation grounds and parks. Although local non-potable water sources are available (such as treated wastewater and local dams), they do not provide a sufficient and reliable resource. Accordingly, scheme water is often used for watering public areas.

The current water price, while it may be considered high by the shires, is nevertheless heavily subsidised by the State Government, so that the introduction of any new water supply may be limited by current water pricing policy. It is important to define conditions/circumstances when an alternative supply may be cost effective (such as government subsidies, price policy alteration, etc).

Interestingly, many communities desire to beautify their townsites, which largely relates to improvement of vegetation ('leafy streets') and therefore requires additional water for irrigation.

New alternative local water supply sources may be possible through:

- surface water harvesting in the vicinity of the townsite;
- restoration of the existing large dams previously used for the water supply (and still owned by the Water Corporation); and/or
- desalination of groundwater, produced by methods to control groundwater levels under the towns.
Each town requires an evaluation and comparison of various, and sometimes conflicting, objectives and water management options. This prioritisation framework aims to navigate a path through townsite’s specific issues and to facilitate development of the strategy for each townsite investigation and water management plan design.

The nature of the task is well suited to an expert system (ES) methodology. An important outcome of this approach is providing a transparent, while structured and knowledge-based appraisal of complex issues and solutions leading to a Water Management Plan that is more likely to be accepted by shareholders. Furthermore, this approach facilitates the integration of outcomes from multidisciplinary research employed in the project. The disciplines encompassed hydrogeology, geophysics, surface hydrology, water quality, urban drainage, social and economic studies.

A general description of expert systems approach is provided in Section 2. Section 3 details the methodology as applied to this project. The methodology is presented in several steps; each step is illustrated in Section 4 using the information collected/generated for the four towns currently undergoing investigations.

The approach described has been developed and adopted within Rural Towns – Liquid Assets and approved by the project management team.

2. EXPERT SYSTEMS AND THEIR APPLICATIONS

The study of water related management issues and decision options are a complex interaction of disciplines and social and economic criteria. Development of expert systems (ES) and multi-criteria analysis (MCA) enables a simpler framework to tackle a complex problem for the decision maker. Use of MCA and ES provide a greater understanding of the problem for decision makers through a simplistic, transparent and systematic evaluation that can be repeated and modified as required (Özelkan and Duckstein 1996, Verbeek et al. 1996). MCA and ES provide a better general understanding of the structure of problems as well as a better understanding of possible outcome options and the prioritisation of options (Özelkan and Duckstein 1996). This is increasingly important as public awareness of environmental issues increase and valuable public input is included in a MCA or ES. (Khadam et al. 2003).

Expert systems are a branch of applied artificial intelligence (AI), which were broadly developed in mid-1960s (Liao 2005). An ES allows expert knowledge to be transferred to a computer program in a structured manner, which can then be used if specific advice is needed. They often use heuristic reasoning rather then numeric calculations, focus on acceptable rather then optimal solutions, allow separation knowledge and control, and incorporate human expertise. They also tend to be suitable for ill-structured and semi-structured problems (Shepard 1997). They are usually developed for specific domains rather then for a generic application. ES development requires a degree of interaction between the system developer and the user.

An ES can provide a powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional methods. They are particularly useful when multi-disciplinary complex problems are addressed. There are a number of ES categories (e.g. rule-based systems, knowledge-based systems, neural networks, fuzzy expert systems etc) which may be applied to a variety of the subjects such as system development (Mulvaney and Bristow 1997), geoscience (Soh et al. 2004), environmental protection (Gomolka and Orlowski 2000), urban design (Xirogiannis et al. 2004), waste management (Fu 1998), ecological planning (Zhu et al. 1996), water supply forecast (Mahabir et al. 2003) and others.
The report presents the initial stage of an expert system development aiming to support decision making on water management improvement in WA rural towns. As such it describes an algorithm which in the later stage could be translated to a computer-based ES.

Key to the development of MCA and ES systems is the identification of decision objectives. Decision objectives will form the foundation of criteria used in the MCA and ES. The objectives can be translated into measurable criteria that reflect the common questions of the decision maker (Rosa et al. 1993, Verbeek et al. 1996, Khadam et al. 2003). Carter et al. (2005) and Chen et al. (2005) used MCA for water management based on a long term objective of water demand and consumption coupled with resource availability and efficiency of use. Objective based criteria and expert knowledge can be factored together with management policy, public values and political and administrative criteria that is difficult to quantify (Rosa et al. 1993, Verbeek et al. 1996). An integrated approach to water management is widely accepted, it can highlight the interactions between ground and surface water and between water and human factors (Carter et al. 2005). Carter et al. (2005) gives the example of urban development policy compromising groundwater recharge and quality. Rosa et al. 1993 used an ES to assess the field vulnerability of agrochemicals. The system combined local factors relating to soils, climate, water and chemicals with land management factors. Verbeek et al. 1996 used and MCA that combined various models and administrative policies to create an integrated decision support system.

The majority of MCA and ES within water management can be classed into two groups. Those that assess the physical aspect of water management, such as risk assessment (Khadam et al. 2003), condition classification, vulnerability (Rosa et al. 1993), and those that assess the outcomes of water management such as, reactions to policy and various options (Bethune 2004). Khadam et al. (2003) used MCA to assess risk of contaminated ground water, when risk was analysed as being un-acceptable a number of remedial alternative were identified. MCA analysis was also used to rank the remedial measures. Khadam et al. (2003) stated that when no one dominant measure can be identified as either the best or worst, MCA was a useful tool in ranking the outcomes. MCA has been used to assess options for the abstraction of bores at risk of chlorinated solvents. MCA was used in two parts, firstly problem identification and secondly for the prioritisation of monitoring strategies (Tait et al. 2004). Lee et al. (1997) studied the use of a fuzzy ES for the classification of stream water quality. The ES was focused on streams for which quantitative water quality data was not collected. Using ecological information to classify the streams, based on physical characteristics (e.g. turbidity) and biological indicator species, the results showed that the fuzzy ES represented the real world well and better than conventional ES.
3. **Framework for Prioritisation of the Water Management Options**

A proposed framework is presented in Figure 1 and outlined below. RT-LA has two main objectives: mitigation of townsite salinity and opportunities for new water supply resources.

Within these objectives, the framework will help identify the townsite’s specific issues, related to current water management and within existing and forecasted constraints such as

- policy changes;
- consideration for regional priorities; and / or
- water pricing changes.

As shown in Figure 1, the identified issues could be outside the project scope (e.g. limitation in energy supply, demographic trends), but those which are relevant to the project objectives need to be considered within the context of the Triple Bottom Line (TBL). Those solutions may be directly related to water resources management (groundwater or surface water) or water use/demand management. Alternatively they may be addressed by measures unrelated to the water management options, such as infrastructure modification providing a barrier between infrastructure and soil moisture or water efficient appliances, reducing potable water demands in the town.

The proposed solutions can be ranked, costed and brought to the stakeholders’ attention. The water management options selected as a result of community consultations will be recommended for an engineering evaluation and be included in the Town Integrated Water Management Plan.

The framework was developed to accommodate the project specific conditions, and as such is applicable at various stages in project development. It is also based on the data available to the project at its different stages.

1. **Townsite investigation strategy.** The framework enables to help define the townsite specific issues and to guide the townsite investigation program.

   At this stage the discussion-making process is largely based on the data generated by the Department of Agriculture Rural Towns Program, which among other aspects includes groundwater monitoring records, preliminary geological/hydrogeological system description based on the drilling program and a flood risk evaluation.

2. **Evaluation of the town’s water needs and the availability of local water resources to satisfy demands.** At this stage the framework guides the ‘water audit’ process, when the local water resources, defined during the townsite investigation program, are considered simultaneously with town water demand and in the context of the current water supply.

   Local water resources include stormwater generated within the townsite, waste water and local groundwater. The methodology for the townsite water balance evaluation is described in the report Water Balance Study of Wagin, Lake Grace, Nyabing and Woodanilling’ (Grant and Sharma 2005). Groundwater resources were defined as a result of the hydrogeological investigations (supported by a geophysical survey, CRC LEME and DAWA) and groundwater modelling, outlined in the report by Barr 2005.

   Water supply data for each town has been provided by the Water Corporation, while local shires supplied information on water use for community purposes within each town.
APPENDIX I: METHODOLOGY

Project steps within an individual Rural town

Main project themes

- Water demand (current and projected)
- Infrastructure damage by salinity/waterlogging

Strategic plans and external constraints:
- policy change
- regional priorities
- water price change
- other

Town specific issues

Is there a need to look for solution within this project?

NO

Another location

YES

Seek solution within Triple Bottom Line context

Water related solutions

- Groundwater
- Surface water
- Change in practices
- Other

Non water related solutions

- Modify infrastructure
- Other

Is solution acceptable to stakeholders?

NO

YES

Water resources management plan

Figure I1: The framework for townsite prioritisation

3. Selection of the townsite water management options. The framework leads to definition of the generic water management options and provides the basis for their prioritisation. It is particularly valuable that the framework facilitates engagement of the local communities in this process.
The main outcome at this stage is a final scope for the Water Management Plan (WMP) individually designed for townsite-specific conditions. Ideally WMPs also need to address new water demands for townsite beautification, industry development and introduction of demand management options (alternative water appliances, third pipe, rainwater tanks for toilet flushing and others).

An integrated townsite water management plan is required to address both urban salinity and the potential for developing new water resources. This framework allows facilitating the selection of water management options, while clarifying three major questions:

- Is salinity a significant problem in a town?
- If so, how is it managed best?
- Is there sufficient demand for a new water supply?

### 3.1 Question 1: Is salinity a significant problem in the town?

As mentioned, townsite salinity is not often considered by the local communities as a pressing issue. However, in some cases this opinion may be contradicted by observed salinity-related damage of local infrastructure. There were also references to the estimated cost of townsite infrastructure damage as close to $50M over the next 30 years (URS 2001).

Figure I2 illustrates a structured approach to verify the query if salinity control should be included in the RT-LA scope. The decision here is largely based on the available data generated during the townsite monitoring undertaken by Rural Towns Program.

At this stage the framework required identification of the following:

1. **Stormwater accumulation**

   If there is a potential for surface water accumulation within the townsite during storm events or flooding, then salinity may potentially become an issue within the affected areas.

2. **Average annual groundwater level within townsite**

   For the purposes of the townsite prioritisation it is feasible to use the trigger value for the groundwater level (1.8 m) proposed by Nulsen (1989). It was assumed that this depth indicates an annual average groundwater level. For more detailed analysis a salinity risk assessment could be used (Barron et al. 2005).
3. Groundwater level trends

If the groundwater level was found to be below the trigger depth, it is also important to define trends in fluctuation. If an upward trend is observed then salinity may potentially become an issue, and further investigations are required to support a decision making process.

4. Section of the townsite affected by shallow groundwater table

Due to landscape, depths to the groundwater table within townsites may vary, and salinity processes may affect only a limited part of the townsite. In this case the requirements for salinity management need to be defined based on an evaluation of infrastructure damage cost, and are unlikely to be significant if the annual average groundwater level <1.8 m occur
within less than 10% townsite. At this stage the assessment is based on the up to date experience within RT-LA, but further evaluation is required.

5. Infrastructure damage within the area affected by salinity

The final decision on an individual case is made based on the type of infrastructure affected and should include consultation with community/shire representatives.

The proposed triggered values for an annual average groundwater level and extent of the affected townsite area are indicative at this stage and require further verification.

3.2 Question 2: How is salinity best managed?

Once salinity is defined as a townsite issue, a number of options may be applied to control the process. They may include shallow and deep drainage, groundwater pumping or surface water rerouting. There may also be options which are not related to water management (such as the use of salt-resistant construction materials, infrastructure relocation or land use alteration). In order to develop the most appropriate salinity control measures, it is important to define the nature of the salinity process in the townsite, which will allow dealing with the causes of salinity development rather then its manifestation. The methodology to verify the answers to this question is shown in Figure I3.

Within the framework the characterisation of the salinity is considered in the context of the shallow groundwater balance, where possible water fluxes within the shallow groundwater system are defined (Table I1).

Often the groundwater systems in the WA wheatbelt consist of shallow and deeper aquifers. The difference between the groundwater table and hydraulic head of the deeper aquifer describes the vertical groundwater gradient, and provides an indication of the shallow water balance components. A downward gradient (the groundwater table is positioned above the hydraulic head of the deeper aquifer (Figure I4) indicates a downward flux from the shallow to the deep groundwater system (providing the shallow and deep aquifers are hydraulically connected). In such a case the drawdown of the shallow groundwater table may be achieved by reduction in the local groundwater recharge, such as the elimination of stormwater accumulation or alteration in the gardens/parks irrigation regime. This scenario provides an opportunity for surface water harvesting in the townsite (subject to water quality).

Where the hydraulic head in the deeper aquifer is above the groundwater table (Figure I4), the upward groundwater fluxes are likely to contribute to salinity development (providing that there is a hydraulic connectivity between these two systems). In such a case, local groundwater recharge control may provide only limited capacity as a salinity control measure, and groundwater abstraction from the deeper groundwater system may be required.

The abstracted water is likely to be brackish or saline and may be reused after treatment (desalination). Additionally there may be an alternative use, such as irrigation of salt tolerant turf and shrubs. The effectiveness of this option will depend upon aquifer transmissivity, which may be limited.
APPENDIX I: METHODOLOGY

Figure I3: Management options for waterlogging and salinity control
Figure I4: Variation in the vertical groundwater gradient (downward and upward)
Table I1: Shallow groundwater fluxes

<table>
<thead>
<tr>
<th>Shallow groundwater recharge</th>
<th>Shallow groundwater discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional infiltration (rainfall)</td>
<td>Evaporation/evapotranspiration from the shallow groundwater table</td>
</tr>
<tr>
<td>Local infiltration (surface water accumulation or water use practice, e.g. parks’ irrigation)</td>
<td>Throughflow</td>
</tr>
<tr>
<td>Upwards fluxes from deeper groundwater systems</td>
<td>Downwards fluxes to deeper groundwater systems</td>
</tr>
</tbody>
</table>

3.3 Question 3: Is there significant demand for new water supply?

Water use in WA rural towns predominantly relies on the scheme water supply, which is supplemented by treated waste water and surface water harvested in the local dams. Commonly water supply from the local resources combines up to 90% treated waste water and up to 25-30 ML harvested water. Local dam capacity in some towns is not sufficient to supply scheme water needs throughout the dry season, and the quality may be poor for drinking. The local fresh water resources are used by the shires for irrigation of the town parks and sport grounds, often in combination with scheme water.

Drinking water demands in towns are commonly satisfied by the existing water supply scheme. Scheme water use is currently restricted only in towns located along the Goldfields and Agricultural Water Scheme.

It is important to identify the motivation of rural town communities to develop a new or alternative water supply. The requirement for new water resources is often driven by the water costs, which are considerable for the larger rural water users, such as Shires and industrial groups. For instance, the annual water cost of the Katanning meatworks (WAMMCO) is in the range of $0.5M, while the Shire of Wagin scheme water use costs up to $20K per year (Woodanilling to $8K, Nyabing to $6K, and Lake Grace up to $18K).

Rural water supply is subsidised by Community Service Obligations (CSOs) and as a result rural town water tariffs at the lower ranks of water use (350 KL) are comparable with metropolitan water prices. The introduction of new local water resources, potentially including desalination of saline groundwater, is likely to carry much greater cost, and as such could be a less favourable alternative to the current water supplies.

The Water Management Plan aims to address the current water demands and water quality constraints for townsite water supply. It also identifies potential water users if additional water supplies become available. This is preferably considered simultaneously with the water management options proposed to mitigate townsite salinity, as proposed within the framework and demonstrated in Figure I5.

On the other hand it is anticipated that there may be demands for three main water types:

1. Potable water for human consumption and some industrial use which may have specific water quality requirements: Supply of this water type is a subject to rigorous regulation and any new potable water resources will need to health standards and risk management.

2. Fresh water for non-potable use for irrigation of domestic gardens and townsite parks and ovals.

3. Brackish/saline water, which is not commonly used in towns, but the opportunities for brackish/saline water use for irrigation of salt-tolerant turf or aquiculture are within the scope of this project.
The potential sources for those water demands are summarised in Table I2.

**Table I2: Sources of the local water resources**

<table>
<thead>
<tr>
<th>Water quality</th>
<th>Sources of water resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Potable water</strong></td>
<td>Potable water demand may be reduced by the introduction of alternative indoor water appliances or supplementing outdoor water use with fresh, but non-potable water supply.</td>
</tr>
<tr>
<td></td>
<td>New potable water may be generated via groundwater desalination, providing the local groundwater water quality and quantity are adequate for desalination (contributing to salinity risk reduction).</td>
</tr>
<tr>
<td><strong>Fresh water for non-potable use</strong></td>
<td>New resources may be generated via townsite stormwater harvesting (contributing to salinity risk reduction).</td>
</tr>
<tr>
<td></td>
<td>Catchment water harvesting or improvement of the existing dams (dam catchment enhancement, dams’ alteration) may provide additional fresh water resources. In some cases (as in Lake Grace) this option will also reduce the salinity risk within the townsite.</td>
</tr>
<tr>
<td></td>
<td>Abandoned Water Corporation dams, previously used for local water supplies.</td>
</tr>
<tr>
<td><strong>Brackish/saline water</strong></td>
<td>Brackish/saline water used for irrigation of salt-tolerant turf.</td>
</tr>
<tr>
<td></td>
<td>Brackish/saline water used for aquiculture.</td>
</tr>
</tbody>
</table>
Figure I5: Townsite water demands
3.4 Identifying the scope for the Townsite Water Management Plan and ranking water management options

As described above the framework is designed to identify both key issues and potential water management options which in turn lead to the definition of the townsite water management plan scope.

The most commonly considered generic water management options are given in Table 3. The final decision on the WMP scope is based on comparisons and ranking of the preliminary selected options in view of the cost of their implementation and maintenance, local community preferences and environmental safety.

To guide community engagement in the process of water management option selection, a multi-criteria ranking system was employed. The method allowed the ranking of water management options, based on the following:

- 12 selection criteria;
- criteria weighting as an identification of its relevance to an individual town’s needs and/or community aspiration; and
- option score identifying the relevance of an individual water management option to satisfy the relevant criteria.
Table 13: Water management options aimed at improving rural town water management (the current batch of rural towns fit within a number of the shaded yellow boxes)

<table>
<thead>
<tr>
<th>Additional water demands</th>
<th>Potable water</th>
<th>Non-Potable Water</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
<td>Brackish/Saline</td>
<td></td>
</tr>
<tr>
<td>Townsite stormwater management</td>
<td>Direct use</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment and reuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater abstraction</td>
<td>Direct use</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement in townsites water use</td>
<td>Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of the salt resistant building materials</td>
<td>Reuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An example of the criteria, their weighting and scoring system is given in Table 14. While there is a suite of common criteria, their final selection is town-specific and needs to be defined in consultation with main stakeholders.

This approach may be further expanded to more refined multi-criteria analysis.
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weighing factor (1-10)</th>
<th>Option score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in infrastructure damage</td>
<td>$&gt;100,000</td>
<td>$50,000-$100,000</td>
</tr>
<tr>
<td>Additional water supply</td>
<td>Reliable new water resource available for new user</td>
<td>Above current Shire water demand to support townsites beautiful</td>
</tr>
<tr>
<td>Capital cost for the option</td>
<td>$&lt;0.25M</td>
<td>$0.25-$1.0M</td>
</tr>
<tr>
<td>Annual operating and maintenance cost</td>
<td>$&lt;50,000</td>
<td>$50,000-$100,000</td>
</tr>
<tr>
<td>Is the technology proven?</td>
<td>Yes</td>
<td>Sometime used</td>
</tr>
<tr>
<td>Energy requirements</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Ease of operation</td>
<td>Fully automated</td>
<td>Some manual input</td>
</tr>
<tr>
<td>Downstream income</td>
<td>Economic Profitable</td>
<td>Positive benefit within TBL</td>
</tr>
<tr>
<td>Shire resources to implement the option</td>
<td>No resources required</td>
<td>Minimum resources required</td>
</tr>
<tr>
<td>Potential external funding</td>
<td>Fully sponsored by external sources</td>
<td>Partly sponsored by external sources</td>
</tr>
<tr>
<td>Employment</td>
<td>Long term employment</td>
<td>Short-term and long-term employment</td>
</tr>
<tr>
<td>Downstream environmental impact</td>
<td>Low risk</td>
<td>Medium risk</td>
</tr>
</tbody>
</table>
4. **CONCLUSIONS**

The proposed methodology facilitates prioritisation of water management options in WA rural towns. The framework has been adopted by the project team to guide the project through investigations of the next 12 towns.

The framework identifies the most important issues related to townsite water management, which provides a number of benefits:

- Identification of the research focus area within each town;
- Simultaneous identification of issues and opportunities which could be addressed by townsite water management plans;
- Linkage of water demands with potential water resources;
- Engagement of local community in the decision make process; and
- The structured format for a further expert system development.

The framework is applicable at various stages of the townsite investigations and water management plan development:

- Research initiation which can be focused on the identify priority issue;
- Selection of water management options to utilise local water resources and match them to townsite water demands; and
- Prioritisation of the water management options in consultation with the local community.

It is anticipated that the framework will be advanced during the next stages of the RT-LA project with opportunities possible in the following areas:

- Advancement in the integration of the social aspects in the framework, which will provide greater community engagement in the water management plan design and therefore ensure community ownership and its implementation;
- Deliver greater scientific platform for the expert system and multi-criteria analysis; and
- Potential computerisation of the framework aiming for design of a user-friendly tool for decision making process by various stakeholders.
5. References


ATTACHMENT I1. WATER MANAGEMENT OPTIONS FOR WOODANILLING

The generic water management options are given below, while WMPs developed by KBR provide detailed description of the finally selected option and their cost.

Woodanilling water management plan

1. Salinity management options (lower priority)
   a. Stormwater management
      Scenario 1: stormwater harvesting within the townsite eliminating stormwater accumulation in the lower part of the town
   a. Non water related management options
      Scenario 1: introduction of salt resistant constriction materials in the new urban development

2. Water supply options
   a. Fresh non-potable water supply
      Scenario 1: from stormwater harvesting within the townsite, subject to water quality
      Scenario 2: new water supply dam development
      Scenario 3: improvement of the current water supply dam (dam catchment improvement/extension, leakage limitation, evaporation reduction)
   b. Brackish water supply
      Scenario 1: salt-tolerant turf irrigation.
APPENDIX J

Engineering Analysis

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Telephone (08) 9278 4100  Facsimile 9278 4200

21 December 2005
# Contents

1 INTRODUCTION ......................................................................................................................... J3

1.1 Objectives of this Study ................................................................................................................J3

2 TOWN WATER DEMAND .......................................................................................................... J3

3 OPTION 1 - EXISTING TOWN DAM .......................................................................................... J4

3.1 Description of Option ....................................................................................................................J4
3.2 Engineering Methodology and Assumptions ................................................................................J4
3.3 Results of Engineering Analysis ...................................................................................................J6
3.4 Capital Investment and Costs ......................................................................................................J6

4 OPTION 2A - TOWN RUN-OFF TO EXISTING DAM .............................................................. J10

4.1 Description of Option ..................................................................................................................J10
4.2 Engineering Methodology and Assumptions ..............................................................................J10
4.3 Results of Engineering Analysis .................................................................................................J12
4.4 Capital Investment and Costs ....................................................................................................J12

5 OPTION 2B - TOWN RUN-OFF TO NEW DAM ....................................................................... J16

5.1 Description of Option ..................................................................................................................J16
5.2 Engineering Methodology and Assumptions ..............................................................................J16
5.3 Results of Engineering Analysis .................................................................................................J16
5.4 Capital Investment and Cost ......................................................................................................J17

6 CONCLUSION .......................................................................................................................... J21

7 REFERENCES .......................................................................................................................... J22

ATTACHMENTS

A - Dam Water Balance Calculation ......................................................................................... J23
B - Town Run-off Calculations .................................................................................................... J34
C - Other Engineering Calculations .......................................................................................... J40
D - Details of Cost Estimates ..................................................................................................... J55
1 Introduction

Through research work undertaken by the various stakeholders on all components for the water cycle and water usage within Woodanilling, and in consultation with the Shire, the following water management options were identified:

- Option 1: Improve the existing town dam and catchment to increase run-off reliability to supply irrigation demand.
- Option 2a: Capture stormwater run-off from the townsite via a sump then pump it into the existing dam for storage.
- Option 2b: Capture stormwater run-off from the townsite via a sump then pump it into the new dam for storage.

1.1 OBJECTIVES OF THIS STUDY

Kellogg Brown and Root Pty Ltd (KBR) was appointed to undertake engineering analysis of the water management options. The objectives of the engineering analysis and purpose of this document are to:

- Quantify the volume of water which can be harvested in each engineering option with improvements to existing dams/catchment and compare this with existing demand for irrigation;
- Identify the capital requirements for each proposed option; and
- Identify the operation and maintenance cost associated with each proposed option.

The engineering analysis is preliminary and based on limited site specific data supplied to KBR by RT-LA and its stakeholders. Prior to implementation of any engineering options, further design will have to be undertaken.

2 Town Water Demand

Existing water demand for irrigation has been identified at the oval and park within the town. This demand is currently supplied by the existing town dam and augmented by scheme water when the dam is dry. The watering demand for Woodanilling is outlined in Table J2.1, which combines information supplied by DAWA and CSIRO.

The total watering demand is higher than that reported by CSIRO of 9 ML/year because CSIRO only allowed for six months of watering per year. The watering months were adopted on DAWA advice.

It is reported that approximately 5 ML/year of irrigation water comes from the dam catchment, but no yield was recorded for the first two years after its construction.

Table J2.1. Woodanilling irrigation water demand

<table>
<thead>
<tr>
<th>Location</th>
<th>Area (hectares)</th>
<th>Watering depth (mm/week)</th>
<th>Frequency per week</th>
<th>Watering months per year</th>
<th>Annual volume (kL/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oval</td>
<td>2.0</td>
<td>18</td>
<td>7</td>
<td>8 (Sep-Apr)</td>
<td>11,520</td>
</tr>
<tr>
<td>Park</td>
<td>0.5</td>
<td>18</td>
<td>7</td>
<td>8 (Sep-Apr)</td>
<td>2,880</td>
</tr>
<tr>
<td>Total</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td>14,400</td>
</tr>
</tbody>
</table>
3 Option 1 - Existing Town Dam

3.1 DESCRIPTION OF OPTION

Demand for irrigation at the oval and park is being supplied by the existing town dam, which has a capacity of 40 ML. The dam is fed by roaded catchment and run-off from nearby farmland with an area of 1 hectare and 99 ha, respectively. A pipe and pump supply water to the demand points. The inlet, outlet and overflow structures at the dam require upgrade to ensure structural integrity and performance (shown in Figure J3.1).

The requirements for this option are to:

- Undertake analysis of the existing dam to determine the likely yield based upon historical data; and
- Undertake preliminary engineering design to allow for costing of capital requirements.

3.2 ENGINEERING METHODOLOGY AND ASSUMPTIONS

3.2.1 Methodology

This option requires a yield analysis to be performed on the dam, roaded catchment and farm catchment to quantify volume of water available for irrigation. Subsequently, the size of the pipe and pump from the dam required to supply peak demand is to be verified.

The yield analysis was performed using a monthly water balance from a spreadsheet model developed in EXCEL, which requires the following inputs:

- Monthly rainfall and evaporation data;
- Area and threshold of the roaded catchment and farm catchment;
- Monthly water demand; and
- Geometry of the existing town dam.

Sizing of pipe and pump for this scheme requires peak demand and ground surface levels between the town dam and the demand points.

3.2.2 Data availability and assumptions

Rainfall and evaporation data

Monthly rainfall data for Woodanilling Station 010659 was obtained from the Bureau of Meteorology. Only the last 10 years (1994 to 2004) of data were used in the water balance. This provided a more conservative result considering the reduction in rainfall in WA during recent years. Annual rainfall average over 90 years was 4% higher than the last 10 years.

Average monthly evaporation data from Kojonup Station 010582 was used in the analysis, as this was the nearest station to Woodanilling with recorded evaporation.

Area and threshold of roaded catchment

The area of the roaded catchment was supplied by DAWA, which was 1 ha, and has been assumed to be accurate for the purpose of this water balance.
A threshold of 8 mm was used for the roaded catchment based on advice from DAWA. Any rainfall recorded daily (for data between 1994 and 2004) greater than 8 mm was assumed to produce run-off into the dam. A monthly run-off volume and hence run-off coefficient was then derived. The derived run-off coefficient was used in the monthly water balance to obtain the portion of monthly rainfall which produces run-off.

**Area and threshold of farm catchment**

The area of the farm catchment, supplied by DAWA was 99 hectares, and has been assumed to be accurate for the purpose of this water balance.

A threshold of 25 mm was used for the farm catchment based on advice from DAWA. Any rainfall recorded daily (for data between 1994 and 2004) greater than 25 mm was assumed to produce run-off into the dam. A monthly run-off volume and hence run-off coefficient was then derived from the daily rainfall record between 1994 and 2004. The derived run-off coefficient was then used in the monthly water balance to obtain the portion of monthly rainfall which produces run-off.

**Monthly and peak water demand**

Monthly water demand was calculated based on the pattern described in Table J2.1 taking into account the different water pattern at each demand point. A water demand of 72 mm/month or 1800 kL/month for 2.5 hectares of irrigation area was used. Following discussions with the RT-LA team, watering was assumed between September and April every year.

Peak water demand was estimated based on the maximum watering rate at any one time, which is 3 mm/day at the town oval and park (2.5 ha). DAWA advised that the duration of watering is 20 minutes per station per day at 12 stations. Watering occurs over seven days per week. Thus, a peak demand of 6 L/s was used for sizing of pipe and pump.

**Geometry of existing town dam**

Geometry of the existing town dam has to be assumed. It was given by DAWA that the town dam has a capacity of 40 ML. Surface area at the top and bottom water level was estimated based on measurements from an aerial photograph. A dam slope of 1:3 was assumed and adjusted to meet the given dam capacity. A depth of 8 m was used based on information obtained.

No specific data were available on seepage from the dam. For the purpose of this analysis it was assumed that the seepage is 5% of the monthly volume stored in the dam. The dam was assumed to be empty at the beginning of the simulation period.

**Surface levels**

The surface level at the dam and demand point was taken from 2 m ground level contours supplied by DAWA. The top water level at the dam and water level at the demand point is assumed to be at the ground level depicted by the contours.

**Pump operation**

A minimum water depth of 0.5 m was to be retained in the dam at all times. This minimum depth is necessary to ensure optimal operation of the pump.

**Pipe velocity**

Peak demand/flow rate and a pipe velocity of 1m/s were used to size all pipes.
3.3 **RESULTS OF ENGINEERING ANALYSIS**

Results from the water balance analysis reveal that the dam has an average annual yield of 4.8 ML based on the last 10 years of rainfall record. This corresponds to the yield which has been reported by the Shire. The annual average yield represents 34% of the current water demand, which is 14 ML/year. The annual yield is also less than the 40 ML capacity of the existing town dam.

The water balance also shows that the maximum yield from the dam was 14.4 ML/year over the 10 years; there was also one occasion within this record of no yield.

Two areas contribute to dam yield, roaded catchment and natural farmland. It was found that the roaded catchment produces an average of 1 ML/year of run-off into the dam due to its small size (1 ha). The natural farmland catchment produces an average of 7 ML/year based on the last 10 years of rainfall records. However, this number should be interpreted with care as run-off may be largely due to the large catchment size (99 ha) but is a lot more sporadic as farmland catchment has a higher threshold (25 mm), and hence would only produce run-off from high rainfall events. As such, there is less reliability in obtaining high volume of run-off from the farmland catchment.

Analysis of increasing the size of the roaded catchment was also undertaken. It was found that a roaded catchment of 25 ha would be adequate to meet the existing demand of 14 ML/year. This is assuming that the 99 ha of natural farmland catchment would be retained. A detailed output from the water balance is attached in Attachment A.

The pipe size and pump required for this scheme are outlined in Attachment A. Results of the engineering analysis, which includes a profile plot of the pipe route and system curve for the pump, are shown in Attachment C.

3.4 **CAPITAL INVESTMENT AND COSTS**

The capital requirements and costs for these options are shown in Table J3.1. The capital requirements and costs are provided for KBR commercial rates, the basis of which is described in Section 3.4.1, and DAWA/Shire rates, described in Section 3.4.2. Additional assumptions for the rates and cost details are included in Attachment D.

3.4.1 KBR Commercial Rates

Cost estimates on capital requirements for KBR commercial rates are based on the following:

*Engineering Assumptions*

- As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate, sized as in Section 3.2.

*Construction Assumptions*

- All works are quality controlled and adhere to construction and engineering standards for quality assurance of the product;
- Works will be fully supervised and comply with WorkSafe regulations;
- Work contractors are fully insured and have total liability for construction and accept risks for completion eg material and labour conditions;
- Work contractors will conduct testing and commissioning of installed equipment (e.g. pressure testing of pipes);
Excavation assumed as in rippable ground. Rock excavation excluded;

Assumed dam access reasonably dry;

Assumed power supply is available at the location of the pumps;

Assumed power supply to pump stations adjacent - no allowance for incoming supplies.

Cost Assumptions

- Land cost excluded;
- GST excluded;
- Inflation excluded;
- Environmental management excluded;
- Costs for supervision of work by DAWA or Shire representative excluded;
- Unit rate for electrical power of $0.17/kWh was assumed;
- All estimates are based on current commercial construction rates in WA and assume a competitive tender process.

Costs may be refined when options are further optimised at the detailed engineering design stage.

3.4.2 DAWA/Shire Rates

The cost estimates on capital requirements for DAWA/Shire rates are based on various assumptions. These rates were provided by David Stanton and Mark Pridham from the Department of Agriculture based on experience from past rural towns projects.

Engineering Assumptions

- As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate, sized as per Section 3.2.

Construction Assumptions

- Excavation assumed as in rippable ground; rock excavation excluded;
- Dam access reasonably dry.

Cost Assumptions

- Land cost, GST, Inflation and environmental management excluded.
Table J3.1. Capital and operation and maintenance cost for Option 1

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($20%+30%)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase size of town dam roaded catchment</td>
<td>Additional 24 hectares</td>
<td>144,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td></td>
<td>5,300</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td></td>
<td>4,283</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td></td>
<td>9,570</td>
<td>2,950</td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location factor eg transportation etc as costs are based on metro rates</td>
<td>32,631</td>
<td>-</td>
</tr>
</tbody>
</table>

| Sub-total capital costs                          | 195,784                                                                 | 123,960                         |

| Additional project costs                         |                                                                         |                                 |
| General contractors prelims (20%)                 | For mobilisation/demobilisation, site set-up, site clean-up etc         | 39,159                          | -                    |
| EPCM fees (@10% of cost)                         | Engineering, Procurement, Construction and Management fees              | 23,494                          | -                    |
| Contingency (@10% of cost)                       |                                                                         | 23,494                          | -                    |

| Sub-total for additional project costs           | 86,145                                                                 | -                               |

| Total for capital investment                     | 281,929                                                                 | 123,960                         |

<table>
<thead>
<tr>
<th>Operation and Maintenance items</th>
<th>Details</th>
<th>Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump operation (6L/s @ 78m head)</td>
<td>4hrs/day, 7days/week, 8months/year of 10kW pump and $0.17/kWh</td>
<td>1,523</td>
</tr>
<tr>
<td>Maintenance personnel &amp; repairs</td>
<td>$80/hr 2hrs/week 7months/year</td>
<td>4,480</td>
</tr>
</tbody>
</table>

| Total for operation and maintenance              |                                                                         | 6,003                          |
Figure J3.1. Schematic for Woodanilling Option 1
4 Option 2a - Town Run-off to Existing dam

4.1 DESCRIPTION OF OPTION

Town surface run-off is to be collected at a new sump and pumped into the existing town dam for storage for irrigation of parks and ovals. As per the advice from DAWA, some upgrades of the existing drainage system within the town would be required. The upgrades include a new drainage channel along Yairabin Street and the existing main drain along Burt Road. Based on advice from DAWA, the main drain along Burt Road discharges at the northern end of the town into a natural creek. As such, it was determined that the best location for the new sump is along Burt Road at the intersection between Burt Road and Yairabin Street to follow this existing drainage arrangement.

The requirements for this option are as follows:

- Construction of the new sump;
- Sizing of upgrades of all drainage features;
- Determine volume of surface run-off which can be captured; and
- Yield analysis for the existing town dam with augmentation of town surface run-off.

A schematic for this option is shown in Figure J4.1.

4.2 ENGINEERING METHODOLOGY AND ASSUMPTIONS

The analyses required in this option include:

- Quantifying volume of surface run-off from town, and peak flow events;
- Sizing of the sump and pump for surface run-off collection, and for pumping from the sump to the existing town dam;
- Determine the upgrade requirement for the drainage channel along Burt Road; and
- Determine the design requirement for the installation of:
  - Drainage channel along Yairabin Street; and
  - Drainage pit to connect existing and upgraded drainage channel between Robinson and Burt Roads.

Considering that this option has several common elements the discussion below concentrates on those key components that represent the key elements of the option.

4.2.1 Town surface run-off

Monthly volume of surface run-off from town was estimated based upon daily rainfall data for the last 10 years after applying a run-off coefficient, and a 1 in 5 year extreme rainfall event as daily rainfall threshold. The 1 in 5 year extreme daily rainfall event was calculated from the Rational Method (ARR 1987).

It was assumed that any run-off exceeding the 1 in 5 year rainfall event will not be collected ie it will overflow the collection sump. Thus the 1 in 5 year daily rainfall threshold of 13.5 mm was used, which was based on the peak flow analysis of rainfall intensity and duration for the 1 in 5 year event applicable to the boundary of the town site (see Section 4.2.2).
The boundary of surface run-off catchment in town (Figure J4.1) was determined based on 2 m topographic information and known existing drainage pattern for the town. Only two catchment surface types were considered, which were pervious (bush, vegetation and garden) and impervious (paved areas). The total areas estimated were 40 ha and 0.3 ha for pervious and impervious surface, respectively. The percentage perviousness and imperviousness within the residential area was obtained from a water balance study of Wagin, Lake Grace, Nyabing and Woodanilling draft report by CSIRO. Surface area was derived from aerial photography and land tenure information from the Department of Land Information. The extent of the town boundary presented here is also consistent with the CSIRO report.

Run-off coefficients of 0.15 and 0.9 were assumed for pervious and impervious area, respectively (ARR 1987). The same daily rainfall data as in Option 1 was used here.

Peak surface run-off

Peak surface run-off is required to size new drainage structures, namely the new sump and drainage channels. It was assumed that the sump would contain peak flow from a single extreme 1 in 5 year rainfall event. Any drainage channel would be sized for peak run-off from the 1 in 10 year rainfall event.

The Rational Method as described by Australian Rainfall and Run-off – A Guide to Flood Estimation Volume 1 (1987), was used to determine the peak flow. For the 1 in 5 year rainfall event, a peak flow of 1123 L/s with a time of concentration of 25 minutes and rainfall intensity of 32.65 mm/hour was estimated. For the 1 in 10 year rainfall event, a peak flow of 1369 L/s with a time of concentration of 23 minutes and rainfall intensity of 39.8 mm/hour was estimated.

4.2.2 Town drainage

Based upon the advice from the RT-LA team, upgrade of the existing main drainage channel along Burt Road would be required. To incorporate with this upgrade, a pit is proposed to be installed in the vicinity of the intersection between Burt Road and Robinson Road connecting the existing channel along Robinson road with the channel along Burt Road. To further help collect stormwater run-off on the northern side of the town catchment, a new drain would be required along Yairabin Street. The existing, upgraded and new drainage channels will be an integrating system that captures surface run-off and convey it to the location of the new sump.

All drainage channels have been sized for a 1 in 10 year rainfall event, with a peak flow of 1369 L/s. A freeboard of 0.3 m was also assumed for the drainage channel.

4.2.3 Sump and pump

The new sump was sized for a peak flow of 1123 L/s to cope with a 1 in 5 year rainfall event. The sump was assumed to be lined and thus allow no infiltration or leakage. Considering that water would be pumped out, no evaporation of town run-off from the sump has been assumed. Therefore, volume of water estimated from surface run-off analysis would be pumped and result in inflow to the existing dam.

The pumping arrangement at the collection sump was assumed to be such that there will be two pumps to act as duty/assist and duty/standby. The pump was sized based on the sump size that would cause minimal aesthetic issue.

To size the sump, an inflow hydrograph was assumed such that the peak flow occurs at the time concentration determined by the Rational Method (see Attachment B for typical inflow hydrograph).

4.2.4 Pipes and pumps

All pipes were sized by assuming a maximum velocity of 1 m/s.
Reticulation pipes were sized at the peak demand of 6 L/s as in Option 1. Reticulation pumps were sized to produce the peak flow rate and with enough pressure head to overcome friction losses and static head based on the ground surface profile.

**4.3 RESULTS OF ENGINEERING ANALYSIS**

**4.3.1 Town surface run-off**

Based on the last 10 years of rainfall record the average annual surface run-off that can be collected from the town site is 24 ML/year, with a maximum of 29 ML/year and a minimum of 19 ML/year. Detailed outputs of town surface run-off analysis are shown in Attachment B.

The surface run-off calculated from the CSIRO water balance study for residential and semi-rural areas which is the equivalent extent of surface run-off for this analysis was 27.9 ML/year (see Appendix J). Thus, the average annual surface run-off of 24 ML/year derived from this study is consistent with the CSIRO analysis, keeping in mind that this study considered only the last 10 years of rainfall record which is 4% drier than using 90 years of record, done for the CSIRO water balance.

**4.3.2 Total yield from Option 2a**

The town surface run-off and yield from the existing town dam produce a combined average annual yield of 14 ML/year, which would meet the current water demand.

Observations of the behaviour of the dam water balance show that water in the dam is in excess of the existing demand for this option. Another yield analysis was performed to determine the maximum yield from the dam (Appendix A). This shows that by withdrawing all available water out of the dam there is an average annual yield of 27 ML/year, with a maximum yield of 39 ML/year and a minimum yield of 17 ML/year.

Thus, after satisfying the existing demand of 14 ML/year, there is an average of 13 ML/year of excess water from the dam which could be used. Details of this yield analysis are shown in the water balance in Attachment A.

**4.4 CAPITAL INVESTMENT AND COSTS**

The capital requirements and costs for these options are shown in Table J4.1. The capital requirements and costs are provided for KBR commercial rates, the basis of which is described in Section 4.4.1, and DAWA/Shire rates, the basis of which is described in Section 4.4.2. Additional assumptions for the rates and cost details are included in Attachment D.

**4.4.1 KBR Commercial Rates**

The cost estimates on capital requirements for KBR commercial rates are based on:

*Engineering Assumption*

- As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate, sized as per Section 4.2.

*Construction Assumptions*

- All works are quality controlled and adhere to construction and engineering standards for quality assurance of the product;
- Works will be fully supervised and comply with Work Safe regulations;
• Work contractors are fully insured and have total liability for construction and accept risks for completion e.g. material and labour conditions;
• Work contractors will conduct testing and commissioning of installed equipment (e.g. pressure testing of pipes);
• Excavation in rippable ground; rock excavation excluded;
• Dam access reasonably dry;
• Power supply is available at the location of the pumps;
• Power supply to pump stations adjacent - no allowance for incoming supplies.

Cost Assumptions
• Land cost excluded.
• GST excluded.
• Inflation excluded.
• Environmental management excluded.
• Costs for supervision of work by DAWA or Shire representative excluded.
• Unit rate for electrical power of $0.17/kWh was assumed.
• All estimates are based on current commercial construction rates in WA and assume a competitive tender process.

Costs may be further refined when options are further optimised at the detailed engineering design stage.

4.4.2 DAWA/Shire Rates

The cost estimates on capital requirements for DAWA/Shire rates are based on the following assumptions. These rates were provided by David Stanton and Mark Pridham from the Department of Agriculture based on experience from past projects.

Engineering Assumption
• As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate, sized as per Section 4.2.

Construction Assumptions
• Excavation as in rippable ground; rock excavation excluded;
• Dam access reasonably dry.

Cost Assumptions
• Land cost excluded.
• GST excluded.
• Inflation excluded.
• Environmental management excluded.
Table J4.1. Capital and operation and maintenance costs for Option 2a

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($20%+30%)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td></td>
<td>5,300</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td></td>
<td>4,283</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td></td>
<td>9,570</td>
<td>2,960</td>
</tr>
<tr>
<td>Upgrade drainage channel along Burt Road for 1:10year peak flow</td>
<td>362m long, 2m bottom width, 1:4 side slope, 1m deep</td>
<td>48,500</td>
<td>900</td>
</tr>
<tr>
<td>Install new drainage channel along Yairabin Street for 1:10year peak flow</td>
<td>535m long, 2m bottom width, 1:4 side slope, 1m deep</td>
<td>88,500</td>
<td>14,124</td>
</tr>
<tr>
<td>New sump</td>
<td>40m×20m×2.5m fully lined</td>
<td>76,040</td>
<td>5,400</td>
</tr>
<tr>
<td>Pump from new sump to existing town dam</td>
<td>1× 4L/s @ 70m head</td>
<td>35,420</td>
<td>33,080</td>
</tr>
<tr>
<td>Pipe to connect from new sump to existing dam</td>
<td>Extra 100m of 90mm PVC</td>
<td>11,050</td>
<td>7,190</td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location factor eg transportation etc as costs are based on metro rates</td>
<td>56,333</td>
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</table>

**Sub-total for capital costs**

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<tr>
<th></th>
<th>333,996</th>
<th>64,654</th>
</tr>
</thead>
</table>

**Additional project costs**

<p>| | | |</p>
<table>
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<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>General contractors prelims (20%)</td>
<td>For mobilisation/demobilisation, site set-up, site clean-up etc</td>
<td>67,599</td>
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<tr>
<td>EPCM fees (@10% of cost)</td>
<td>Engineering, Procurement, Construction and Management fees</td>
<td>40,560</td>
</tr>
<tr>
<td>Contingency (@10% of cost)</td>
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<td>40,560</td>
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</table>

**Sub-total for additional project costs**

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<th>148,719</th>
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**Total for capital investment**

<table>
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<tr>
<th></th>
<th>486,714</th>
<th>64,654</th>
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</thead>
</table>

**Operation and Maintenance items**

<table>
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<tr>
<th></th>
<th></th>
<th>Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation of pump from existing town dam to oval</td>
<td>4hrs/day, 7days/week, 8months/year of 10kW pump and $0.17/kWh</td>
<td>1,523</td>
</tr>
<tr>
<td>Operation of pumps from new sump to existing town dam</td>
<td>more intensive during winter months, 4hrs/session, Nominal operations = 3 times/week, 8months/year of 10kW pump and $0.17/kWh</td>
<td>653</td>
</tr>
<tr>
<td>Maintenance personnel &amp; repairs</td>
<td>$80/hr 2hrs/week 7months/year</td>
<td>4,480</td>
</tr>
</tbody>
</table>

**Total for operation and maintenance**

<table>
<thead>
<tr>
<th></th>
<th>6,656</th>
</tr>
</thead>
</table>
Figure J4.1. Schematic for Woodanilling Option 2a
5  Option 2b – Town Run-off to New Dam

5.1 DESCRIPTION OF OPTION

This is similar to Option 2a except the town surface run-off is to be stored at a new dam instead of the existing town dam. Upgrades of the existing drainage system in town would still be required. A schematic of this option is shown in Figure J5.1.

5.2 ENGINEERING METHODOLOGY AND ASSUMPTIONS

The engineering analysis required for this option is the same as performed for Option 2a, only the outcomes associated with pipe lengths and pumping head will differ due to the different pipe route arrangement and location of infrastructure. Thus, refer to Section 4.2 for the engineering methodology.

One additional analysis was required, which was to perform a yield analysis or water balance to size the new dam. The methodology for dam sizing uses the water balance approach outlined in Option 1, but in this case the geometry as well as capacity of the dam needs to be assumed. An iterative process applied to vary the geometry and capacity of the dam until no overflow was observed from the dam. It is important to note that the dam has been sized based on the last 10 years of rainfall record and surface run-off.

One further assumption was made in the location of the new dam. This site was selected based on advice from the DAWA. It has been assumed that the site will be obtainable.

5.3 RESULTS OF ENGINEERING ANALYSIS

5.3.1 Town surface run-off

As with Option 2a, the average annual town surface run-off was estimated to be 24 ML/year, with a maximum run-off of 29 ML/year and a minimum run-off of 18 ML/year.

5.3.2 New dam yield

The size of the new dam required is 25 ML assuming a geometry of 40x40x6m at a 1:3 side slope. Based on the last 10 years’ rainfall record, the annual average yield from the new dam is enough to supply the existing demand of 14 ML/year.

Observations of the behaviour of the dam water balance show that water in the dam is in excess of the existing demand for this option. Another yield analysis was performed to determine the maximum yield from the dam (Attachment A). This shows that by withdrawing all available water out of the dam, there is an average annual yield of 19.5 ML/year, with a maximum yield of 24 ML/year and a minimum yield of 14 ML/year over the 10 years rainfall record. Thus, after satisfying the existing demand of 14 ML/year, there is an average of 5.5 ML/year of excess water from the dam.

It is possible to make the size of the new dam less than 25 ML if all water available in the dam at any one time is withdrawn. However, as future demand has not been identified, the dam size of 25 ML is still recommended.

The yield from Option 2b is less than 2a, as augmentation from the town dam is not included. Details of this yield analysis are shown in the water balance in Attachment A.
5.4 CAPITAL INVESTMENT AND COST

The capital requirements and costs for these options are shown in Table J5.1. They are provided for KBR commercial rates, the basis of which is described in Section 5.4.1, and DAWA/Shire rates, described in Section 5.4.2. Additional assumptions for the rates and cost details are included in Attachment D.

5.4.1 KBR Commercial Rates

The cost estimates on capital requirements for KBR commercial rates are based on the following:

*Engineering Assumption*

- As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate sized as per Section 5.2.

*Construction Assumptions*

- All works are quality controlled and adhere to construction and engineering standards for quality assurance of the product;
- Works will be fully supervised and comply with WorkSafe regulations;
- Work contractors are fully insured and have total liability for construction and accept risks for completion e.g. material and labour conditions;
- Work contractors will conduct testing and commissioning of installed equipment (e.g. pressure testing of pipes);
- Excavation assumed as in rippable ground. Rock excavation excluded;
- Dam access reasonably dry.
- Power supply is available at the location of the pumps.
- Power supply to pump stations adjacent - no allowance for incoming supplies.

*Cost Assumptions*

- Land cost excluded
- GST excluded
- Inflation excluded
- Environmental management excluded
- Costs for supervision of work by DAWA or Shire Representative excluded
- Unit rate for electrical power of $0.17/kWh was assumed
- All estimates are based on the current commercial construction rates in Western Australia and assume a competitive tender process

Costs may be further refined when options are optimised at the detailed engineering design stage.
5.4.2 DAWA/Shire Rates

The cost estimates on capital requirements for DAWA/Shire rates are based on rates provided by David Stanton and Mark Pridham from the Department of Agriculture based on past projects.

**Engineering Assumption**

- As the size of the existing pipe and pump at the sports dam is not known, pipe and pump have been included in the cost estimate. Pump and pipe have been sized as per section 5.2.

**Construction Assumptions**

- Excavation as in rippable ground; rock excavation excluded;
- Dam access reasonably dry.

**Cost Assumptions**

- Land cost excluded;
- GST excluded;
- Inflation excluded;
- Environmental management excluded.
Table J5.1. Capital, operation and maintenance costs for Option 2b

<table>
<thead>
<tr>
<th>Capital items</th>
<th>Details</th>
<th>KBR Commercial Rates ($20%+30%)</th>
<th>DAWA/Shire Rates ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade drainage channel along Burt Road for 1:10year peak flow</td>
<td>362m long, 2m bottom width, 1:4 side slope, 1.5m deep</td>
<td>48,500</td>
<td>900</td>
</tr>
<tr>
<td>Install new drainage channel along Yairabin Street for 1:10year peak flow</td>
<td>535m long, 2m bottom width, 1:4 side slope, 1.5m deep</td>
<td>80,500</td>
<td>14,124</td>
</tr>
<tr>
<td>New sump</td>
<td>40m×20m×2.5m fully lined</td>
<td>79,040</td>
<td>5,400</td>
</tr>
<tr>
<td>Pump from new sump to new dam</td>
<td>1× 4L/s @ 34m head</td>
<td>35,420</td>
<td>31,880</td>
</tr>
<tr>
<td>Pipe to connect from new sump to new dam</td>
<td>750m of 90mm PVC</td>
<td>53,950</td>
<td></td>
</tr>
<tr>
<td>New dam</td>
<td>25ML capacity 40m×40m×6m with 1:3 side slope</td>
<td>200,560</td>
<td></td>
</tr>
<tr>
<td>Reticulation line from new dam to oval</td>
<td>500m of 90mm PVC with 10m head</td>
<td>37,450</td>
<td></td>
</tr>
<tr>
<td>Pump from new dam to oval</td>
<td>6L/s @ 10m head</td>
<td>35,420</td>
<td></td>
</tr>
<tr>
<td>Location allowance (20%)</td>
<td>Adjustment for regional location factor eg transportation etc as costs are based on metro rates</td>
<td>114,168</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total for capital costs</strong></td>
<td><strong>685,008</strong></td>
<td><strong>264,934</strong></td>
</tr>
<tr>
<td></td>
<td>with liner</td>
<td><strong>total with liner</strong></td>
<td><strong>200,984</strong></td>
</tr>
<tr>
<td>Additional project costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General contractors prelims (20%)</td>
<td>For mobilisation/demobilisation, site set-up, site clean-up etc</td>
<td>137,002</td>
<td></td>
</tr>
<tr>
<td>EPCM fees (@10% of cost)</td>
<td>Engineering, Procurement, Construction and Management fees</td>
<td>82,201</td>
<td></td>
</tr>
<tr>
<td>Contingency (@10% of cost)</td>
<td></td>
<td>82,201</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total for additional project costs</strong></td>
<td><strong>301,404</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total for capital investment</strong></td>
<td><strong>986,412</strong></td>
<td><strong>264,934</strong></td>
</tr>
<tr>
<td>Operation and Maintenance</td>
<td>Details</td>
<td>Cost ($/year)</td>
<td></td>
</tr>
<tr>
<td>Operation of pump from existing town dam to oval</td>
<td>4hrs/day, 7days/week, 8months/year of 10kW pump and $0.17/kWh</td>
<td>1,523</td>
<td></td>
</tr>
<tr>
<td>Operation of pumps from new sump to existing town dam</td>
<td>more intensive during winter months, 4hrs/session, Nominal operations = 3 times/week, 8months/year of 10kW pump and $0.17/kWh</td>
<td>653</td>
<td></td>
</tr>
<tr>
<td>Maintenance personnel &amp; repairs</td>
<td>$80/hr 2hrs/week 7months/year</td>
<td>4,480</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total for operation and maintenance</strong></td>
<td><strong>6,656</strong></td>
<td></td>
</tr>
</tbody>
</table>
Figure J5.1. Schematic for Woodanilling Option 2b
6 Conclusion

Current annual average water demand in Woodanilling is 14.4 ML. The existing town dam has a capacity of 40 ML, however results of the annual yield analysis based on the last 10 years of rainfall record determined the annual average yield to be 4.8 ML. This represents 33% of the annual average demand.

Over the 10 year rainfall record, the maximum yield from the dam was 14.4 ML/year and there was no yield on one occasion. This unreliability is a result of the nature of the catchment which consists of a small, low threshold roaded catchment (1 ha) and a large, high threshold farmland catchment (99 ha).

The water management options identified for Woodanilling for engineering analysis are outlined below:

- Option 1: Improve the existing town dam and catchments to increase run-off reliability to supply irrigation demand;
- Option 2a: Collect surface run-off from town and stored in the existing town dam to supply irrigation demand;
- Option 2b: Collect surface run-off from town and stored in a new dam to supply irrigation demand.

The engineering analysis involved quantifying the water yield for each option and the associated capital, and operation and maintenance costs in each option. Analysis was based on limited site specific data supplied by RT-LA and is not suitable for construction purposes. Further design will be required at a later stage for implementation of any option presented. Results from the engineering analysis are summarised in Table J6.1 and capital investment costs in Table J6.2.

### Table J6.1. Yield for all options

<table>
<thead>
<tr>
<th>Option</th>
<th>Average annual water yield (ML/year)</th>
<th>% of demand</th>
<th>Excess water for future demand (ML/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>2a</td>
<td>13.7</td>
<td>100</td>
<td>13</td>
</tr>
<tr>
<td>2b</td>
<td>13.4</td>
<td>100</td>
<td>5.5</td>
</tr>
</tbody>
</table>

1. Yield combines run-off of 24.22 ML/year town surface and 4.8 ML/year from existing town dam
2. Yield combines run-off of 24.2 2ML/year town surface.

### Table J1.2. Cost for all options

<table>
<thead>
<tr>
<th>Option</th>
<th>KBR Commercial Rates ($) (Including location allowance) (-20%+30%)</th>
<th>Additional Cost ($) (-20%+30%)</th>
<th>TOTAL Commercial Rates Capital Investment Costs ($) (-20%+30%)</th>
<th>TOTAL DAWA/Shire Rates Capital Investment Costs ($)</th>
<th>O &amp; M Cost ($)</th>
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</thead>
<tbody>
<tr>
<td>1a</td>
<td>195,784</td>
<td>86,145</td>
<td>281,929</td>
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<td>2a</td>
<td>333,996</td>
<td>148,719</td>
<td>486,714</td>
<td>64,654</td>
<td>6,656</td>
</tr>
<tr>
<td>2b</td>
<td>685,008</td>
<td>301,404</td>
<td>986,412 with liner</td>
<td>284,934</td>
<td>6,656</td>
</tr>
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<td></td>
<td>685,008</td>
<td>301,404</td>
<td>986,412 without liner</td>
<td>200,984</td>
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</tr>
</tbody>
</table>

1. See Capital Investment and Costs for calculation methodology and assumptions.
7 References


APPENDIX K

Woodanilling

A cost-benefit analysis for water management incorporating data from KBR, DAWA and the Shire

Jo Pluske, Michael Burton & Richard Reeve

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The University of Western Australia
35 Stirling Hwy
Crawley Western Australia 6009

16 February 2006

ACKNOWLEDGEMENTS

We are grateful for constructive recommendations for changes in this report from Olga Barron (CSIRO) and Mark Pridham (Department of Agriculture, Western Australia).
Summary

This report provides information to decision makers considering three water management options in Woodanilling.

Option 1: Improve the existing town dam and town dam catchment to increase run-off reliability to supply irrigation demand.

Option 2a: Capture storm water run-off from the town site via a sump then pump it into the existing dam for storage.

Option 2b: Capture storm water run-off from the town site via a sump then pump it into the new dam for storage.

More specifically, the analyses outlined in this paper stem from a systems model designed to evaluate net benefits from water harvesting, treatment and water reuse. As the model is not an optimisation model, the optimal strategies are determined for different scenarios through a series of model runs. The model allows the user to simulate different water management options and to provide management strategies so as to determine the optimal management regime to implement.

Results derived from the model are contingent upon the assumptions driving them and should be interpreted accordingly. The specific assumptions for each option are outlined in the report proper. Furthermore, the analyses depend on data provided in scientific reports completed within the Rural Towns - Liquid Assets project.

Costs and benefits arising from the proposed water management options and the current use of the existing town dam form the basis of this study. However, because there isn’t a market price for locally produced water, instead of documenting net benefits, the results are expressed in terms of the breakeven water price that would need to be achieved so that total costs are equivalent to total benefits.

General base case assumptions that pertain to each of the options include surface water harvested in Woodanilling and in its current state, would be fit for irrigation purposes only. It is also assumed that if necessary scheme water will supplement the water available from the dam (dependent on the selected water management option as outlined below) and all 14.4 ML that is assumed to be required annually (Appendix J) will actually be used (despite e.g. the rainfall in any particular year). Based on Water Corporation (2005) data, the cost of scheme water provided by the Integrated Water Supply System to vacant non-residential land is assumed to be $1.20 per kilolitre. This cost benefit analysis has been done over a 20 year time period with a 7% discount rate. The discount rate is slightly higher than the current bank interest rate so that long term risk of an interest rate increase can be factored into the analysis. However, the rate is dropped to 4% in a sensitivity analysis to determine if the discount rate has a bearing on the overall outcome. In other sensitivity analyses the costs are varied up by 30% and down by 20% and the quantity of water produced by any of the options is increased and decreased by 10%. If the overall results do not change when these analyses are imposed then they can be considered to be robust.

For water produced by the dam in its current state, it is assumed that operating and maintenance costs are the same as for Option 1 (based on DAWA/Shire rates) and that there is a capital contingency of $5,000 in year 1. In addition, for each option all pumps are replaced in year 11. For the current option the cost of the pump is equivalent to that in Option 1 (based on DAWA/Shire rates). Details of the complete schedule of costs are presented in Appendix J. It is assumed that 95% of capital costs will be funded up front in the form of a grant and/or other such funding, while the remaining costs are annualised over the 20 year period. This report also complements scientific reports produced by others involved in the project and therefore will not duplicate contents found in these reports or that of KBR. Work by Barron et al. (2005a & b) has been used to estimate the
benefits of removing or at least reducing water from the ground and/or surface to infrastructure such as buildings and roads.

Acknowledging the base case assumptions set for these analyses, use of the town dam to produce water as is currently done costs more than the estimated average price of scheme water. Water provided by the means stated in each of Options 1, 2a or 2b would need to be sold above the estimated scheme water price if it was produced by the processes that incur KBR commercial rates. However, in the case when DAWA/Shire rates were used in the analyses for Option 2a and possibly Option 1 the breakeven water price was below the average scheme water price. For this latter option, changing the base case values to increase the product water by just 15% or reduce costs by around 12% in a sensitivity analysis would bring the cost of water in line with that of scheme water. Therefore, due to the sensitivity of this outcome to relatively small changes in the parameters, decision makers may wish to consider the potential of Option 1 more thoroughly. For all options, decreasing the discount rate to 4% from the base of 7% did not change the overall outcome of the results.

Option 2 provides additional benefits of up to $4,018 per year resulting from a reduction in risk of salinity and water damage to infrastructure such as buildings and roads. However, even if it was assumed that the total benefit from reduced damage could be achieved, it would not change the overall outcome. That is, the number of options having a breakeven water price under the average price of scheme water would remain the same. As expected the breakeven water price for Option 2a (calculated using DAWA/Shire rates) would be a little more attractive when infrastructure damage reduction is considered ($0.43/kL), while the other scenarios for Option 2 would still have breakeven water prices above the average scheme water price.

In this study it is assumed in the base case analysis that all of the water produced in Options 1 and 2a results from the improvements made to the dam, and if these alterations were not done the existing dam in its current state would yield nothing. Alternatively, if the costs for Options 1 and 2a are linked specifically to the additional water produced over and above that currently generated by the dam in its existing state (4.8 ML), then the breakeven water price for each option would increase. However, the general outcome for each option would not alter from the base case analysis has stated above. That is, Option 2a (calculated using DAWA/Shire rates) would still be a better option than simply using scheme water while the other options would produce water at a price above the average scheme water price.

While total costs are included in the above analysis, the breakeven water price can be divided into annual operating costs per kilolitre of water produced, and the combined capital and opportunity cost of investment per kilolitre of product water for each option. Note that commercial costs and the DAWA/Shire estimation for operating and maintenance were assumed to be the same.

Excess water that is expected to be produced over and above the current estimated demand for Woodanilling for Options 2a and 2b, would be beneficial in terms of providing additional water as an ‘insurance measure’ for exceptional years when there is drought. Alternatively, if it is deemed viable to do so, uses for the excess irrigation water may include application in industry or for beautifying the town. However, if the value placed on this water is below the breakeven price as calculated then the ‘water production enterprise’ would be making a loss or in other words being subsidized by the supplier. Hence town decision makers should be mindful of how best to consider this excess water.

Overall it would appear convincingly that Option 2a (using DAWA/Shire rates) is the water management option that produces the greatest net benefits for Woodanilling. It should also be noted that this also accounts for benefits arising from a reduction in salinity and water damage to townsite infrastructure.

The break-even price of water calculated in Option 1 (based on DAWA/Shire rates) could be potentially competitive with scheme water. This may occur if: the base cost is at least 12% lower than the total value of capital and operating costs for this option; water production is 15% above the estimated base value; there are additional unquantifiable benefits. However, in any case this option is less economically viable that Option 2a (calculated using DAWA/Shire rates). All other options are unlikely to be viable propositions given the assumptions and data used in this study.
Even though great care has been taken in data collection and model development, there are opportunities for changing parameters should alternative data become available and so reach new outcomes. Also, as the values included in this analysis are representative of a specific town in Western Australia, model parameters will need adjusting for other towns and for other regions.
1 Introduction

The analyses presented in this appendix are designed to provide information to decision makers considering options aimed at improving water management in Woodanilling. In addition the costs and benefits arising from the current use of the existing town dam will be estimated to calculate net benefits of this activity and hence provide additional information.

More specifically, the analyses outlined in this paper stem from a systems model designed to evaluate net benefits from water harvesting, treatment and water reuse. As the model is not an optimisation model, the optimal strategies are determined for different scenarios through a series of model runs. The model allows the user to simulate different water management options and to provide management strategies so as to determine the optimal management regime to implement.

TERMS OF REFERENCE

Under the terms of reference for this project, the following options will be considered within an economic framework and reported on in this report:

Option 1: Improve the existing town dam and its catchment to increase run-off reliability to supply irrigation demand.
Option 2a: Capture storm water run-off from the townsit via a sump then pump it into the existing dam for storage.
Option 2b: Capture storm water run-off from the townsit via a sump then pump it into the new dam for storage.

ASSUMPTIONS

Results derived from the model are contingent upon the assumptions driving them and should be interpreted accordingly. The specific assumptions for each option are outlined below. Furthermore, the analyses depend on data provided in scientific reports completed within the project.

General assumptions for each of the options are discussed. It will be assumed that surface water harvested in Woodanilling and in its current state, would be fit for irrigation purposes only. The existing town dam is capable of yielding 4.8 ML of water each year. Water yield is based on the rainfall record, 1994 to 2004, and hence is an estimate of likely yield in any one year. Varying the yield in sensitivity analyses will provide an indication of how changes in rainfall over the time of the analyses, could affect the overall outcome. The time period for all analyses is 20 years. Based on analyses completed by KBR (Appendix J), it is expected that total requirement for irrigation water is 14.4 ML per year. It is assumed that scheme water is a direct substitute for water from the dam and all 14.4 ML will be used. The cost of scheme water provided by the Integrated Water Supply System is based on a country vacant land usage charge of 122.4 cents per kilolitre (Water Corporation 2005) and rounded to $1.20/KL for the purpose of this study.

THIS REPORT

This report will complement scientific reports outlining the physical requirements associated with the specific water management plan for Woodanilling as well as the KBR report detailing costs for various options for this plan. This document is designed to provide a complete overview of a series of cost benefit analyses completed using a model developed in Microsoft Excel. We present details of the general economic analyses in Section 2, an economic overview of current water use in Section 3,
and analyses focusing on Options 1 and 2 in Sections 4 and 5 respectively. The options are compared in Section 6 and the capacity of the work discussed in Section 7.
2 Economic analysis

As the aim of this work is to compare the costs and benefits of each of the options as outlined in the terms of reference the economic framework will involve cost benefit analyses. As alluded to in Robison and Barry (1996), long-term investments can be analysed by adding all present costs and benefits for each year of the project and using a discounting approach to calculate the net present value. For the purpose of this report this methodology will be used in its simplest form so will not include differing inflationary effects associated with inputs and/or outputs, revenue earned from interest on profit or tax implications.

As it is assumed from the outset that at least one of the specified options will not necessarily be better than the status quo, the ‘do nothing’ option will also be considered in this report. By running various simulations the net benefits for the various options under different conditions will be found.

COSTS

Capital costs

The current costs associated with each option are used as default values. However, to account for specific changes in costs that may occur in any one year, these costs can be independently increased or decreased for that year. Should this be necessary for any options, the actions taken will be reported in the relevant proceeding chapters. It is further assumed that 95% of capital costs are incurred in year 1 with the rest being annualised over the 20 years. Even so, in the spreadsheet model it is possible to vary this ratio depending on how these costs are likely to be financed. The combined opportunity cost of money and the cost of capital are also presented as an annual cost per kilolitre of product water.

Total variable costs

The total variable costs per year are found by summing all operational costs. These costs will also be presented as annual operating costs per kilolitre of product water. However, such figures should be used with caution as capital costs and benefits are also important when comparing the viability of any options.

Indirect costs

Costs, arising from the establishment of any of the options that impose upon an external party can be referred to as indirect costs. Such costs may be derived from forms of pollution, or a change in water allocation.

BENEFITS

Revenue

Revenue may be accrued directly from the sale of the water or other actions directly related to the resources produced. Even if the water is not literally sold and hence cash is not exchanged between two parties (primarily because the council may not buy the water from itself if it owns the infrastructure) in order to estimate the benefits of the water a ‘selling price’ is attached to the product water and it is referred to as being sold. Specific revenue will be described along with each of the three options.

Reduction in damage to infrastructure

By removing or at least reducing water from the ground and/or surface, the costs of maintaining infrastructure such as buildings and roads should decline. The benefit of this reduced damage is estimated using physical and economic data and is specific for each option.
Evaluation of the salinity risk associated with infrastructure damage and subsequent damage costs are described in Barron et al. (2005a). The level of risk is estimated in accordance with the soil saturation level one meter below the surface and is based on the long term average groundwater level for the shallow observation bores. These bores only cover a portion of the town and therefore the extent of the salinity risk area considered in this study is confined by the extent of the observation bores in the town.

Barron et al. (2005a) calculate the town infrastructure damage costs using the USEAP model\(^2\). This model is based on the simultaneous analysis of the salinity risk and infrastructure type within each land parcel, where surface types, area and structures have been identified. Land parcels are divided into six key groups in USEAP: residential housing, commercial/offices, ovals/playing fields, public open space sealed roads and unsealed roads. Each category has an assigned annual damage cost assuming a 100% impact. This impact is then moderated based upon estimated degree of soil saturation so that damage falls as soil saturation falls. The average salinity risk of each land parcel is estimated, and using an algorithm adapted, damage can be calculated (Table K1).

**Table K1. Damage costs derived from USEAP for specific urban land parcels**

<table>
<thead>
<tr>
<th>Land parcel</th>
<th>Units</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Building</td>
<td>/household</td>
<td>563</td>
</tr>
<tr>
<td>Commercial Building</td>
<td>/1000 m(^2)</td>
<td>663</td>
</tr>
<tr>
<td>Oval</td>
<td>/ha</td>
<td>1,900</td>
</tr>
<tr>
<td>Open Space</td>
<td>/ha</td>
<td>685</td>
</tr>
<tr>
<td>Sealed Road</td>
<td>/1000 m</td>
<td>400</td>
</tr>
<tr>
<td>Unsealed Road</td>
<td>/1000 m</td>
<td>200</td>
</tr>
</tbody>
</table>

It is important to note that these damage costs are an indication of actual costs, and that only a part of the gazetted town site is considered. Furthermore, it is assumed that the water level is at equilibrium. If the intention is to identify the impact of changes in management, then an assessment of those areas that may feasibly be impacted by that management need only to be considered. It is also important to note that these costs represent the MAXIMUM cost reduction that could be achieved if management options were introduced that completely ameliorated the problem. It is almost certainly the case that such total amelioration options will not be achieved and hence are not considered in the water management plans\(^3\).

However, these damage costs provide a basis on which to estimate the overall infrastructure damage problem within the town. The salinity risk for Woodanilling is confined to the lower western slopes of the town site, roughly following the railway line. Assuming a water management plan is not implemented, the estimated damage cost for each infrastructure type has been calculated by Barron et al. (2005b) as an annual damage cost (Table K2). As this annual damage cost is a maximum, sensitivity analyses will be completed using reduced levels of infrastructure damage costs.

\(^2\)For further details regarding USEAP and the associated methodology see RTMC (2001).

\(^3\)For more information regarding this methodology see Barron et al. (2005a).
Table K2. Infrastructure damage costs estimated for Woodanilling

<table>
<thead>
<tr>
<th>Infrastructure type</th>
<th>Annual cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>55</td>
</tr>
<tr>
<td>Industrial</td>
<td>76</td>
</tr>
<tr>
<td>Local rural</td>
<td>133</td>
</tr>
<tr>
<td>Public Purposes</td>
<td>79</td>
</tr>
<tr>
<td>Railway</td>
<td>1,967</td>
</tr>
<tr>
<td>Recreation</td>
<td>940</td>
</tr>
<tr>
<td>Residential</td>
<td>598</td>
</tr>
<tr>
<td>Roads</td>
<td>167</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4,018</strong></td>
</tr>
</tbody>
</table>

Indirect revenue

Indirect revenue may arise if benefits accrue to a third party and or the environment due to implementation of a water management plan. Flow-on effects from a water management option to the local community can be used as a proxy for general indirect benefits should they emerge. To calculate these benefits, input-output multipliers can be used. It is assumed that if any new businesses emerge as a result of a greater availability of water, for every $1 spent on wages, a fair amount, e.g. $0.25, will be spent locally. And for the wage earner, for every $1 earned, an amount, e.g. $0.25, will be spent locally. Without having completed further research using e.g. non-market valuation methodology addressing the environmental benefits that may arise from implementation of an option is difficult. Therefore in this report environmental benefits may be acknowledged but a value will not be assigned to them.

Total benefits

Total benefits are calculated by summing all benefits as outlined above. While it is assumed that benefits are constant over time, as with costs, if a specific benefit accrues in any one year it is possible to alter the value of that benefit for that year.

**SIMPLE NET BENEFITS**

To calculate the net benefits, for any one year, the total costs are subtracted from the total returns for that year. However, this calculation does not directly include inflation, interest or tax as the analyses is a social cost benefit analysis as opposed to a private analysis.

**ACCOUNTING FOR RISK**

There is uncertainty associated with supply of water due to unpredictable climatic variations as well as demand for water as it is contingent upon population growth and/or behaviour. While the discount rate could be altered to account for uncertainty, it assumes constant uncertainty over time, which may not be the case. Instead, the impact of risk associated with relevant parameters in the model will be assessed by varying those parameters in a sensitivity analysis so as to determine the importance of these changes on the overall outcome.

**TIME**

The model integrates economic (e.g. cost of water bought for irrigation or household use) and physical components (e.g. flow volumes and timing). For economic aspects, the time step is annual. For physical processes, input can be varied and so the length of time depends on management plans set in place. Nevertheless, the analyses are based on a 20 year time period. At the end of this period is assumed that all benefits derived from each option would have been realised. Furthermore, extending the time period beyond 20 years results in benefits and costs after this time being significantly discounted and hence the impact of these values do not weight heavily on the overall outcome.
DISCOUNT RATE

Discounting is necessary in CBA because people value things (such as money) more highly now than in the future. $1,000 now could be put to another use e.g. invested and return $80 (at 8% p.a. interest). Also, there is the issue of uncertainty. Faced with a choice of being given $1,000 now or $1,000 in a year, a person will likely take it now; to avoid any risk (whether small of large) that something might happen during that year for the money not to be delivered.

To take account of this, therefore, costs and benefits for every year after year 1 are discounted to be equivalent to year 1, or present, values. So when costs are taken away from benefits, we get the net present value. It is convention that the discount rate should be equivalent to the real bank interest rate and so for the purpose of this analysis it will be set to 7% (a conservative value to acknowledge potential interest rate rises). However as the time period is relatively long, lower rates of 4% will be considered in sensitivity analyses to determine the effect on the overall outcome.

DECISION CRITERIA

In cost benefit analyses, decision criteria can be presented as the net present value (NPV), the internal rate of return (IRR), or as the benefit cost ratio. To calculate the NPV for the period of the project, the total costs are subtracted from the total returns for each year, summed and discounted. The option with the highest NPV will likely be the preferred option, although NPV is a tool and the final outcome rests with the decision maker. That is, the decision maker can choose an option with a lesser NPV if he or she feels it includes a benefit that wasn't able to be included in the CBA (wasn't able to have a dollar value placed on it. The IRR is calculated as the discount rate when the NPV is set to equal zero. A strategy would be preferred if the IRR is greater than the discount rate. The benefit cost ratio is simply the net benefits divided by the net costs and if greater than zero it indicates that benefits derived from the project are greater than the costs.

In this project harvested water is not traded in the market price and hence price of this water is not available. Hence calculating the NPV is not a straightforward process. Therefore perhaps the most informative information for decision makers would be to determine the price of harvested water so as to ‘break even’. That is when the NPV is zero or the IRR is equivalent to the discount rate.
3 Current water use

Currently the existing town dam is providing 4.8 ML of water annually, in part for the oval and park within the town. As total requirement for irrigation water in Woodanilling is 14.4 ML per year (KBR 2005), the remaining water is provided by scheme water. The aim of this chapter is to present an analysis outlining the potential costs and benefits of providing water from the existing town dam for irrigation purposes.

COSTS

Capital costs

It is assumed that there is an existing pump and for the purpose of this analysis a new pump will be replaced in year 11 at a cost of $27,380. This costing is in line with the expected cost of a pump for the new dam as estimated in DAWA/Shire rates\(^4\) for Option 2b and reported in KBR (2005). Contingencies amount to $5,000 in year 1. It is assumed that over the 20 year period no further capital costs are required. Opportunity cost of money and capital costs per kilolitre of product water amount to $0.35/kL.

Annual operating costs

Pump operating is assumed to cost $1,523 per year and repairs and maintenance total $4,480 annually giving a total annual operating cost of $6,003. This cost is as reported by KBR (2005) for Option 1. Annual operating costs per kilolitre of product water equates to $1.25/kL.

BENEFITS

Water sales

Benefits from water sales are calculated by multiplying the sale price by the quantity sold over a year. It is assumed that the price of water is not contingent upon demand and hence remains constant over the year.

Other benefits

It is assumed that no other direct benefits arise from the presence of this dam.

RISK

Life of the dam and water yield

It is assumed that the town dam in its existing state will remain viable for the 20 year period of this analysis and will maintain a consistent yield of 4.8 ML/yr. As minimal allowances have been made for repairs and maintenance it is possible that the dam will yield less than the expected amount. Furthermore, it is assumed that rainfall will remain reasonably consistent so ensuring yield is reliable which may not be the case. Therefore sensitivity analyses will be completed with the yield at plus and minus 10% of the expected water yield.

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\(^4\) DAWA and the Shire of Woodanilling provided supplementary costings as described in KBR 2005.
WATER PRICE AND NET BENEFITS

Given the assumptions outlined above, water must be sold by the ‘water enterprise’ for at least $1.61/kL for the project to break even given a discount rate of 7%. However, if 4.8 ML of water was purchased annually for the oval and park at this price, and the remaining 9.6 ML of water required was purchased at $1.20/kL, the average cost of water would fall to $1.34/kL.

SENSITIVITY ANALYSES

Discount rate

Decreasing the discount rate to 4% results in the water price falling very slightly to $1.60/kL in order for the ‘water enterprise’ to break even.

Yield of product water

With a discount rate of 7%, increasing the volume of product water by 10% results in the break even water price falling to $1.46/kL. However, an increase of just under 34% in water volume, so giving a total yield of 6.42ML annually, would result in a breakeven price of $1.20.

Decrease in costs

With a discount rate of 7%, decreasing all costs by 20%, as suggested by KBR (2005), would mean the price of water could decrease to $1.28/kL, for the dam enterprise to break even. Decreasing costs by just over 25% results in water having to be sold at $1.20/kL for the project to be viable.

CONCLUSIONS

Given the base case assumptions outlined, water provided by the existing town dam would need to be sold above the price of scheme water for it to be a viable proposition. It is unlikely that the town would be prepared to waste resources in such a way. It is more possible that the actual costs are lower than assumed in the base case and therefore as indicated in the sensitivity analyses the price of dam water could then be priced at that for scheme water and still return a benefit. It is possible that annual water yield could increase by a third and therefore water yield could be considered to have an effect on the overall outcome of the base case scenario.
4 Option 1

The aim of Option 1 is to determine the net benefits of upgrading the existing town dam and catchment area. It is assumed that the expenditure is required to deliver the total volume of water and not just the increase in water over and above that provided by the dam in its existing state. The benefits include delivery of 14ML\(^5\) of water annually to the oval, and park in Woodanilling. As surface water is not directed out of the town it is assumed that there aren’t any benefits from reduced damage to town infrastructure. Two scenarios are investigated in this chapter. The first relies on data provided by KBR and the second by DAWA and the Shire of Woodanilling.

**COSTS**

**Capital costs**

Initial capital costs are presented in Table K3. In addition the pump will be replaced in year 11 at a current cost of $35,420 for Option 1 (KBR data) and $27,380 for Option 1 (DAWA/Shire data).\(^6\) It is assumed that over the 20 year period no further capital costs are required. Opportunity cost of money and capital costs per kilolitre of product water amount to $2.01/kL for Option 1 (KBR data) and $0.95/kL for Option 1 (DAWA/Shire data).

<table>
<thead>
<tr>
<th>Description of capital cost</th>
<th>Option 1 (KBR data)</th>
<th>Option 1 (DAWA/Shire data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase size of town dam roadded catchment</td>
<td>$144,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td>$5,300</td>
<td>$500</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td>$4,283</td>
<td>$500</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td>$9,570</td>
<td>$2,950</td>
</tr>
<tr>
<td>Allowances, fees and contingencies</td>
<td>$118,778</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$281,931</strong></td>
<td><strong>$123,950</strong></td>
</tr>
</tbody>
</table>

Source: KBR (2005)

**Annual operating costs**

Based on KBR (2005), pump operating for both scenarios is assumed to be $1,523 per year and repairs and maintenance total $4,480 giving a total annual operating cost of $6,003. Annual operating costs per kilolitre of product water equates to $0.43/kL.

**BENEFITS**

**Water sales**

Benefits from water sales are calculated by multiplying the sale price by the quantity of water sold over a year. It is assumed that the price of water is not contingent upon demand and remains constant.

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\(^5\) As estimated by KBR (2005)

\(^6\) As estimated for Option 2b (see Section 5)
Other benefits

It is assumed that no other direct benefits arise from the presence of this dam.

RISK

It is assumed that rainfall will remain reasonably consistent ensuring yield is reliable which may not happen. Therefore sensitivity analyses will be completed at ±10% of expected water yield.

NET BENEFITS AND WATER PRICE

Given the assumptions outlined above, water must be sold for at least $2.44/kL for Option 1 (KBR data) and $1.38 for Option 1 (DAWA/Shire data) to break even (given a discount rate of 7%).

SENSITIVITY ANALYSES

Discount rate

Decreasing the discount rate to 4% results in the water price falling to $2.05/kL for Option 1 (KBR data) and $2.22/kL and that for Option 1 falling to $1.26/kL. Water production would have to increase by just $1.22 for Option 1 (DAWA/Shire data) so as to break even.

Yield of product water

With a discount rate of 7%, reducing the volume of product water by 10% would mean the price would have to increase to $2.71/kL for Option 1 (KBR data) and to $1.54 for Option 1 (DAWA/Shire data) to break even. A 10% increase in water volume would see the price for Option 1 (KBR data) fall to $2.22/kL and that for Option 1 falling to $1.26/kL. Water production would have to increase by just under 104% to give 28.5 ML annually for Option 1 (KBR data) to be a better option than simply using scheme water. For Option 1, the increase would only around 15%, thereby giving a total product of 16.2 ML of water per year for this scenario to be considered as a better alternative to scheme water.

A 35% reduction in water volume is approximately equivalent to assuming that the total costs have been attributed only to the ‘new’ water produced from these capital works (9.2ML). Or in other words, none of the additional capital costs are required to produce the 4.8ML of water that is currently available from the existing dam each year. If this is actually the case then for Option 1 (KBR data) the breakeven water price would be $3.76/kL and for Option 1 (DAWA/Shire data), $2.13/kL.

Change in costs

Given a discount rate of 7%, increasing costs by 30% would mean the price of water would have to increase to $3.18/kL for Option 1 (KBR data) and to $1.84 for Option 1 (DAWA/Shire data) before breaking even. However, if costs were decreased by 20% then the price of water required to break even would decrease to $1.95/kL for Option 1 (KBR data) and to $1.09 for Option 1 (DAWA/Shire data). To give a break-even dollar value equivalent to scheme water, costs would have to decrease by almost 51% for Option 1 (KBR data) but only by around 12% for Option 1 (DAWA/Shire data).

CONCLUSIONS

Given the assumptions outlined, water provided by the existing dam with additional roaded catchment would have to be sold above the current scheme water price of $1.20/kL to be viable. Achieving a reasonable decrease in costs or increase in t water yield would not alter this conclusion for Option 1 (KBR data). However, decreasing the costs by a feasible amount could see Option 1 (DAWA/Shire data) being a sound alternative to purchasing scheme water. It must be noted that the analysis has been completed on delivering the total water yield and not just additional yield above that produced currently. As a consequence, the prices found for the base case scenario may be underestimated. If the costs pertained to ‘new water’ only, then for Option 1 (KBR data), the breakeven water price would
need to increase by almost $1/kL over the base case and by around $0.50/kL for Option 1 (DAWA/Shire data).
Option 2 involves capturing surface water run-off from within the Woodanilling townsite and pumping it into the existing town dam for storage (Option 2a) or pumping the water into a new dam for storage (Option 2b). The cost of upgrading the existing town dam is also included among the costs for Option 2a. A new dam will be constructed as part of the plan for Option 2b and hence relevant costs associated with this dam will be included in this option. Costs associated with integrating a sump into the water management plan will be included in both options. Based on explanations produced in KBR (2005), Options 2a and 2b (KBR data) include cost estimates from KBR, while Options 2a and 2b (DAWA/Shire data) are based on costs provided by DAWA and the Shire of Woodanilling.

It is anticipated that Option 2a will provide 26.7 ML of water annually because surface run-off is pumped back into the existing town dam and hence combines with the water captured from the roaded catchment. It is assumed that the expenditure associated with this option is required to deliver the total volume of water and not just the increase in water over and above that provided by the dam in its existing state. Option 2b is expected to yield 18.9 ML of water per year derived from the surface run-off flowing into the new dam\(^7\). This water will provide direct benefits for the town.

**COSTS**

**Capital costs**

Initial capital costs for Options 2a and 2b are presented in Table K4.

<table>
<thead>
<tr>
<th>Description of capital cost</th>
<th>Option 2a (KBR data)</th>
<th>Option 2a (DAWA/Shire data)</th>
<th>Option 2b (KBR data)</th>
<th>Option 2b (DAWA/Shire data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade inlet structure for existing town dam</td>
<td>$5,300</td>
<td>$500</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Upgrade outlet structure for existing town dam</td>
<td>$4,283</td>
<td>$500</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Upgrade overflow structure for existing town dam</td>
<td>$9,570</td>
<td>$2,960</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Upgrade drainage channel Burt Road</td>
<td>$48,500</td>
<td>$900</td>
<td>$48,500</td>
<td>$900</td>
</tr>
<tr>
<td>Install new drainage channel Yairabin St</td>
<td>$88,500</td>
<td>$14,124</td>
<td>$80,500</td>
<td>$14,124</td>
</tr>
<tr>
<td>New sump</td>
<td>$76,040</td>
<td>$5,400</td>
<td>$79,040</td>
<td>$5,400</td>
</tr>
<tr>
<td>Pump from new sump to existing/new dam</td>
<td>$35,420</td>
<td>$33,080</td>
<td>$35,420</td>
<td>$31,880</td>
</tr>
<tr>
<td>Pipe from new sump to dam</td>
<td>$11,050</td>
<td>$7,190</td>
<td>$53,950</td>
<td>$28,250</td>
</tr>
<tr>
<td>New dam (with liner)</td>
<td>$0</td>
<td>$0</td>
<td>$200,560</td>
<td>$136,850</td>
</tr>
<tr>
<td>Reticulation line from new dam to oval</td>
<td>$0</td>
<td>$0</td>
<td>$37,450</td>
<td>$20,150</td>
</tr>
<tr>
<td>Pump from new dam to oval</td>
<td>$0</td>
<td>$0</td>
<td>$35,420</td>
<td>$27,380</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$483,715</strong></td>
<td><strong>$64,654</strong></td>
<td><strong>$986,412</strong></td>
<td><strong>$264,934</strong></td>
</tr>
</tbody>
</table>

Source: KBR (2005)

In addition, for Options 2a and 2b, the two pumps will be replaced in year 11 at the same current cost as stipulated in Table K4. It is assumed that over the 20 year period no further capital costs are required. Opportunity cost of money and capital costs per kilolitre of product water amount to $1.83/kL for Option 2a (KBR data), $0.33/kL for Option 2a (DAWA/Shire data), $5.09/kL for Option 2b (KBR data) and $1.46/kL for Option 2b (DAWA/Shire data).

\(^7\) As a note, available water yield does not equal surface run-off due to evaporation and leakage from the dam, and the requirement for the water to be at least 0.5m deep so that the pumps work (see KBR (2005) for more detail)
Annual operating costs

Annual operating costs for all Options are detailed in Table K5. Annual operating costs per kilolitre of product water equates to $0.25/kL for Options 2a (KBR data) and 2a (DAWA/Shire data) and $0.35/kL for Options 2b (KBR data) and 2b (DAWA/Shire data).

Table K5. Annual operating costs for all Options.

<table>
<thead>
<tr>
<th>Description of annual operating costs</th>
<th>Cost for all Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation of pump to oval</td>
<td>$1,523</td>
</tr>
<tr>
<td>Operation of pumps from sump</td>
<td>$653</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>$4,480</td>
</tr>
<tr>
<td>Total</td>
<td>$6,656</td>
</tr>
</tbody>
</table>

Source: KBR (2005)

BENEFITS

Water sales

Benefits from water sales are calculated by multiplying the sale price by the quantity of water sold over a year. It is assumed that the price of water is not contingent upon demand and hence remains constant over the year.

Other benefits

There may also be benefits from reduced damage to infrastructure within the townsite due to these water management options. As explained in KBR (2005), the drainage system within the townsite (especially that associated with Burt Road and Yairabin Street) requires upgrading. Hence it is possible that a further reduction in infrastructure damage could be significant. Therefore results incorporating benefits arising from reduced damage will be presented in the sensitivity analyses below.

RISK

Water yield

It is assumed that rainfall will remain reasonably consistent so ensuring yield is reliable which may not be the case. Therefore sensitivity analyses will be completed with the yield at plus and minus 10% of the expected water yield.

NET BENEFITS AND WATER PRICE

Given the assumptions outlined for Option 2a (KBR data), water must be sold for at least $2.08/kL for the project to break even with a discount rate or IRR at 7%. Likewise for Option 2a (DAWA/Shire data) water should be priced at $0.58/kL. Assuming Option 2b is considered independently of any other options, the price of water must be at least $5.44/kL for Option 2b (KBR data) and $1.82/kL for Option 2b (DAWA/Shire data) (also assuming a discount rate of 7%).

SENSITIVITY ANALYSES

Discount rate

For Option 2a (KBR data), decreasing the discount rate to 4% would result in the water price falling to $1.73/kL so that the project breaks even and for Option 2a (DAWA/Shire data) to $0.54/kL. Likewise,
the water price would fall to $4.42/kL for Option 2b (KBR data) and to $1.55/kL for Option 2b (DAWA/Shire data).

Yield of product water

With a discount rate of 7%, reducing the volume of product water by 10% would mean the price of water would have to increase to $2.31/kL for Option 2a (KBR data) and to $0.64/kL for Option 2a (DAWA/Shire data). For Option 2b (KBR data) if the same decrease in volume was incurred then the price would have to increase to $6.05/kL and for Option 2b (DAWA/Shire data), to $2.02/kL.

A 10% increase in water volume would result in the price of water falling to $1.89 for Option 2a (KBR data), to $0.53 for Option 2a (DAWA/Shire data), to $4.95 for Option 2b (KBR data) and to $1.65 for Option 2b (DAWA/Shire data). Reducing the water volume by 18% is approximately equivalent to assuming that the total costs have been attributed only to the ‘new’ water produced from these capital works. Or in other words, none of the additional capital costs are required to produce the 4.8ML of water that is currently available from the existing dam each year. If this is actually the case, then for Option 2a (KBR data), the breakeven water price would be $2.53/kL and for Option 2a (DAWA/Shire data), $0.71/kL.

Given a discount rate of 7%, an increase of 73% in water volume to give a total of 46.2ML per year would have to be achieved for Option 2a (KBR data) to breakeven at a water price of $1.20/kL. However, for Option 2a (DAWA/Shire data), the volume could fall by almost 53% to 12.6ML per year and still be a better option than purchasing scheme water. So as to sell water at $1.20/kL and ensure the option is viable, the increase in water volume required for Option 2b (KBR data) would be just under 354% (i.e. a total water volume of 85.7ML annually would have to be produced). For Option 2b (DAWA/Shire data), an increase of 51% or a total water volume of 28.6ML per year would be required for this scenario to be a better option than the purchase of scheme water.

Change in costs

With a discount rate of 7%, increasing costs by 30% would mean the price of water would have to increase to $2.70/kL for Option 2a (KBR data), to $0.75/kL for Option 2a (DAWA/Shire data), to $7.08/kL for Option 2b (KBR data) and to $2.36/kL for Option 2b (DAWA/Shire data). With a 20% decrease in costs for Option 2a (KBR data), the breakeven price for water would drop to $1.66/kL, for Option 2a (DAWA/Shire data), to $0.46/kL, for Option 2b (KBR data), to $4.36 and for Option 2b (DAWA/Shire data), to $1.45/kL. So as to breakeven at a water price of $1.20/kL, the cost of producing water in Option 2a (KBR data) would have to fall by just over 42%. Like wise the costs would have fall by just under 78% for Option 2b (KBR data) and by almost 34% for Option 2b (DAWA/Shire data). However, for Option 2a (DAWA/Shire data), the cost of producing water could increase by up to 107% and still be produced at a price less than scheme water.

Benefits from reduced damage to infrastructure

As explained in Section 2, the maximum benefit from reducing damage to infrastructure amounts to $4,018 per year (assuming a discount rate of 7%). If this total value is included in Option 2a (KBR data) the water must be sold at $1.93/kL, a drop of $0.15/kL on the base price reported above. Likewise, for Option 2a (DAWA/Shire data), the water could be priced at $0.43 resulting also in a decrease of $0.15/kL. With regard to Option 2b (KBR data), so as to break even the price of water would have to sell at $5.23/kL ($0.21/kL down on the base price) and for Option 2b (DAWA/Shire data), the price falls to $1.60/kL or a $0.22/kL drop in the initial price. Even though this equates to a fall in price for all options, apart from Option 2a (DAWA/Shire data), the price of water is still well in excess of that for scheme water.

CONCLUSIONS

Allowing for the assumptions outlined in this chapter, product water provided by Options 2a (KBR data), 2b (KBR data) and 2b (DAWA/Shire data) would have to be sold above the current scheme water price of $1.20/kL for each option for it to be a viable proposition. The only Option that produced consistently positive results for any action associated with water management to be taken in Woodanilling was Option 2a (DAWA/Shire data). Changing the water yield, discount rate or costs by a reasonable amount did not affect the general outcome of any options. This was also the case when benefits from reduced damage to infrastructure were included in the analyses. It must be noted that if
the capital costs are linked specifically to the ‘new water’ produced in Option 2a (KBR data) then the breakeven water price would be increased by around $0.45 over the base analysis and likewise in the case of Option 2a (DAWA/Shire data), by $0.13/kL.

As both Options 2a and 2b will provide water in excess of the current water requirements for Woodanilling, this extra water will be worth nothing unless it can be utilised. While Option 2a (DAWA/Shire data) would still be a viable alternative to scheme water (price of water doesn’t increase to $1.20/kL until the volume sold is just over 12.5ML per year), the other options would not. Even so, it could be assumed that uses could be found for excess irrigation water for industry or for beautifying the town if it was viable to do so. However, under the given assumptions, the prices of total water generated from Options 2a (KBR data), 2b (KBR data) and 2b (DAWA/Shire data) are in excess of the scheme water price. Therefore unless the dam water is subsidized or there are scheme water restrictions in place, and so inhibiting options for new water use, it would not be in the town’s best interest (given the assumptions outlined) to generate additional water.
6 Comparison of Options

In this section each of the options are summarised and ranked in order of highest net benefits. However, decision makers should have full understanding of the reasons for ranking them in such an order so that they can use these ranking effectively when making their decisions.

OVERVIEW OF THE CASES

Acknowledging the assumptions stated in the preceding chapters, water provided by the existing town dam would need to be sold above the price of scheme water for it to be a viable proposition except in the case of Option 2a (DAWA/Shire data) and possibly Option 1 (DAWA/Shire data). Based on the assumptions detailed in this study, the town dam in its existing state does not appear to be an economically viable water source.

Options 1 (KBR data) and 1 (DAWA/Shire data) deal with upgrading the existing town dam and town dam catchment to increase run-off reliability to supply irrigation water within Woodanilling. Based on the assumptions, the break-even water price would have to be above the current scheme water price of $1.20/kL if each option was to be a viable proposition. However, increasing the product water by just 15% or reducing costs by around 12% for Option 1 (DAWA/Shire data) would bring the cost of water produced by this option in line with that of scheme water. The analysis has been completed on delivering the total water yield and not the marginal yield. If the costs pertained to the ‘new water’ only then the break-even water price would certainly be in excess of the scheme water price.

In Option 2 the plan is to capture storm water run-off from the town site via a sump then pump it into the existing dam for storage (Option 2a) or to the new dam for storage (Options 2b). Even if, on a practical basis, the costs were decreased, the product water increased or provision made for reduced damage to infrastructure, for all options except Option 2a (DAWA/Shire data), product water would have to be sold above the current scheme water price of $1.20/kL so as to be viable. In addition it must be recognized that if the capital costs are linked specifically to the ‘new water’ produced in Option 2a then the break-even water price would increase, although not by any level that would change the overall outcome of the results. Given the assumptions outlined, because excess water is produced for both Options 2a and 2b with costs above that for scheme water, except of Option 2a (DAWA/Shire data), unless the dam water is subsidized for the other options or there are scheme water restrictions in place, and so inhibiting options for new water use, it would not be in the town’s best interest to generate additional water.

RANKING OF THE OPTIONS

Based on the assumptions used in this study it would appear convincingly that Option 2a (DAWA/Shire data) is the best option to pursue (Table K6). Even if costs are overestimated for the ‘do nothing’ option it is unlikely that it would be a better option even when the generated water price is averaged with the scheme water price to produce a value of $1.34/kL. Option 1 (DAWA/Shire data) should be considered if the costs have been overestimated or water production undervalued. However, it is unlikely that this option could match Option 2a (DAWA/Shire data). All other options are unlikely to be viable propositions. Should the increase in capital costs be attributed to the extra (marginal) water produced in each scenario then the ranking changes marginally (Table K6). In all cases except for Option 2a (DAWA/Shire data), the product water prices are all in excess of the scheme water prices (Table K6). Therefore it may be reasonable for policy makers to consider Option 2a (DAWA/Shire data) as an alternative water management plan to what they currently have in place in Woodanilling.
Table K6. Ranking options in ascending order of water price required to break-even

<table>
<thead>
<tr>
<th>Option</th>
<th>Water Price $/kL (based on capital costs to supply total yield)</th>
<th>Option</th>
<th>Water Price $/kL (based on capital costs to supply marginal yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 2a</td>
<td>0.58</td>
<td>Option 2a</td>
<td>0.71</td>
</tr>
<tr>
<td>(DAWA/Shire data)</td>
<td></td>
<td>(DAWA/Shire data)</td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>1.38</td>
<td>Current</td>
<td>1.61</td>
</tr>
<tr>
<td>(DAWA/Shire data)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>1.61</td>
<td>Option 2b</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(DAWA/Shire data)</td>
<td></td>
</tr>
<tr>
<td>Option 2b</td>
<td>1.82</td>
<td>Option 1</td>
<td>2.13</td>
</tr>
<tr>
<td>(DAWA/Shire data)</td>
<td></td>
<td>(KBR data)</td>
<td></td>
</tr>
<tr>
<td>Option 2a</td>
<td>2.08</td>
<td>Option 1</td>
<td>2.44</td>
</tr>
<tr>
<td>(KBR data)</td>
<td></td>
<td>(KBR data)</td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>2.44</td>
<td>Option 2b</td>
<td>3.76</td>
</tr>
<tr>
<td>(KBR data)</td>
<td></td>
<td>(KBR data)</td>
<td></td>
</tr>
<tr>
<td>Option 2b</td>
<td>5.44</td>
<td></td>
<td>5.44</td>
</tr>
<tr>
<td>(KBR data)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Even so, decision makers must realise that Options 2a and 2b provide water in excess of the current water requirements for Woodanilling. Hence this extra water will be worth nothing unless it can be utilised. Uses for the excess irrigation water may include application in industry or for beautifying the town if it is deemed viable to do so.
7 Capacity of this work

Understanding the scope of this project is important for interpreting the results derived from the analyses. This work will not automatically calculate which strategy is ‘best’. The strategies have been evaluated using experimentation and ‘trial and error’. Furthermore, generally the analyses do not represent year-to-year variation in weather, potential yield or water output. However, general changes can be manually placed in the model.

Even though great care has been taken in data collection and model development so as to create a robust model, there are always opportunities for changing parameters to reach alternative outcomes. Also, as the values included in this analysis are representative of a specific town in Western Australia, model parameters will need adjusting for other towns and for other regions.

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8 References


Barron, O., Smales, T., and Burton, M. (2005b). Evaluation of cost associated with the town site infrastructure damage caused by salinity, CSIRO.


APPENDIX L

HYDROGEOLOGICAL MODELLING OF WOODANILLING

Anthony D. Barr

WATER FOR A HEALTHY COUNTRY
National Research Flagship

August 2005
APPENDIX L: HYDROGEOLOGICAL MODELLING

CONTENTS

1. Hydrogeological Setting
   1.1 Catchment
   1.2 Town
   1.3 Soil

2. CURRENT DATA
   2.1 Groundwater Piezometric Heads
   2.2 Groundwater EC
   2.3 Analysis
   2.4 Climate
   2.5 Recharge

3. MODELLING
   3.1 Unsaturated Zone
   3.2 Groundwater

4. CONCLUSIONS

5. REFERENCES
1. Hydrogeological Setting

Woodanilling is located 252 km south-east of Perth within the Blackwood catchment (Figure L1).

Figure L1. Location of Woodanilling in the south-west of Western Australia

1.1 Catchment

Town catchments are the areas which contribute water to the town, either through surface run-off or groundwater flow. These catchments include any rivers or paleochannels that flow through or near the town and affect the watertable or cause flooding.
Woodanilling is in the middle reaches of the fifth-order Boyerine Creek catchment of the Blackwood River basin (Figure L2). The upper part of the catchment is about 13 km from town, with a catchment width of approximately 8 km. It is south-east of Lake Norring and the creek discharges into the lake. The headwaters of Boyerine Creek are a dense network of incised streams in farmland (Whitfield 2001). The catchment has retained less than 10% remnant vegetation.

![Figure L2. Woodanilling catchment](image)

1.2 Town

The hydrogeology of the town has been investigated through drill core logs and geophysics.

The gazetted Woodanilling townsite straddles the catchment's main drainage line, but most of the built-up area is on the floodplain and lower slopes, east of Boyerine Creek (Whitfield 2001). There is considerable remnant vegetation within the town area to the east of the creekline although the catchment above town has been extensively cleared. The town aquifer has been divided into two layers – a deep layer comprising saprock/saprolite grits and a shallow layer comprising of the overlying saprolite and tertiary sediments.

1.3 Soil

The soil maps produced for agricultural regions are generally focussed on the upper few metres of the regolith. This is the root zone of the major crop species and is thus the major interest to the agricultural practices. In the absence of deep roots associated this is also the zone of evapotranspiration from the regolith.

The soils in the vicinity of Woodanilling consist of sandy duplex soils in the east on the slopes with saline wet sandy duplex soils in the floodplain valley in the west of town. Both have slow to moderately slow soil permeability indicating that run-off will be generated from the slopes and also along the valley floors (Schoknecht 2001).
2. Current Data

Previous investigations of the town have left a legacy of boreholes drilled to investigate the groundwater levels and salinity underneath the town. A large number of bores were installed as part of the Rural Towns Program in 2000 and these and other bores within the town have been monitored at quarterly intervals since installation. Figure L3 shows the location of the monitored bores.

The observations made at these bores are the depth to water and water quality parameters. The water quality parameters include electrical conductivity (EC), temperature and intermittently pH and chloride concentration. In this section the observed depth to water and EC are analysed along with the derived piezometric heads. The piezometric heads are extrapolated for different lithological layers to present watertable levels and piezometric surfaces through the majority of the town.

2.1 Groundwater Piezometric Heads

The depth to water and heads in each bore for the period of record is shown in Figures L4 and L5 respectively. The flat records in Figure L4 indicate the watertable level at these bores is below the screened interval (00BY04D, 00BY06I, 00BY08S, 00BY08D). All the bores have a discernable decreasing trend over the period of observation. The shallowest depth to water occurs in bore 00BY01S. The deeper bore 00BY01D usually has a greater head than the shallow bore, indicating upward head gradient at this location.
Each bore has been allocated to various lithological layers under the town and the head distribution within the town has been extrapolated from this data for the observation dates. The extrapolation procedure has been performed using the software SURFER (Version 7, Golden Software) for kriging onto a 20 x 20 m grid. Only valid water levels are used for the kriging, with dry bores not included.
2.2 Groundwater EC

Figure L7 shows the time series of EC observed in each of the monitored bores. Again there are large initial increases in the observed values indicating some residual effect of the drilling. After the observed values have settled, the highest observed EC occurs in bore 00BY03M in the centre of the south of town. This bore also shows the greatest rate of increase in salinity. Bore 00BY09M in the north of town shows consistently the lowest EC with the greatest changes indicating influx of fresher or saline water at times of the year occurring in bore 00BY10M.
2.3 Analysis

The Woodanilling data shows a head gradient from the east to the west, with a small overlying south to north gradient, through the town in the shallow layer. The gradient moves towards an east-west gradient during the summer, with a similar pattern occurring in the deep layer. The depth to water is smallest in the southwest of the town on the western side of the railway, ranging from 0.5 m in winter to around 2.0 m in summer, and the gradient is upwards except sometimes during the winter. There exists a downwards head gradient under the majority of the town area except in the western part of town where there is a upwards gradient. The electrical conductivity in the town has a maximum value in the south east of town around bore 00BY03M. At this site there is a trend of increasing salinity, with an increase of around 30% between 2000 (3000 mS/m) and 2004 (4000 mS/m). This could be due to the proximity of the bore to the break in slope, where groundwater is from a perched aquifer, where it is subject to high evapotranspiration, can recharge to the regional aquifer. In the remainder of the town, the salinity is either steady or declining between 2001 and 2004. The minimum salinity is observed at bore 00BY09M in the north-west of town in the vicinity of the playing fields. The salinity under the town increases from the north to the south. In the deeper layer, the salinity increases from the northeast to the southwest.

2.4 Climate

In Woodanilling the average monthly maximum temperatures range from 30.5°C in January to 15.0°C in July with average monthly minimums varying between 14.4°C in February and 5.6°C in July. The town has a current average annual rainfall of 462 mm and an average evaporation of 1561 mm. These values show strong seasonal variation, with higher rainfall occurring during winter, consistent with a Mediterranean climate. Figure L8 shows the annual rainfall at Woodanilling for the period 1900-2004 in the point-patched database (PPD) (Bureau of Meteorology) with 5, 10 and 20 year moving averages. Figure L9 shows the same information for the evaporation from the point-patched database. The evaporation data prior to 1970 is not interpolated within the PPD.
2.4.1 Current climate change

The climate in south-west Western Australia is changing. Decreases in average annual rainfall have been observed in a number of locations including Woodanilling (Figure L8).
The observed decrease in the annual average rainfall in south-west Western Australia has not affected
the annual occurrence of high intensity rainfall (measured on a daily basis) prior to 1990. Instead the
reduction of high intensity rainfall during the winter (Yu and Neil 1993, Li et al. 2005) has been
balanced by an increase in high intensity rainfall during spring and summer (Yu and Neil 1993).
Suppiah and Hennessy (1998) found that though the overall trend in most of the southwest of Australia
was for increasing amount and intensity in the summer months, there were some locations where the
opposite was true. Timbal (2004) analysed the rainfall records for the period 1958-1998 for winter and
spring rainfall at a number of sites. He found that at Dumbleyung there was a decline in rainfall of
about 0.29 mm/year in winter and an increase of 0.21 mm/year during spring.

The greenhouse effect is not thought to be a major driver for the currently observed climate change in
the south-west of Western Australia. Instead there are conflicting hypotheses as to whether large-
scale clearing has disturbed the hydrological cycle and thus induced the climate change (Pitman et al.
2004), or that changes to the mean sea level pressure (MSLP) and sea-surface temperature (SST) in
the Indian Ocean (Smith et al. 2000). The implications of the two hypotheses are that if it is clearing
induced, then the likelihood of the climate returning to its previous regime is small as it will depend on
reforestation or some other process to restore the previous hydrological regime. Alternatively if it is a
circulation induced change, then a restoration of the previous circulation may mean a return to the
previous wetter clime. As the precise drivers for the circulation change are not known no probability
may be attached to the possibility of change.

2.4.2 Predicted climate change

In addition to the pre-existing climate change, there will also be changes due to the greenhouse effect.
These changes will be superimposed on the existing changes. Timbal (2004) used a number of
climate models and found predictions of further rainfall decline of 11-26% for winter rainfall at
Dumbleyung and 15-23% for spring rainfall at Dumbleyung. Rainfall events in the southwest are also
predicted to fall by between 3 and 19% in winter and between 6 and 26% in spring. He also predicted
a reduction in the number of events with magnitude greater than 20 mm. Charles (pers. comm.) found
that current changes in climate are small with rainfall changes of between -2.6% and +1.3% and
temperature changes between +0.13 and +0.16 C. By 2030, with no policy of reduction in greenhouse
gases, the predictions include: a decrease in winter rainfall is between 2 and 20%; possible increases
or decreases in summer rainfall; temperature rises of between 0.5 and 2 C in winter and 0.5 and 2.1 C
in summer; and potential evaporation increases of 10%. By 2070 the predictions include: a decrease
in winter rainfall is between 5 and 60%; again possible increases or decreases in summer rainfall;
temperature rises of between 1.0 and 5.5 C in winter and 1.0 and 6.5 C in summer; and potential
evaporation increases of 30%. If policy changes are implemented to reduce greenhouse gas
emissions, the changes are likely to be less.

2.5 Recharge

2.5.1 Recharge in rural areas

Recharge to rural areas has been divided into three types (de Vries and Simmers 2002): direct
recharge via vertical infiltration; indirect recharge via surface accumulations of water; and localised
recharge, an intermediary between the first two types that arises from unchannelled surface flows.

Recharge is a function of climate, soil type, land use or vegetation type and topography. Climate can
be categorised into a number of zones for the southwest of Western Australia: a humid zone along
the southwest coast; an arid zone in the interior of Western Australia; and an intermediate semi-arid
zone that encompasses the majority of the wheatbelt. Scanlon et al. (2002) stated the characteristics
of humid zones are usually shallow watertables and gaining streams, where groundwater is
discharged via baseflow to streams and evapotranspiration, whereas the characteristics of arid regions
are deep watertables and losing streams. The wheatbelt of Western Australia comprised, prior to
clearing, deep watertables; but since clearing the watertables have risen near to the surface in places.
Typically in arid and semi-arid areas the majority of recharge is via indirect recharge. However in the
Western Australian wheatbelt, the removal of deep-rooted vegetation, which intercepted the majority of
the infiltration, and replacement with shallow-rooted annual crops, has changed the balance of the
system. Now more recharge reaches the watertable than prior to clearing (Asseng et al. 2001). This
additional recharge is not the sole cause of the rising watertables in the wheatbelt of Western Australia; it is the additional recharge in excess of the export capacity of the catchments that causes the rise in watertable. This rise will continue to occur until equilibrium is reached such that the export processes such as catchment discharge and evapotranspiration balance the recharge. The reason for the low export capacity of the catchments in the wheatbelt is the low gradients and hydraulic conductivity (Clarke et al. 2002).

The lithology and soil type can have an important influence on the recharge. In the wheatbelt the duplex nature of the soils means that infiltration may occur rapidly into the shallow A level horizon of the soil profile to form a perched watertable over the clayey B horizon. This store may rapidly fill leading to overland flow, as well as subsurface flow to a discharge area. Typically such systems occur above the change of slope in the wheatbelt.

Lewis (1998) and Lewis and Walker (2002) investigated the effects of episodic recharge events within the wheatbelt on the overall recharge under shallow annual and perennial crops. It was found that the percentage of episodic recharge was greatest in the areas close to the arid zone; however the largest recharge amount due to episodic rainfall was in the region close to the humid areas.

2.5.2 Recharge in urban areas

Urban recharge is more complicated than recharge in rural areas. There are large impervious areas such as buildings and roads, infrastructure such as pipe networks and roads that transport water around the area and irrigated garden areas. Lerner (2002) found that in almost all environments the urbanisation of an area increases the recharge.

An additional source of recharge is from urban water infrastructure. Howard (2002) estimated that a minimum of 10%, in a modern network, to 70%, in an extreme case, of water into a water-supply pipe network is lost somewhere in the system. Although similar figures are not available for the waste-water network, it is assumed that similar percentage losses occur. If an area is not sewered but instead relies on septic systems, then the localised recharge may be large and be a source of potential contamination. Such recharge under a semi-arid urban area may provide a considerable amount of the total recharge. An additional source of localised recharge is leakage from water storages such as swimming pools and dams.

Another potential source of recharge is stormwater, particularly from impervious surfaces. In some places the stormwater readily infiltrates the surface and can be used to recharge the aquifer (e.g. Perth). In other places a network of pipes or channels may be provided that transports the stormwater out of the town.

The last major source of urban recharge is irrigation of gardens, playing fields and similar open spaces. Colwill and Row (2004) provide guidelines for watering regimes for different groups of plants; however these guidelines have only been recently introduced and may not be followed in all areas.

3. Modelling

Modelling of different parts of the water cycle in the rural towns is used for a number of purposes. These include the investigation of various options for managing the watertable level and the salinity impacts on the town infrastructure, including an economic assessment of whether such intervention is justified.

3.1 Unsaturated Zone

The modelling of the unsaturated zone is used for two purposes: calculation of net recharge to the saturated groundwater model; and calculation of the saturation level in the unsaturated zone for use in the system model.
3.1.1 Construction

The model WAVES (Zhang and Dawes 1998) is used to simulate the water and salt movement in the unsaturated zone. The model is based on one-dimensional vertical movement of water and salt through a soil profile under vegetation. The soil profile is derived from the core logs from the bore drilling. For Woodanilling, three representative soil profiles are used based on bores 00BY01D, 00BY06D and 00BY11D. The three profiles are shown in Table L1. The soil profile is assigned to the various categories of soil type to using the hydrological properties as provided in Table A2.2 of Dawes et al. (1998). The vegetation parameters used are provided in Appendix 1 of Dawes et al. (in the absence of alternative data) for winter annual pasture and eucalypts. WAVES allows the use of two vegetation layers, but the eucalypt simulations use only the eucalypt over-storey.

### Table L1. Soil profiles for chosen bores

<table>
<thead>
<tr>
<th></th>
<th>00BY01D</th>
<th>00BY06D</th>
<th>00BY11D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Soil</td>
<td>Depth</td>
<td>Soil</td>
</tr>
<tr>
<td>0-4</td>
<td>Sandy clay</td>
<td>0-1</td>
<td>Silt loam</td>
</tr>
<tr>
<td>4-10</td>
<td>Clay</td>
<td>1-24</td>
<td>Sandy clay</td>
</tr>
<tr>
<td>10-11</td>
<td>Heavy clay</td>
<td>24-28</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>11-19</td>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The eucalypt simulations are run for a period of $10^5$ years using repeated hundred year sequence (1900-1999) of rainfall from the point-patched data set (Bureau of Meteorology) for Lake Grace. The boundary condition at the bottom of the profile means that the profile is free-draining. The initial conditions used are a salt free profile with water pressure at -10 m and a root density of 1 m$^3$ m$^{-1}$. The resulting water content and salt content profiles are shown in Figures L10 and L11 respectively. In the water content the change in soil type can be clearly seen.

![Figure L10. Water content profiles for three bores under three types of eucalypts](image-url)
Figure L11. Salt content profiles for three bores under three types of eucalypts

The final conditions from the eucalypt simulations are used as initial salinity profiles for the pasture simulations. Two simulations are run for each pasture type for a total of 100 years (climate data 1900-1999). The first simulation retains the existing free-draining boundary condition and calculates the increased recharge under pasture. The second simulation specifies the head at the base of the profile at a depth of 29 m at the start of the simulation, and rising at a rate of 0.27 m/year. However the watertable is assumed to be at the base of the profile if the specified watertable is deeper than the base of the watertable. Thus after 100 years, the head will be 2.0 m below the ground surface. Figures L12 and L13 show the water content and salt content respectively for medium winter pasture 100 years after clearing of medium eucalyptus. Figure L14 shows the drainage from the base of the profile for these simulations. Negative values of drainage indicate uptake of regional groundwater into the profile. The free-draining simulations show a lowering of the recharge rate since the 1970s in response to the reduced rainfall. The specified watertable level simulations show a considerable variation in the drainage, however in the field these are likely to result in changes to the watertable level with only small changes in the drainage quantities.
Figure L12. Water content profiles under medium winter pasture after 100 years of clearing

Figure L13. Salt concentration profiles under medium winter pasture after 100 years of clearing
Although WAVES does not include important processes such as macropore flow and may not accurately represent the profile and vegetation throughout the town, these simulations can be used qualitatively to compare different scenarios.

### 3.2 Groundwater

Previously a groundwater model was constructed for Woodanilling after the drilling program in 2000 (Crossley 2001). This model was based on data from the first sets of bore readings, which as shown in Figure L5, contained some anomalous data. Therefore a new model was constructed for the town.

#### 3.2.1 Construction

The new model comprises two layers as interpreted from the cores. The two layers were a surface layer comprising of saprolite and tertiary sediments, and a deep layer comprising of saprock and saprolite grits. These lithological layers were combined because the topmost layer, the tertiary sediments, had a maximum thickness of 3.0 m, and is unlikely to have much saturated thickness (at bore 00BY01D, where the groundwater is the most shallow, the tertiary sediments were only 1 m thick). Similarly the discontinuous nature and thinness of the saprock and saprolite grits meant that to get a consistent layer these two units needed to be combined. The base elevation of each layer was calculated using the elevations from the Digital Elevation Model (DEM) and subtracting the thickness of each overlying layer.

The flow through the town is thought to occur from the east to the west. The eastern boundary is assumed to be the groundwater as well as surface water divide and does not need to be specified within the model. The western boundary in the model is the paleochannel system. This is included as a thin strip of higher conductivity nodes in the deeper layer and general head boundaries on the northern and southern ends of this strip. Average recharge to the system is calculated from WAVES simulations. WAVES was selected to calculate the recharge in the urban areas even though it is applicable to vegetation that it provides a dynamic mechanism to calculate both recharge and evapotranspiration from natural causes. The town is a patchwork of different land uses with some areas having little or no trees, whilst others having a large number of trees interspersed with the buildings. There are also different systems for stormwater run-off and disposal. The net recharge for
different areas of town is thus a combination of recharge and evapotranspiration for various vegetation types, with additional amounts for irrigation, stormwater disposal and infrastructure leakage such as from septic systems and water supply systems. The recharge amounts are presented in Table L2. Evapotranspiration from the watertable is specified as 70 mm/year at the surface falling to nothing at a depth of 1.8 m.

<table>
<thead>
<tr>
<th>Area</th>
<th>Recharge rate [mm/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>12</td>
</tr>
<tr>
<td>Playing fields and parks</td>
<td>15</td>
</tr>
<tr>
<td>Cleared rural</td>
<td>10</td>
</tr>
<tr>
<td>Uncleared or tall vegetation</td>
<td>1</td>
</tr>
</tbody>
</table>

The hydrogeological parameters are estimated from the lithology, bore logs, and the literature (Peck 1980; George 1992; Salama et al. 1993; Clarke et al. 2000). The initial conditions for the flow simulations are based on the extrapolated head distribution in December 2000.

3.2.2 Calibration

The model is calibrated against the observed heads from 2001 to mid-2004. The parameters used for the calibration are the hydraulic conductivities in the two layers and the anthropogenic recharge under the town. Calibration by varying the recharge and hydraulic conductivity results in finding the ratio between the two, without specific values for either. Due to the short time span of the observed data set no verification of the calibrated model was performed.

3.2.3 Predictive Scenarios

The scenarios for Woodanilling are aimed at reducing the groundwater recharge to the ground within the town area. The simulations run for 20 years using the constant recharge and evapotranspiration. The base scenario for all this work is ‘do-nothing’ to examine what happens without any intervention. The depth to water distribution after 20 years is shown in Figure L15. Additional scenarios include the reduction in recharge in urban areas to 90%, 75%, 50% and 0% of the original recharge. These results are presented in Figure L16 as comparisons effects on the depth to the watertable elevation at selected bores in the town. These show that 10% reduction in recharge may increase the depth to water by up to 0.06 m; a 25% decrease may increase the depth to water by up to 0.15 m; and complete removal of all recharge in the town lowers the average watertable by up to 0.65 m.
Figure L15. Depth to water after 20 years of 'do-nothing' scenario

Figure L16. Increased depths to water for three bores resulting from decrease in town recharge
4. Conclusions

The hydrogeological investigation of the town of Woodanilling found that the vertical groundwater gradient through the town was in general in a downwards direction, indicating that the recharge within the town and in its immediate surroundings were creating the high water tables and associated problems with salinity. It is therefore recommended that surface water controls be implemented in order to reduce the recharge within the town. The modelling showed that with recharge reduction within the town, decreases in the watertable of up to 60 cm can be achieved.

5. References


APPENDIX M

H₂OBeef

A decision tool for water management in beef feedlots

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Summary

In many intensive beef production enterprises water is not considered limiting and commands a price that is too insignificant to be included in any decision-based models. However, water allocation will have greater importance in future decision making associated with intensive animal production enterprises as it becomes increasingly scarce in many regions around the world. Furthermore, there is increasing potential to treat water. The decision as to whether this should be done will depend on the net benefits of the water treatment process in question with part of these benefits being realized by the end-user of this water.

This report is designed to provide readers with a complete overview of how the H₂OBeef computer model works. Detailed descriptions of biological and economic relationships are presented throughout the Sections.

H₂OBeef is a tool designed to help decision makers evaluate long-term options associated with water management in beef feedlots. It is also an integral part of a larger systems model that has been developed to evaluate the net benefits of abstracting, treating and reusing saline ground water from under Western Australian rural towns. As the model is a simulation model several management strategies are considered and run through the model. Based on the output generated, the decision maker can decide on the optimal management regime to implement.

A single feedlot is represented in H₂OBeef. The user can specify the number of cattle, entering the feedlot, diet and water type, quality and quantity. An alternative water type other than desalinated water is also included in the model so that if desalinated water is not produced in sufficient quantities the feedlot will still be able to function.

H₂OBeef is relevant for any town providing the relevant model parameters are altered to reflect the characteristics of a particular town. While the model does not represent year-to-year variation in weather or advances in technology associated with beef production, changes in costs and/or benefits connected with these factors can be manually entered into the model.

The biological equations in the H₂OBeef are ultimately used to determine the water demand for the feedlot, including water intake and water used for dust control. Feed intake is a main driver of water intake and is modified by salt content of the ration and the environmental impact of temperature and rainfall to maintain animal production. In this model the feed is assumed to be a dry ration and as there is no access to pastures, water intake is an important component of production. Water consumption is calculated on a monthly basis in the model and hence maximum temperatures are used in the water intake calculations.

Net economic benefits for a desired project over a 10 or 20-year period are produced in H₂OBeef. However, it must be noted that the results are contingent upon the assumptions driving them and should be interpreted accordingly. To provide information to help with this interpretation, an outline for conducting a sensitivity analysis is provided in Section 8.

While extensive detail regarding composition of the feedlot, feed intake and weight gain, waste management, water demand and balance and the economic analyses are all presented in this report, H₂OBeef does have some limitations. Understanding these shortcomings is important and hence they are described in the final section. Furthermore the authors welcome any constructive feedback on any aspects of H₂OBeef.
Contents

1 INTRODUCTION........................................................................................................................................M4

2 CATTLE IN THE FEEDLOT .................................................................................................................M6
   CATTLE SHEET .......................................................................................................................... M6
   LOTS SHEET ............................................................................................................................. M7

3 FEED INTAKE AND WEIGHT GAIN ...............................................................................................M8
   FEED ISSUE SHEET ....................................................................................................................... M8
   LIVE WEIGHT (LWT) PREDICTION SHEET ......................................................................................... M9

4 WASTE MANAGEMENT ....................................................................................................................M15
   WASTE OUTPUT ............................................................................................................................. M15

5 WATER DEMAND AND BALANCE ...............................................................................................M17
   WATER DEMAND SHEET ................................................................................................................. M17
   WATER SHEET ............................................................................................................................... M19

6 ECONOMIC DATA..........................................................................................................................M20
   COSTS ............................................................................................................................................. M20
   ASSETS ........................................................................................................................................... M22
   REVENUE ...................................................................................................................................... M23

7 ECONOMIC ANALYSIS ....................................................................................................................M24
   COSTS ............................................................................................................................................. M24
   BENEFITS ...................................................................................................................................... M24
   NET BENEFITS ............................................................................................................................... M24

8 CAPACITY OF H2OBEEF .................................................................................................................M27

REFERENCES .........................................................................................................................................M29

ATTACHMENT 1: KEY TO VARIABLES USED IN EQUATIONS .........................................................M30

ATTACHMENT 2: RECOMMENDATIONS FOR DAIRY COWS (AFRC 1993) .................................M35
1 Introduction

Water is not often a limiting factor in intensive beef production enterprises and usually is priced so low that the cost of water is not considered in decision based models. However, water use and cost is likely to have a greater importance in future decision making associated with intensive animal production enterprises due to it becoming increasingly scarce in many regions around the world. One consequence of this scarcity will be the increased amount of treated water made available. However, the amount of treated water that will be produced will depend on the benefits returned by the consumers of the water.

H₂OBeef is a decision support tool that is designed to provide information and insight to users in helping them make long-term decisions about water management in beef feedlots. More specifically, it is an integral part of a larger systems model designed to evaluate saline water that has been abstracted from under Western Australian rural towns, treated and reused.

As the model is not an optimisation model, the optimal strategies are determined for different scenarios through a series of runs. H₂OBeef allows the user to simulate different management options including those associated with water. The user considers management strategies and, using the model, decides on the optimal management regime to implement. Economic and biological components are integrated into the model with the time step for economic aspects being annual. For biological processes cattle input can be varied, so the length of time cattle are in the system depends on management plans that are selected by the user. It is possible to generate results from H₂OBeef for either a 10 or 20 year time period. The model is implemented in a spreadsheet program, Microsoft Excel®.

H₂OBeef represents a single feedlot. The user can specify number of cattle, Bos indicus and/or Bos taurus, entering the feedlot, diet and water type, quality and quantity. If desalinated water is in short supply and does not meet the feedlot requirement, the model specifies the amount of alternative water that would be required so that the feedlot is still able to function. This also means that H₂OBeef can easily be used for decision making other than that associated with desalinated water.

The applicability of H₂OBeef is not limited to a specific town as parameters within the model can be altered to reflect the town that it is used in. Default values pertain to Wagin, WA (Latitude:-33.3075 S, Longitude: 117.3403 E). Although it is recognised that climatic conditions, in particular temperature and rainfall, influence output as do changes in technology, H₂OBeef does not represent year-to-year variation in weather or advances in technology associated with beef production. However, there is scope in the model to manually account for these changes.

The key factors that drive water intake in cattle over time include feed intake, temperature, rainfall and salt content of the feed. In this model the feed is assumed to be a dry ration with no access to pastures and hence such an operation requires extra water to account for the lack of water in the feed ration. The equations in H₂OBeef are predominately used to determine the animal water demand for the feedlot, including water intake and water used for dust control and relief from heat stress.

For the purpose of this model, the year is broken into a number of lots (i.e. the period of time the cattle are in the feedlot from day of entry to day of exit). Each lot is of equal duration with equal time in between lots. This option can be changed depending on the starting and finishing live weights that are required to meet market specifications. Live weight changes are determined by feed intake and the energy density of the ration with the final live weight being determined from the surplus energy available for growth and the planned duration of the growth phase.

Solid excreta are estimated as the non-digestible dry matter component of the ration. The concentrations of nitrogen in the faeces are estimated from protein not digested and all urinary nitrogen is assumed to be lost to the atmosphere as ammonia. Faecal and urine phosphorus is calculated using nominal apparent digestibility and live weight. Total sodium and potassium excretions are calculated using nominal values from the literature. All values are estimated on a daily basis per head and then converted to annual production rates.
H2OBeef does not include detailed simulation of cattle growth, water intake or total excretion as the parameters used represent these biological functions in relatively simple ways and is a summation of the feedlot periods defined in the model. The water consumption models produce monthly intakes and in the model in the present format do not estimate daily water intakes. This limitation should be borne in mind for periods of extremely high temperatures that can occur in summer. If there is a requirement to estimate likely peak demands then the monthly temperatures could be set to the estimated extreme temperatures to estimate likely water requirements for the period of interest.

The main outputs that can be obtained from H2OBeef are the effect of feed composition on growth rate and water intake, the effect of climate on water intake and the effect these parameters together with alternative costs and benefits have on the net return for the project over a 10 or 20-year period. In addition, other biological and economic aspects are provided in the various sheets as outlined in the following Sections.

Results derived from a model such as H2OBeef are contingent upon the assumptions driving them and should be interpreted accordingly. The principal assumptions have been presented in this Section with minor assumptions described in relevant proceeding sections. Please note that as it is possible to input different values for the parameters pertaining to a specific breed of cattle, any parameters with a subscript, $\text{subscript}$ refers specifically to $\text{Bos taurus}$ and likewise $\text{BI}$ refers to $\text{Bos indicus}$. Where the equations are the same for each cattle type, either a generic equation is presented (in which case there is no subscript) or that for $\text{Bos taurus}$ is given as an example.

Outline of this report

This report is designed to provide a complete overview of how the H2OBeef computer model works. Details regarding the number, type and characteristics of cattle in the feedlot are presented in Section 2. The derivation of feed intake and weight gain is described in Section 3. An overview of a waste management plan is presented in Section 4. The detail underpinning the expected water demand is outlined in Section 5 along with the explanation for water balance in the feedlot. Economic data requirements are outlined in Section 6 and economic analyses described in Section 7. The capacity of H2OBeef is described in Section 8. The key variables used in the equations are listed in the attachment.
2 Cattle in the feedlot

The number of cattle in the feedlot and time that they are there throughout the year is based on two Microsoft Excel® sheets. The Cattle sheet provides the structure for the feedlot, and change in weight of the cattle over time. The Lots sheet relies on input in the Cattle sheet and shows the duration in days for each lot for the corresponding months and the times during the year when the feedlot is free of cattle.

Cattle sheet

The total number of cattle expected to go through the feedlot in a year, the days the cattle are in each lot (i.e. the period of time the cattle are in the feedlot from day of entry to day of exit) and the days between each lot are entered directly into the spreadsheet by the user. The user also enters the percentage of Bos taurus and Bos indicus within the herd. The percentages entered should not exceed 100 per cent. If they do an “error” message will appear in this row, otherwise the message will read, “ok”. Likewise, the natural death rate per annum and the purchase live weight are all deemed to be feedlot specific and so are directly entered into this sheet. The remaining parameters are calculated within this sheet as described in the sections below.

Number of lots per year

The number of lots per year (B) will influence the total time cattle are in the feedlot and the animal weight that they gain. It is calculated using the entered information for the time cattle are in the lot, $t_c$ (days) and time in between lots $t_b$ (days) and is assumed to be the same for all cattle.

$$B = \frac{365}{t_c + t_b}$$

Natural death rate

The total number of cattle that go through the feedlot during a year, $N$ (hd/yr) as well as the proportion that are Bos taurus (τ) and Bos indicus (ι) are selected by the user. These parameters together with the natural death rate ($d$) of each cattle breed in the feedlot are directly entered by the user. Hence the number of natural deaths per annum ($d_{yr}$) and per day ($d_{day}$) for Bos taurus would be:

$$d_{yrBT} = N\tau d_{BT}$$

$$d_{dayBT} = \frac{d_{yrBT}}{365}$$

Cattle entering and exiting the feedlot

Using parameters described in the above sections, the number of Bos taurus entering the feedlot at the beginning of each lot ($e_{BT}$) would be:

$$e_{BT} = \frac{N\tau}{B}$$

The number of Bos taurus exiting the feedlot ($x_{BT}$) accounts for natural deaths that are expected to occur over the period of time cattle are in the lot.

$$x_{BT} = e_{BT} - (d_{dayBT}t_c)$$
The procedure for *Bos indicus* is similar but specific parameters for this cattle breed would need to be entered.

The total number of cattle in the feedlot at any one time ($\varsigma$) could be approximated by taking the average number of *Bos taurus* and *Bos indicus*.

$$\varsigma = \frac{e_{BT} + x_{BT}}{2} + \frac{e_{BI} + x_{BI}}{2}$$

**Cattle weights**

The live weight of cattle at purchase ($W_p$) (kg/hd) is assumed to reflect the average live weight for yearling steers. In the model, a default of 220kg is used but this figure may be simply altered as required. Sale live weight ($W_s$) is a function of kilograms live weight gain per day ($W_{day}$) (from the LWT Prediction sheet as described in Section 3), the number of days that the cattle stay in the feedlot and the purchase weight. While different values for these parameters can be entered for different cattle breeds, the generic equation is:

$$W_s = W_p + (t \cdot W_{day})$$

**Feedlot area required**

The land area (ha) required for the feedlot ($A$) is based on the maximum number of cattle present at any one time multiplied by the square meters required per head *Bos taurus* ($A_{BT}$) or *Bos indicus* ($A_{BI}$) plus a miscellaneous area ($A_M$) (ha).

$$A = \frac{e_{BT} A_{BT} + e_{BI} A_{BI}}{1000} + A_M$$

According to Powell (1994) the recommended area for feedlot cattle is 15m$^2$ per head. A miscellaneous area of 3 hectares is assumed to be reasonable. These values are the default values used in this model but can be changed to reflect individual feedlot circumstances.

**Lots sheet**

The Lots sheet in H2OBeef provides a calendar of cattle activities for a typical year. Users are not required to input any data into the two tables in this sheet. Instead the figures in these tables will change depending on the time users select for the cattle to be in the feedlot and the time in between lots. In summary this sheet shows the days per month where activity in each lot occurs. Table M1 as displayed in this sheet, shows the time cattle in each lot spend in the feedlot as well as the 'resting' time after removal of cattle from the feedlot. The months that cattle are in particular lots can be clearly identified. Table M2 in the Lots sheet shows the total days of 'resting' time after removal of cattle from each lot. Managers can use this table to see the months when this activity will occur. Information from both tables is also used in other sheets that require information about specific cattle numbers in specific months e.g. for the calculation of water intake.
2 Feed intake and weight gain

Feed intake is assumed to be the main driver of water intake but is modified by salt content of the ration and the environmental impact of temperature and rainfall to maintain animal production. Hence dietary components and total quantity of feed given to each animal is explored in the Feed Issue sheet. The process of feed intake, conversion and waste output is detailed in the Live weight (LWT) Prediction sheet. Parameters associated with each of these activities are used to predict individual live weight gain, water demand and other factors required by the sheets that provide economic output.

Feed Issue sheet

The total quantity of ration fed per head per day, $F$ (kg/hd/day) is entered by the user into this sheet. The amount entered has a direct bearing on feed intake and water demand.

There are a total of 53 different dietary components (Table M1) presented in the Feed Issue sheet of H2OBeef with space for inclusion of an additional 36 components should the user have feed ingredients not included in the list. However, if additional components are added then their associated nutritional parameters must also be included in the appropriate rows. There is also a row representing a ‘no feed component’ option with a “code 0” that may be selected if the user wishes to have less than seven components in the diet (see below for more detail). It is assumed in H2OBeef, that cattle do not have any access to pasture. For each component the nutritional parameters specified are dry matter content ($DM$), metabolisable energy ($ME$), fermentable metabolisable energy ($FME$), crude protein ($CP$), gross energy ($GE$), fat, neutral detergent fibre ($NDF$), acid detergent insoluble nitrogen ($ADIN$), nylon bag nitrogen degradation parameters ($aN$, $bN$, $cN$) and dry matter digestibility ($DMD$). Values for these parameters are included in the table and should only be changed if the user has good reason to do so.

Table M1. List of dietary components and codes listed in the H2OBeef model

<table>
<thead>
<tr>
<th>Code</th>
<th>Component</th>
<th>Code</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No feed component</td>
<td>27</td>
<td>Moist barley</td>
</tr>
<tr>
<td>1</td>
<td>Apple pomace (wet)</td>
<td>28</td>
<td>Molasses, cane</td>
</tr>
<tr>
<td>2</td>
<td>Apples</td>
<td>29</td>
<td>Oat grain</td>
</tr>
<tr>
<td>3</td>
<td>Barley straw</td>
<td>30</td>
<td>Oaten straw</td>
</tr>
<tr>
<td>4</td>
<td>Barley grain</td>
<td>31</td>
<td>Orange peel</td>
</tr>
<tr>
<td>5</td>
<td>Bread</td>
<td>32</td>
<td>Palm kernel ext.</td>
</tr>
<tr>
<td>6</td>
<td>Brewer’s grains</td>
<td>33</td>
<td>Pea straw</td>
</tr>
<tr>
<td>7</td>
<td>Cabbage</td>
<td>34</td>
<td>Peas</td>
</tr>
<tr>
<td>8</td>
<td>Carrots</td>
<td>35</td>
<td>Potatoes</td>
</tr>
<tr>
<td>9</td>
<td>Cassava meal</td>
<td>36</td>
<td>Rape</td>
</tr>
<tr>
<td>10</td>
<td>Cereal straw</td>
<td>37</td>
<td>Rapseseed meal</td>
</tr>
<tr>
<td>11</td>
<td>Citrus pulp</td>
<td>38</td>
<td>Rye grain</td>
</tr>
<tr>
<td>12</td>
<td>Cottonseed meal</td>
<td>39</td>
<td>Silage 55-60 Days</td>
</tr>
<tr>
<td>13</td>
<td>Fat</td>
<td>40</td>
<td>Silage 60-65 Days</td>
</tr>
<tr>
<td>14</td>
<td>Fishmeal (white)</td>
<td>41</td>
<td>Silage 65-70 Days</td>
</tr>
</tbody>
</table>
Each component has a diet selection code that is used to represent that component should it be selected in the feedlot ration. Users select seven dietary components ‘codes’ in total along with the percentage of each component, \( n \), in the ration \( f_n \). Code “0” (no feed component) can be selected more than once if fewer than seven components are required. However, each of the seven spaces must be completed. An ‘error’ check is provided in this sheet to ensure that the total percentage of dietary components is 100%.

### Live weight (LWT) prediction sheet

Unless otherwise stated, specified estimations are based on published feeding standards. Specific references are recorded in the LWT prediction sheet and can be found by scrolling to the right of the sheet.

### Dry matter intake and output

The total dry matter intake, \( D \) (kg/hd/day) is the summation of the feed ration, \( F \) (kg/hd) multiplied by the proportion of each component in the ration \( f_n \) and the dry matter content \( \alpha_n \) for each component selected using the following formula:

\[
D = \sum_n F f_n \alpha_n
\]

Faecal output (dry matter) per head per day, \( K \) (kg/hd/day) is determined by multiplying the dry matter intake by one minus the average dry matter digestibility of the components in the feed ration, where \( G_n \) is the proportion dry matter digestibility of component, \( n \).

\[
K = D \left( 1 - \frac{\sum_n G_n}{n} \right)
\]
The total salt added to diet, \( S \) (g/hd/day) is determined from dry matter intake (in grams) multiplied by dietary salt added, \( s \).

\[
S = 1000 D s
\]

Energy and live weight gain

Total metabolisable energy in the ration, \( M \) (MJ/hd/day) is the summation of the energy density of each component in the ration, \( e_n \) (MJ/kg dry matter) multiplied by the dry matter intake of each component.

\[
M = \sum_n e_n F f_n \alpha_n
\]

Net energy stored (\( E_g \)) is calculated using the prediction equation in Bulletin 33 (1977) where:

\[
E_g = 0.0414 \left( \frac{M}{D} \right) \left\{ M - (8.3 + 0.091L) \right\}
\]

and \( L \) is live weight (kg).

Live weight gain (\( L_g \)) is calculated using the prediction equation in Bulletin 33 (1977) where:

\[
L_g = \frac{E_g}{6.28 + 0.3E_g + 0.0188L}
\]

The NRC beef cattle feeding standards (1996) indicated that \( Bos indicus \) breeds of cattle maintenance energy requirements are about 10% lower than the \( Bos taurus \) breeds. The maintenance requirement in \( E_g \) has been modified in line with this finding and there are no reported differences between the two breeds in the efficiency of utilization of energy for live weight gain.

This sheet also allows for an alternative estimation of live weight change, energy requirements, as well as, protein surpluses or deficiencies as a guide to the adequacies of the proposed dietary formulations. The calculations are based on AFRC (1993) and are independent of the parameters used to estimate live weight change for this model. The AFRC (1993) parameters used in this sheet were initially developed by S. Liu (pers. comm.), primarily to determine the energy and protein adequacy, or in-adequacies of rations, and have the potential to include other classes of cattle. The AFRC (1993) parameters calculated are presented in Appendix 2.

A mean value for the gross energy of ruminant diets is assumed to be 18.8 MJ/kg DM (AFRC 1993) and has been used throughout when tabulating metabolisable energy requirements. Gross energy intake, \( E \) (MJ/hd/day) is calculated from the sum of the gross energy contained in each of the dietary components \( e_n \) (MJ/kg) multiplied by daily dry matter intake of each component per head.

\[
E = \sum_n e_n F f_n \alpha_n
\]

Metabolisable energy intake is calculated using the same formulae as for total metabolisable energy in the ration (\( M \)).

The metabolisability of the gross energy in the diet dry matter (\( q_m \)) is defined as the proportion of metabolisable energy in the gross energy of the feed using the following formula.

\[
q_m = \frac{M}{E}
\]
The fasting metabolism, $q_f$ (MJ/hd/day) requirements for cattle are calculated using the following formula with $C_1=1.15$ for bulls and 1.0 for other cattle and $W_p$ is the live weight of cattle at purchase:

$$q_f = C_1 \left\{ 0.53 \frac{W_p}{1.08} \right\} 0.67$$

Assuming horizontal movement of 200 m, 12 hours of standing and six changes in position, AFRC (1993) estimated the energy costs of activity, $a$ (MJ/hd/day) in beef cattle from the following formula:

$$a = 0.0071W_p$$

Net energy for maintenance, $E_m$ (MJ/head.day) is the sum of energy required for fasting metabolism and activity. This net energy evaluation is adjusted using an estimation of the efficiency of utilization of ME for maintenance ($k_m$).

$$k_m = 0.35q_m + 0.503$$

The efficiency of utilization of ME for weight gain ($k_f$) is estimated using the following formula:

$$k_f = 0.78q_m + 0.006$$

Energy value of tissue gained or lost, $E_v$ (MJ/kg) is estimated using the following equation:

$$E_v = \frac{C_2 \left( 4.1 + 0.0332W_p - 0.0000009W_p^2 \right)}{1 - C_3 \left( 0.1475W_{day} \right)}$$

where $C_3 = 1$ where the value of $\lambda$ (see next page for definition) is assumed $t > 1$ for feedlots. $C_2$ corrects for mature body size and sex of the animal, in accordance with the values given in Tables M2 and M3.

### Table M2. Values of correction factor $C_2$ for $E_v$ content of live weight gains in cattle by maturity group and sex

<table>
<thead>
<tr>
<th>Maturity type</th>
<th>Bulls</th>
<th>Castrates</th>
<th>Heifers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>1.00</td>
<td>1.15</td>
<td>1.30</td>
</tr>
<tr>
<td>Medium</td>
<td>0.85</td>
<td>1.00</td>
<td>1.15</td>
</tr>
<tr>
<td>Late</td>
<td>0.70</td>
<td>0.85</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Table M3. Classification of cattle breeds into maturity groups

<table>
<thead>
<tr>
<th>Early</th>
<th>Medium</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberdeen Angus</td>
<td>Hereford</td>
<td>Charolais</td>
</tr>
<tr>
<td>North Devon</td>
<td>Lincoln Red</td>
<td>Limousin</td>
</tr>
<tr>
<td>Friesian</td>
<td>Sussex</td>
<td>Simmental</td>
</tr>
</tbody>
</table>

Initial live weight ($W_p$) and the predicted live weight gains ($W_{day}$) are used from the model to predict final weight gains.

Level of feeding as a multiplier of megajoules of metabolisable energy for maintenance ($\lambda$) is estimated as a ratio of $M_{mp}$ to $M_m$. 

M11
\[ \lambda = \frac{M_{mp}}{M_m} \]

The metabolisable energy required for maintenance, \( M_m \) (MJ/day) is estimated using the following formula:

\[ M_m = \frac{E_m}{k_m} \]

The metabolisable energy requirement for maintenance and production, \( M_{mp} \) (MJ/day) can be estimated using the prediction equation:

\[ M_{mp} = \left( \frac{E_m}{k_m \ln \frac{k_m}{k_f}} \right) \ln \left( \frac{\beta}{\beta - E_r - 1} \right) \]

\( \beta \) is found through calculation of the formula:

\[ \beta = \frac{k_m}{k_m - k_f} \]

\( E_r \) is the retention of Net Energy to adjust the ME intake of growing cattle in order to decrease the overestimation of energy retention implied by a linear model (Blaxter and Boyne 1970) and is estimated from:

\[ E_r = \beta \left\{ 1 - e^{-\left( \frac{k_m \ln \frac{k_m}{k_f}}{k_f} \right) M} \right\} - 1 \]

The net energy retained by the growing cattle, \( E_f \) (MJ/hd/day) is determined from:

\[ E_f = E_r E_m \]

Live weight gain per day, \( W_{day} \) (kg/hd/day) is predicted using the following formula:

\[ W_{day} = \frac{E_f}{C_4 \left( 4.1 + 0.0332W_p - 0.000009W_p^2 + 0.1475E_f \right)} \]

where \( C_4 \) is correction factor for cattle sex; 1.15 for bulls and castrate males, 1.10 for heifers.

**Protein**

Net protein equivalent of basal endogenous nitrogen requirements, \( N_b \) (gCP/hd/day), is estimated using the following formula:

\[ N_b = 6.25 \left( 0.35W_p^{0.75} \right) \]

Net protein requirements for scurf and hair growth, \( N_d \) (gCP/hd/day) is found from:
Net protein requirements for maintenance, $N_m$ (gCP/hd/day) is the sum of $N_b$ and $N_d$.

$$N_m = N_b + N_d$$

The efficiency of utilization of $N_m$ for maintenance ($k_{nm}$) is defined in ARFC (1993) as $k_{nm}=1$.

Metabolisable protein required for basal maintenance, $M_b$ (gCP/hd/day) is calculated using the following formula:

$$M_b = 2.1875W_p^{0.75}$$

Metabolisable protein required for scurf and hair growth, $M_d$ (gCP/day) is estimated using the equation:

$$M_d = 0.1125W_p^{0.75}$$

Metabolisable protein required for maintenance, $M_p$ (gCP/hd/day) is found using:

$$M_p = M_b + M_d$$

Crude protein supplied by the diet, $J$, is the summation of the crude protein content of each dietary component, $\rho$ (gCP/kg) multiplied by the dry matter content of each component consumed in the total diet.

$$J = \sum \rho_n F_f \alpha_n$$

Rumen degradable protein, $D_p$ (gCP/hd/day) in the diet for a given rumen outflow rate is predicted from the summation of quickly degradable protein, $D_q$ (g/kg) in the dietary components plus the summation of slowly degradable protein, $D_s$ (g/kg) in the dietary components multiplied by the dry matter intake of each component per head.

$$D_p = \sum (D_q + D_s)F_f \alpha_n$$

with

$$D_q = \rho_n a_n$$

where $a_n$ is the constant measured on the feed component. (quickly degradable protein is the cold water extracted fraction on the feed total crude protein content)

and

$$D_s = \rho_n \left( \frac{a_n b_n}{c_n + r_n} \right)$$

with $a$, $b$, $c$ and $r$ being parameters measured on the feed components (slowly degradable protein is the amount of protein slowly degradable during the residence of the feed in the rumen).

The measure of the total nitrogen supply that is captured and utilized by the rumen microbes for growth and synthesis purposes is called effective rumen degradable protein, $D_e$ (gCP/kgDM) and is calculated using the following formula:
Undegradable protein, $D_u$ (gCP/day) is estimated as crude protein minus the rumen degradable protein:

$$D_u = J - D_p$$

Digestible undegraded protein (gCP/day) is the amount of undegraded feed protein that is truly absorbed and is calculated using the following formulae:

$$D_d = 0.9D_u - 6.25N_u$$

where $N_u$ is acid detergent insoluble nitrogen in the diet.

Yield of rumen microbial protein synthesis $Y_r$ (gMCP/MJ FME) is predicted as follows:

$$Y_r = 7.0 + 6.0\left(1 - e^{-0.352}\right)$$

Fermentable metabolisable energy of the diet $M_f$ (MJ/day) is a product of the sum of the intake of the individual FME components of the ration and the dry matter intake of each component per head.

$$M_f = \sum_n \xi_n Ff_n \alpha_n$$

An estimation of the microbial crude protein, $M_c$ (gMCP/day) supplied by the rumen is calculated from fermentable metabolisable energy of the diet and yield of rumen microbial protein synthesis.

$$M_c = M_f Y_r$$

The ratio of effective rumen degradable protein ($D_e$) and fermentable metabolisable energy of the diet ($M_f$) has three possible outcomes and is used to balance the protein component in the diets:

1. If $D_e$ supply is less than $D_e$ requirement, then the diet is $D_e$ limited and the microbial crude protein supply is equivalent to $D_e$.
2. If $D_e$ supply exceeds $D_e$ requirements, then $M_f$ is first limiting microbial crude protein supply and is determined from $M_f$ and yield of rumen microbial protein synthesis.
3. If $D_e$ supply matches the supply of $M_f$, this is the objective of diet formulations using the metabolisable protein system. This avoids both unnecessary surplus nitrogen excretions, which has environmental implications in feedlots, or else limitations of forage/diet intake caused by a shortage of $D_e$.

Digestible microbial true protein, $M_t$ (gCP/day) is produced by the activities of the rumen microbes, which synthesizes protein from fermentable energy sources in and amino acids or non-protein nitrogen from the breakdown of feed proteins in the rumen.

$$M_t = 0.6375M_c$$

Total metabolisable protein, $M_T$ (gCP/day) is calculated from:

$$M_T = 0.6375M_c + D_d$$
3 Waste management

While waste management associated with a beef feedlot does not require additional water, the products derived from processing the waste contribute to the total returns generated by the enterprise. Furthermore regulations associated with feedlots generally require effluent produced from such operations to be dealt with in a manner that meets health and safety standards. The following sections outline the waste output, treatment, costs and returns as described in the Waste Management sheet.

Waste output

Dietary concentration of nitrogen, $N_D$ (g/kgDM) is calculated using crude protein intake and dry matter intake as found in the LWT prediction sheet.

\[
N_D = \left( \frac{J}{6.25} \right) \left( \frac{1}{D} \right)
\]

Dietary concentrations of phosphorus, potassium and sodium have been directly placed into H$_2$OBeef. These concentrations along with operator selected values for excretion, based on Spears et al. (1989) for apparent digestion of minerals, are required in H$_2$OBeef to calculate how much of each component is retained in the faeces and urine as described in the sections below.

Faeces

The proportion of each of the elements in the faeces is currently estimated in the model based again on Spears et al. (1989), except for faecal nitrogen ($N_f$), which is calculated using total metabolisable protein supplied and total crude protein intake from the diet, so as to estimate the non-metabolisable component. The generic equation used to determine the proportion of nitrogen in faeces is:

\[
N_f = 1 - \left( \frac{M_f}{J} \right)
\]

Faecal concentration will then simply be the dietary concentration multiplied by the proportion of the element found in the faeces. Hence for nitrogen, the faecal concentration, $N_F$ (g/kgDM) would be:

\[
N_F = N_D N_f
\]

The total dry matter of elements in the faeces can then be determined from the faecal concentration for that element multiplied by the remainder left from the feed digestible fraction reported as faecal output in the LWT prediction sheet. Therefore the total amount of nitrogen derived from the faeces and available for sale, $N_S$ (kg) would be:

\[
N_S = N_F K
\]

All faecal nitrogen is assumed to be stable and remain in the faeces.

Urine

Urinary weight output, $U_o$ (g/hd/day) is estimated using the prediction equation of Fox et al. (2004) using the parameters of total DMI intake, crude protein intake and live weight.
All urinary nitrogen is assumed to be lost to the atmosphere as ammonia, thus making no contribution to mature nitrogen levels. Urinary phosphorus output, $U_P$ (g/hd/day) is determined as a function of body weight (Fox et al. 2004).

$$U_P = \left( \frac{W_P + W_s}{2} \right) \left( \frac{0.9}{454} \right)$$

Urinary sodium, $U_{Na}$ (g/hd/day) and potassium $U_K$ (g/hd/day) outputs are estimated using excretion coefficients based on Spears et al. (1989).

$$U_{Na} = 0.79 Na_D D$$

$$U_K = 0.35 K_D D$$

The total amount of each mineral excreted per day in the feedlot is simply the total faecal and urinary outputs for those minerals converted from grams to kilograms.

### Processing costs

The annual processing costs for an element, e.g. for nitrogen $C_N$ ($/yr$) is estimated in H2OBeef by multiplying the cost of processing for that element, $c_N$ ($/kg$) by the total amount of nitrogen produced, $N_T$ (kg/day) and the number of days per year that the cattle are in the feedlot, $t_y$ (days).

$$C_N = c_N N_T t_y$$

The total annual processing costs for all waste produced are found by summing the processing costs for each mineral.

### Revenue from minerals

The annual revenue derived from selling a mineral processed from feedlot waste, e.g. for nitrogen $R_N$ ($/yr$) is estimated in H2OBeef by multiplying the price that element can be sold for, $P_N$ ($/kg$) by the total amount of nitrogen produced, $N_T$ (kg/day) and the number of days per year that the cattle are in the feedlot, $t_y$ (days).

$$R_N = P_N N_T t_y$$

The total annual revenue that can be derived from mineral sales is the sum of revenue produced by each mineral. It is assumed that these minerals will be sold as compost at a price equivalent to fertilizer containing similar elements. It should also be noted that waste water passing into the groundwater table meets regulation quantity and quality.
4 Water demand and balance

Water demand is a factor that is commonly overlooked in most animal enterprises. Usually this is because water is not a limiting input and its cost is often seen as being insignificant when compared to the costs of other inputs. However, as water becomes less available and/or more expensive it should not be overlooked in animal enterprises. In the following sections, details describing how water demand is calculated in H2OBeef are provided. Furthermore, a description regarding the water sources for the feedlot and water balance will be provided. The parameters are inclusive for determination of water intake and are based upon feedlot measurements, although the data is for US feedlots that include lower temperatures and less extreme temperatures than those experienced in Australian feedlots. Nevertheless it is possible to alter these values if the user wishes to assume different values for the parameters based on their own experiences.

Water demand sheet

The Water demand sheet relies on rainfall and temperature data for the area that the feedlot is located in so as to calculate water required for dust control and water intake for cattle.

Climatic data

For each month of the year average monthly rainfall data, Wm (mm), average days each month where the rainfall is less than 3 mm, Wl (days), the maximum temperature in each month, T (°C) and that amount of water required for dust control on a daily basis, Wd (mm) are all directly placed in H2OBeef.

Dust control and spray for heat stress

The Water demand sheet includes estimations of total water used for dust control and spray for heat stress in the feedlot. As a default, it is assumed that watering would be required to maintain the manure surface moisture content at 25 to 35 per cent. Assuming 1 mm/ha is equivalent to 10,000 L, it would be necessary to spray 3 L/m² to ensure the equivalent of 3 mm/day.

The water required for dust and stress control for *Bos taurus* cattle in the feedlot in any one month, $W_{BT} (L/mth)$ would be:

$$W_{BT} = A_{BT} e_{BT} W_d W_t$$

Likewise the water needed for dust and stress control for *Bos indicus* cattle in the feedlot in any one month $W_{BI} (L/mth)$ could be calculated using relevant data for this cattle type.

Water intake for cattle

Daily water intake for a cow, $H_A$ is estimated from Hicks *et al.* (1988) and uses dry matter intake ($D$) (kg /hd/day), maximum daily temperature, $T$ (°C), average monthly precipitation, $W_m$ (mm) divided by the number of days in a specific month, $t_m$ and dietary salt added, $s$ (Na%). Therefore the feedlot monthly water intake for *Bos taurus*, $H_A (L/mth)$ can be estimated as:

$$H_A = e_{BT} t_m \left\{-6.1 + 0.708T + 2.44D - 0.387 \left( \frac{W_m}{t_m} \right) - 4.445s \right\}$$

where $t_m$ represents the number of days in a specific month.
This prediction of water intake needs to be treated with caution for salt inclusions in the diet of greater that 0.5%. The equation predicts decreasing water intakes with increasing salt content in the diet. This is contrary to the prediction equation developed by Murphy et al (1983) where increasing salt content in the diet resulted in increased water consumption. However, the above estimation of water intake based on Hicks et al. (1988) is similar to that produced by Winchester and Morris (1956) for cattle 450 kg at 20°C but diverges for larger cattle at higher temperatures.

As there are few available published references for estimation of water intake the model developed by Hicks et al. (1988) was selected for H2OBeef as it is the most inclusive and the temperature range was appropriate for this environment. However, there needs to be some caution exercised using this model with large cattle in extreme temperatures. The Winchester and Morris (1956) predictions also differentiated between Bos indicus and Bos taurus cattle. Hence, substituting the relevant parameters for Bos indicus into the equation suggested by Hicks et al. (1988) and multiplying by this correction factor would give the monthly water intake for that cattle type.

\[
H_A = e^{BT \cdot t_m \cdot \phi} \{ -6.1 + 0.708T + 2.44D - 0.387 \left( \frac{W_m}{t_m} \right) - 4.445S \}
\]

Where: \( \phi \) (value can be calculated from Winchester and Morris (1956) or operator choice) is the correction factor for water intake for Bos indicus. Please note that the outputs from the Hicks et al. (1988) calculation for water intake is referred to as “Option 1” in the Water demand sheet.

The predictions for daily water intake based on Winchester and Morris (1956) for Bos taurus (\( H_{BT} \)) and Bos indicus (\( H_{BI} \)) are also included in the Water demand sheet as an alternative estimation of daily water requirements and is referred to as “Option 2”. The equations used are:

\[
H_{BT} = D \left\{ 3.413 + 0.01595 \left( -e^{0.17596 T_a} \right) \right\}
\]
\[
H_{BI} = D \left\{ 3.076 + 0.008461 \left( -e^{0.17596 T_a} \right) \right\}
\]

Where \( T_a \) is the average daily maximum temperature for the year.

A further check predicts minimum water intake based on Doreau et al. (2004) assuming that water intake will be 25.3 mL/kg live weight/day. Intake is doubled if cattle are fed ad libertum. The generic equation for both cattle types is presented as:

\[
H = \left( \frac{W_p + W_s}{2} \right) \left( \frac{25.3 \times 2}{1000} \right)
\]

This check is referred to as “Option 3” in the Water demand sheet and serves as warning in cases where cattle are fed very restricted intakes and the weather conditions can then start to become a prime determinant of water intake. These minimal metabolic requirements should be considered as the minimal water allowance for beef cattle.

**Total water requirements for the feedlot**

The total feedlot water requirements each month, \( W_R \) (L/mth) are simply the sum of water required per month for both cattle types for dust control and water intake. These amounts can then be fed directly into the Water sheet.
Water sheet

The Water sheet presents an overview of the water balance for the feedlot for each month of the year.

Water sources

Any water source can be used in the model with the quantity of water available per month for each month of the year $W_D$ (L/mth) being entered directly into the Water sheet. However, the main reason for the development of H2OBeef was to integrate desalinated water and therefore it will be assumed that this source of water refers to that water type. More specifically, the exact amount available will be derived from the larger systems model that will provide an estimation of the desalinated water that has been derived from extracted water from under a specific rural town.

The water balance, $W_B$ (L/mth) can then be calculated as the difference between the water requirements as calculated in the Water demand sheet and the desalinated water available.

$$W_B = W_D - W_R$$

If the water balance is positive the remaining desalinated water is displayed in the Water sheet and if it is negative the quantity of water required from another source, e.g. scheme, is also presented.

Please note that as a check regarding the quantity of salt in the water sources, the user is required to input the Moles of NaCl/m$^3$ in the water into the Water sheet. Depending on the quantity a message as outlined in Table M4 will appear.

Table M4. Symptoms occurring in cattle when consuming water with various salt contents

<table>
<thead>
<tr>
<th>Moles of NaCl/m$^3$ in water</th>
<th>Symptoms in the Cattle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 12.7</td>
<td>no problems</td>
</tr>
<tr>
<td>Over 12.7 and up to 38.2</td>
<td>temporary diarrhoea in unaccustomed stock, won't restrict long term performance</td>
</tr>
<tr>
<td>Over 38.2 and up to 63.7</td>
<td>satisfactory but can cause serious problems in unaccustomed stock</td>
</tr>
<tr>
<td>Over 63.7</td>
<td>can cause serious problems in all stock</td>
</tr>
</tbody>
</table>

Cost of water

The price of desalinated water, $P_T$ ($/kL$) and of the alternative source $P_S$ ($/kL$) are directly placed into the Water sheet in H2OBeef. The cost of desalinated water will be derived from the larger systems model while the cost of the ‘other’ water should equal the marginal cost of scheme (or other) water. The total cost of desalinated water $C_T$ ($/mth$) will therefore be the quantity of desalinated water used in the feedlot multiplied by the price.

$$C_T = P_T W_D$$

Likewise the cost of scheme or ‘other’ water can be calculated in the same way. The total cost of water is then simply the summation of the water costs for each type.

There is a facility in H2OBeef to also include water transport costs. In the case of desalinated water it is assumed that the feedlot will be some distance away from the desalination plant and hence the cost of transport would be the total amount of desalinated water used multiplied by the cost of transporting each litre of water over each kilometre.
5 Economic Data

H2OBeef provides a long-term view of the economics of beef feedlot management with special consideration of water. Management decisions will impact on the output of the feedlot, and these decisions together with input costs and output prices, will determine whether the feedlot produces long term economic benefits. In the following sections data that are required for the economic analysis in this model is outlined. Details regarding assets, revenue and most costs are contained within the Econs data sheet whilst those pertaining to loan repayments are presented in the Loan repay sheet and those describing indirect costs and benefits are outlined in the Indirect B&C sheet. The parameters in these sheets are either based directly on data obtained from various sources or derived from calculations based on this data, some of which are described in previous Sections of this document.

Costs

Cattle purchases

The total value of cattle purchases (CC) ($/yr) is a function of number of lots per year, Ln (rounded up to the nearest whole number), cattle inputs per lot, purchase live weight (from Cattle sheet) and purchase price in dollars per kilogram live weight Bos taurus (PpBT) or Bos indicus (PpBI).

\[ C_C = L_n (e_{BT} W_{pBT} P_{pBT} + e_{BI} W_{pBI} P_{pBI}) \]

The purchase price will change depending on the market and weight and type of cattle bought. Therefore the model allows for the default value of $1.90/kg to be changed.

Feed costs

The feed cost per animal per day (cF) ($/hd/day) is calculated using feed in the ration, F (kg/hd/day), percentage of each component in the ration, fn (%) and the price of each component, Pn ($/t) as found in the Feed Issue sheet.

\[ c_F = \sum_{n=0}^{n} F_n L_n \frac{P_n}{1000} \]

Total cost of feed used in the feedlot each year, CF ($/yr) can then be found by including the time that the cattle are in the feedlot throughout the year and the number in the feedlot at any one time.

\[ C_F = c_F t_y (e_{BT} + e_{BI}) \]

Water costs

Annual water costs are taken directly from the Water sheet.

Health and veterinary costs

Average health and veterinary costs are calculated on a per head basis for the time the animal is in the feedlot (cHV). As a small percentage will die a natural death some animals will not incur the full cost. However, to ensure these costs are not underestimated, total health and veterinary costs per year (CHV) are based on the number of cattle entering the feedlot in each lot and the number of lots per year (rounded up to the nearest whole number).

\[ C_{HV} = c_{HV} L_n (e_{BT} + e_{BI}) \]
Cattle transport costs

It is assumed that the enterprise pays for transporting the cattle to the feedlot and also to the place of sale. As a default, average input, cTI and output, cTO transport costs ($/hd) are estimated based on the distance from the Mount Barker saleyards to Wagin. While this value is used as a default in the model, it is possible to use alternative values to represent transport costs. The total cost of transport per year for cattle entering the feedlot (CTI) is found by multiplying the average input cost by number of cattle entering the feedlot in each lot and the number of lots per year (rounded up to the nearest whole number).

\[ C_{TI} = c_{TI}L_n(e_{BT} + e_{BL}) \]

Likewise the total transport costs per year for cattle leaving the feedlot (CTO) are based on the number of cattle exiting the feedlot in each lot and the number of lots per year (rounded down to the nearest whole number).

\[ C_{TO} = c_{TO}L_n(x_{BT} + x_{BL}) \]

Waste management costs

Annual waste management costs are taken directly from the Waste management sheet.

Labour costs

Whilst it is recognized that the feedlot will require a minimum amount of ‘fixed’ labour no matter the number of cattle, it is assumed that the feedlot would be running to capacity and would require labour every day of the year. It is also assumed that during the ‘time in between lots’ labour costs will remain the same as there will be some requirement for cleaning etc. as well as provision made for employees to take leave. Hence for simplicity, the labour required per day is estimated on a per hundred head of cattle basis (Lday). Basing labour on the input number of cattle, maximum total labour required per year (Lyr) is therefore:

\[ L_{yr} = L_{day}(e_{BT} + e_{BL})/100 \]

The total annual labour cost (CL) will then be a function of labour required per year and the average annual wage (ϖ) (includes all on-costs etc and recognizes that employees will be scheduled to work some weekends)

\[ C_L = L_{yr}\varpi \]

Cost of fuel

The default fuel is assumed to be diesel with the total cost per year, CD ($) being based on the price of diesel, PD ($/L) and the average quantity used per day, QD (L/d). Other fuel costs such as for oil and grease are assumed to be negligible so are not included as individual costs.

\[ C_D = 365(P_DQ_D) \]

Other costs

The cost of machinery expenses, CM ($/yr), repairs and maintenance, CR ($/yr), electricity and phone, CE ($/yr), rates and insurance, CI ($/yr), and contingencies, CG ($/yr), are all directly inputted into the Econ data sheet.
Indirect costs

Costs arising out of a cattle feedlot that impose upon an external party can be referred to as indirect costs. Such costs may include pollution arising from odour and/or from nutrient flow into the ground water. The simplest way to recognize these costs would be to relocate the feedlot site far enough from the town for these costs to be negligible. To enable this relocation to occur, water would then have to be transported to the site from the town. Hence the costs associated with water transport could be considered to represent the upper-bounds of these indirect costs. Care must be taken so as not to double count water transport costs if these same costs are included in the Water sheet as direct costs.

Sensitivity analysis can be completed to determine the impact of such costs on the project. This indirect cost, $C_p (\$/yr)$ could then be calculated by multiplying the amount of desalinated water required by the feedlot by the distance the feedlot is from town, $DT$ (km) and the cost of transporting the water to the feedlot $CB$ ($/km)$.

\[ C_p = W_D D_T C_B \]

Total variable costs

The total variable input cost ($CV$) ($/yr$) is found by summing all of the variable costs as described above.

\[ C_V = C_C + C_F + C_W + C_{HV} + C_{TI} + C_{TO} + C_L + C_D + C_P + C_M + C_B + C_K + C_I + C_G \]

Assets

Total assets

In dollar terms, total fixed assets, $AT$ ($) are assumed to include the value of: cattle held in the feedlot at any one time, $VC$ ($); land as described below, $CA$ ($); feedlot sheds and infrastructure, $VSI$ ($); feed silos $VFS$ ($); waste storage $VWS$ ($), and other assets as specified $VOS$ ($); where:

\[ V_C = (e_{bt} W_{bt} P_{bt}) + (e_{bi} W_{bi} P_{bi}) \]

\[ A_T = V_C + C_A + V_{st} + V_{fs} + V_{ws} + V_{os} \]

The value of the feedlot sheds and associated infrastructure will depend on the number of cattle that are kept in each lot. However, because there are other factors associated with quality of building materials used and other like costs, for simplicity, the default value of $1,000,000$ is used in this model. Likewise the value of feed silos is set at $150,000$, waste facilities at $100,000$ and other assets at $0$. Nevertheless, the option to alter any of these values is available. It is assumed that the feedlot is custom built depending on the expected number of cattle that will be held within the feedlot.

Cost of land

The total cost of land for the feedlot, $CA$ ($) will be a function of land area required (from the Cattle sheet) multiplied by the price of land per hectare (it assumed that this price includes any costs required to make the land ‘building ready’) (PA).

\[ C_A = A P_A \]

Land prices vary depending on location. However, in the model it is assumed that the feedlot will be located just outside the Wagin townsit in an area not favoured for residential development and hence will have a lower value of around $5,000/ha.
Net assets

Net assets are simply total assets minus liabilities. In H2OBeef there is the option to enter the percentage of total assets (not including the value of cattle) that are on loan. The total amount on loan is taken from the Loan repay sheet (described in Section 7) and this amount represents total liabilities. Initial equity is the ratio of net assets over total assets and provides an indication of the viability of the enterprise. According to Kerrigan and Kelliher (1992) the greater the equity, the greater the proportion of the business owned by decision maker and hence the greater the capacity he or she has in decision making. They recommend that a reasonable amount of equity in a business should be around 70 per cent.

Revenue

Cattle sales

The total value of cattle sales, RC ($/yr) is a function of the number of lots per year, cattle outputs, sale live weight (from the Cattle sheet) and sale price in dollars per kilogram live weight Bos taurus (PsBT) or Bos indicus (PsBI).

\[ R_C = L_o (x_{BT} W_{sBT} P_sBT + x_{BI} W_{sBI} P_{sBI}) \]

The sale price will change depending on the supply, demand, weight and type of cattle sold. Therefore the model allows for the default value of $2.50/kg to be changed as necessary.

Feedlot waste sales

Revenue derived from annual waste management, RW ($/yr), is taken directly from the Waste management sheet.

Other revenue

There is facility to directly enter into the Econs data sheet, an amount for other revenue that is directly related to the feedlot and has not already been included in the above categories, RO ($/yr).

Indirect revenue

Flow-on effects from the beef feedlot to local communities are used as a proxy for indirect benefits. To calculate these flow-on effects input-output multipliers are used. It is assumed that for the feedlot business, for every $1 spent on wages, XW ($), will be spent locally. Also for the wage earner, for every $1 earned, XE ($), will be spent in local businesses.

A direct increase in employment (full-time equivalents) in the town as a result of the feedlot is equivalent to total labour required per year in the feedlot (Ly) as noted above. The salary level ($/yr) is equivalent to the total annual labour cost (CL) also as noted above. It is also assumed that there will not be any expansion over time. Annual indirect benefits, RI ($/yr) can then be calculated as:

\[ R_I = (X_W + X_E)L_y C_L \]

Total revenue

Total revenue, R ($) is the returns before production costs have been deducted for all enterprises associated with the feedlot and are calculated by summing revenue as outlined above.

\[ R = R_C + R_W + R_O + R_I \]
7 Economic Analysis

As explained in numerous texts such as in Robison and Barry (1996), long-term investments are analysed by adding all costs and benefits for each year of the project (as present day values) and using a discounting approach so as to calculate the net present value. In its simplest form this method does not include differing inflationary effects associated with inputs and/or outputs, revenue earned from interest on profit or tax implications. The components of the cost benefit analysis as presented in H2OBeef are described in the following sections. In addition a description of how sensitivity analysis can be conducted is presented at the end of the Section.

Costs

The current costs as identified in the Econ data sheet (described in the preceding Section) are used as default total annual costs for each of the 20 years, $C_n$ ($/yr). However there is an option to independently increase or decrease each of these costs over the time period. This option may be selected to account for changes in risk and hence changes in expected costs, or for costs such as machinery replacement. The loan principle and interest costs are calculated separately in the Loan repay sheet as described below.

Repayment costs on loan

In the Loan repay sheet the interest rate, length of the loan, total number of repayments per year, principle left at the end of the loan, and time when the payments are due are all entered by the user. The total loan on fixed assets is selected in the Econ data sheet and as a consequence the principle and interest at the end of each year for the time of the loan can be calculated. This calculation is based on a constant payment at the end of each payment period. As outlined in Malcolm et al. (2005), the payment, $P_m$ ($/yr) is calculated using a constant interest rate, $r$ (%), the value of the fixed costs on loan, $L_f$ ($), and a time period stretching over the life of the project, $t$ (yr).

$$P_m = \frac{L_f \left[ r(1+r)^t \right]}{(1+r)^t - 1}$$

It must be noted that the repayments are due each month in H2OBeef and hence this yearly repayment is divided evenly over a 12 month period.

There is also the option to take out a short-term loan. As a default in H2OBeef, it is assumed that finance for significant purchases over the first four months of the year is sought with the full amount repaid at the end of this period. However, these default values can be easily changed in the model to reflect an actual situation.

Benefits

As for costs, the time period for which benefits are considered in H2OBeef is 20 years. Current revenue from cattle sales, fertiliser revenue, other revenue directly related to the feedlot and indirect benefits as detailed in the Econ data sheet (as described in Section 7) are transferred into the Benefits sheet for each year $R_n$ ($/yr). However, there is facility in this sheet for total revenue in any one of the 20 years to be altered if required. This alteration may be required to reflect a change in benefits due to e.g. price risk and other such changes in benefits that may occur in a particular year.

Net benefits

To calculate the net benefits, $B_n$ ($/yr) for any one year, the total costs are subtracted from the total returns for that year.

$$B_n = R_n - C_n$$
However, this calculation does not include inflation, interest or tax. Inclusion of these parameters is discussed in the section below.

**Inflation, interest and tax**

In H$_2$OBeef it is assumed that production doesn’t increase over time and the inflation rate for costs and revenue is constant and therefore is not included in the model. However if production and/or inflationary effects are important in certain years then these can be indirectly added into the model by increasing the percentage costs and/or benefits in any one year.

Furthermore, if a profit is made in any one year within the feedlot then this profit could be invested and hence would generate additional revenue. As a simple proxy for this additional revenue there is the option in H$_2$OBeef to enter the interest rate that would be associated with this investment and hence the resulting revenue can be calculated.

Pannell (2004) suggests including taxation implications in cost benefit analyses that pertain to private investment. If H$_2$OBeef is considered only in such terms then the effects of taxation should be considered in the decision making. Hence the user indicates that this is the case by entering the marginal tax rate into the model where it is assumed that tax is simply calculated on the previous year’s earnings. Alternatively if H$_2$OBeef is part of a government program aimed at reducing saline ground water in rural towns then it would not necessary be appropriate to include tax as a cost.

**Net present value**

To calculate the net present value, $NPV$ ($\$$) for the period of the project the total costs are subtracted from the total returns for each year, summed and discounted. While the discount rate can be selected by the user, it is suggested that the discount rate should be equivalent to the real bank interest rate.

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1 + r)^t}$$

The preferred strategy has the highest $NPV$. The internal rate of return, $IRR$ is calculated as the discount rate when the $NPV$ is set equal to zero. A strategy would be preferred if the $IRR$ is greater than the discount rate. The benefit cost ratio is simply the net benefits divided by the net costs and if greater than zero it indicates that benefits derived from the project are greater than the costs.

**Sensitivity analysis**

In bioeconomic models, parameter values and assumptions presented in a base case analysis may not be perfect and hence sensitivity analysis can be done to investigate how changing these values and/or assumptions can impact on outcomes derived from model results. Pannell (1997) presents a detailed account of how sensitivity analyses can be effectively carried out. The following account is loosely based on his paper and provides a brief overview of a plan that could be followed for conducting sensitivity analyses for H$_2$OBeef.

It is not feasible to vary the values of every parameter in a model and therefore only the parameters that are most likely to impact on the results should be selected as part of a sensitivity analysis. Having selected a parameter, it is best to identify a realistic range of values with a maximum and minimum value. Entering these values one at a time in place of the base case value generates a new set of results. If these results are not particularly different from those of the base case then it can be assumed that the model outcome is not very responsive to that parameter. However, if the outcome does change significantly with a change in value of a parameter then the model is responsive to this parameter. The first step then is to review the base case model and make sure that the initial values were reasonable. This being the case, the results need to be documented in a sensible manner so that it is very clear what they mean. This may involve the use of graphs or tables with a logical explanation as to how they affect the outcome of the base case model. This procedure can be done for every parameter selected as part of the sensitivity analysis. However, care is required to make sure that none of the parameters are correlated. If they are then the values of the parameters should be altered together. While this procedure could involve a great number of combinations.
to run through an analysis, common sense should prevail in selecting only the values that are likely to impact upon the outcome so that a feasible number of model runs can be completed.

An alternative to selecting various values for parameters and then determining the effect on the outcome is to work backwards. This involves altering the value of the parameter until a breakeven point is reached. So in the case of H\textsubscript{2}OBeef, the price of water might be increased until the feedlot returns a zero NPV. Often results of such an analysis provide an interesting story.

The results of a sensitivity analysis should provide justification for arguing how confident the researcher is about the outcomes generated from the base case scenario. Even if the probability of an event occurring is not known, a subjective assessment on how likely a parameter is likely to change can be presented. This information can then be passed on to decision makers who need to be able to assess a project before they can decide on progressing with it. Part of this process also requires that they are very much aware of the parameters that may change the outcome so that they can take appropriate steps to account for these changes should they occur.
8 Capacity of H$_2$OBeef

H$_2$OBeef was developed to enable water usage and subsequent costs in beef feedlots to be included in decision making associated with such an enterprise. While the model is comprehensive there are limitations that need to be acknowledged by users of the model and those interpreting the results derived from the model.

H$_2$OBeef will not automatically calculate which strategy is ‘best’. Users evaluate strategies using experimentation and ‘trial and error’. That is a number of model runs with varying parameter values are required to work out desired strategies. Furthermore, H$_2$OBeef does not represent year-to-year variation in climate, beef output or prices. However, general changes can be manually placed in the model to reflect these variations.

Even though great care has been taken in data collection and model development so as to create a robust model, there may be times when constant figures in equations need to be altered. Justification for making these changes should always be carefully documented so that the results can be interpreted correctly. Also, as many of the default values included in this version of H$_2$OBeef are representative of a typical town in a region of Western Australia, these values will need adjusting for other towns and for other regions so that the model output is relevant for a particular situation.

As with most computer-based models, time and funding constraints have restricted further model development and refinement of H$_2$OBeef. Nevertheless, the authors welcome constructive feedback regarding this model.
Contact details for information regarding H$_2$OBeef

For information about H$_2$OBeef or to suggest improvements or changes contact Jo Pluske or Tony Schlink.

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References


### Attachment 1: Key to Variables used in Equations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>% dry matter content for each dietary component</td>
<td>%</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Parameter = km/(km-kf)</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Percentage of Bos taurus in the feedlot</td>
<td>%</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Gross energy in each dietary component</td>
<td>MJ</td>
</tr>
<tr>
<td>$\zeta_n$</td>
<td>Fermentable metabolizable energy of components in each feed</td>
<td>MJ</td>
</tr>
<tr>
<td>$\rho_n$</td>
<td>Protein content of components in each feed ration</td>
<td>gCP/kg</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Correction factor for water intake for <em>Bos indicus</em> constant</td>
<td></td>
</tr>
<tr>
<td>$\tau$</td>
<td>Percentage Bos taurus in feedlot</td>
<td>%</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Level of feeding as a multiplier of MJ of ME for maintenance</td>
<td></td>
</tr>
<tr>
<td>$\iota$</td>
<td>Percentage Bos indicus in feedlot</td>
<td>%</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>Total number of cattle in the feedlot at any one time</td>
<td>hd</td>
</tr>
<tr>
<td>A</td>
<td>Land area required for the feedlot</td>
<td>ha</td>
</tr>
<tr>
<td>$A_{BT}$</td>
<td>Land area required per head Bos taurus</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$A_{BI}$</td>
<td>Land area required per head Bos indicus</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$A_M$</td>
<td>Miscellaneous area required for feedlot</td>
<td>ha</td>
</tr>
<tr>
<td>A</td>
<td>Energy costs of activity</td>
<td>MJ/hd/day</td>
</tr>
<tr>
<td>B</td>
<td>Number of lots per year</td>
<td>lots/yr</td>
</tr>
<tr>
<td>$B_n$</td>
<td>Net benefits</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_A$</td>
<td>Total cost of land for the feedlot</td>
<td>$</td>
</tr>
<tr>
<td>$C_B$</td>
<td>Cost of transporting the water to the feedlot</td>
<td>$/km</td>
</tr>
<tr>
<td>$C_C$</td>
<td>Total value of cattle purchases</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Total cost of fuel per year</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_E$</td>
<td>Electricity and phone</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_F$</td>
<td>Total feed costs</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_F$</td>
<td>Feed cost per animal per day</td>
<td>$/hd/day</td>
</tr>
<tr>
<td>$C_G$</td>
<td>Cost of contingencies</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_{HV}$</td>
<td>Total health and veterinary costs per year</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_{HV}$</td>
<td>Average health &amp; veterinary costs whilst the animal is in the feedlot</td>
<td>$/hd</td>
</tr>
<tr>
<td>$C_I$</td>
<td>Cost if insurance per year</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_L$</td>
<td>Total annual labour cost (equivalent to salary level)</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_M$</td>
<td>Cost of machinery expenses</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_N$</td>
<td>Annual processing costs for an element, e.g. for nitrogen</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_N$</td>
<td>Cost of processing for element, e.g. for nitrogen</td>
<td>$/kg</td>
</tr>
<tr>
<td>$C_n$</td>
<td>Total annual costs for each of the 20 years</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_P$</td>
<td>Indirect costs</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_R$</td>
<td>Costs of repairs and maintenance</td>
<td>$/yr</td>
</tr>
<tr>
<td>$C_{TI}$</td>
<td>Total cost of input transport per year</td>
<td>$/yr</td>
</tr>
<tr>
<td>Variable</td>
<td>Data Name</td>
<td>Units</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>cT1</td>
<td>Average input transport costs</td>
<td>$/hd</td>
</tr>
<tr>
<td>C_T</td>
<td>Total cost of desalinated water</td>
<td>$/mth</td>
</tr>
<tr>
<td>C_COD</td>
<td>Total cost of output transport per year</td>
<td>$/yr</td>
</tr>
<tr>
<td>cT_O</td>
<td>Average output transport costs</td>
<td>$/hd</td>
</tr>
<tr>
<td>C_V</td>
<td>Total variable input costs</td>
<td>$/ha</td>
</tr>
<tr>
<td>D</td>
<td>Dry matter intake</td>
<td>kg/ha/day</td>
</tr>
<tr>
<td>D_d</td>
<td>Digestible undegradable protein</td>
<td>gCP/day</td>
</tr>
<tr>
<td>d_day</td>
<td>Natural deaths/day</td>
<td>No./day</td>
</tr>
<tr>
<td>D_e</td>
<td>Effective rumen degradable protein</td>
<td>gCP/kg DM</td>
</tr>
<tr>
<td>D_p</td>
<td>Rumen digestible protein</td>
<td>gCP/day</td>
</tr>
<tr>
<td>D_q</td>
<td>Quickly degradable protein</td>
<td>g/kg</td>
</tr>
<tr>
<td>D_s</td>
<td>Slowly degradable protein</td>
<td>g/kg</td>
</tr>
<tr>
<td>D_u</td>
<td>Undegradable protein</td>
<td>gCP/day</td>
</tr>
<tr>
<td>D_T</td>
<td>Distance the feedlot is from town</td>
<td>km</td>
</tr>
<tr>
<td>d yr</td>
<td>Natural deaths/annum</td>
<td>No./yr</td>
</tr>
<tr>
<td>E</td>
<td>Gross energy intake</td>
<td>MJ/hd/day</td>
</tr>
<tr>
<td>e_BI</td>
<td>No. Bos indicus entering the feedlot at the beginning of each lot</td>
<td>hd</td>
</tr>
<tr>
<td>e_BT</td>
<td>No. Bos taurus entering the feedlot at the beginning of each lot</td>
<td>hd</td>
</tr>
<tr>
<td>E_g</td>
<td>Net energy retained by the growing cattle</td>
<td>MJ</td>
</tr>
<tr>
<td>E_n</td>
<td>Net energy stored</td>
<td>MJ</td>
</tr>
<tr>
<td>E_m</td>
<td>Net energy for maintenance</td>
<td>MJ/hd/day</td>
</tr>
<tr>
<td>e_n</td>
<td>Energy density of each component in feed ration</td>
<td>MJ/kgDM</td>
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<tr>
<td>E_i</td>
<td>Retention of net energy</td>
<td>(0-1)</td>
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<tr>
<td>E_v</td>
<td>Energy value of tissue gained or lost</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>F</td>
<td>Feed ration</td>
<td>kg/ha/day</td>
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<tr>
<td>f_n</td>
<td>% of component in feed ration</td>
<td>%</td>
</tr>
<tr>
<td>G_n</td>
<td>% dry matter digestion of component n in feed ration</td>
<td>%</td>
</tr>
<tr>
<td>H</td>
<td>Water intake</td>
<td>L</td>
</tr>
<tr>
<td>H_BI</td>
<td>Water intake for Bos indicus</td>
<td>L/day</td>
</tr>
<tr>
<td>H_BT</td>
<td>Water intake for Bos taurus</td>
<td>L/day</td>
</tr>
<tr>
<td>I</td>
<td>Daily precipitation</td>
<td>mm</td>
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<tr>
<td>J</td>
<td>Crude protein in diet</td>
<td>gCP/kg</td>
</tr>
<tr>
<td>K</td>
<td>Faecal output (dry matter)</td>
<td>Kg/ha/day</td>
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<tr>
<td>k_i</td>
<td>Efficiency of utilization of ME for weight gain</td>
<td>(0-1)</td>
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<tr>
<td>k_m</td>
<td>Efficiency of utilization of ME for maintenance</td>
<td>(0-1)</td>
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<tr>
<td>L</td>
<td>Live weight</td>
<td>Kg</td>
</tr>
<tr>
<td>L_day</td>
<td>Labour required per day</td>
<td>No./day</td>
</tr>
<tr>
<td>Variable</td>
<td>Data Name</td>
<td>Units</td>
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<td>L_f</td>
<td>Value of the fixed costs on loan</td>
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<td>L_n</td>
<td>Number of lots per year</td>
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<td>L_yr</td>
<td>Maximum total labour required per year</td>
<td>No./yr</td>
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<td>L_y</td>
<td>Total labour required per year in the feedlot</td>
<td>No./yr</td>
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<td>M</td>
<td>Metabolisable energy in the ration</td>
<td>MJ</td>
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<td>M_b</td>
<td>Metabolisable protein required for basal maintenance</td>
<td>gCP/hd/day</td>
</tr>
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<td>M_c</td>
<td>Metabolisable crude protein</td>
<td>gCP/day</td>
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<tr>
<td>M_d</td>
<td>Metabolisable protein required for scurf &amp; hair growth</td>
<td>gCP/hd/day</td>
</tr>
<tr>
<td>M_f</td>
<td>Fermentable metabolisable energy of the diet</td>
<td>MJ/day</td>
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<td>M_m</td>
<td>Metabolisable energy for maintenance</td>
<td>MJ/day</td>
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<tr>
<td>M_mp</td>
<td>Metabolisable energy for maintenance and production</td>
<td>MJ/day</td>
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<tr>
<td>M_p</td>
<td>Metabolisable protein required for maintenance</td>
<td>gCP/hd/day</td>
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<td>M_t</td>
<td>Total metabolisable protein</td>
<td>gCP/day</td>
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<td>M_t</td>
<td>Digestible microbial true protein</td>
<td>gCP/day</td>
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<td>N</td>
<td>Total number of cattle that go through the feedlot during a year</td>
<td>hd/yr</td>
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<tr>
<td>n</td>
<td>A dietary component</td>
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<td>N_a</td>
<td>Acid detergent insoluble nitrogen in diet</td>
<td>gCP/hd/day</td>
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<td>N_b</td>
<td>Basal endogenous nitrogen requirements</td>
<td>gCP/day</td>
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<tr>
<td>n_BI</td>
<td>Number of lots of Bos indicus cattle</td>
<td>lots/yr</td>
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<tr>
<td>n_BT</td>
<td>Number of lots of Bos taurus cattle</td>
<td>lots/yr</td>
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<tr>
<td>N_D</td>
<td>Dietary concentration of nitrogen</td>
<td>g/kgDM</td>
</tr>
<tr>
<td>N_aD</td>
<td>Dietary concentration of sodium</td>
<td>g/kgDM</td>
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<td>N_kD</td>
<td>Dietary concentration of potassium</td>
<td>g/kgDM</td>
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<td>N_d</td>
<td>Net protein requirements for scurf &amp; hair growth</td>
<td>gCP/day</td>
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<td>N_F</td>
<td>Faecal concentration: nitrogen</td>
<td>g/kgDM</td>
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<td>N_f</td>
<td>Faecal nitrogen</td>
<td>proportion</td>
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<td>Net protein requirements for maintenance</td>
<td>gCP/hd/day</td>
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<td>NPV</td>
<td>Net present value</td>
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<td>N_S</td>
<td>Total nitrogen derived from faeces and available for sale</td>
<td>kg</td>
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<td>N_T</td>
<td>Total amount of nitrogen produced</td>
<td>kg/day</td>
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<td>P_A</td>
<td>Price of land per hectare</td>
<td>$/ha</td>
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<td>P_D</td>
<td>Price of fuel (diesel)</td>
<td>$/L</td>
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<td>P_pBI</td>
<td>Live weight purchase price Bos indicus</td>
<td>$/kg</td>
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<tr>
<td>P_pBT</td>
<td>Live weight purchase price Bos taurus</td>
<td>$/kg</td>
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<td>Variable</td>
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<td>$P_m$</td>
<td>Loan payment</td>
<td>$/yr</td>
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<td>$P_N$</td>
<td>Price that element can be sold for e.g. nitrogen</td>
<td>$/kg</td>
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<td>$P_n$</td>
<td>Price of each component</td>
<td>$/t</td>
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<td>$P_S$</td>
<td>Price of alternative water source</td>
<td>$/kL</td>
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<td>$P_{B_i}$</td>
<td>Live weight sale price Bos indicus</td>
<td>$/kg</td>
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<td>$P_{B_T}$</td>
<td>Live weight sale price Bos taurus</td>
<td>$/kg</td>
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<td>$P_T$</td>
<td>Price of desalinated water</td>
<td>$/kL</td>
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<td>$Q_D$</td>
<td>Average quantity diesel used per day</td>
<td>L/day</td>
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<td>$q_f$</td>
<td>Fasting metabolism</td>
<td>MJ/day</td>
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<td>$q_m$</td>
<td>Metabolisability of gross energy</td>
<td>MJ/day</td>
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<tr>
<td>$R$</td>
<td>Total revenue</td>
<td>$/yr</td>
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<td>$r$</td>
<td>Long term interest rate</td>
<td>%</td>
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<td>$R_C$</td>
<td>Total value of cattle sales</td>
<td>$/yr</td>
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<td>$R_l$</td>
<td>Indirect benefits</td>
<td>$/yr</td>
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<td>$R_n$</td>
<td>Revenue processed from feedlot waste, e.g. for nitrogen</td>
<td>$/yr</td>
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<td>$R_n$</td>
<td>Revenue each year</td>
<td>$/yr</td>
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<td>$R_O$</td>
<td>Other revenue directly related to the feedlot</td>
<td>$/yr</td>
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<td>$R_W$</td>
<td>Revenue from annual waste management</td>
<td>$/yr</td>
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<td>$S$</td>
<td>Total salt added to diet</td>
<td>g/hd/day</td>
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<td>$s$</td>
<td>Dietary salt added</td>
<td>Na%</td>
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<td>$T$</td>
<td>Daily maximum temperature</td>
<td>ºC</td>
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<td>$t$</td>
<td>Life of the project</td>
<td>yr</td>
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<td>$TA$</td>
<td>Total assets</td>
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<td>$T_a$</td>
<td>Average daily maximum temperature for the year</td>
<td>ºC</td>
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<td>$T_b$</td>
<td>Time in between lots</td>
<td>days</td>
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<tr>
<td>$T_c$</td>
<td>Time cattle are in each lot</td>
<td>days</td>
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<td>$t_m$</td>
<td>Number of days in a specific month</td>
<td>days</td>
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<tr>
<td>$t_y$</td>
<td>Days per year that cattle are in the feedlot</td>
<td>days</td>
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<tr>
<td>$U_{Na}$</td>
<td>Urinary sodium</td>
<td>g/hd/day</td>
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<tr>
<td>$U_k$</td>
<td>Urinary potassium</td>
<td>g/hd/day</td>
</tr>
<tr>
<td>$U_O$</td>
<td>Urinary weight output</td>
<td>g/hd/day</td>
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<tr>
<td>$U_p$</td>
<td>Urinary phosphorus output</td>
<td>g/hd/day</td>
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<td>$V_C$</td>
<td>Value of cattle held in the feedlot at any one time</td>
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<td>$V_{FS}$</td>
<td>Value of feed silos</td>
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<td>Units</td>
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<tr>
<td>$V_{OS}$</td>
<td>Value of other assets</td>
<td>$</td>
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<tr>
<td>$V_{SI}$</td>
<td>Value of feedlot sheds and infrastructure</td>
<td>$</td>
</tr>
<tr>
<td>$V_{WS}$</td>
<td>Value of waste storage</td>
<td>$</td>
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<tr>
<td>$W_A$</td>
<td>Feedlot monthly water intake for <em>Bos taurus</em></td>
<td>L/mth</td>
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<tr>
<td>$W_B$</td>
<td>Water balance</td>
<td>L/mth</td>
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<tr>
<td>$W_D$</td>
<td>Quantity water available per month for each month of the year</td>
<td>L/mth</td>
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<tr>
<td>$W_d$</td>
<td>Amount of water required for dust control on a daily basis</td>
<td>mm</td>
</tr>
<tr>
<td>$W_{day}$</td>
<td>Live weight gain per day</td>
<td>kg/hd/day</td>
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<tr>
<td>$w_{BI}$</td>
<td>No. weeks that <em>Bos indicus</em> cattle stay in the feedlot</td>
<td>weeks</td>
</tr>
<tr>
<td>$W_{BT}$</td>
<td>Water required for dust control in any one month: <em>Bos taurus</em></td>
<td>L/mth</td>
</tr>
<tr>
<td>$w_{BT}$</td>
<td>No. weeks that <em>Bos taurus</em> cattle stay in the feedlot</td>
<td>weeks</td>
</tr>
<tr>
<td>$W_{BI}$</td>
<td>Water needed in any one month for dust control: <em>Bos indicus</em></td>
<td>L/mth</td>
</tr>
<tr>
<td>$W_l$</td>
<td>Average days each month where the rainfall is less than 3mm</td>
<td>days</td>
</tr>
<tr>
<td>$W_m$</td>
<td>Average monthly rainfall data</td>
<td>mm</td>
</tr>
<tr>
<td>$W_p$</td>
<td>Live weight of cattle at purchase</td>
<td>kg/hd</td>
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<tr>
<td>$W_R$</td>
<td>Total water requirements each month</td>
<td>L/mth</td>
</tr>
<tr>
<td>$W_s$</td>
<td>Live weight of cattle at sale</td>
<td>kg/hd</td>
</tr>
<tr>
<td>$x_{BI}$</td>
<td>No. <em>Bos indicus</em> exiting the feedlot at the end of each lot</td>
<td>hd</td>
</tr>
<tr>
<td>$x_{BT}$</td>
<td>No. <em>Bos taurus</em> exiting the feedlot at the end of each lot</td>
<td>hd</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Average annual wage</td>
<td>$/yr</td>
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<tr>
<td>$X_E$</td>
<td>For every $1$ earned, amount spent locally: wage earner</td>
<td>$</td>
</tr>
<tr>
<td>$XW$</td>
<td>For every $1$ spent on wages amount spent locally: business</td>
<td>$</td>
</tr>
<tr>
<td>$Y_r$</td>
<td>Yield rumen microbial protein synthesis</td>
<td>gl</td>
</tr>
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</table>
## Attachment 2: Recommendations for dairy cows (AFRC 1993)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Units</th>
<th>Description</th>
<th>Formulae</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE:</td>
<td>MJ/day</td>
<td>Gross energy in the feeds *DMI</td>
<td>18.8MJ/kgDM</td>
<td>p. 02</td>
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<tr>
<td>ME:</td>
<td>MJ/day</td>
<td>Metabolisable energy of feeds *DMI</td>
<td>[ME]* DMI</td>
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<tr>
<td>Qm:</td>
<td>decimal</td>
<td>The metabolisability of [GE] at maintenance</td>
<td>[ME]/[GE]</td>
<td>p. 02</td>
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<tr>
<td>F:</td>
<td>MJ/day</td>
<td>Fasting metabolism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1:</td>
<td>decimal</td>
<td>1.15 for bulls and 1.0 for other cattle</td>
<td>1.0 for all cattle, 1.5 bulls</td>
<td>p. 23</td>
</tr>
<tr>
<td>A:</td>
<td>MJ/day</td>
<td>Activity allowance</td>
<td>0.0095W</td>
<td>p. 24</td>
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<tr>
<td>Em:</td>
<td>MJ/day</td>
<td>Net energy for maintenance</td>
<td></td>
<td></td>
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<tr>
<td>Km:</td>
<td>decimal</td>
<td>Efficiency of utilising ME for maintenance</td>
<td>0.35qm+0.503</td>
<td>p. 03</td>
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<td>Kc:</td>
<td>decimal</td>
<td>Efficiency of utilising ME for growth of concepta</td>
<td>0.133</td>
<td>p. 04</td>
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<tr>
<td>Mg (gain)/kg:</td>
<td>MJ/kg</td>
<td>ME needed/kg of LW gain</td>
<td>19/Kg</td>
<td>p. 31</td>
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<tr>
<td>L:</td>
<td>decimal</td>
<td>Level of feeding as a multiple of ME for maintenance, Mmp/Mm</td>
<td>Mmp(unadjusted)/MEM</td>
<td>p. 54</td>
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<td>Maintenance (Mm):</td>
<td>MJ/day</td>
<td>ME requirement for maintenance</td>
<td>(F+A)/Km</td>
<td>p. 23</td>
</tr>
<tr>
<td>Mmp (unadjusted):</td>
<td>MJ/day</td>
<td>ME for maint &amp; prod.- no correction for feed level</td>
<td>Mm+Ml+Mc+Mg</td>
<td>p. 09</td>
</tr>
<tr>
<td>CL:</td>
<td>decimal</td>
<td>Feed level correction</td>
<td>1+0.018(L-1)</td>
<td>p. 04</td>
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<td>Total ME required:</td>
<td>MJ/day</td>
<td>ME requirement for maintenance and production</td>
<td>Mmp=CL*(Mm+Ml+Mg+Mc)</td>
<td>p. 09</td>
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<td>ME supplied by the diet:</td>
<td>MJ/day</td>
<td>ME available from the diet</td>
<td>DMI * ME pasture</td>
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<tr>
<td>ME supply - ME required:</td>
<td>MJ/day</td>
<td>If +ive = excess ME in diet, if -ive = diet is energy deficient</td>
<td>ME from diet - Total ME required</td>
<td>-</td>
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<tr>
<td>NPb:</td>
<td>g/day</td>
<td>Net protein equivalent of basal endogenous N</td>
<td>6.25 * 0.35*W0.75</td>
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<tr>
<td>NPd:</td>
<td>g/day</td>
<td>Net protein for scurf and hair growth</td>
<td>6.25<em>0.018</em>W0.75</td>
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<td>NPm:</td>
<td>g/day</td>
<td>Net protein requirements for maintenance</td>
<td>NPb + NPd</td>
<td>p. 33</td>
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<td>Knm:</td>
<td>decimal</td>
<td>Efficiency of MP utilisation for maintenance</td>
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<td>p. 33</td>
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<tr>
<td>MPb:</td>
<td>g/day</td>
<td>MP requirement for basal maintenance</td>
<td>2.1875W0.75 or NPb/Knm</td>
<td>p. 34</td>
</tr>
<tr>
<td>MPd:</td>
<td>g/day</td>
<td>MP requirement for scurf and hair growth</td>
<td>0.1125W0.75 or NPd/Knm</td>
<td>p. 19</td>
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<tr>
<td>MPm:</td>
<td>g/day</td>
<td>MP requirement for maintenance</td>
<td>MPb+MPd or 2.30W0.75</td>
<td>p. 35</td>
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<td>Total MP required:</td>
<td>g/day</td>
<td>Total MP required for maintenance and production</td>
<td>MPR = MPm+MPI+MPg+MPc</td>
<td>p. 35</td>
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<tr>
<td>CPI:</td>
<td>g CP/day</td>
<td>Crude protein intake</td>
<td>DMI*CP in pasture</td>
<td>p. 34</td>
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<td>RDP:</td>
<td>g/day</td>
<td>Rumen degradable protein or QDP + SDP</td>
<td>CP intake * p</td>
<td>p. 33</td>
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<td>ERDP:</td>
<td>g/day</td>
<td>Effective rumen degradable protein</td>
<td>CP intake * ERDP</td>
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<td>UDP:</td>
<td>g/day</td>
<td>Undegradable protein</td>
<td>CPI-p (in g/day)</td>
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<tr>
<td>Abbreviation</td>
<td>Units</td>
<td>Description</td>
<td>Formulae</td>
<td>Page</td>
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<td>--------------</td>
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</tr>
<tr>
<td>DUP:</td>
<td>g/day</td>
<td>Digestible undegraded protein</td>
<td>$(0.9(UDP - (ADIN)*6.25))*DMI$</td>
<td>-</td>
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<tr>
<td>y:</td>
<td>gMCP/ MJ FME</td>
<td>Rumen microbial protein yield</td>
<td>$7.0+6.0(1-exp-0.35L)$</td>
<td>p. 13</td>
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<tr>
<td>FME:</td>
<td>MJ/day</td>
<td>Fermentable metabolisable energy per day</td>
<td>$FME$ per kgDM * DMI</td>
<td>p. 14</td>
</tr>
<tr>
<td>MCPenergy = y*FME:</td>
<td>g MCP/day</td>
<td>MCP per day (limited by energy in diet)</td>
<td>$FME * y$</td>
<td>p. 14</td>
</tr>
<tr>
<td>ERDP/FME:</td>
<td>g/MJ of FME</td>
<td>If $&gt; y$ than FME is limiting, if $&lt; y$ than ERDP limiting</td>
<td>$ERDP/FME$</td>
<td>p. 16</td>
</tr>
<tr>
<td>ERDP/FME is $&gt; y$ than y:</td>
<td>Energy supply is limiting microbial activity so MCP=MCPenergy</td>
<td>See explanation</td>
<td>-</td>
<td></td>
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<tr>
<td>MCP:</td>
<td>g/day</td>
<td>(If ERDP$&gt; y$*FME)=$(MCP$=y$*FME),(if ERDP$&lt; y$*FME)=$(MCP$=ERDP)$</td>
<td>See explanation</td>
<td>p. 17</td>
</tr>
<tr>
<td>DMTP:</td>
<td>g/day</td>
<td>Digestible microbial true protein</td>
<td>$0.75<em>0.85</em>MCP$</td>
<td>p. 17</td>
</tr>
<tr>
<td>Total MP supplied:</td>
<td>g/day</td>
<td>Metabolisable protein (protein supply to the animal from MCP+UDP)</td>
<td>$0.6375 MCP + DUP$</td>
<td>p. 17</td>
</tr>
<tr>
<td>MP supply - MP required:</td>
<td>g/day</td>
<td>If +ive = excess CP in diet, if -ive = diet is protein deficient</td>
<td>Total MP supply - total MP required</td>
<td>p. 17</td>
</tr>
</tbody>
</table>