ELIZABETH RIVER WATERWAY

GROUNDWATER MODEL

JANUARY 2000

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DEPARTMENT OF TRANSPORT AND WORKS

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1.1 General

The Northern Territory Department of Transport and Works (DTW) is currently assessing the development of the Elizabeth River Recreational Waterway. Aquaterra have been engaged by the DTW to develop a numerical groundwater flow model to predict the impacts of water level regulation along Elizabeth River on the underlying dolomite aquifer, which is used to irrigate a number of parks in the nearby Palmerston area.

Palmerston is located 20km south east of Darwin. The region has a tropical climate with distinct wet and dry seasons.

1.2 Previous Work

A number of investigations, including geophysics and drilling programmes have been completed in the Palmerston area by the Northern Territory Department of Lands, Planning and Environment (DLPE), previously the Power and Water Authority, to assess the potential of the weathered dolomite aquifer as a groundwater source. Reports completed in 1983, 1988 and 1996 provide detailed descriptions of the geology and hydrogeology of the area.

Investigations have suggested that to the north and south of Palmerston where Hudson and Mitchells Creek form hydraulic boundaries to the groundwater system, there is the potential for saline tidal water to be drawn into the aquifer if over abstraction from irrigation bores occur.

1.3 Scope of Work

The scope of work for this study is the development of a regional three-dimensional groundwater model to assess the impact of raising water levels along Mitchells and Brookings Creek on the underlying dolomite aquifer used to irrigate the parks of Palmerston. The model is to be used to assess whether the increase in water levels will cause saline tidal water to be drawn into the irrigation bores.

The model was has features that simulate

- Geological features of the groundwater system
- Wet season rainfall recharge
- Evapotranspiration from vegetation
- Discharge from surface water features
- Particle tracking to trace the potential movement of saline water from Mitchells and Brookings Creek into irrigation bores, and to identify the pumping bore capture zones.

The model has been calibrated to available monitoring data for the Palmerston area.
2.1 Conceptual Model

The geology and hydrogeology of the Palmerston area are described in reports completed as part of investigations by the Northern Territory Power and Water Authority (Power and Yin Foo 1988; Tickell, 1993). A conceptual model was developed based on information contained in these reports, discussions with DLPE staff during a site visit by Aquaterra in September 1999 and work completed by Aquaterra for the DLPE in early 1999 in a similar environment (Middle Point, near the Adelaide River east of Darwin).

The conceptual model presents an idealised picture of the essential features of the groundwater system of the Palmerston area. These features are presented in west-east section in Figure 2.1.

Features of the model are discussed in some detail in the following sections, but may be summarised as follows:

- Two layers: one to represent the upper sands and clay and the upper part of the Wildman Siltstone to the east, and one to represent the underlying fresh dolomite, weathered dolomite and Wildman Siltstone.
- Rainfall recharge in the wet season, based on a soil moisture deficit model.
- Surface outflows from numerous drains in the Palmerston area and along Elizabeth River, Hudson Creek, Brookings Creek and Mitchells Creek.
- Discharge via evapotranspiration from high water tables under areas of native vegetation and via shallow surface drainage pathways (see Section 2.5 for more detail).

2.2 Model Selection, Grid and Boundaries

The numerical groundwater flow modelling package MODFLOW (McDonald and Harbaugh, 1988) was used for this work, operating under the PMWin Graphical User Interface (Chiang and Kinzelbach, 1996). Modflow is the industry leading groundwater flow modelling package and has modules suitable for simulating surface and groundwater interaction and particle tracking.

The extent, boundary conditions and features of the regional model are shown in Figure 2.2. A uniform grid size of 50 metres was used. The model covers an area of approximately 8km (north-south) by up to 8km (east-west). The eastern and northern most boundaries are specified as no flow while all other boundaries, which coincide with Elizabeth River or creeks (Hudson Creek, Brookings Creek and Mitchells Creek), were assigned as fixed head type and set at 0mAHD.

The model comprises two layers. Layer 1 represents the upper sands and clays over the west of the modelled area and the upper parts of the Wildman Siltstone to the east (Figure 2.3). Layer 2 represents the main weathered dolomite aquifer, the fresher dolomite to the west and the Wildman Siltstone aquifer to the east (Figure 2.4). The top of layer 1 (ground surface) was defined by topographic maps of the Palmerston area produced by the Mapping and Information Division of the DLPE. The top of the
weathered zone of the dolomite aquifer has been identified at various depths during drilling, but the available information could not be used to define a consistent surface trend. Instead, a uniform value of -30mAHD was adopted for the model, broadly consistent with the data. The base of layer 2 was set at -100mAHD, a nominal value that is not used in the flow model because the transmissivity parameter is used for layer 2; this effectively fixes the ability of the lower units to transmit water.

Inflow to the model is predominantly provided by rainfall recharge to the dolomite and overlying units. Outflow occurs via the fixed head boundaries to the west. The Elizabeth River does have significant tidal variation, but analysis of 1998 tidal data indicated that the average value was close to 0mAHD. Additionally, as the model calibration uses a monthly time step, variations in tidal level on a shorter time scale than this cannot be accurately resolved. During the latter part of the dry season, there is some inflow into the model across the boundaries but this is generally only a small amount of the overall water balance (typically less than 1%). When it occurs, it is manifest along the Mitchells and Brooking Creek boundaries in the south of the modelled area and near Hudson Creek to the north.

Outflow from the model also occurs via unlined earth drains in and around the Palmerston area (Figure 2.2). A concrete lined drain is known to extend from south east of Palmerston to Mitchells Creek. Discussion with Peter Jolly (DLPE) indicated that this drain is somewhat “leaky” and could provide pathways for surface-groundwater interaction and this drain was also represented in the model. The drain bed conductance parameter was adjusted during calibration and a value of 50m$^2$/day was adopted for all drains. The assigned elevation of drain beds was consistent with drain sections obtained from Willing and Partners and levels taken from topographic maps.

### 2.3 Aquifer Properties

Aquifer properties assigned in the model are summarised in Table 2.1. The distribution of Layer 1 and Layer 2 aquifer parameters is presented in Figures 2.3 and 2.4.

<table>
<thead>
<tr>
<th>Table 2.1 Aquifer Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquifer Unit</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Layer 1</td>
</tr>
<tr>
<td>Sand/Clays</td>
</tr>
<tr>
<td>Wildman Siltstone</td>
</tr>
<tr>
<td>Layer 2</td>
</tr>
<tr>
<td>Weathered Dolomite and Fresh Dolomite</td>
</tr>
<tr>
<td>Wildman Siltstone</td>
</tr>
</tbody>
</table>

### 2.4 Recharge

Recharge is applied in the model to the upper sands and clays only (see Figure 2.3), not to the Wildman Siltstone. A recharge model has been developed which accounts for the soil moisture deficit present at the end of the dry season, consistent with previous work at Middle Point. The recharge model adopted assumed that a soil moisture deficit (SMD) of 100mm must be overcome before any effective recharge to
the aquifer occurs. Once the soil moisture deficit is overcome, recharge to the aquifer is assigned at 50% of recorded rainfall. There are exceptions to this to simulate the increase in groundwater elevation that occurs by December in some very wet years, when a recharge figure of 100% of rainfall above the SMD is adopted. In some very wet January months, approximately 37% of rainfall is assigned as recharge to represent the reduced rate of recharge (or greater rate of runoff) that is possible when near-surface layers are virtually saturated.

2.5 Evapotranspiration

Evapotranspiration is applied uniformly over the sand and clay area of layer 1. This feature is used to represent evapotranspiration from shallow water tables as well as short discharge paths to surface drainage features in the landscape in layer 1. This approach has been used in recent projects set in environments around Darwin (Aquterra, 1999). Evapotranspiration was set at 65% of annual average pan evaporation recorded at Darwin airport (annual mean evaporation 2538mm/year or 6.9 mm/day).

The model requires the specification of an evapotranspiration surface elevation and maximum evapotranspiration rate, such that, if the aquifer water level rises to or exceeds the evapotranspiration surface, evapotranspiration occurs at the maximum specified rate. The evapotranspiration surface adopted for this work was set 2 metres below ground level. The extinction depth was set at a minimum value (0.1 metres), to provide model stability such that if water levels dropped 0.1 metres below the elevation of the specified evapotranspiration surface, evapotranspiration ceased.

In this way the model simulates evaporative losses once aquifer water levels have risen close to the surface, which occurs rapidly following substantial rainfall in the wet season. This is consistent with understory vegetation growth (a major water balance sink in tropical savanna systems) and also helps represent discharge to surface depressions via short (surface or sub-surface) drainage paths. The evapotranspiration sink in the model helps reproduce the measured recession in groundwater levels from the end of the wet season. As the evapotranspiration surface is based on topography, areas of higher elevation around Palmerston do not generally experience evaporative losses as depths to groundwater are generally greater than 2 metres.

2.6 Groundwater Pumping

Groundwater pumping for irrigation is believed to have commenced around Palmerston in the late 1980’s. Bores used to irrigate parkland and ovals are known to exist at 10 locations around Palmerston (Figure 2.4). Comprehensive pumping records are not available for the entire calibration period. Groundwater pumping was recorded manually for some periods from 1992 to 1993, and since the beginning of 1998 via a telemetry system for most bores. Monthly pumping volumes recorded in 1992 and 1993 are consistent with those recorded in 1998 and 1999. Comprehensive data is only available for the whole of 1998 and this data was used for model calibration and predictions, along with recorded pumping from bores at Tiverton and Lindsay Park (which commenced in 1993). For bores RN 22120 (Moulden) and RN22457 (Golf Course), pumping rates were taken from previous DLPE work.

It was assumed that there was no deep infiltration to the water table of water used for irrigation.
3.1 General

Groundwater monitoring data has been collected from bores around Palmerston since 1983. The ten year calibration period (1989 to 1998) was chosen as sufficient data for calibration was available or could be generated for this period.

Due to the pronounced wet and dry seasons, there are dynamic annual groundwater responses, with variations in groundwater level of up to 6 metres. It was therefore not appropriate to undertake a steady state calibration to represent long term average hydrological conditions. Instead, a dynamic calibration was undertaken using hydrological data from 1989 to 1998. The model results for the first year (or two) of this period should not be relied on, as the model is adjusting from the assumed initial conditions to dynamic conditions.

3.2 Calibration Results

During model calibration, aquifer parameters were varied (within realistic limits) until a satisfactory match was obtained between the measured and predicted data. The results are presented in Figures 3.1 to 3.5 and discussed below. It should be noted that ground levels at some bores were estimated from topographic information as no survey data were available. It should also be noted that the predicted water level responses are from layer 1 of the model, but there is very little difference between the layer 1 and layer 2 predicted responses.

Model calibration is generally very good, with seasonal variations in water levels matched well in bores 22111, 22112, 22116, 22117 (Figure 3.1), 22156, 22280 (Figure 3.2) 22282, 22283, 22284 (Figure 3.3, 23584 (Figure 3.4) and 24409 (Figure 3.5). Bores 22152 (Figure 3.2) 23942 (Figure 3.4) and 23943 (Figure 3.5) match the observed pattern of the hydrograph response, but the predicted water levels are lower than those measured. Numerous attempts to improve the model match to the water levels in these two bores were unsuccessful. Bore 22281 (Figure 3.3) matches the measured pattern of water levels with the exception of the peak wet season water level. This is also somewhat apparent at bores 22283, 22284 (Figure 3.3) and 23943 (Figure 3.5). The data suggest that a perched water table may develop at the height of the wet season. The model in its current configuration cannot simulate this, although it could be upgraded to do so by adding a thin upper layer with high storage and permeability. Also, the different rates of recharge required (refer Section 2.4) to replicate monitoring data trends indicate that such a change to the model configuration would probably help to improve model calibration.

Model calibration at bores 22151 (Figure 3.2) and 23813 (Figure 3.4) is not particularly good but this is due to uncertainty regarding their hydrogeological setting. At bore 22151 the measured seasonal variation in water level is much less than that measured at other bores (2 metres compared with up to 6 metres). This is believed to be a result of bore 22151 reflecting water levels in the adjacent Wildman Siltstone rather than the dolomite aquifer that it was reportedly drilled into. The measured water levels in bore 23813 show a large seasonal variation, with water levels dropping below 0mAHD by the end of the dry season. The reason for this response is not known, and further field investigations in this area would be required to improve understanding of the groundwater processes. Predicted water levels in 23813 show...
very little variation, which is to be expected for the Wildman Siltstone. The trend predicted at 23813 is in fact closer to the pattern measured in 22151, indicating that the model can simulate water level responses for the Wildman Siltstone aquifer when it is configured to do so.

Predicted groundwater levels for March and October 1998 are presented in Figure 3.6 and 3.7. Areas of low relief around Palmerston close to surface discharge features are prone to flooding at the end of the wet season. Predicted water levels at the end of the wet season in these areas are sometimes slightly above specified ground level, but water levels generally decrease to be below ground level within one to two months.

### 3.3 Water Balance

Components of the simulated annual water balance for the calibration period (1989 to 1998) are listed in Table 3.1, showing that the major components are recharge, evapotranspiration and boundary outflow.

#### Table 3.1

<table>
<thead>
<tr>
<th>Year</th>
<th>Recharge (ML)</th>
<th>Constant Head Inflow</th>
<th>Total (ML)</th>
<th>Evapotranspiration</th>
<th>Storage Change (ML)</th>
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</thead>
<tbody>
<tr>
<td>1989</td>
<td>26543</td>
<td>186</td>
<td>26729</td>
<td>11043</td>
<td>-2552</td>
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<tr>
<td>1990</td>
<td>25940</td>
<td>181</td>
<td>26121</td>
<td>10117</td>
<td>2321</td>
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<td>1991</td>
<td>25793</td>
<td>204</td>
<td>25997</td>
<td>12456</td>
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<tr>
<td>1992</td>
<td>26124</td>
<td>169</td>
<td>26293</td>
<td>9372</td>
<td>5596</td>
</tr>
<tr>
<td>1993</td>
<td>28066</td>
<td>195</td>
<td>28261</td>
<td>11213</td>
<td>495</td>
</tr>
<tr>
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<td>132</td>
<td>42296</td>
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<td>4224</td>
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</table>

1. Evapotranspiration also includes components of the water balance representing shallow drainage to surface features
2. Negative storage change indicates storage decrease

Table 3.2 lists selected predicted monthly water balance figures from the end of the wet and dry seasons for each year of the calibration period. Again the major components of the water balance are recharge, evapotranspiration and boundary outflow. Table 3.2 shows that predicted drain flow is reduced by the end of the dry season and evapotranspiration is also decreased by this time consistent with the reduction in groundwater levels by this time.

### 3.4 Predevelopment Outflow

The predicted groundwater outflows (and minor inflows) along Elizabeth River (upstream) of the proposed dam site, Brookings Creek and Mitchells Creek are presented in Table 3.3. These figures are presented for 1990, which represents a low rainfall year during the calibration period. For most of the year, groundwater outflow occurs along this boundary, but during the dry months there is some inflow from the creeks into the aquifer but this ceases once the wet season commences.
### Table 3.2
Selected Monthly Water Balances

<table>
<thead>
<tr>
<th>Year</th>
<th>Recharge (kL)</th>
<th>Constant Head (kL)</th>
<th>Total (kL)</th>
<th>Constant Head Outflow (kL)</th>
<th>Wells (kL)</th>
<th>Drains (kL)</th>
<th>Evapotranspiration(^1) (kL)</th>
<th>Total (kL)</th>
<th>Change in Storage(^2) (kL)</th>
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</thead>
<tbody>
<tr>
<td>March 1989</td>
<td>314070</td>
<td>0</td>
<td>314070</td>
<td>77360</td>
<td>54</td>
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<td>October 1989</td>
<td>0</td>
<td>1066</td>
<td>1066</td>
<td>11340</td>
<td>1943</td>
<td>258</td>
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<td>1995</td>
<td>9292</td>
<td>33593</td>
<td>74815</td>
<td>31737</td>
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</tbody>
</table>

\(^1\) Evapotranspiration also includes components of the water balance representing shallow drainage to surface features

\(^2\) Negative storage change indicates storage decrease
<table>
<thead>
<tr>
<th>Month</th>
<th>Outflow (kL/day)</th>
<th>Inflow (kL/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1990</td>
<td>16810</td>
<td>0</td>
</tr>
<tr>
<td>February 1990</td>
<td>15540</td>
<td>4</td>
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<tr>
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<td>May 1990</td>
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<td>160</td>
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<td>June 1990</td>
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<td>640</td>
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<td>December 1990</td>
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4.1 Development of the Elizabeth River Recreational Waterway

The proposed development of a recreational waterway on the upper reaches of the Elizabeth River will involve the stabilisation of water levels. Of the options considered, the option of constructing a dam and using sea water pumping to stabilise water levels behind the dam at an average of about 4.5mAHD is currently preferred by the DTW. To simulate the impact on the aquifer in areas along Mitchells and Brookings Creek that will be inundated (ie. where the ground level is at or below 4.5 metres), the fixed head boundary condition was set at 4.5mAHD (Figure 4.1).

Using the pumping figures and recharge model developed during calibration, the model was run in predictive mode for a period of 10 years. Predicted hydrographs are shown in Figure 4.2 to 4.6. The hydrographs include the 10 years of calibration (to 1998) plus 10 years of prediction assuming a repeat of the 1988-98 hydrological conditions. It is assumed that the prediction begins immediately after the calibration but in reality there will be a delay before the dam is constructed and the water levels raised.

Figures 4.2 to 4.6 show a seasonal variation in water levels similar to those predicted during the calibration. There is no evidence of any water level increases due to pressurisation of the southern extent of the aquifer, nor of long term aquifer depletion. Examination of monthly water balances shows groundwater outflow volumes consistent with those predicted prior to development. Predicted water level gradients from Palmerston toward Mitchells Creek were already quite steep, and imposing a fixed head water level of around 4.5 mAHD along this boundary does not impose a significant increase in water levels during the wet season. At the end of the dry season, however, predicted water levels are generally lower and the influence of regulating water levels at the proposed dam site is shown in Figure 4.7 (ie the difference between predicted dry season water levels prior to and after construction of the dam). Contours of increase in water level indicate that the predicted effect of the dam could be observed approximately 2.5km away although this is not sufficient to reverse flow directions ie there is still groundwater outflow. It may be concluded that there is little risk of saline inflow affecting the water resource supporting the Palmerston irrigation bores due to construction of the dam.

4.2 Particle Tracking

Particle tracking was undertaken to assess the potential for the increase in water levels along Mitchells and Brookings Creek to cause saline water to be drawn toward irrigation bores. Predictions were performed using the simulated hydrological conditions from 1990 and 1998.

Particle tracking requires the specification of effective porosity values. The values assumed are summarised in Table 4.1. In addition to this, the base of layer 2 was adjusted to –50mAHD so that the model uses a realistic hydraulic conductivity value in particle tracking simulations.
Table 4.1
Aquifer Parameters Adopted for Particle Tracking

<table>
<thead>
<tr>
<th>Aquifer Unit</th>
<th>Effective Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td></td>
</tr>
<tr>
<td>Sands and gravels</td>
<td>0.09</td>
</tr>
<tr>
<td>Wildman Siltstone</td>
<td>0.01</td>
</tr>
<tr>
<td>Layer 2</td>
<td></td>
</tr>
<tr>
<td>Weathered dolomite</td>
<td>0.05</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.01</td>
</tr>
<tr>
<td>Wildman Siltstone</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Figure 4.8 illustrates the capture zones around the irrigation bores under 1990 recharge conditions, continued for a period of 8 years (particle tracking under 1998 flow conditions produces almost identical results). Groundwater continues to flow radially away from the groundwater mound underneath Palmerston. Particle tracking suggests that groundwater entering the aquifer via the southern dam boundary is drawn toward the western most boundary of the model (Elizabeth River) rather than toward Palmerston irrigation bores.
5.1 Conclusions

A groundwater flow model has been developed for the Palmerston area. The model is well calibrated to available groundwater monitoring data with a few exceptions. In these areas the calibration could be improved, subject to more obtaining more information (from field investigations) and possibly revising the model to add another (upper) layer.

Predictive modelling indicates that the construction of a dam and associated sea water pumping to regulate water levels for the proposed Elizabeth River recreational waterway would not pressurise the weathered dolomite aquifer sufficiently to reverse flow directions and cause saline water to be drawn towards the Palmerston irrigation bores under current levels of abstraction.

5.2 Recommendations to Improve Ongoing Groundwater Management

Continued monitoring of existing monitoring bores and continued metering of irrigation water use from production bores will enable future re-calibration of the model and thus allow its predictive reliability to be validated and improved in the future.

Survey data should be obtained for all monitoring bores. This information could provide greater reliability in predicted groundwater levels.

Further field investigations are required in the area to the south of Palmerston where the exact extent of the weathered dolomite is unknown and groundwater flow paths are uncertain.
Aquaterra (1999), Department of Lands Planning and Environment, Middle Point Groundwater Model, May 1999.


FIGURES
Evapotranspiration from vegetation and short drainage paths

Wet Season Rainfall Recharge

Groundwater Pumping (for irrigation)

Elizabeth River
Fixed Head Outflow
Boundary at OmAHD
(Layer 1 only)

~ NOT TO SCALE ~

No Flow Boundary
(Layer 2)

Evapotranspiration from vegetation and short drainage paths*

Layer 1 (unconfined)
Wildman Siltstone
Kh=0.05m/d
Kv=0.005m/d
Sy=0.01

Top of weathered/fresh dolomite (-30mAHD)

Layer 2 (confined)
Wildman Siltstone
T=5m²/d,
Kv=0.005m/d
S=0.0001

Base of dolomite -100mAHD (nominal)

8km (approximately)

WEST

EAST

*denotes recharge and evapotranspiration applied to layer 1 Dolomite and overlying units only (ie not to Wildman Sandstone)
Finite Difference Grid and Monitoring Bore Locations

Figure 2.2
### Layer 1 Aquifer Properties

<table>
<thead>
<tr>
<th>Zone</th>
<th>Aquifer Unit</th>
<th>Kh</th>
<th>Kv</th>
<th>Sy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sands/clays</td>
<td>5.00</td>
<td>0.50</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>Wildman Siltstone</td>
<td>0.05</td>
<td>0.005</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Layer 2 Aquifer Properties and Pumping Bore Locations

<table>
<thead>
<tr>
<th>Zone</th>
<th>Aquifer Unit</th>
<th>T (m³/d)</th>
<th>Kv (m/d)</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fresh Dolomite</td>
<td>5</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
<tr>
<td>2</td>
<td>Weathered Dolomite</td>
<td>1000</td>
<td>5</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>Wildman Siltstone</td>
<td>5</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Calibration Hydrographs

Figure 3.3

Department of Transport and Works
Elizabeth River Groundwater Model
Calibration Hydrographs

Figure 3.4
Figure 3.5

Aquaterra

Department of Transport and Works

Elizabeth River Groundwater Model

Calibration Hydrographs

Figure 3.5
Predicted Water Levels (Layer 2) March 1998

Figure 3.6
Figure 3.7

Predicted Water Levels (Layer 2) October 1998

aquaterra
Figure 4.1

- Outflow Boundary
- Proposed Dam Site
- Drains
- Fixed Head Boundary Condition at 4.5mAHD

Prediction Run Boundary Conditions

aquaterra
aquaterra  Department of Transport and Works  Elizabeth River Groundwater Model  Prediction Hydrographs  Figure 4.2
Figure 4.3

Department of Transport and Works
Elizabeth River Groundwater Model
Prediction Hydrographs
Figure 4.3
Department of Transport and Works
Elizabeth River Groundwater Model
Prediction Hydrographs
Figure 4.4
Department of Transport and Works
Elizabeth River Groundwater Model
Prediction Hydrographs
Figure 4.5
Department of Transport and Works
Elizabeth River Groundwater Model

Figure 4.6
Contours of predicted increase in water levels (metres) after development of waterway (ie difference between predicted 1990 dry season water levels prior to and after construction of the dam)

![Map showing predicted increase in water levels](image-url)

*Figure 4.7*
Distance between arrow heads represents distance travelled in one year. Blue tracks represent layers 2 (weathered dolomite) particle tracks while green tracks represent tracks in the upper sands/clays.

Area where water levels maintained at 4.5mAHD by boundary condition.