# North Tuncurry Development Project
# Groundwater Modelling Technical Report

**For: UrbanGrowth NSW**

**June, 2014**

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| Project Name: | North Tuncurry Development Project – Groundwater Modelling Technical Report |
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## PREPARATION, REVIEW AND AUTHORISATION

| Revision # | Date | Prepared by | Reviewed by | Approved for Issue by |
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| B – For Submission | 10/06/2014 | Chris Kuczera[1] | Glenn Mounser<br>Ben Patterson[2]<br>Urban Growth | Daniel Sutcliffe |
| | | | | |
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Note 1: Chris Kuczera prepared this report whilst on secondment from Royal HaskoningDHV

Note 2: Ben Patterson from Royal HaskoningDHV was engaged by SMEC to undertake a peer review of this report

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# ABBREVIATIONS

| | |
|---|---|
| AHD | Australian Height Datum |
| AIP | Aquifer Interference Policy |
| ARI | Average Recurrence Interval |
| AR&R | Australian Rainfall and Runoff (1987) |
| BoM | Bureau of Meteorology |
| DPI | NSW Department of Planning & Infrastructure |
| ET | Evapotranspiration |
| EP&A Act 1979 | Environmental Planning & Assessment Act 1979 |
| FFA | Flood Frequency Analysis |
| ha | hectare |
| IWCMS | Integrated Water Cycle Management Strategy |
| LGA | Local Government Area |
| ML | Megalitre |
| NTDP | North Tuncurry Development Project |
| NOW or OoW | NSW Office of Water |
| PET | Potential Evapotranspiration |
| Project area | Refers to the North Tuncurry Development Project Area |
| SSS | State Significant Study |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |

# 1 INTRODUCTION

The North Tuncurry Development Project (NTDP) is a proposed residential development sponsored by UrbanGrowth NSW under a Project Delivery Agreement with the Crown Lands Branch of NSW Trade and Investment, who control the land. The NTDP area (project area or the site) comprises 615ha of land located to the north of the Township of Tuncurry. The proposed development area comprises 261.6 ha of land that is located in the southern portion of the project area. **Plate 1-1** shows the project area and development area.

UrbanGrowth NSW has commissioned a State Significant Site (SSS) study for the project that will include the establishment of land use zones and performance standards that will apply to future development of the site. SMEC were engaged by UrbanGrowth NSW to prepare an Integrated Water Cycle Management Strategy (IWCMS) to form part of the SSS study. This report documents the detailed groundwater modelling that was undertaken by SMEC as part of the IWCMS. Refer to IWCMS report for a detailed description of the development proposal and the planning and approvals process.

***Plate 1-1** – Project area and development area.*

The project area is located above an unconfined coastal aquifer. The site topography is characterised by undulating aeolian dune systems, which have no distinct surface drainage paths as they are shaped by the wind rather than water. Accordingly, all rainfall that falls over the project area is either lost to evapotranspiration or drains vertically through the upper soil layer into the aquifer through a process referred to as recharge. Water leaves the aquifer through both evapotranspiration and lateral groundwater flow to the east (to the Pacific Ocean) and to the west (to the Wallamba River). The dynamics of these processes vary depending on the groundwater flow characteristics, prevailing rainfall and evapotranspiration rates.

A comprehensive groundwater assessment was undertaken to gain an understanding of the abovementioned groundwater dynamics and to identify groundwater related development constraints within the project area. This report documents the approach, methodologies and results of this assessment.

## 1.1 Assessment Approach

During periods of high rainfall, groundwater levels rise as a result of recharge. The rate of rise and the ultimate peak groundwater level from a given rainfall event is governed by numerous factors, which include:

- Antecedent conditions such as the groundwater level and soil moisture content at the beginning of the rainfall event.
- Rainfall durations and intensities.
- Recharge characteristics that govern the portion of rainfall that recharges into the underlying groundwater system.
- Groundwater flow characteristics which govern the rate at which groundwater flows from the project area into either the Pacific Ocean to the east or the Wallamba River to the west.
- Evapotranspiration loss rates from the aquifer.
- Groundwater and surface storage characteristics that govern the rate of rise of the groundwater table.

A comprehensive assessment considering the abovementioned factors that influence groundwater behaviour was undertaken. The assessment required the development of the following models:

- A recharge model was developed to estimate the site recharge characteristics (i.e. the portion of rainfall that recharges into the groundwater system) for a wide range of rainfall events.
- An Empirical Groundwater Model was developed (utilising the recharge model) to assess the likely groundwater conditions within the development area for a wide range of historic events. This model was used to:
    - Estimate typical groundwater levels within the development area between 1900 to May 2013, using a long-term rainfall record.
    - Identify rainfall durations and intensities that are likely to result in groundwater flooding within the development area.
    - Identify an historic rainfall event that is likely to have produced the highest groundwater levels within the development area between 1900 to May 2013. The governing event was adopted as the design event for the project.

  - Estimate antecedent groundwater levels for the design event.

  The Empirical Groundwater Model was also used to estimate the project's impacts on the existing groundwater regime during non-flood periods.

- A detailed three–dimensional groundwater model was developed using the Visual MODFLOW SURFACT modelling platform. This model was applied to estimate the peak groundwater levels within the development area (and surrounds) for the flood planning event that was identified using the Empirical Groundwater Model.

The abovementioned models were developed for both existing and developed conditions.

## 1.2 Assessment Methodology

The following assessment methodology was applied to the groundwater assessment:

- **Step 1 – Data Collection:** A range of data was collected to provide information on the physical properties of the aquifer and the groundwater response to rainfall. This data was used to develop and calibrate both the groundwater and recharge models.

- **Step 2 – Model Development**: Using the data collected as part of Step 1, the following models were developed:

  - A recharge model was developed to estimate the site recharge characteristics.

  - An Empirical Groundwater Model was developed to estimate typical groundwater levels within the development area from 1900 to May 2013, using a continuous simulation approach and a long-term rainfall record.

  - A detailed three-dimensional groundwater model was developed for the project area (and surrounds) using the Visual MODFLOW SURFACT modelling platform.

- **Step 3 – Model Calibration and Verification:** Both the recharge and groundwater models were calibrated using data collected between March 2010 and March 2012. Following calibration, the Empirical Groundwater Model was verified using data collected between March 2012 and May 2013.

- **Step 4 – Identification of Historic Rainfall Events:** The calibrated and verified Empirical Groundwater Model was used to estimate groundwater conditions between 1900 to May 2013, using a local long term rainfall record. The model identified a 3 month rainfall event that occurred in 1963 as producing the highest groundwater levels within the development area between 1900 and May 2013. This historic event was adopted as the flood planning event for the project.

- **Step 5 – Detailed Modelling of Existing Conditions:** Detailed modelling of the 1963 event was undertaken using the Visual MODFLOW SURFACT model, which required input from the Empirical Groundwater Model. Model runs were undertaken for existing and potential climate change scenarios.

- **Step 6 – Detailed Modelling of Developed Conditions**: The existing conditions models were updated to reflect the proposed Masterplan. This modelling was used to demonstrate that the proposed groundwater management methods will be effective in meeting the groundwater management objectives that are established in the IWCMS.

## 1.3 Report Structure

This report documents the abovementioned groundwater assessments and is structured as follows:

- **Section 2 – Review of Available Data:** Details data used for the groundwater assessment.
- **Section 3 – Recharge Model**: Describes the development and calibration of the recharge model.
- **Section 4 – Empirical Groundwater Model:** Describes the development, calibration and verification of the Empirical Groundwater Model.
- **Section 5 – Detailed Groundwater Model:** Describes a conceptual groundwater model for the region and the development and calibration of the three–dimensional groundwater model that was developed using the Visual MODFLOW SURFACT modelling platform.
- **Section 6 – Model Confidence Level Classification:** establishes confidence levels for the various models and model applications.
- **Section 7 - Assessment of Groundwater Flooding:** Presents model results that describe the groundwater flooding characteristics within the development area for both existing and developed conditions.
- **Section 8 – Assessment of Groundwater Regime:** Presents model results that describe the existing and developed conditions groundwater regime within the development area for a full range of climatic conditions.

# 2 REVIEW OF AVAILABLE DATA

This section presents and discusses data that relates to the existing environment of the project area.

## 2.1 Climatic Data

This section reviews available climatic information and establishes representative climatic data for use in this assessment.

### 2.1.1 Rainfall Records

There are three regional Bureau of Meteorology (*BoM*) operated rain gauges that are located within 1km of the coast and have long term rainfall records. **Table 2-1** presents key information and statistical data from these rain gauges.

***Table 2-1** – Local Rainfall Records[1]*

| Statistics | Forster – Tuncurry Marine Rescue[2] (60013) | Harrington - Oxley Anchorage Caravan Park (60023) | Seal Rocks Camping Reserve (60028) |
|---|---|---|---|
| Rainfall Record | 1896 to Present | 1887 to Present | 1897 to 2012 |
| Distance from site | 2km to south-east | 34km to the north-east | 30km to the south |
| Location | Within 1km of the coast | Within 1km of the coast | Within 1km of the coast |
| Elevation (m AHD) | 4 | 6 | 4 |
| Lowest Annual Rainfall (mm/year) | 653 | 737 | 605 |
| 5th Percentile Rainfall (mm/year) | 731 | 839 | 779 |
| 10th Percentile Rainfall (mm/year) | 806 | 906 | 924 |
| Average Rainfall (mm/year) | 1217 | 1344 | 1323 |
| 90th Percentile Rainfall (mm/year) | 1595 | 1797 | 1830 |
| 95th Percentile Rainfall (mm/year) | 1706 | 2131 | 1931 |
| Highest Annual Rainfall (mm/year) | 2395 | 2548 | 2232 |

*Note 1: Data Source: Bureau of Meteorology*

*Note 2: Also referred to as the Forster or South Forster Gauge*

With reference to **Table 2-1**, comparison of the rainfall records from the three regional gauges indicate that the rainfall in dry, average and wet years is marginally lower at Forster than at Seal Rocks (30km to the south) and Harrington (34km to the north–east). The Forster rainfall record is considered to be the most representative data set for use in this study due to the proximity of the rain gauge to the project area (2km to the south–east). It is noted that rainfall data from other local non-BoM operated gauges has also been used in this study for model calibration purposes.

**Plate 2-1** plots the annual rainfall depths recorded at Forster between 1900 and 2013. A 7 year moving average is also provided to demonstrate medium term trends over the 114 year period. The annual rainfall data demonstrates that the majority of the higher annual rainfall totals occurred in the 1920s, 1950s and 1960s and that no significant (greater than 90th Percentile) annual rainfall events have been recorded since 1985, expect for 2013 which was the third highest annual rainfall total on record.

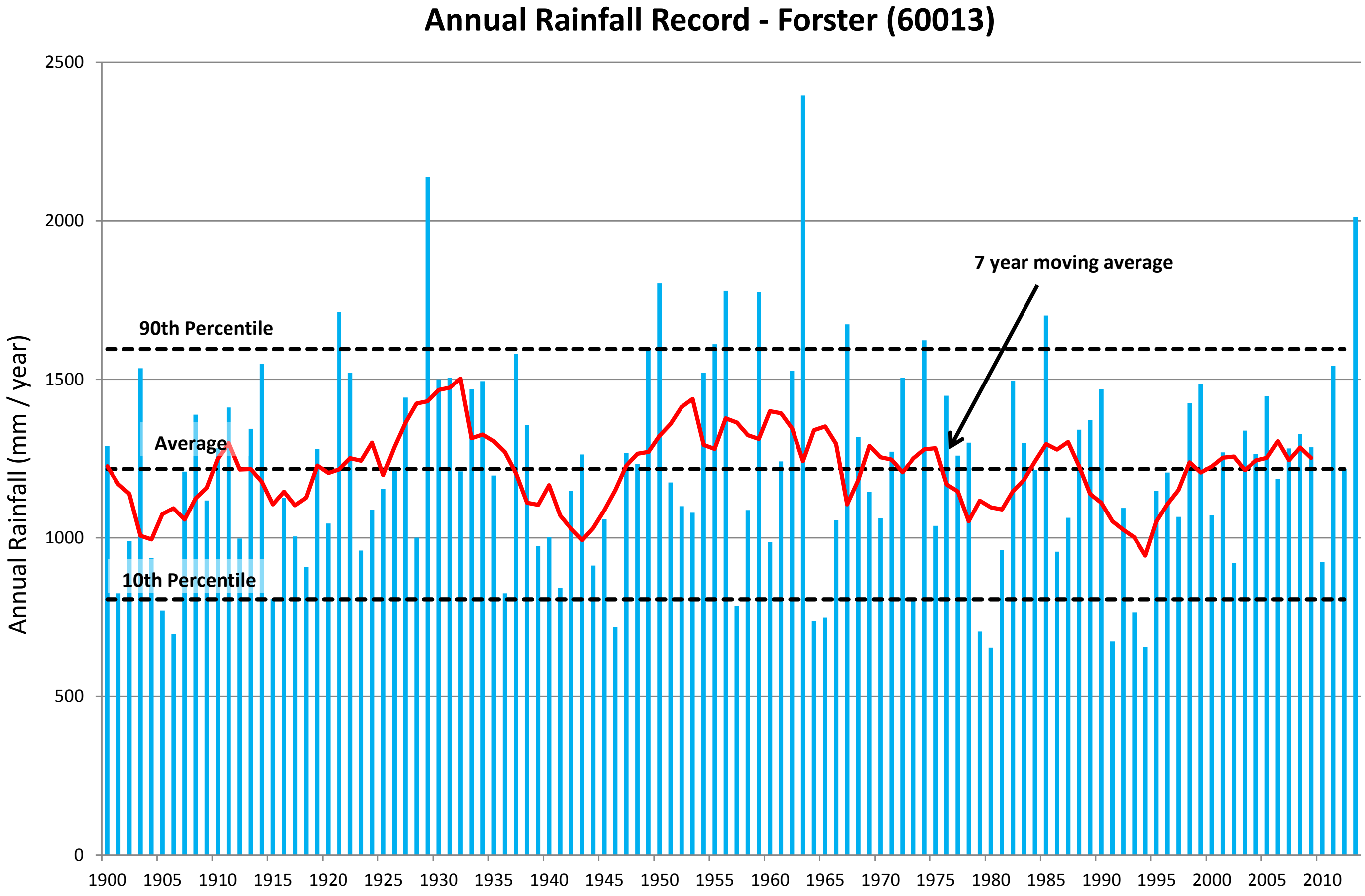


**Plate 2-1** – *Annual rainfall at Forster – 60013 (Source: BoM)*

**Plate 2-2** plots the average and 10th and 90th Percentile monthly rainfall totals recorded at Forster. The monthly data demonstrates that summer and autumn months are the wettest and the spring and winter months are generally dryer.

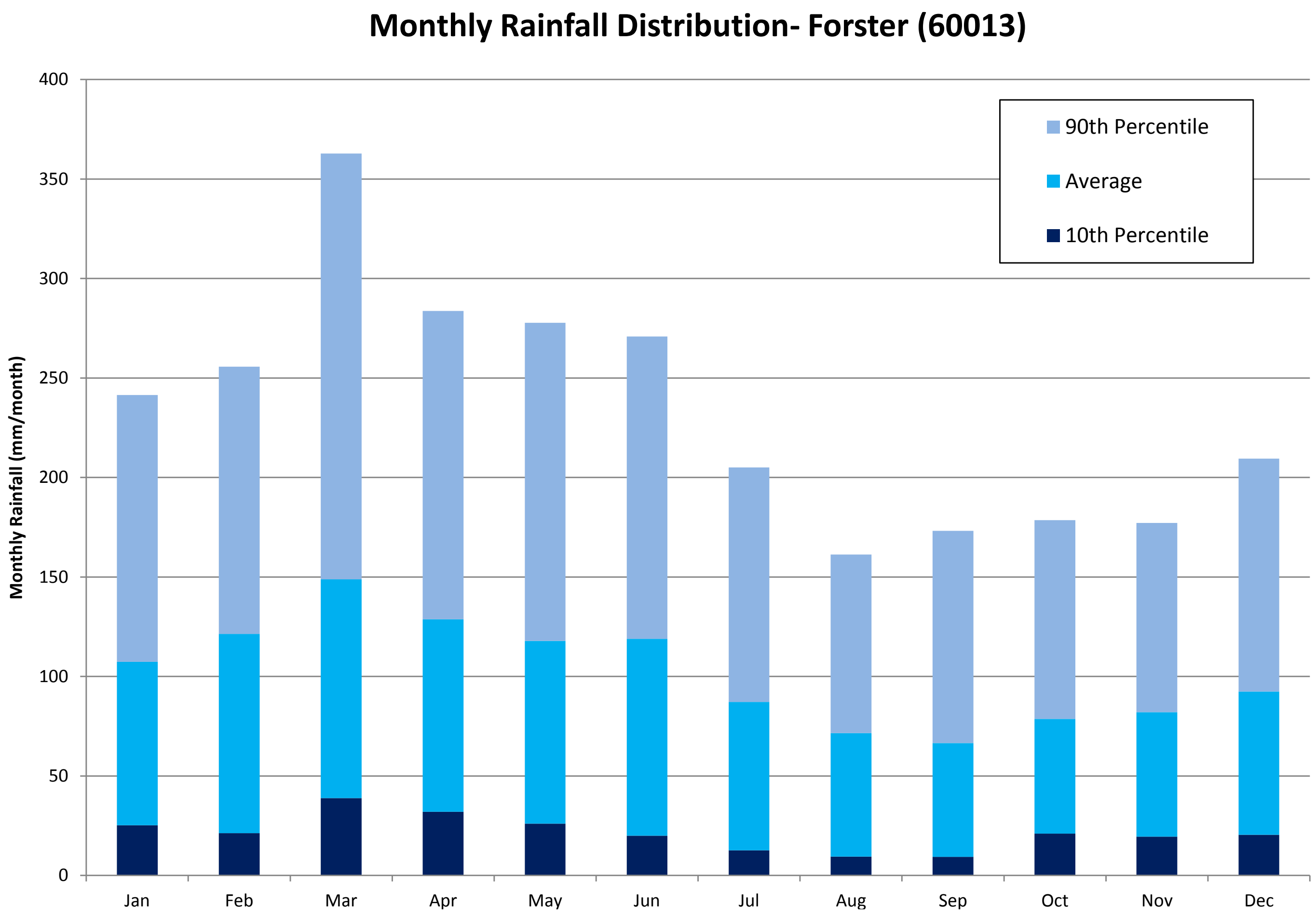


***Plate 2-2** – Monthly rainfall statistics at Forster – 60013 (Source: BoM)*

### 2.1.2 Evaporation Data

Estimates of regional evaporation and evapotranspiration rates are available from the following sources:

- **Regional Data** - Daily pan evaporation rates have been recorded at the BoM operated weather station at Taree Airport (60141) from 1999 to present.
- **Climate Maps –** Regional estimates of monthly evaporation and potential evapotranspiration are available from climate maps that were downloaded from the BoM website.

**Table 2-2** compares average monthly rates from the above data sources.

**Table 2-2** - *Average monthly evaporation and potential evapotranspiration data.*

| **Month** | **Average Monthly Pan Evaporation (mm / month)** | | **Average Areal Potential Evapotranspiration (mm / month)** |
|---|---|---|---|
| | **Taree (60141)** | **Climate Maps (BoM)** | |
| January | 202 | 175 | 180 |
| February | 154 | 150 | 150 |
| March | 149 | 125 | 150 |
| April | 105 | 100 | 105 |
| May | 84 | 80 | 75 |
| June | 66 | 60 | 60 |
| July | 71 | 80 | 60 |
| August | 99 | 100 | 75 |
| September | 143 | 125 | 105 |
| October | 158 | 150 | 150 |
| November | 162 | 175 | 165 |
| December | 198 | 200 | 180 |
| **Annual** | **1,591** | **1,520** | **1,455** |

*Source: Bureau of Meteorology*

### 2.1.3 Potential Impact of Climate Change on Climatic Trends

The most recent and comprehensive estimate of projected climate change impacts in the Great Lakes Council LGA is documented in a report titled "*NSW Climate Impact Profile: The Impacts of Climate Change on the Biophysical Environment of New South Wales*" (DECCW, 2010). The report projects that:

- Maximum and minimum temperatures will increase in all seasons.
- Rainfall will increase in spring, summer and autumn but decrease in winter.
- Evaporation will increase in all seasons.

**Table 2-3** presents the reported projected climate change impacts by 2050 in the Great Lakes Council LGA.

***Table 2-3** – Projected climatic changes in the Great Lakes Council LGA by 2050 (DECCW, 2010)*

| Season | Minimum Temperature | Maximum Temperature | Rainfall | Evaporation |
|---|---|---|---|---|
| **Spring** | 2 to 3°C warmer | 2 to 3°C warmer | 5 to 20% increase | 20 to 50% increase |
| **Summer** | 2 to 3°C warmer | 1 to 1.5°C warmer | 10 to 50% increase | 10 to 20% increase |
| **Autumn** | 2 to 3°C warmer | 1.5 to 2°C warmer | 5 to 10% increase | 5 to 20% increase |
| **Winter** | 2 to 3°C warmer | 2 to 3°C warmer | 5 to 20% decrease | 10 to 20% increase |

### 2.1.4 Potential Sea Level Rise

The guideline titled *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments* (DECCW, 2010) provides guidance on incorporating sea level rise benchmarks in flood risk management planning and flood risk assessments for new developments. This guideline applies to areas where the sea level rise planning benchmarks are likely to have an impact on predicted flood levels. The guideline recommends sea level rise bench marks, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100. The 2100 sea level rise predictions have been applied to the groundwater flood assessment that was undertaken as part of this study.

This guideline was adopted as policy by Great Lakes Council in June 2011.

## 2.2 Topographic Characteristics

The topography within the project area is characterised by undulating aeolian dune systems, which have no distinct surface drainage paths as they are shaped by the wind rather than water. The dunes are stabilised by vegetation and are typically orientated along a north-south alignment, parallel to the coast. Spacing between dune crests ranges between 20 and 100m, while the variation in height between a peak and a corresponding trough typically ranges between 0.5 to 2.5m.

Analysis of LiDAR data indicates that surface levels within the project area range between 2 to 10m AHD. With reference to **Plate 2-3**, which thematically shows the surface levels within the project area, the highest levels (8 to 10m AHD) are associated with the fore dune system which is offset from the beach by approximately 100 to 150m. The hind dune area (located to the west of the fore dune system), is characterised by lower topography, with levels typically ranging between 3 to 7m AHD. The topography is generally higher in the western portion of the hind dune area than the eastern portion. The proposed 255ha development area is located in the hind dune area. The average surface level within the 255ha development area is estimated (from the LiDAR) to be 5.1m AHD.

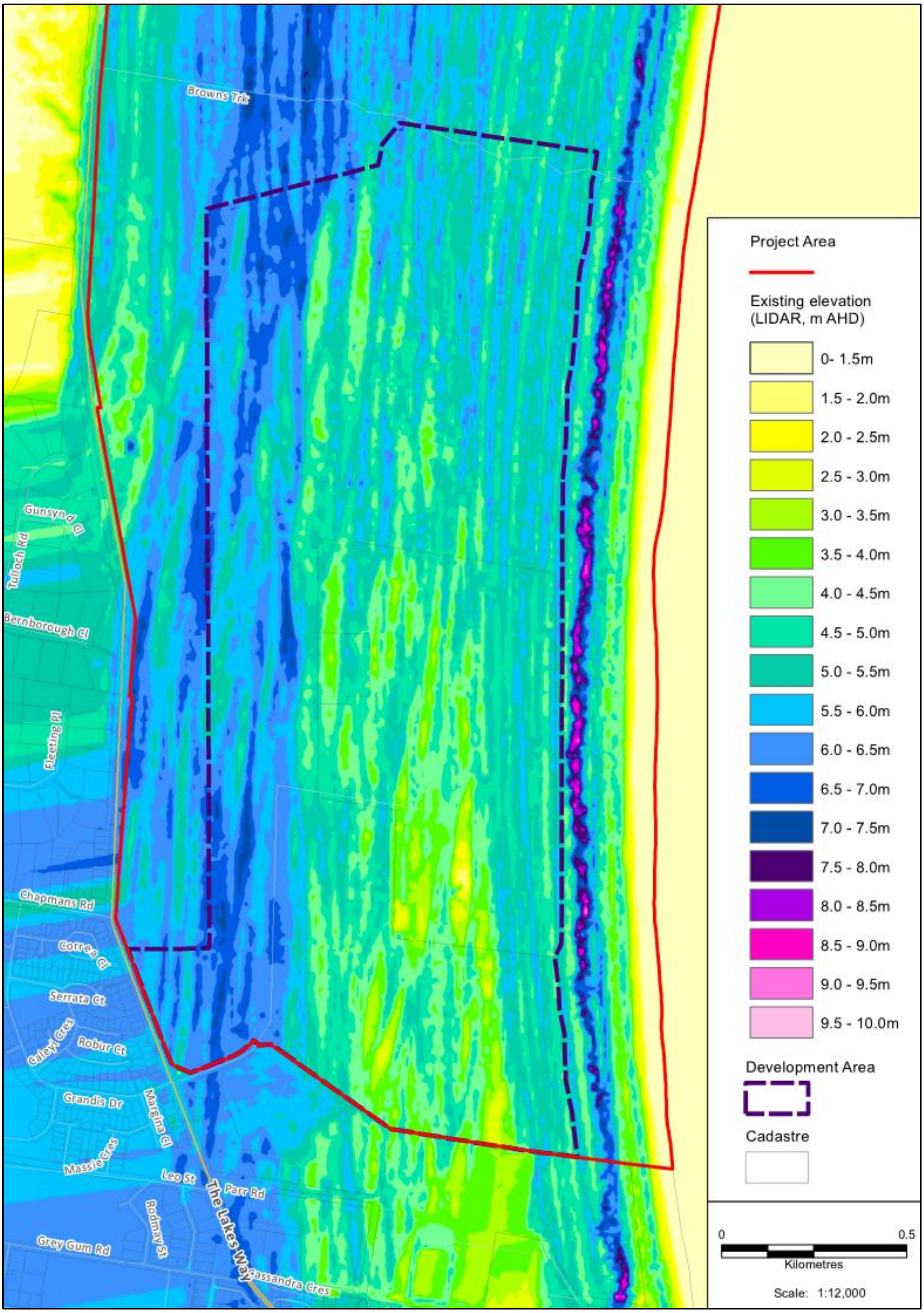
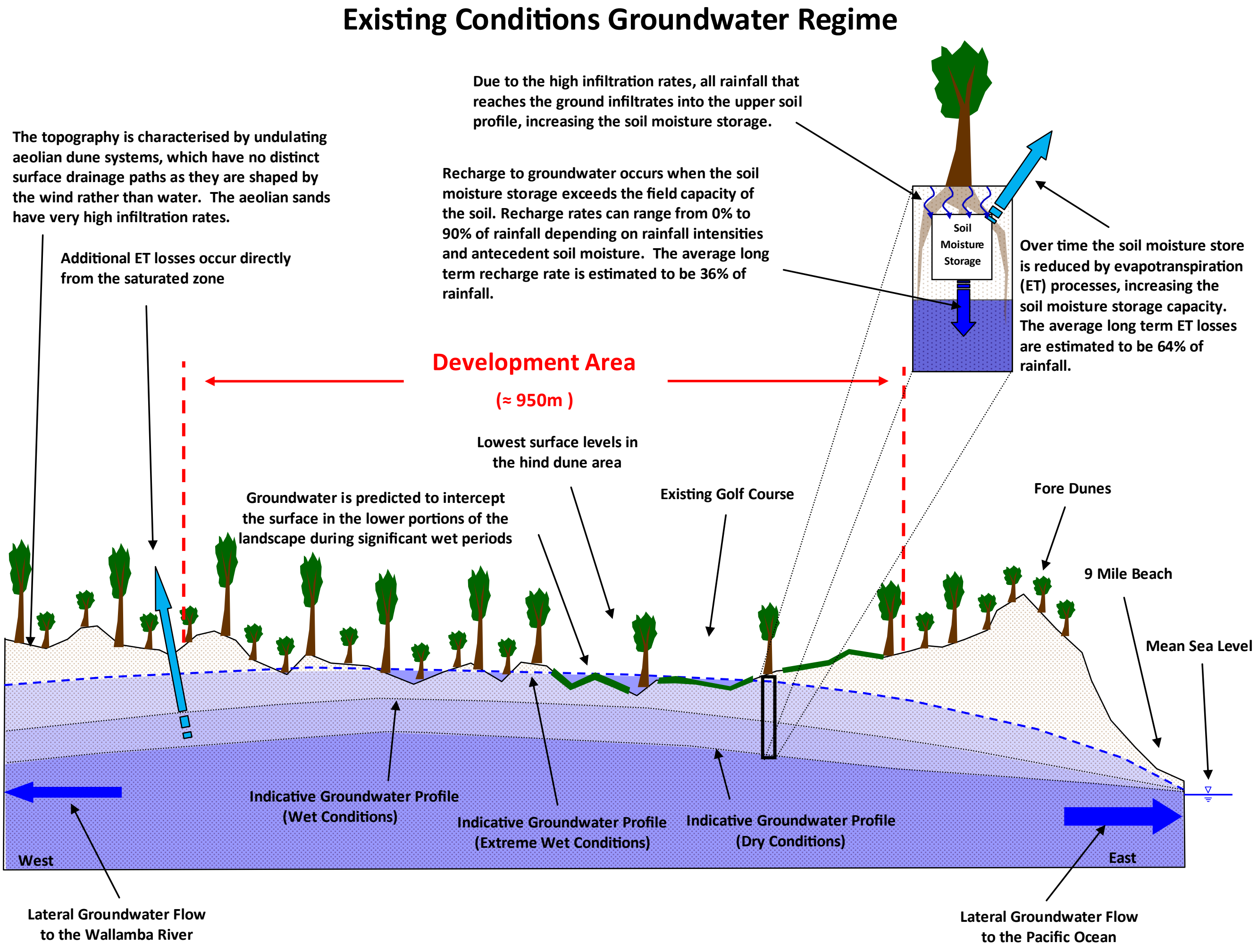


***Plate 2-3** – Existing Surface Levels within the Project Area (from LiDAR survey)*

## 2.3 Existing Groundwater Conditions

As described above, the project area is located above an unconfined coastal aquifer. The site topography is characterised by undulating aeolian dune systems, which have no distinct surface drainage paths as they are shaped by the wind rather than water. Accordingly, all rainfall that falls over the project area is either lost to evapotranspiration processes or drains vertically through the upper soil layer into the aquifer through a process referred to as recharge. Water leaves the aquifer through both evapotranspiration processes and lateral groundwater flow to the east (to the Pacific Ocean) and to the west (the Wallamba River). The dynamics of these processes vary depending on the groundwater flow characteristics, prevailing rainfall and evapotranspiration rates.

**Plate 2-4** diagrammatically describes the existing conditions groundwater regime. The various aspects of the regime are discussed in detail in subsequent sections of this report.



Existing Conditions Groundwater Regime

Due to the high infiltration rates, all rainfall that reaches the ground infiltrates into the upper soil profile, increasing the soil moisture storage.

The topography is characterised by undulating aeolian dune systems, which have no distinct surface drainage paths as they are shaped by the wind rather than water. The aeolian sands have very high infiltration rates.

Recharge to groundwater occurs when the soil moisture storage exceeds the field capacity of the soil. Recharge rates can range from 0% to 90% of rainfall depending on rainfall intensities and antecedent soil moisture. The average long term recharge rate is estimated to be 36% of rainfall.

Over time the soil moisture store is reduced by evapotranspiration (ET) processes, increasing the soil moisture storage capacity. The average long term ET losses are estimated to be 64% of rainfall.

Additional ET losses occur directly from the saturated zone

Groundwater is predicted to intercept the surface in the lower portions of the landscape during significant wet periods

**Plate 2-4** – *A diagram describing the existing conditions groundwater regime.*

A comprehensive groundwater monitoring program has been undertaken by various consultants on behalf of UrbanGrowth NSW. The objective of the program was to establish baseline groundwater level and quality data for use in this study. This section describes the monitoring program and analyses the monitoring results to established base line groundwater conditions. The information presented in this section is also frequently referred to in subsequent sections of this report as well as the IWCMS (SMEC, 2014).

## *Description of Monitoring Program*

The groundwater monitoring program commenced in March 2010 and is ongoing. Monitoring results between March 2010 and May 2013 (a 38 month period) have been used for this assessment. This period comprised a good diversity of climatic conditions including:

- A period of below average rainfall that occurred between March 2010 and June 2011.
- A period of above average rainfall that occurred between June 2011 and June 2012.
- A significant recharge event occurred between January 2013 and March 2013. Analysis in subsequent sections of this report established that this event was a 10 year Average Recurrence Interval (ARI) event.

Monitoring included the measurement of groundwater levels and the extraction of groundwater samples for both insitu and laboratory testing of a range of water quality analytes. Additional groundwater quality data was provided by Mid Coast Water from a number of bores located within the golf course and to the south of the development area. **Plate 2-5** shows the location of monitoring bores. The following sections provide further information on the groundwater level and quality data collected.

Note: refer to **Section 2** of the IWCMS (SMEC, 2014) for information on the monitoring bores installed by the Department of Conservation and Land Management (DCLM) in 1988 and by Worley Parsons in 2010.

*__Plate 2-5__ - Location of monitoring bores.*

### 2.3.1 Groundwater Level Monitoring Data

The groundwater monitoring program included the following measurements of groundwater levels within the project area over the monitoring period:

- Pressure sensors were installed at MB01, MB02 (installed in March 2013) and MB05. The pressure sensors recorded the groundwater pressure at 30 minute increments over the period. The groundwater level was calculated from the pressure records following correction for atmospheric pressure.

- Spot groundwater levels were taken at most monitoring bore locations on 14 occasions over the monitoring period.

**Plate 2-6** provides a summary of groundwater level data recorded over the monitoring period. Observed daily rainfall (from the South Forster BoM gauge 60013) over the period is also provided on the secondary axis for context.

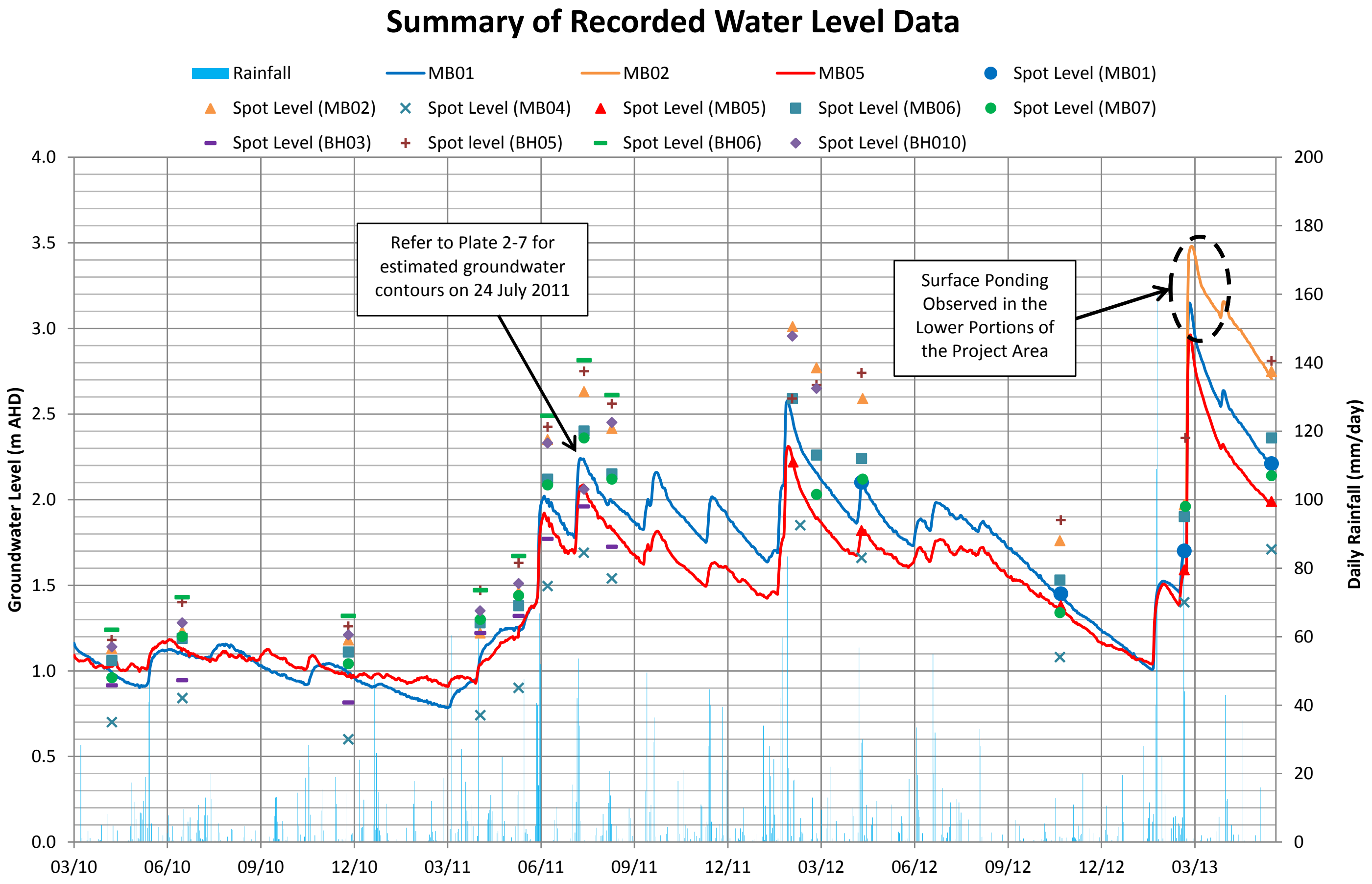


***Plate 2-6** – Observed groundwater level data*

Numerical models were established to estimate recharge and groundwater regimes within the project area. The models were developed and calibrated using available groundwater data and other geological information. To provide context to the discussion in this section, groundwater contours estimated on 24 July 2011 using the numerical model are provided in **Plate 2-7**. As noted in **Plate 2-6**, a moderate recharge event occurred prior to 24 July 2011. Hence the groundwater contours in **Plate 2-7** are indicative of wet weather conditions. Refer to **Section 5** for further information on the numerical models.

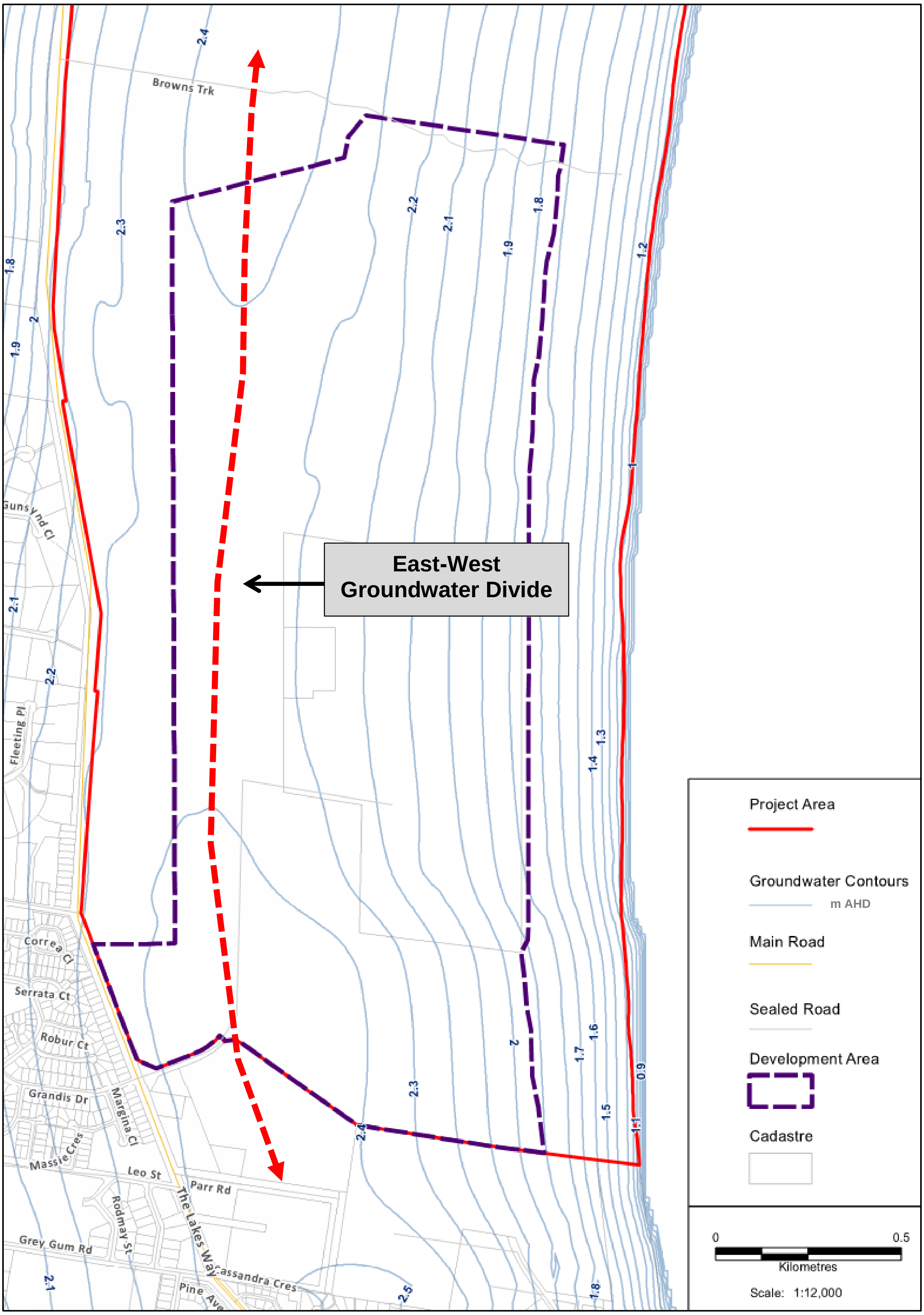


***Plate 2-7** – Indicative groundwater profile following a recharge event (24 July 2011)*

The following observations can be made from the groundwater level data presented in **Plate 2-6** and the numerical model results presented in **Plate 2-7**:

- Recorded groundwater levels ranged from 0.6m to 3.5m AHD over the period. The lowest groundwater levels occurred in March 2010, following an extended period of below average rainfall over the summer months. The highest levels were recorded in March 2013 following a significant (10 year ARI) recharge event. Surface ponding was observed in the lower portions of the site following this event.

- With reference to **Plate 2-7**, an east-west groundwater divide is located in the western portion of the project area. Groundwater to the east of the divide flows into the Pacific Ocean to the east and groundwater to the west of the divide flows into the Wallamba River Estuary to the west. It is noted that the alignment of the groundwater divide is likely to be somewhat dynamic with model results indicating it moves further to the west under higher groundwater conditions.

- Typical variations in groundwater levels across the project area at a point in time ranged from 0.6m during dry periods to 1.2m during wet periods. Groundwater levels were consistently higher in the western portion of the project area than the eastern portion. This is due to the location of the groundwater divide.

- The continuously recorded groundwater level profiles at MB01, MB02 and MB05 provide a comprehensive database of the groundwater’s response to rainfall over the period. The observations indicate that following a dry period, a moderate amount (100 to 150mm) of rainfall is required to initiate a recharge event. Once a recharge event is initiated, any additional rainfall is likely to result in further recharge. The recharge characteristics of the site are discussed in detail in **Section 3** of this report.

Further information on the groundwater regime under existing and developed conditions is provided in **Section 8**.

### 2.3.2 Groundwater Quality Monitoring Data

A comprehensive groundwater quality monitoring program has been undertaken by SMEC on behalf of Urban Growth NSW. The program included 7 sampling rounds over the 38 month period (March 2010 to May 2013). Some additional data was provided by Mid Coast Water from a monitoring program they are undertaking to assess the water quality impacts associated with the irrigation of treated effluent on the golf course and existing playing fields that are located to the south of the development area.

The groundwater quality monitoring program included sampling and analysis of a full suite of water quality analytes. **Table 2-4** provides a summary of analytes tested. It is noted that the monitoring program was progressively revised to manage costs and to ensure adequate data was collected. This has resulted in some variation in the monitoring program between sampling rounds.

***Table 2-4*** *– Water Quality Sampling Program*

| Category | Analytes Tested |
|---|---|
| **Insitu Measurements** | pH, Electrical Conductivity (EC) and Dissolved Oxygen (DO) were taken shortly after samples were bailed from the monitoring bores |
| **Nutrients** | • **Nitrogen –** Total Nitrogen (TN), Oxidised Nitrogen ($NO_x$), Ammonia, Ammonium, Nitrate, Nitrite and Total Kjeldahl Nitrogen (TKN)<br>• **Phosphorous –** Total Phosphorus (TP) and Reactive Phosphorus |
| **Metals** | • **Dissolved Metals –** Manganese (Mn) and Iron (Fe)<br>• **Total Metals –** Arsenic (As), Cadmium (Cd), Chroumium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Zinc (Zn), Molybdenum (Mo), Selenium (Se), Silver (Ag), Tin (Sn), Iron (Fe) and Mercury (Hg) |
| **Anions and Cations** | • **Dissolved Major Cations –** Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K)<br>• **Dissolved Major Anions** - Fluoride (Fl) and Silicon (Si)<br>• **Dissolved Ions –** Chloride (Cl) and Sulphate ($SO_4$) |
| **Oxygen Demand Potential** | Biological and Chemical Oxygen Demand |
| **Olfactory Compounds** | Unionised Hydrogen Sulphide |
| **Biological** | Faecal Coliforms (FC) and Escherichia Coli (E. Coli) |
| **Herbicides and Pesticides** | A full suite of herbicides and pesticides. |
| **Hydrocarbons** | Oil and Grease and Total Petroleum Hydrocarbons (TPHs) |

The following sections provide a summary of the water quality results. A full set of all results are attached as **Appendix C**.

### *Nitrogen and Phosphorous Results*

Groundwater quality results for nitrogen and phosphorous have been broadly arranged into the following categories:

- **Non Golf Course Bores**: are defined as bores that are located within the project area but outside of the golf course. Groundwater at these bores is expected to have originated from undisturbed bushland located within the project area.
- **Golf Course Bores**: are defined as bores that are located within the project area and are located either within the golf course or at a location where groundwater quality may be affected by the golf course. Groundwater at these bores is potentially degraded by golf course management practices such as the application of fertiliser to the golf greens and fairways.

- **MCW Bores**: are located on existing playing fields located to the south of the development area.

**Table 2-5** provides a summary of results for Organic Nitrogen (as TKN) Oxidised Nitrogen (as $NO_x$) and Total Nitrogen (TN) and **Table 2-6** provides a summary of results for Reactive Phosphorous and Total Phosphorous (TP). A full set of all results are attached as **Appendix C**.

It is noted that irrigation of treated effluent commenced at the golf course and existing playing fields that are located to the south of the development area in early 2013. The results in **Appendix C** depict the samples that were collected before and after the commencement of treated effluent irrigation.

***Table 2-5** – Summary of Nitrogen Results*

| | Organic Nitrogen (as TKN) | | | Oxidised Nitrogen (as $NO_X$) | | | Total Nitrogen (TN) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min / P10[1] | Avg | Max / P90[1] | Min / P10[1] | Avg | Max / P90[1] | Min / P10[1] | Avg | Max / P90[1] |
| | Units for all results are **mg/l.** Results have been rounded to 1 decimal place | | | | | | | | |
| **Non Golf Course Bores** | | | | | | | | | |
| MB01 | 0.1 | 0.4 | 0.6 | 0.0 | 0.1 | 0.1 | 0.1 | 0.4 | 0.8 |
| MB02 | 0.4 | 0.6 | 0.8 | 0.0 | 0.1 | 0.1 | 0.4 | 0.7 | 0.8 |
| MB04 | 0.9 | 2.2 | 3.3 | 0.0 | 0.3 | 1.3 | 0.9 | 2.7 | 4.6 |
| MB05 | 0.4 | 0.9 | 1.4 | 0.0 | 0.0 | 0.1 | 0.4 | 0.9 | 1.4 |
| BH05 | 0.2 | 0.4 | 0.6 | 0.2 | 0.5 | 0.6 | 0.5 | 0.8 | 1.2 |
| LC12-03 | 0.2 | 0.5 | 1.1 | 0.3 | 0.5 | 0.5 | 0.5 | 0.9 | 1.6 |
| **All Bores** | **0.2** | **0.8** | **2.1** | **0.0** | **0.2** | **0.6** | **0.4** | **1.1** | **2.1** |
| **Golf Course Bores** | | | | | | | | | |
| MB06 | 1.2 | 1.6 | 2.1 | 0.8 | 2.0 | 3.3 | 2.2 | 3.6 | 4.9 |
| MB07 | 0.4 | 0.8 | 1.1 | 0.0 | 0.1 | 0.1 | 0.5 | 0.8 | 1.1 |
| P2 | 1.2 | 1.4 | 1.6 | 0.0 | 0.0 | 0.0 | 1.2 | 1.4 | 1.6 |
| TU11[2] | 0.4 | 1.7 | 2.9 | 1.6 | 5.8 | 15.6 | 3.1 | 7.3 | 17.2 |
| TU12[2] | 0.7 | 1.4 | 2.9 | 0.9 | 8.9 | 17.2 | 2.2 | 10.2 | 20.0 |
| Golf Course Pond[3] | 0.4 | 0.6 | 0.8 | 0.0 | 0.1 | 0.1 | 0.5 | 0.7 | 0.9 |
| **All Bores** | **0.5** | **1.3** | **2.1** | **0.0** | **3.6** | **9.9** | **0.7** | **4.9** | **11.2** |
| **MCW Bores** (located on existing playing fields to the south of the development area) | | | | | | | | | |
| TU13[2] | 0.1 | 0.8 | 1.9 | 0.6 | 4.4 | 8.0 | 1.2 | 5.2 | 9.4 |
| TU14[2] | 0.2 | 0.3 | 0.5 | 0.0 | 0.6 | 2.5 | 0.3 | 0.9 | 2.9 |
| TU15[2] | 0.9 | 1.0 | 1.0 | 0.1 | 0.4 | 0.9 | 1.1 | 1.3 | 1.7 |
| TU16[2] | 0.0 | 0.5 | 0.7 | 0.7 | 1.5 | 2.5 | 1.3 | 2.0 | 3.2 |
| **All Bores** | **0.2** | **0.6** | **1.0** | **0.1** | **1.7** | **5.0** | **0.5** | **2.4** | **6.0** |
| **Summary of All Results** | | | | | | | | | |
| **All Results** | **0.3** | **1.0** | **1.9** | **0.0** | **1.9** | **6.1** | **0.5** | **2.9** | **7.5** |

Note 1 – Minimum and maximum values have been reported for each monitoring location. 10th and 90th Percentile values are reported for totals (in bold).

Note 2 – Some data was provided by Mid Coast Water.

Note 3 – Golf Course Pond is a surface water sample.

*Table 2-6* – *Summary of Phosphorous Results*

| | **Reactive Phosphorous** | | | **Total Phosphorous (TP)** | | |
|---|---|---|---|---|---|---|
| | Min / P10[1] | Avg | Max / P90[1] | Min / P10[1] | Avg | Max / P90[1] |
| | Units for all results are **mg/l.** Results have been rounded to 2 decimal places. | | | | | |
| **Non Golf Course Bores** | | | | | | |
| MB01 | 0.01 | 0.01 | 0.01 | 0.05 | 0.12 | 0.18 |
| MB02 | 0.01 | 0.01 | 0.01 | 0.11 | 0.21 | 0.27 |
| MB04 | 0.05 | 0.21 | 0.32 | 0.32 | 0.41 | 0.48 |
| MB05 | 0.01 | 0.02 | 0.03 | 0.02 | 0.14 | 0.33 |
| BH05 | 0.01 | 0.01 | 0.01 | 0.01 | 0.13 | 0.39 |
| LC12-03 | 0.02 | 0.09 | 0.23 | 0.02 | 0.09 | 0.23 |
| **All Bores** | **0.01** | **0.06** | **0.22** | **0.02** | **0.18** | **0.42** |
| **Golf Course Bores** | | | | | | |
| MB06 | 0.01 | 0.02 | 0.06 | 0.02 | 0.08 | 0.11 |
| MB07 | 0.01 | 0.02 | 0.03 | 0.16 | 0.62 | 1.02 |
| P2 | 0.01 | 0.01 | 0.01 | 0.05 | 0.10 | 0.17 |
| TU11[2] | 0.01 | 0.02 | 0.04 | 0.02 | 0.04 | 0.07 |
| TU12[2] | 0.00 | 0.01 | 0.01 | 0.02 | 0.04 | 0.07 |
| Golf Course Pond[3] | 0.06 | 0.08 | 0.09 | 0.04 | 0.10 | 0.13 |
| **All Bores** | **0.01** | **0.02** | **0.06** | **0.02** | **0.15** | **0.44** |
| **MCW Bores** (located on existing playing fields to the south of the development area) | | | | | | |
| TU13[2] | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 |
| TU14[2] | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 |
| TU15[2] | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.05 |
| TU16[2] | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| **All Bores** | **0.02** | **0.02** | **0.03** | **0.03** | **0.03** | **0.05** |
| **Summary of All Results** | | | | | | |
| **All Results** | **0.01** | **0.03** | **0.06** | **0.02** | **0.13** | **0.33** |

Note 1 – Minimum and maximum values have been reported for each monitoring location. 10th and 90th Percentile values are reported for totals (in bold).

Note 2 – Some data was provided by Mid Coast Water.

Note 3 – Golf Course Pond is a surface water sample.

The following key conclusions can be made from the nitrogen and phosphorus monitoring results:

- A total of 86 nitrogen and phosphorus samples have been collected over a 38 month monitoring period from 16 monitoring locations. Accordingly, the available data is considered sufficient to enable the temporal and spatial variation in nitrogen and phosphorous concentrations to be captured and key statistics such as average, 10th and 90th Percentile values to be reliably estimated.

- **Summary of Nitrogen Results**: For non-golf course bores, TN concentrations typically ranged between 0.4 (P10) to 2.1 (P90) mg/l with an average value of 1.1 mg/l. On average, TN comprised 80% organic nitrogen and 20% oxidised nitrogen. These results are considered typical for undisturbed groundwater systems. Conversely, for golf course bores, TN concentrations were significantly higher, with results typically ranging between 0.7 (P10) to 11.2 (P90) mg/l with an average value of 4.9 mg/l. On average, TN in golf course bores comprised 30% organic nitrogen and 70% oxidised nitrogen, indicating that the elevated nitrogen concentrations are associated with anthropogenic influences such as fertiliser application. Elevated TN with similar speciation characteristics was also observed at the MCW bores. This analysis indicates that the application of fertilisers to the golf course and playing fields has resulted in elevated nitrogen concentrations in the underlying groundwater.

- **Summary of Phosphorous Results**: Phosphorous concentrations ranged considerably in both a temporal and spatial context over the period. The highest average concentrations occurred from the non-golf course bores. As phosphorous in groundwater can be readily fixed by iron, aluminium, manganese and calcium (as a function of the pH), the phosphorous data is likely to reflect geochemical conditions rather than potential anthropogenic influences.

- As mentioned previously, irrigation of recycled effluent to the golf course and the playing fields located to the south of the development area commenced in early 2013. Three sampling rounds were undertaken following the commencement of this program (Refer to **Appendix C** for detailed results). Nitrogen and phosphorous results from these sampling rounds were within a similar range to the pre-irrigation results, indicating that the application of recycled effluent has not resulted in increased nutrient concentrations in the groundwater. However, as data from only three sampling rounds was available further data and evaluation would be required to confirm this.

## *Other Water Quality Results*

Water quality results for the following analytes are summarised in **Table 2-7**:

- Insitu measurements (pH, DO and EC);

- All metals, anions and cations sampled (as listed in **Table 2-4**);

- Biological Oxygen Demand and Chemical Oxygen Demand;

- Olfactory compounds; and

- Biological Compounds.

All results are compared to relevant trigger values where available. Values exceeding the relevant trigger values (or range) are shaded in the table. A full set of all results are attached as **Appendix C**.

***Table 2-7*** *– Summary of other water quality results*

| Analyte & Units | Relevant Trigger Value | LOR[4] | | Non Golf Course Bores | | | | | | Golf Course Bores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MB01 | MB02 | MB04 | MB05 | BH05 | LC12-03 | MB06 | MB07 | P2 | TU11 | GC Pond |
| **pH (field)** | 6.5 – 8[1] | 0.1 | Samples | 5 | 5 | 5 | 5 | 3 | 4 | 5 | 5 | 3 | 4 | 4 |
| | | | Min | 4.5 | 5.0 | 4.5 | 5.3 | 5.5 | 5.5 | 5.1 | 5.8 | 4.2 | 6.4 | 6.5 |
| | | | Avg | 5.1 | 5.7 | 5.2 | 5.8 | 5.7 | 6.5 | 5.8 | 6.3 | 4.9 | 6.6 | 7.0 |
| | | | Max | 5.6 | 7.1 | 6.0 | 7.1 | 5.9 | 7.6 | 7.5 | 7.0 | 5.6 | 6.8 | 7.5 |
| **pH (Lab)** | 6.5 – 8[1] | 5 | Samples | 6 | 6 | 5 | 7 | 7 | 3 | 7 | 5 | 0 | 0 | 0 |
| | | | Min | 5.6 | 5.8 | 5.4 | 5.7 | 6.7 | 7.1 | 5.9 | 6.5 | - | - | - |
| | | | Avg | 6.1 | 6.5 | 5.7 | 6.6 | 6.8 | 7.3 | 6.5 | 6.9 | - | - | - |
| | | | Max | 8.0 | 8.1 | 6.1 | 7.9 | 6.8 | 7.5 | 7.9 | 7.4 | - | - | - |
| **Electrical Conductivity (µS/cm)** | - | 1 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 3 | 4 | 4 |
| | | | Min | 102 | 158 | 122 | 126 | 138 | 247 | 114 | 142 | 300 | 328 | 383 |
| | | | Avg | 116 | 285 | 293 | 354 | 152 | 261 | 405 | 201 | 517 | 386 | 407 |
| | | | Max | 144 | 366 | 384 | 487 | 165 | 274 | 652 | 230 | 733 | 480 | 425 |
| **Total Dissolved Solids (mg/l))** | - | 5 | Samples | 5 | 5 | 5 | 6 | 3 | 3 | 6 | 5 | 2 | 2 | 2 |
| | | | Min | 65 | 136 | 186 | 227 | 93 | 110 | 238 | 110 | 194 | 213 | 257 |
| | | | Avg | 71 | 186 | 217 | 275 | 99 | 164 | 292 | 186 | 335 | 222 | 267 |
| | | | Max | 84 | 232 | 292 | 318 | 111 | 205 | 382 | 300 | 476 | 231 | 276 |
| **Dissolved Oxygen (mg/l)** | - | 0.1 | Samples | 4 | 3 | 5 | 4 | 3 | 2 | 4 | 4 | 2 | 3 | 3 |
| | | | Min | 6.0 | 4.2 | 4.9 | 4.5 | 5.0 | 6.5 | 4.1 | 3.8 | 6.9 | 1.2 | 5.1 |
| | | | Avg | 6.6 | 4.7 | 6.0 | 5.9 | 6.9 | 6.6 | 6.0 | 6.2 | 8.6 | 6.1 | 9.1 |
| | | | Max | 7.4 | 5.7 | 8.1 | 7.9 | 9.0 | 6.7 | 8.1 | 9.0 | 10.2 | 9.4 | 14.7 |
| **Faecal Coliforms (CFU/100ml)** | - | 2 | Samples | 4 | 4 | 5 | 5 | 3 | 2 | 5 | 3 | - | 4 | - |
| | | | Min | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | - | 2 | - |
| | | | Avg | 4 | 4 | 5 | 4 | 2 | 2 | 2 | 32 | - | 2 | - |
| | | | Max | 10 | 10 | 10 | 10 | 2 | 2 | 2 | 62 | - | 2 | - |
| **Escherichia coli (CFU/100ml)** | - | 2 | Samples | 5 | 5 | 5 | 6 | 3 | 2 | 6 | 4 | - | - | - |
| | | | Min | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | - | - | - |
| | | | Avg | 5 | 5 | 5 | 5 | 2 | 2 | 3 | 27 | - | - | - |
| | | | Max | 10 | 10 | 10 | 10 | 2 | 2 | 10 | 62 | - | - | - |
| **Biological Oxygen Demand (mg/l)** | - | 2 | Samples | 4 | 4 | 5 | 5 | 3 | 2 | 5 | 3 | - | 4 | - |
| | | | Min | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | - | 2 | - |
| | | | Avg | 2 | 2 | 23 | 2 | 2 | 2 | 2 | 2 | - | 2 | - |
| | | | Max | 2 | 2 | 31 | 2 | 2 | 2 | 2 | 2 | - | 2 | - |
| **Chemical Oxygen Demand (mg/l)** | - | 2 | Samples | 4 | 4 | 5 | 5 | 3 | 2 | 5 | 3 | - | - | - |
| | | | Min | 16 | 18 | 97 | 45 | 9 | 5 | 32 | 67 | - | - | - |
| | | | Avg | 22 | 32 | 117 | 78 | 12 | 12 | 63 | 73 | - | - | - |
| | | | Max | 34 | 54 | 145 | 111 | 18 | 18 | 88 | 81 | - | - | - |
| **Unionised Hydrogen Sulfide (mg/l)** | 0.05[3] | 0.01 | Samples | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 4 | - | - | - |
| | | | Min | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | - | - | - |
| | | | Avg | 0.02 | 0.02 | 0.08 | 0.03 | 0.01 | 0.02 | 0.03 | 0.01 | - | - | - |
| | | | Max | 0.05 | 0.06 | 0.17 | 0.10 | 0.02 | 0.04 | 0.10 | 0.01 | - | - | - |
| **Total Hardness as $CaCO_3$ (mg/l)** | - | 1 | Samples | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 4 | - | - | - |
| | | | Min | 8 | 17 | 17 | 26 | 43 | 61 | 33 | 53 | - | - | - |
| | | | Avg | 8 | 24 | 24 | 45 | 45 | 72 | 55 | 59 | - | - | - |
| | | | Max | 8 | 33 | 35 | 60 | 48 | 83 | 78 | 78 | - | - | - |
| **Total Alkalinity as $CaCO_3$ (mg/l)** | - | 1 | Samples | 5 | 5 | 5 | 6 | 3 | 3 | 6 | 5 | - | - | - |
| | | | Min | 1 | 13 | 8 | 1 | 32 | 57 | 11 | 53 | - | - | - |
| | | | Avg | 3 | 27 | 11 | 19 | 35 | 63 | 30 | 60 | - | - | - |
| | | | Max | 4 | 44 | 15 | 32 | 37 | 74 | 100 | 68 | - | - | - |
| **Sulfate as $SO_4$ (mg/l)** | - | 1 | Samples | 5 | 5 | 5 | 6 | 3 | 3 | 6 | 5 | - | - | - |
| | | | Min | 3 | 2 | 5 | 5 | 2 | 4 | 6 | 1 | - | - | - |
| | | | Avg | 4 | 11 | 8 | 8 | 3 | 5 | 22 | 6 | - | - | - |
| | | | Max | 5 | 17 | 13 | 18 | 4 | 6 | 34 | 13 | - | - | - |

| Analyte & Units | Relevant Trigger Value | LOR[4] | | Non Golf Course Bores | | | | | | Golf Course Bores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MB01 | MB02 | MB04 | MB05 | BH05 | LC12-03 | MB06 | MB07 | P2 | TU11 | GC Pond |
| **Chloride (mg/l)** | - | 1 | Samples | 5 | 5 | 6 | 6 | 3 | 3 | 6 | 6 | - | - | - |
| | | | Min | 4 | 25 | 67 | 42 | 15 | 29 | 66 | 21 | - | - | - |
| | | | Avg | 23 | 65 | 80 | 91 | 19 | 32 | 100 | 35 | - | - | - |
| | | | Max | 42 | 80 | 106 | 122 | 24 | 37 | 180 | 85 | - | - | - |
| **Arsenic (mg/l)** | 0.001[2] | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.007 | 0.001 | 0.001 | 0.001 | 0.010 | 0.006 | 0.004 | 0.007 |
| | | | Avg | 0.003 | 0.007 | 0.009 | 0.010 | 0.001 | 0.001 | 0.003 | 0.014 | 0.015 | 0.005 | 0.011 |
| | | | Max | 0.009 | 0.024 | 0.035 | 0.016 | 0.001 | 0.001 | 0.008 | 0.022 | 0.024 | 0.006 | 0.014 |
| **Cadmium (mg/l)** | 0.0002[2] | 0.0001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| | | | Avg | 0.0002 | 0.0002 | 0.0001 | 0.0026 | 0.0001 | 0.0001 | 0.0002 | 0.0003 | 0.0001 | 0.0001 | 0.0001 |
| | | | Max | 0.0005 | 0.0005 | 0.0002 | 0.0174 | 0.0001 | 0.0001 | 0.0005 | 0.0005 | 0.0001 | 0.0001 | 0.0001 |
| **Chromium (mg/l)** | 0.001[2] | 0.001 | Samples | 6 | 5 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.004 | 0.002 | 0.002 | 0.001 | 0.001 | 0.003 | 0.004 | 0.006 | 0.002 | 0.001 |
| | | | Avg | 0.006 | 0.019 | 0.003 | 0.008 | 0.001 | 0.001 | 0.005 | 0.008 | 0.007 | 0.003 | 0.001 |
| | | | Max | 0.021 | 0.069 | 0.004 | 0.020 | 0.001 | 0.001 | 0.010 | 0.016 | 0.007 | 0.004 | 0.001 |
| **Copper (mg/l)** | 0.001[2] | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.001 | 0.001 |
| | | | Avg | 0.003 | 0.006 | 0.003 | 0.003 | 0.001 | 0.001 | 0.002 | 0.011 | 0.002 | 0.001 | 0.001 |
| | | | Max | 0.006 | 0.023 | 0.005 | 0.008 | 0.001 | 0.001 | 0.005 | 0.016 | 0.002 | 0.001 | 0.001 |
| **Iron (Dissolved) (mg/l)** | 0.3[3] | 0.05 | Samples | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 4 | 2 | 3 | 3 |
| | | | Min | 0.05 | 0.68 | 1.72 | 2.12 | 0.05 | 0.05 | 0.09 | 0.20 | 6.42 | 0.18 | 0.12 |
| | | | Avg | 0.08 | 1.35 | 2.31 | 3.35 | 0.05 | 0.05 | 0.30 | 0.29 | 6.45 | 0.28 | 0.17 |
| | | | Max | 0.10 | 1.64 | 3.54 | 4.50 | 0.05 | 0.05 | 0.81 | 0.44 | 6.47 | 0.38 | 0.26 |
| **Iron (Total) (mg/l)** | 0.3[3] | 0.05 | Samples | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 4 | 2 | 3 | 3 |
| | | | Min | 0.33 | 5.01 | 2.34 | 3.09 | 0.06 | 0.13 | 0.43 | 13.80 | 7.68 | 0.55 | 0.32 |
| | | | Avg | 0.98 | 5.86 | 4.13 | 4.82 | 0.22 | 0.25 | 0.67 | 16.90 | 8.34 | 0.78 | 0.55 |
| | | | Max | 2.03 | 7.48 | 7.23 | 5.60 | 0.32 | 0.38 | 1.13 | 23.30 | 8.99 | 0.92 | 0.88 |
| **Lead (mg/l)** | 0.003[2] | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.039 | 0.020 | 0.001 | 0.001 |
| | | | Avg | 0.007 | 0.016 | 0.008 | 0.006 | 0.003 | 0.001 | 0.005 | 0.057 | 0.023 | 0.001 | 0.001 |
| | | | Max | 0.028 | 0.062 | 0.016 | 0.022 | 0.006 | 0.001 | 0.010 | 0.087 | 0.025 | 0.001 | 0.001 |
| **Manganese (mg/l)** | 1.9[2] | 0.001 | Samples | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 4 | 2 | 3 | 3 |
| | | | Min | 0.005 | 0.101 | 0.013 | 0.009 | 0.001 | 0.001 | 0.019 | 0.065 | 0.024 | 0.002 | 0.003 |
| | | | Avg | 0.010 | 0.135 | 0.027 | 0.024 | 0.002 | 0.001 | 0.021 | 0.089 | 0.046 | 0.004 | 0.007 |
| | | | Max | 0.016 | 0.161 | 0.058 | 0.033 | 0.003 | 0.001 | 0.024 | 0.104 | 0.068 | 0.006 | 0.010 |
| **Mercury (mg/l)** | 0.00006[2] | 0.0001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| | | | Avg | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| | | | Max | 0.0002 | 0.0003 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0010 | 0.0003 | 0.0001 | 0.0001 | 0.0001 |
| **Molybdenum (mg/l)** | - | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| | | | Avg | 0.002 | 0.002 | 0.005 | 0.002 | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 |
| | | | Max | 0.005 | 0.005 | 0.022 | 0.005 | 0.001 | 0.001 | 0.005 | 0.005 | 0.001 | 0.001 | 0.001 |
| **Nickel (mg/l)** | 0.011[2] | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.007 | 0.001 | 0.001 | 0.001 |
| | | | Avg | 0.002 | 0.010 | 0.002 | 0.003 | 0.001 | 0.001 | 0.002 | 0.008 | 0.004 | 0.001 | 0.001 |
| | | | Max | 0.006 | 0.028 | 0.004 | 0.005 | 0.001 | 0.001 | 0.005 | 0.011 | 0.006 | 0.001 | 0.001 |
| **Selenium (mg/l)** | 0.005 | 0.01 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.005 | 0.005 | 0.005 | 0.005 | 0.010 | 0.010 | 0.005 | 0.005 | 0.010 | 0.010 | 0.010 |
| | | | Avg | 0.009 | 0.008 | 0.009 | 0.009 | 0.010 | 0.010 | 0.009 | 0.016 | 0.010 | 0.010 | 0.010 |
| | | | Max | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.038 | 0.010 | 0.010 | 0.010 |

| Analyte & Units | Relevant Trigger Value | LOR[4] | | Non Golf Course Bores | | | | | | Golf Course Bores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MB01 | MB02 | MB04 | MB05 | BH05 | LC12-03 | MB06 | MB07 | P2 | TU11 | GC Pond |
| **Silver (mg/l)** | 0.00005[2] | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| | | | Avg | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| | | | Max | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| **Tin (mg/l)** | - | 0.001 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| | | | Avg | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 |
| | | | Max | 0.005 | 0.005 | 0.005 | 0.005 | 0.001 | 0.001 | 0.005 | 0.005 | 0.001 | 0.001 | 0.001 |
| **Zinc (mg/l)** | 0.008[2] | 0.005 | Samples | 6 | 6 | 6 | 7 | 3 | 3 | 7 | 6 | 2 | 3 | 3 |
| | | | Min | 0.001 | 0.001 | 0.001 | 0.007 | 0.005 | 0.005 | 0.005 | 0.028 | 0.011 | 0.005 | 0.005 |
| | | | Avg | 0.012 | 0.030 | 0.016 | 0.026 | 0.007 | 0.005 | 0.012 | 0.647 | 0.014 | 0.005 | 0.005 |
| | | | Max | 0.043 | 0.110 | 0.040 | 0.064 | 0.012 | 0.006 | 0.018 | 2.110 | 0.016 | 0.005 | 0.005 |

Note 1: Default trigger value for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems as defined in Table 3.3.2 of the ANZECC 2000 guidelines have been applied as the relevant trigger value.

Note 2: Trigger values for slightly-moderately disturbed systems as defined in Table 3.4.1 of the ANZECC 2000 guidelines have been applied as the relevant trigger value.

Note 3: Aesthetic guideline values from Table 10.5 from the Australian Drinking Water Guidelines (Australian Government, 2011) have been applied as the relevant trigger value.

Note 4: Results that were reported below the Limit of Reporting (LOR) have been set at the LOR level for the purposes of statistical calculations. This may inflate some average and minimum values.

The following key conclusions can be made from the water quality results presented in **Table 2-7**:

- Insitu pH measurements were typically between 5 and 7 indicating the groundwater is mildly acidic.

- EC and TDS results confirmed that the groundwater is fresh water, with no evidence of salt water intrusion at any bore hole.

- Elevated iron concentrations were detected at most monitoring locations. Elevated iron is common in groundwater systems that are characterised by marine geology. When exposed to oxygen, iron in the groundwater is likely to oxidise, forming an orange coloured precipitate. This is likely to occur in areas where groundwater seeps into a surface water body or if untreated groundwater is used within dwellings as an alternative non potable water supply. Elevated iron can also be an indicator of acid sulphate soils.

- Elevated hydrogen sulphide (rotten egg gas) was detected at MB01, MB02, MB04 and MB05. The highest results were at MB04 (which is outside of the development area) where odours were clearly noticeable during sampling. These results indicate that there is potential for elevated hydrogen sulphide levels to exist in groundwater within the northern and western portions of the development area. Hydrogen sulphide is a non-toxic gas but may create odour issues in areas where groundwater is exposed to the surface (i.e. where groundwater seeps into an open basin) or if untreated groundwater is used within dwellings as an alternative non potable water supply. Hydrogen sulphide can also be an indicator of acid sulphate soils.

- Some results for Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Selenium and Zinc were above ANZECC trigger values for slightly to moderately disturbed ecosystems. It is expected that these results are associated with the natural geochemical characteristic of the aquifer.

## *Herbicide and Pesticides Results*

Limited testing of a full suite of herbicide and pesticides was undertaken. All results were below detection limits indicating that there is no significant herbicide and pesticide contamination within the groundwater at the monitoring locations. Refer to **Appendix C** for all results.

## *Hydrocarbon Results*

Limited testing for oil and grease and TPHs was undertaken. The majority of results were below detection limits indicating that there is no significant hydrocarbon contamination within the groundwater at the monitoring locations. Refer to **Appendix C** for all results.

## 2.4 Geological Conditions

This section discusses the geological characteristics that are relevant to this assessment.

### *Summary of Field Investigations and Data Collection*

As discussed in **Section 2** of the IWCMS (SMEC, 2014), geotechnical investigations have been previously undertaken by Douglas Partners in 1988, WorleyParsons in 2010 and by SMEC in 2012. The following field investigations were undertaken as part of these studies:

- 10 test pits were excavated to approximately 2.5m as part of the 1988 Douglas Partners study.
- It is understood that twenty-one boreholes (BH01 to BH021) were installed within the project area by the Department of Conservation and Land Management in 1988. Of the twenty-one existing boreholes, only four boreholes (BH03, BH05, BH06 and BH010) were located by WorleyParsons as part of the 2010 study.
- An additional seven monitoring bores were established by WorleyParsons in 2010. These bores were established to a depth of approximately 6m and are referred to as MB01, MB02, MB03, MB04, MB05, MB06 and MB07.
- Four additional boreholes were established by SMEC in 2012 as part of the pump test that was undertaken. These boreholes were established to the base of the sand deposits (depths of 25 to 30m) and are referred to as LC12-01 PB, LC12-02 MB A, LC 12-02 MB B and LC12-03. The bores were drilled using rotatory air blast and casing advance (Tubex) methods. **Table 2-8** provides construction details for these bores. Bore logs are provided in **Appendix A**.

***Table 2-8** – Construction Details*

| Borehole ID | Constructed Depth | Screen interval | Screen Length | Screen ID | Gravel Pack Interval | Casing Interval | Casing ID | Bentonite Seal |
|---|---|---|---|---|---|---|---|---|
| | (m) | (mbgl) | (m) | (mm/Type) | (mbgl) | (mbgl) | (mm/Type) | (mbgl) |
| LC12-01 PB | 26 | 14-26 | 12 | 150/SSWW | Natural | 0-14 | 200/Steel | N/A |
| LC12-02 MB A | 28.5 | 28.5-29.5 | 1 | 50/PVC | 26-30 | 0-28.5 | 50/PVC | 24-26 |
| LC12-02 MB B | 19.5 | 4.5-19.5 | 15 | 50/PVC | Natural | 0-7.5 | 50/PVC | N/A |
| LC12-03 | 16.5 | 7.5-16.5 | 9 | 50/PVC | Natural | 0-7.5 | 50/PVC | N/A |

**Plate 2-5** shows the locations of the abovementioned bores.

### *Interpreted Geological Profiles*

The data collected from the geological investigations described above indicate that the development area comprises relatively homogeneous geological characteristics, with fine to medium aeolian sands encountered in all test pits and boreholes. The deeper boreholes drilled by SMEC in 2012 encountered fine to medium marine sands at 12m below ground level (mbgl) and marine clays from

24mbgl. Importantly, no low permeability material such as clay or indurated sands has been encountered in any borehole or test pit to date. This indicates that no significant geological barriers to groundwater flow exist within the development area.

**Photos 1** and **2** show examples of the sandy soils that exist throughout the development area. **Table 2-9** presents a geological profile that has been interpreted from available data. The local and regional geology is discussed further in **Section 5**.

***Photo 1*** *on the left shows the sandy soils that are encountered throughout the development area.* ***Photo 2*** *on the right shows sand extracted during the development of production borehole LC 12-01 PB.*

***Table 2-9*** *– Interpreted Geological Profiles*

| Geological Layer | Depth | Description |
|---|---|---|
| Holocene Aeolian Sands<br>(Top Soil) | 0 to 0.5 mbgl | **Sand:** Fine to medium with organic matter and roots. |
| Holocene Aeolian Sands<br>(below 0.5 metres) | From 0.5 to 12 mbgl | **Sand**: Fine to medium, moderately sorted with shells. Some roots encountered. |
| Holocene Marine Sands | From 12 metres to 24 mbgl | **Sand**: Fine to medium, moderately sorted with shells and some occasional clay bands. |
| Marine Clay | From 24 mbgl | **Sandy Clay**: Dark grey, high plasticity with fine to medium sand |

Note: No geotechnical data is available for the northern employment lands that are detached from the primary development area.

## *Surface Infiltration Testing*

Infiltration rates vary in response to soil water content and the hydraulic properties of the soil. During rainfall events, the initial infiltration rates tend to be rapid if the soils are dry. As rainfall continues and the soil water content increases towards saturation, the infiltration rates decrease towards the saturated hydraulic conductivity. Rainfall rates which exceed infiltration rates give rise to surface runoff.  Understanding this relationship is important to investigations of stormwater as well as the processes affecting soil water flux and the rainfall recharge to groundwater.

Surface infiltration testing using a Double Ring Infiltrometer was undertaken by SMEC in 2012 (4 test locations) and Douglas Partners in 1988 (2 test locations). Test locations are indicated in **Plate 2-8**.

***Plate 2-8** – Surface Infiltration Test Locations*

**Table 2-10** provides a summary of the saturated hydraulic conductivity derived from the Double Ring Infiltrometer tests.  With reference to **Plate 2-8**, surface infiltration tests at IT 1 to IT 5 were undertaken on undisturbed soil. The estimated saturated conductivity from these tests ranged from 432mm/hr to 1,700mm/hr, with an average rate of 954mm/hr. A significantly lower rate was reported at IT 6, which was located on a golf fairway.  This lower rate is most likely due to a thin layer of topsoil that would have been imported to establish the golf fairway.  The IT 6 result (70mm/hr) is considered to be indicative of surface infiltration rates of any lawn areas that are established within the NTDP. Given that the average rainfall intensity for a one hour duration 100 year ARI event is approximately 80mm/hr, surface runoff is generally not expected to occur from pervious areas within the development area.

***Table 2-10*** *– Saturated Hydraulic Conductivity Results*

| Infiltration Test Site | Saturated hydraulic conductivity at soil surface (mm/h) | Test location |
|---|---|---|
| IT1 (SMEC) | 960 | Undisturbed soil |
| IT2 (SMEC) | 432 | Undisturbed soil |
| IT3 (SMEC) | 1140 | Undisturbed soil |
| IT4 (SMEC) | 540 | Undisturbed soil |
| IT5 (DP)[1] | 1700 | Undisturbed soil |
| IT6 (DP)[1] | 70 | Golf fairway |

Note 1: Data sourced from Douglas Partners (1988)

## 2.5 Aquifer Pump Test Methodology and Observations

A pump test was performed at a constant rate over 24 hours. The test was conducted by Australian Groundwater Services Pty Ltd under the supervision of a SMEC hydrogeologist. A 100 mm mono head drive pump was installed in LC12-01 PB with the intake at approximately 12 mbgl. The test commenced on 22 February 2012, pumping at a constant rate of 16 L/sec. To avoid discharged water from interfering with the test result, the water was pumped via a 240 m long pipe to a low lying part of the access road to the west of the pumping bore as shown in **Photos 3** and **4**. This low lying area is adjacent to bore MB02 enabling ponding and water levels to be monitored as water soaked back into the sandy soils.

***Photo 3*** *on the left shows the discharge pipeline and* ***Photo 4*** *on the right shows the ponded discharge*.

Electronic data loggers and manual readings were used to record water levels at the relevant observation sites during the test period. These sites included LC12-01PB, LC12-02A, LC12-02B, LC12-03, MB02, BH06 and BH10.

**Plate 2-9** shows the drawdown trajectory of piezometric surfaces (water levels) at pumping and observation wells tested in response to the 24 hour pump test period and a subsequent 18 hour recovery period. The Plate shows a rapid measurable drawdown at the Production Bore (LC12-01 PB) when pumping commenced, followed by a period with a relatively stable water level for the duration of the steady state pump test, and then rapid recovery once pumping stopped. The nearest monitoring bores (LC12-02A and LC12-02B) initially responded quickly and then more gradually as the depression cone tended towards an equilibrium state reflecting the hydraulic response of the unconfined sandy aquifer to the steady state pumping. Post-pumping recovery was rapid. Bores located more than 60 m away only showed a small response to the pumping (e.g. BH06). The positive mounding at the discharge site was observed at MB02. The mounded piezometric levels at this site took longer to decline than the levels in the depression cone took to recover.

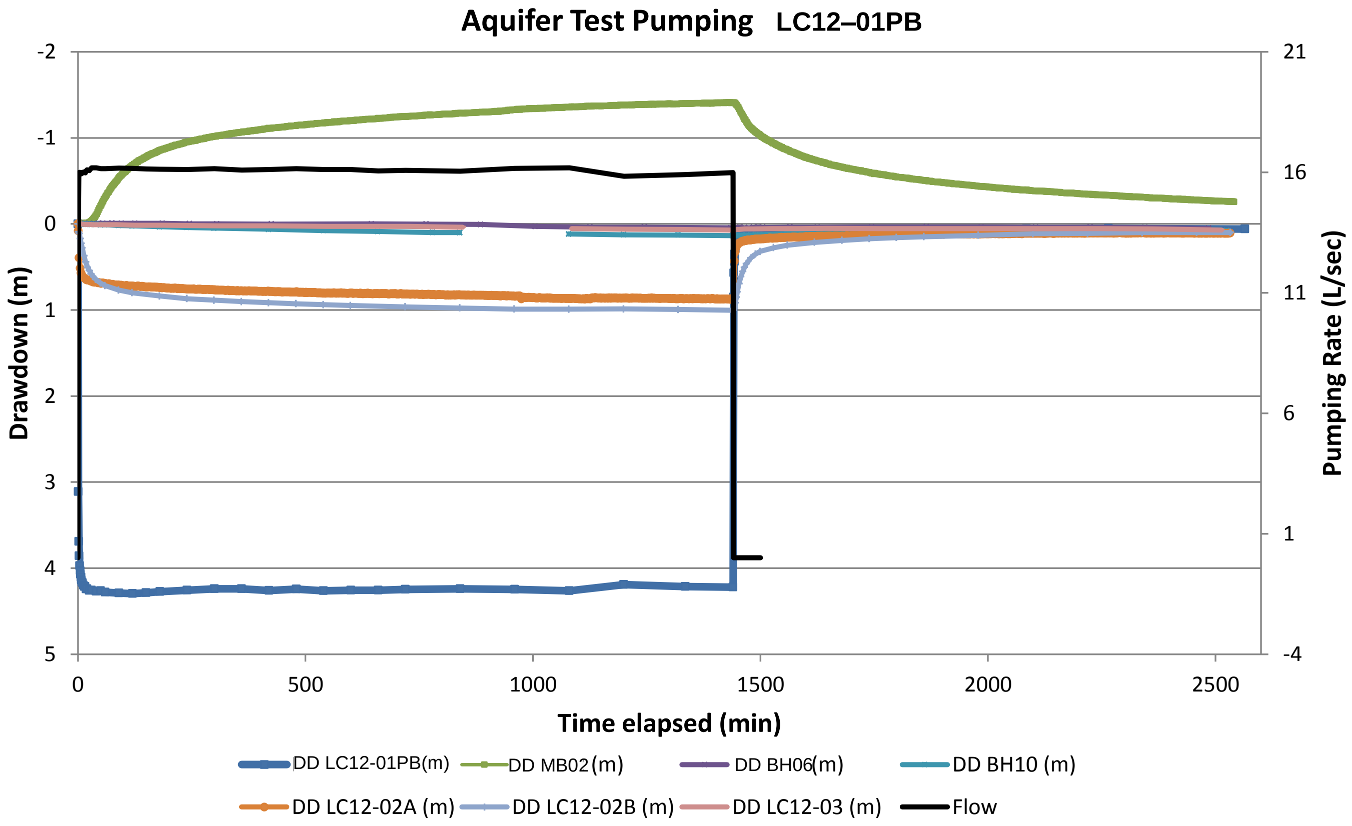


***Plate 2-9*** *- Water table drawdown (DD) at the production and observation bores and mounding of the water table below the discharge site.*

**Table 2-11** provides a summary of the pump test results. From **Table 2-11** it can be seen that the water levels in all wells (apart from at the discharge site MB02, recovered after less than 24 hours to depths of five to eleven centimetres lower than the depth at the start of the test. The difference is also observed at bore BH06 located beyond the zone of influence of the pumping, implying that the levels had recovered to natural levels. The observed residual drawdown is therefore taken to be the result of the natural decline in water levels generally observed in this area during dry periods in which rainfall recharge to groundwater is negligible.

**Table 2-11** - *Aquifer Pump Test Summary*

| Bore ID | Distance to LC12-01PB | Initial Water level | Max observed drawdown | Water level 24 hours after pump test commenced | Comment |
|---|---|---|---|---|---|
| | (m) | (mbtoc) | (m) | (mbtoc) | |
| LC12-01PB | 0 | 2.8 | 4.30 | 2.86 | Pumping bore |
| LC12-02A | 10 | 3.08 | 0.88 | 3.19 | |
| LC12-02B | 10 | 2.97 | 1.00 | 3.07 | |
| LC12-03 | 197 | 2.75 | 0.07 | 2.82 | |
| MB02 | 242 | 2.5 | -1.41 | 2.27 | Mounding near discharge site |
| BH10 | 66 | 2.62 | 0.14 | 2.70 | |
| BH06 | >60 | 1.91 | 0.05 | 1.96 | |

mbtoc refers to metres below top of casing

Drawdown observations that occurred during the test pumping, especially those at LC12-01PB, LC12-02A and LC12-02B and the mounding observations at MB02 provided sufficient data for deriving aquifer hydraulic properties. The data derived from these bores was analysed and interpreted using the industry standard software Aqtesolv Version 4.5 Professional©. The application involved methods developed by Theis (1935) for unconfined aquifers and Hantush-Jacob (1955)/ Hantush (1964) for a leaky confined aquifer. These were chosen based on the conceptual model that is described in **Section 5**. The water level trends in response to the pump test are presented in **Appendix B**. For interpretation purposes, preference was given to the data for bores that responded more noticeably. These included LC12-02B and BH10 and the bore at the discharge site MB02. Drawdown trends observed in the other bores were less meaningful. The results are summarised in **Table 2-12**.

**Table 2-12** - *Results of Pump Tests*

| Parameter | Units | Range | LC12-02B (Theis) | LC12-02B (Hantush) | BH10 (Theis) | BH10 (Hantush) | MB02 (Theis) |
|---|---|---|---|---|---|---|---|
| Transmissivity (T) | ($m^2$/day) | 363 - 1606 | 808 | 570 | 1571 | 1606 | 363 |
| Hydraulic Conductivity (K) | (m/day) | 24 - 68 | 34 | 24 | 67 | 68 | 30 |
| Storativity (S) | (unit less) | <0.01 - 0.18 | <0.01 | 0.016 | 0.13 | 0.12 | 0.18 |
| Hydraulic Conductivity Aniostropy Ratio (Kz/Kr) | (unit less) | 0.1 - 1 | 0.1 | 0.2 | 1 | 1 | 1 |

The following conclusions were made from the interpretation of pump test results:

- LC12-02B and BH 10 are screened in different units with different hydrogeological characteristics:

    - LC12-02B is screened in a unit with a hydraulic conductivity of 24 to 34 m/day, a ratio of vertical to horizontal permeability between 0.1 and 0.2 and a Storativity of 0.016 to 0.0012.

    - BH10 is screened in a unit with a possible hydraulic conductivity of 67 to 68 m/day, a ratio of vertical to horizontal permeability of 1 and a Storativity of 0.12 to 0.13. As only minimum drawdown was observed, these results may not be reliable.

- The range of results for hydraulic conductivity as determined in earlier studies and reported by Worley Parsons (2010) are between 9 m/day and 68 m/day which is similar to those calculated from the pump test results.

The pump test results were considered when calibrating the groundwater and recharge models.

# 3 RECHARGE MODEL

A groundwater recharge model was developed to quantify the groundwater recharge characteristics for both existing and developed conditions. The predicted recharge profile is a key input into the groundwater models that SMEC has developed for the study. This section describes the modelling approach and presents the recharge model results for both existing and proposed conditions.

## 3.1 Model Overview

The project area is characterised by an undulating aeolian dune system, which comprises clean dune sands that have very high infiltration rates. The aeolian dune system, being shaped by the wind, has no natural surface drainage paths so all rainfall that falls within the project area will infiltrate into the upper soil layer (the unsaturated zone), which sits above the saturated groundwater table. Water stored in the unsaturated zone will either percolate into the underlying groundwater table (a process that is referred to as recharge) or be up taken by vegetation through evapotranspiration processes. These processes are influenced by the physical properties of the soil, which are described using the following terminology:

- **Soil Moisture Storage Capacity:** refers to the water holding capacity of the soil. At saturation, the water holding capacity is similar to the soil porosity.
- **Field Capacity:** Is the moisture content at which water will no longer drain from the soil profile under gravity. When the moisture content is above the field capacity, excess water will drain into the underlying saturated zone. This is referred to as a recharge event. Generally, the rate of recharge increases in line with increases to the soil moisture storage.
- **Wilting Point:** Plants access soil moisture below the field capacity through evapotranspiration processes. Wilting point is the moisture content at which plants can no longer draw water from the soil.

The physical soil properties discussed above are expressed as a function of the water depth per unit metre of the unsaturated zone (i.e. mm of storage per m of soil depth). Accordingly, the soil moisture storage capacity of the unsaturated zone is a function of the depth of the unsaturated zone, which is characterised by the vertical distance between the surface and the groundwater table. The depth of the unsaturated zone varies on a spatial scale in line with elevation changes in the site topography and on a temporal scale as a result of groundwater level fluctuations.

**Plate 3-1** describes these processes diagrammatically.

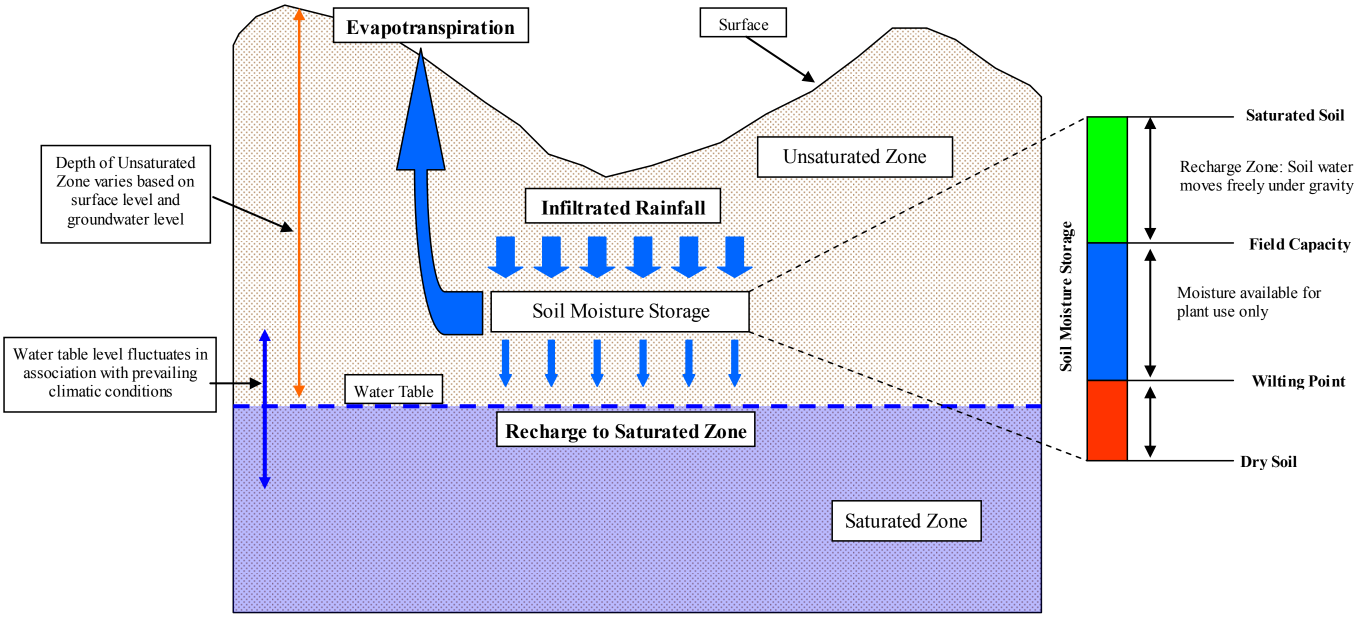


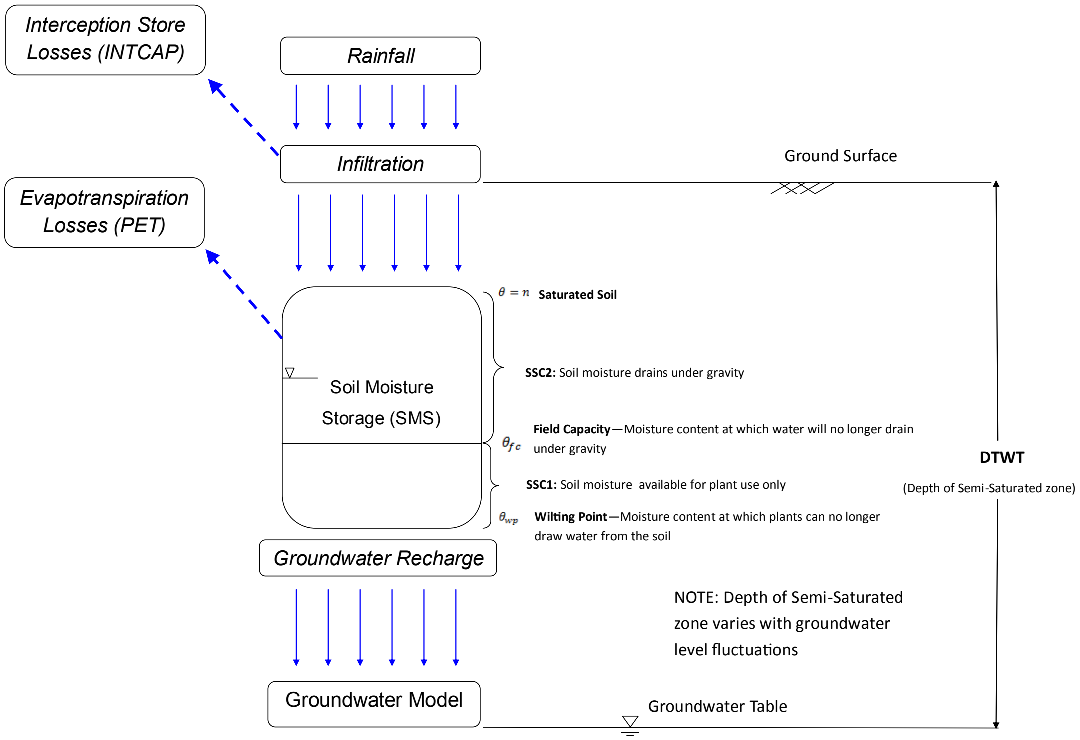
***Plate 3-1** – Recharge Process*

## 3.2 Model Description

SMEC has developed a conceptual recharge model to simulate the recharge response to rainfall events. The model framework and parameters are described in **Plate 3-2**. Key elements of the recharge model are described as follows:

- The model runs on a daily time-step and requires daily rainfall and evaporation rates as model inputs.
- The model runs as a continuous simulation for any given period of time. Soil moisture storage in the unsaturated zone is calculated at each model time-step based on the soil moisture storage from the previous model time-step, water addition due to rainfall and water lost to evapotranspiration and recharge.
- Recharge is calculated as a function of the estimated soil moisture storage (above field capacity) at each model time-step. Hence, recharge rates increase as the soil moisture storage increases.
- The depth of the unsaturated zone varies based on the surface level and the estimated depth to the water table at each model time-step. This is an important feature of the model as the depth of the unsaturated zone expands and contracts as the groundwater levels fluctuate. For example, the available storage in the unsaturated zone reduces as the water table rises, increasing the rate of recharge. Conversely, during dry periods the storage increases, resulting in a reduced rate of recharge.

## Structure of Groundwater Recharge Model



## Recharge Model Functions

*Infiltration = Rainfall — INTCAP*

*SMS1 = DTWT x SSC1*

*PET = Pan Evaporation x K2*

*SMS2= DTWT x SSC2*

*Recharge (if SMS2 >0) =* $(SMS-SMS1)^2 / (SMS1+SMS2) \times K1$

$\Delta SMS = Infiltration — PET — Recharge$

## Recharge Model Parameters

**Forcing Data**

**Rainfall (mm/day)** = Daily rainfall

**Pan Evaporation (mm/day)** = Daily Pan Evaporation

**MODEL Coefficients**

**Infiltration (mm/day) =** Daily infiltration into the semi-saturated zone

**PET = Evapotranspiration (mm/day)** = Daily Evapotranspiration from the semi-saturated zone

**DTWT = Depth to Water Table (m)** = The thickness of the semi-saturated zone

**SMS = Soil Moisture Storage (mm)** = Total Soil Moisture Storage at time (t)

**SMS1 (mm)** = Soil moisture storage capacity below field capacity at time (t)

**SMS2 (mm)** = Soil moisture storage capacity above field capacity at time (t)

**Recharge (mm/day)** = Daily recharge from the semi-saturated zone into the groundwater table

**MODEL Parameters**

**INTCAP = Interception Store Capacity (mm/day)** = Rainfall losses from interception by vegetation

**SSC1 = Soil Storage Capacity 1 (mm/m of semi-saturated zone)** = Soil moisture storage capacity between the wilting point and field capacity.

**SSC2 = Soil Storage Capacity 2 (mm/m of semi-saturated zone)** = Soil moisture storage capacity between the field capacity and saturation point.

**K1 (dimensionless)** = Adjusts recharge rates

**K2 (dimensionless)** = Adjusts Pan Evaporation to Potential Evapotranspiration

**Plate 3-2** – *Description of the recharge model*

## 3.3 Model Calibration

The recharge model was calibrated using water level and meteorological data recorded between 25 March 2010 and 9 March 2012. This section discusses the calibration approach, methodologies and results.

### *Calibration Approach*

The recharge model was calibrated using water level data recorded at two monitoring bores (MB01 and MB05) that are located within the project area (refer to **Plate 2-5** for bore locations). The following three step calibration methodology was applied:

- Recorded water level data was processed to estimate the daily recharge depths over the period for each monitoring bore. This required general cleaning of the data and adjustments for groundwater level recession due to evapotranspiration losses and the lateral flow of groundwater to either the Pacific Ocean or the Wallamba River. This process resulted in an interpreted recharge profile for each data set.
- Once recharge profiles were established, the recharge model parameters were calibrated using the NILFIT parameter optimisation software.
- Minor adjustments were made to the calibrated parameters to achieve the best overall fit between the predicted and interpreted cumulative recharge profiles over the period.

### *Available Data*

The recharge model was calibrated using the following data that was collected between 25 March 2010 and 9 March 2012:

- Groundwater level data recorded at MB01 and MB05 using continuous pressure meters.
- Daily rainfall data recorded at the following local rain gauges:
    - The BoM rain gauge at South Forster (BoM Gauge 060013), which is located 2.0km to the south-east of the southern boundary of the project area; and
    - A Mid Coast Water operated rain gauge at Halidays Point, which is located 6.0km to the north-east of the northern boundary of the project area.
- Daily pan evaporation recorded at the BoM metrological station in Taree (BoM Gauge 060141).

**Plate 3-3** plots available rainfall and evaporation data over the period. As there was no site specific rainfall data available, the assumed rainfall profile within the project area was interpolated from the Hallidays Point and South Forster rain gauge records using distance weighted interpolation methods. Interpolated daily and cumulative rainfall profiles are shown in **Plate 3-3**. The interpolated profile was adopted for calibration purposes.

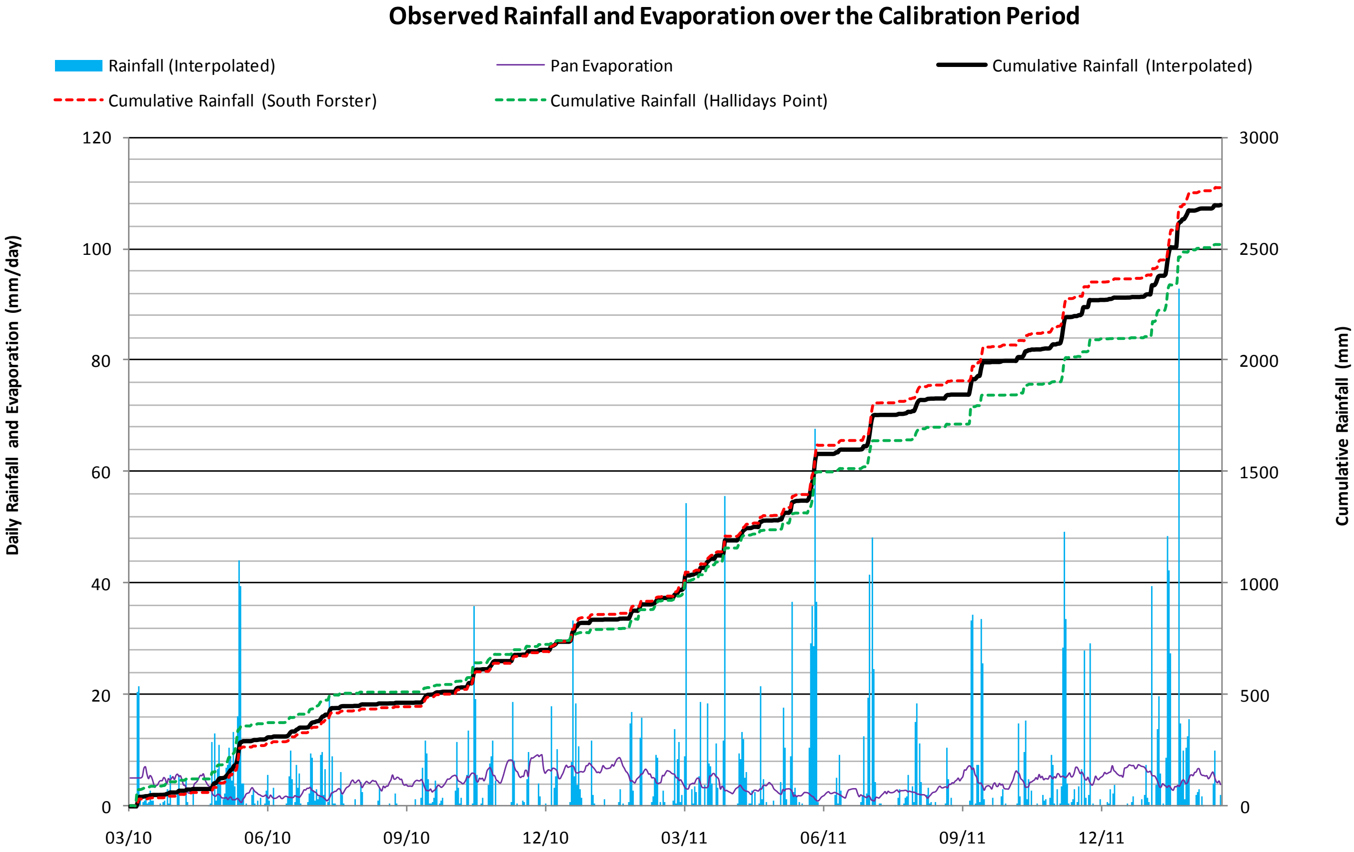


**Plate 3-3** – *Observed rainfall and evaporation over the calibration period*

The cumulative rainfall profiles presented in **Plate 3-3** demonstrate that:

- The South Forster rain gauge recorded approximately 2,750mm of rainfall over the period which was approximately 10% higher than the recorded total at Hallidays Point (2,500mm).
- Approximately 1,000mm was recorded during the initial 12 months of the period and 1750mm of rainfall was recorded in the last 12 months of the 2 year period. Hence, the second half of the period was significantly wetter than the first half.

**Plate 3-4** plots the observed groundwater level profiles at MB01 and MB05 over the period. Recorded spot levels at other monitoring bore locations are also plotted. Refer to **Plate 2-5** for monitoring bore locations.

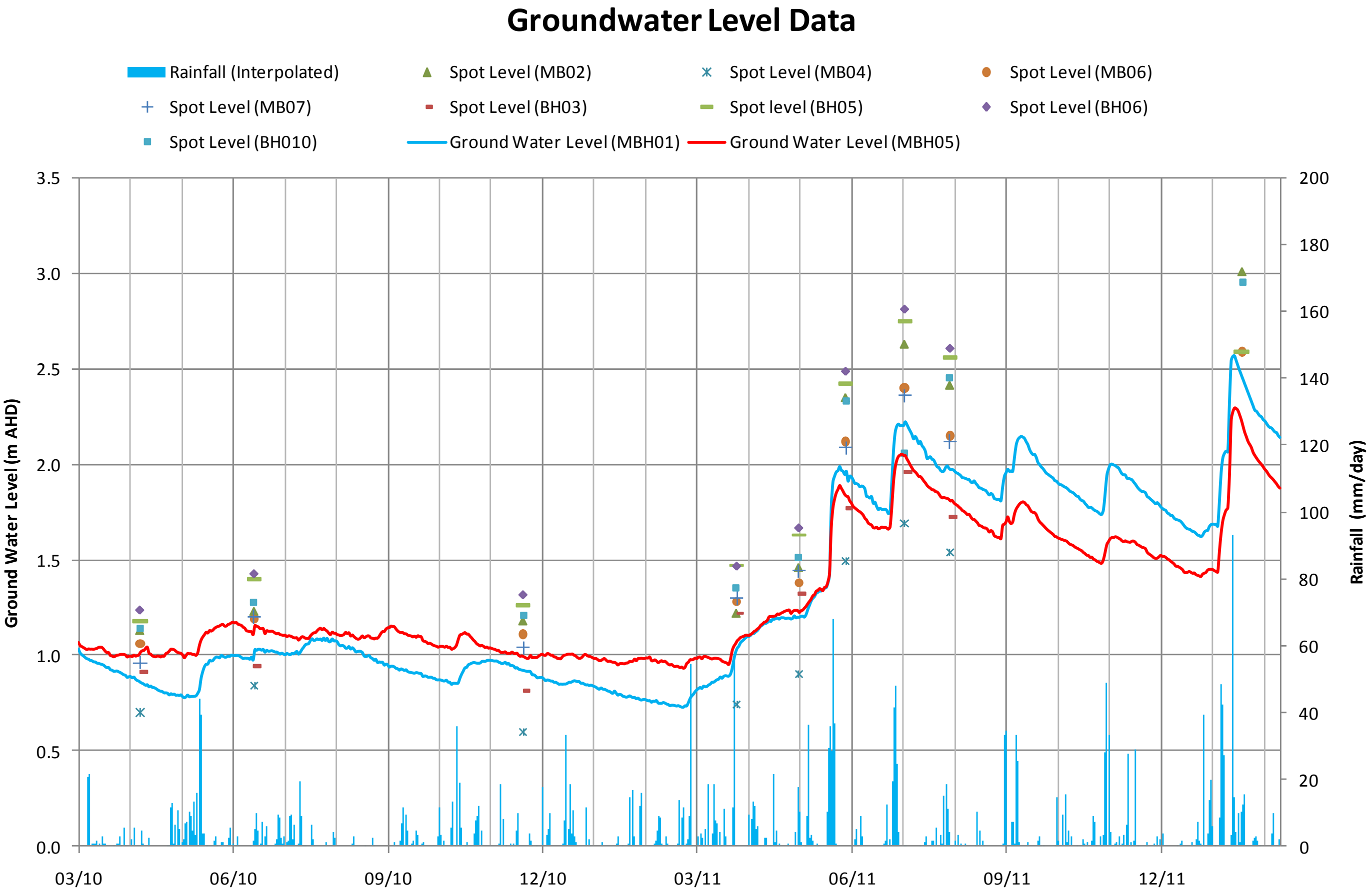


***Plate 3-4** – Observed groundwater levels over the calibration period*

The observed water level data plotted in **Plate 3-4** indicates that:

- There were only two minor recharge events during the first 12 months of the calibration period. As noted above, this period was characterised by below average rainfall with approximately 1,000mm of rainfall recorded.
- During the second half of the period, which was characterised by above average rainfall with 1,750mm recorded, five distinct recharge events occurred. This resulted in the groundwater level (at MB01) increasing from approximately 1m AHD in April 2011 to a peak of 2.6m AHD in February 2012.

## *Estimation of Recharge Profile*

In order to calibrate the recharge model, the recharge depth (i.e. equivalent amount of rainfall that percolates into the saturated zone) needs to be estimated from the recorded groundwater level data. This requires corrections to be made for groundwater recession and specific yield.

### Correction for Groundwater Recession

As indicated in **Plate 3-4**, during non-recharge periods the groundwater level generally recedes due to lateral groundwater flow and evapotranspiration losses. These processes continue during recharge events, when the groundwater level is rising as a result of recharge. Hence, in order to calculate the water level increase associated with a given recharge event, the observed increase in water level needs to be corrected to account for the groundwater recession that would have occurred during the recharge event. This is explained conceptually in **Plate 3-5**.

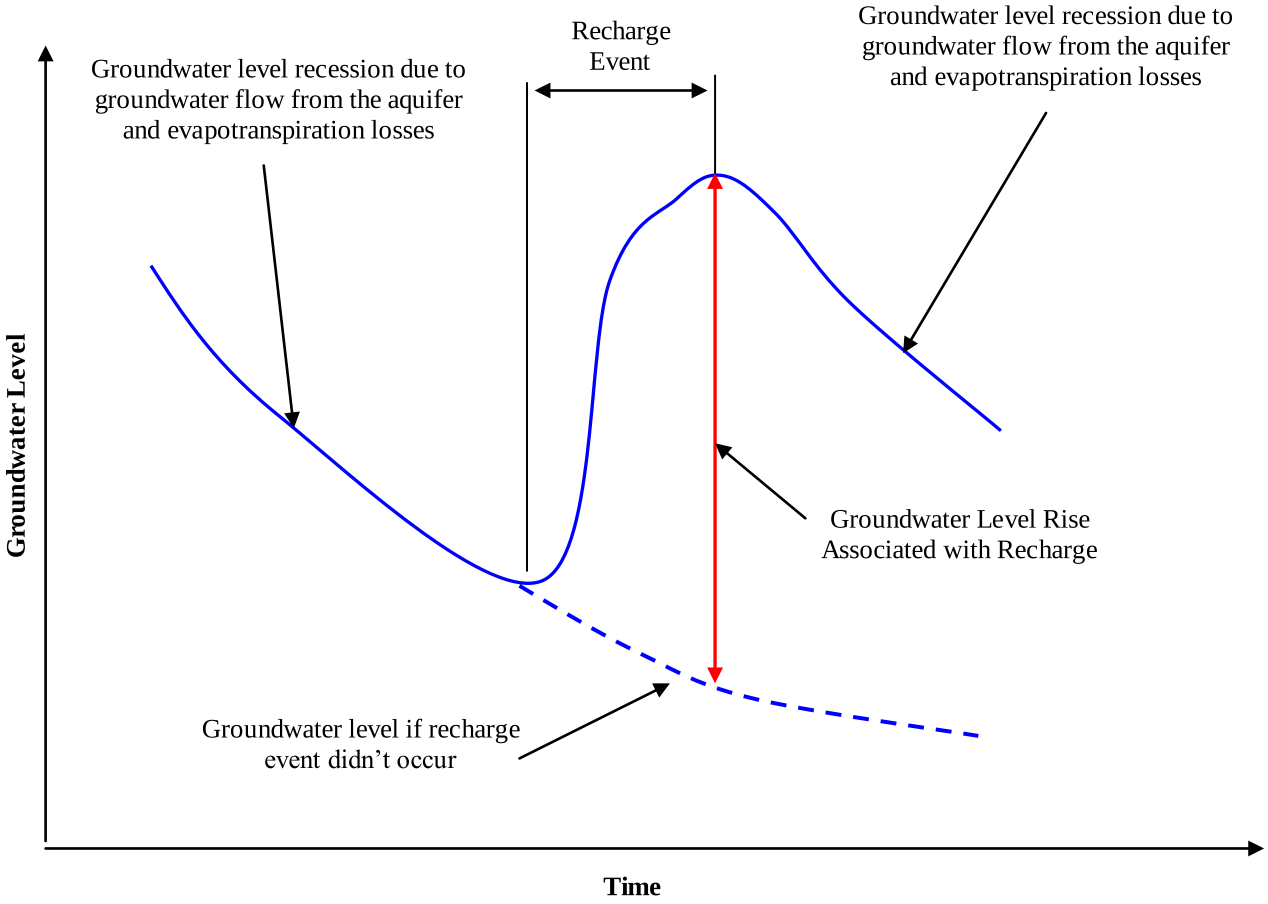


***Plate 3-5 –*** *Conceptual sketch demonstrating the methods applied to calculate the recharge profile*

The groundwater level recession profile for both MB01 and MB05 was established by calculating the average daily reduction in groundwater level calculated from each of the eight recession events observed during the calibration period (refer to **Plate 3-4**).   A linear trend line was established for each bore from this data. **Plate 3-6** presents the results from this analysis.

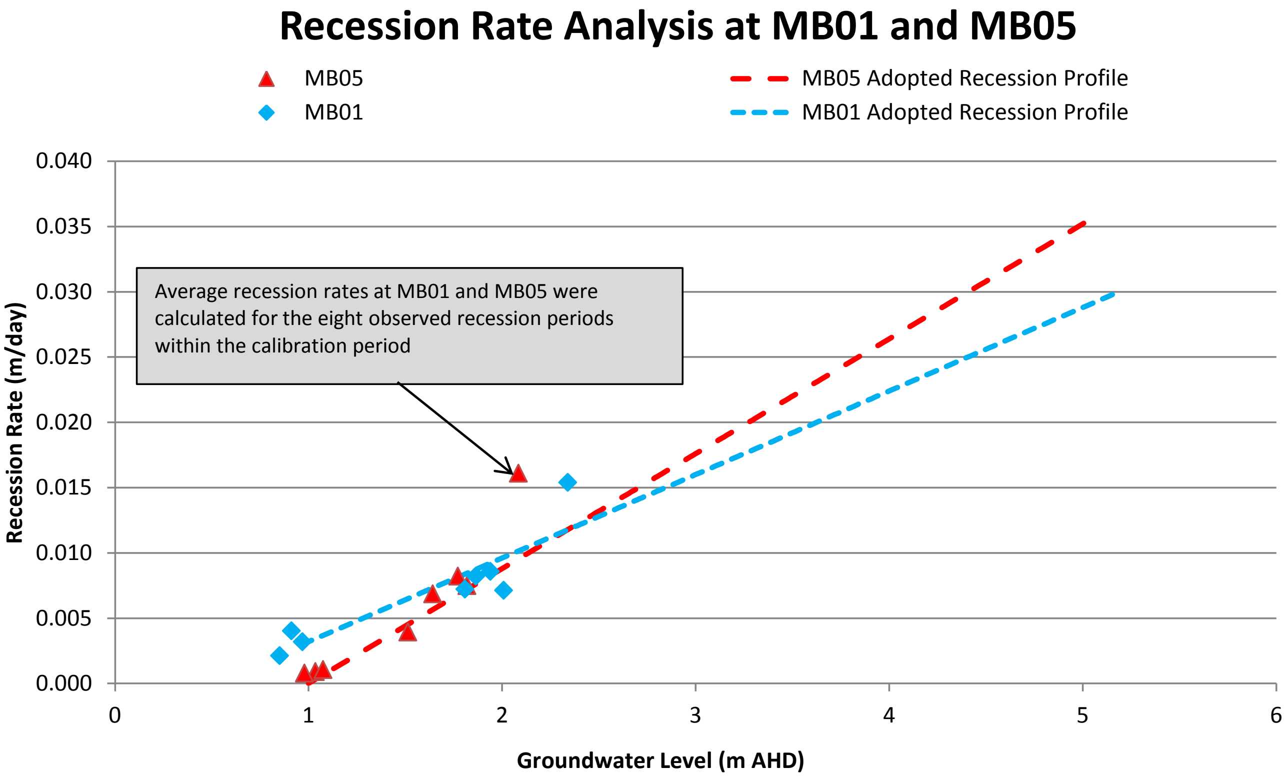


**Plate 3-6 –** *Calculated groundwater recession profiles for MB01 and MB05.*

Groundwater level rises associated with recharge were calculated by adding the assumed groundwater recession rate (calculated as a function of the groundwater level as established in ***Plate 3-6***) to the observed groundwater level increase.

### Correction for Specific Yield (Sy)

Specific Yield (Sy) describes the quantity of water, which a unit volume of aquifer will yield under gravity, after saturation. Sy is a key parameter when calculating the recharge depth for a given rise in groundwater level as it defines the storage efficiency of the aquifer. Hence, once the daily groundwater level rise associated with recharge is known, the recharge depth (i.e. similar to rainfall depth) can be calculated using the following equation:

$$Recharge\ Depth\ (mm/day) = \ Increase\ in\ Groundwater\ Level\ (mm/day)\ \times Sy$$

Sy cannot be easily measured in the field and as with most geotechnical characteristics, it is likely to vary spatially across the project area. However, for the purposes of this groundwater assessment, a constant Sy has been adopted as there is insufficient data to reliably identify spatial variations in Sy across the project area. Given that the site comprises homogeneous geology, this assumption is considered suitable. A Sy of 0.17 was selected for the site based on the following information:

- Typical Sy values for sandy soils range between 0.1 to 0.3.
- Analysis of pump test results indicated that the aquifer Storativity ranges between 0.12 to 0.18 for the portion of the aquifer located to the west of the golf course. Sy is similar to Storativity in unconfined aquifers.
- Parameter optimisation methods applied to the calibration of the recharge model achieved a best fit using a Sy of 0.17. This is discussed further in the following section.

- Applying a Sy of 0.17 to the calibration of the Detailed Groundwater Model achieved a good fit to observed data (refer to **Section 5** for details regarding the calibration of the Detailed Groundwater Model).

### Interpreted Recharge Profile

The interpreted recharge profile for both MB01 and MB05 was established by applying the methodologies discussed above. The results are presented in the following charts:

- **Plate 3-7** compares the interpreted cumulative recharge profile for MB01 and MB05 to the cumulative rainfall over the period.
- **Plate 3-8** plots the monthly rainfall and recharge depths and calculated monthly recharge coefficient for MB01.
- **Plate 3-9** plots the monthly rainfall and recharge depths and calculated recharge coefficient for MB05.

Note: the term recharge coefficient refers to the fraction of rainfall that converts to recharge over a given period.

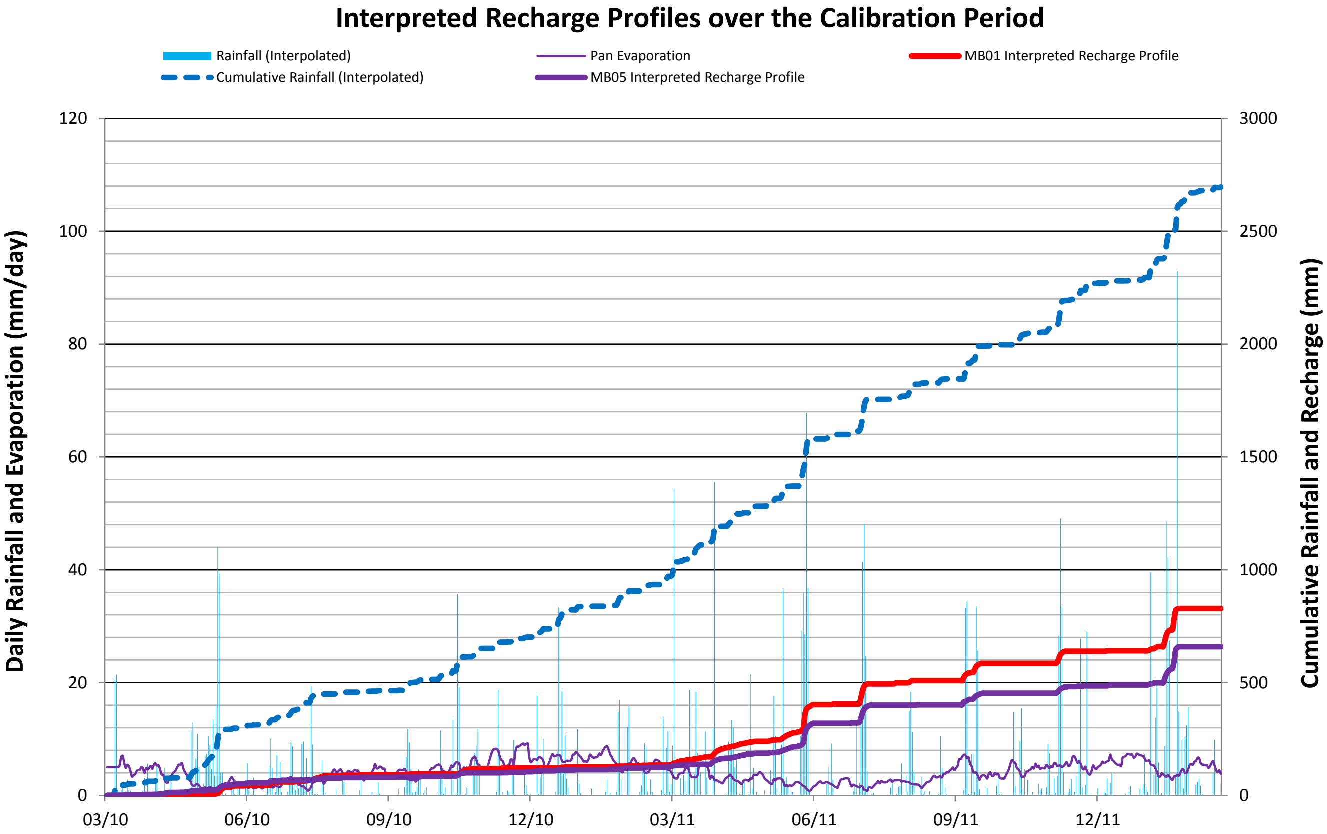


*Plate 3-7 – Interpreted cumulative recharge profiles over the calibration period*

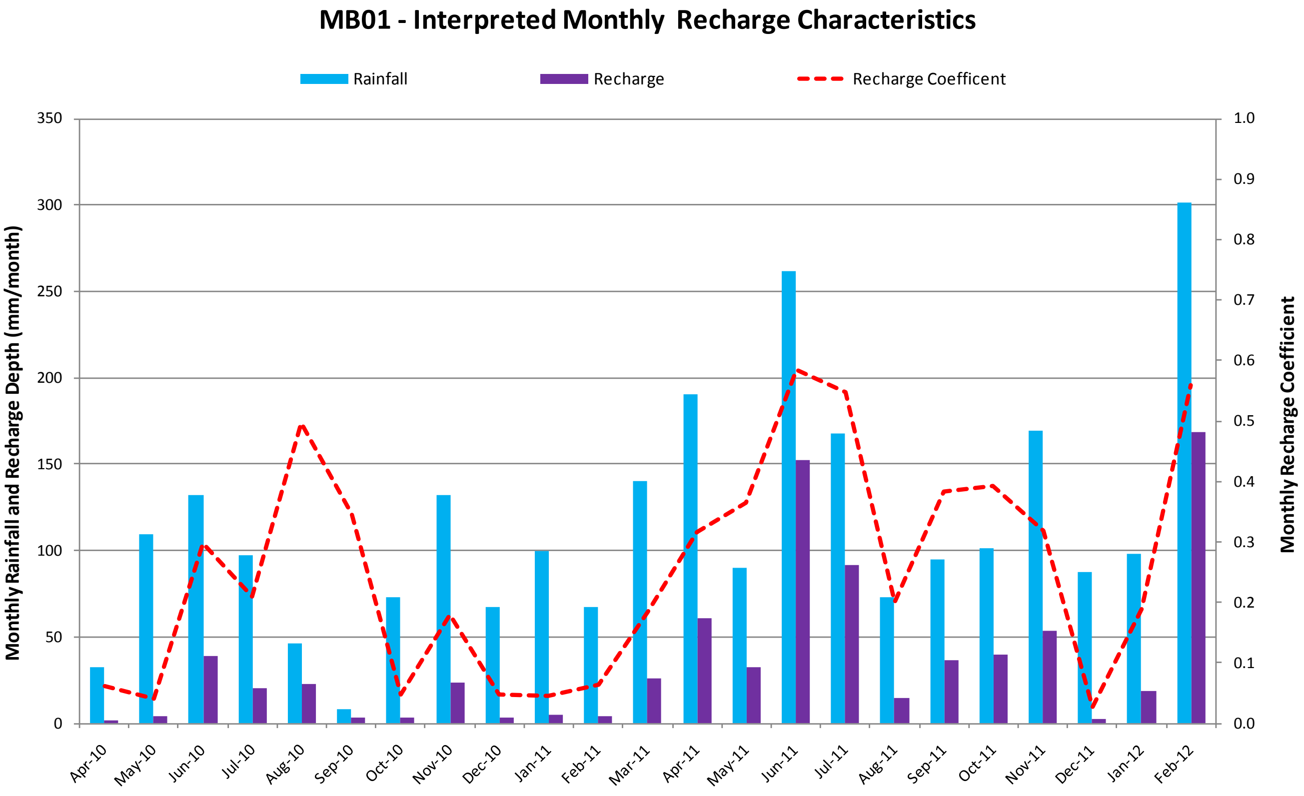


***Plate 3-8*** *– MB01 interpreted monthly recharge characteristics*

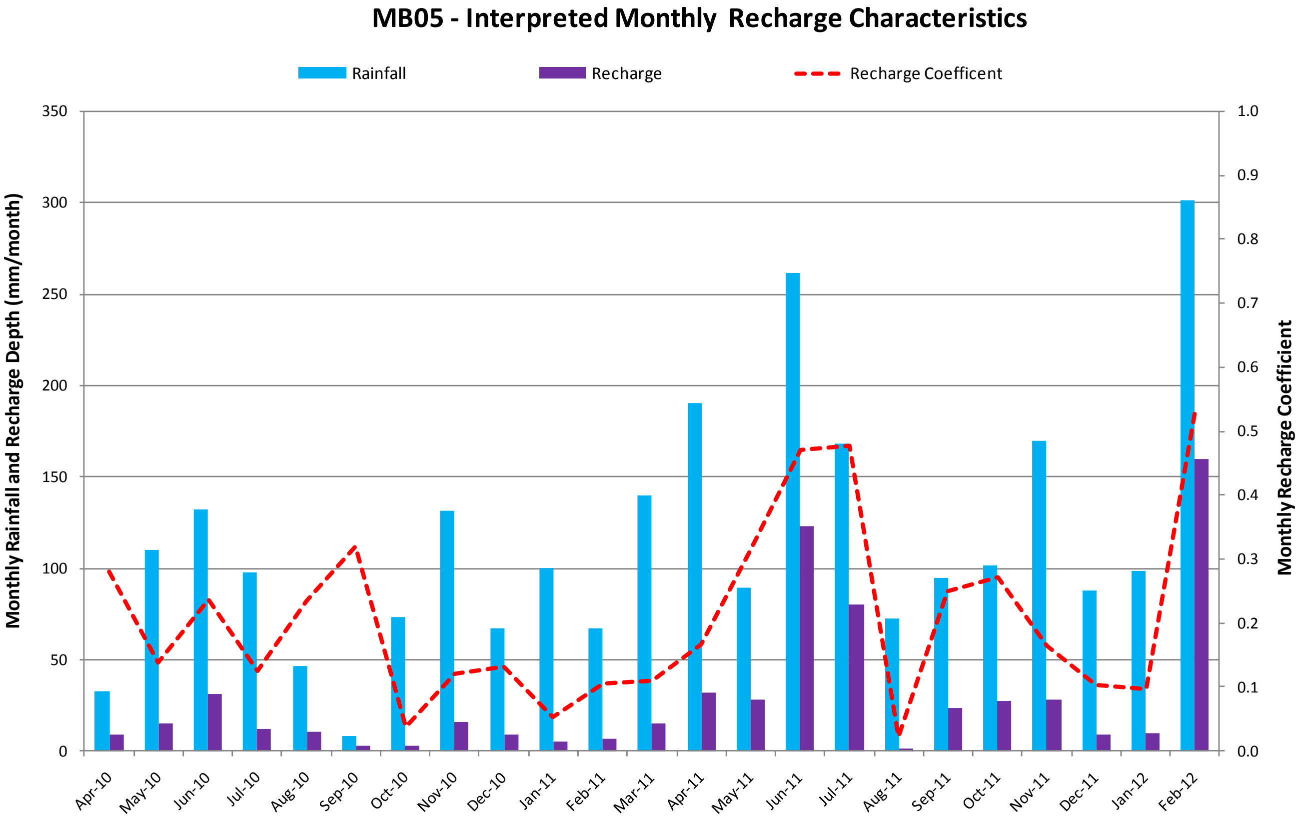


***Plate 3-9*** *– MB05 interpreted monthly recharge characteristics*

The following trends can be established from the interpreted recharge profiles:

- It is estimated that 828 mm of recharge occurred at MB01 from 2,750mm of rainfall, representing a recharge coefficient of 0.30 (i.e. recharge is 30% of rainfall) over the period.
- It is estimated that 659 mm of recharge occurred at MB05 from 2,750mm of rainfall, representing a recharge coefficient of 0.24 (i.e. recharge is 24% of rainfall) over the period.
- The monthly data presented in **Plate 3-8** and **Plate 3-9** demonstrates that the recharge response to rainfall varies significantly from month to month. The following broad trends are evident:
    - For dryer months (less than 100mm of rainfall recorded), the estimated recharge coefficient ranged between 0.05 to 0.20 (between 5 to 20% of rainfall).
    - For average rainfall months (between 100 and 200mm of rainfall recorded), the estimated recharge coefficient ranged between 0.10 to 0.40 (between 10 to 40% of rainfall), with higher recharge coefficients generally associated with months following wet periods.
    - More than 250mm of rainfall was recorded in June 2011 and February 2012. The estimated recharge coefficient was approximately 0.50 (50% of rainfall) at both MB01 and MB05 for both of these months.

In summary, the interpreted recharge profiles demonstrate that the recharge response to rainfall is dynamic and heavily influenced by antecedent soil moisture conditions and the intensity and duration of rainfall.

### *Recharge Model Calibration*

The recharge model described in **Plate 3-2** comprises 5 model parameters that can be adjusted to achieve a reliable fit between the predicted and interpreted recharge profiles at MB01 and MB05. The following methodology was applied to the calibration process:

- The recharge model was integrated into the NILFIT parameter optimisation software package. NILFIT searches for the optimum parameter values between user specified upper and lower bound values. As discussed above, Sy was included as a sixth model parameter as part of the parameter optimisation process. NILFIT was used to establish parameter values for all recharge model parameter values as well as Sy.
- Minor adjustments to INTCAP (interception loss) and K2 (Evapotranspiration factor) were made to achieve a good fit between the predicted and interpreted cumulative recharge profiles.

The calibration results are presented in the following charts and tables:

- **Table 3-1** lists the adopted parameter values and the Coefficient of Efficiency (E) achieved for the calibration of the recharge models to the interpreted recharge profiles at MB01 and MB05.
- **Plate 3-10** and **Plate 3-11** present cumulative and daily time series plots comparing the predicted recharge to the interpreted recharge profile at MB01.

- **Plate 3-12** and **Plate 3-13** present cumulative and daily time series plots comparing the predicted recharge to the interpreted recharge profile at MB05.

***Table 3-1** – Recharge model calibration parameters*

| Parameter | Parameter Description | Units | MB 01 | MB 05 |
|---|---|---|---|---|
| INTCAP | Interception Loss | (mm/day) | 4.5 | 4.5 |
| SSC1 | Soil moisture storage capacity between the wilting point and field capacity. | (mm/m of unsaturated zone) | 2 | 2 |
| SSC2 | Soil moisture storage capacity between the field capacity and saturation point | (mm/m of unsaturated zone) | 350 | 350 |
| K1 | Adjusts recharge rates | (unit less) | 2 | 0.64 |
| K2 | Adjusts evapotranspiration rates | (unit less) | 0.45 | 0.64 |
| Sy | Specific Yield of saturated zone | (unit less) | 0.17 | 0.17 |
| Achieved Coefficient of Efficiency | A measure of the reliability of the calibration fit | (unit less) | 73% | 66% |

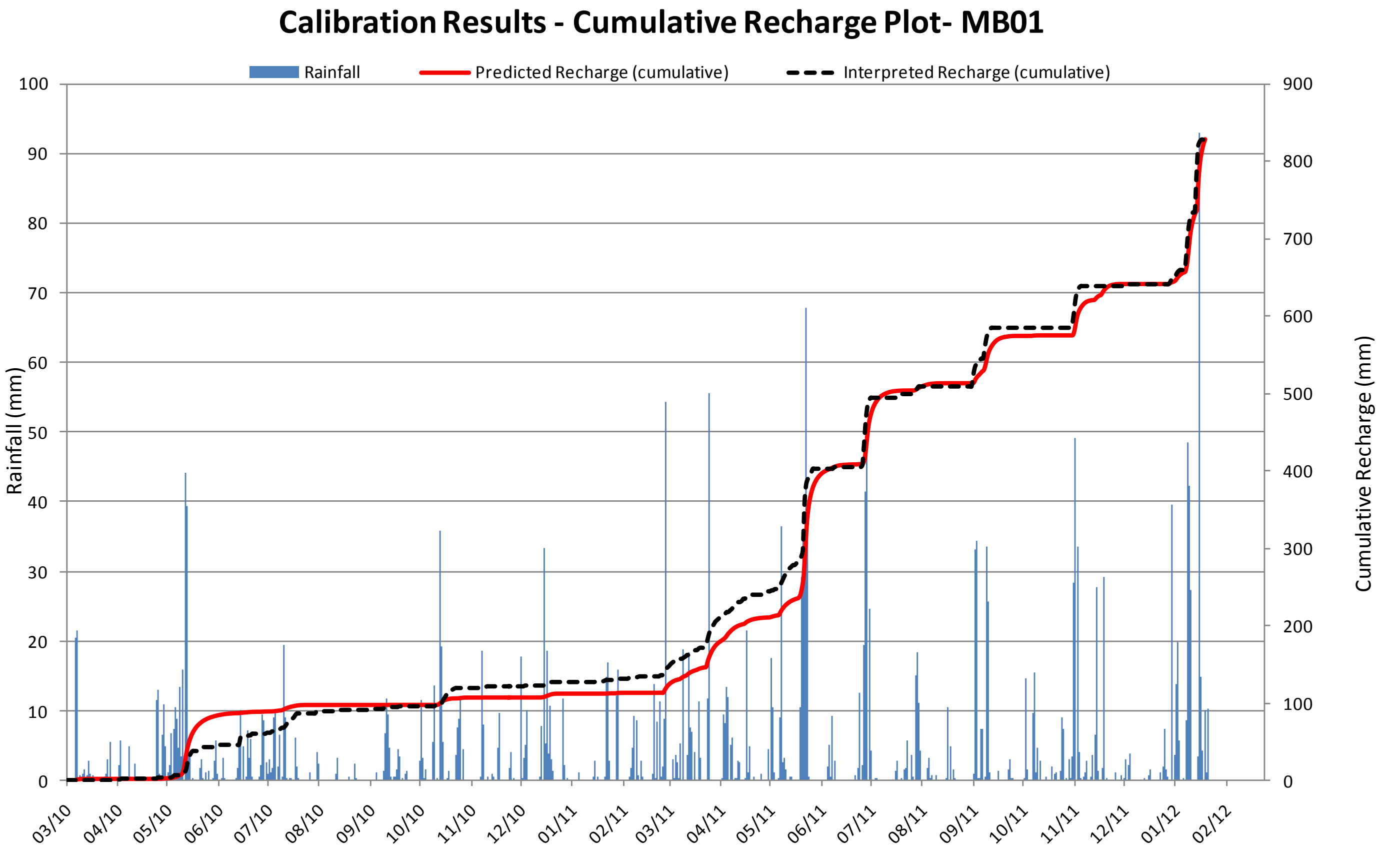


*Plate 3-10 – MB01 Calibration Results - Cumulative Plot*

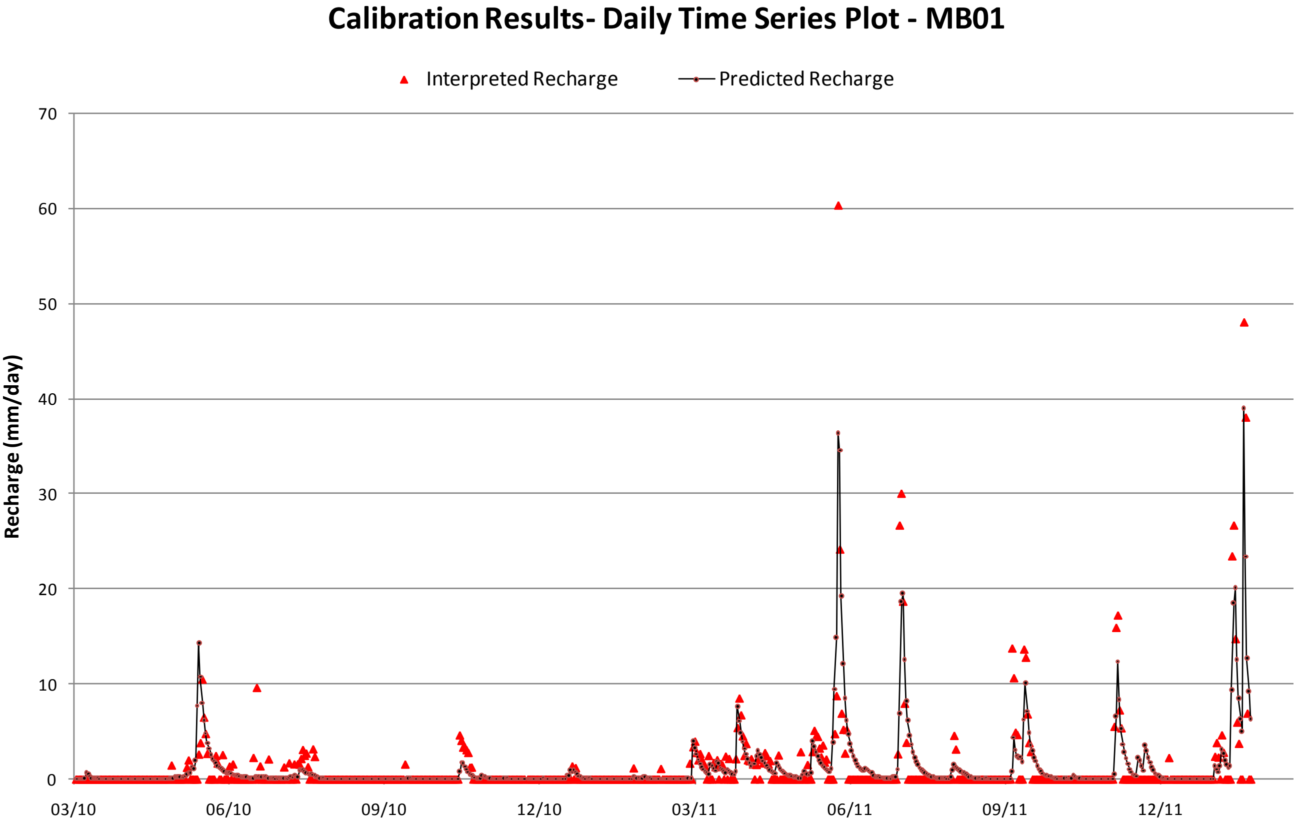


*Plate 3-11 – MB01 Calibration Results – Daily Time Series Plot*

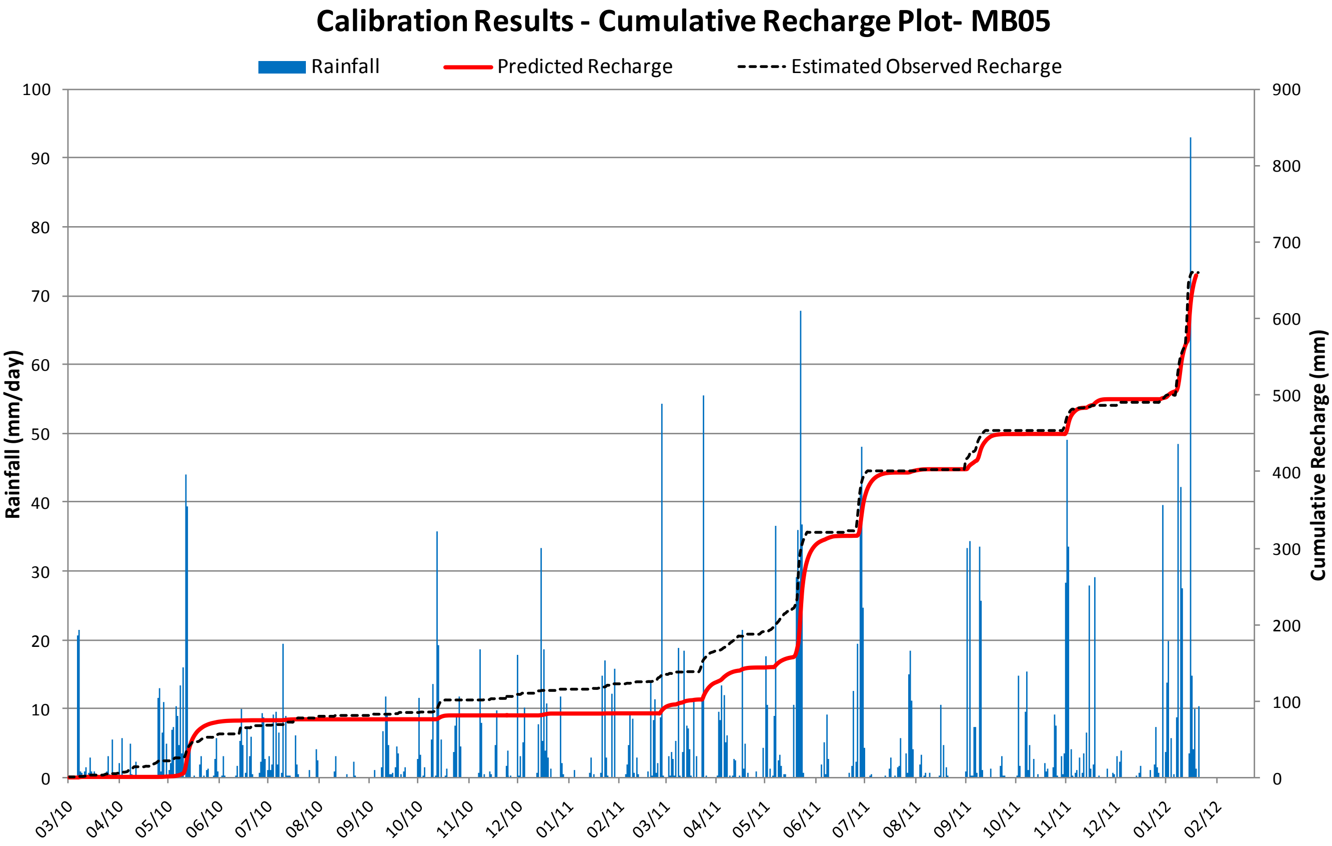


*Plate 3-12* – *MB05 Calibration Results - Cumulative Plot*

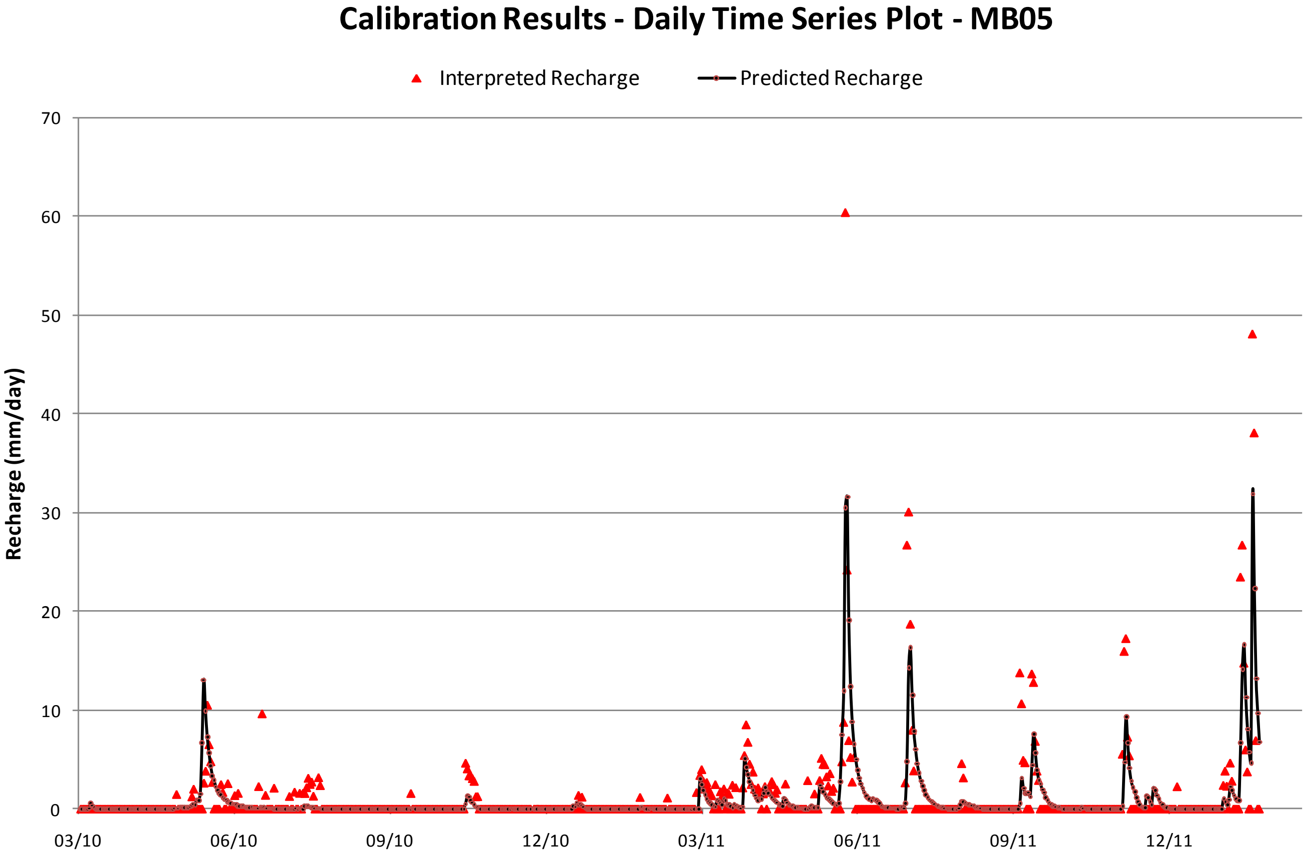


*Plate 3-13* – *MB05 Calibration Results – Daily Time Series Plot*

The following key trends can be established from comparison of the predicted and interpreted recharge profiles:

- The initial 12 months of the calibration period comprised below average rainfall conditions, with groundwater level data indicating that little recharge occurred, despite 1,000mm of rainfall recorded. The second half of the calibration period was significantly wetter (1,750mm of rainfall) with five distinct recharge events recorded. The recharge model achieved a good overall agreement to the observed data, with minimal recharge predicted during the initial 12 months and the five recharge events captured in the second half of the period. This indicates that the model framework and parameterisation is broadly effective in replicating the recharge dynamics observed during the calibration period.

- The cumulative predicted recharge depth was similar to the interpreted recharge depth at both MB01 and MB05 over the 24 month calibration period. In addition, similar recharge depths were also achieved for the five recharge events that occurred in the second half of the calibration period, indicating that the model reliably estimates total recharge over a given event.

- Comparison of predicted and interpreted recharge depths on a daily time scale indicates that the predicted recharge depths are generally below the interpreted depths on high rainfall days and higher on days following a rainfall event. This indicates that the modelled recharge profiles are moderately attenuated when compared to the interpreted profiles (this is evident in both the cumulative and daily time series plots). However, as discussed above, predicted recharge depths over the total event were similar to the interpolated depths, indicating that the model reliably estimates total recharge over a given event.

- A Nash-Sutcliffe Coefficient of Efficiency (E) of 73% and 66% was achieved for MB01 and MB05 respectively, indicating a good overall fit was achieved.

In conclusion, model calibration results demonstrate that the conceptual recharge model is a reliable tool for estimating the recharge response to rainfall within the project area, under a range of climatic conditions.

It is noted that the best calibration fit was achieved by setting the soil moisture storage capacity between the wilting point and field capacity (SSC 1) to 2mm/m. This is well below a typical field capacity value used for sandy soils (100 to 150mm/m) in hydrologic models that simulate surface runoff. The low SSC 1 value is the result of applying the soil storage model to the entire depth of the unsaturated zone, which can vary between 0 to 4m in thickness depending on the groundwater level at the model time step. It is expected that if a more sophisticated “multi bucket” recharge model was developed, the soil moisture model for the upper (500mm) soil zone could be parameterised with a SSC 1 value that is similar to typical field capacity value. However, as the model calibration results achieved a good overall fit to the observed data, a more sophisticated “multi bucket” model, with significantly more model parameters, was not considered necessary.

## 3.4 Application of Recharge Model to Groundwater Modelling

In order to simplify the modelling process, the calibration parameters for MB01 were adopted for the modelling of recharge for use in groundwater model simulations. From a flooding perspective, this is considered conservative as the MB01 parameters yielded a higher recharge coefficient than the MB05 parameters. The recharge model was incorporated into the groundwater models developed for the project through the following means:

- **Empirical Groundwater Model**: The recharge model was integrated into the Empirical Groundwater Model, which applies a continuous simulation approach to estimate typical groundwater levels within the project area over an extended period of time. As the Empirical Groundwater Model calculates groundwater level, the depth of the semi-saturated zone (a key variable in the recharge model) is calculated for each time step. Refer to **Section 4** for further information on the Empirical Groundwater Model.

- **Detailed Groundwater Model**: The Empirical Groundwater Model was used to calculate recharge profiles for use in the Detailed Groundwater Model. As the depth of the semi-saturated zone varies spatially (due to topography), separate recharge zones for the higher and lower portions of the Detailed Groundwater Model domain were established. Recharge for each zone was calculated by varying the assumed surface level in the Empirical Groundwater Model. Refer to **Section 5** for further information on the Detailed Groundwater Model.

## 3.5 Developed Conditions Recharge Characteristics

Establishment of an urban landscape within the development area is expected to alter the existing site recharge characteristics through the following means:

- It is expected that approximately 41% of the 255ha development area will comprise impervious surfaces such as roofs and road and drive pavements. The introduction of impervious surfaces such as roads and roofs will eliminate recharge from within the impervious area footprint. The stormwater strategy detailed in the IWCMS (SMEC, 2014) proposes to directly connect runoff (following treatment) from more than half of the impervious surfaces into the proposed open basins. As the open basins will be hydraulically connected to the local groundwater, runoff from impervious areas is expected to increase the volume of water entering the groundwater system. The stormwater strategy also includes some infiltration only areas, where runoff from all impervious surfaces will be directed into infiltration systems. As flow to these infiltration systems will be concentrated (i.e. each infiltration unit will receive runoff from a small impervious catchment such as a roof or road area), the majority of runoff is expected to recharge directly into the groundwater.

- It is expected that approximately 29% of the 255ha development area will comprise lawn or golf green and fairway areas. The establishment of lawns will require the laying of approximately 200mm of top soil (such as a sandy loam) that has a higher water holding capacity than the sandy soils that exists onsite. The introduction of top soil is expected to reduce the frequency of infiltration into the underlying sandy soils that will continue to form the unsaturated zone of the aquifer under developed conditions. This reduction in infiltration frequency may reduce recharge volumes. However, the removal of the existing deep rooted native vegetation will reduce evapotranspiration losses from the unsaturated zone. This is likely to offset the abovementioned impact of topsoil. Hence, recharge characteristics from lawn areas that are established within the development area are not expected to change significantly from existing conditions.

- It is expected that 30% of the 255ha development area will be retained or established native vegetation. Recharge characteristics from these areas are expected to be similar to existing conditions.

- It is expected that increased irrigation under developed conditions will not materially alter recharge characteristics as application rates are expected to be broadly in line with potential evapotranspiration rates. Hence, the majority of irrigated water is expected to be lost to evapotranspiration.

Refer to **Appendix B** in the IWCMS (SMEC, 2014) for a detailed breakdown of the proposed land uses within the development area.

## *Developed Conditions Modelling Assumptions*

- **Impervious Areas**: As discussed above, the introduction of impervious surfaces is expected to increase the volumes of water entering the groundwater. Accordingly, recharge from impervious surfaces is calculated using the following equation:

  *ImpRecharge (t) = Rainfall (t) – Daily Loss*

  *Where:*

  *ImpRecharge (t) = Daily recharge depth from impervious surface (mm/day)*

  *Rainfall (t) = Daily rainfall depth (mm/day)*

  *Daily Loss = Daily loss rate accounting for evaporation losses (mm/day)*

  A daily loss of 5mm/day was adopted to account for evaporation losses from the impervious surfaces and within the stormwater management and infiltration systems. This modelling approach was applied to all impervious surfaces.

- **Rainwater Tanks**: 5KL rainwater tanks are proposed for all dwellings. Runoff from roof areas was adjusted to account for water harvesting from rainwater tanks. This is discussed further in **Section 5**.

- **Pervious Areas**: As discussed above, pervious surfaces such as lawn and landscaped areas are expected to have similar recharge characteristics to the existing vegetated areas of the site. Hence, the existing conditions recharge model has been applied to the pervious areas of the development.

- **Water Management Basins**: It is assumed that all direct rainfall to the open basins will accumulate in the basins with no loss. Evapotranspiration losses from the basins are modelled separately.

**Section 8** provides information on the expected changes to the groundwater regime resulting from the development. This information includes analysis of site recharge characteristics for both existing and developed conditions.

# 4 EMPIRICAL GROUNDWATER MODEL

The Empirical Groundwater Model is a groundwater modelling tool that was developed specifically for this project. The model is capable of applying continuous simulation methods to estimate representative groundwater levels within the development area using a long-term rainfall record as a means of model forcing. The model was used to:

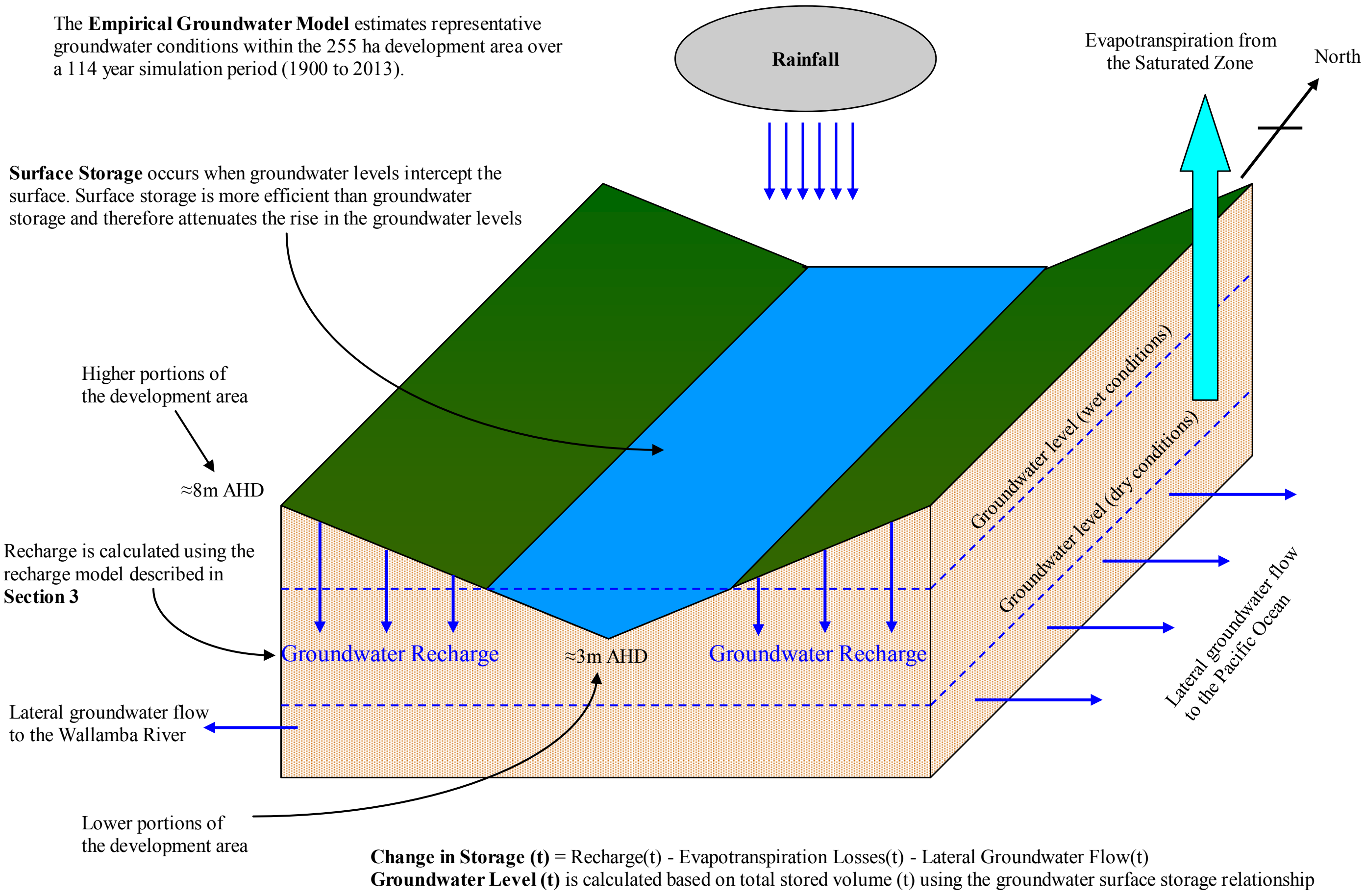
- Estimate groundwater dynamics under a full range of climatic conditions for both existing and developed conditions.
- Identify an historic rainfall event that is likely to have generated the highest groundwater levels within the development area. This identified event was subject to further assessment using the Detailed Groundwater Model described in **Section 5**.
- Assess the suitability of a wide range of development scenarios and groundwater management methods.

This section describes the modelling approach, model development and calibration. Model results are presented in **Sections 7** and **8**.

## 4.1 Model Description and Key Assumptions

The Empirical Groundwater Model was established to estimate representative groundwater conditions within the development area over a 114 year simulation period (1900 to May 2013). The model conceptualises the groundwater dynamics by applying a three dimensional “box” around the 255ha development area. It is noted that the model does not consider the 6.6ha of employment lands that are detached from the main development area. For each model time step, the change in water volume stored within the “box” is calculated based on inflows (due to recharge) and outflows (due to evapotranspiration and groundwater flows). A representative groundwater level is calculated based on the calculated volume of storage in the “box” and the groundwater / surface storage characteristics for the given groundwater level.

**Plate 4-1** diagrammatically illustrates the Empirical Groundwater Model framework. Key model features are also discussed below.



The **Empirical Groundwater Model** estimates representative groundwater conditions within the 255 ha development area over a 114 year simulation period (1900 to 2013).

**Surface Storage** occurs when groundwater levels intercept the surface. Surface storage is more efficient than groundwater storage and therefore attenuates the rise in the groundwater levels

Recharge is calculated using the recharge model described in **Section 3**

**Change in Storage (t)** = Recharge(t) - Evapotranspiration Losses(t) - Lateral Groundwater Flow(t)
**Groundwater Level (t)** is calculated based on total stored volume (t) using the groundwater surface storage relationship

***Plate 4-1 –*** *Empirical Groundwater Model Framework*.

The following sections describe the key characteristics of the Empirical Groundwater Model.

## *Climatic Data*

The model runs on a daily time step, applying the 114 year (1900 to May 2013) daily rainfall record from the BoM rainfall gauge at South Forster (Station 60013). Daily evaporation rates were applied based on recorded data from Taree (Station 60141) for the simulation period between 1999 and 2013. Average monthly evaporation rates were applied for the simulation period pre 1999 as no recorded data was available.

## *Model Inflows*

Recharge is the only source of inflow into the model. Recharge depths were calculated on a daily time step using the recharge model described in **Section 3**. The groundwater level from the previous time-step was applied to calculate the depth of the semi-saturated zone, one of the key parameters of the recharge model. The calculated recharge depths were adjusted for surface area to calculate the recharge volume within the 255ha model domain.

## *Model Outflows*

Model outflows occur though the following means:

- Lateral groundwater flows; and

- Evapotranspiration losses from the saturated zone.

These outflows are described in more detail below.

### Lateral Groundwater Flow

Groundwater flows laterally from the development area primarily into the Pacific Ocean (to the east) and the Wallamba River (to the west). Lateral groundwater flow rates depend on a range of factors including aquifer properties (such as hydraulic conductivity and Specific Yield) and the available head. A detailed assessment of these factors is beyond the capability of the Empirical Groundwater Model. Accordingly, an empirical relationship was established to estimate lateral groundwater flow rates as a function of the groundwater level within the development area. This relationship was established based on:

- Review of output from the Detailed Groundwater Model (refer to **Section 5** for details); and
- Adjustments to achieve a good agreement with the observed water level data at MB01 and MB05 over the 2010 – 2012 calibration period.

**Plate 4-2** presents the adopted groundwater level / flow rate profile that was applied to the Empirical Groundwater Model to represent the combined lateral groundwater flows to both the Pacific Ocean and the Wallamba River.

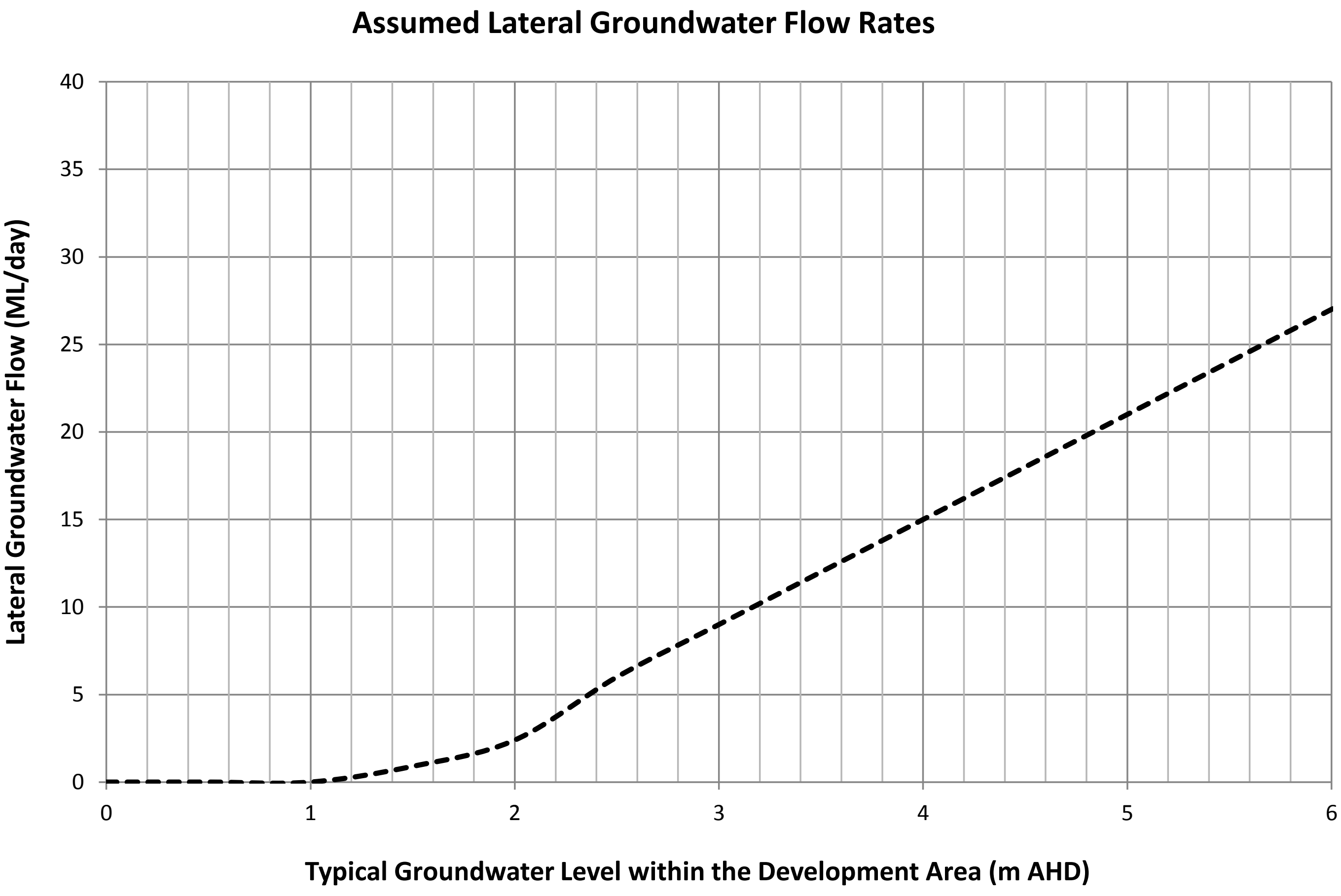


***Plate 4-2** – Assumed lateral groundwater flow rates*

### Evapotranspiration Losses from the Saturated Zone

In most portions of the development area, the existing vegetation is expected to access water from the saturated zone, resulting in evapotranspiration losses from the aquifer. Evapotranspiration loss rates were calculated as a function of the prevailing evaporation rate using the following formula:

*ETLoss(t) = Evap(t) x K*

Where

*ETLoss(t) = Daily evapotranspiration loss rate from the saturated zone (mm/day)*

*Evap(t) = Prevailing pan evaporation rate (mm/day)*

*K = Evapotranspiration adjustment factor*

Evapotranspiration losses would only occur in portions of the development area were the root systems can access the groundwater table. Root system access is dependent on both the surface levels and the prevailing groundwater level. Accordingly, a cut-off depth was applied to calculate the effective evapotranspiration area for each model time step. This results in the calculated evapotranspiration losses increasing in line with increases in groundwater levels.

Calibration to observed water level data at MB01 and MB05 indicated that a K value of 0.28 and a cut-off depth of 3.6m achieved good agreement with the observed data.

## *Calculation of Storage and Water Level*

As noted in **Plate 4-1**, the Empirical Groundwater Model calculates the total water storage within the “box” on a daily time step. The change in storage for each time step is based on inflows due to recharge and outflows due to lateral groundwater flow and evapotranspiration losses. The total storage volume was used to calculate a typical groundwater level within the development area by applying the storage / level curves that were independently calculated for groundwater and surface storage, using the following methods:

- **Groundwater Storage**: Groundwater storage volumes were calculated as a function of the volume of the subsurface media (calculated from LiDAR survey) and the specific yield (Sy) of the aquifer. A Sy value of 0.17 was adopted for all groundwater storage calculations.

- **Surface Storage**: Surface storage volumes were calculated using LiDAR survey data. Refer to **Section 2** for details on the LiDAR survey.

**Plate 4-3** shows the calculated groundwater and surface storage curves for the 255ha development area. Note: 0m AHD was used as a datum for all storage calculations.

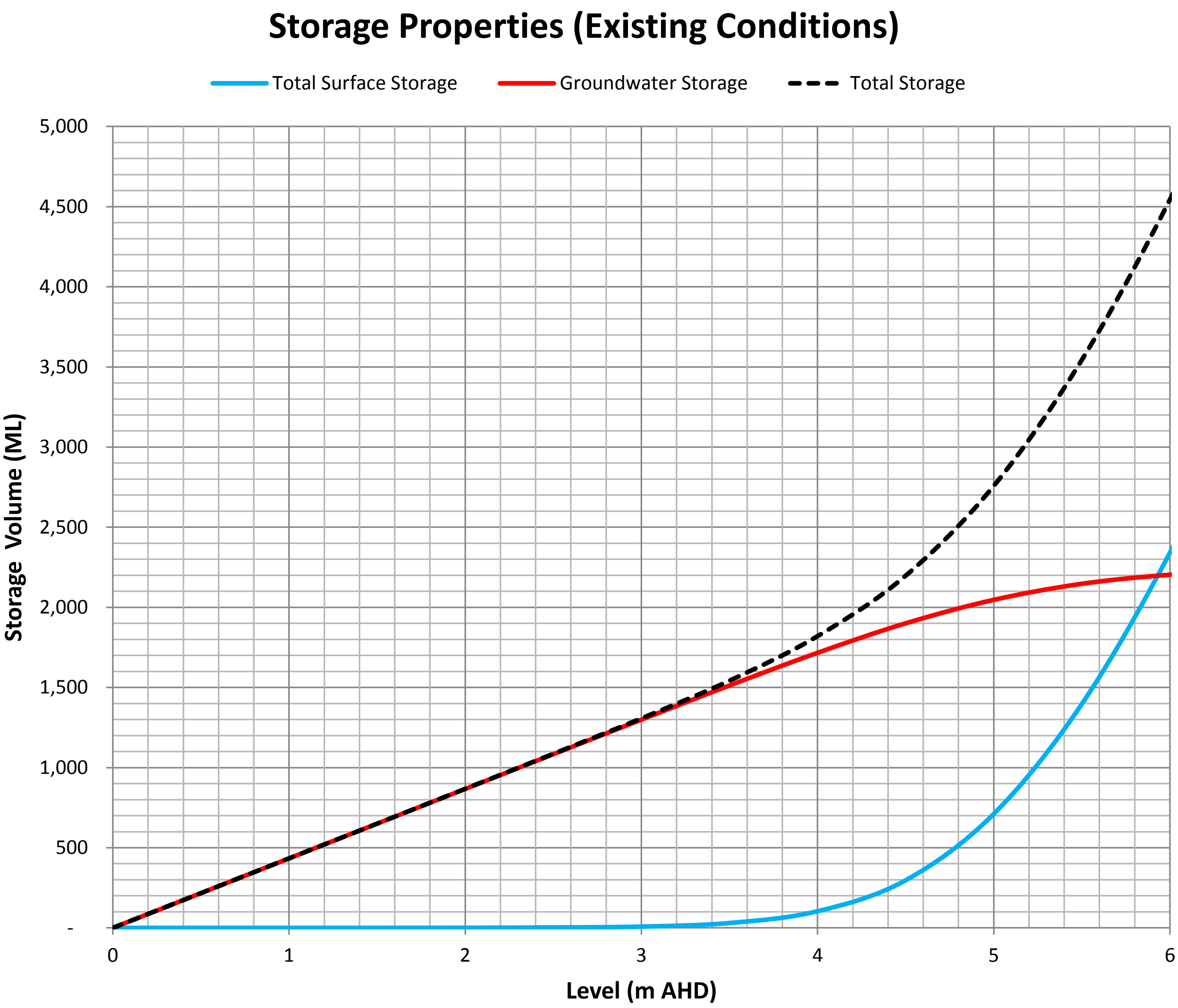


***Plate 4-3*** *– Groundwater and surface storage properties for the 255ha development area.*

The groundwater and surface storage curves presented in **Plate 4-3** demonstrate that:

- When groundwater levels are below 4m AHD, water is stored predominately as groundwater storage (as expected). The storage efficiency (defined as the total volume of storage within the 255ha development area per vertical metre) is estimated to be 450ML per vertical metre.

- When groundwater levels exceed 4m AHD, water begins to accumulate as surface storage within the lower portions of the development area. This results in a significant increase in the storage efficiency, with the storage efficiency between 4m AHD and 5m AHD estimated to be 1,000ML per vertical metre. This increase in storage efficiency significantly attenuates the rise in groundwater level, as more volume is required for a given level increase.

## 4.2 Model Calibration and Verification

As discussed above, the Empirical Groundwater Model, which incorporates the recharge model, was calibrated using water level data collected from March 2010 to March 2012. The model was verified using 14 months of groundwater level data collected from March 2012 to May 2013.

Recorded groundwater level data over both the calibration and verification periods is presented in **Section 2**.

## *Review of Calibration Period*

The Empirical Groundwater Model was calibrated using water level and meteorological data recorded between 25 March 2010 and 9 March 2012. This is the same period applied to the calibration of the recharge model. Refer to **Section 3.3** for a review of the model calibration period.

## *Review of Model Verification Period*

As discussed in **Section 2**, a significant recharge event was recorded from 27 January to 3 March 2013. During this 36 day period, three significant rainfall events occurred, which resulted in groundwater within the development area rising from around 1m AHD to between 3.0 to 3.5m AHD. **Photo 5** was taken by UrbanGrowth NSW in early March 2013, which shows groundwater intercepting the surface in a low portion of the development area. The groundwater flooding was validated by detailed survey on 11 March 2013 with surveyed surface ponding levels ranging between 2.64 to 3.28m AHD. The greenkeeper at the golf course advised SMEC staff that surface ponding remained in some areas of the golf course for up to 8 weeks and that he had never seen flooding of this magnitude in over 20 years of working at the golf course. Flood frequency analysis (discussed in **Section 7**) indicates that this event had a 10 year ARI.

***Photo 5** - A photograph taken in early March 2013 showing groundwater intercepting the surface.*

As mentioned above, three significant rainfall events were recorded during the abovementioned 36 day recharge period. Rainfall data for these events was sourced from both the BoM operated gauge at South Forster (60013) and the Great Lakes Fire Control Centre, located on South Street in Tuncurry. **Table 4-1** compares the recorded rainfall at each gauge for the three rainfall events. The observed groundwater level rise at MB01 for each event is also provided for reference.

***Table 4-1***- *Comparison of Rainfall Data*

| Rainfall Event | Observed Groundwater Level Rise (MB01) | Recorded Rainfall (BoM, South Forster) | Recorded Rainfall (South Street, Tuncurry) |
|---|---|---|---|
| **Event 1**<br>(27 to 29 January 2013) | 0.50m | 309mm | 212mm |
| **Event 2**<br>(23 to 24 February 2013) | 0.25m | 126mm | 104mm |
| **Event 3**<br>(1 to 3 March 2013) | 1.40m | 188mm | 263mm |
| **Total**[1]<br>(27 January to 3 March 2013) | 2.15m | 694mm | 649mm |

**Note 1**: rainfall totals include some rainfall that occurred outside of the 3 main events.

The data presented in **Table 4-1** shows that the recorded rainfall at South Street Tuncurry was significantly lower than the recorded rainfall at the South Forster BoM gauge for Event 1, similar for Event 2 and significantly higher for Event 3. While neither gauge is located within the development area, the discrepancy between recorded rainfall depths demonstrates that significant spatial variation in rainfall intensity occurred in the Tuncurry area during Event 1 and Event 3. This variation is not uncommon for significant rainfall events. The implication of the variation in rainfall depths on the groundwater / recharge model results is discussed further below.

## *Model Calibration and Verification Results*

Model results for the calibration and verification periods are presented in the following plates:

- **Plate 4-4** compares the water level predicted by the Empirical Groundwater Model to observed groundwater level data recorded for the March 2010 to May 2013 period.
- **Plate 4-5** is a similar chart that shows results for the January 2013 to May 2013 period, clearly showing the models response to the recent significant recharge event.

As mentioned above, comparison of rainfall data from the BoM gauge at South Forster to data from the South Street Tuncurry gauge indicates that significant spatial variation in rainfall occurred in the Tuncurry area during the significant recharge event that occurred in 2013. Hence, the Empirical Groundwater Model was simulated using both the BoM data only (green dashed line) and the combined BoM and South Street data (black dashed line). It is noted that South Street rainfall was only available between 1 January 2013 and 1 May 2013. BoM data was used for all simulations outside of this period.

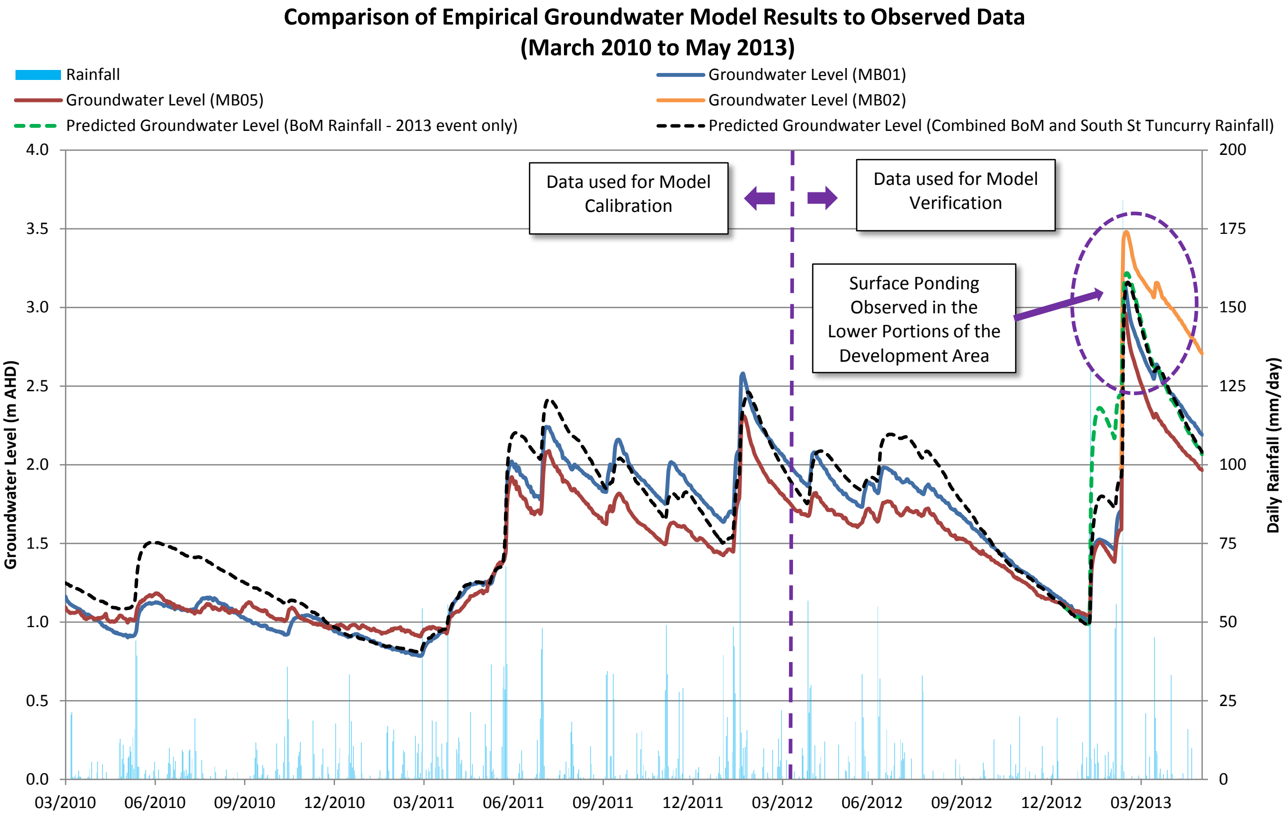


*Plate 4-4 – Empirical Groundwater Model Results (March 2010 to May 2013)*

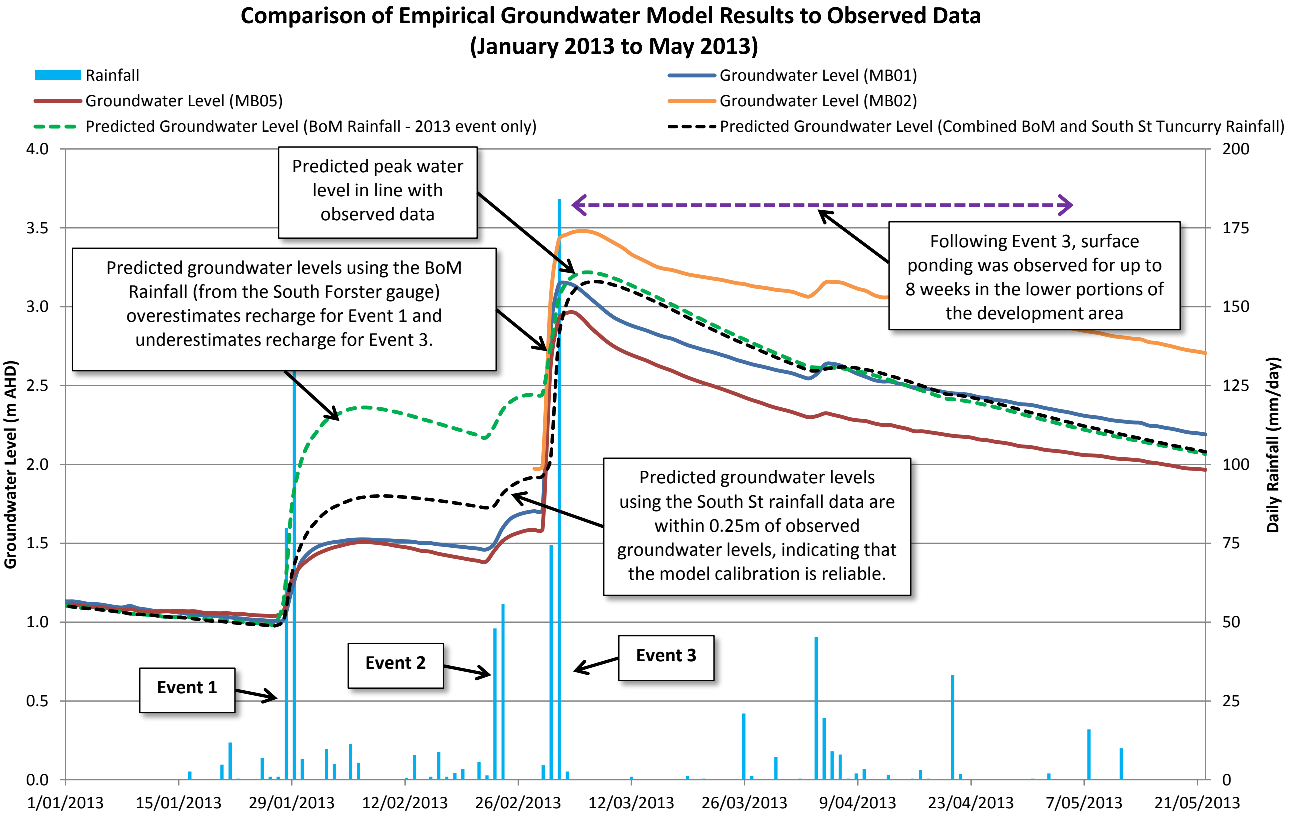


*Plate 4-5 – Empirical Groundwater Model Results (January 2013 to May 2013)*

The following key conclusions can be made from **Plate 4-4** and **Plate 4-5**, which compare the modelled and recorded groundwater levels from March 2010 to May 2013:

- The model results presented in **Plate 4-5** indicate that predicted groundwater levels for the 2013 event using the South Street rainfall data are within 0.3m of the recorded groundwater levels at MB01, MB 02 and MB05. Conversely, when the BoM rainfall data was applied, the model significantly overestimated recharge for Event 1 and underestimated recharge for Event 3. This analysis demonstrates that the reliability of the model is limited by the reliability of the assumed rainfall within the project area. As there is no site specific rainfall data available, this uncertainty is unavoidable. Notwithstanding, given that the model results using the South Street data reliably estimated the groundwater level response to rainfall, it would not be unreasonable to assume that rainfall over the development area was similar to the rainfall recorded at South Street, Tuncurry.

- With reference to **Plate 4-4**, a total of eleven recharge events were recorded over the calibration and verification periods. Each of these events was predicted by the model. For nine of the eleven events, the model predicted groundwater level rises similar to the recorded rise. The model moderately overestimated the predicted groundwater rise for two events (occurring in June 2010 and January 2013) that followed extended dry periods. Further data is required to establish if this is due to variations between assumed and actual rainfall or whether the recharge model overestimates recharge following dry periods. Notwithstanding, considering all data, the model results demonstrate that the both the recharge model and assumed Specific Yield (Sy) are reliably parameterised.

- The predicted recession rates are broadly similar to the recorded rates over the period. This indicates that the empirical methods applied to estimating lateral groundwater flow and evapotranspiration losses from the saturated zone are appropriate.

In conclusion, the results presented in **Plate 4-4** and **Plate 4-5** demonstrate that the Empirical Groundwater Model is a useful tool for estimating representative groundwater levels within the development area, with predicted groundwater levels consistently within ± 400mm of the recorded data over the 3 year and 2 month data record, which included a 10 year ARI magnitude event.

## 4.3 Empirical Groundwater Model for Developed Conditions

The calibrated and verified Empirical Groundwater Model that was developed for existing conditions was adapted to reflect the functionality of the proposed surface and groundwater management measures that are described in detail in the IWCMS (SMEC, 2014). Key changes to the model included:

- The model formulation was revised so that surface and groundwater storages were modelled independently. This was done to more reliably model the effects of directly connecting runoff from impervious areas to the water management basins. Interchange between the surface storage and groundwater was calculated as a function of the difference in water levels.

- The recharge model was adapted to reflect the expected increase in recharge volumes due to the introduction of impervious surfaces to the urban landscape.

- The surface storage characteristics were adapted to reflect the developed conditions landform, which was established using an earthworks model. The developed conditions landform includes 18ha of low lying water management basins.

- Evapotranspiration losses from the saturated zone were reduced to reflect lower loss rates that are expected due to the removal of some of the existing deep rooted vegetation.

- Evapotranspiration losses from the water management basins were added to the model.

- Gravity drainage from the water management basins was added to the model.

The developed conditions model was used to test the effectiveness of a wide range of water management and development options. The assumptions applicable to the adopted development proposal are described below.

### *Changes to Model Formulation*

The Empirical Groundwater Model for modelling developed conditions was reformulated to reflect the functionality of the proposed surface and groundwater management measures that are described in detail in the IWCMS (SMEC, 2014). The key change to the model formulation was to model surface storages and groundwater storages independently. This was done to:

- More reliably model the effects of directly connecting runoff from impervious areas to the water management basins.

- More reliably model the effects of gravity drainage from the water management basins.

- Enable evapotranspiration losses from the water management basins to be reliably modelled.

Interchange between the surface storage and groundwater storage was calculated as a function of the difference in water levels in the two storages. Recharge from pervious areas and impervious areas that will not be connected to the piped drainage system were assumed to recharge to the groundwater storage.

**Plate 4-6** describes the developed conditions model functionality, noting in red, key changes that have been made to the existing conditions model.

# Developed Conditions Empirical Groundwater Model Functionality

**Zone D4**
**Urban Development**
**(Piped Drainage Zone)**

- All runoff from roof and road areas is to be treated in above pipe rain gardens before discharging to the open basins via a stormwater pipe system.
- Under elevated groundwater conditions, subsurface drainage under roads will dewater groundwater to the open basins via the stormwater pipe system.
- Runoff from all pervious areas and impervious areas that are not connected to the piped drainage system will recharge to groundwater.
- ET losses from groundwater reduced due to less deep rooted vegetation.

**Zone D2**
**Water Management Basins**

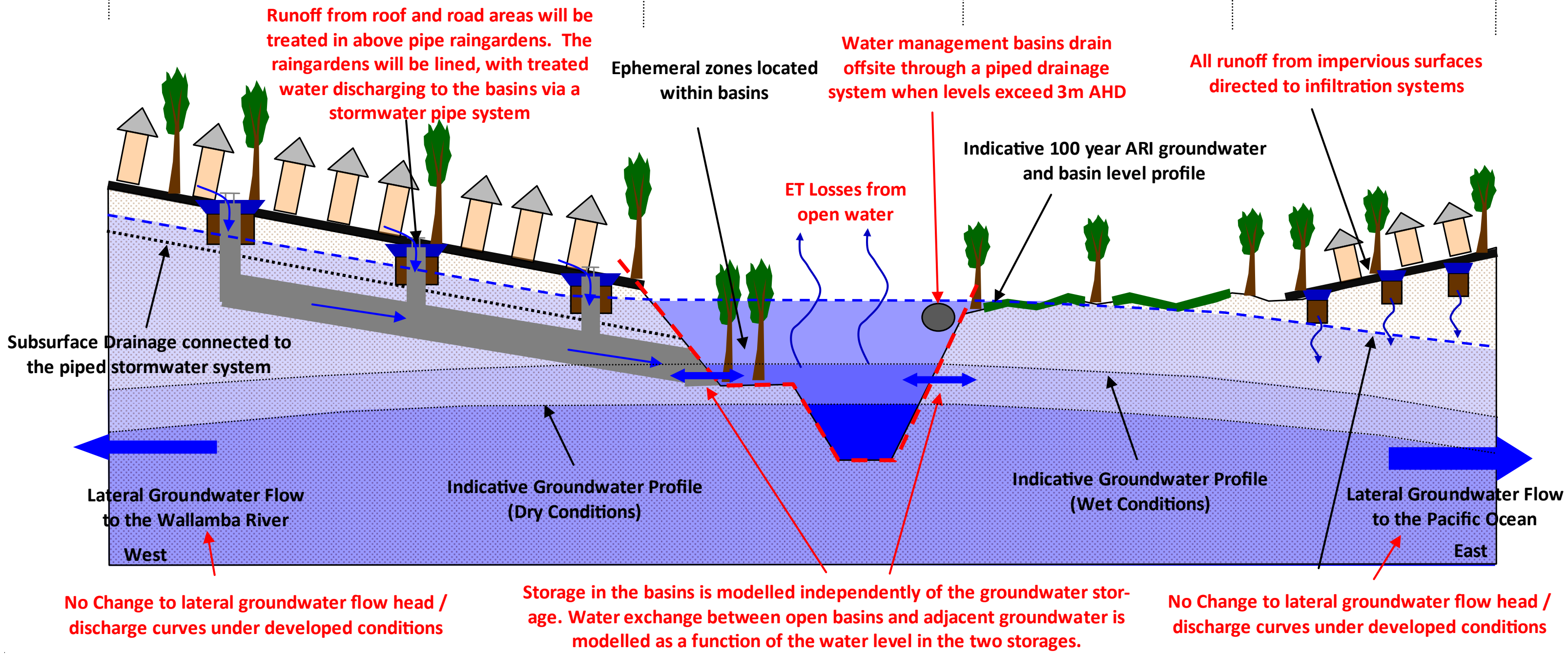
- All direct rainfall will accumulate in the basins.
- Outflow from the basins via the proposed gravity drainage system when the basin level exceeds 3m AHD.
- ET losses from surface water.

**Zone D1**
**Golf Course & Open Space**

- Groundwater recharge occurs during extended wet periods
- Irrigated water mostly lost to ET.
- ET losses from groundwater from deep rooted vegetation.

**Zone D3**
**Urban Development**
**(Infiltration Zone)**

- Runoff from both impervious and pervious surfaces will infiltrated to groundwater.
- ET losses from groundwater reduced due to less deep rooted vegetation.



Runoff from roof and road areas will be treated in above pipe raingardens. The raingardens will be lined, with treated water discharging to the basins via a stormwater pipe system

Water management basins drain offsite through a piped drainage system when levels exceed 3m AHD

All runoff from impervious surfaces directed to infiltration systems

ET Losses from open water

No Change to lateral groundwater flow head / discharge curves under developed conditions

Storage in the basins is modelled independently of the groundwater storage. Water exchange between open basins and adjacent groundwater is modelled as a function of the water level in the two storages.

No Change to lateral groundwater flow head / discharge curves under developed conditions

***Plate 4-6** – Describes the functionality of the developed conditions Empirical Groundwater Model. The notes in red describe the key adaptions that have been made to the existing conditions model.*

## *Changes to Recharge Model*

A consistent approach to modelling developed conditions recharge was applied to both the Empirical and Detailed Groundwater Models. This approach is described in **Section 5.4.1**

## *Surface Storages*

The development proposal includes 18.1ha of water management basins, which will comprise 8.4ha of deep water zones (assumed invert of 0m AHD) and 4.6ha of ephemeral zones (assumed invert of 2.5m AHD). Level and storage properties within the development area were established for existing conditions (from LiDAR) and for developed conditions (from the earthworks model). The estimated storage in the developed conditions model was reduced by 20% for basin areas under 3.5m AHD to allow for some design flexibility / contingency. The reasons for this are discussed in **Section 7** of the IWCMS (SMEC, 2014).

**Plate 4-7** compares the level storage curves for existing and developed conditions, demonstrating that the proposed water management basins will provide 400ML of storage between 0 and 4m AHD. This will assist in attenuating the rise in groundwater and basin water levels during extended wet periods or extreme rainfall events.

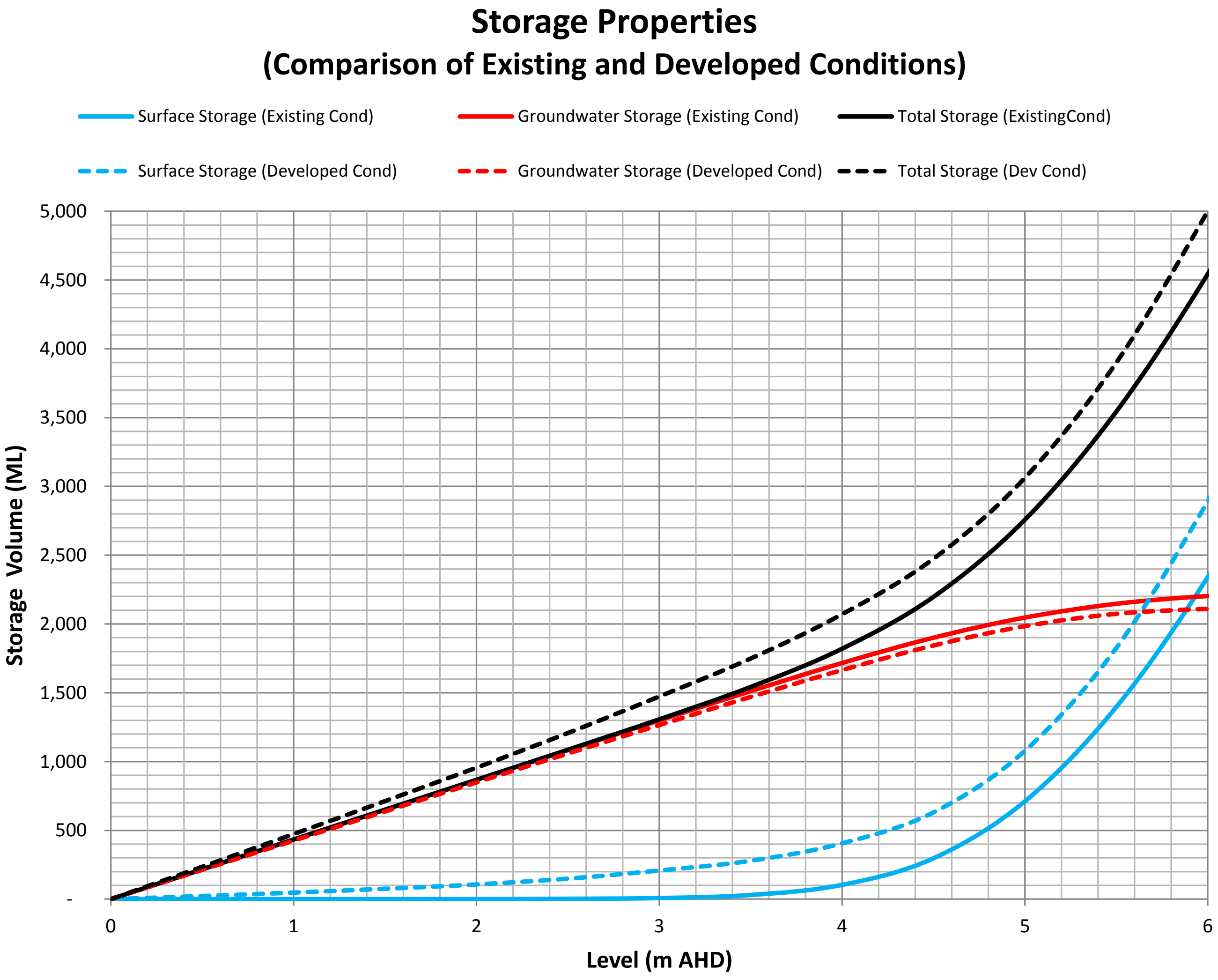


***Plate 4-7** – Level storage curve for developed and existing conditions.*

## *Evapotranspiration Losses*

The following changes to modelling evapotranspiration were applied to the developed conditions Empirical Groundwater Model:

- As described in **Section 4.1** evapotranspiration losses from the saturated zone are calculated as a function of the prevailing evaporation rate, an ET factor and an extinction depth. It is expected that approximately 76ha (equivalent to 30% of the development area) of deep rooted vegetation will be either retained or planted in the developed landscape. Hence, the ET factor was reduced by a factor of 3 (from 0.28 to 0.09) to account for the reduction in ET losses from deep rooted vegetation.

- Evapotranspiration losses from the open basins were calculated on a daily basis as a function of the basin area, the prevailing pan evaporation rate and an ET factor. An ET factor of 1.3 was adopted as the basin area will include significant ephemeral zones (vegetated by Swamp Mahogany Forest) and macrophyte benches which are expected to facilitate significant evapotranspiration losses.

## *Open Basin Outflow Works*

It is proposed to construct a stormwater pipe system that will drain excess water from the open basins. The inlet for this gravity drainage system will be located in the southern portion of the open basins and will convey excess water to the Wallis Lake Entrance Channel. Conceptually, the pipe will be aligned along the Beach Street Road Reserve and will have a length of approximately 1,950m and a grade of between 0.2 and 0.3%. Further details on this pipe drainage system are provided in the IWCMS (SMEC, 2014).

Due to the limited available grade, the inlet of the pipe is expected to be at an elevation of 3m AHD, hence, gravity drainage will only commence once the basin water level exceeds 3m AHD. A range of pipe sizes were assessed using the Empirical Groundwater Model. Put simply, a smaller pipe, with lower capacity will result in a higher peak basin level or require larger storages to provide more attenuation than a system with a larger pipe with higher capacity. However, the benefits of a larger pipe need to be considered against the higher construction costs associated with a larger pipe.

Conceptually, a 1050mm diameter stormwater pipe was considered to provide an appropriate balance between discharge capacity and implementation cost and was adopted for the developed conditions modelling. Such a system is expected to have a capacity of approximately 1m$^3$/s or 86ML/day when the basin level is at the 100 year ARI level of 3.9m AHD. Hydraulic modelling indicates that potential sea level rise of 0.91m will not significantly constrain the capacity of the gravity drainage system.

The adopted rating curve for outflow from the water management basins is provided in **Plate 4-8**.

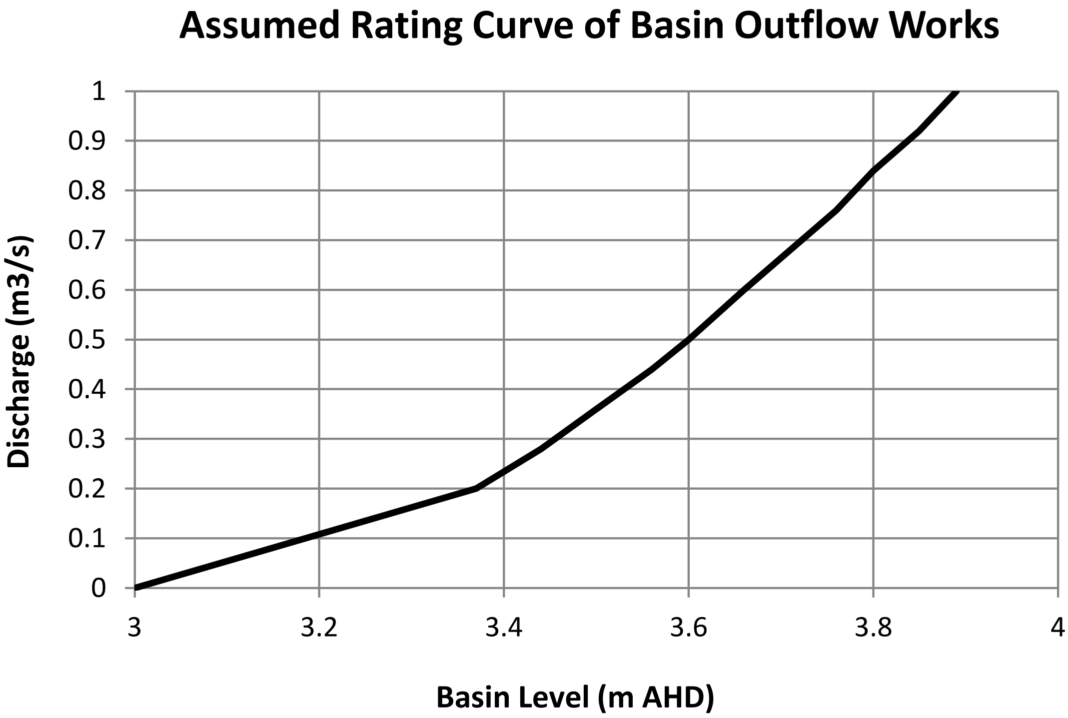


***Plate 4-8** – Assumed rating curve for basin outlet works*

## *Lateral Groundwater Flows*

The proposed development is not expected to significantly alter the groundwater conveyance capacity of the aquifer. Hence, the groundwater head / flow relationship established for existing conditions (as described in **Section 4.1**) was adopted unchanged for developed conditions.

# 5 DETAILED GROUNDWATER MODEL

A detailed three-dimensional groundwater model was developed using the MODFLOW-SURFACT modelling platform. The model was applied to estimate groundwater conditions within the development area for a significant groundwater flood event that occurred in 1963. Modelling was undertaken for both existing and developed conditions. The model was also used to assess the effects of potential sea level rise on groundwater flooding within the development area.

This section describes the modelling approach, model development and calibration. Model results are presented in **Sections 7** and **8**.

## 5.1 Conceptual Model

To develop a numerical three-dimensional model of groundwater storages and movements, the structural geology; spatial distribution of aquifer parameters; surface topography and any factors that influence the interaction between surface and groundwater must be clearly depicted in a conceptual model design and supported by quantitative information. The conceptual model design is an attempt to present a complex natural system in a more simplistic conceptual manner but expanded in 3 dimensions at a level of detail that can be applied in a numerical model. The spatial details were extrapolated from spatial data and one-dimensional information such as borehole logs and reported knowledge of geological structures. The information was compiled to develop the three dimensional layers with zones of cells containing similar hydrogeological parameters. These make up the inputs to the three-dimensional numerical groundwater model.

Groundwater flow paths are influenced by hydraulic and aquifer storage conditions in areas extending well beyond the boundaries of the proposed development area. The development of a conceptual model is therefore needed to consider a much larger area (model domain) than the boundary of the development area.

### 5.1.1 Structural Geology

The structural geology as depicted in the numerical model was compiled by taking into account the historical processes that gave rise to the present understanding of the regional and local geology and the spatial orientation of the structural features. This knowledge was essential to interpreting and extrapolating information from borehole logs and geological maps so that the hydrogeology could be depicted in three dimensions for use in developing the numerical groundwater model. The regional and local geology are therefore described below. The Regional Geological Map (**Plate 5-1**) together with Borehole Logs presented in **Appendix A** and the conceptual model section views presented in **Appendix D** contain additional information relevant to interpreting the descriptions presented below.

### 5.1.2 Regional Geology

The study area (and model domain) lies in the south eastern part of the New England Fold Belt (Roy et al., 1997). Here the geological structure consists mostly of consolidated bedrock material which is overlain by loose Quaternary sediments (estuarine clay as well as estuarine and aeolian sand). From a hydrogeological perspective, the unconsolidated sediments are the main water bearing aquifers applicable to the project area. The sediments are mostly unconfined and connected to the ocean on the eastern side, and the deeper parts of the Wallamba Estuary to the west. These water bodies serve to define the limits of the model domain in these directions. The bedrock defines the base of the model domain. It outcrops further towards the west and northwest and determines the remaining boundaries of the model domain as explained further below.

The hydraulic properties of the mostly unconfined sedimentary material are significantly larger than those of the bedrock material. Semi-confining clay layers do, however, occur in thin scattered lenses of limited spatial extent within the sedimentary material. They are more prominent closer to older swampy areas near rivers and are known (Roy et al., 1997) to also exist at the contact between the bedrock and overlying sedimentary materials. The stratigraphy and associated aquifer properties and flow directions are a product of the geological history as described below.

The geological structure of South Eastern Australia was relatively passive (not subjected to large pressures causing folding and fractures) during the Tertiary period except for the fact that it slowly subsided throughout the Tertiary, becoming stable in the late Quaternary (Roy et al., 1997). The landscape prior to subsidence had included several relatively deep valleys which favoured the development of large estuaries and lakes as subsidence progressed while coastal erosion shaped the bedrock and generated sediment. This gave rise to a coastline comprising headlands which alternate with coastal sand barriers and estuaries. Sediment types on the coast and inner shelf are comprised of mature, quartz rich sands which have experienced prolonged reworking (Roy et al., 1997).

According to Roy et al., 1997, the Forster Tuncurry coastal area is near the transition between the flow regimes of two currents, namely, the East Australian Current which flows southwards and a smaller northward littoral drift. These currents dominate the sand transport with sedimentation patterns across subsidised areas being affected by shallow marine processes (Roy et al., 1997).

In summary, sea level changes have played a major role in determining the current landscape and depositional environments as impacted on by natural forces associated with currents, wave action, wind, rainfall and surface runoff.

The local depositional environments of the project area (and surrounding model domain) were dominated by the above mentioned sea level changes, wind, and the erosion / depositional processes inclusive of those of the Wallamba River. The most dominant resultant geological units thought to be present in the project area (and model domain) are discussed below. The surface geology is shown on **Plate 5-1**.

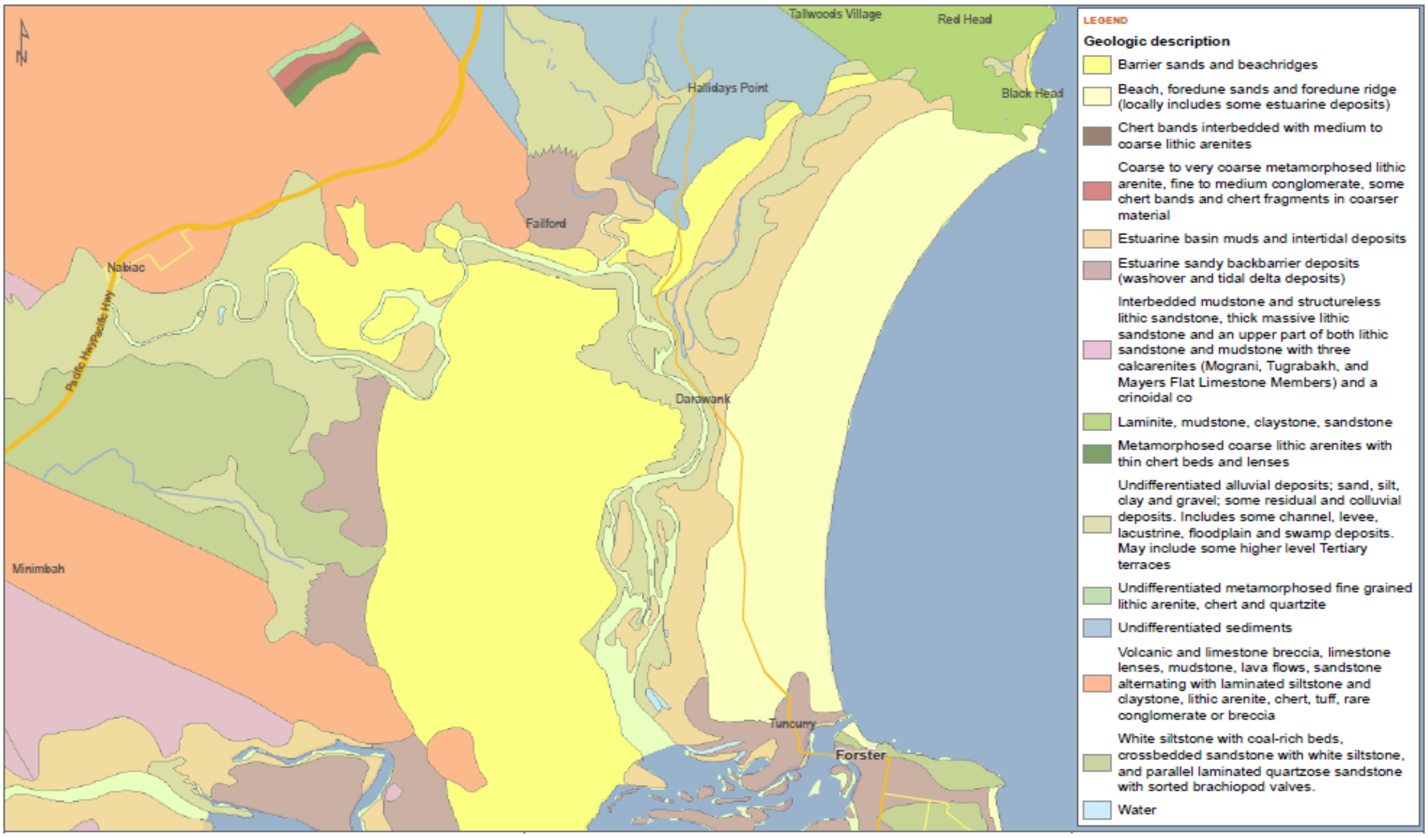


***Plate 5-1** – Regional Geology Map (Department of Mineral Resources, 2001)*

## *Bedrock (Devonian)*

The older (Devonian) bedrock makes up the base of the unconsolidated sediments observed in the North Tuncurry area. The bedrock dips slightly downwards towards the east (i.e. towards the ocean) as indicated by offshore seismic surveys (Roy et al., 1997 and Planet Management and Research Pty Ltd, 1970). It rises and outcrops towards the interior (west) and more gradually towards the north. The top of the bedrock and the mapped outcrops (Department of Mineral Resources, 2001) define, as mentioned earlier, the minimum required extent of the groundwater model domain (discussed later) in the north and north west with the permeability of the bedrock being negligible in comparison to that of the overlying, highly porous, unconsolidated sediments which connect to the estuaries to the south and the ocean towards the east.

The depth to bedrock below the project area has not been accurately defined in all places. A resistivity survey undertaken by the Water Resource Commission in 1979 was inconclusive (PPK, 2001) due to discrepancies between the survey results and information from borelogs. The depth to bedrock sediments (siltstone) has been confirmed at 33 mbgl in a cored borehole (DH1 reported in Roy et al., 1997) and at 35 mbgl in borehole P4 (PPK 2001) below the project area. Further north at the Hallidays Point Waste Water Treatment Plant (WWTP) the depth is slightly shallower based on observations of weathered siltstone and shale which occurs at 22-25 mbgl in borehole HP12 (PPK, 2001).

From maps produced in 2001 by the Department of Mineral Resources, the outcrop of bedrock occurs about one kilometre north of the exfiltration beds at Hallidays Point. The material comprised of Devonian Laminite, Mudstone and Claystone. Some Sandstone layers are also present. The outcrops to the west of the project area and the Wallamba River comprise Devonian Mudstone, Sandstone, Conglomerates, Greywacke, Tuff, Chert, as well as possible volcanics. Roy et al., 1997 also reported known bedrock depths in the vicinity of the project area, based on the Nabiac Cored Drill holes, Numbers 1 and 2 to be 18.5 mbgl and 26 mbgl respectively.

A review of the NSW Office of Water drillers log database (NSW Office of Water, 2010) revealed bedrock at depths of:

- 3 mbgl at GW200429 (south of Hallidays Point settlement between Darawank Creek and Tuncurry Road, comprising of siltstone).
- 2 mbgl at GW078300 (west of Failford, comprising of shale).
- 11.7 mbgl at GW200264 (which is about 2.5 km southwest of Failford).

## *Estuarine Clay*

Estuarine clay is evident in some borehole logs (PPK, 2001; SMEC, 2012) and also reported to occur in the entire project area (Roy et al. 1997). The clay is reported to be grey, stiff, medium plasticity with varying silt and sand content. It overlies the bedrock with a varying thickness of 2 to 15 m. A thickness of 9m was reported at depths of 18 mbgl at the project area (Roy et al., 1997). The clay layer is between 4 to 7 m thick at the Hallidays Point WWTP and occurs at a depth of about 24 mbgl (PPK, 2001). The borehole logs for Nabiac Cored Drill holes Numbers 1 and 2 show a depth to clay of 12 and 20 mbgl respectively (Roy et al., 1997). A review of the NSW Office of Water drillers log database (NSW Office of Water, 2010) revealed the presence of estuarine clays at:

- 7.5 mbgl with a minimum thickness of 2m at GW078869 (Failford).
- 21.0 mbgl with a minimum thickness of 1m at GW078858 (Tuncurry).
- 15.9 mbgl with a minimum thickness of 1m at GW273030 (Nabiac).
- 19.8 mbgl with a minimum thickness of 9.3m at GW273031 (Nabiac).

There is no clear evidence of any remnant gravel and sand filled paleochannels within or underlying the estuarine clay layers below the NTDP area. Such channels were therefore not considered in preparing the input data for the groundwater model setup. However, it is noted that such paleochannels do exist in similar coastal environments. No estuarine clay was reported in the log of GW200264 which is located west of the bedrock outcrop (outside of the model domain).

## *Pleistocene Barrier Sands and Beachridges*

These sands overlie the estuarine clay on the western side of the Wallamba River in the Nabiac area. The Unit is reported to slope gently towards the sea (Roy et al., 1997) but it was not encountered during recent drilling in the NTDP area (SMEC, 2012) which is east of the river. The Unit is interpreted to “pinch out” or to be eroded at places east of the Wallamba River. Roy et al, 1997 describes this unit as a quartz rich, relatively clean sand, typically fine to medium grained, originating from wave-action and modified in parts by tidal and aeolian processes.

## *Holocene Sandy Backbarrier Deposits*

This Unit is situated above the estuarine clay deposits. Its existence below the NTDP area was evident at depths between 12 mbgl and 24 mbgl in the boreholes drilled by SMEC in 2012. The Borelogs are presented in **Appendix A**. Roy et al, 1997 states that this Unit outcrops east of and along the Wallamba River and is covered by Holocene Aeolian Sands (Barrier Sand) to the east.

This Unit consists typically of fine to coarse sand with varying clay and silt contents. It is likely that clay and gravel occurs in thin bands and/or lenses. The colour of this Unit is grey reflecting the reducing conditions during deposition. The thickness of this Unit is interpreted to increase towards the northern end of the NTDP area and "pinches out" towards the ocean. It may have been partly reworked in the area of the Hallidays Point WWTP.

## *Holocene Aeolian Sand (Barrier Sand)*

The Holocene Aeolian Sand can be found below the project area and stretching northwards to Hallidays Point. The drilling by SMEC, 2012 indicated a thickness of 12 to 13 m within the project area. This Unit consists of fine to medium grained sand which is moderately sorted (**Appendix A**). The colour is yellow or brown suggesting deposition under oxidising conditions. This Unit is interpreted to thin towards the north of the project area.

## *Alluvial Deposits*

This Unit occurs along the Wallamba River and its tributaries. Alluvial deposits are present just west of the project area along the Wallamba River and in the tidal reaches of the braided streams and channels to the south west of Tuncurry.

### 5.1.3 Regional Hydrogeology

The hydrogeology is largely influenced by the regional structural geology, discussed above, as well as other factors such as the climate, topography, hydrology and vegetation. The Hydrogeological Map of Australia (G.Jacobson and JE.Lau, 2000) categorises the project area as part of the "porous, extensive highly productive aquifers" that cover a total area of 195 km$^2$. The eastern limit of this aquifer system is formed by the Pacific Ocean and the southern limit by the Wallamba River Inlet and Wallis Lake. To the north and west of this area (i.e. the bedrock outcrops referred to previously) the hydrogeological map describes the aquifers as "*Fractured or fissured, extensive aquifers of low to moderate productivity*". The groundwater flow direction on a regional scale is thought to be eastwards towards the ocean.

The development of a numerical groundwater model of the project area and the surrounding aquifer area interacting with project area requires a more detailed understanding of the local geology and hydrogeology, which is discussed below.

### 5.1.4 Local Geology and Conceptual Hydrogeological Model

## *Major Aquifers and Aquifer Connection*

The major aquifers within the Conceptual Model are the Nabiac Sand Aquifer west of the Wallamba River and the Sand Dune Aquifer below the project area on the eastern side of the Wallamba River. Both aquifers are categorised as highly productive (G. Jacobson and JE. Lau, 2000). Both are unconfined, however, recent field work undertaken by SMEC in 2012 indicated that the Dune Aquifer may be "leaky confined" in places due to the occasional presence of clay bands and lenses. The degree of connection between these two aquifers and with the underlying estuarine clay and bedrock is not well understood due to a lack of data. However, these areas of uncertainty are largely below sea-level and most of the groundwater movements applicable to the project area are at higher elevations.

Section views showing the conceptual model developed based on SMEC's understanding of the regional hydrogeological processes are provided in **Appendix D.** The conceptual model that was made up of spatial layers of various thickness based on the aquifer thickness presented in

**Appendix F.** Each layer is further subdivided (as mentioned earlier) into zones of similar aquifer properties which are discussed further below.

### *Groundwater Levels and Gradients*

The depth to groundwater is typically very shallow but varies both temporally and spatially throughout the Model Domain. Within the Dune and Nabiac Aquifers the water table can in places be more than 5 mbgl during dry periods. The water table is usually at or very near to the surface adjacent to the ocean and estuarine areas.

Interpreted flow vectors are generally towards the ocean and estuarine water bodies. Fluxes at these interfaces are affected by tidal effects and the water levels in rivers. If sea level rise is realised, the higher water levels in the ocean and estuarine water bodies will impact groundwater flow characteristics within the project area. This is discussed in more detail later in the report.

Groundwater levels in areas surrounding the open water bodies tend to fluctuate in response to rainfall recharge to groundwater, evapotranspiration and lateral drainage. Fluctuating groundwater levels affect groundwater gradients and associated flow velocities over time. Gradients tend to decrease during dry and warm periods (less recharge and more net evapotranspiration) and increase during cold wet periods. The interactions between surface and groundwater are discussed in more detail below within the context of the parameters needed for numerical modelling. Refer to **Section 2.3.1** for a description of available groundwater data.

### *Open Water Bodies and the Interactions between Surface and Groundwater*

Surface water bodies within the Model Domain are the Pacific Ocean, the Wallamba River, Darawank Creek, wetlands (i.e. Frognalla Swamp) and smaller ponds. Water level data from the following stations were provided by NSW Public Work's Manly Hydraulics Laboratory (MHL) for:

- Darawank Swamp: (Station Number DARAW).
- Forster: (Station Number 209470).
- Tuncurry: (Station Number 209401).
- Nabiac: (Station Number 209404).

The data consisted of water level recordings at 15 minute intervals. The information is summarised graphically in **Appendix E** for the period between January 2001 and January 2012. The locations of the stations Forster and Tuncurry are included on **Plate 5-2**. The exact location of the Darawank Swamp Station is not known but is assumed to be associated with Darawank Creek. Nabiac is located some 28.5 km upstream from Tuncurry on the Wallamba River. Available water level data is summarised in **Table 5-1**.

***Table 5-1*** *- Summary of Tidal and River Height Monitoring Data*

| | Forster (209470) | Tuncurry (209401) | Nabiac (209401) | Darawank Swamp |
|---|---|---|---|---|
| Data Available | 1/1/2001 to 28/11/2011 | 1/1/2001 to 1/2/2012 | 1/1/2001 to 1/2/2012 | 1/07/2008 to 14/10/2009 |
| Approximate River Distance from Wallis Lake (m) | 0 | 7,000 | 35,450 | N/A |
| Highest Recorded (m AHD) | 1.02 | 1.17 | 11.65 | 1.32 |
| Lowest Recorded (m AHD) | -1.11 | -0.31 | 4.95 | 0.05 |
| Average Level (m AHD) | -0.05 | 0.08 | 5.64 | 0.56 |
| Influenced by tides | Yes | Yes | No | Yes |
| Influenced by rainfall | Yes | Yes | Yes | Yes |

These levels were applied to the development of a map of indicative groundwater level contours (**Plate 5-2**). It was assumed that the groundwater levels (piezometric surfaces) of the highly permeable unconfined and semi-confined aquifers adjacent to and underlying the open water features would, at the edge of these open water bodies, be at the same elevation. The map presents the average groundwater levels based on all monitoring bores and open water surfaces for which data could be obtained. The gradients of the flow vectors indicate that open water bodies are gaining water from the Nabaic Aquifer and Dune Aquifer. The data also indicates that a groundwater divide is located in the western portion of the project area.

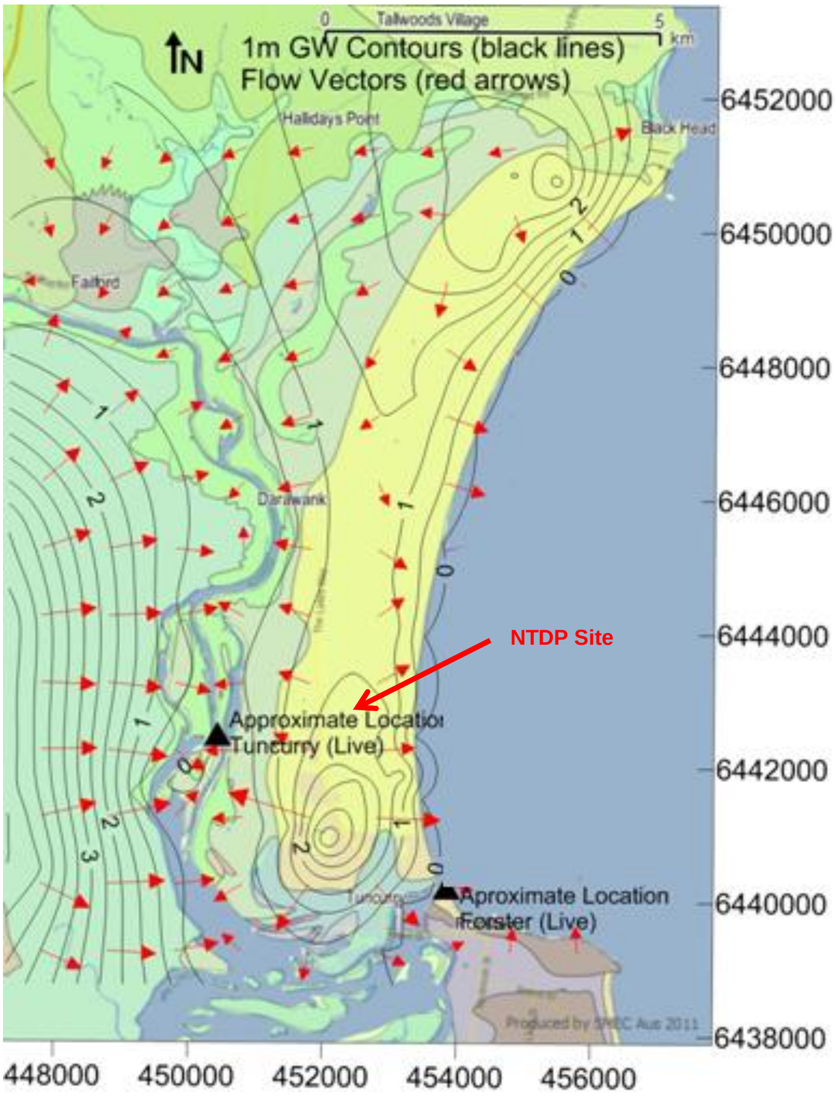


***Plate 5-2** – Indicative groundwater level (black lines) and flow direction of daily averaged values*

## *Fluxes into Aquifers (Groundwater Recharge)*

The main sources or mechanisms contributing to the replenishment of groundwater into the aquifers in the vicinity of Tuncurry include:

- Recharge from rainfall.
- Effluent exfiltration at Hallidays Point WWTP.
- Effluent exfiltration at Tuncurry WWTP (ceased in 2008).
- Recharge from bedrock into the unconsolidated sediment aquifer(s).
- Stormwater drainage system infiltration.

Available data indicates that the Wallamba River and its tributaries in the project area are “gaining” systems, therefore no significant contributions of flow from the river into the aquifers is expected. Little is known about the potential recharge from the bedrock into the unconsolidated sediment aquifer(s). Clay layers exist between the bedrock and sediments although the extent of coverage has not been proven. This recharge (if any) will depend on the presence of fractures and faults in the bedrock together with discontinuities in the clay layers. As the structural elements of the New England Fold Belt intersect the coast at a high angle (Roy et al., 1997) in the project area, it is likely that recharge may not occur (or be of negligible amounts) where the bedrock contacts with the unconsolidated sediments in the northern parts of the Model Domain. Some interaction may be present along the western boundary of the Model Domain. The relatively high groundwater levels near the contact between the Nabiac Aquifer and bedrock in the west indicates some recharge. However, the groundwater quality in the sandy aquifers indicates that rainfall is the main source of recharge.

## *Fluxes Out (Water Losses from Aquifers)*

Mechanisms contributing to fluxes out of the existing aquifer(s) are:

- Lateral aquifer drainage contributing to baseflow in the Wallamba River (to the west).
- Lateral aquifer drainage towards the ocean (to the east).
- Lateral aquifer drainage towards swamps and mudflats (to the west and north-west).
- Lateral aquifer drainage resulting in seepage along the slopes on the western side of the Dune Aquifer.
- Evapotranspiration.
- Evaporation from open water surfaces (ponds, rivers and creeks that include some water originating from groundwater).
- Pumping (Nabiac boreholes, Residential Spear points, and extractions from low lying ponds connected to the water table e.g. Tuncurry Golf Course).

Evapotranspiration is highest in wetland areas and in areas of denser vegetation where roots of trees and tall shrubs reach further down. Contributions of groundwater towards base flows in rivers tend to decrease during prolonged dry periods due to less recharge resulting in the gradual decline in water tables. This reduction is also affected by pumping. Little is known about volumes taken from residential spear points and the Nabiac Borefield. Estimates of pumping were provided for the Tuncurry Golf Course. Outflows due to pumping are considered to be negligible in relation to the other outflows mentioned above and were therefore not included in the modelling.

## *Assumptions*

Where shortfalls in relevant hydrogeological information existed, the following assumptions were made in developing a conceptual groundwater model:

- There is no clear evidence of paleo channels within the estuarine clay, therefore, it is assumed that they are not present. However, it is acknowledged that paleo channels are, according to PPK (2001) known to occur in similar coastal environments.
- The Nabiac Aquifer is homogenous and has the same or very similar properties as the Tuncurry Aquifer.
- Seepage occurs along the slope west of the Dune Aquifer.

- The wetland areas and the alluvial deposits associated with the Wallamba River have a permeability of approximately one order of magnitude lower than the Dune Aquifers.
- Groundwater within the aquifers is assumed to be fresh water. Accordingly, groundwater is assumed to have a different density, dynamic viscosity and temperature than saline ocean water.
- No groundwater flux occurs between the bedrock and unconsolidated sediments.

## 5.2 Model Development

The conceptual hydrogeological model provided the basis for developing a numerical model. This section summarises the software used, the main components of the model (domain, layers, and boundary conditions) and the calibration of its parameters. The calibration was repeated twice, once for steady state conditions and once for transient conditions. The steady state calibration results provided a basis for interpreting the adequacy of the structural depiction of the geology and hydrogeology within a numerical model, relative to its ability to simulate spatial groundwater information (water levels in boreholes). Supported by sensitivity studies it also provided an opportunity to test assumptions, revise the Model Domain and parameter zones within the constraints of known hydrogeological information. Once the steady state calibration had been finalised the parameters were further refined using a transient calibration which superseded the steady state calibrations. Model results used for the NTDP study were all based on the transient calibration. The transient calibration is therefore discussed in more detail in this report.

### 5.2.1 Modelling Software

#### *Rainfall Recharge to Groundwater*

In groundwater modelling it is not uncommon for the amounts of rainfall recharge to groundwater to be expressed as a simple proportion of rainfall. However, the process is much more complex and proportional relationships do not apply during extreme wet and dry periods. To address groundwater related flood risks, a detailed model of rainfall recharge to groundwater was therefore developed.

The Empirical Groundwater Model was applied separately to simulate recharge across a number of recharge zones used in the transient model. Refer to **Section 4** for further details on the Empirical Groundwater Model.

#### *Saturated Groundwater Flow*

The numerical model selected for use in this study is Groundwater Vistas (GWV) (Professional Version 6.22, Build 3). GWV is essentially a pre- and post- processing user interface enabling windows based applications of the MODFLOW model (McDonald and Harbaugh, 1988) which is a three-dimensional finite-difference flow and transport modelling system. It is used extensively throughout the world and is recognised as a leading industry benchmark for groundwater modelling. It simulates dynamic subsurface flow conditions as well as the interactions between surface and groundwater and the subsurface interface between saline and fresh water. The saturated groundwater response can be modelled under varying boundary conditions and stress situations.

#### *Unsaturated Moisture Content and Flow*

MODFLOW-SURFACT V4 (Hydrogeologic, 2011) features enhanced capability in dealing with unsaturated flow conditions, delayed recharge and unsaturated moisture distribution through the unsaturated zone in three dimensions. The input of rainfall recharge was, as mentioned above, simulated separately in the vertical dimension using the Empirical Groundwater Model. The Empirical Groundwater Model includes a daily moisture budgeting component which enabled realistic simulations of evapotranspiration (from the unsaturated zone) and daily rainfall recharge to groundwater in a vertical dimension. Relationships between lateral flow rates and piezometric heads were derived using outputs from the MODFLOW-SURFACT model and applied in the Empirical Groundwater Model. These two model platforms were therefore mutually dependent and an iterative calibration procedure was therefore necessary.

MODFLOW-SURFACT has two main simulation modules of particular relevance to the project area:

- The RSF4 recharge module enables additional recharge from open water sources to be accounted for.
- The BCF4 module which simulates unsaturated flow using a formula for unsaturated permeability (Van Genuchten, 1980) and the relationship of relative permeability versus water saturation (Brooks and Corey, 1966).

### 5.2.2 Steady State Model

The establishment and calibration of the steady state model and subsequent sensitivity analysis of its model parameters formed part of an initial model development stage. The established parameters were then used as initial parameters for the Transient Model calibration, which is discussed further below. As the model parameters were established from the Transient Model Calibration process, the results from the steady state modelling process are superseded and are not documented in this report.

### 5.2.3 Transient Model

#### *Model Domain*

The area presented in a groundwater model (i.e. the model domain) needs to be large enough to ensure that all interactions between the groundwater within the project area and the groundwater in surrounding areas are adequately represented. The structural geology and presence of large scale water bodies determined the Model Domain for the project area. The adequacy of the domain was tested in the steady state model and then revised slightly for use in the transient model. The project area is about 6.2 km$^2$ and the proposed development area being considered is about 2.6 km$^2$. In contrast, the model domain comprises a rectangle of 9.8 km x 13.45 km (**Plate 5-3**), totalling approximately 131.8 km$^2$. Nested within this area is the project area. Surrounding areas in which differences in groundwater head are deemed to influence the flow at the project area are regarded as active parts of the model domain and the remaining areas are treated as inactive or no flow zones. The spatial distribution of active hydraulic heads (active cells) and areas containing inactive or no flow zones (inactive cells) in the model setup, are shown on **Plate 5-3**. For the purposes of this study, the inactive areas are mostly areas in which head differences are unlikely to change (the ocean) or are separated from active areas by boundary conditions (outcrops or layers of impermeable bedrock) beyond which changes in heads have no or negligible influence on groundwater levels in the active area.

The steady state modelling demonstrated that the low lying Wallamba River acts as a natural barrier to influences or changes in piezometric heads on opposite sides of the river, i.e. the water levels and groundwater movements on the eastern side of the river have negligible impact on those of the western side and vice versa. This is due to water levels in the Wallamba River Estuary being governed by tidal influences and catchment runoff during wet weather conditions. The implication of this was that the aquifer to the west of the river (Nabiac Aquifer) could also be treated as a no flow zone in all layers of the model. The Nabiac Aquifer immediately adjacent to the river and underlying the river was retained within the model.

The active model area is further subdivided into layers, zones and grid cells which are discussed further below.

The bounding coordinates of the model domain (projection GDA95 / MGA zone 56) are:

| | |
|---|---|
| South-West Corner | E 447300, N 6438750 |
| North-East Corner | E 457100, N 6452200 |

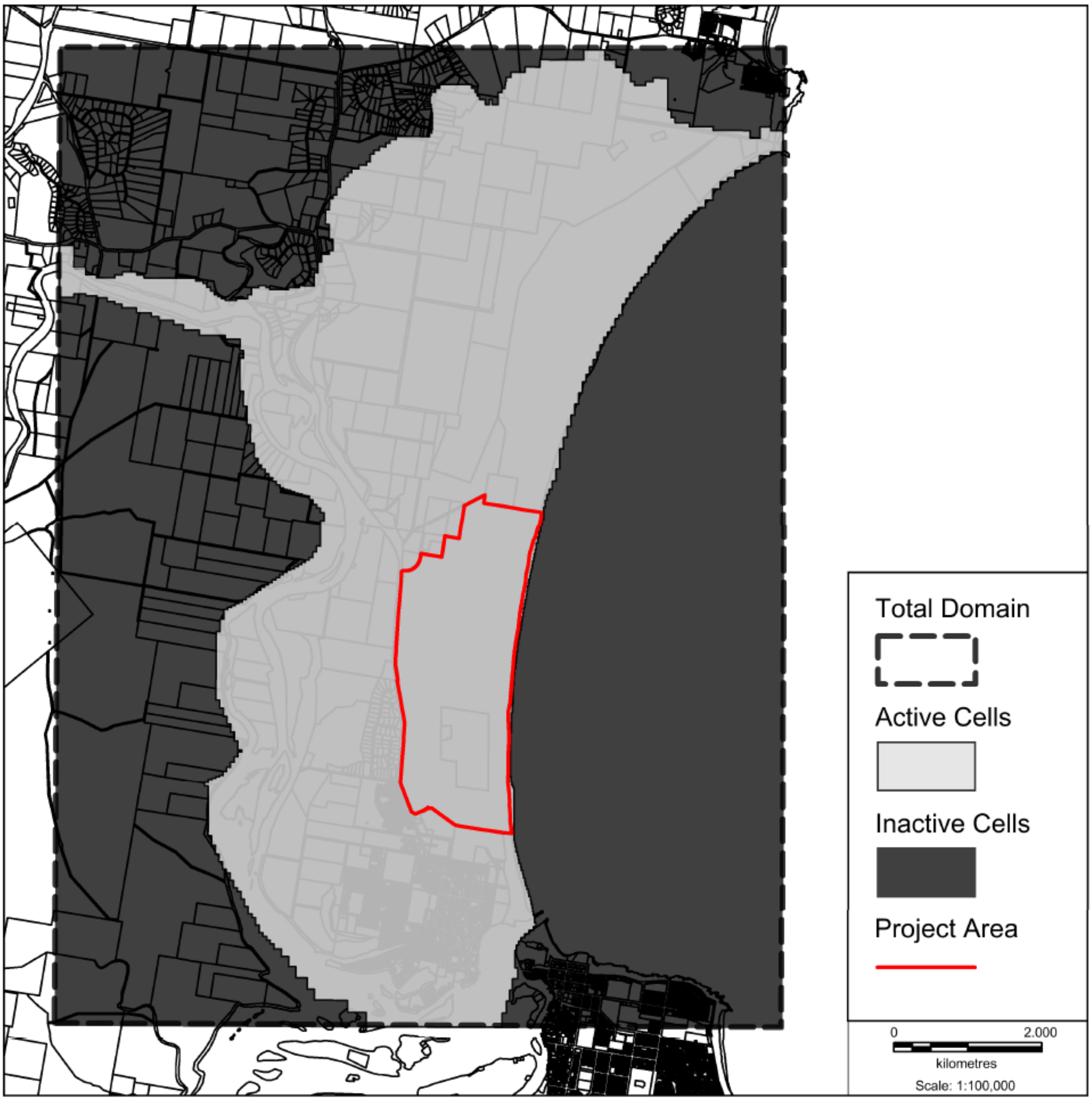


**Plate 5-3** - *Model Domain and active and inactive cells*

## *Model Grid*

The grid spacing was varied to accommodate the structural geology and the need for more detail to be presented in the project area so that possible surface flooding within dune low points could be mapped. The final grid used in the transient model consisted of 647 rows north-south and 325 columns east-west, comprising 210,275 cells per layer giving a total of 841,100 cells. A 10m X 10m grid was applied across the entire project area.

### *Layers*

The conceptual model applied to the transient model is depicted as containing 4 layers. The layers are described in **Table 5-2**. **Appendix D** contains a conceptual depiction of the layers. The thickness of each layer varies across the study area. The thicknesses of layers 1 and 2 are presented as contour maps in **Appendix F**. This information is based on spatial extrapolation of information from borehole logs, interpretation of maps and reviews of descriptions of structural geology and hydrogeology given in the various reports discussed earlier. The upper two layers are the layers in which most groundwater flow occurs. The underlying layers are aquitards (characterised by material with low permeability). The sensitivity studies had shown that groundwater movements within Layer 4 were negligible and had very little impact on groundwater movements in the unconfined and semi-confined aquifers closer to the surface. Layer 4 was therefore also treated as a no-flow zone for transient modelling purposes.

None of the layers are homogenous. They are therefore sub-divided into zones based on the dominant geological strata and aquifer characteristics. The zones are discussed further below.

***Table 5-2*** *- Summary of Modelled Layers*

| Layer | Thickness (m) | Geological Unit Represented | Aquifer |
|---|---|---|---|
| 1 | Varies | ▪ Top of Pleistocene Barrier Sands and Beachridges<br>▪ Holocene Sandy Backbarrier Deposits<br>▪ Holocene Aeolian Sand<br>▪ Alluvial Deposits | ▪ Upper, unconfined Dune Aquifer |
| 2 | Varies | ▪ Top of Pleistocene Barrier Sands and Beachridges<br>▪ Holocene Estuarine Backbarrier Sand | ▪ Nabiac Aquifer<br>▪ Lower, semi confined Dune Aquifer |
| 3 | Varies | ▪ Estuarine Clay | ▪ Aquitard |
| 4 | Varies | ▪ Bedrock | ▪ Aquitard |

The surface elevations of the different layers were calculated by subtracting the depth of the layer (as depicted in the borehole data and conceptual model) from the surface elevation. In areas of little or no geological information, realistic estimates were made. Surfer Version 9.11.947 © was used to create grid data for each layer.

Surface elevation data (LiDAR Data) was provided by WMA Water (with Great Lakes Council's consent). The LiDAR covers the area defined by the following coordinates, which includes the project area, but does not cover the northern parts of the Model Domain:

| | | | |
|---|---|---|---|
| • xMin: | 447300 | xMax: | 456365 |
| • yMin: | 6438750 | yMax: | 6449700 |

Elevations for the areas outside of the LiDAR coverage were estimated by extrapolating data from GIS data sets with contour intervals of 2 m and in some cases 10 m in the northern part of the Model Domain.

*(Note: WMA Water advised SMEC that some discrepancies between the LiDAR data (AusGeoid98) and Australian Height Datum (AHD) exists. Data validation undertaken by WMA Water indicated that the standard deviation between these two datasets at Failford and Tuncurry are 0.07 m and 0.15 m respectively. This surface discrepancy is considered negligible for the purpose of this sub-surface groundwater model calibration study.*

## *Transient Model Boundary Conditions*

### No Flow Boundaries

No flow boundary conditions (inactive cells) are assigned in areas in which no geological information is included in the model input. (These are areas that are not within the active parts of the Model Domain shown on **Plate 5-3**). A total of 325,346 cells were assigned as “no flow” areas. These include:

- Areas at and beyond known bedrock outcrops in all layers.
- Wallis Lake, the southern part of the Nabiac Aquifer and the Nabiac Aquifer to the west of the Wallamba River valley.
- Layer 4 which is the consolidated bedrock below the clay layers of layer 3.

### Ocean Boundary

The following processes were considered in transient modelling to accommodate the effects of the ocean on groundwater movements:

- Tides.
- Density differences of salt and freshwater (assuming the salt-freshwater interface is located at sea level).
- The “over height” or additional hydraulic head effects due to wave run-up on the beach.

For the calibration event, tidal heights were averaged for each day based on the tidal data from Forster (data provided by MHL).

A density correction was applied using the following approximation:

$$\mathbf{H_b \approx -0.0125 * Z_b} \qquad \textbf{Formula 1}$$

Where $H_b$ is the equivalent freshwater head of the particular boundary cell (in m AHD) and $Z_b$ is the elevation of the base of the particular boundary cell (in m AHD).

To account for the additional over height effects, the wave height data from the Waverider buoy at Crowdy Head was obtained from MHL. The Waverider bouy is installed in deep water (>75m water depth). Formula 2 as described by Hong-Yoon Kan et al. (unknown date) was used to calculate the over height effect.

$$\mathbf{\eta_w = 0.55\tan\beta \sqrt{}H'oRMS * L_o} \qquad \textbf{Formula 2}$$

Where $\eta_w$ is the over height (in m AHD), tanβ is the assumed slope of the beach (8%), H’oRMS is the root mean square of the deep sea wave heights and $L_o$ is the wavelength. A wavelength of 42m was adopted based on Goda (2000).

The head for each stress period and layer (Hd) is the sum of daily averages of water level (tide), density correction ($H_b$) and over height ($\eta_w$) as shown in Formula 3.

$$\mathbf{Hd = tide + H_b + \eta_w} \quad \textbf{Formula 3}$$

The following boundary conditions were applied for different layers at the ocean boundary:

- Layer 1: Constant Head (Average 0.94m AHD ranging from 0.57 to 2.01m AHD)
- Layer 2: General Head (Average 1.13m AHD ranging from 0.75 to 2.19m AHD)
- Layer 3: General Head (Average 1.23m AHD ranging from 0.86 to 2.30m AHD)

## *Rivers*

The Wallamba River and Darawank Creek were modelled using the MODFLOW river module.

The following transient river boundary parameters were applied:

- The riverbed conductance was fixed at 100m$^2$/day based on previous modelling undertaken (PPK, 2001 and Parsons Brinkerhoff, 2007) and checked during the steady state calibration for the Wallamba River and Darawank Creek.
- Water levels in the Wallamba River were calculated using the average daily water levels measured at Tuncurry and adjusted along the river length using the following estimated gradients:
  - From Nabiac to Tuncurry: 0.000198m/m
  - From Tuncurry to Forster : 0.000015m/m
  - Wallamba River upstream of Tuncurry: 0.000198m/m (assumed)
- Water levels in Darawank Creek were initially set at 2.6m AHD in the north (headwater of the creek) and 0.15m AHD in the south (confluence with the Wallamba River). The daily water level variations were based on Wallamba River water level changes.

## *Drains*

Drain cells were included in the transient model to simulate the seepage observed at the base of the slopes west of the development area during wet periods. The RSF4 package was used to simulate the seepage events.

Drain cells were also included in the model for the sporting fields that are located to the south of the development area, where a review of topographic data indicated that surface drainage would occur when groundwater levels in the vicinity of the sporting fields reaches 3.5 to 4.0m AHD.

## *Domestic Boreholes and Wells*

Pumping from boreholes and wells is known to occur for domestic purposes and golf course irrigation within the Model Domain. No data was available for use in this study. The pumping amounts are assumed to be relatively small and were not included in the transient modelling.

## 5.3 Transient Model Calibration for Existing Conditions

As mentioned earlier, the primary groundwater constraint for the project is the risk of groundwater flooding. For calibration purposes, a period of measured data was sought that would be representative of the groundwater flux in the study area and include a recharge event that resulted in an above average increase in elevation of the water table. At the time of undertaking the model calibration (2012) there were no measured records of the groundwater response to major rainfall events, such as the 1963 event. The only representative relatively wet, but not extremely wet, period containing sufficient amounts of reliable data for transient calibration purposes was a 51 day period between 9 June 2011 to 29 July 2011. Transient model calibration was undertaken using available data collected over a 51 day period extending from 9 June 2011 to 29 July 2011. The calibration period commences at the end of a dry period, is followed by an above average rainfall event with some groundwater level rise, a period in which the water table gradually declined and then a second period of above average amounts of rainfall and further water level rise.

This section describes the data used for the transient calibration, the adopted model parameters that were established through the calibration process and the calibration results.

### 5.3.1 Stress Periods

Fifty one daily stress periods (representing the period 9 June 2011 to 29 July 2011) were applied in the transient model calibration together with daily meteorological data consisting of rainfall recharge to groundwater and pan evaporation. The model was run on a daily time step with the exception of Day 18 and 19 of the 51 day calibration period, where an hourly time step was applied so that the model results could be compared to the test pumping data (discussed below).

### 5.3.2 Available Data for Model Calibration

Groundwater level data during the calibration period was available from 10 boreholes located within the project area. They included MB01, MB02, MB03, MB04, MB05, MB06, MB07 and BH05, BH06 and BH10. Two of these boreholes, MB01 and MB05, were equipped with electronic data loggers. Logging equipment at a third borehole was vandalised. Monitoring at the other 8 boreholes consisted of manual measurements on two occasions during the 51 day period. These two occasions served to provide valuable information about the spatial differences in water levels.

**Plate 5-4** shows the rainfall and groundwater level response recorded over the transient calibration period. Refer to **Plate 2-5** for monitoring bore locations.

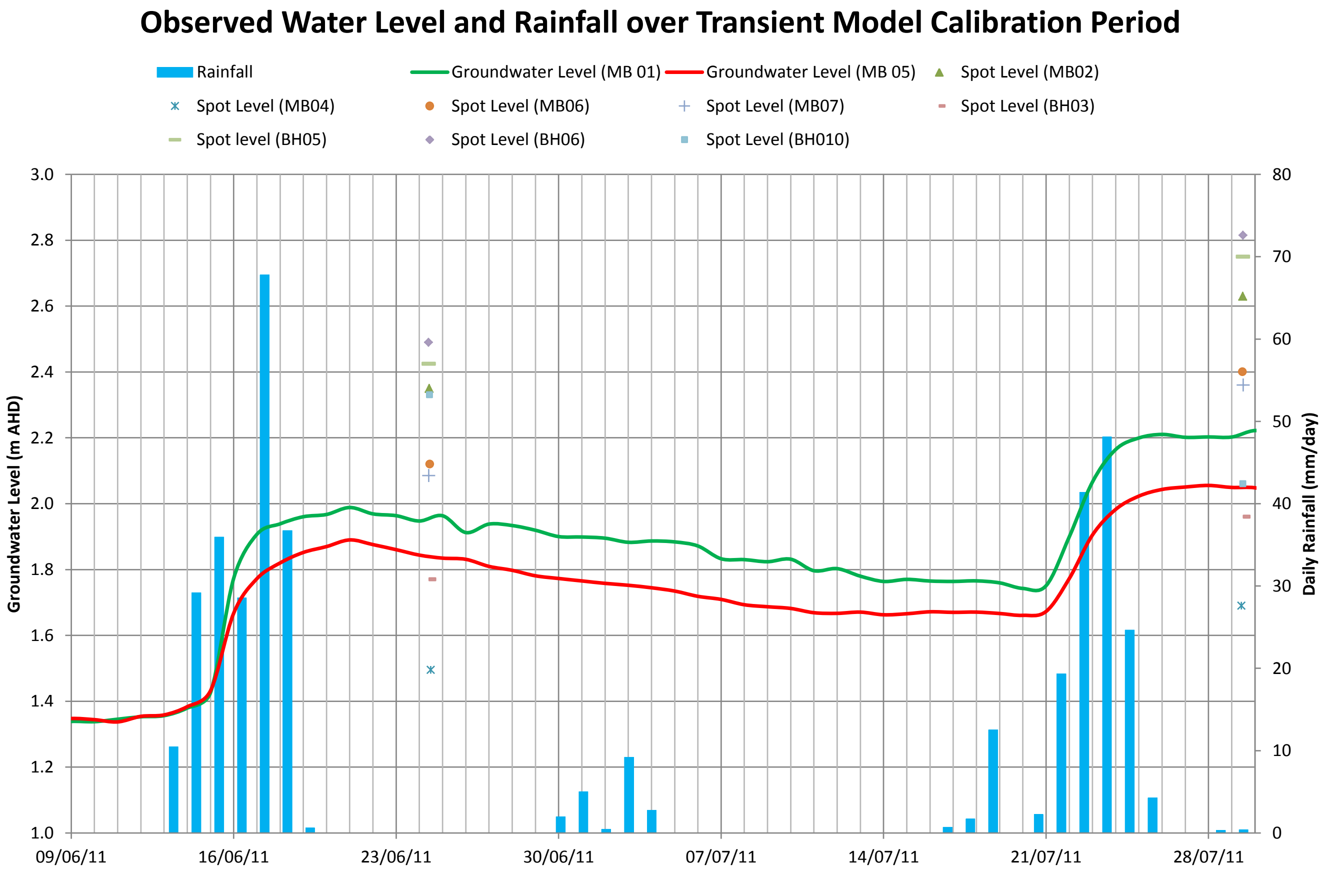


***Plate 5-4*** *- Observed groundwater levels and rainfall during the transient model calibration period.*

Level logger data was available for the calibration period from five boreholes located near the Hallidays Point WWTP (HPBH3, HPBH7, HPBH10, HPBH14 and HPBH20). Hallidays Point is located to the north of the project area but within the model domain. This data was used for the transient model calibration.

## *Pump Test Data*

The aquifer pump test did not occur during the 51 day calibration period. However, it provides additional data that was used to understand local drawdown and recovery effects which was beneficial for transient calibration purposes. The test had utilised boreholes LC12-01 PB, LC12-02B and MB02, which had data loggers installed during the test period. Refer to **Section 2.5** for further information on the pump test.

As part of the calibration process, the pump test data was nested within the 51 day calibration period, commencing on day 18 as the water levels at the test site were the same as the day on which the pump test commenced. This provided a means of adding diversity to the flux ranges and stress conditions used in the calibration and served to further verify the calibration results. The following information from the aquifer pump test was used in the transient calibration:

- Observations at LC12-01 PB, which is the abstraction well. In the transient model set up, these observations represent pumping during stress period (day) 18, from layer 2 at a rate of 1,385m$^3$/day (16l/sec) applied over 24 time steps (hourly data).

- Observations at borehole LC12-02B, provided the transient target for calibrating the drawdown (using hourly time steps) due to the pumping from layer 2 during stress period (day) 18 and the recovery that followed during stress period (day) 19.

- Observations at MB02 which is located alongside the discharge site for the water pumped out of the aquifer provided the transient target for calibrating the groundwater mounding due to infiltration (recharge) of the discharge into layer 1 during stress period (day) 18 and the subsequent settling of the mound during stress period (day) 19.

The MODFLOW SURFACT stream module (SFR2) was used for the transient calibration of saturated and unsaturated flow at the pump test discharge site. Here a single cell (10m x 10m) was converted into a stream boundary. It was assumed that ponding of 0.1m occurred at that cell from the beginning to the end of pumping. For the unsaturated flow parameter (SFR2 data) the following data was assumed:

- Saturated water content (THTS): 0.32 based on the porosity.
- Initial water content (THTI): 0.1 was assumed. However, this proved to be an insensitive parameter.
- Brooks Corey Exponent (EPS): 3.5 was assumed. However, this proved to be an insensitive parameter.
- Saturated $K_z$ of unsaturated zone (UHC): 20m/day, the same as the assumed $K_z$ of Zone 3.

### 5.3.3 Aquifer Properties

The transient model contains four layers. Each layer was divided into a number of zones where one or more of the following parameters are assumed to be spatially homogenous:

- Hydraulic Conductivity (K)
    - Horizontal (Kx,y)
    - Vertical (Kz)
- Specific Storage (Ss)
- Specific Yield (Sy)
- Evapotranspiration (ET) (extinction depth and rate)
- Riverbed Conductance

Layers one and two have several zones to represent the diversity of the local hydrogeological conditions. Layer three is an aquitard and is simulated as a homogeneous unit. It is therefore presented as a single zone with a single value for each type of parameter. Layer 4 is also an aquitard which has virtually no influence on groundwater movements within the other layers. It is therefore treated as a no flow zone in the model. Accordingly, no parameters have been assigned to Layer 4.

Parameter zones are shown in **Plate 5-5**, **Plate 5-6**, and **Plate 5-7** for layers 1, 2 and 3 respectively. Parameter values assigned to each zone are presented in **Table 5-3**.

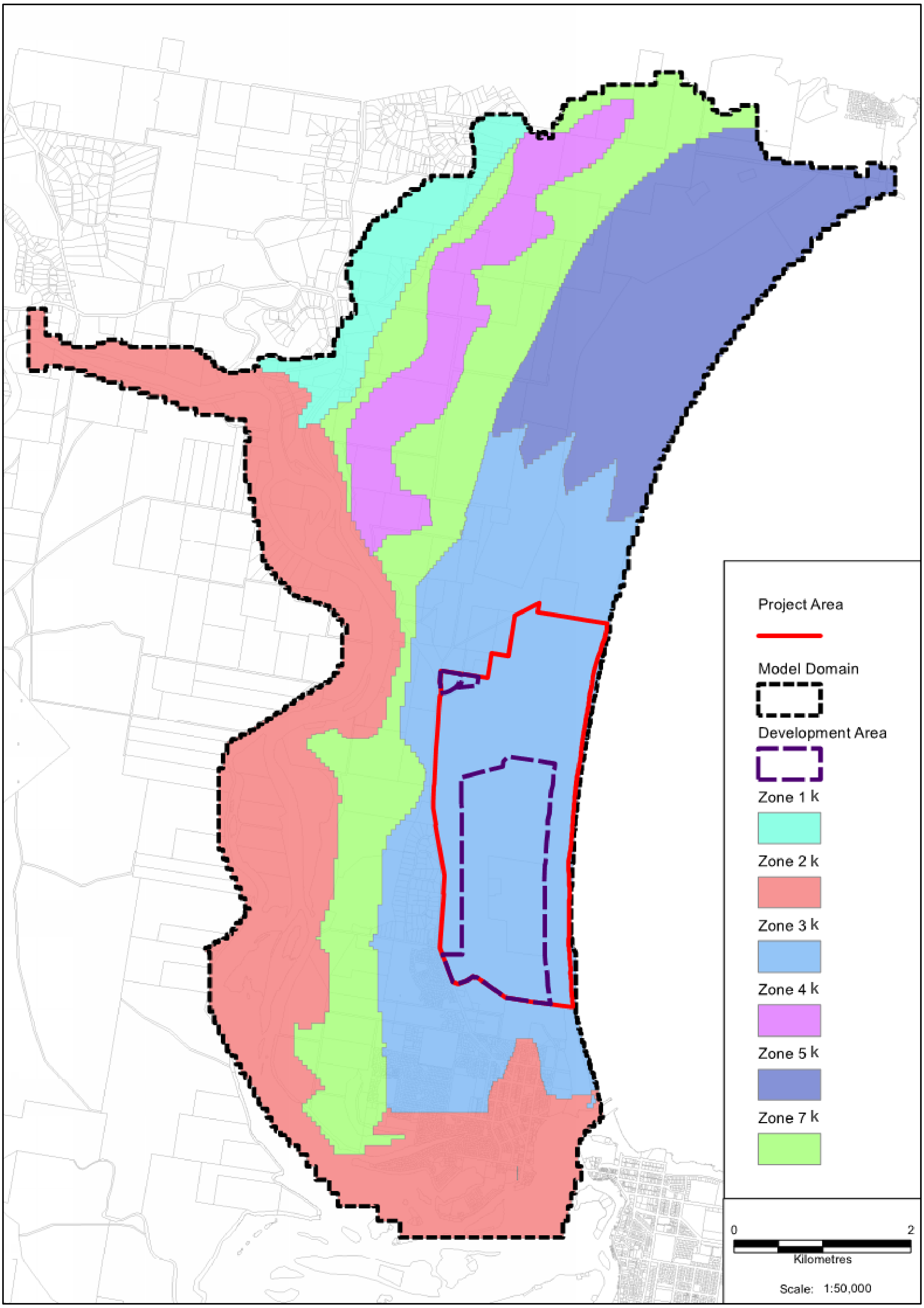


**Plate 5-5** – *Hydraulic conductivity and storage zone boundaries in layer 1*

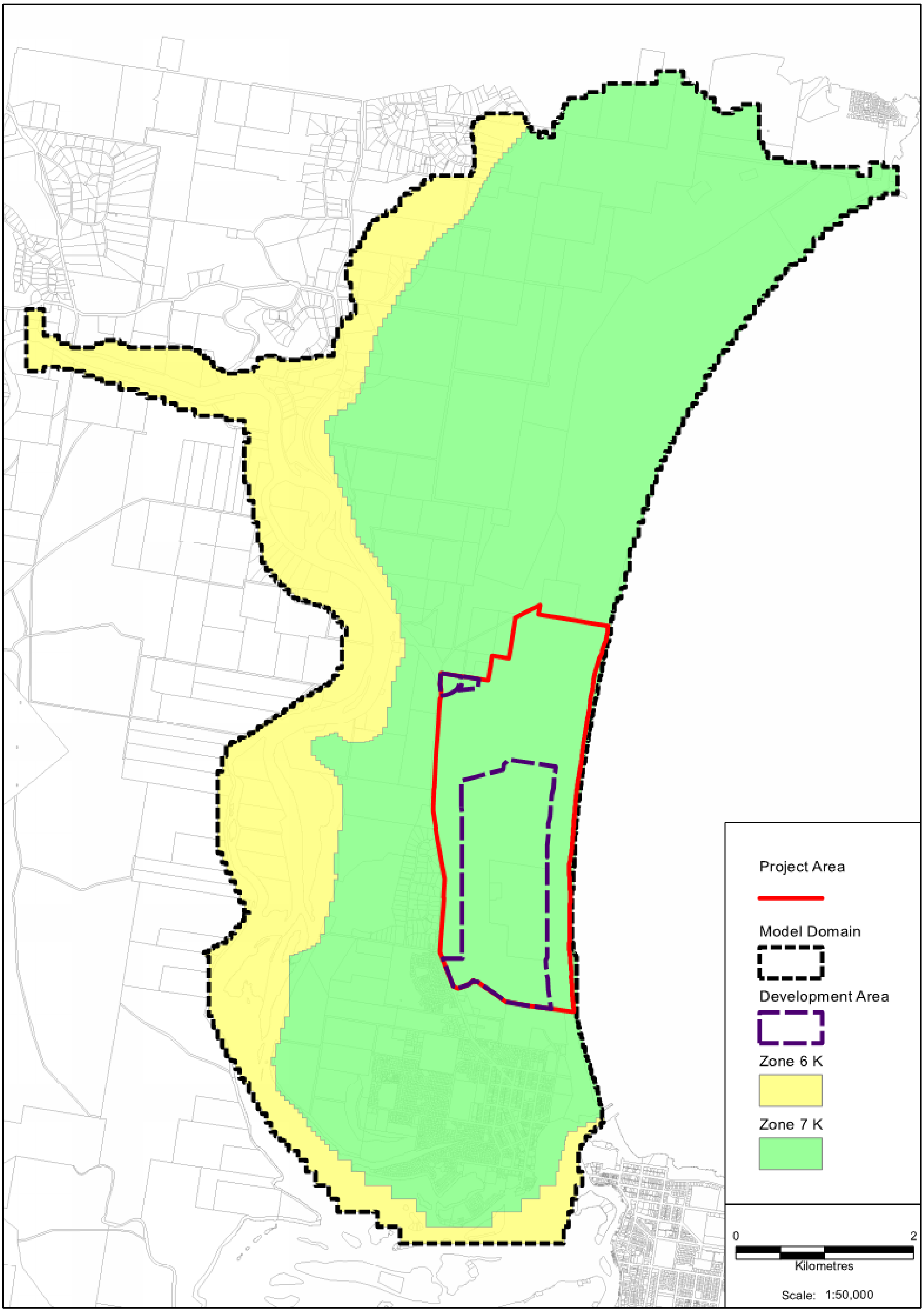


**Plate 5-6** - *Hydraulic conductivity and storage zone boundaries in layer 2*

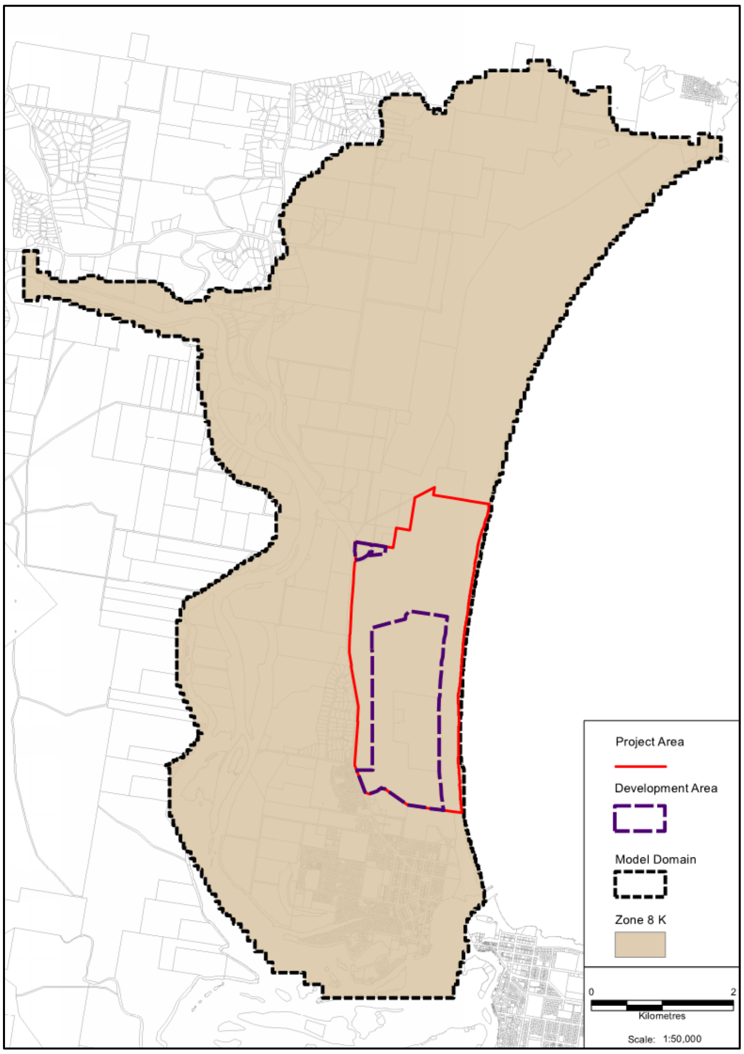


***Plate 5-7*** *- Hydraulic conductivity and storage zone boundaries in layer 3*

***Table 5-3*** *- Calibrated Transient Permeability Parameters*

| Zone | Zone Description | Kx,y / Kz (m/day) | Ss | Sy |
|---|---|---|---|---|
| 1k | Layer 1: Nabiac Aquifer *(not active west of Wallamba River, but active north of the river)* | 25/2.5 | 0.0050 | 0.1 |
| 2k | Layer 1: Wallamba River | 2/0.2 | 0.0035 | 0.07 |
| 3k | Layer 1: Tuncurry Aquifer South | 44/20 | 0.0085 | 0.17 |
| 4k | Layer 1: Darawank Swamp | 2/0.2 | 0.0025 | 0.07 |
| 5k | Layer 1: Tuncurry Aquifer North | 30/3 | 0.003 | 0.05 |
| 6k | Layer 2: Nabiac Aquifer/ Wallamba River | 25/5 | 0.025 | 0.05 |
| 7k | Layer 2: Tuncurry Aquifer | 30/3 | 0.003 | 0.05 |
| 8k | Layer 3 | 0.05/0.005 | 0.00001 | 0.02 |
| 9k | Layer 4 | Not Active | | |

### 5.3.4 Recharge

The Empirical Groundwater Model that was developed specifically for the project by SMEC, calculates recharge as a function of the soil moisture storage and depth to groundwater. This model was calibrated and verified using water level data collected over a 38 month period. The model was applied to estimate recharge profiles for use in the detailed groundwater model. Refer to **Section 4** for a detailed description of the Empirical Groundwater Model.

The detailed groundwater model incorporates 6 different recharge zones in which daily amounts of recharge are assumed to be similar. The recharge zones are shown in **Plate 5-8**. The recharge for each zone was calculated using the Empirical Groundwater Model, based on the calibration parameters for MB01 (refer to **Section 3.4** for further information). Changes to recharge characteristics for each zone were made by varying the assumed surface level. A higher surface level effectively increases the depth of the unsaturated zone (defined as the depth to water table) resulting in more soil water storage capacity and less recharge than a model with the same parameters, but a lower surface level. The adopted modelling approach for each zone is described as follows:

- **Zone 1**: comprises land that is typically between 4 to 8m AHD. Recharge was calculated using the Empirical Groundwater Model applying a surface level of 5.0 m AHD.
- **Zone 2**: comprises the existing golf course which has elevations ranging between 2.5 to 5.0 m AHD. Recharge was calculated using the Empirical Groundwater Model applying a surface level of 3.5 m AHD. It was assumed that no irrigation from the golf course would occur during the wet weather periods assessed by the model.
- **Zone 3**: comprises existing urban areas that are located to the south and west of the project area. Zone 3 was assumed to be 50% impervious and recharge from impervious surfaces was assumed to be rainfall less a 5 mm daily loss. This would be conservative in areas where impervious surfaces are directly connected to stormwater drainage. Recharge from pervious areas was modelled as per the Zone 2 recharge.
- **Zone 4:** comprises the Hallidays Point WWTP exfiltration beds. Recharge from these beds was applied at rates determined from information provided by Mid Coast Water.
- **Zone 5**: is assumed to be a groundwater discharge (or outflow) area associated with the Wallamba River Estuary, so no recharge was applied in this zone.
- **Zone 7**: comprises low lying land surrounding the golf course. Recharge was calculated using the Empirical Groundwater Model applying a surface level of 3.5 m AHD. Recharge from Zone 7 is the same as recharge from Zone 2.

The 51 day calibration period comprised 384 mm of rainfall. Estimated total recharge depths for each of the zones over the period are:

- **Zone 1**: 219 mm or 57% of rainfall.
- **Zones 2** and **7**: 263 mm or 68% of rainfall.
- **Zone 3**: 245 mm or 64% of rainfall.

It is noted that groundwater behaviour within the project area is primarily influenced by the recharge from Zones 1, 2 and 7. The other zones are outside of the project area and therefore have limited influence on the groundwater behaviour within the project area.

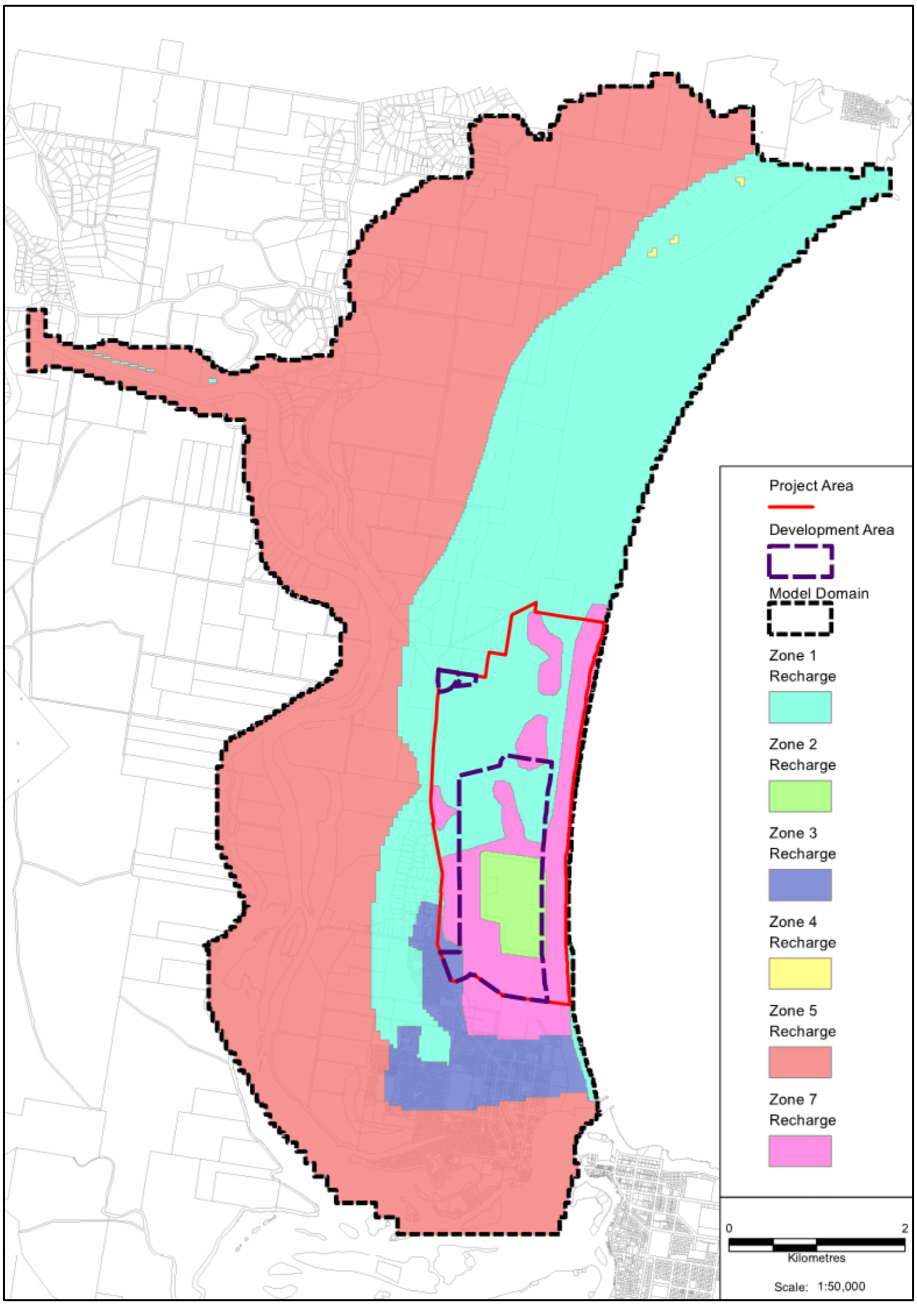


***Plate 5-8*** *- Recharge Zones applied in the Transient Model*

### 5.3.5 Evapotranspiration

Evapotranspiration (ET) losses from the saturated zone are applied as a function of ET rate and an extinction depth. In order to account for evapotranspiration in vegetated areas, urban areas and open water areas such as the Darawank Swamp, a relatively shallow extinction depth of 1.5 m was initially applied in the transient model and then modified during calibration using the PEST parameter optimisation tool. The value remained unchanged below the dune areas and the golf course represented by Zones 1 and 2 respectively. In Zone 3, which includes urban areas, the ET rate is set to zero as groundwater losses to ET are considered to be negligible in urban areas. In Zone 4 the extinction depth was reduced to 0.01m for the exfiltration beds at the Hallidays Point WWTP.

The ET rates (applied during the 51 day calibration period) and extinction depths are presented in **Table 5-4**. The ET zones are shown in **Plate 5-9**.

It is noted that the ET rates and extinction depths adopted in the detailed groundwater model calibration differ from those applied to the Empirical Groundwater Model (refer to **Section 4.1** for details on the ET model adopted in the Empirical Groundwater Model). Preference was given to achieving the best possible fit in both models over achieving consistency between the two models. As the Empirical Groundwater Model was calibrated and verified over a 38 month period, the ET loss methods applied to the Empirical Groundwater Model are deemed to be more reliable than those applied to the Detailed Groundwater Model, which has only been calibrated over a 51 day wet period that occurred during the winter months of 2011, when ET rates would be at seasonal lows. It is also noted that the Detailed Groundwater Model has only been applied to modelling groundwater conditions during wet periods when ET losses only have a marginal impact on groundwater dynamics.

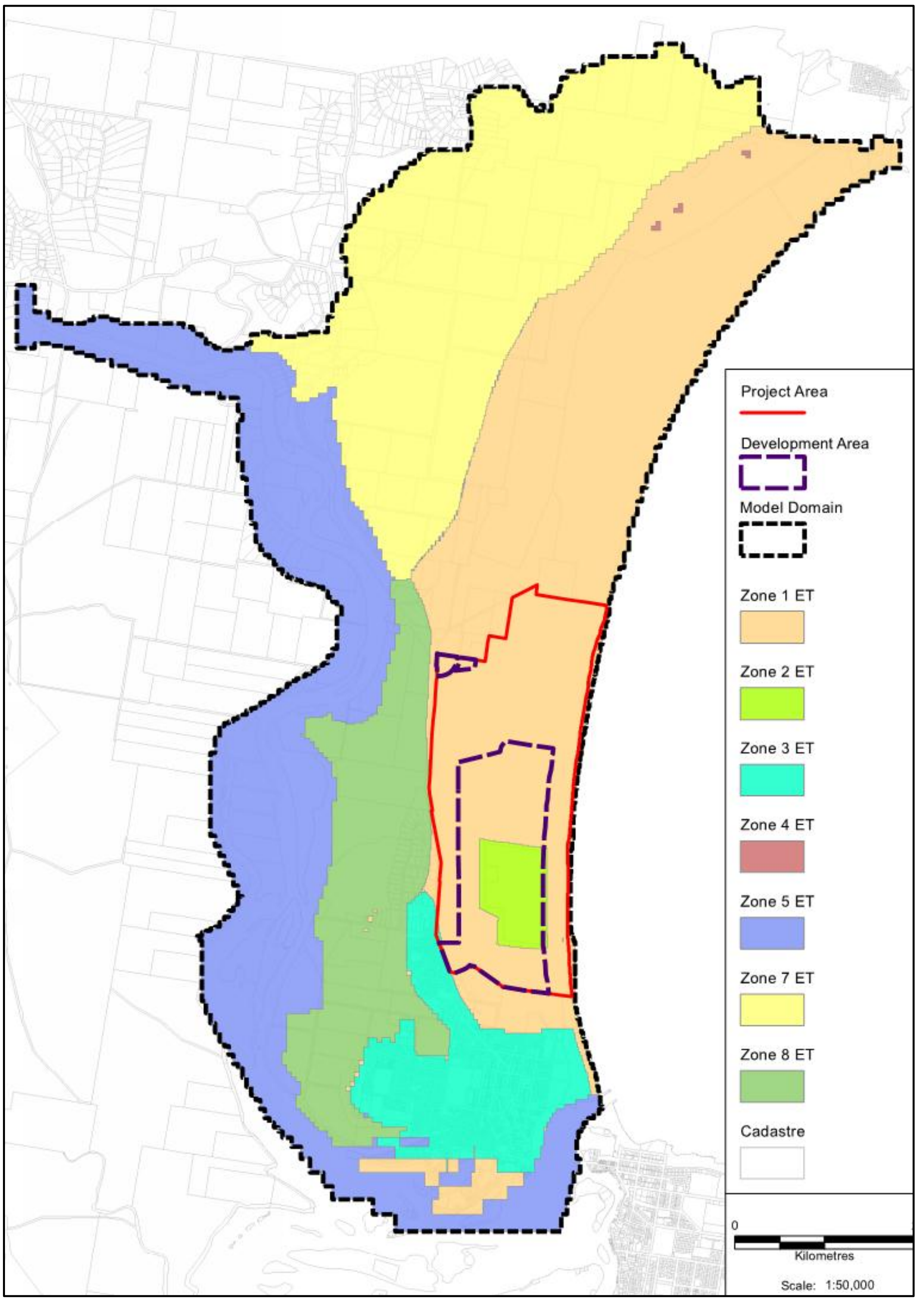


***Plate 5-9*** *- Transient model ET zones*

***Table 5-4*** *- Calibrated Transient Recharge and ET values*

| Zone | Zone Description | ET Rate (mm/day) | Extinction Depth (m) |
|---|---|---|---|
| 1 ET | Layer 1: Nabiac Aquifer *(not active west of Wallamba River, but active north of the rver)* | 2.2 | 1.5 |
| 2 ET | Layer 1: Wallamba River | 2.2 | 1.5 |
| 3 ET | Layer 1: Tuncurry Aquifer South | Urban area | |
| 4 ET | Layer 1: Hallidays Point WWTP exfiltration beds. | 2.2 | 0.01 |
| 5 ET | Layer 1: Tuncurry Aquifer North | 2.0 | 0.5 |
| 6 ET | Layer 2: Nabiac Aquifer/Wallamba River | Not active | |
| 7 ET | Layer 2: Tuncurry Aquifer | 0.9 | 4 |
| 8 ET | Layer 3 | 2.0 | 4 |
| 9 ET | Layer 4 | Not active | |

### 5.3.6 Evaluation of Transient Model Calibration Results

The reliability of the transient model calibration was evaluated by comparing observed and simulated groundwater levels at monitoring locations. A total of 525 observed water levels (or target values) were available for comparison. The results from the calibration are presented as follows:

- **Plate 5-10** compares observed and simulated water levels.
- **Plate 5-11** plots the residuals of observed and simulated water levels.
- **Plate 5-12** presents the average residuals at specific sites within the project area.
- Hydrographs comparing simulated and observed water levels at monitoring locations are presented in **Appendix G**.

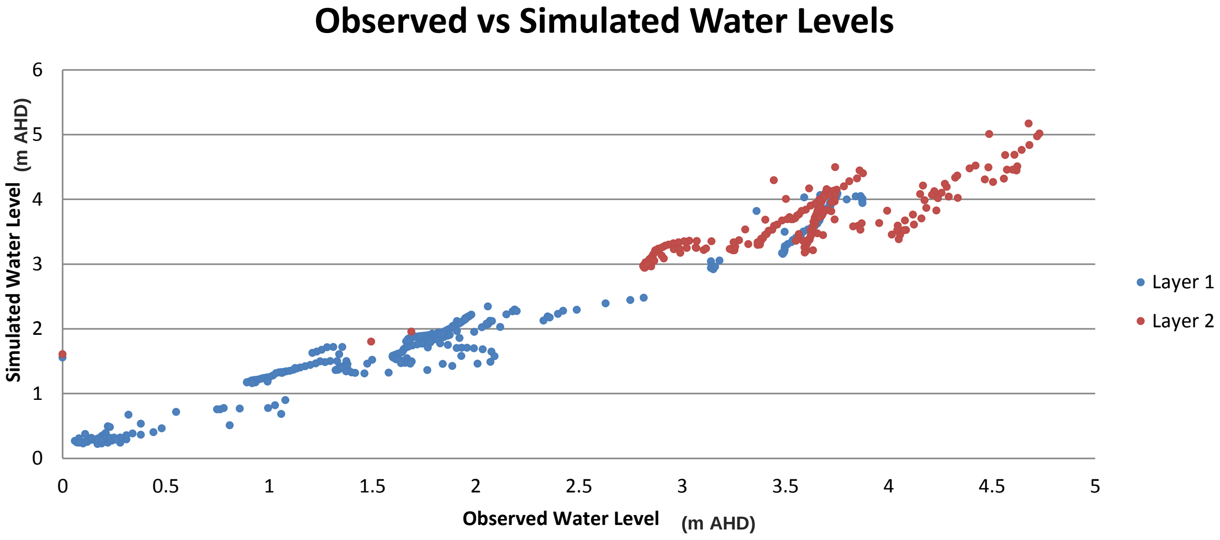


**Plate 5-10** - Simulated versus Observed Water Level

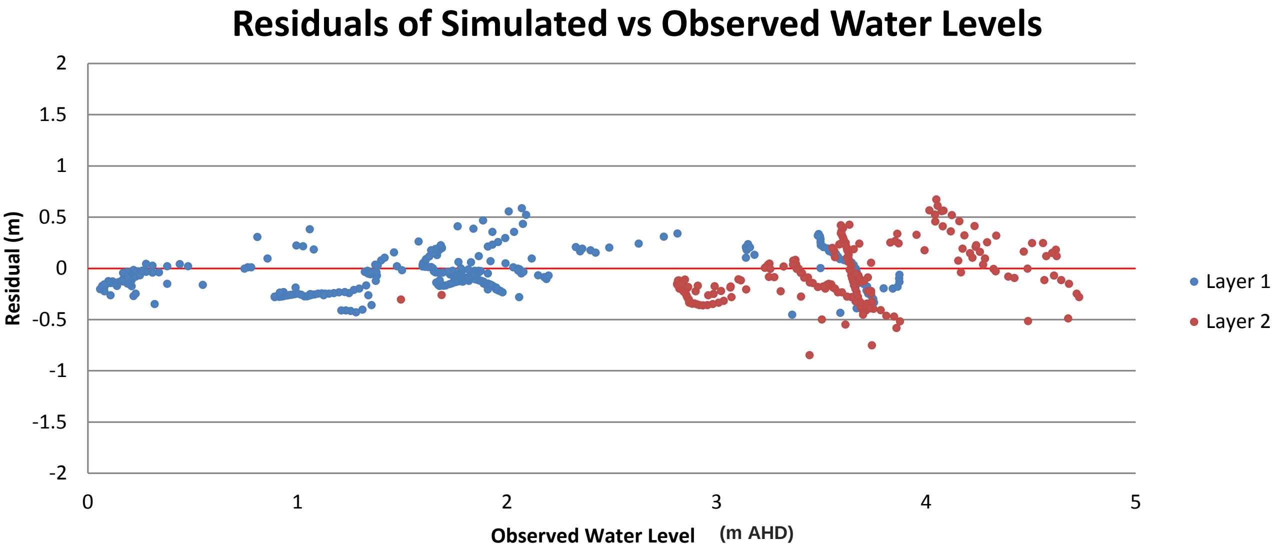


**Plate 5-11 -** *Residual of Simulated versus Observed Water Level*

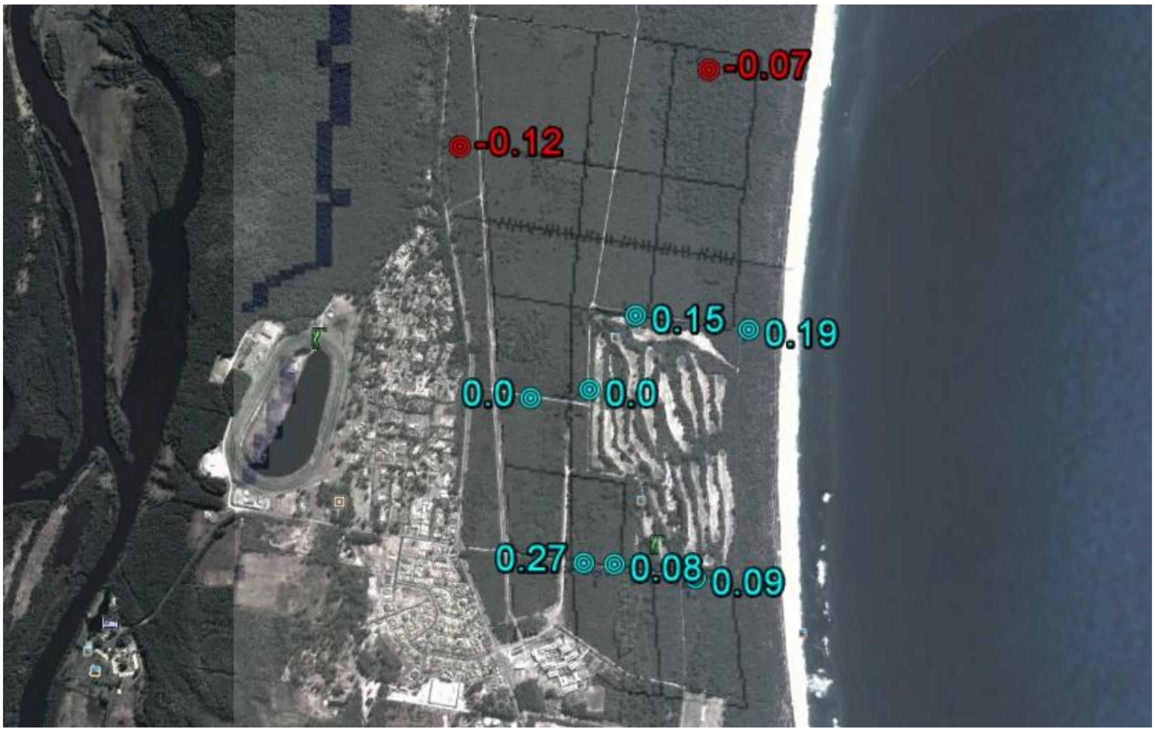


***Plate 5-12*** *- Average residuals (m) at specific sites within the Development Area. Red = negative; Blue = positive*

The following key trends can be identified from the calibration results:

- With reference to **Plate 5-11** the majority of the observed water levels are between the +0.5 m and -0.5 m residual line indicating that simulated groundwater levels were broadly consistent with observed levels.
- With reference to **Plate 5-12**, the average residuals at specific boreholes located within the project area ranged between +0.27 m and -0.12m, indicating a good agreement between observed and simulated values within the project area.

- The hydrographs presented in **Appendix G** show that simulated values are generally within ±0.3m of observed water levels at boreholes located within the project area.
- The scaled RMS (Residual Mean Square) calculated from all 525 target values is approximately 5% which is within the groundwater modelling guideline value of 5-10% (Barnett et al, 2012) for acceptable model calibration.

It is noted that given the groundwater within the project area is heavily influenced by the site’s variable recharge characteristics, the detailed groundwater model’s reliability is influenced by the reliability of the recharge model.

In summary, the transient model calibration results demonstrate that the model is reliably calibrated and is suitable for use as a predictive model. As with any model that is used for predictive purposes, there is potential for the model reliability to be reduced when the model is applied beyond the bounds of the calibration data. Model confidence is discussed in **Section 6**.

### 5.3.7 Water Balance

A water balance for the model was produced to verify the performance of the transient model over the calibration period. The water balance results were determined for each layer from the final calibration runs. The results are presented in **Appendix H**. The transient model fluxes indicate that:

- During times of high river stages (associated with peak flows after large rainfall events) the flux direction between the river and adjacent aquifers becomes influent. Effluent conditions resume one or two days after peak river water levels.
- Rainfall related recharge and General Head Boundary inflow are the major fluxes into the aquifer.
- Channel outflow, evapotranspiration, recharge outflow (seepage) and river outflow are the major fluxes out of the aquifer.
- The aquifer absorbs and releases water from storage.

A separate water balance of the daily flux in a horizontal direction in layers one and two was produced for the calibration period, focussing only on the project area. The resulting water balance results were applied to estimating the lateral groundwater flow / head relationships in the Empirical Groundwater Model.

### 5.3.8 Sensitivity Analysis and Assessment of Model Limitations

Sensitivity analysis was undertaken utilising the auto sensitivity function from Groundwater Vistas. The analysis identified the detailed groundwater model within the project area was highly sensitive to variations in the following model parameters:

- Recharge.
- Horizontal Permeability.
- Specific Yield (Layer 1) and Specific Storage (Layer 2).

Refer to **Appendix I** for a detailed description of the sensitivity analysis and assessment of model limitations.

## 5.4 Developed Conditions Groundwater Model

The existing conditions detailed groundwater model was modified for developed conditions. This section details the modelling methodologies and associated assumptions applied to the developed conditions groundwater model.

### 5.4.1 Recharge

For the purposes of modelling developed conditions recharge (in both the Empirical and Detailed Groundwater Models), the 255 ha development area was divided into the following recharge area zones:

- **Zone D1 - Golf Course and Open Space:** comprising the golf course and open space areas. Recharge in this zone was assumed to be similar to the existing recharge characteristics in Recharge Zones 2 and 7 (existing conditions model).

- **Zone D2 - Water Management Area**: comprises the deep water zones, ephemeral zones, ephemeral finger drains and basin batters. It is assumed that all direct rainfall over the water management area accumulates in the basins without loss. ET losses from the basins are calculated independently.

- **Zone D3 - Development Area (Infiltration Zone):** Comprises all development within the infiltration zone. The pervious portions within this zone were assumed to have similar recharge characteristics to Recharge Zone 3 (existing conditions model). Runoff from impervious surfaces was assumed to recharge to the groundwater when daily rainfall exceeds 5mm/day.

- **Zone D4 - Development Area (Piped Drainage Zone):** Comprises all development within the piped drainage zone. The pervious portions within this zone were assumed to have similar recharge characteristics to Recharge Zone 3 (existing conditions model). Runoff from impervious surfaces was assumed to occur when daily rainfall exceeds 5mm/day. 80% of this runoff was assumed to discharge directly to the open basins (via the piped drainage system). The remaining 20% of the runoff was assumed to recharge to the groundwater, accounting for some non-connected impervious areas (such as garden sheds and footpaths) and some leakages and overflows from the stormwater system.

The extent of the abovementioned zones are depicted in **Plate 5-13**. Note that these zones were nested into the existing conditions recharge zones that are depicted in **Plate 5-8**.

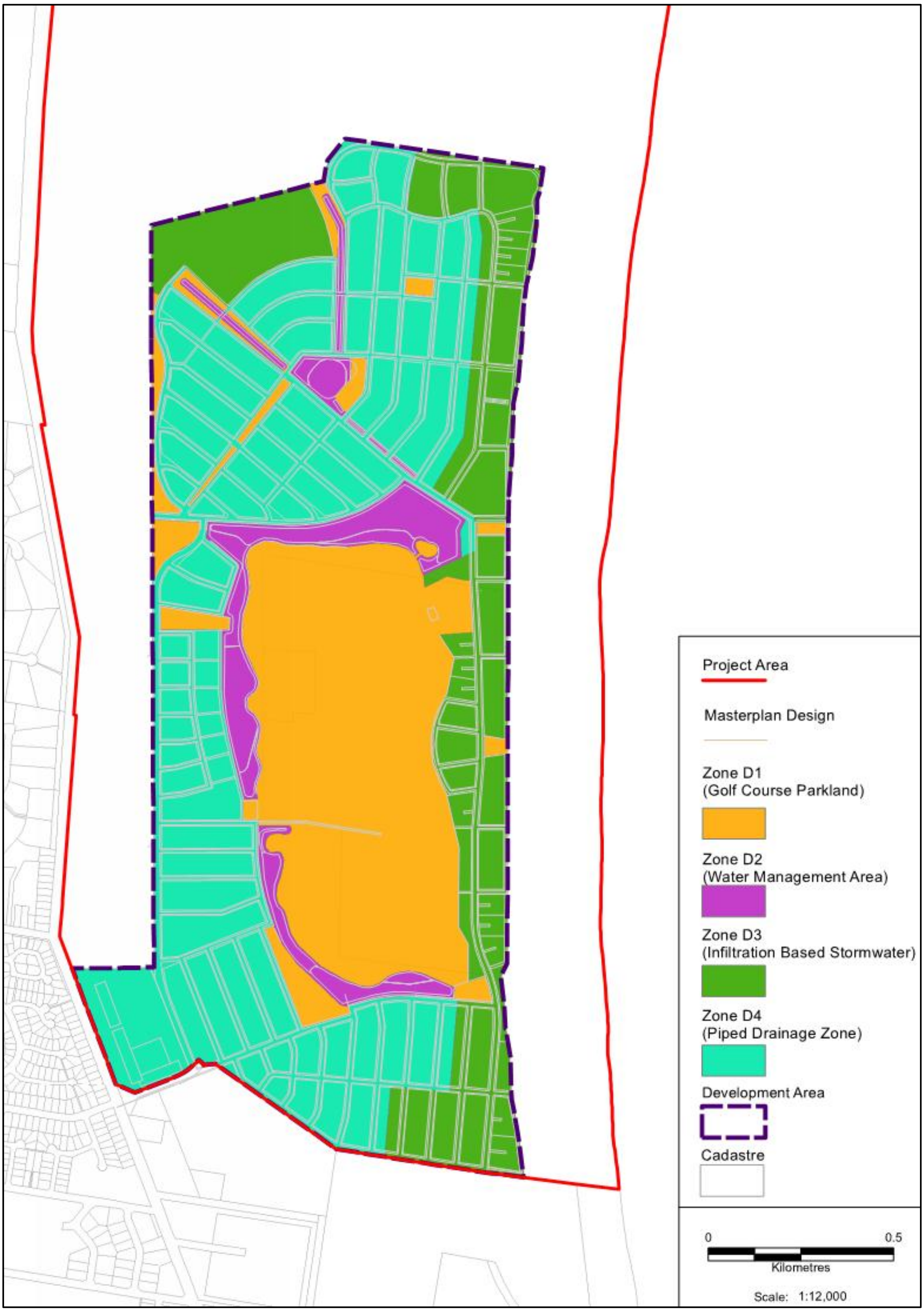


***Plate 5-13*** *- Developed conditions recharge zones*

**Table 5-5** details the adopted land use configurations applied to each recharge zone. These assumptions were applied to both the developed conditions Detailed Groundwater Model and Empirical Groundwater Model.

***Table 5-5** – Adopted land use configurations for developed conditions recharge zones.*

| Recharge Zone | Total Catchment (ha) | | Impervious Area (ha) | | Pervious Area (ha) | |
|---|---|---|---|---|---|---|
| | Total Area | Impervious Percentage | Inflows to Basins | Infiltrates to Groundwater | Inflows to Basins | Infiltrates to Groundwater |
| **Zone D1 - Golf Course and Open Space** | 68.6 | 4% | 0 | 2.4 | 0 | 66.2 |
| **Zone D2 - Water Management Area**[1] | 18.1 | 0% | 0 | 0 | 18.1 | 0 |
| **Zone D3 - Development Area**<br>(Infiltration Zone) | 55.9 | 57% | 0.0 | 32.0 | 0 | 23.9 |
| **Zone D4 - Development Area**[2]<br>(Piped Drainage Zone) | 112.3 | 62% | 56.1 | 14.0 | 0.0 | 42.2 |
| **Total** | **254.9** | **41%** | **56.1** | **48.4** | **18.1** | **132.3** |

**Note 1:** Recharge and ET loses were not applied to Zone D2 in the developed conditions Detailed Groundwater Model as the basin level was applied as a dynamic (head / time) boundary that was calculated independently in the Empirical Groundwater Model.

**Note 2**: It is assumed that runoff from 80% of impervious surfaces in piped drainage catchments will be collected in the piped stormwater system and directed to the basins. The remaining 20% is assumed to be infiltrated at source. This accounts for some non-connected areas (such as footpaths and shed roofs) and leakages and overflows from the stormwater system. It is noted that the water quality modelling described in Section 6 of the IWCMS (SMEC, 2014) applies a slightly higher impervious area (62ha) connected to the basins. This was done to ensure the water quality controls were sized treat all runoff from road and driveway pavements.

### 5.4.2 Rainwater Tanks

The Potable Water Demand Reduction Strategy that is presented in the IWCMS (SMEC, 2014) proposes that all dwellings will be fitted with a 5KL (or larger) rainwater tank that will be plumbed to supply water for toilet flushing, laundry, hot water and all outdoor tap fittings. It is assumed that 80% of the roof areas (equivalent to 47.4ha) within the 255ha development area contribute runoff to the tanks. Water balance modelling was undertaken to estimate the effectiveness of rainwater tanks in reducing potable water demand for a range of climatic conditions. The water balance modelling also calculated daily overflows from the rainwater tanks. The overflow volume was adopted as the runoff profile from the equivalent roof area.

### 5.4.3 Surface Levels

The existing conditions surface elevation data was updated with the design levels established for the 255ha development area. Refer to the IWCMS (SMEC, 2014) for further information on the design surface levels.

### 5.4.4 Evapotranspiration

Evapotranspiration losses from the saturated zone in the developed conditions Detailed Groundwater Model were applied to the same recharge zones depicted in **Plate 5-13**. The following assumptions were adopted:

- **Zone D1 - Golf Course and Open Space:** Applied as per ET Zone 2 from the existing conditions model.

- **Zone D2 - Water Management Area**: Recharge and ET loses were not applied to Zone D2 in the developed conditions Detailed Groundwater Model as the basin level was applied as a dynamic (head/time) boundary that was calculated independently in the Empirical Groundwater Model. This is discussed further in **Section 5.4.5**

- **Zone D3 - Development Area (Infiltration Zone):** Applied as per ET Zone 1 from the existing conditions model. However, ET rates were reduced by a factor of 3 to account for lower ET losses due to the introduction of impervious areas and the reduction of deep rooted vegetation.

- **Zone D4 - Development Area (Piped Drainage Zone):** Applied as per ET Zone 1 from the existing conditions model. However, ET rates were reduced by a factor of 3 to account for lower ET losses due to the introduction of impervious areas and the reduction of deep rooted vegetation.

### 5.4.5 Modelling the Functionality of the Open Basins

The open basins receive water from direct rainfall and connected impervious areas. Outflows from the basins include ET losses, overflows into the gravity drainage system and seepage into the adjoining groundwater. The MODFLOW-SURFACT modelling platform does not have the capability to model outflows from a surface water storage as a function of a level discharge curve. Accordingly, the basin level was applied to the detailed groundwater model as a dynamic (head/time) boundary, with the basin level calculated independently in the Empirical Groundwater Model.

### 5.4.6 Ocean and River Boundary Conditions

The ocean and Wallamba River boundary conditions established for the existing conditions model were applied to the developed conditions groundwater model.

### 5.4.7 Aquifer Properties

The proposed development is not expected to result in any meaningful change to the aquifer properties below typical groundwater levels. Accordingly, the aquifer properties established for the existing conditions model were applied to the developed conditions groundwater model. As discussed in the IWCMS (SMEC, 2014) subsurface drainage will be installed within the road corridors in the piped drainage zone (Zone D4). The subsurface drainage will begin to collect groundwater when groundwater levels are within 1.5m of the surface. The effect of subsurface drainage was not accounted for in the Detailed Groundwater Modelling as it is considered to be a contingency measure rather than a control. Hence, predicted peak groundwater levels in some areas of Zone D4 are likely to be conservative.

# 6 MODEL CONFIDENCE LEVEL CLASSIFICATION

The Australian Groundwater Modelling Guideline (Barnett et al, 2012) provides details on the best practice methods for the development, calibration and application of groundwater models. The guideline recommends that the confidence in any groundwater model is discussed so that realistic expectations are established for the reliability of the model results.

*Table 2.1* from the guideline describes model characteristics and indicators that can be applied to infer a model confidence level classification (Class 1, Class 2 and Class 3 in order of increasing confidence). This information has been applied to the groundwater modelling methods (i.e. considering both the Empirical and Detailed Groundwater Models) established for this project. The following model confidence classifications have been established:

- The geological information used to develop the Detailed Groundwater Model within the project area is considered to be of Class 3 level of confidence due to the homogeneous nature of the geology within the project area.

- The existing conditions modelling methods are considered to be of Class 3 confidence level classification when the models are applied to assessing average and typical wet weather conditions for existing conditions. This level of confidence is achieved because:

    - The Empirical Groundwater Model was calibrated and verified using 38 months of groundwater level data, which included numerous recharge events and extended periods of groundwater recession.

    - The Detailed Groundwater Model was calibrated during a period that was characterised as having above average wet weather conditions. The scaled RMS (Residual Mean Square) calculated from all target values is approximately 5% which is within the groundwater modelling guideline value of 5-10% (Barnett et al, 2012) for acceptable model calibration.

- The existing conditions modelling methods are considered to be of Class 2 level of confidence when used for assessing groundwater characteristics within the project area during extreme wet weather events. This is because the Detailed Groundwater Model has not been calibrated using data obtained during an extreme wet weather event. It is noted that the Empirical Groundwater Model reliably predicted the groundwater level response to a 1 in 10 year ARI event that occurred in May 2013. This model verification improves the confidence of the recharge model in predicting the magnitude of recharge during an extreme rainfall event.

- The existing conditions modelling methods are considered to be of Class 2 level of confidence when used for assessing groundwater characteristics within the project area during below average rainfall conditions. This is due to the Detailed Groundwater Model being developed specifically for wet weather conditions. The calibration and verification of the Empirical Groundwater Model has demonstrated that the model effectively replicates groundwater levels within the development area during below average rainfall conditions.

- The modelling methods are considered to be of Class 2 level of confidence when used for assessing groundwater characteristics under developed conditions. While the unavoidable lack of any developed conditions calibration data reduces the model's confidence, this is offset by the simple functionality of the proposed water management system, which in SMEC's view can be reliably modelled.

In summary, the groundwater modelling methods (i.e. considering both the Empirical and Detailed Groundwater Models) are characterised as having a Class 3 confidence level classification when the models are applied to assessing average and typical wet weather conditions under existing conditions.   A Class 2 confidence level classification is achieved when the models are applied to assessing dry weather and extreme wet weather scenarios under existing conditions and developed conditions scenarios.

It is noted that all models have been developed specifically to assess groundwater characteristics within the 255ha development area.  The confidence level of the Detailed Groundwater Model results are expected to be lower in areas of the model domain that are not within or immediately adjacent to the development area due to the lower resolution of data used to develop and calibrate the model in these areas.

# 7 ASSESSMENT OF GROUNDWATER FLOODING

The Empirical and Detailed Groundwater Models were applied to assess groundwater flooding characteristics within the development area for existing and developed conditions. The models were used to:

- Identify existing groundwater flooding constraints.
- Develop and assess a range of groundwater management solutions.
- Assess groundwater and surface water flooding characteristics for developed conditions.

The following sections detail the abovementioned assessment approach.

## 7.1 Identification of Historic Flood Events

The Empirical Groundwater Model was applied to estimate typical groundwater conditions within the development area over a 114 year simulation period (1900 to May 2013) for both existing and developed conditions. **Plate 7-1** plots the predicted maximum monthly water levels over this period for existing conditions, noting key flood events. Average, and 10th and 90th Percentile groundwater levels (calculated from daily results) are also indicated on the chart for reference.

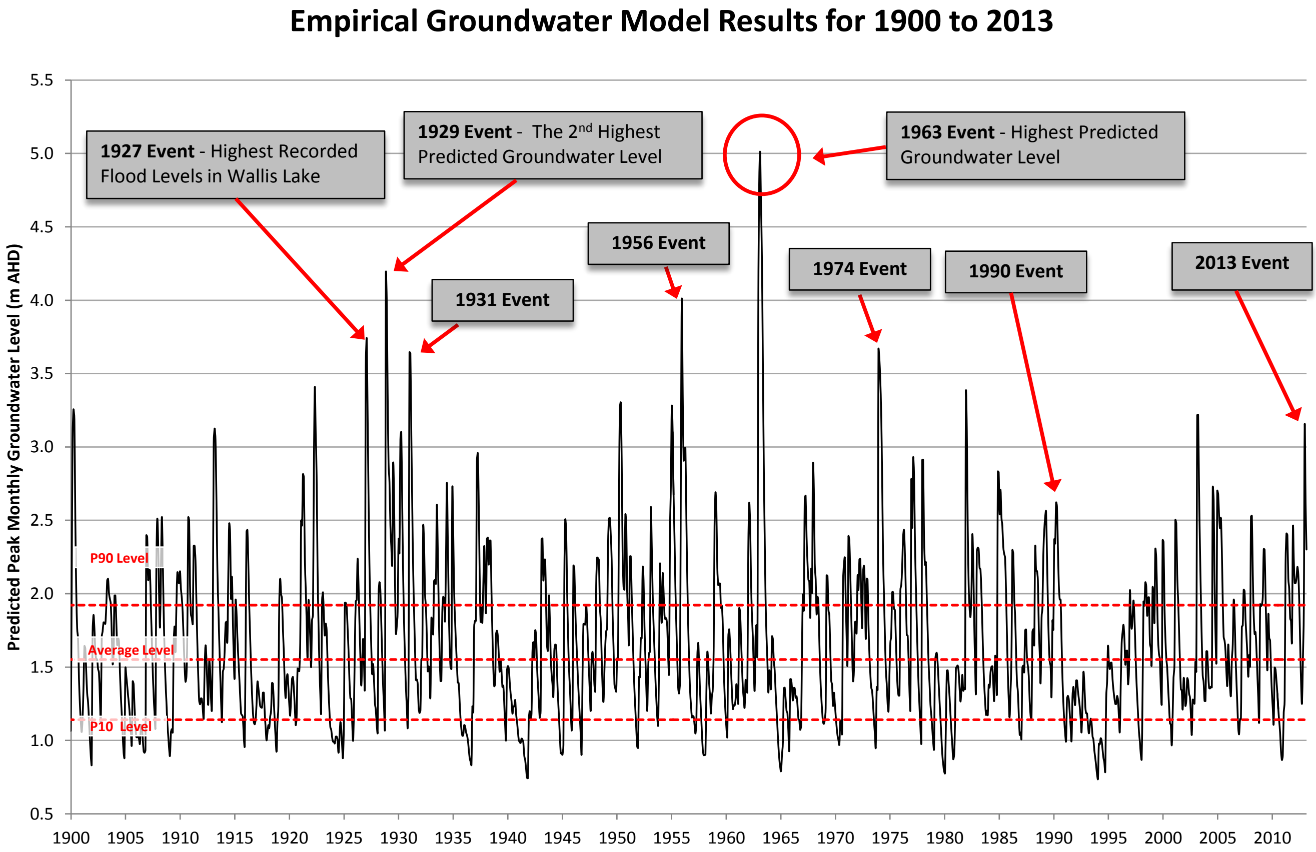


**Plate 7-1** – *Existing conditions results: Maximum monthly groundwater levels from 1900 to 2013*

**Plate 7-2** provides a similar chart comparing peak groundwater and surface water levels for existing and developed conditions. Annual maximum levels are plotted for clarity.

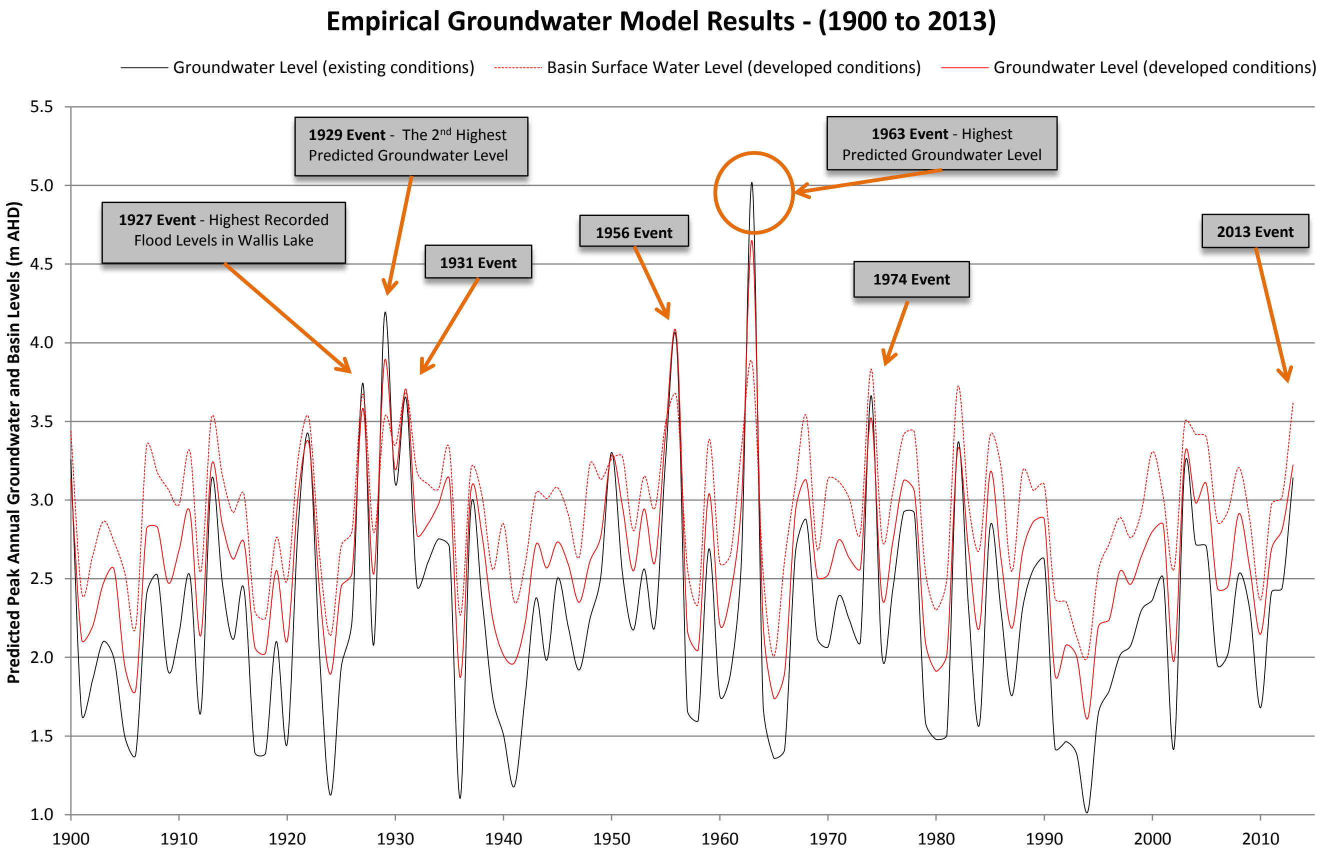


*Plate 7-2 – Existing and Developed Conditions Results – Annual Maximums 1900 to 2013*

Key trends from **Plates 7-1** and **7-2** include:

- Six historic events were identified from the existing conditions model results where the groundwater level is predicted to have exceeded 3.5m AHD. The highest predicted groundwater level (5.0m AHD) occurred in 1963. These groundwater flood events are further discussed below.
- There have been no significant groundwater flood events (i.e. a peak groundwater level greater than 3.5m AHD) since 1974. Hence, the general perception of the potential magnitude of groundwater flooding within the development area may not be reliably held in the community.
- Developed conditions model results indicate that as expected, groundwater flooding will be generated by similar events to existing conditions. However, peak levels during more frequent, higher return period events will be higher (due to higher recharge) and lower during less frequent lower return period events due to the proposed groundwater management system (water management basins and gravity drainage).

**Plates 7-1** and **7-2** identified six historic rainfall events that were likely to have produced the highest groundwater flood levels within the development area between 1900 and 2013 (i.e. exceeding 3.5m AHD). As noted in both plates, an event that occurred in 1963 is predicted to have generated the greatest magnitude groundwater flooding over the period, for both existing and developed conditions. **Table 7-1** provides a brief description of these six historic events and compares the cumulative rainfall (recorded at the South Forster Gauge, BoM 60013), the cumulative recharge and the peak groundwater level (as predicted by the Empirical Groundwater Model) for each event for both existing and developed conditions. Similar information is also provided for the 2013 event for comparative purposes.

***Table 7-1*** *– Key information for historic flood events.*

| Historic Event | Description | Recorded Rainfall | Existing Conditions | | | Developed Conditions | | |
|---|---|---|---|---|---|---|---|---|
| | | | Rank[1] | Recharge Depth[2] | Peak Groundwater Level[2] | Rank[1] | Recharge Depth[2] | Peak Groundwater Level[2] |
| 1963 | The 1963 event comprised a 2 ½ month extended wet period with four embedded +150 mm events. Further information on this event is provided in **Section 7.2** | **1464 mm** over 69 days | **1** | **1179 mm** over 69 days | 5.0 m AHD | **1** | **1258 mm** over 69 days | **Basin** = 3.9 m AHD<br>**Groundwater** = 4.6 m AHD |
| 1929 | The 1929 event comprised and initial 5 day event where 515 mm was recorded. An additional 310 mm occurred over the following 12 days. | **825 mm** over 17 days | **2** | **681 mm** over 17 days | 4.2 m AHD | **9** | **713 mm** over 17 days | **Basin** = 3.5 m AHD<br>**Groundwater** = 3.9 m AHD |
| 1956 | The 1956 event comprised a 1 ½ month extended wet period with 200 mm of rainfall recorded over 2 days at the end of the wet period. | **837mm** over 38 days | **3** | **619 mm** over 38 days | 4.0 m AHD | **6** | **676 mm** over 38 days | **Basin** = 3.7 m AHD<br>**Groundwater** = 4.0 m AHD |
| 1927 | The 1927 event comprised 300 mm of rainfall over two days followed by a 150 mm event two weeks later. The initial event resulted in the highest flood levels on record in Wallis Lake. | **635 mm** over 28 days | **4** | **541 mm** over 28 days | 3.7 m AHD | **5** | **555 mm** over 28 days | **Basin** = 3.7 m AHD<br>**Groundwater** = 3.6 m AHD |
| 1974 | The 1974 event comprised an initial event where 400 mm was recorded over 4 days. This was followed a week later by 140 mm over 4 days. | **644 mm** over 16 days | **5** | **500 mm** over 16 days | 3.7 m AHD | **2** | **544 mm** over 16 days | **Basin** = 3.8 m AHD<br>**Groundwater** = 3.5 m AHD |
| 1931 | The 1931 event comprised an initial 5 day event where 460 mm was recorded. An additional 80 mm occurred over the following 9 days. | **540 mm** over 14 days | **6** | **442 mm** over 14 days | 3.6 m AHD | **4** | **472 mm** over 14 days | **Basin** = 3.7 m AHD<br>**Groundwater** = 3.7 m AHD |
| 2013 | The 2013 event comprised three rainfall events where 649 mm was recorded over a 36 day period. Refer to **Plate 4-5** for a chart of the recorded water level and daily rainfall for this event. | **649 mm** over 36 days | **13** | **423 mm** over 36 days | 3.1 m AHD | **7** | **475 mm** over 36 days | **Basin** = 3.6 m AHD<br>**Groundwater** = 3.2 m AHD |

**Note 1**: Flood rank is calculated from an annual times series of the predicted peak groundwater levels (for existing conditions) and predicted basin levels (for developed conditions) in each calendar year between 1900 and 2013.

**Note 2**: Predicted results refer to results extracted from the Empirical Groundwater Model.

A Flood Frequency Analysis (FFA) was undertaken to estimate the Average Recurrence Interval (ARI) of the historic events identified in **Table 7-1** and to establish a Flood Planning Event for the project. This analysis required the extraction of peak groundwater levels (for existing conditions) and basin levels (for developed conditions), as predicted by the Empirical Groundwater Model, for each calendar year between 1900 and 2013. The annual series was fitted to a Log-Pearson III (LP3) probability distribution, which is one of the methods for FFA recommended in AR&R (IEAust, 1987). The resulting flood frequency plots are presented in **Plate 7-3** for existing conditions and **Plate 7-4** for developed conditions.

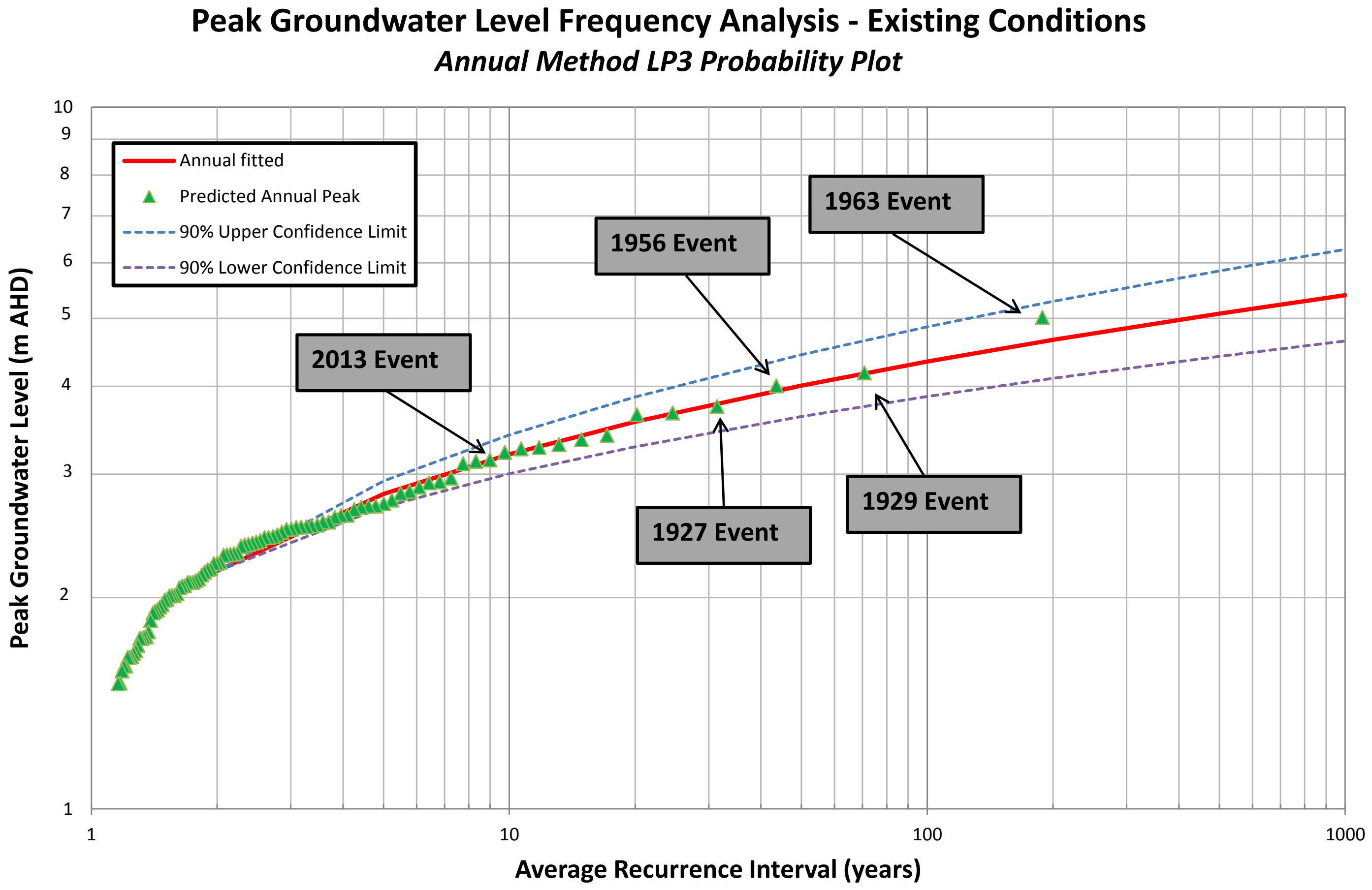


***Plate 7-3** – Flood frequency plot of the predicted peak annual groundwater levels - Existing Conditions*

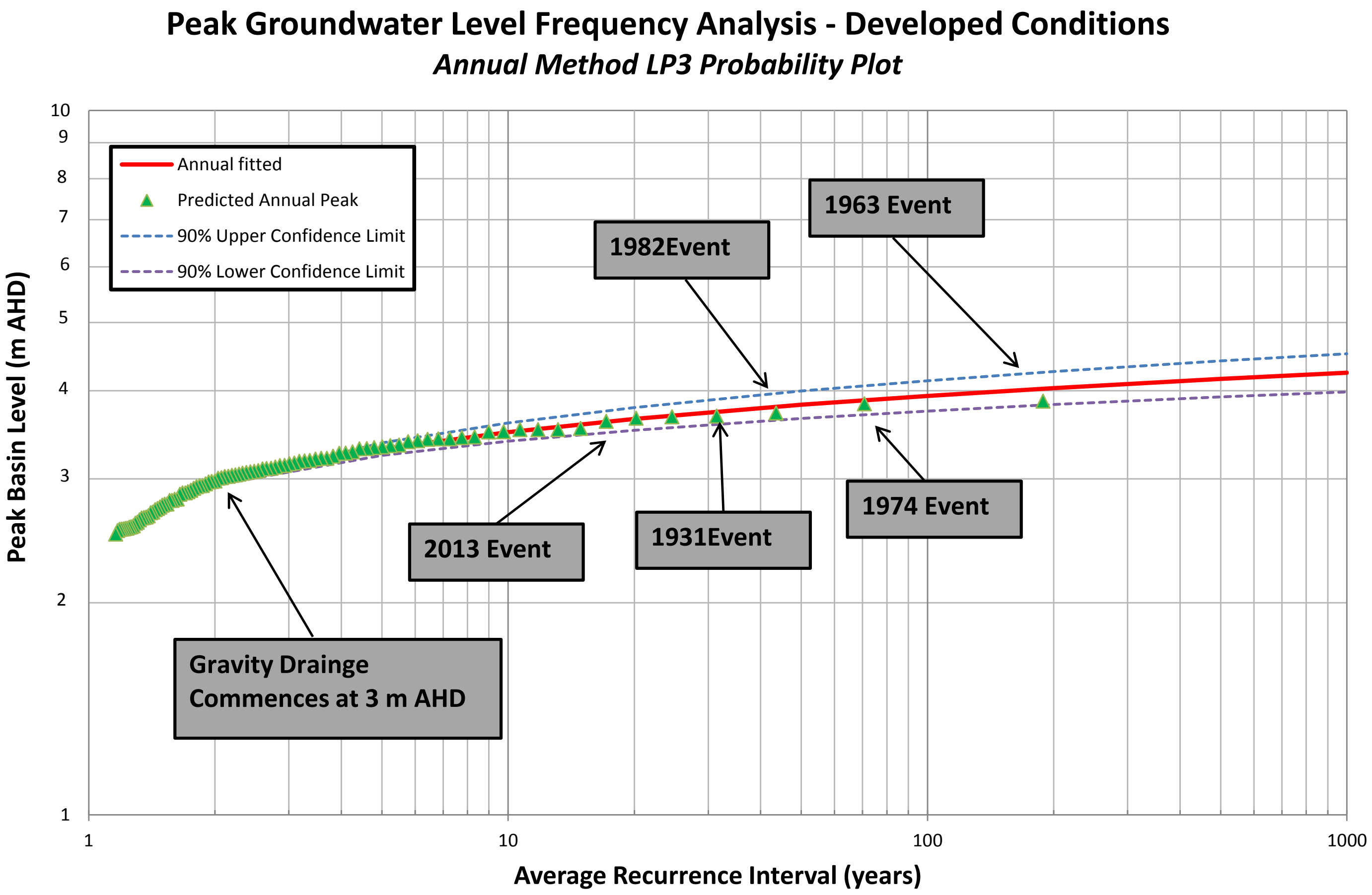


***Plate 7-4** – Flood frequency plot of the predicted peak annual basin level - Developed Conditions*

The FFA results presented above indicate that the 1963 event was an extreme groundwater flooding event with an estimated +100 year ARI for existing conditions. For developed conditions, peak groundwater levels for extreme events are predicted to be lower due to the proposed groundwater management system (water management basins and gravity drainage). Furthermore, as the proposed gravity drainage system will effectively remove water from the development area, peak flood events are more likely to occur from intense rainfall bursts (i.e. 200 to 300mm over 48 hours) that occur following an extended wet period. Notwithstanding, developed conditions model results indicate that the 1963 event would be the governing event over the period assessed, with the FFA indicating that this event would have a similar magnitude to a 100 year ARI event.

It is noted that as the FFA is based on predicted, not measured peak levels and therefore the reliability of the FFA is limited by the reliability of the Empirical Groundwater Model. Notwithstanding, the FFA and the comparison of historic events in **Table 7-1** establishes that the 1963 event is likely to be an event of equal or greater magnitude than the 100 year ARI event for both existing and developed conditions. Accordingly, the 1963 event has been adopted as the **Flood Planning Event** for the project. The 1963 event is discussed further below.

## 7.2 Review of the 1963 Event

The 1963 event comprised more than 1500mm of rainfall over a 3 month period (March to May). The 1963 event was not isolated to the Forster / Tuncurry area with the following totals recorded at regional rain gauges over the 3 month period:

- Coolongalook (60009) – 1277mm

- Bungwahl (Buttaba – 60047) – 1520mm
- Seal Rocks Camping Reserve (60028) – 1071mm

**Plate 7-5** shows the rainfall recorded at the South Forster Gauge (60013) over the event. Both daily depths and cumulative totals are plotted.

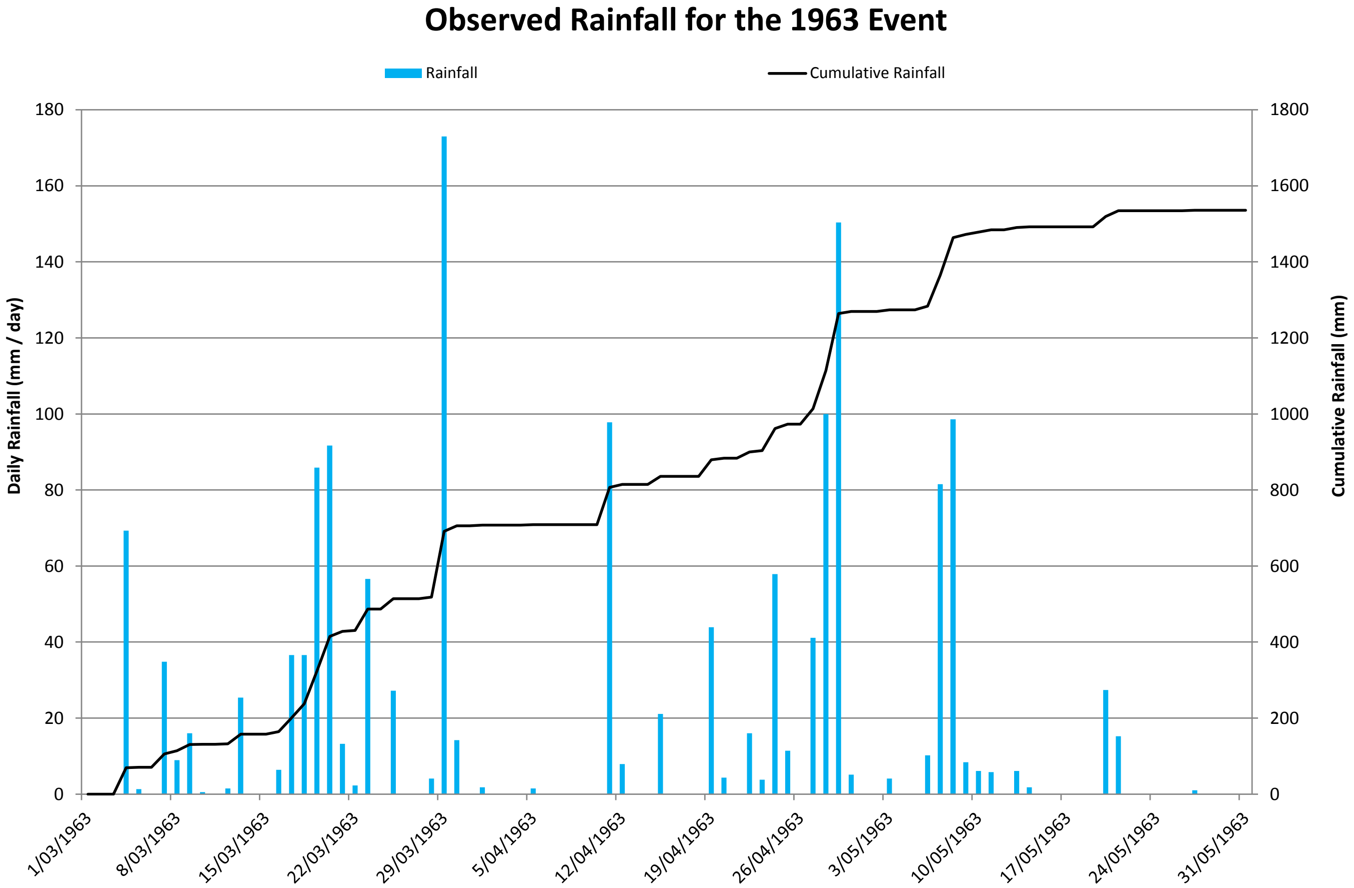


***Plate 7-5*** *- Observed rainfall during the 1963 event.*

The cumulative and daily rainfall profiles plotted in **Plate 7-5** show that the 1963 event comprised a prolonged period of heavy rainfall that included five significant 24 to 48 hour rainfall bursts where between 100 to 250mm was recorded. The predicted recharge profiles for the various recharge zones are discussed in **Section 7.4 .**

Both the Empirical and Detailed Groundwater Models were applied to predict groundwater and surface water flooding characteristics within the development area during the 1963 event. The assessment methodologies, assumptions and model results are discussed in the following sections.

## 7.3 1963 Event – Empirical Groundwater Model Results

The Empirical Groundwater Model applies a continuous simulation modelling approach to estimate typical groundwater and surface water levels within the development area over the 114 year simulation period (1900 to May 2013). Model results for the 1963 event were extracted from the broader results and are presented as follows:

- **Results Summary - Plate 7-6** plots the estimated groundwater levels (for both developed and existing conditions), the water management basin surface water level, rainfall depth and the volume of water predicted to drain through the proposed gravity drainage system.

- **Mass Balance Results** - Mass balance results for the 1963 event are presented in **Plate 7-7** and **Plate 7-8** for existing and developed conditions respectively. The mass balance results diagrammatically show the estimated water fluxes into and out of the 255ha development area as well as the change of groundwater and surface water storage within the development area. The fluxes presented are the cumulative totals over a 69 day period between 1/3/1963 (the day which rainfall commenced) and 8/5/1963 (the day at which the peak water level occurs).

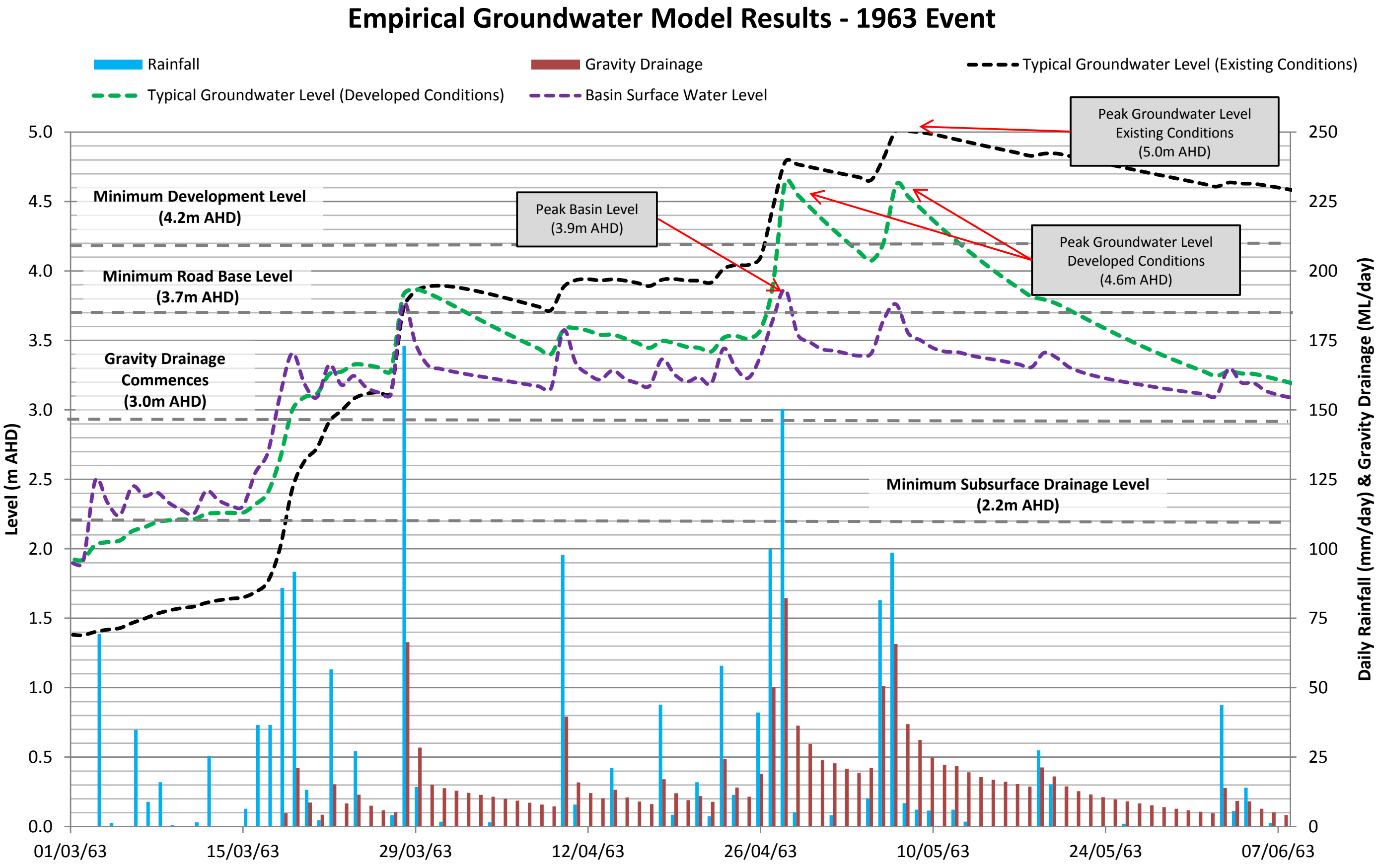


***Plate 7-6 –*** *1963 Event: Empirical Groundwater Model Results Summary*

The model results presented in **Plate 7-6** indicate that the combination of gravity drainage and attenuation provided by the water management basins is effective in maintaining peak basin levels below 3.9m AHD, 0.3m below minimum development levels. In addition, following periods of significant rainfall, the water management basins and gravity drainage will enable basin and adjoining groundwater levels to recede significantly faster than under existing conditions. This significantly reduces the risk of damage to road bases and subgrades due to water logging.

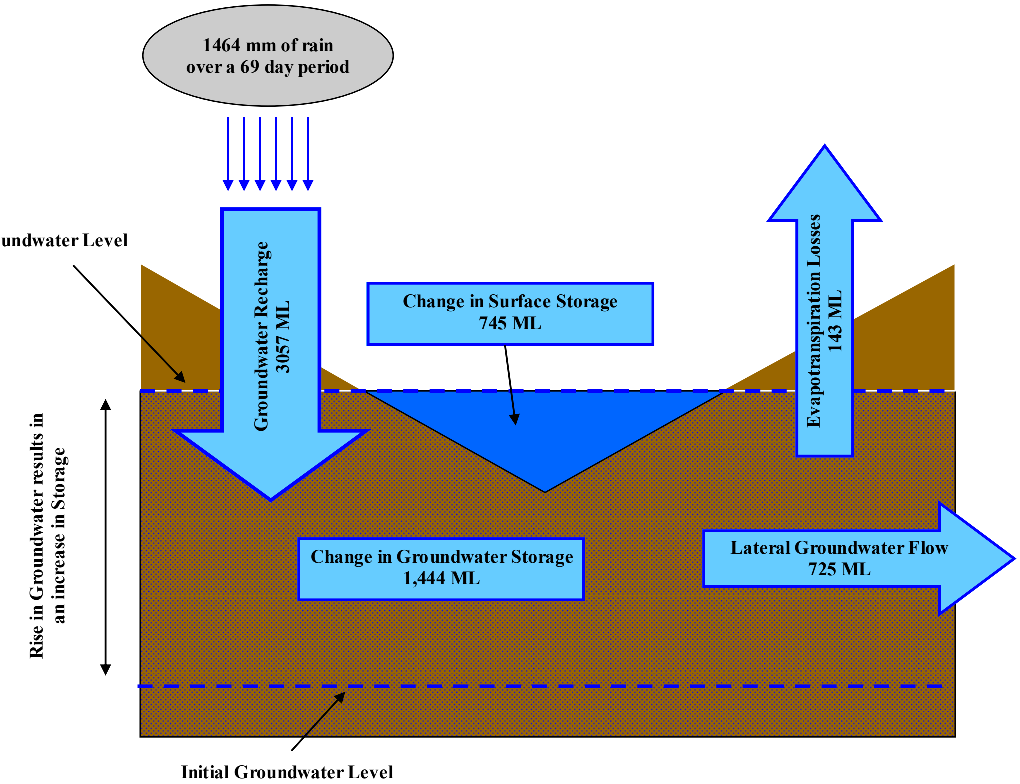


**Plate 7-7** - *Mass balance at the peak of the 1963 event – Existing Conditions.*

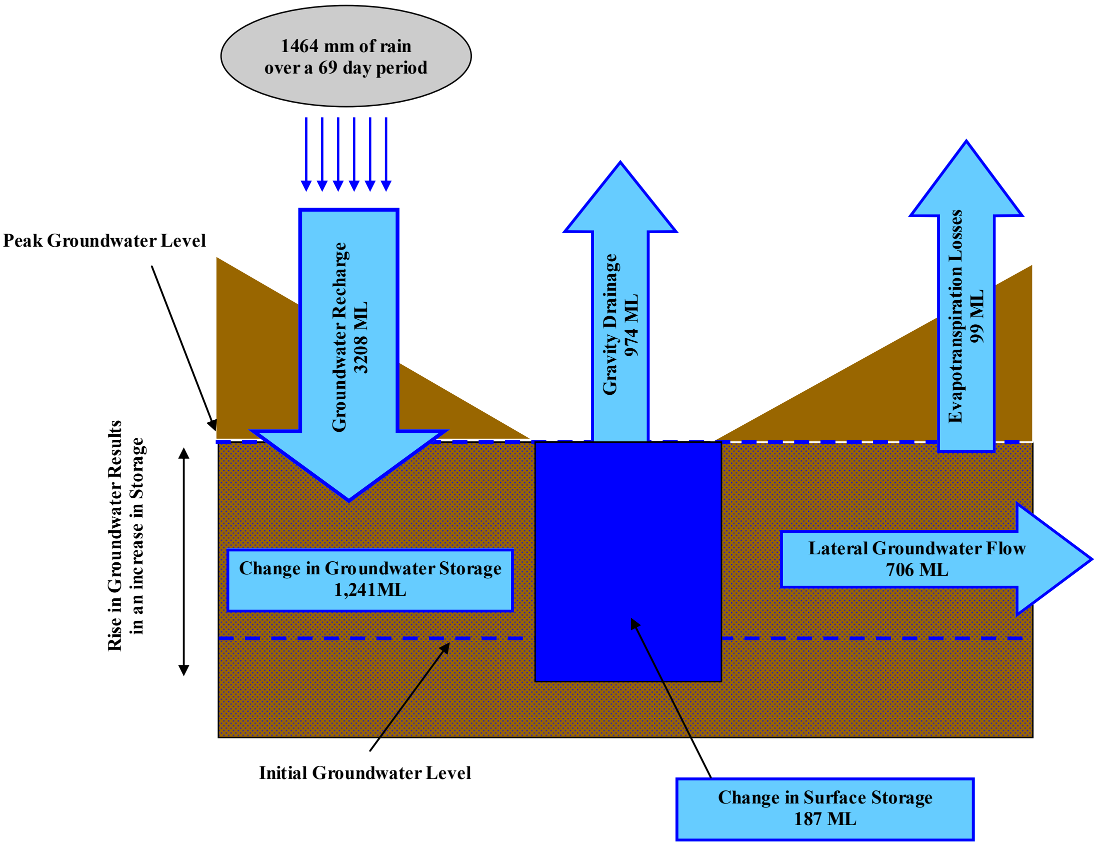


**Plate 7-8** - *Mass balance at the peak of the 1963 event – Developed Conditions.*

The mass balance results for the 255ha development area presented in **Plate 7-7** (existing conditions) and **Plate 7-8** (developed conditions) indicate that over the 69 day period between 1/03/1963 to 8/05/1963 the following fluxes would occur:

- Total recharge within the development area is predicted to be 3,007ML and 3,208ML for existing and developed conditions respectively. The higher recharge for developed conditions is due to a higher conversion of rainfall to recharge from impervious surfaces.

- Lateral groundwater flows from the development area are predicted to be 721ML and 706ML for existing and developed conditions respectively. The slight reduction in the developed conditions flows is due to lower groundwater levels. Lateral groundwater flows are equivalent to approximately 24% of the total recharge. Accordingly, lateral groundwater flows have a moderate influence on peak groundwater flood levels.

- Evapotranspiration losses from the saturated zone (and open basins) are predicted to be 135ML and 99ML for existing and developed conditions respectively. This is equivalent to less than 5% of the total recharge. The lower ET losses for developed conditions is due to the introduction of impervious surfaces and a reduction in deep rooted vegetation. The model results indicate that as expected, evapotranspiration losses will only have a minimal influence on peak groundwater levels during flood events.

- For the developed conditions model, total outflows through the gravity drainage system are estimated to be 974 ML. This is equivalent to 30% of total recharge. Hence, the gravity drainage will be a key measure in managing peak groundwater flood levels.

- Change in groundwater storage would be 1,424ML (47% of recharge) for existing conditions and 1,241ML (37% of recharge) for developed conditions.

- Change in surface water storage would be 727ML (24% of recharge) for existing conditions and 187ML (6% of recharge) for developed conditions. The lower change in storage volume for developed conditions is due to lower peak surface and groundwater levels and the proposed changes to the topography under developed conditions.

In summary, existing conditions model results indicate that fluxes out of the development area are equivalent to 28% of total recharge, with 72% of recharge being stored within the development area, resulting in significant groundwater and surface water flooding. For developed conditions, fluxes out of the development area increase to 55% of total recharge, due to the proposed gravity drainage. Peak flood levels will be lower under developed conditions as the collective groundwater and surface storage volumes will peak at 45% of the total recharge volume.

## 7.4 1963 Event – Detailed Groundwater Model Results

A three-dimensional groundwater model (referred to as the Detailed Groundwater Model) was developed using the MODFLOW-SURFACT modelling platform. The model was applied to estimate groundwater conditions within the development area for the 1963 event. Modelling was undertaken for both existing and developed conditions. The model was also used to assess the effects of potential sea level rise on groundwater flooding.

This section documents model assumptions and results for the following modelled scenarios:

**Existing Conditions**:

- **Scenario EC 1:** Assesses the 1963 event for existing climate conditions.

- **Scenario EC 2**: Assesses the 1963 event for a sea level rise scenario, incorporating a 0.91m increase in the ocean and Wallamba River Estuary water levels, as discussed in **Section 2**.

**Developed Conditions** (with mitigation measures):

- **Scenario DC 1**: Assesses the 1963 event for existing climate conditions.
- **Scenario DC 2**: Assesses the 1963 event for a sea level rise scenario, incorporating a 0.91m increase in the ocean and Wallamba River Estuary water levels, as discussed in **Section 2**.

### 7.4.1 Adopted Parameters

For all scenario runs, the transient calibrated model parameters (horizontal and vertical permeability, specific storage, specific yield and porosity) and the parameter zones remained unchanged. Boundary conditions (recharge, evapotranspiration and ocean and river boundary) were formulated for each modelled scenario and are discussed further below.

### 7.4.2 Model Assumptions

#### *Initial Conditions*

For each scenario, initial groundwater levels are required over the Model Domain. As there is no available information on groundwater conditions on 1 March 1963 (day 1 of the 1963 event simulation), initial groundwater levels were inferred from the level calculated by the Empirical Groundwater Model on 1 March 1963. As the Empirical Groundwater Model was calibrated based on groundwater level data from MB01, a representative groundwater surface was extracted from the transient calibration model results file that aligns with the target level at MB01. For climate change scenarios (Scenarios EC2 and DC2) the initial water level surface was increased by 0.6m to account for the effects of sea level rise on the likely groundwater conditions. This adjustment is considered to be conservative in areas that are more than 500m from the ocean or Wallamaba River Estuary.

Adopted representative levels at MB01 for each scenario are as follows:

- Scenarios **EC 1** and **DC 1**: 1.45m AHD
- Scenarios **EC 2** and **DC 2**: 2.05m AHD

#### *Recharge*

Recharge profiles for the 1963 event were calculated independently using the Empirical Groundwater Model and the methods described in **Section 5**. As described in **Section 5**, there are three separate recharge zones in the existing conditions model (Zone 1, 2 & 7 and 3) for which recharge was calculated using the Empirical Groundwater Model. The developed conditions model includes an additional two recharge zones (Zones D3 and D4) for which recharge was calculated using the Empirical Groundwater Model. Estimated total recharge depths applied to the 1963 event simulations for these zones are as follows:

- **Zone 1** (existing conditions): 1,268mm or 83% of rainfall.
- **Zones 2** and **7** (existing conditions): 1,331mm or 87% of rainfall.

- **Zone 3** (existing conditions): 1,342mm or 87% of rainfall.
- **Zone D3** (developed conditions): 1,307mm or 85% of rainfall.
- **Zone D4** (developed conditions): 657mm or 43% of rainfall.

It is noted that the recharge in Zone D4 is significantly lower than other zones as it is assumed that 80% of the runoff from impervious areas is discharged directly into the open basins via the piped drainage system.

**Plate 7-9** compares the cumulative recharge profiles for the abovementioned zones to the cumulative rainfall over the period.

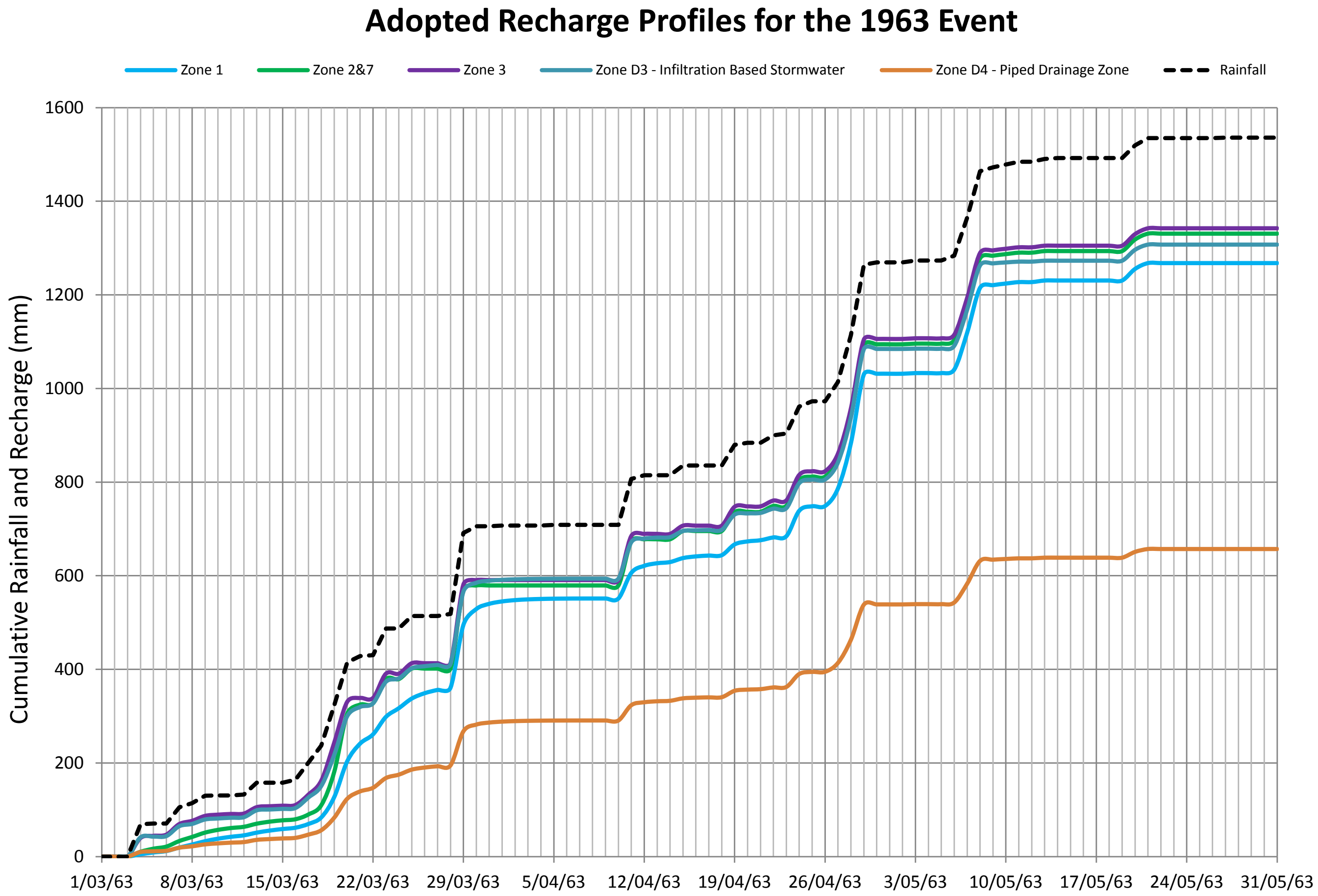


***Plate 7-9** – Adopted recharge profiles for the 1963 event.*

## *Evapotranspiration*

No evaporation or evapotranspiration data is available for 1963. Monthly averages from the Taree Weather Station (BoM 60141) were adopted.

## *River Boundary*

No data for river stage heights was available for the 1963 event. To estimate these values, comparisons between recent river stage measurements and existing rainfall were compared to establish indicative river stage heights over the period. **Plate 7-10** plots the predicted river stage profiles at Tuncurry and Nabiac for existing climate scenarios (Scenarios EC 1 and DC 1). The model interpolates between these two profiles. The calculated river stage levels at Tuncurry were increased by 0.91m for the climate change scenarios (Scenarios EC 2 and DC 2) due to sea level rise.

No changes to the river boundary were made for the corresponding developed conditions scenarios.

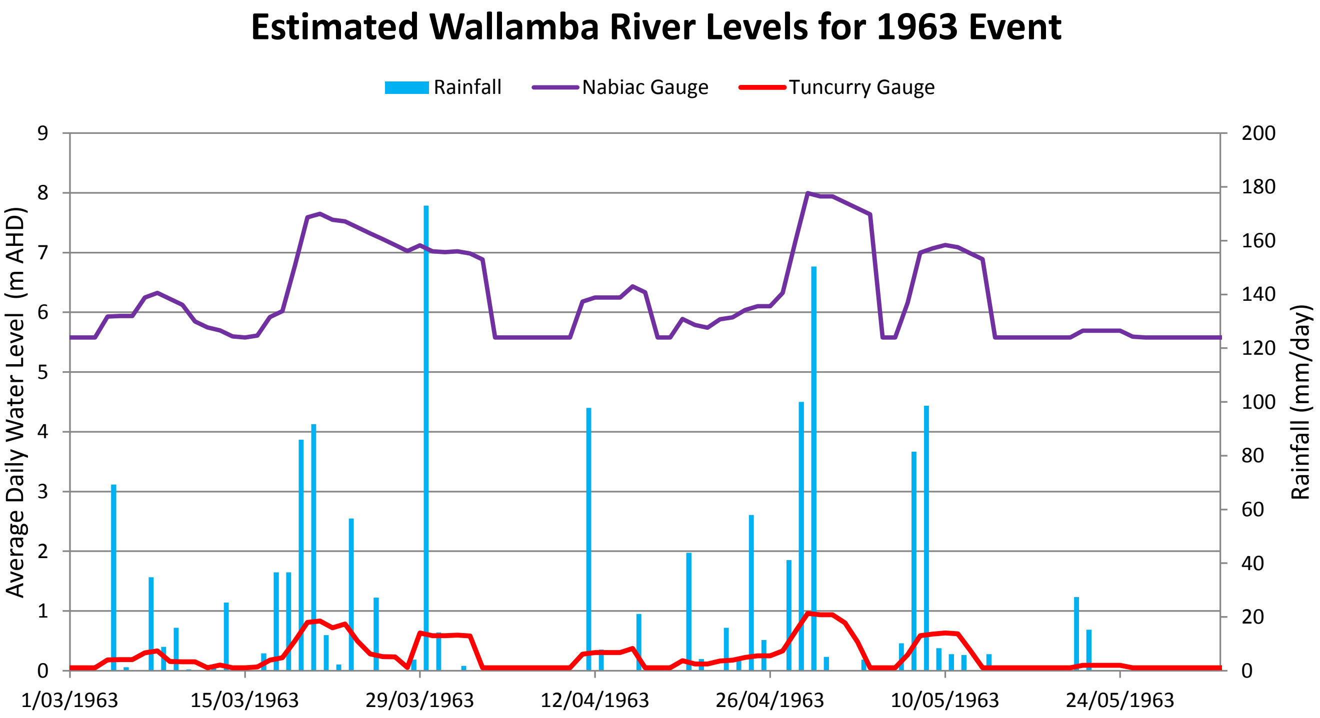


***Plate 7-10*** *- Adopted Wallamba River boundary levels for the 1963 event (existing climate conditions).*

## *Ocean Boundary*

No site specific tidal data or wave height data was available for the 1963 event. Ocean boundary levels were calculated using the methods described in **Section 5**, applying the following assumptions:

- Predicted tides were generated for the 1963 event using fitted tidal constituents derived from the harmonic analysis of offshore water level data recorded by the Waverider buoy at Crowdy Head.
- Wave over height effects were calculated using indicative 80th Percentile wave conditions between March and May that were calculated from water level data recorded by the Waverider buoy at Crowdy Head.

**Plate 7-11** plots the predicted tide, calculated wave over height and adopted still level for the 1963 event for existing climate scenarios (Scenarios EC 1 and DC 1). The calculated still levels were increased by 0.91m for the climate change scenarios (Scenarios EC 2 and DC 2) due to sea level rise.

No changes to the ocean boundary were made for the corresponding developed conditions scenarios

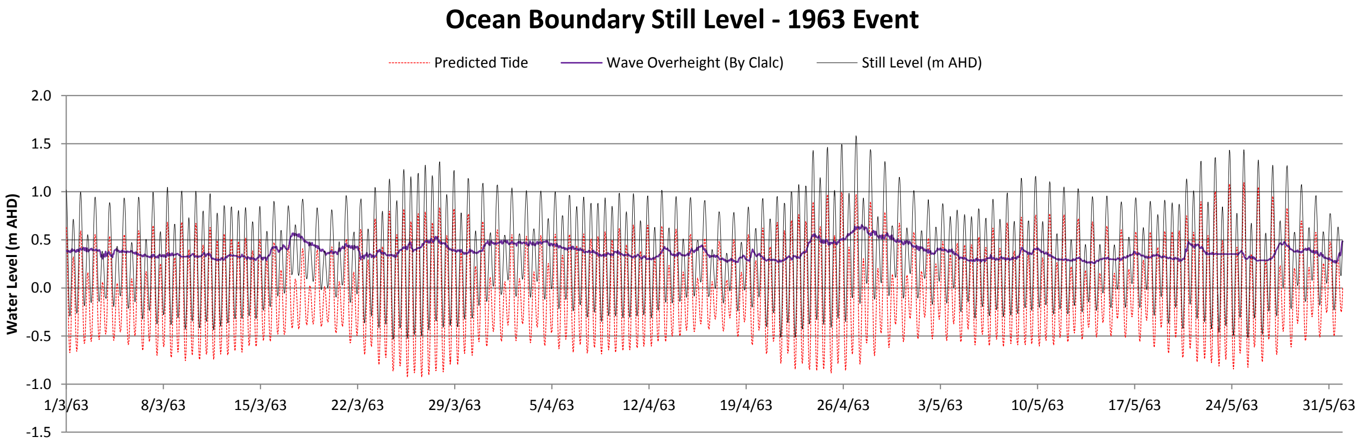


***Plate 7-11*** *- Adopted ocean boundary levels for the 1963 event (existing climate conditions).*

### *Water Management Basin Boundary*

The water management basins receive runoff from direct rainfall and connected impervious areas and groundwater inflows (when the groundwater level is higher than the basin water level). Outflows from the basins include ET losses, overflows into the gravity drainage system and seepage into the adjoining groundwater (when the groundwater level is lower than the basin level). The MODFLOW-SURFACT modelling platform does not have the capability to model outflows from a surface water storage as a function of a level discharge curve (or rating curve). Accordingly, the basin water level was applied to the Detailed Groundwater Model as a transient (head/time) boundary, with the basin level calculated independently in the Empirical Groundwater Model. The applied transient basin boundary level is depicted in **Plate 7-6**.

The boundary area was applied to Zone D2 that is depicted in **Plate 5-13**.

While it is acknowledged that the Empirical Groundwater Model estimates the flow exchange between the water management basins and the surrounding groundwater using a simplistic approach, applying a forced boundary is not considered to reduce the model's reliability. This is because the basin level can be predicted with confidence by the Empirical Groundwater Model due to basin level regime being primarily governed by:

- The inflow volumes from direct rainfall and connected impervious surfaces.
- The storage profiles of the water management basins.
- Outflows through the gravity drainage system, which as established in **Plate 7-8** accounts for 30% of the total recharge volume within the development area.

## 7.4.3 Model Results

### *Existing Conditions Results*

The existing conditions detailed groundwater modelling results for the 1963 event are presented as follows:

- **Plate 7-12** shows the predicted peak groundwater head contours and surface ponding depths for the 1963 event with no sea level rise (Scenario EC 1).
- **Plate 7-13** shows the predicted peak groundwater head contours and surface ponding depths for the 1963 event with a 0.91m sea level rise (Scenario EC 2).

- **Plate 7-14** shows a difference map depicting changes in peak groundwater level due to a 0.91m rise in sea levels.

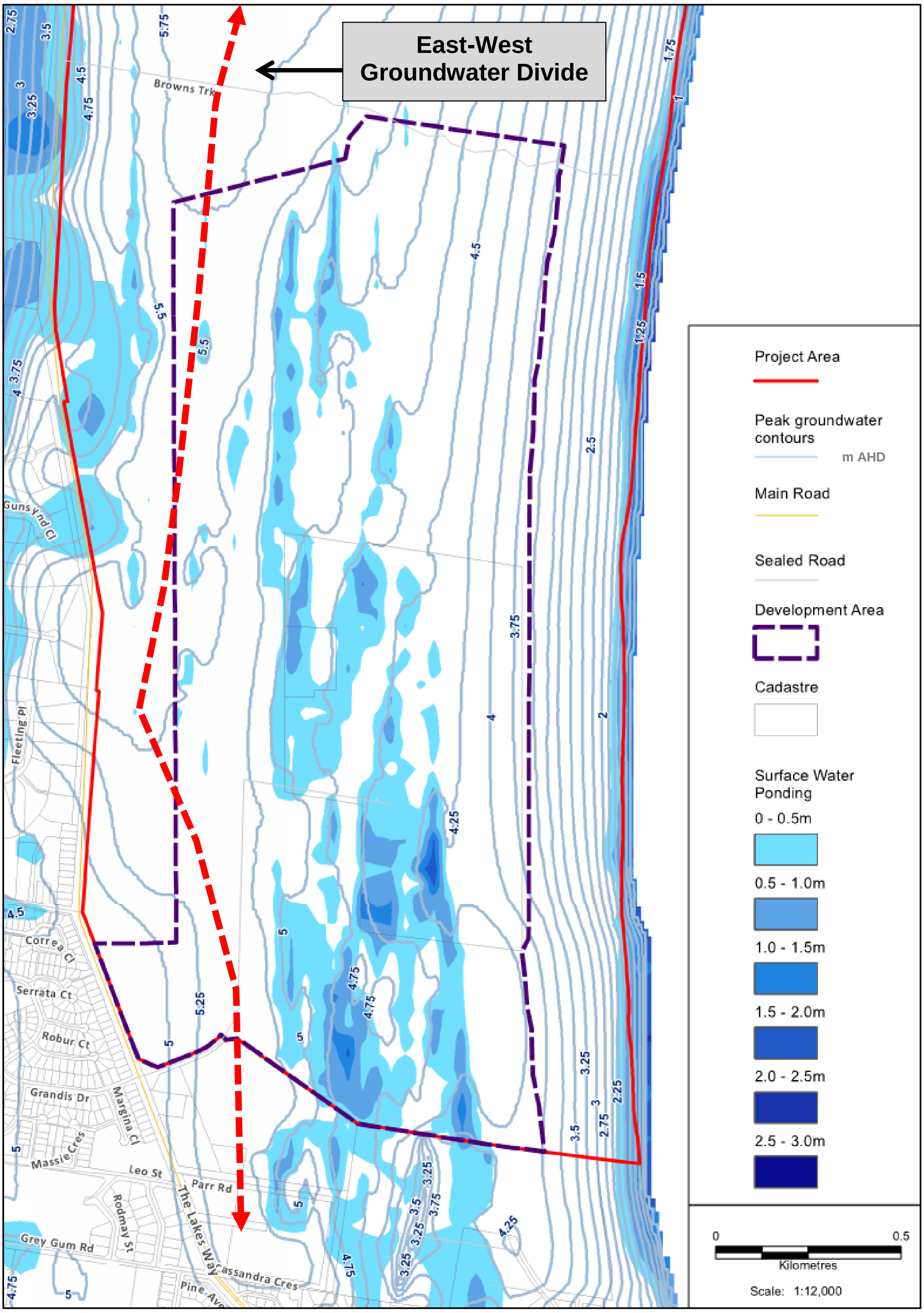


***Plate 7-12** – Existing Conditions Results: Predicted peak groundwater head contours and surface ponding depths for the 1963 event with no sea level rise (Scenario EC 1).*

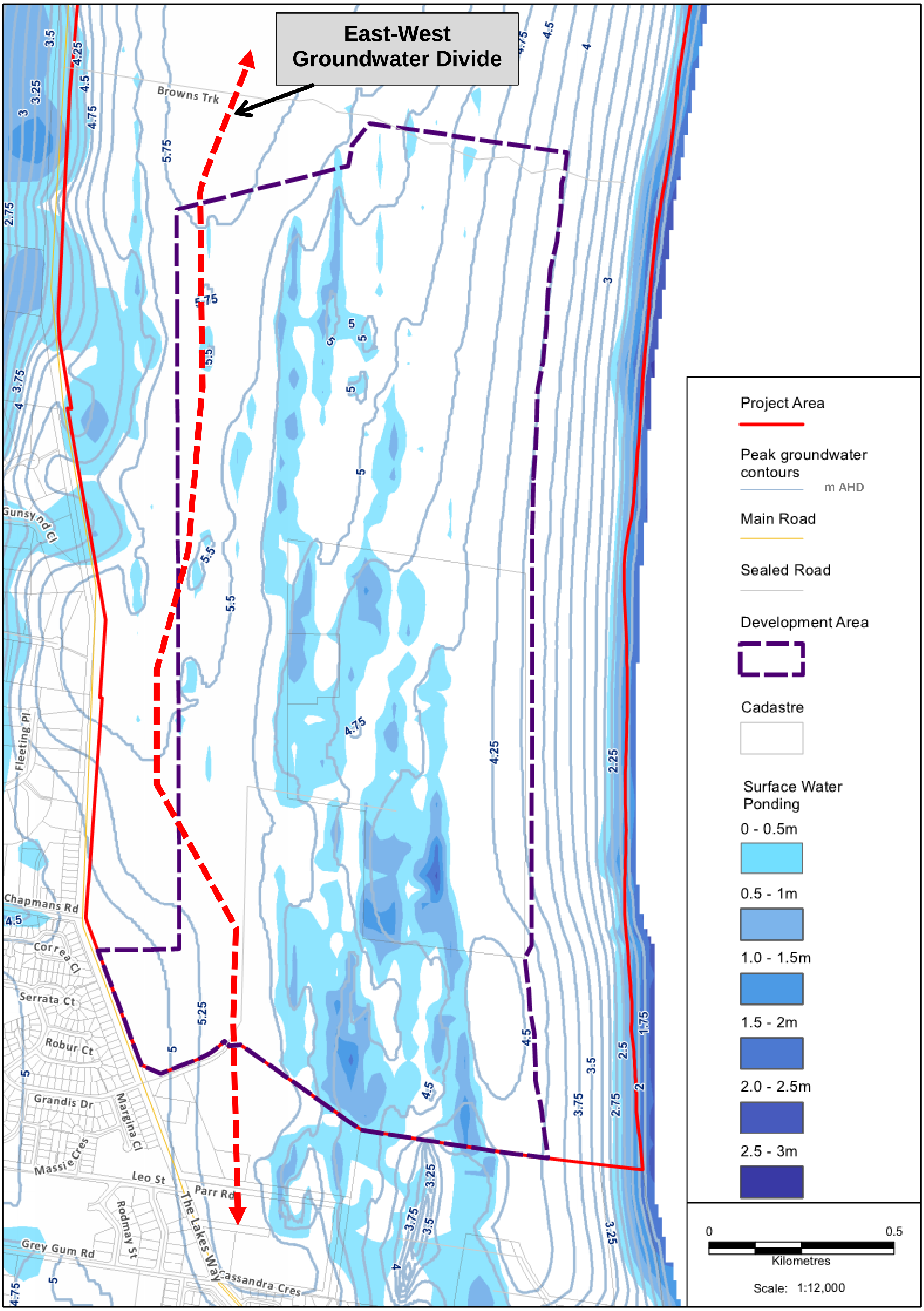


***Plate 7-13 -*** *Existing Conditions Results: Predicted peak groundwater head contours and surface ponding depths for the 1963 event with 0.91m sea level rise (Scenario EC 2).*

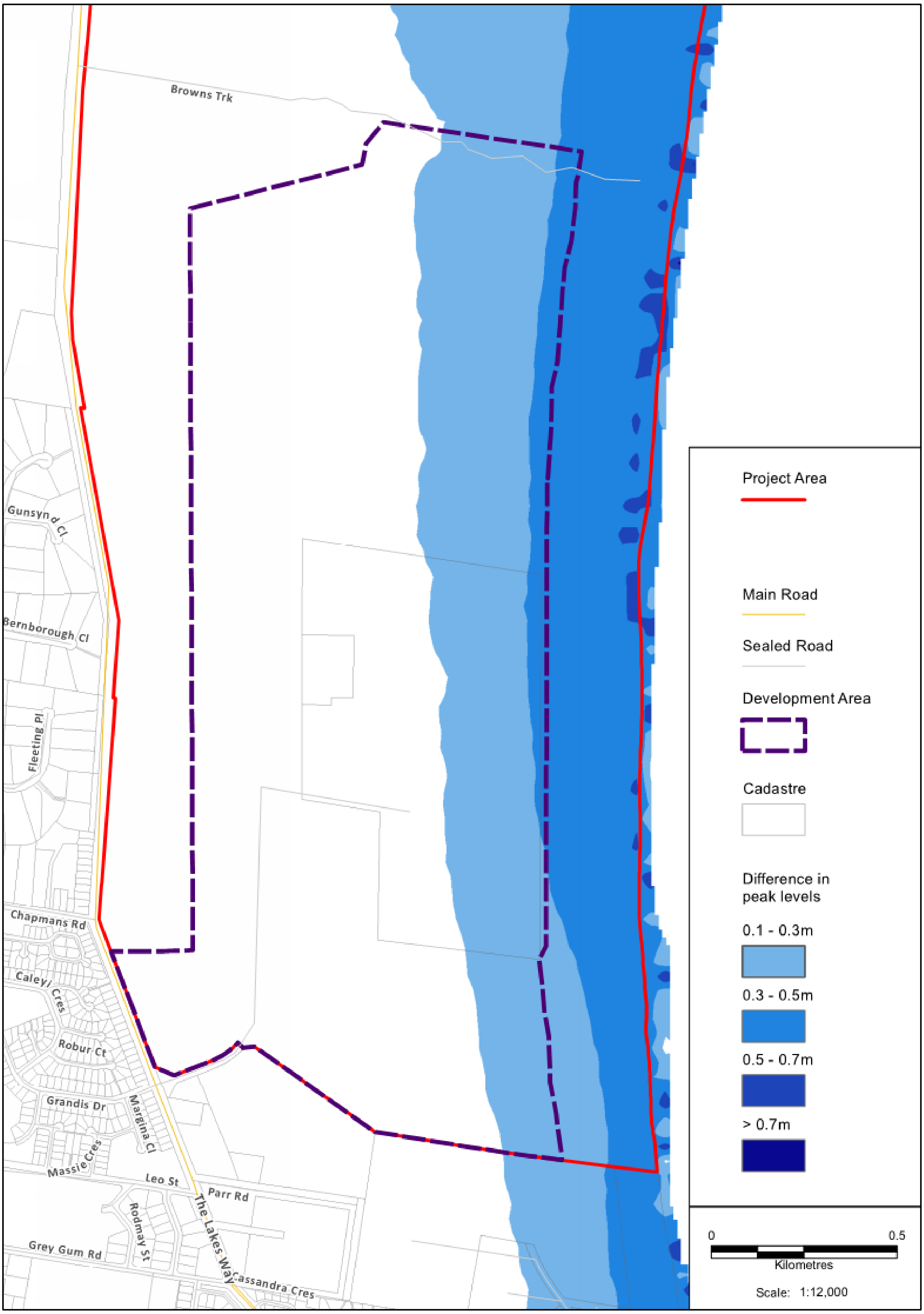


**Plate 7-14** - *Existing Conditions Results: Difference map showing changes in in peak groundwater level due to 0.91m sea level rise.*

The following key conclusions can be made from the existing conditions model results:

- **Peak Groundwater Levels** - With reference to **Plate 7-12**, peak groundwater levels are predicted to range between 3.75m AHD in the eastern portion of the development area to 5.5m AHD in the western portion of the development area. Model results indicate that groundwater flow within the development area is generally to the east, towards the ocean. The groundwater divide (between groundwater flows to the east and west) is located approximately in line with the western boundary of the development area.

- **Surface water ponding** is predicted to occur in areas where the existing surface level is below the peak groundwater level. Surface ponding depths are indicated thematically in **Plate 7-12** (EC 1) and **Plate 7-13** (EC 2). These plates show that surface ponding is concentrated in the middle portion of the development area where existing surface levels are generally lower than the levels in the eastern and western portions of the development area. Model results indicate that the majority of surface ponding would be less than 1m deep. However, depths in excess of 2m are predicted in some localised areas where surface levels are below 3m AHD. As discussed in **Section 4**, surface water ponding attenuates the rise of groundwater levels as surface water storage is more efficient (volumetrically) than groundwater storage. Hence, if the ponded areas are filled, groundwater levels would rise further to compensate for the loss in surface storage.

- **Impacts of Sea Level Rise** - **Plate 7-14** compares the difference in the peak groundwater levels for the existing climate conditions (EC 1) and the sea level rise scenario (EC 2). Model results indicate that a 0.91m rise in sea level would result in an increase in peak groundwater levels of approximately 0.3m at the eastern boundary of the development area. Negligible increases are predicted for development areas that are offset from the eastern boundary by 300m or more.

In summary, the existing conditions model results have demonstrated that significant groundwater flooding constraints exist within the development area. Without mitigation measures, these constraints would significantly reduce the portion of the development area that is suitable for urban land use.

### *Developed Conditions Results*

The developed conditions detailed groundwater modelling results for the 1963 event are presented as follows:

- **Plate 7-15** shows the predicted peak groundwater head contours and surface ponding depths for the 1963 event with no sea level rise (Scenario DC 1).

- **Plate 7-16** shows the predicted peak groundwater head contours and surface ponding depths for the 1963 event with a 0.91m sea level rise (Scenario DC 2).

- **Plate 7-17** shows a difference map depicting changes in peak developed conditions groundwater levels due to a 0.91m sea level rise.

- **Plate 7-18** shows a difference map depicting changes in peak groundwater levels due to the development. The groundwater level differences are calculated from the sea level rise scenarios (EC 2 and DC 2). It is noted that the relative changes in groundwater levels are expected to be similar for both the with and without sea level rise scenarios. Hence a difference map comparing EC 1 and DC 1 has not been prepared.

The model results described above are discussed after the plates. Proposed flood risk management measures and predicted flood impacts are also discussed, making reference to the abovementioned results.

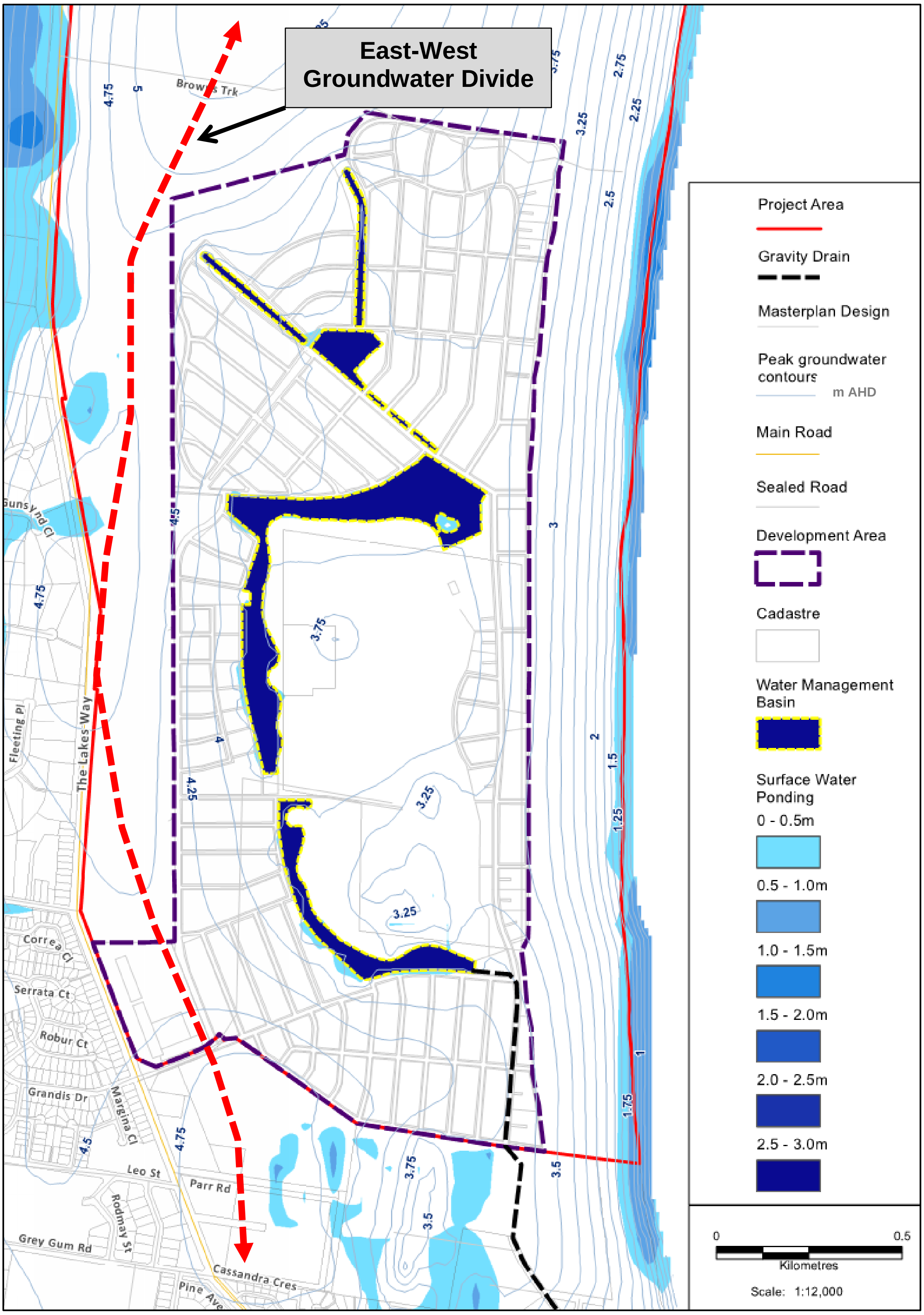


**Plate 7-15 –** *Developed Conditions Results: Predicted peak groundwater head contours and surface ponding depths for the 1963 event with no sea level rise (Scenario DC 1).*

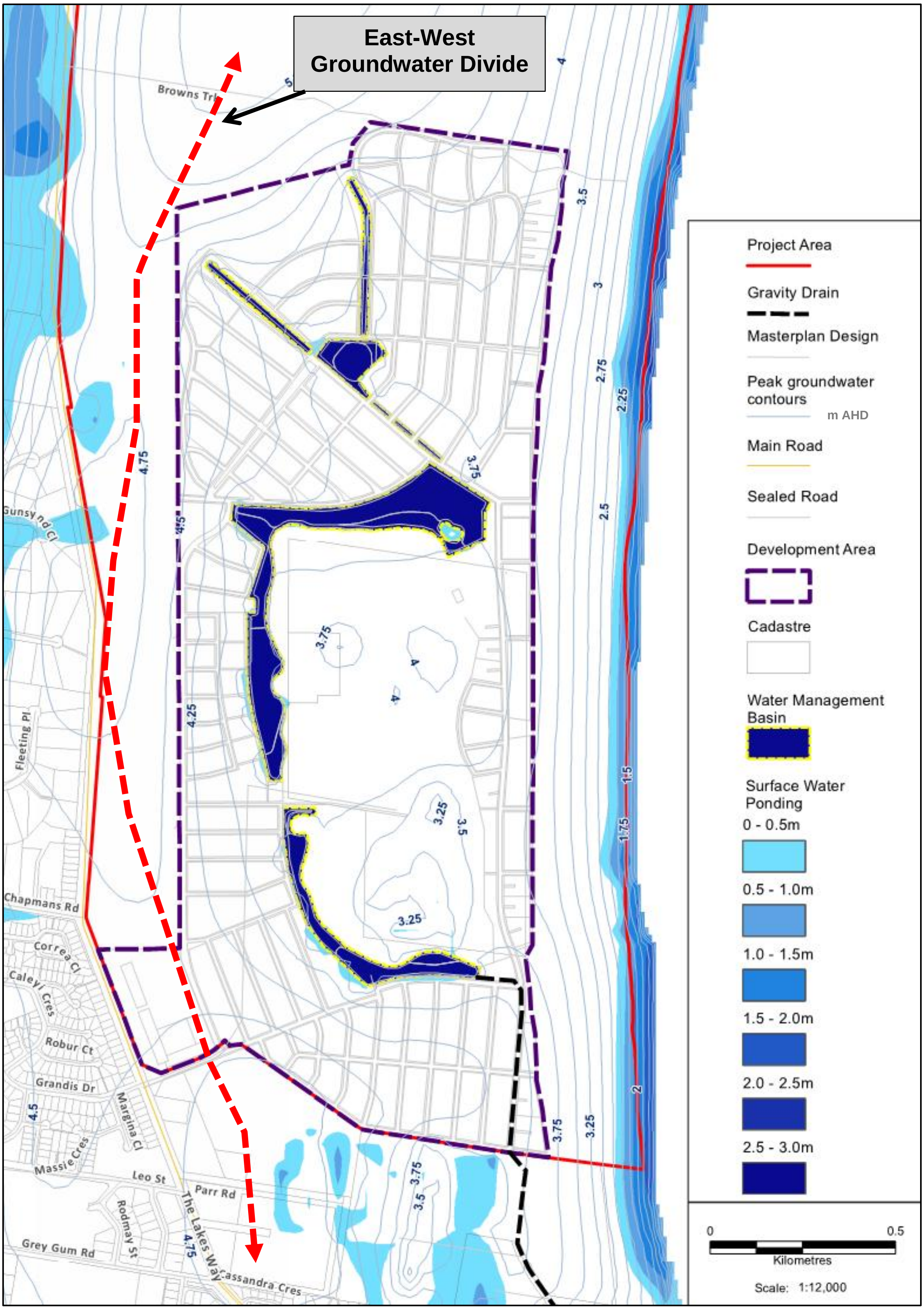


***Plate 7-16 -** Developed Conditions Results: Predicted peak groundwater head contours and surface ponding depths for the 1963 event with 0.91m sea level rise (Scenario DC 2).*

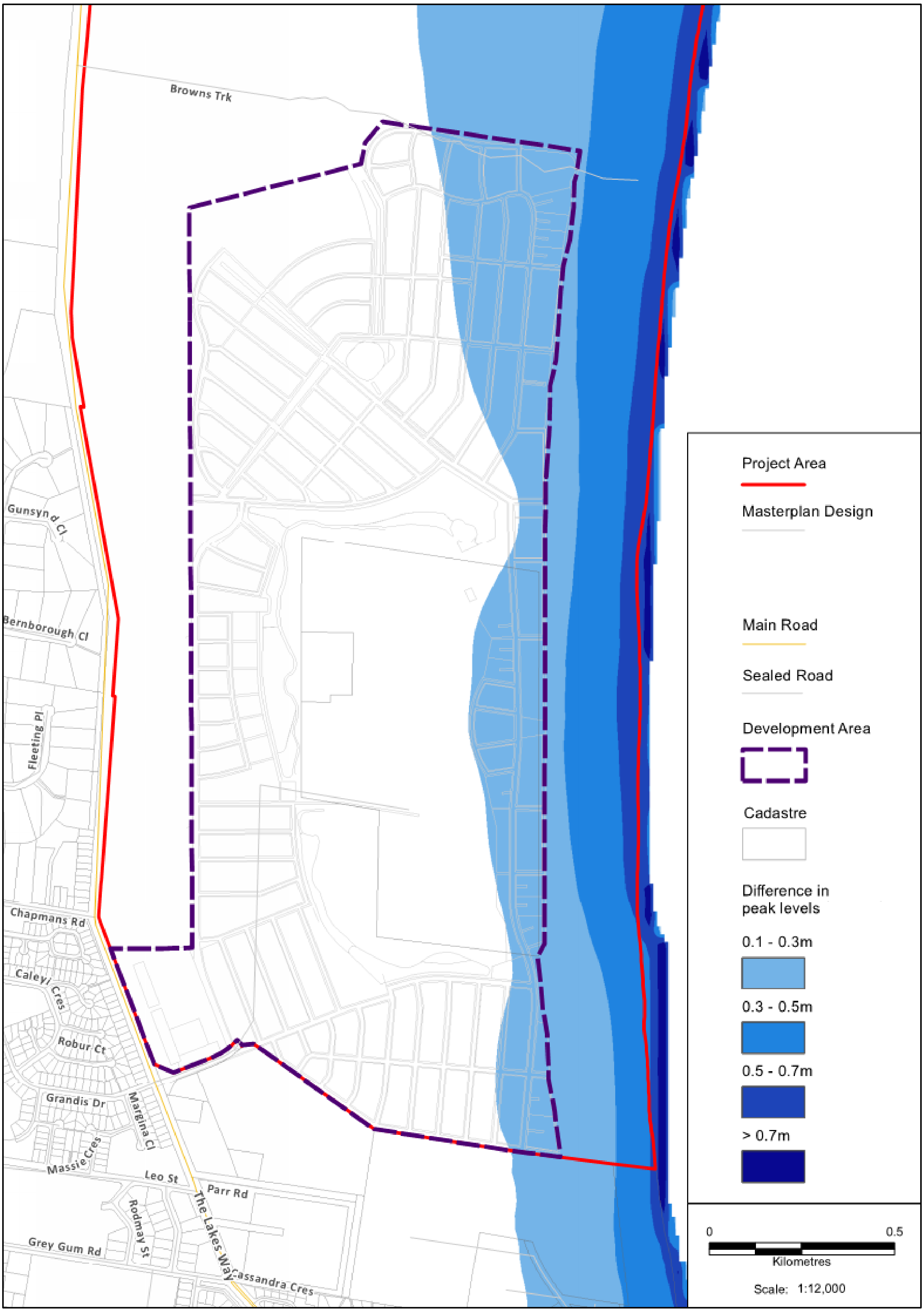


***Plate 7-17 -*** *Developed Conditions Results: Difference map showing changes in peak groundwater level due to 0.91m sea level rise.*

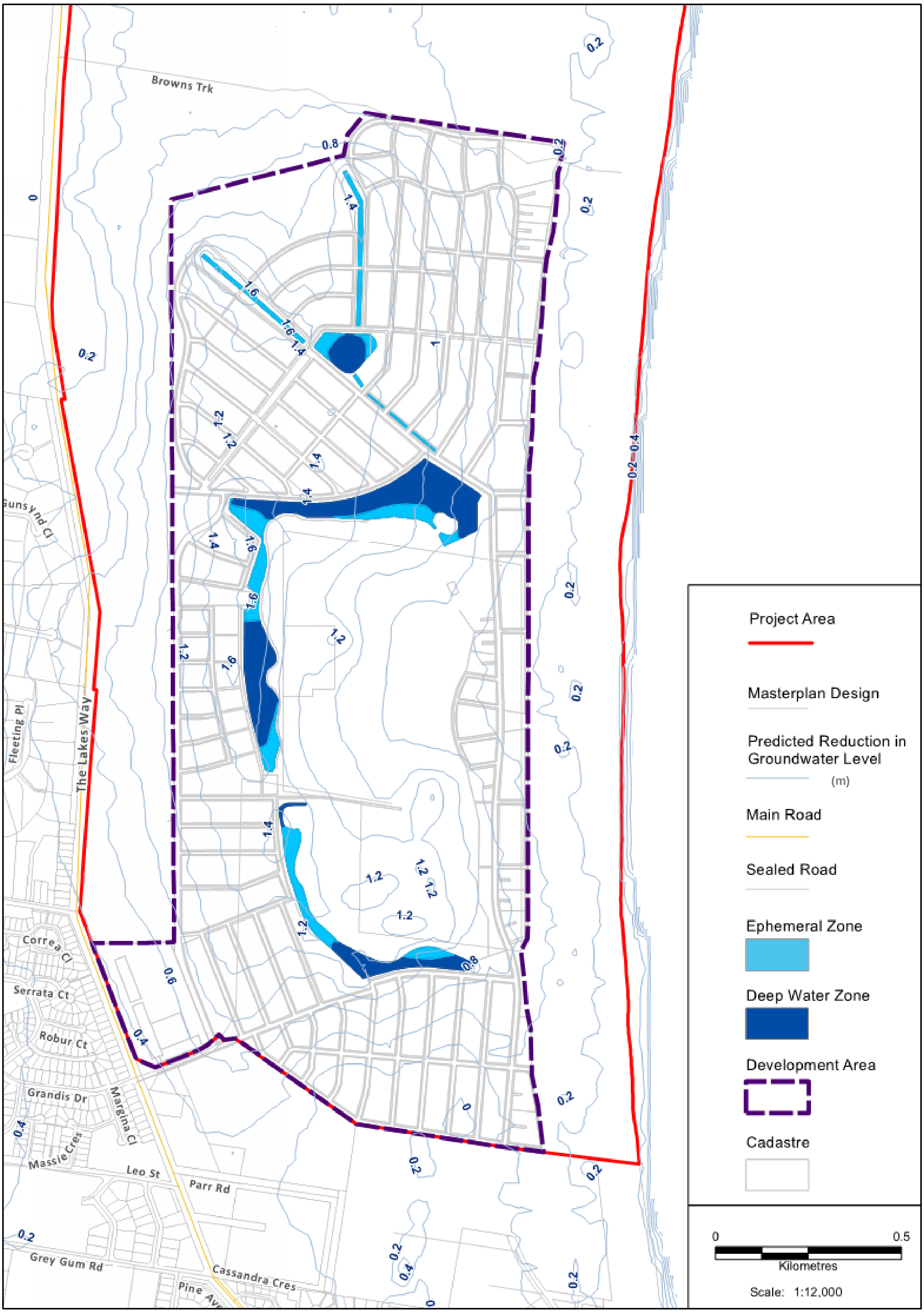


***Plate 7-18** – Flood Impacts: Difference map showing changes in peak groundwater levels due to the development (Compares EC2 to DC2 i.e. includes 0.91m sea level rise).*

The following key conclusions can be made from the developed conditions model results:

- **Peak Groundwater Levels** - With reference to **Plate 7-15** and **Plate 7-16**, peak groundwater levels are predicted to range between 3.50 m AHD to 4.75 m AHD within the development area. Model results indicate that during flood conditions, groundwater flow within the development area will be generally towards the water management basins, which will be dewatered by the gravity drainage system.

- **Surface water ponding** – as indicated in **Plate 7-15** and **Plate 7-16**, due to the lower groundwater levels and modified design surface levels, peak groundwater levels are not predicted to intercept the surface within development areas. Hence, no surface ponding beyond the water management basins is expected.

- **Impacts of Sea Level Rise** - **Plate 7-17** compares the difference in the peak groundwater levels for the existing climate conditions (DC 1) and the sea level rise scenario (DC 2). Similarly to the existing conditions results, a 0.91m rise in sea level would result in an increase in the peak groundwater levels of less than 0.3m at the eastern boundary of the development area. Negligible increases are predicted for development areas that are offset from the eastern boundary by 300m or more.

- **Flood Impacts** – With reference to **Plate 7-18** model results indicate that the proposed flood risk mitigation measures will significantly reduce peak groundwater levels during the 1963 event, with the following reductions predicted:

    - Reductions of +1m are predicted for development areas adjacent to the water management basins and within the piped drainage zone (Zone D4).

    - Reductions of +1m are predicted for the majority of the golf course. This significantly reduces the risk of groundwater flooding intercepting the surface and killing grass on the golf greens and fairways.

    - Peak groundwater levels are generally lower in areas outside of the development area. Hence, the project is expected to reduce the existing groundwater flood risk in adjacent properties.

In summary, the developed conditions model results have demonstrated that the proposed flood risk mitigation measures will be effective in reducing peak flood levels for both current and 2100 sea rise scenarios. Flood planning levels and flood risk management measures are discussed in the following sections.

## 7.5 Adopted Flood Planning Levels

As established earlier in this section, the 1963 event is considered to be representative of a 100 year ARI event and has been adopted as the flood planning event for the project. Model results from this event were used to establish the following 100 year ARI levels for the project:

- **3.9m AHD** has been adopted as the 100 year ARI surface water level in the Golf Course Basins, based on the Empirical Groundwater Model Results.

- **4.1m AHD** has been adopted as the 100 year ARI surface water level in the Northern Basin and Northern Finger Drains, based on the Empirical Groundwater Model Results. This includes a 0.2m contingency to allow for some head loss between the northern water management basins and the inlet to the gravity drain. The 0.2m contingency is expected to be conservative as only minor head losses are expected due to the low flow rates (less than 1m$^3$/s) and significant flow conveyance areas in the basins and connecting surface drains (Note: all culverts that connect basin areas under roads will be adequately sized to have negligible head loss).

- The groundwater levels (assuming a 0.91m sea level rise) that are presented in **Plate 7-16** have been adopted as the 100 year ARI Groundwater Levels.

Refer to the IWCMS (SMEC, 2014) for further information on the water management basins.

## 7.6 Flood Risk Management Measures

The following flood risk management measures are proposed:

- The **water management basins** and **gravity drainage system** will be designed to collectively maintain the 100 year ARI basin water level at 3.9m AHD.
- **Subsurface drainage** will be provided under road bases in the piped drainage zone (Zone D4). The subsurface drainage will dewater the local groundwater into the stormwater pipes that will drain to the water management basins. When basin levels are elevated, it is expected that the subsurface drainage will be temporarily constrained by basin tailwater effects. It is noted that the effect of the subsurface drainage was not considered in the groundwater modelling as the subsurface drainage is considered to be a contingent control that will be effective in managing elevated groundwater levels in localised areas.
- **Minimum road surface levels** will be 4.2m AHD in areas adjacent to the Golf Course Basins and 4.4m AHD in development areas adjacent to the Northern Basin and Finger Drains, providing approximately 0.3m freeboard to the predicted peak basin levels.
- **Minimum habitable floor levels** will be 4.7m AHD in areas adjacent to the Golf Course Basins and 4.9m AHD in development areas adjacent to the Northern Basin and Finger Drains. These levels will provide 0.8m freeboard to the predicted 100 year ARI peak basin levels. This freeboard is 0.3m higher than typical freeboards applied in NSW, which adds additional contingency to the flood risk management measures. This is considered appropriate given the uncertainties in estimating recharge and groundwater flow characteristics within the development area.

Refer to the IWCMS (SMEC, 2014) for further information on the abovementioned flood risk management measures.

# 8 ASSESSMENT OF GROUNDWATER REGIME

The Empirical and Detailed Groundwater Models were applied to assess the existing and developed conditions groundwater regime within the development area for a full range of climatic conditions. The models were specifically used to:

- Estimate groundwater recharge characteristics and groundwater level regimes within the development area.
- Estimate groundwater levels within and adjacent to the development area during a typical wet weather event.
- Estimate water fluxes (or rates of flow) into and out of the groundwater system within the development area.
- Assess the project’s impact on the local and regional groundwater regime.

The following sections detail the results from the abovementioned assessments.

## 8.1 Site Recharge Characteristics

Groundwater recharge is calculated in the Empirical Groundwater Model on a daily time step over the 114 year simulation period (1900 to May 2013). An annual recharge coefficient, which is defined as the net annual recharge expressed as a percentage of net annual rainfall, was calculated for each year of the simulation period from the daily results. **Plate 8-1** provides a percentile chart that compares the estimated annual recharge coefficients within the development area for existing and developed conditions. For simplicity, the developed conditions recharge coefficient has been calculated based on the net recharge from the collective land uses proposed within the 255ha development area. Refer to **Table 5-5** for further details on the proposed land use configurations. The calculated annual recharge coefficient for impervious areas, with and without rainwater tanks, is also shown in **Plate 8-1** for comparative purposes. It is also noted that developed conditions recharge includes water discharged to the water management basins via the piped drainage system (in Zone D4).

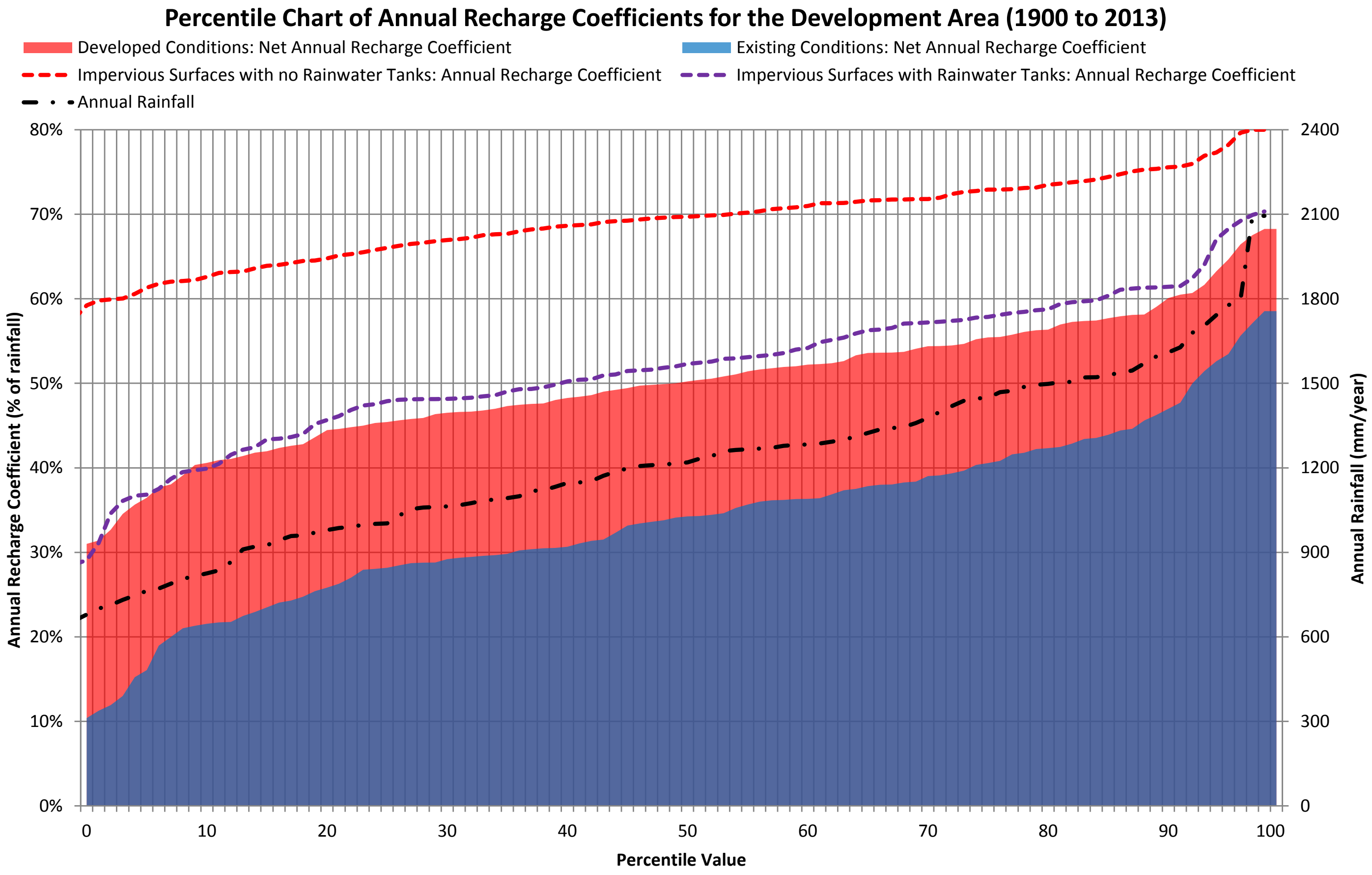


***Plate 8-1-*** *Empirical Groundwater Model Results: Percentile Chart: Annual Recharge Coefficients for the 255ha Development Area*

The model results presented in **Plate 8-1** indicate that under developed conditions, recharge within the development area will increase from 21% of rainfall to 40% of rainfall during low (10th percentile) rainfall years. The relative magnitude of the increase progressively reduces in wetter years, with model results indicating that recharge during a typical wet (90th Percentile) year will be 46% and 59% of rainfall for existing and developed conditions respectively.

The increased recharge under developed conditions is primarily attributed to the introduction of impervious surfaces to the urban landscape. It is estimated that 41% of the development area will comprise impervious surfaces. The model results presented in **Plate 8-1** indicate that annual recharge from impervious surfaces will be:

- 62% and 75% of rainfall for typical dry (10th Percentile) and wet (90th Percentile) conditions respectively for impervious surfaces that do not drain to rainwater tanks; and
- 39% and 61% of rainfall for typical dry (10th Percentile) and wet (90th Percentile) conditions respectively for impervious surfaces that do drain to rainwater tanks

## 8.2 Groundwater Level Regimes

The Empirical Groundwater Model calculates typical groundwater and basin water levels (developed conditions only) on a daily time step over the 114 year simulation period (1900 to May 2013). Model results for both existing and developed conditions are presented as follows:

- **Plate 8-2** shows a percentile chart that compares groundwater and basin levels. The percentile values were calculated from the daily results over the simulation period.

- **Plate 8-3** is a daily exceedance chart that compares groundwater and basin water levels. The charted values were calculated from the daily results over the simulation period. Note a logarithmic scale has been applied to the horizontal axis.

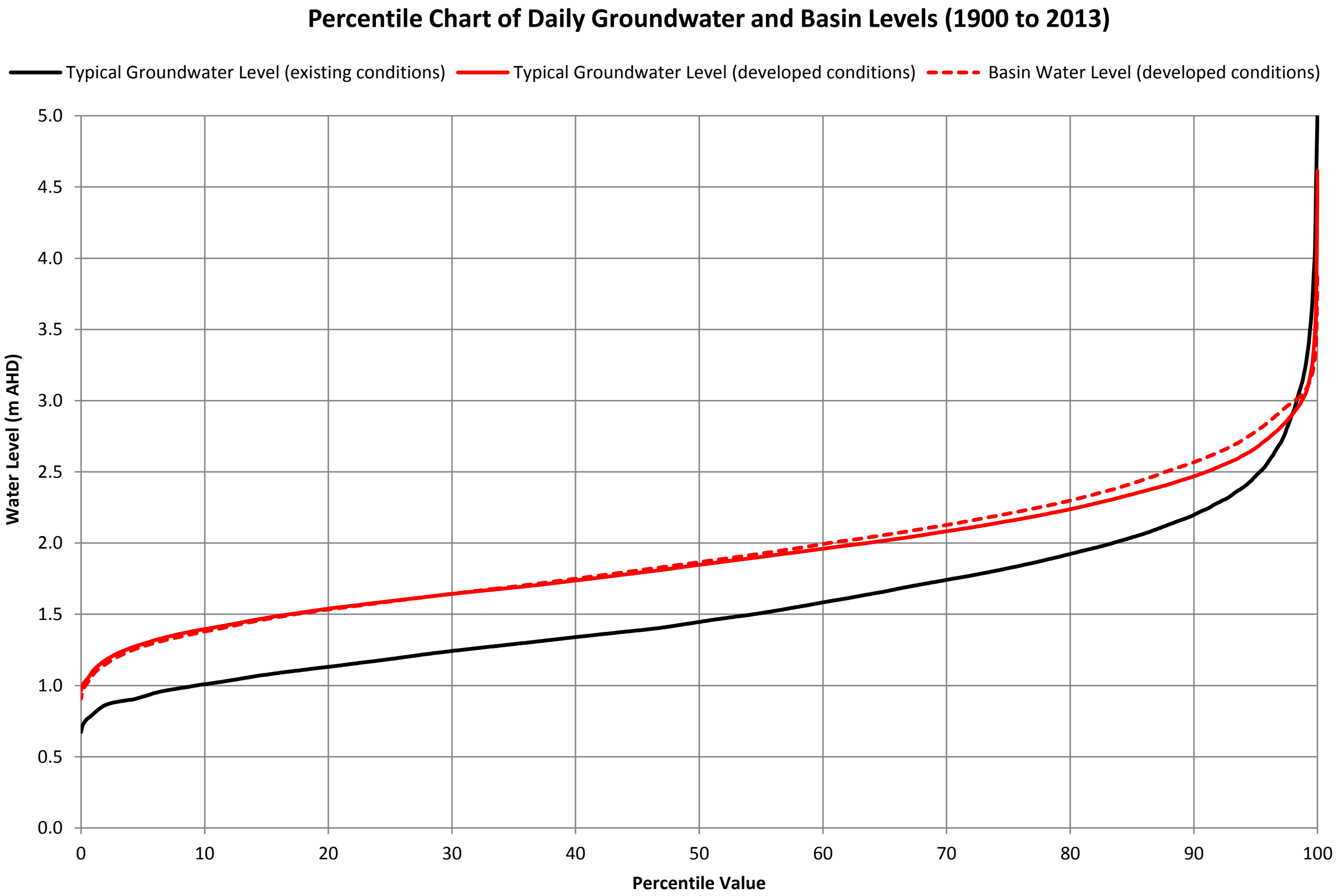


**Plate 8-2 -** *Empirical Groundwater Model Results: Daily Percentile Chart: Groundwater and Basin Water Levels*

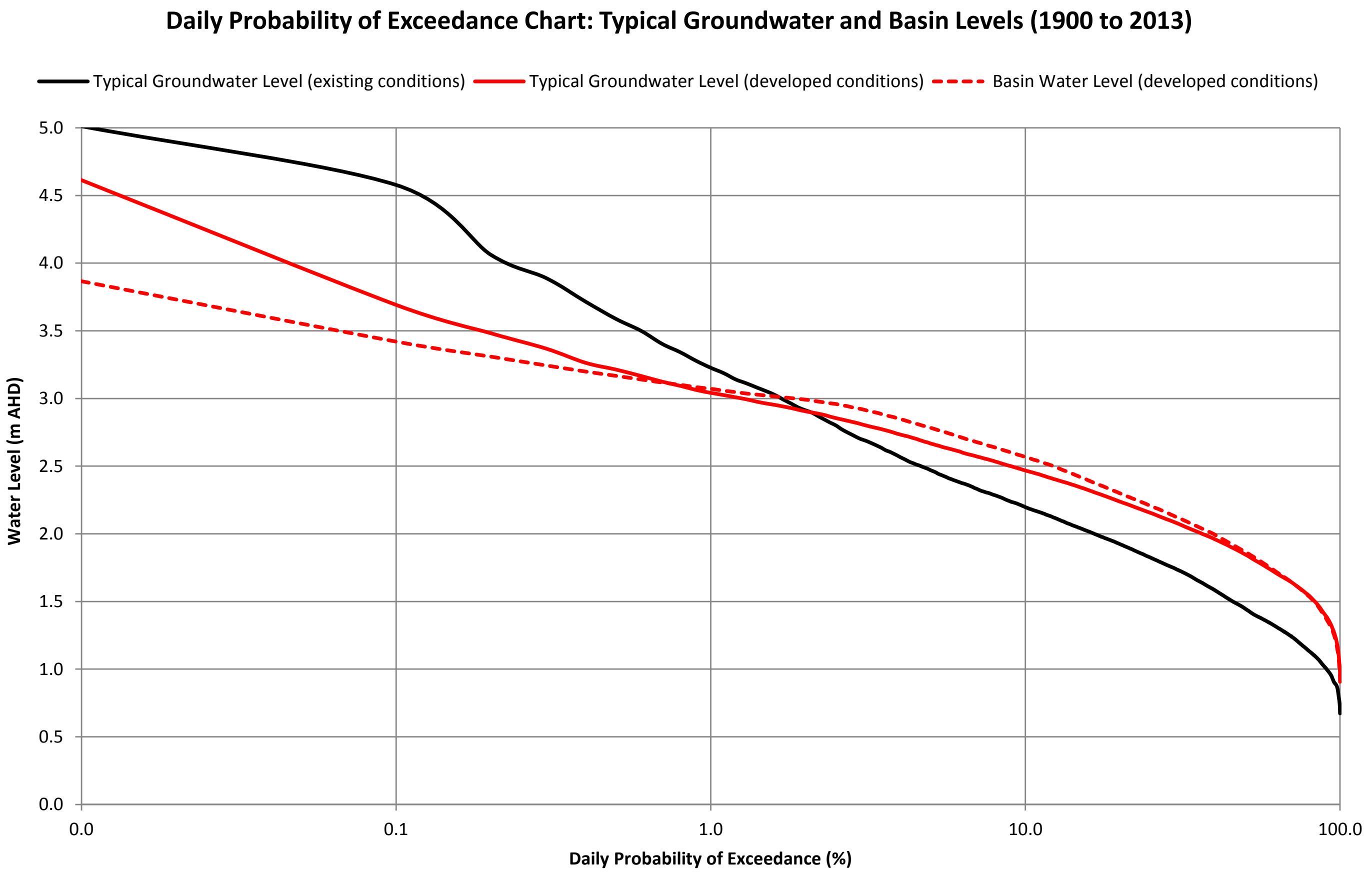


***Plate 8-3-*** *Empirical Groundwater Model Results: Daily Probability of Exceedance Chart: Groundwater and Basin Water Levels*

The model results presented above indicate that:

- Typical developed conditions groundwater levels will be approximately 0.3 to 0.4m higher than existing conditions levels at all times except for very wet conditions. The higher levels are primarily due to the increased recharge volumes described in **Section 8.1**.

- During very wet conditions, developed conditions groundwater levels will be lower than existing conditions due to the proposed groundwater management controls (open basins and gravity drainage). These higher levels are estimated to occur 2% of the time.

- Under developed conditions, basin water levels will generally be higher than the adjoining groundwater. This is due to the basins receiving treated runoff from impervious areas within the pipe drainage zone (Zone D4).

## *Application of the Detailed Groundwater Model*

As described in **Section 5**, the Detailed Groundwater Model was calibrated using data collected during a period of wet weather that occurred from 9 June 2011 to 29 July 2011. This 51 day period comprised 384mm of rainfall and is considered to be representative of a typical wet weather period. Accordingly, a developed conditions scenario for this period was established using the modelling approach described in **Section 5**. The model results from the calibration event were applied to establish the following information for typical wet weather conditions:

- Groundwater levels within the vicinity of the 255ha development area for both existing and proposed conditions.

- Changes in regional groundwater levels due to the development.

For simplicity, results from 24 July 2011 were selected for presentation in this report as the Empirical Groundwater Model predicted a typical groundwater level of 2.3m AHD on this date, which with reference to **Plate 8-2** is approximately a 90th Percentile groundwater level. Hence, groundwater conditions on 24 July 2011 are considered to be representative of 90th Percentile groundwater conditions.

Results from 24 July 2011 are presented as follows:

- **Plate 8-4** shows the groundwater head contours predicted for the existing conditions scenario. The east-west groundwater divide is also indicated.
- **Plate 8-5** shows the groundwater head contours predicted for the developed conditions scenario. The east-west groundwater divide is also indicated.
- **Plate 8-6** shows a difference map showing changes to the regional groundwater level due to the development.

Groundwater flux lines are also indicated in **Plate 8-4** and **Plate 8-5.** Groundwater fluxes across these lines were extracted from the Detailed Groundwater Model results over the calibration period to estimate the distribution of groundwater flows from the development area. These results are discussed after the abovementioned plates.

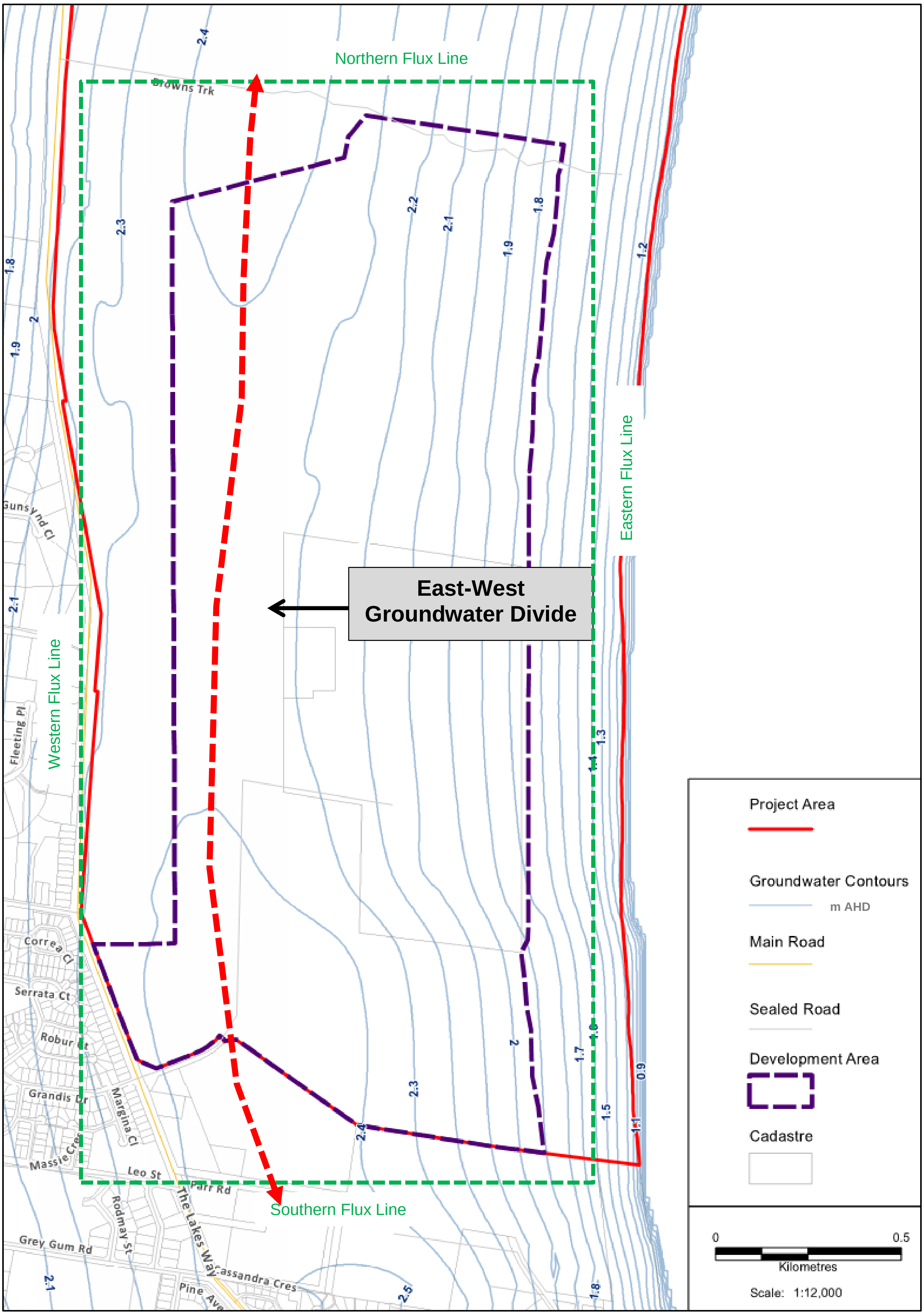


**Plate 8-4** – *Existing Conditions Results: Predicted peak groundwater head contours during 90th Percentile (wet weather) groundwater conditions.*

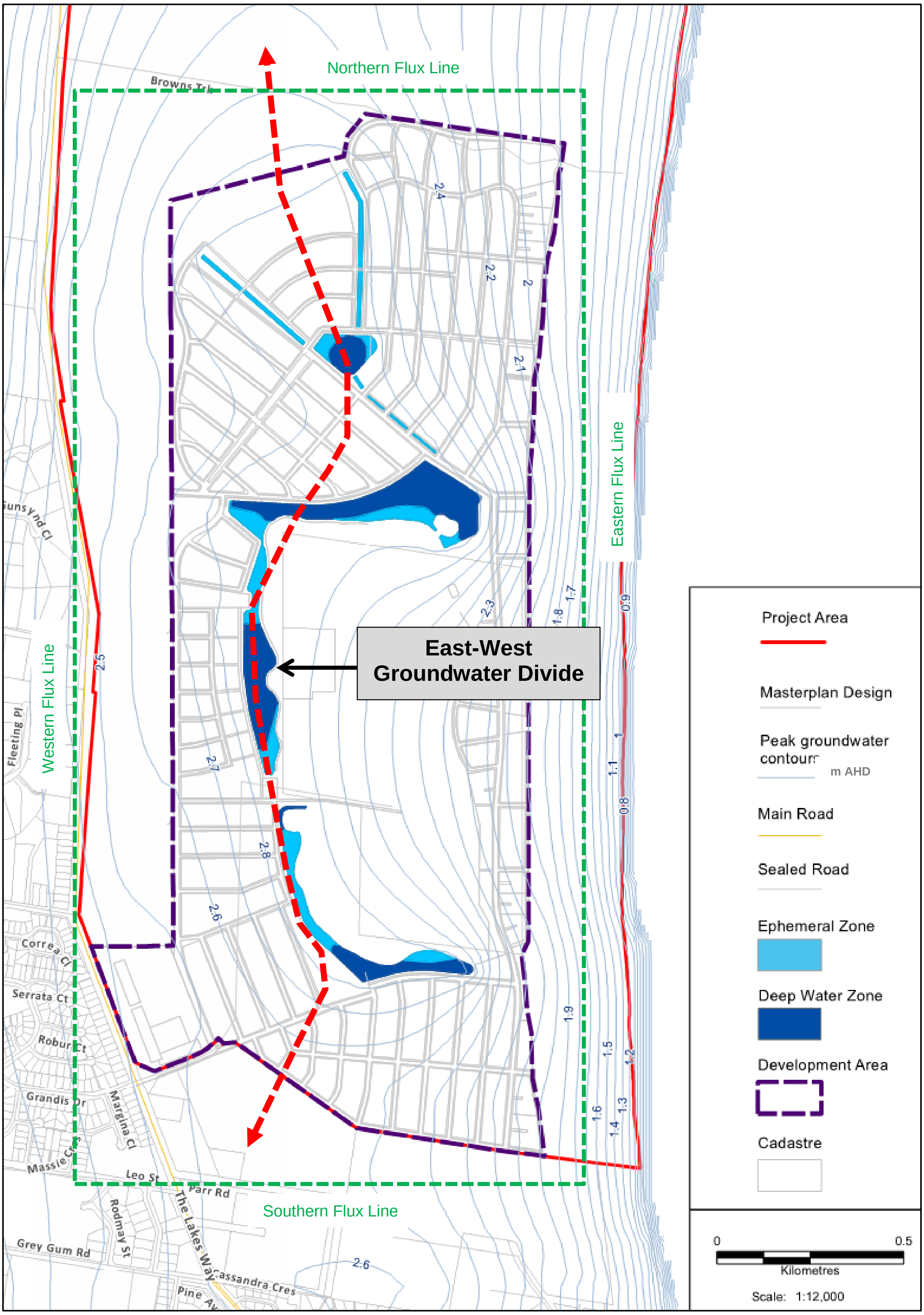


***Plate 8-5 -** Developed Conditions Results: Predicted peak groundwater head contours during 90th Percentile (wet weather) groundwater conditions*

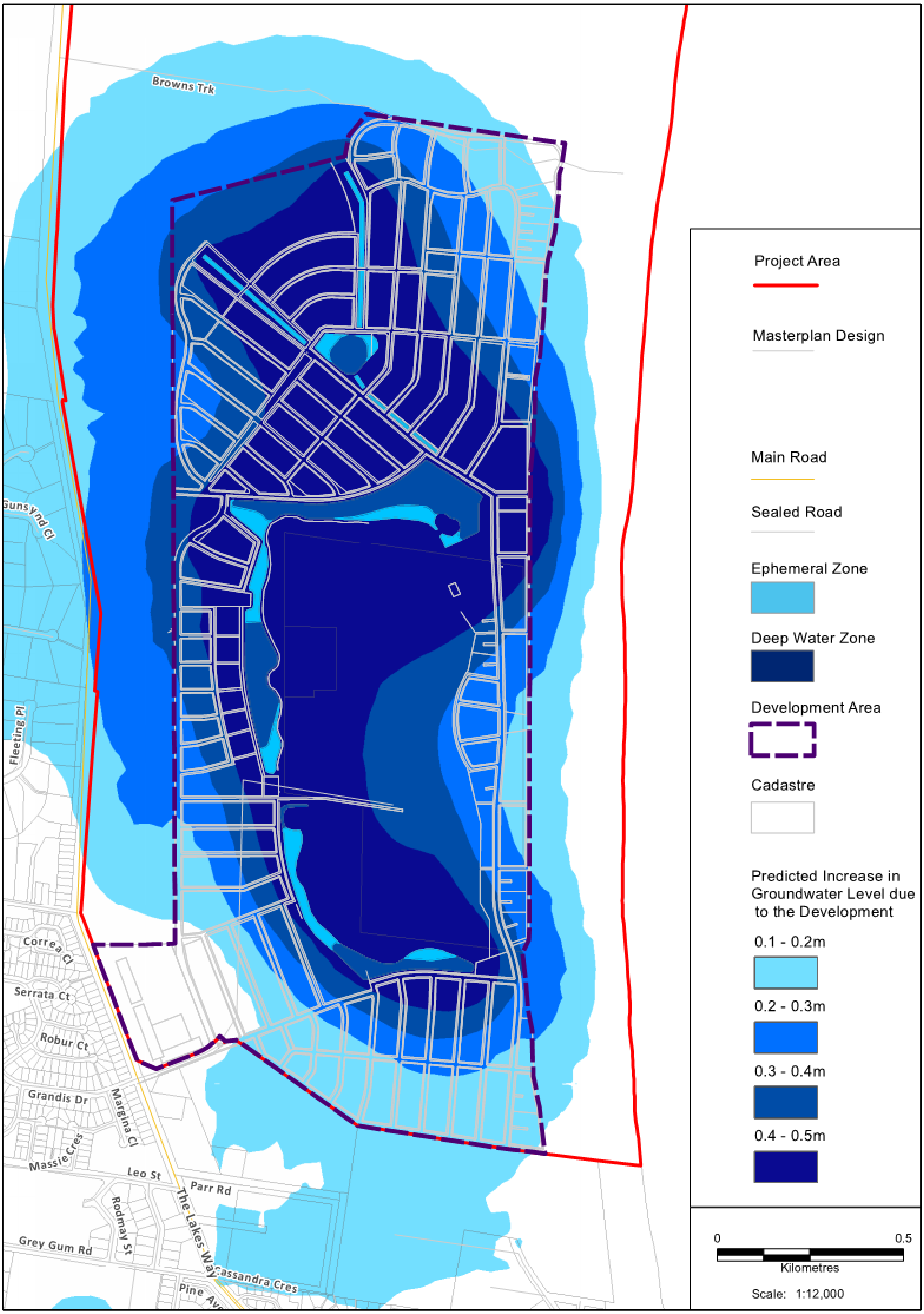


***Plate 8-6*** *- Difference map showing changes in groundwater levels during 90th Percentile (wet weather) groundwater conditions.*

The following key conclusions can be made from the detailed groundwater model results that depict typical 90th Percentile (wet weather) groundwater conditions:

- For existing conditions, the east-west groundwater divide is located in the western portion of the development area. Groundwater to the east of the divide flows into the Pacific Ocean and groundwater to the west of the divide flows into the Wallamba River Estuary. It is noted that the alignment of the groundwater divide is likely to be somewhat dynamic with model result indicating it moves further to the west under higher groundwater conditions

- With reference to **Plate 8-5**, developed conditions model results indicate that the east-west groundwater divide will be defined by the water management basins. This is expected as the basins receive runoff from connected impervious areas in Zone D4. The model results confirm that:

    - Water will generally flow from the basins into the adjoining groundwater. This is due to the basin water level being higher than the adjoining groundwater.

    - Groundwater originating from the golf course, which as established in **Section 2** has elevated nitrogen levels, will flow to the east into the ocean. No groundwater from the golf course is predicted to flow into the basins when the basin water level is below the gravity drainage inlet level (i.e. below 3m AHD).

    - Predicted changes to groundwater fluxes to the west are discussed further below.

- With reference to **Plate 8-6**, developed conditions groundwater levels during typical 90th Percentile conditions are expected to be between 0.1 to 0.5m higher than existing conditions levels within the development area. Outside of the development area, groundwater level increases are also expected, with increases of up to 0.5m predicted in areas immediately to the east of the development area. Increases are predicted to be less than 0.2m in all areas that are 300m or more from the development boundary. The higher levels are primarily due to the increase in recharge volumes.

- With reference to **Plate 8-6**, developed conditions groundwater levels during typical 90th Percentile conditions are expected to be between 0.4 to 0.5m higher than existing conditions levels within the golf course. These higher levels are not expected to materially impact the golf course as the groundwater levels (ranging from 2.2 to 2.8m AHD) are expected to be 0.5m or more below existing surface levels at nearly all locations within the existing golf greens and fairways that are to be retained. However, it is recommended that groundwater constraints are considered when the surface levels of the reconfigured golf greens and fairways are established at a latter design stage. As discussed in **Section 7**, the proposed flood mitigation controls will substantially lower the groundwater flooding risk to the golf course greens and fairways by reducing peak levels and inundation times during major flood events.

### *Groundwater Flow Regimes*

The detailed groundwater model was used to estimate groundwater flows from the development area to the north, south, east and west over the 51 day calibration period. These results can be used to infer the local groundwater flow regime for both existing and developed conditions.

Daily groundwater flows were calculated at the flux lines indicated in **Plate 8-4** and **Plate 8-5. Table 8-1** provides a breakdown of the percentage of the total flow that crosses each flux line. Predicted increases in the flows across each flux line due to the development are also shown as a percentage. It is noted that flow volumes are not reported as the area within the flux lines (386ha) is larger than the development area (255ha). Hence, flow volumes across the flux lines would not be representative of flow volumes from the development area only.

**Table 8-1** – *Estimated groundwater flows over the calibration period.*

| | Percentage of Total Groundwater Flows Across Flux Lines over the Calibration Period | | | |
|---|---|---|---|---|
| | *West* | *East* | *North* | *South* |
| **Existing Conditions** | 33% | 50% | 8% | 9% |
| **Developed Conditions** | 33% | 50% | 8% | 9% |
| **Increase in Groundwater Flow Volumes due to the Development** | 37% | 37% | 38% | 39% |

The model results presented in **Table 8-1** indicate that during typical wet weather conditions, as characterised by the 51 day calibration period:

- The development is not expected to significantly change the distribution of groundwater flows from the development area.
- Groundwater flows from the development area are expected to increase by approximately 37-39%. This is due to the higher groundwater levels discussed above.

## 8.3 Mass Balance Results

The Empirical Groundwater Model calculates water fluxes into and out of the 255ha development area on a daily time step over the 114 year simulation period (1900 to May 2013). Annualised results were calculated from the daily results. Mass balance calculations were undertaken from the annualised results to estimate model inflows (net recharge), model outflows (net ET losses, net groundwater flows and gravity drainage) as well as changes to storage volumes over the year.

**Table 8-2** presents the mass balance results for typical dry (10th Percentile), average and typical wet (90th Percentile) rainfall years for both existing and developed conditions. Average annual groundwater and basin water levels are included for reference.

***Table 8-2*** *– Empirical Groundwater Model results: Annual Mass Balance Results*[1]

| | | **Typical Dry Year (10th Percentile)** | | **Typical Average Year** | | **Typical Wet Year (90th Percentile)** | |
|---|---|---|---|---|---|---|---|
| | Units | Existing Conditions | Developed Conditions | Existing Conditions | Developed Conditions | Existing Conditions | Developed Conditions |
| **Rainfall** | mm/year | 810 | | 1,243 | | 1,576 | |
| **Average Groundwater Level** | m AHD | 1.3 | 1.7 | 1.6 | 2.0 | 1.7 | 2.1 |
| **Average Basin Level** | m AHD | N/A | 1.7 | N/A | 2.0 | N/A | 2.1 |
| **Inflows** | | | | | | | |
| **Net Runoff** | ML/year | N/A | 1,003 | N/A | 1,835 | N/A | 2,441 |
| Less Rainwater Tank Harvesting | ML/year | N/A | 174 | N/A | 212 | N/A | 249 |
| **Net Recharge** | ML/year | 447 | 829 | 1,112 | 1,623 | 1,601 | 2,192 |
| **Outflows** | | | | | | | |
| Evapotranspiration Losses[2] | ML/year | 541 | 515 | 642 | 534 | 692 | 533 |
| Groundwater Flows[3] | ML/year | 206 | 553 | 567 | 1,010 | 806 | 1,282 |
| Gravity Drainage | ML/year | N/A | 0 | N/A | 14 | N/A | 62 |
| Groundwater extraction – Irrigation of Public Open Space | ML/year | N/A | 67 | N/A | 67 | N/A | 67 |
| **Total Outflows** | ML/year | **747** | **1,135** | **1,209** | **1,625** | **1,498** | **1,944** |
| **Change in Storage** | ML/year | **-300** | **-306** | **-97** | **-2** | **103** | **248** |

Note 1: Results for typical dry, average and typical wet years were taken as the average results from 5 representative years that were selected based on annual rainfall depth.
Note 2: Evapotranspiration losses refer to evapotranspiration losses from the saturated zone (both existing and developed conditions models) and open water bodies (developed conditions model only).
Note 3: Groundwater flow refers to the net groundwater flows out of the development area in all directions.

The model results presented in **Table 8-2** indicate that:

- Harvesting from rainwater tanks will partially mitigate the increase in recharge volume under developed conditions.
- The higher groundwater levels predicted under developed conditions are due to higher recharge volumes and to a lesser extent, reduced evapotranspiration losses.
- Groundwater flows (out of the development area) will be higher for developed conditions due to the higher groundwater levels.

The gravity drainage flow regimes are discussed further in the following section.

## 8.4 Gravity Drainage Flow Regimes

As discussed in **Section 4**, it is proposed to construct a stormwater pipe system that will drain excess water from the water management basins to the Wallis Lake Entrance Channel. The gravity drainage will only operate during elevated basin levels (when the basin level exceeds 3m AHD) and will provide significant flood mitigation benefits during major flood events, such as the 100 year ARI event. **Plate 8-7** shows a percentage chart of the annual drainage volumes through the gravity drainage system. Peak annual basin water levels are also shown for context.

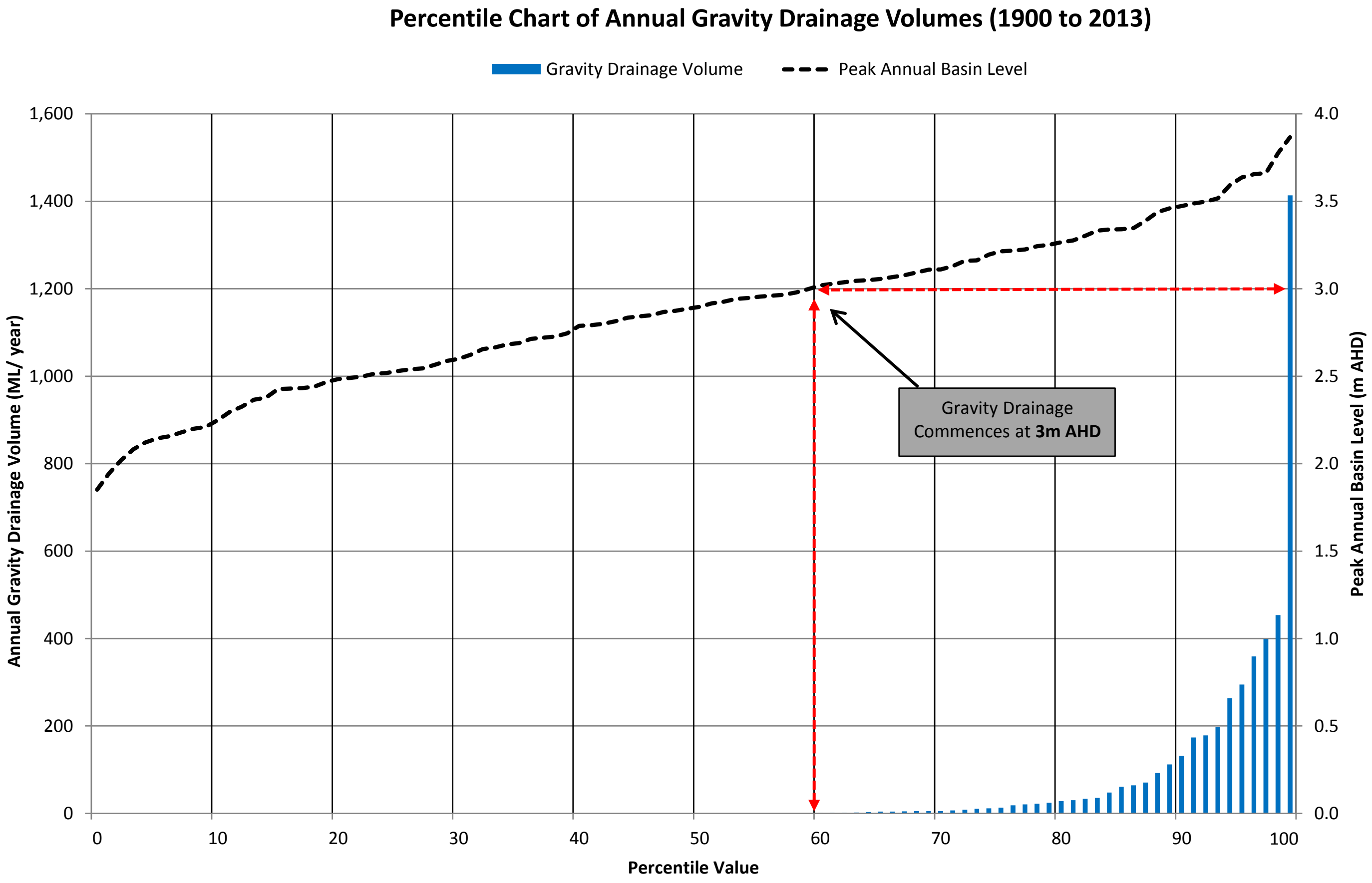


***Plate 8-7** - Empirical Groundwater Model Results: Annual Percentile Chart: Annual Gravity Drainage Volumes*

The model results in **Plate 8-7** show that gravity drainage is expected to occur in some capacity in 40% of years. However, significant flow volumes are only expected following major rainfall events such as the 1963 event.

# 9 REFERENCES

*1)* Australian and New Zealand Environment Consultation Council (2000), *'Australian and New Zealand Guidelines for Fresh and Marine Water Quality'*

*2)* Barnett et al (2012), *'Australian Groundwater Modelling Guidelines. Waterlines Report 82, National Water Commission, Canberra.'*

*3)* Brooks, R.H. and A.T. Corey (1966): *'Properties of porous media affecting fluid flow. ASCE J. Irrig. Drain. Div., 92 (IR2): 61-88'*

*4)* BMT WBM Pty Ltd (2010): *'Chapman's Road, Tuncurry Amended Stormwater Management Strategy. Commissioned by Great Lakes Council'*

*5)* Bureau of Meteorology Website *(Climatic Information):* *http://www.bom.gov.au/climate/*

*6)* Coastplan Consulting (2005): *'Report on Planning and Development Investigations for North Tuncurry Urban Release Area. Commissioned by Landcom'*

*7)* Department of Environment, Climate Change and Water, NSW (June 2010), *'NSW Climate Impact Profile: The Impacts of Climate Change on the Biophysical Environment in NSW'*

8) Department of Environment Climate Change and Water (2010), *'Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments'*

*9)* Department of Infrastructure, Planning and Natural Resources (2005), *'Floodplain Development Manual: the management of flood liable land'*

*10)* Douglas Partners (1988), *'Report on Geotechnical Investigation North Tuncurry Planning Study – Southern Precinct'*

*11)* Douglas Partners Pty Ltd (2003): *'Report on Installation of Monitoring Bores – Hallidays Point Waste Water Treatment Plant. Commissioned by Mid Coast Water'*

12) Environmental Resource Management (2006): '*Preliminary Phase 2 Environmental Site Assessment - North Tuncurry, NSW. Commissioned by Landcom'*

13) Institution of Engineers Australia (1987), '*Australian Rainfall and Runoff – A Guide to Flood Estimation'*

14) Goda, Y. (2000): *'Random Seas and Design of Maritime Structures. World Scientific. Advanced Series on Ocean Engineering, Volume 15'*

15) Hantush-Jacob (1955)/Hantush (1964):'*Solution for a Pumping Test in a Leaky Aquifer'*

16) Hong-Yoon Kang (unknown date): *'Watertable Overheight Due to Wave Runup on a Sandy Beach'*

17) HydroGheoLogic, Inc (2011): *'A Comprehensive MODFLOW-Based Hydrologic Modelling System'*

18) Ian L. Turner, Bruce P. Coates and R. Ian Acworth: ' *Tides, Waves and the Superelevation of Groundwater at the Coast, Journal of Coastal Research, Vol. 13, No. 1 (Winter, 1997), pp. 46-60 Published by: Coastal Education & Research Foundation, Inc.'*

*19)* McDonald and Harbaugh, (1988)*: 'A modular three-dimensional finite-difference ground-water flow model. Techniques of Water-Resources Investigations, Book 6. US Geological Survey. http://pubs.usgs.gov/twri/twri6a1/'*

*20)* NSW Department of Primary Industries (first published in September 2012), *'*NSW Aquifer Interference Policy: NSW Government policy for the licensing and assessment of aquifer interference activities'

21) PPK Environment & Infrastructure Pty Ltd (2001): '*Tuncurry WWTP and Golf Course Area – Groundwater Investigation to Assess Dune Exfiltration and Reuse Expansion Options. Commissioned by Mid Coast Water'*

22) PPK Environment & Infrastructure Pty Ltd (2002): '*Groundwater Concepts and Additional Groundwater Modelling at the Hallidays Point WWTP. Commissioned by Mid Coast Water'*

23) PPK Environment & Infrastructure Pty Ltd (2001): '*Hallidays Point WWTP – Groundwater Investigation to Assess Dune Exfiltration Expansion Options. Commissioned by Mid Coast Water'*

24) Parsons Brinckerhoff Australia Pty Ltd (2007): *'Hallidays Point WWTP Numerical Groundwater Model and Data Review. Commissioned by Mid Coast Water'*

*25)* Planet Management and Research Pty Ltd (1970): '*Preliminary Survey off Forster E.L.A. 407/8 Central Coast, New South Wales. Commissioned by Planet Metals Ltd'*

*26)* Roy P.S et al. (1997): *'Quaternary Geology of the Forster – Tuncurry Coast and Shelf, Southeast Australia'*

27) SMEC (2014): *'North Tuncurry Development Project – Integrated Water Cycle Management Strategy'*

28) Sterrett, Robert J. (2007): '*Groundwater and Wells, Third Edition'*

*29)* Theis (1935): *'Solution for a Pumping Test in an Unconfined Aquifer'*

*30)* WorleyParsons (2010)*, 'North Tuncurry Coastal Hazard and Flood Study – Hydrogeology'*

31) Van Genuchten (1980): '*A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Science of American Journal 44, 892-898*'

## *GIS Datasets*

- **Department of Mineral Resources (2001):** NSW Statewide Geological Database - NSW Attribute Data Set contains Southern CRA, Upper NE, Lower NE, Bohena, Sydney, Central & standard geological mapping datasets
- **NSW Office of Water (2010):** Groundwater Works
- **G.Jacobson and JE.Lau (2000)**: Hydrogeology Map of Australia
    - 2m contours
    - 10m contours

## *Requested Data*

- **NSW Public Work's Manly Hydraulics Laboratory (MHL):** DARAWANK SWAMP, Station Number DARAW with surface water level data from 1/07/2008 to 14/10/2009
- **NSW Public Work's Manly Hydraulics Laboratory (MHL):** Forster, Station Number 209470 with sea level data from 1/1/1988 to 28/11/2011
- **NSW Public Work's Manly Hydraulics Laboratory (MHL):** Tuncurry, Station Number 209401with Wallamba River water level data from 1/1/2000 to 1/2/2012
- **NSW Public Work's Manly Hydraulics Laboratory (MHL):** Nabiac, Station Number 209404 with Wallamba River water level data from 1/1/2000 to 1/2/2012.
- **Great Lakes Council (2009):** Light Detection and Ranging (LiDAR) Dataset

# APPENDIX A – BOREHOLE LOGS

# Log of Groundwater Borehole

on behalf of

*Mid Coast Water*

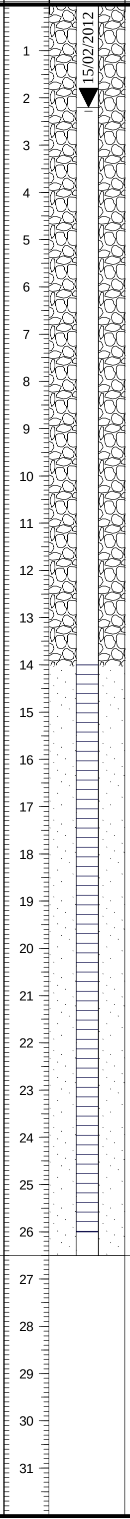
**Hole No:** *LC12-01 PB*
**Sheet No:** 1 of 1
**Project No:** *30011196*

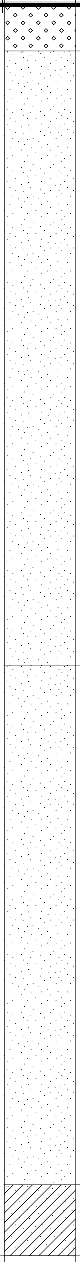
**Project:** North Tuncurry Development
**Purpose:** Groundwater Investigation
**Location:** North Tuncurry

**Coordinate System:** UTM WSG84
**E:** 452490
**N:** 6442627

**Top of Casing:** m.a.s.l.
**Ground Level:** m.a.s.l.
**Angel from Horz:** -90

| Drilling | | | | | Well Construction/Water Level | | Lithology | | | Testing | | Other Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Support** | **Penetration** | **Elevation** | **Depth (mbgl)** | **Well Construction Water Level** | **Construction Notes** | **Lithology Graphic** | **Description** | **Density/ Consitency** | **Test** | **Result** | **Other Observations (Origin,penetration speed,...)** |
| RAB 210 mm | | | | 0–1 | | | | SAND: dark brown, fine to medium with some organic matter | | | | |
| | | | | 1–14 | 15/02/2012 | Natural Backfill<br>200mm Steel Casing | | SAND: yellow brown, fine to medium, moderately sorted with shells | | Pump Test | 16 | Aeolian Sand |
| | | | | 14–25 | | 150mm Steel Screen<br>Natural Gravel Particles | | SAND: grey, fine to medium, moderately sorted with shells, some occasional coarse gravel and trace clay | | | | Marine Sand |
| | | | | 25–26.5 | | | | SANDY CLAY: dark grey, high plasticity with fine to medium sand | | | | Marine Clay |
| | | | | | | | | Bore discontinued at 26.50m | | | | |





Note: mbgl = metre below ground level;  m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.)

**Contractor:** Ultradrilling
**Equipment:**

**Commenced:** 14/02/2012
**Completed:** 15/02/2012

**Logged By:** ARP
**Checked By:**

Basis of descriptions and details of abbreviations are given on explanatory notes

# Log of Groundwater Borehole

on behalf of

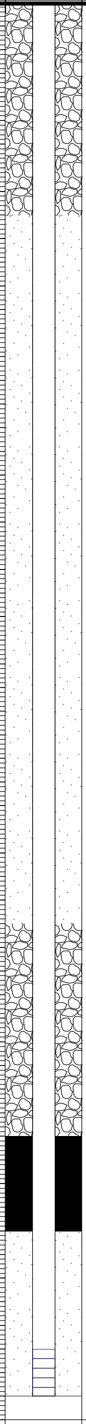
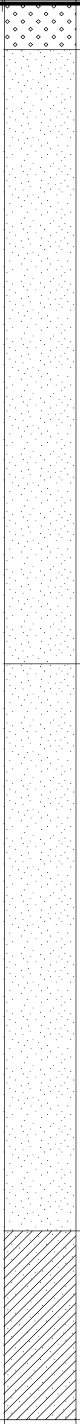
*Mid Coast Water*

**Hole No:** ***LC12-02 MB A***
**Sheet No:** 1 of 1
**Project No:** *30011196*

**Project:** North Tuncurry Development
**Purpose:** Groundwater Investigation
**Location:** North Tuncurry

**Coordinate System:** UTM WSG84
**E:** 452489
**N:** 6442824

**Top of Casing:** m.a.s.l.
**Ground Level:** m.a.s.l.
**Angel from Horz:** -90

| Drilling | | | | | Well Construction/Water Level | | Lithology | | | Testing | | Other Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Support** | **Penetration** | **Elevation** | **Depth (mbgl)** | **Well Construction Water Level** | **Construction Notes** | **Lithology Graphic** | **Description** | **Density/ Consitency** | **Test** | **Result** | **Other Observations (Origin,penetration speed,...)** |
| | | | | |  | |  | SAND: dark red brown, fine to medium with organic matter and roots | | | | |
| | | | | 1 | | | | SAND: yellow brown, fine to medium, moderately sorted with shells | | | | |
| | | | | 2 | | | | | | | | |
| | | | | 3 | | Natural Backfill | | | | | | |
| | | | | 4 | | | | | | | | |
| | | | | 5 | | | | | | | | |
| | | | | 6 | | | | | | | | |
| | | | | 7 | | | | | | | | Aeolian Sand |
| | | | | 8 | | | | | | | | |
| | | | | 9 | | | | | | | | |
| | | | | 10 | | | | | | | | |
| | | | | 11 | | | | | | | | |
| | | | | 12 | | Gravel Pack<br>50mm PVC Casing<br>50mm PVC Casing | | | | | | |
| | | | | 13 | | | | | | | | |
| | | | | 14 | | | | SAND: grey, fine to medium, moderately sorted with shells and some occasional gravel and clay bands | | | | |
| RP 130 mm | | | | 15 | | | | | | | | |
| | | | | 16 | | | | | | | | |
| | | | | 17 | | | | | | | | |
| | | | | 18 | | | | | | | | |
| | | | | 19 | | | | | | | | |
| | | | | 20 | | | | | | | | Marine Sand |
| | | | | 21 | | | | | | | | |
| | | | | 22 | | Natural Backfill | | | | | | |
| | | | | 23 | | | | | | | | |
| | | | | 24 | | | | | | | | |
| | | | | 25 | | Bentonite Seal | | | | | | |
| | | | | 26 | | | | SANDY CLAY: dark grey, high plasticity with fine to medium sand | | | | |
| | | | | 27 | | | | | | | | |
| | | | | 28 | | Gravel Pack | | | | | | Marine Clay |
| | | | | 29 | | 50mm PVC Screen | | | | | | |
| | | | | 30 | | | | Bore discontinued at 30.00m | | | | |
| | | | | 31 | | | | | | | | |

Note: mbgl = metre below ground level; m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.)

**Contractor:** Ultradrilling
**Equipment:**

**Commenced:** 15/02/2012
**Completed:** 16/02/2012

**Logged By:** ARP
**Checked By:**

Basis of descriptions and details of abbreviations are given on explanatory notes

# Log of Groundwater Borehole

on behalf of

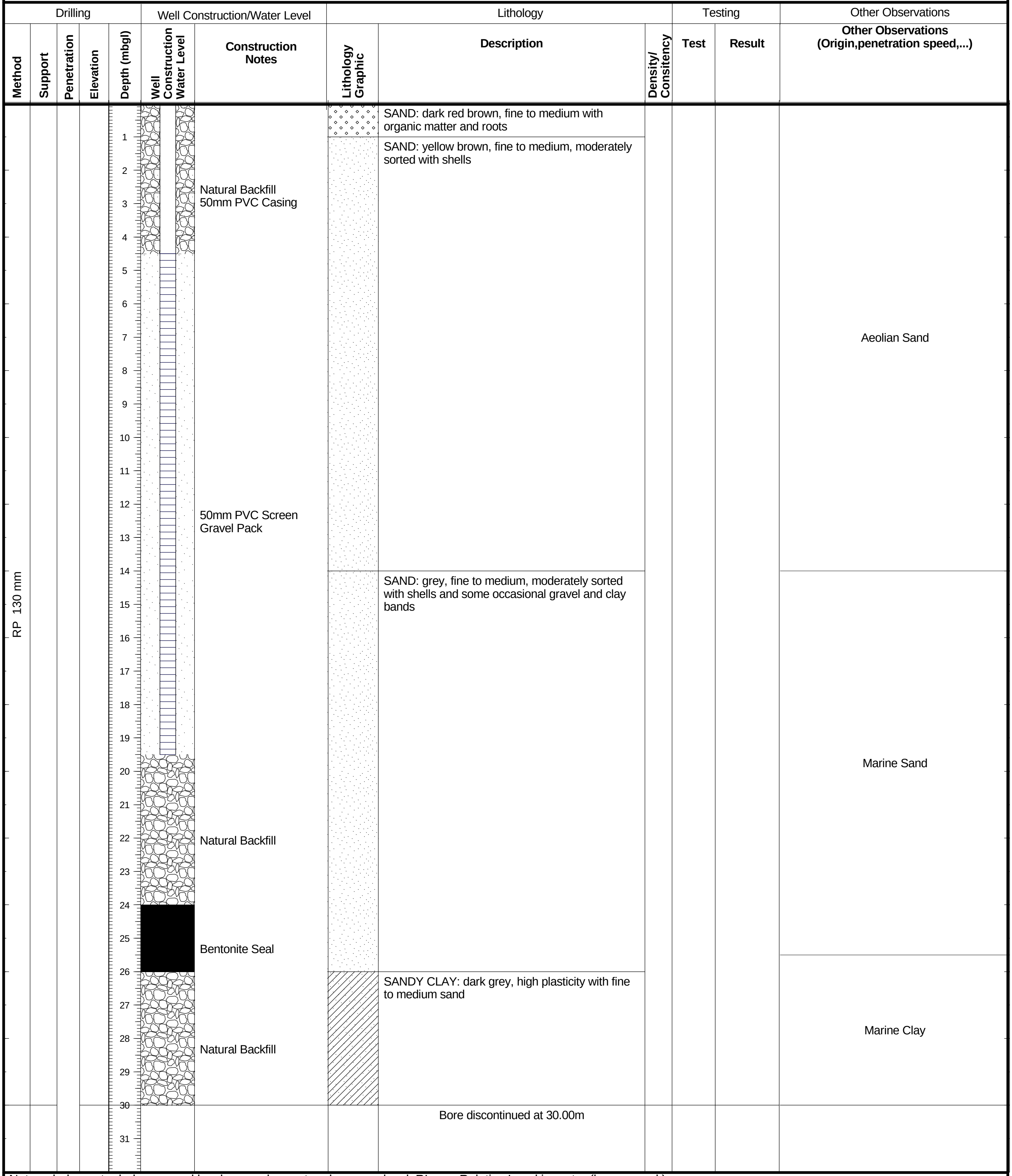
*Mid Coast Water*

**Hole No:** ***LC12-02 MB B***
**Sheet No:** 1 of 1
**Project No:** *30011196*

**Project:** North Tuncurry Development
**Purpose:** Groundwater Investigation
**Location:** North Tuncurry

**Coordinate System:** UTM WSG84
**E:** 452489
**N:** 6442824

**Top of Casing:** m.a.s.l.
**Ground Level:** m.a.s.l.
**Angel from Horz:** -90



| Construction Notes | Description | Other Observations (Origin,penetration speed,...) |
|---|---|---|
| Natural Backfill<br>50mm PVC Casing | SAND: dark red brown, fine to medium with organic matter and roots | Aeolian Sand |
| 50mm PVC Screen<br>Gravel Pack | SAND: yellow brown, fine to medium, moderately sorted with shells | |
| Natural Backfill | SAND: grey, fine to medium, moderately sorted with shells and some occasional gravel and clay bands | Marine Sand |
| Bentonite Seal | | |
| Natural Backfill | SANDY CLAY: dark grey, high plasticity with fine to medium sand | Marine Clay |
| | Bore discontinued at 30.00m | |

Note: mbgl = metre below ground level; m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.)

**Contractor:** Ultradrilling
**Equipment:**

**Commenced:** 15/02/2012
**Completed:** 16/02/2012

**Logged By:** ARP
**Checked By:**

Basis of descriptions and details of abbreviations are given on explanatory notes

# Log of Groundwater Borehole

on behalf of

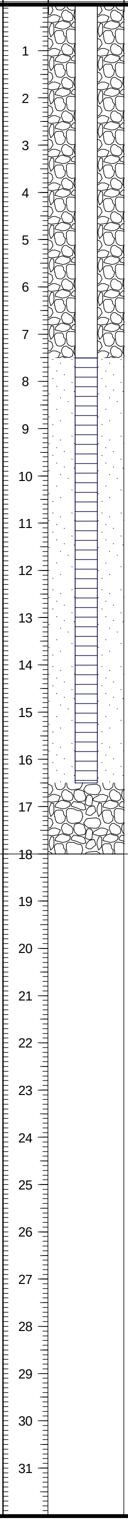
*Mid Coast Water*

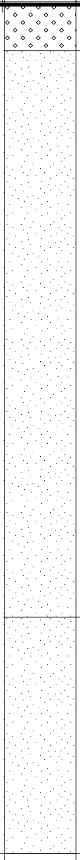
**Hole No:** ***LC12-03 MB***
**Sheet No:** 1 of 1
**Project No:** *30011196*

**Project:** North Tuncurry Development
**Purpose:** Groundwater Investigation
**Location:** North Tuncurry

**Coordinate System:** UTM WSG84
**E:** 452489
**N:** 6442824

**Top of Casing:** m.a.s.l.
**Ground Level:** m.a.s.l.
**Angel from Horz:** -90





| Drilling | | | | | Well Construction/Water Level | | Lithology | | | Testing | | Other Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Support** | **Penetration** | **Elevation** | **Depth (mbgl)** | **Well Construction Water Level** | **Construction Notes** | **Lithology Graphic** | **Description** | **Density/ Consitency** | **Test** | **Result** | **Other Observations (Origin,penetration speed,...)** |
| RP 130 mm | | | | | | | | SAND: dark red brown, fine to medium with some organic matter | | | | Aeolian Sand |
| | | | | | | Natural Backfill<br>50mm PVC Casing | | SAND: yellow brown, fine to medium, moderately sorted with shells | | | | |
| | | | | | | Gravel Pack<br>50mm PVC Casing | | SAND: grey, fine to medium with shells and some coarse gravel and clay | | | | Marine Sand |
| | | | | | | Natural Backfill | | | | | | |
| | | | | | | | | Bore discontinued at 18.00m | | | | |

Note: mbgl = metre below ground level; m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.)

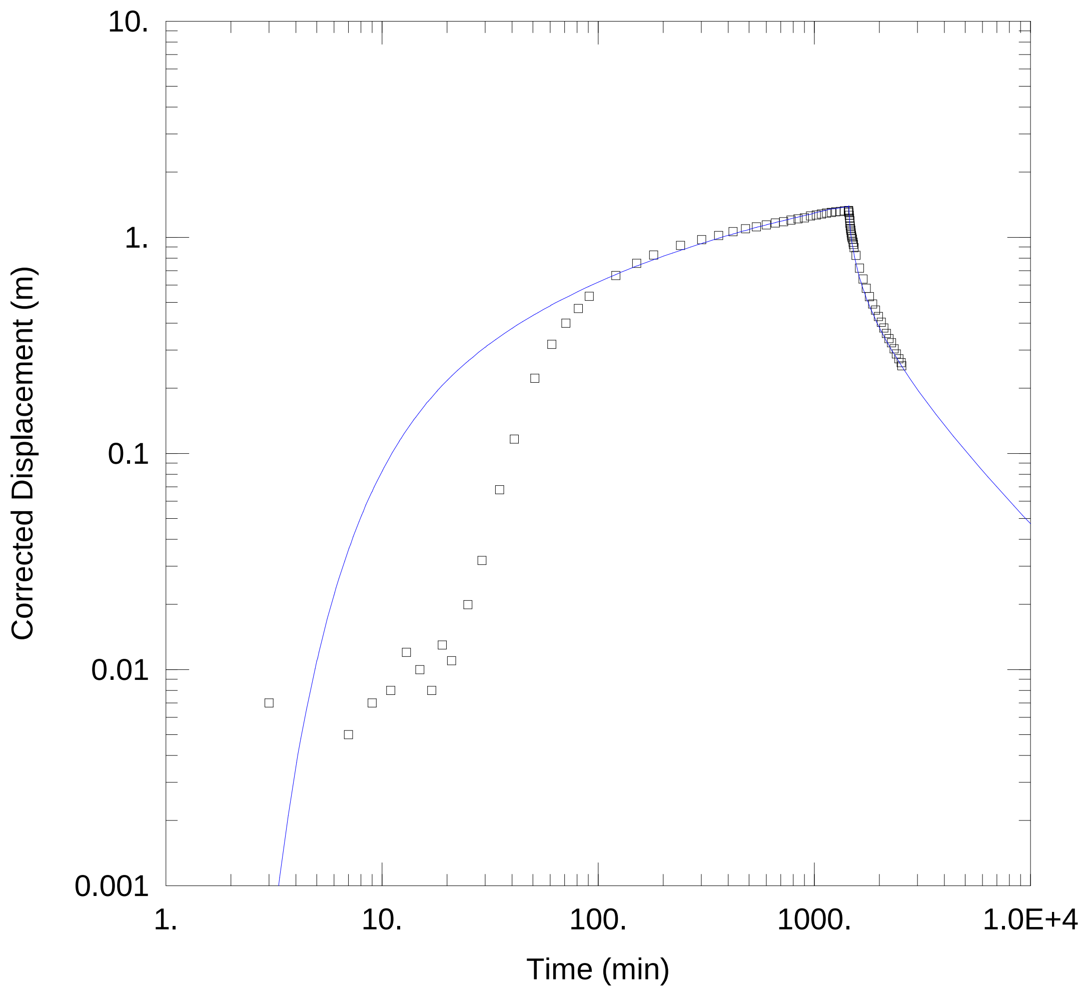
**Contractor:** Ultradrilling
**Equipment:**

**Commenced:** 15/02/2012
**Completed:** 16/02/2012

**Logged By:** ARP
**Checked By:**

Basis of descriptions and details of abbreviations are given on explanatory notes

# APPENDIX B – PUMP TEST ANALYSIS



## WELL TEST ANALYSIS

Data Set: C:\...\Mounding.aqt
Date: 07/24/12 Time: 13:32:29

## PROJECT INFORMATION

Company: SMEC Australia
Client: Landcom
Location: Tuncurry
Test Well: BH02
Test Date: 22.02.2012

## WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| BH2 | 0 | 0 |

Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ BH2 | 0 | 0 |

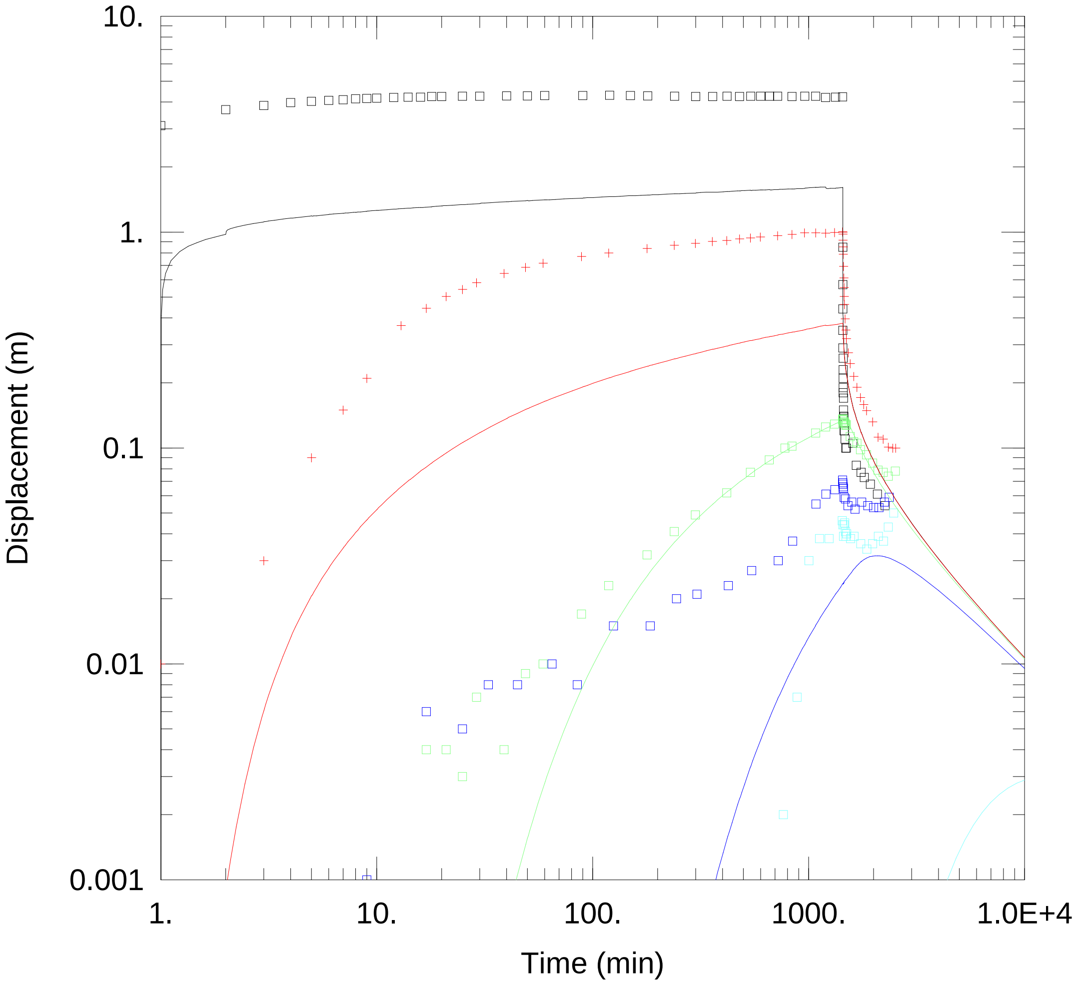
## SOLUTION

Aquifer Model: Unconfined

Solution Method: Theis

T = 362.9 $m^2$/day
Kz/Kr = 1.

S = 0.1756
b = 12.04 m



## WELL TEST ANALYSIS

Data Set: C:\Users\SF10623\Documents\Tuncurry\Seb's Work Folder\Pump Test\Aqtesolv\LC12-PB.aqt
Date: 02/28/12 Time: 17:00:44

## PROJECT INFORMATION

Company: SMEC Australia PTY LTD
Client: Landcom
Project: 30011196
Location: Tuncurry
Test Well: LC12-PB
Test Date: 22.02.2012

## WELL DATA

### Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| LC12-PB | 452490 | 6442627 |

### Observation Wells

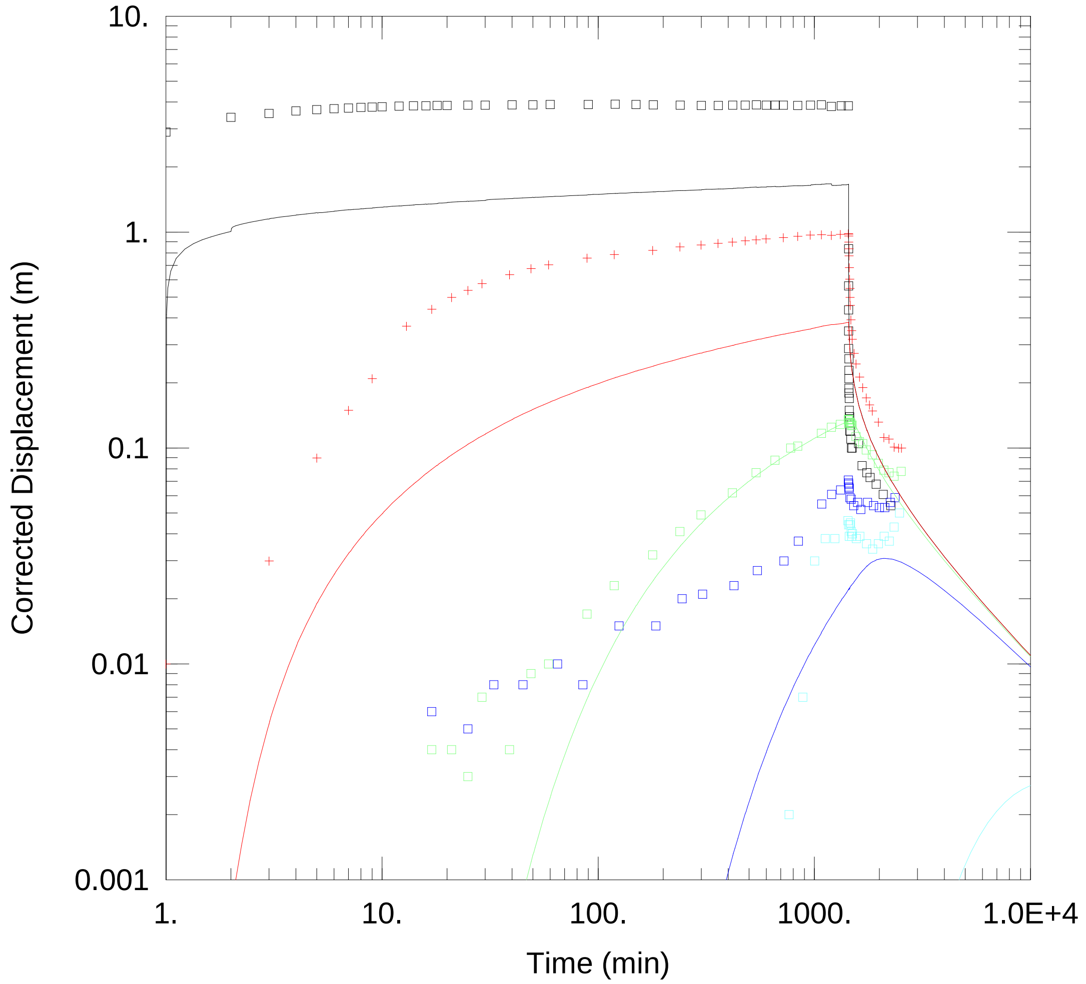
| Well Name | X (m) | Y (m) |
|---|---|---|
| □ LC12-PB | 452490 | 6442627 |
| + LC12-02B | 452489 | 6442617.1 |
| □ LC12-02A | 452489 | 6442617 |
| □ BH 10 | 452486 | 6442694 |
| □ LC12-03 | 452489 | 6442824 |
| □ BH6 | 452476 | 6441968 |

## SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 1606.6 $m^2$/day
1/B = 1.0E-5 $m^{-1}$
b = 23.5 m

S = 0.1244
Kz/Kr = 1.



## WELL TEST ANALYSIS

Data Set: C:\Users\SF10623\Documents\Tuncurry\Seb's Work Folder\Pump Test\Aqtesolv\LC12-PB.aqt
Date: 02/28/12 Time: 12:17:32

## PROJECT INFORMATION

Company: SMEC Australia PTY LTD
Client: Landcom
Project: 30011196
Location: Tuncurry
Test Well: LC12-PB
Test Date: 22.02.2012

## WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| LC12-PB | 452490 | 6442627 |

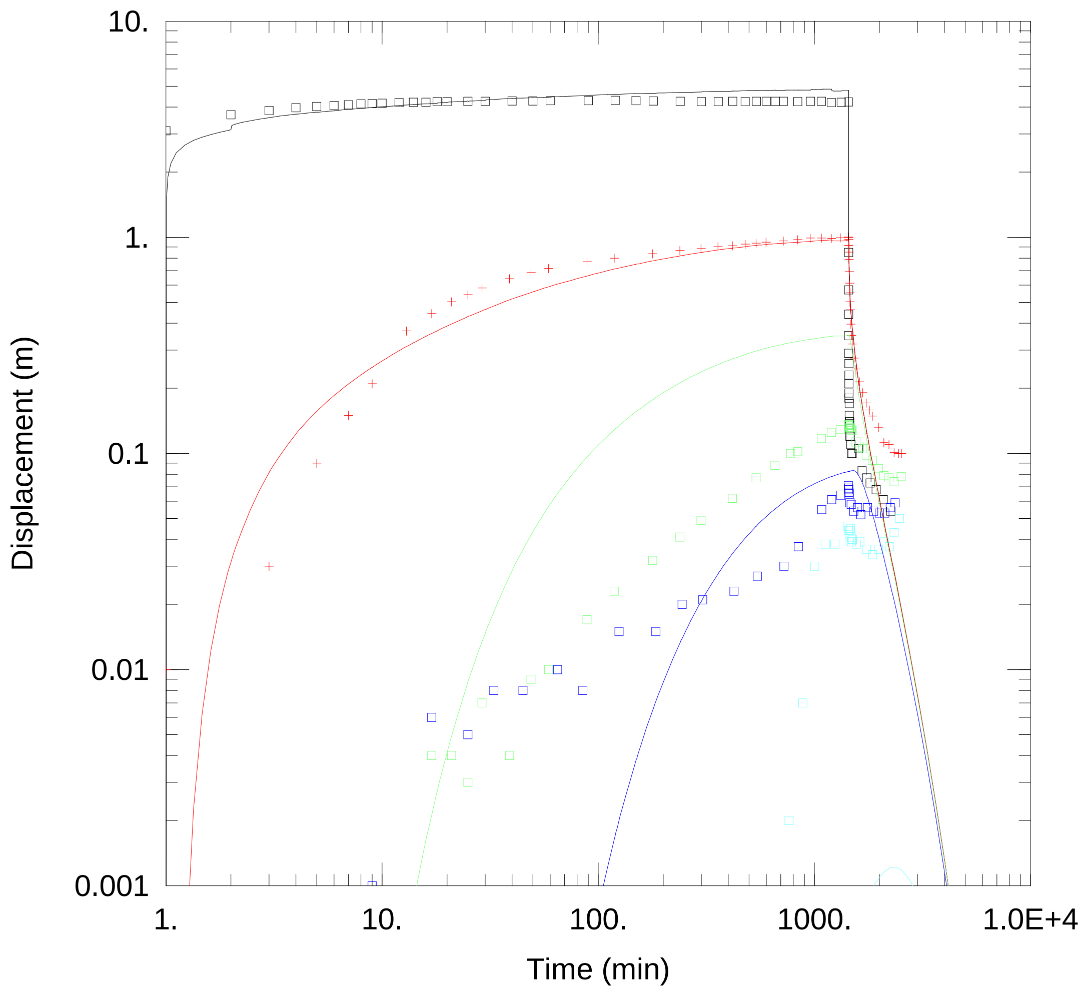
Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ LC12-PB | 452490 | 6442627 |
| + LC12-02B | 452489 | 6442617.1 |
| □ LC12-02A | 452489 | 6442617 |
| □ BH 10 | 452486 | 6442694 |
| □ LC12-03 | 452489 | 6442824 |
| □ BH6 | 452476 | 6441968 |

## SOLUTION

Aquifer Model: Unconfined Solution Method: Theis

T = 1570.6 $m^2$/day S = 0.1289
Kz/Kr = 1. b = 23.5 m



## WELL TEST ANALYSIS

Data Set: C:\Users\SF10623\Documents\Tuncurry\Seb's Work Folder\Pump Test\Aqtesolv\LC12-PB.aqt
Date: 04/30/12 Time: 12:39:20

## PROJECT INFORMATION

Company: SMEC Australia PTY LTD
Client: Landcom
Project: 30011196
Location: Tuncurry
Test Well: LC12-PB
Test Date: 22.02.2012

## WELL DATA

### Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| LC12-PB | 452490 | 6442627 |

### Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ LC12-02A | 452489 | 6442617 |
| □ LC12-PB | 452490 | 6442627 |
| + LC12-02B | 452489 | 6442617.1 |
| □ BH 10 | 452486 | 6442694 |
| □ LC12-03 | 452489 | 6442824 |
| □ BH6 | 452476 | 6441968 |

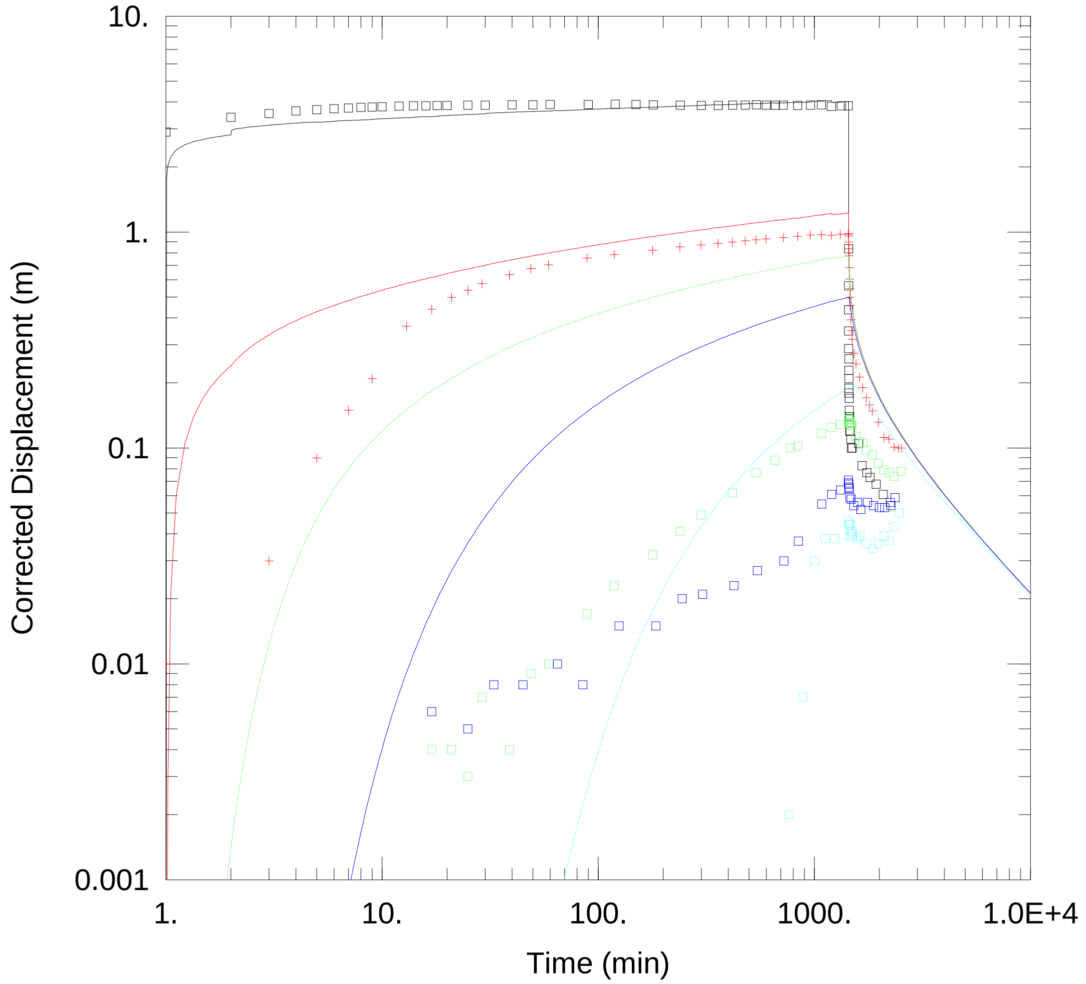
## SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 569.5 m$^2$/day
1/B = 0.007254 m$^{-1}$
b = 23.5 m

S = 0.01555
Kz/Kr = 0.1995



## WELL TEST ANALYSIS

Data Set: C:\Users\SF10623\Documents\Tuncurry\Seb's Work Folder\Pump Test\Aqtesolv\LC12-PB.aqt
Date: 02/28/12 Time: 16:43:52

## PROJECT INFORMATION

Company: SMEC Australia PTY LTD
Client: Landcom
Project: 30011196
Location: Tuncurry
Test Well: LC12-PB
Test Date: 22.02.2012

## WELL DATA

Pumping Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| LC12-PB | 452490 | 6442627 |

Observation Wells

| Well Name | X (m) | Y (m) |
|---|---|---|
| □ LC12-PB | 452490 | 6442627 |
| + LC12-02B | 452489 | 6442617.1 |
| □ LC12-02A | 452489 | 6442617 |
| □ BH 10 | 452486 | 6442694 |
| □ LC12-03 | 452489 | 6442824 |
| □ BH6 | 452476 | 6441968 |

## SOLUTION

Aquifer Model: Unconfined

Solution Method: Theis

T = 808.4 $m^2$/day
Kz/Kr = 0.1

S = 0.001225
b = 23.5 m

# APPENDIX C – WATER QUALITY RESULTS

**Oxidised Nitrogen (NOx)** (All units are mg/l)

| | 27/05/2011 | 16/02/2012 | 22/04/2012 | 30/05/2012 | 11/07/2012 | 15/10/2012 | 31/10/2012 | 8/11/2012 | 13/02/2013 | 27/02/2013 | 22/05/2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall over Pervious 14 days (mm) | 35 | 55 | 160 | 30 | 75 | 11 | 16 | 5 | 40 | 127 | 10 |
| **Non Golf Course Bores** | | | | | | | | | | | |
| MB01 | 0.1 | | 0.1 | | | | 0.0 | | | 0.1 | 0.0 |
| MB02 | 0.1 | | 0.0 | | | | 0.1 | | | 0.1 | 0.1 |
| MB04 | 0.0 | | 0.0 | | | | 0.0 | | | 0.0 | 1.3 |
| MB05 | 0.1 | 0.0 | 0.0 | | | | 0.0 | | | 0.0 | 0.0 |
| BH05 | | | 0.6 | | | | 0.6 | | | 0.4 | 0.2 |
| LC12-03 | | | 0.5 | | | | 0.3 | | | 0.5 | 0.5 |
| **Min** | 0.0 | 0.0 | 0.0 | | | | 0.0 | | | 0.0 | 0.0 |
| **Average** | 0.1 | 0.0 | 0.2 | | | | 0.2 | | | 0.2 | 0.4 |
| **Max** | 0.1 | 0.0 | 0.6 | | | | 0.6 | | | 0.5 | 1.3 |
| | | | | | | | | | | | |
| **Golf Course Bores** | | | | | | | | | | | |
| MB06 | 3.3 | 2.9 | 1.0 | | | | 2.8 | | | 0.8 | 1.0 |
| MB07 | 0.1 | | 0.1 | | | | 0.0 | | | 0.1 | 0.0 |
| P2 | | | 0.0 | | | | | | | 0.0 | 0.0 |
| TU11 | | | 3.0 | 4.8 | 10.1 | 15.6 | 6.2 | 6.7 | 1.7 | 1.6 | 2.3 |
| TU12 | | | | 0.9 | 5.4 | 9.5 | | 17.2 | 17.1 | | 3.3 |
| Golf Course Pond | | | 0.1 | | | | 0.0 | | | 0.1 | 0.0 |
| **Min** | 0.1 | 2.9 | 0.0 | 0.9 | 5.4 | 9.5 | 0.0 | 6.7 | 1.7 | 0.0 | 0.0 |
| **Average** | 1.7 | 2.9 | 0.8 | 2.8 | 7.7 | 12.5 | 2.3 | 12.0 | 9.4 | 0.5 | 1.1 |
| **Max** | 3.3 | 2.9 | 3.0 | 4.8 | 10.1 | 15.6 | 6.2 | 17.2 | 17.1 | 1.6 | 3.3 |
| | | | | | | | | | | | |
| **MCW Bores** | | | | | | | | | | | |
| TU13 | | | | 7.6 | 8.0 | 6.0 | | 2.3 | 1.9 | | 0.6 |
| TU14 | | | | 0.5 | 0.1 | 0.2 | | 0.0 | 0.2 | | 2.5 |
| TU15 | | | | 0.1 | 0.2 | 0.2 | | 0.9 | 0.1 | | 0.7 |
| TU16 | | | | 0.7 | 1.1 | 1.4 | | 1.9 | 1.4 | | 2.5 |
| **Min** | | | | 0.1 | 0.1 | 0.2 | | 0.0 | 0.1 | | 0.6 |
| **Average** | | | | 2.2 | 2.4 | 1.9 | | 1.3 | 0.9 | | 1.6 |
| **Max** | | | | 7.6 | 8.0 | 6.0 | | 2.3 | 1.9 | | 2.5 |

The irrigation of treated effluent commenced at the golf course and existing playing fields in February 2013

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.0 | 0.1 | 0.1 |
| 0.0 | 0.1 | 0.1 |
| 0.0 | 0.3 | 1.3 |
| 0.0 | 0.0 | 0.1 |
| 0.2 | 0.5 | 0.6 |
| 0.3 | 0.5 | 0.5 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.0 | 0.2 | 0.6 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.8 | 2.0 | 3.3 |
| 0.0 | 0.1 | 0.1 |
| 0.0 | 0.0 | 0.0 |
| 1.6 | 5.8 | 15.6 |
| 0.9 | 8.9 | 17.2 |
| 0.0 | 0.1 | 0.1 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.0 | 3.6 | 9.9 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.6 | 4.4 | 8.0 |
| 0.0 | 0.6 | 2.5 |
| 0.1 | 0.4 | 0.9 |
| 0.7 | 1.5 | 2.5 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.1 | 1.7 | 5.0 |

| | **All Samples** | |
|---|---|---|
| **P10** | **Avg** | **P90** |
| 0.0 | 1.9 | 6.1 |

## Organic Nitrogen (as Total Kjeldahl Nitrogen - TKN) (All units are mg/l)

| | 27/05/2011 | 16/02/2012 | 22/04/2012 | 30/05/2012 | 11/07/2012 | 15/10/2012 | 31/10/2012 | 8/11/2012 | 13/02/2013 | 27/02/2013 | 22/05/2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall over Pervious 14 days (mm) | 35 | 55 | 160 | 30 | 75 | 11 | 16 | 5 | 40 | 127 | 10 |
| **Non Golf Course Bores** | | | | | | | | | | | |
| MB01 | 0.6 | | 0.3 | | | | 0.3 | | | 0.5 | 0.1 |
| MB02 | 0.8 | | 0.4 | | | | 0.6 | | | 0.7 | 0.5 |
| MB04 | 0.9 | | 1.6 | | | | 2.8 | | | 2.5 | 3.3 |
| MB05 | 1.4 | 0.9 | 0.4 | | | | 1.0 | | | 1.0 | 0.7 |
| BH05 | | | 0.6 | | | | 0.4 | | | 0.2 | 0.3 |
| LC12-03 | | | 0.3 | | | | 0.2 | | | 0.4 | 1.1 |
| **Min** | 0.6 | 0.9 | 0.3 | | | | 0.2 | | | 0.2 | 0.1 |
| **Average** | 0.9 | 0.9 | 0.6 | | | | 0.9 | | | 0.9 | 1.0 |
| **Max** | 1.4 | 0.9 | 1.6 | | | | 2.8 | | | 2.5 | 3.3 |
| | | | | | | | | | | | |
| **Golf Course Bores** | | | | | | | | | | | |
| MB06 | 1.6 | 1.6 | 1.2 | | | | 1.6 | | | 1.6 | 2.1 |
| MB07 | 0.9 | | 0.4 | | | | 0.6 | | | 0.8 | 1.1 |
| P2 | | | 1.3 | | | | | | | 1.6 | 1.2 |
| TU11 | | | 2.3 | 2.0 | 0.4 | 1.6 | 2.9 | 1.2 | 1.5 | 1.5 | 1.9 |
| TU12 | | | | 1.3 | 0.8 | 1.9 | | 0.7 | 2.9 | | 0.8 |
| Golf Course Pond | | | 0.5 | | | | 0.4 | | | 0.8 | 0.7 |
| **Min** | 0.9 | 1.6 | 0.4 | 1.3 | 0.4 | 1.6 | 0.4 | 0.7 | 1.5 | 0.8 | 0.7 |
| **Average** | 1.3 | 1.6 | 1.1 | 1.7 | 0.6 | 1.8 | 1.4 | 0.9 | 2.2 | 1.3 | 1.3 |
| **Max** | 1.6 | 1.6 | 2.3 | 2.0 | 0.8 | 1.9 | 2.9 | 1.2 | 2.9 | 1.6 | 2.1 |
| | | | | | | | | | | | |
| **MCW Bores** | | | | | | | | | | | |
| TU13 | | | | 1.9 | 0.1 | 1.2 | | 0.5 | 0.7 | | 0.6 |
| TU14 | | | | 0.2 | 0.3 | 0.3 | | 0.3 | 0.5 | | 0.4 |
| TU15 | | | | 1.0 | 1.0 | 0.9 | | 0.9 | 1.0 | | 1.0 |
| TU16 | | | | 0.6 | 0.4 | 0.6 | | 0.0 | 0.5 | | 0.7 |
| **Min** | | | | 0.2 | 0.1 | 0.3 | | 0.0 | 0.5 | | 0.4 |
| **Average** | | | | 0.9 | 0.4 | 0.7 | | 0.4 | 0.7 | | 0.6 |
| **Max** | | | | 1.9 | 1.0 | 1.2 | | 0.9 | 1.0 | | 1.0 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.1 | 0.4 | 0.6 |
| 0.4 | 0.6 | 0.8 |
| 0.9 | 2.2 | 3.3 |
| 0.4 | 0.9 | 1.4 |
| 0.2 | 0.4 | 0.6 |
| 0.2 | 0.5 | 1.1 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.2 | 0.8 | 2.1 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 1.2 | 1.6 | 2.1 |
| 0.4 | 0.8 | 1.1 |
| 1.2 | 1.4 | 1.6 |
| 0.4 | 1.7 | 2.9 |
| 0.7 | 1.4 | 2.9 |
| 0.4 | 0.6 | 0.8 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.5 | 1.3 | 2.1 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.1 | 0.8 | 1.9 |
| 0.2 | 0.3 | 0.5 |
| 0.9 | 1.0 | 1.0 |
| 0.0 | 0.5 | 0.7 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.2 | 0.6 | 1.0 |

| | **All Samples** | |
|---|---|---|
| **P10** | **Avg** | **P90** |
| 0.3 | 1.0 | 1.9 |

🟨 yellow = by calc (TN - Nox)

The irrigation of treated effluent commenced at the golf course and existing playing fields in February 2013

## **Total Nitrogen Results** (All units are mg/l)

| | 27/05/2011 | 16/02/2012 | 22/04/2012 | 30/05/2012 | 11/07/2012 | 15/10/2012 | 31/10/2012 | 8/11/2012 | 13/02/2013 | 27/02/2013 | 22/05/2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall over Pervious 14 days (mm) | 35 | 55 | 160 | 30 | 75 | 11 | 16 | 5 | 40 | 127 | 10 |
| **Non Golf Course Bores** | | | | | | | | | | | |
| MB01 | 0.8 | | 0.4 | | | | 0.3 | | | 0.5 | 0.1 |
| MB02 | 0.8 | | 0.4 | | | | 0.7 | | | 0.8 | 0.6 |
| MB04 | 0.9 | | 1.6 | | | | 3.7 | | | 2.5 | 4.6 |
| MB05 | 1.4 | 0.9 | 0.4 | | | | 1.1 | | | 1.0 | 0.7 |
| BH05 | | | 1.2 | | | | 1.0 | | | 0.6 | 0.5 |
| LC12-03 | | | 0.8 | | | | 0.5 | | | 0.9 | 1.6 |
| **Min** | 0.8 | 0.9 | 0.4 | | | | 0.3 | | | 0.5 | 0.1 |
| **Average** | 1.0 | 0.9 | 0.8 | | | | 1.2 | | | 1.1 | 1.4 |
| **Max** | 1.4 | 0.9 | 1.6 | | | | 3.7 | | | 2.5 | 4.6 |
| | | | | | | | | | | | |
| **Golf Course Bores** | | | | | | | | | | | |
| MB06 | 4.9 | 4.5 | 2.2 | | | | 4.4 | | | 2.4 | 3.1 |
| MB07 | 0.9 | | 0.5 | | | | 0.7 | | | 0.9 | 1.1 |
| P2 | | | 1.3 | | | | | | | 1.6 | 1.2 |
| TU11 | | | 5.3 | 6.8 | 10.5 | 17.2 | | 7.9 | 3.3 | 3.1 | 4.2 |
| TU12 | | | | 2.2 | 6.3 | 11.4 | 9.2 | 18.4 | 20.0 | | 4.1 |
| Golf Course Pond | | | 0.6 | | | | 0.5 | | | 0.9 | 0.7 |
| **Min** | 0.9 | 4.5 | 0.5 | 2.2 | 6.3 | 11.4 | 0.5 | 7.9 | 3.3 | 0.9 | 0.7 |
| **Average** | 2.9 | 4.5 | 2.0 | 4.5 | 8.4 | 14.3 | 3.7 | 13.2 | 11.6 | 1.8 | 2.4 |
| **Max** | 4.9 | 4.5 | 5.3 | 6.8 | 10.5 | 17.2 | 9.2 | 18.4 | 20.0 | 3.1 | 4.2 |
| | | | | | | | | | | | |
| **MCW Bores** | | | | | | | | | | | |
| TU13 | | | | 9.4 | 8.1 | 7.2 | | 2.8 | 2.6 | | 1.2 |
| TU14 | | | | 0.7 | 0.4 | 0.4 | | 0.3 | 0.7 | | 2.9 |
| TU15 | | | | 1.1 | 1.2 | 1.1 | | 1.7 | 1.2 | | 1.7 |
| TU16 | | | | 1.3 | 1.5 | 2.1 | | 2.0 | 1.9 | | 3.2 |
| **Min** | | | | 0.7 | 0.4 | 0.4 | | 0.3 | 0.7 | | 1.2 |
| **Average** | | | | 3.1 | 2.8 | 2.7 | | 1.7 | 1.6 | | 2.2 |
| **Max** | | | | 9.4 | 8.1 | 7.2 | | 2.8 | 2.6 | | 3.2 |

The irrigation of treated effluent commenced at the golf course and existing playing fields in February 2013

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.1 | 0.4 | 0.8 |
| 0.4 | 0.7 | 0.8 |
| 0.9 | 2.7 | 4.6 |
| 0.4 | 0.9 | 1.4 |
| 0.5 | 0.8 | 1.2 |
| 0.5 | 0.9 | 1.6 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.4 | 1.1 | 2.1 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 2.2 | 3.6 | 4.9 |
| 0.5 | 0.8 | 1.1 |
| 1.2 | 1.4 | 1.6 |
| 3.1 | 7.3 | 17.2 |
| 2.2 | 10.2 | 20.0 |
| 0.5 | 0.7 | 0.9 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.7 | 4.9 | 11.2 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 1.2 | 5.2 | 9.4 |
| 0.3 | 0.9 | 2.9 |
| 1.1 | 1.3 | 1.7 |
| 1.3 | 2.0 | 3.2 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.5 | 2.4 | 6.0 |

| | **All Samples** | |
|---|---|---|
| **P10** | **Avg** | **P90** |
| 0.5 | 2.9 | 7.5 |

## Reactive Phosphorus (All units are mg/l)

| | 27/05/2011 | 16/02/2012 | 22/04/2012 | 30/05/2012 | 11/07/2012 | 15/10/2012 | 31/10/2012 | 8/11/2012 | 13/02/2013 | 27/02/2013 | 22/05/2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall over Pervious 14 days (mm) | 35 | 55 | 160 | 30 | 75 | 11 | 16 | 5 | 40 | 127 | 10 |
| **Non Golf Course Bores** | | | | | | | | | | | |
| MB01 | | | 0.01 | | | | 0.01 | | | 0.01 | 0.01 |
| MB02 | | | 0.01 | | | | 0.01 | | | 0.01 | 0.01 |
| MB04 | | 0.05 | 0.32 | | | | 0.31 | | | 0.20 | 0.15 |
| MB05 | | 0.01 | 0.01 | | | | 0.03 | | | 0.02 | 0.01 |
| BH05 | | | | | | | 0.01 | | | 0.01 | 0.01 |
| LC12-03 | | | 0.02 | | | | 0.06 | | | 0.03 | 0.23 |
| **Min** | 0.00 | 0.01 | 0.01 | | | | 0.01 | | | 0.01 | 0.01 |
| **Average** | #DIV/0! | 0.03 | 0.07 | | | | 0.07 | | | 0.05 | 0.07 |
| **Max** | 0.00 | 0.05 | 0.32 | | | | 0.31 | | | 0.20 | 0.23 |
| | | | | | | | | | | | |
| **Golf Course Bores** | | | | | | | | | | | |
| MB06 | | 0.06 | 0.01 | | | | 0.01 | | | 0.01 | 0.01 |
| MB07 | | | 0.03 | | | | 0.01 | | | 0.01 | 0.01 |
| P2 | | | | | | | | | | 0.01 | 0.01 |
| TU11 | | | | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 | 0.01 | 0.01 |
| TU12 | | | | 0.01 | 0.01 | 0.01 | | 0.00 | 0.01 | | 0.01 |
| Golf Course Pond | | | | | | | 0.09 | | | 0.08 | 0.06 |
| **Min** | 0.00 | 0.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| **Average** | #DIV/0! | 0.06 | 0.02 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.02 | 0.02 | 0.02 |
| **Max** | 0.00 | 0.06 | 0.03 | 0.02 | 0.01 | 0.01 | 0.09 | 0.02 | 0.04 | 0.08 | 0.06 |
| | | | | | | | | | | | |
| **MCW Bores** | | | | | | | | | | | |
| TU13 | | | | 0.02 | 0.02 | 0.02 | | 0.02 | 0.02 | | 0.02 |
| TU14 | | | | 0.02 | 0.02 | 0.02 | | 0.02 | 0.02 | | 0.01 |
| TU15 | | | | 0.03 | 0.03 | 0.03 | | 0.02 | 0.03 | | 0.03 |
| TU16 | | | | 0.02 | 0.02 | 0.02 | | 0.02 | 0.02 | | 0.02 |
| **Min** | | | | 0.02 | 0.02 | 0.02 | | 0.02 | 0.02 | | 0.01 |
| **Average** | | | | 0.02 | 0.02 | 0.02 | | 0.02 | 0.02 | | 0.02 |
| **Max** | | | | 0.03 | 0.03 | 0.03 | | 0.02 | 0.03 | | 0.03 |

The irrigation of treated effluent commenced at the golf course and existing playing fields in February 2013

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.01 | 0.01 | 0.01 |
| 0.01 | 0.01 | 0.01 |
| 0.05 | 0.21 | 0.32 |
| 0.01 | 0.02 | 0.03 |
| 0.01 | 0.01 | 0.01 |
| 0.02 | 0.09 | 0.23 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.01 | 0.06 | 0.22 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.01 | 0.02 | 0.06 |
| 0.01 | 0.02 | 0.03 |
| 0.01 | 0.01 | 0.01 |
| 0.01 | 0.02 | 0.04 |
| 0.00 | 0.01 | 0.01 |
| 0.06 | 0.08 | 0.09 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.01 | 0.02 | 0.06 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.02 | 0.02 | 0.02 |
| 0.01 | 0.02 | 0.02 |
| 0.02 | 0.03 | 0.03 |
| 0.02 | 0.02 | 0.02 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.02 | 0.02 | 0.03 |

| | **All Samples** | |
|---|---|---|
| **P10** | **Avg** | **P90** |
| 0.01 | 0.03 | 0.06 |

## **Total Phosphorus Results** (All units are mg/l)

| | 27/05/2011 | 16/02/2012 | 22/04/2012 | 30/05/2012 | 11/07/2012 | 15/10/2012 | 31/10/2012 | 8/11/2012 | 13/02/2013 | 27/02/2013 | 22/05/2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall over Pervious 14 days (mm) | 35 | 55 | 160 | 30 | 75 | 11 | 16 | 5 | 40 | 127 | 10 |
| **Non Golf Course Bores** | | | | | | | | | | | |
| MB01 | 0.16 | | 0.11 | | | | 0.09 | | | 0.05 | 0.18 |
| MB02 | 0.22 | | 0.23 | | | | 0.27 | | | 0.22 | 0.11 |
| MB04 | | 0.32 | 0.33 | | | | 0.48 | | | 0.44 | 0.46 |
| MB05 | 0.19 | 0.33 | 0.02 | | | | 0.14 | | | 0.10 | 0.04 |
| BH05 | | | 0.39 | | | | 0.08 | | | 0.01 | 0.02 |
| LC12-03 | | | 0.02 | | | | 0.06 | | | 0.03 | 0.23 |
| **Min** | 0.16 | 0.32 | 0.02 | | | | 0.06 | | | 0.01 | 0.02 |
| **Average** | 0.19 | 0.33 | 0.18 | | | | 0.19 | | | 0.14 | 0.17 |
| **Max** | 0.22 | 0.33 | 0.39 | | | | 0.48 | | | 0.44 | 0.46 |
| | | | | | | | | | | | |
| **Golf Course Bores** | | | | | | | | | | | |
| MB06 | 0.09 | 0.07 | 0.11 | | | | 0.11 | | | 0.02 | 0.06 |
| MB07 | 0.16 | | 1.02 | | | | 0.63 | | | 0.77 | 0.51 |
| P2 | | | 0.07 | | | | | | | 0.17 | 0.05 |
| TU11 | | | 0.07 | 0.04 | 0.03 | 0.02 | 0.06 | 0.03 | 0.04 | 0.02 | 0.02 |
| TU12 | | | | 0.06 | 0.07 | 0.05 | | 0.03 | 0.02 | | 0.03 |
| Golf Course Pond | | | 0.04 | | | | 0.13 | | | 0.13 | 0.09 |
| **Min** | 0.09 | 0.07 | 0.04 | 0.04 | 0.03 | 0.02 | 0.06 | 0.03 | 0.02 | 0.02 | 0.02 |
| **Average** | 0.13 | 0.07 | 0.26 | 0.05 | 0.05 | 0.04 | 0.23 | 0.03 | 0.03 | 0.22 | 0.13 |
| **Max** | 0.16 | 0.07 | 1.02 | 0.06 | 0.07 | 0.05 | 0.63 | 0.03 | 0.04 | 0.77 | 0.51 |
| | | | | | | | | | | | |
| **MCW Bores** | | | | | | | | | | | |
| TU13 | | | | 0.03 | 0.03 | 0.03 | | 0.03 | 0.03 | | 0.03 |
| TU14 | | | | 0.04 | 0.03 | 0.04 | | 0.03 | 0.04 | | 0.03 |
| TU15 | | | | 0.04 | 0.04 | 0.05 | | 0.04 | 0.05 | | 0.05 |
| TU16 | | | | 0.03 | 0.03 | 0.02 | | 0.02 | 0.03 | | 0.03 |
| **Min** | | | | 0.03 | 0.03 | 0.02 | | 0.02 | 0.03 | | 0.03 |
| **Average** | | | | 0.04 | 0.03 | 0.04 | | 0.03 | 0.04 | | 0.04 |
| **Max** | | | | 0.04 | 0.04 | 0.05 | | 0.04 | 0.05 | | 0.05 |

The irrigation of treated effluent commenced at the golf course and existing playing fields in February 2013

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.05 | 0.12 | 0.18 |
| 0.11 | 0.21 | 0.27 |
| 0.32 | 0.41 | 0.48 |
| 0.02 | 0.14 | 0.33 |
| 0.01 | 0.13 | 0.39 |
| 0.02 | 0.09 | 0.23 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.02 | 0.18 | 0.42 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.02 | 0.08 | 0.11 |
| 0.16 | 0.62 | 1.02 |
| 0.05 | 0.10 | 0.17 |
| 0.02 | 0.04 | 0.07 |
| 0.02 | 0.04 | 0.07 |
| 0.04 | 0.10 | 0.13 |
| | **All Samples** | |
| **P10** | **Avg** | **P90** |
| 0.02 | 0.15 | 0.44 |

| **Min** | **Avg** | **Max** |
|---|---|---|
| 0.03 | 0.03 | 0.03 |
| 0.03 | 0.04 | 0.04 |
| 0.04 | 0.05 | 0.05 |
| 0.02 | 0.03 | 0.03 |
| | **Totals** | |
| **P10** | **Avg** | **P90** |
| 0.03 | 0.03 | 0.05 |

| | **All Samples** | |
|---|---|---|
| **P10** | **Avg** | **P90** |
| 0.02 | 0.13 | 0.33 |

## Water Quality Monitoring Results - Insitu results and Alkalinity

| | | | | | | | | Redox Potential | | Alkalinity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test Site | Sample Date | pH (field) | pH (Lab) | Electrical Conductivity @ 25˚C | Total Dissolved Solids | Dissolved Oxygen | Total Hardness as $CaCO_3$ | Redox Potential | pH Redox | Hydroxide Alkalinity as $CaCO_3$ | Carbonate Alkalinity as $CaCO_3$ | Bicarbonate Alkalinity as $CaCO_3$ | Total Alkalinity as $CaCO_3$ |
| | | *ph Unit* | *ph Unit* | *µS/cm* | *mg/L* | *mg/L* | *mg/L* | *mV* | *pH Unit* | *mg/L* | *mg/L* | *mg/L* | *mg/L* |
| **Limit of Reporting** | | *0.1* | *0.01* | *1* | *5* | *0.1* | *1* | *0.1* | *0.01* | *1* | *1* | *1* | *1* |
| **ANZECC Trigger Values - Freshwater Ecosystems** | | | | | | | | | | | | | |
| **99% Level of Species Protection** | | | | | | | | | | | | | |
| **95% Level of Species Protection** | | | | | | | | | | | | | |
| **90% Level of Species Protection** | | | | | | | | | | | | | |
| **80% Level of Species Protection** | | | | | | | | | | | | | |
| **ANZECC Default trigger values for physical & chemical stressors for south-east Australia for slightly disturbed ecosystems** | | | | | | | | | | | | | |
| **Estuaries** | | 7.0-8.5 | 7.0-8.5 | | | | | | | | | | |
| **Australian Drinking Water Guidelines** | | | | | | | | | | | | | |
| **Health** | | | | | Not necessary | | Not necessary | | | | | | |
| **Aesthetic** | | 6.5 - 8.5 | 6.5 - 8.5 | | 600 | | 200 | | | | | | |
| **MB01** | 13-Mar-10 | 5.6 | 8.0 | 144 | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | - | 5.9 | 120 | 84 | - | - | - | - | 1 | 1 | 1 | 1 |
| | 22-Apr-12 | 5.6 | 5.9 | 102 | 68 | 6.6 | 8 | 272 | 6.4 | 1 | 1 | 4 | 4 |
| | 31-Oct-12 | 4.5 | 5.6 | 116 | 65 | 7.4 | 8 | 259 | 5.6 | 1 | 1 | 4 | 4 |
| | 27-Feb-13 | 5.4 | 5.7 | 113 | 67 | 6.5 | 8 | 266 | 5.2 | 1 | 1 | 4 | 4 |
| | 22-May-13 | 4.6 | 5.7 | 103 | 69 | 6.0 | 8 | 222 | 4.7 | 1 | 1 | 4 | 4 |
| **MB02** | 13-Mar-10 | 7.1 | 8.1 | 158 | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | - | 6.8 | 200 | 160 | - | - | - | - | 1 | 1 | 44 | 44 |
| | 23-Apr-12 | 5.7 | 6.3 | 352 | 188 | 4.2 | 33 | 242 | 6.6 | 1 | 1 | 37 | 37 |
| | 1-Nov-12 | 5.6 | 6.1 | 366 | 232 | - | 26 | 146 | 5.9 | 1 | 1 | 26 | 26 |
| | 27-Feb-13 | 5.0 | 6.0 | 340 | 216 | 5.7 | 17 | 257 | 5.3 | 1 | 1 | 14 | 14 |
| | 22-May-13 | 5.2 | 5.8 | 294 | 136 | 4.3 | 18 | 142 | 5.7 | 1 | 1 | 13 | 13 |
| **MB03** | 13-Mar-10 | 7.9 | 8.2 | 156 | - | - | - | - | - | - | - | - | - |
| **MB04** | 13-Mar-10 | 6.0 | - | 122 | - | - | - | - | - | - | - | - | - |
| | 23-Feb-12 | - | 6.1 | 384 | 292 | 5.2 | 24 | 130 | 6.0 | 1 | 1 | 15 | 15 |
| | 22-Apr-12 | 5.4 | 5.8 | 280 | 186 | 6.0 | 17 | 194 | 6.1 | 1 | 1 | 12 | 12 |
| | 31-Oct-12 | 4.5 | 5.4 | 321 | 204 | 8.1 | 21 | 124 | 5.2 | 1 | 1 | 8 | 8 |
| | 27-Feb-13 | 5.3 | 5.6 | 293 | 198 | 4.9 | 24 | 193 | 5.1 | 1 | 1 | 8 | 8 |
| | 22-May-13 | 4.9 | 5.8 | 359 | 206 | 5.9 | 35 | 153 | 3.5 | 1 | 1 | 12 | 12 |
| **MB05** | 13-Mar-10 | 7.1 | 7.9 | 126 | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | - | 7.2 | 380 | 290 | - | - | - | - | 1 | 1 | 1 | 1 |
| | 16-Feb-12 | - | 6.6 | 362 | 248 | - | 57 | 174 | 6.5 | 1 | 1 | 32 | 32 |
| | 22-Apr-12 | 5.9 | 6.5 | 465 | 272 | 4.5 | 50 | 183 | 6.4 | 1 | 1 | 28 | 28 |
| | 31-Oct-12 | 5.5 | 6.3 | 487 | 318 | 7.9 | 60 | 95.3 | 6.1 | 1 | 1 | 32 | 32 |
| | 27-Feb-13 | 5.3 | 5.7 | 370 | 292 | 5.1 | 26 | 258 | 5.4 | 1 | 1 | 9 | 9 |
| | 22-May-13 | 5.3 | 6.1 | 286 | 227 | 5.9 | 33 | 217 | 5.4 | 1 | 1 | 9 | 9 |
| **MB06** | 13-Mar-10 | 7.5 | 7.9 | 114 | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | - | 7.0 | 480 | 310 | - | - | - | - | 1 | 1 | 100 | 100 |
| | 16-Feb-12 | - | 6.3 | 652 | 382 | - | 78 | 190 | 6.1 | 1 | 1 | 11 | 11 |
| | 22-Apr-12 | 5.4 | 6.3 | 508 | 304 | 4.7 | 69 | 194 | 6.4 | 1 | 1 | 20 | 20 |
| | 31-Oct-12 | 5.1 | 5.9 | 422 | 262 | 8.1 | 55 | 124 | 5.7 | 1 | 1 | 17 | 17 |
| | 27-Feb-13 | 5.5 | 6.1 | 340 | 254 | 4.1 | 40 | 210 | 5.7 | 1 | 1 | 20 | 20 |
| | 22-May-13 | 5.3 | 5.9 | 317 | 238 | 7.1 | 33 | 196 | 5.5 | 1 | 1 | 13 | 13 |
| **MB07** | 13-Mar-10 | 7.0 | - | 142 | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | 6.6 | 7.4 | 230 | 160 | - | - | - | - | 1 | 1 | 66 | 66 |
| | 23-Apr-12 | 6.4 | 6.7 | 229 | 110 | 3.8 | 53 | 187 | 6.4 | 1 | 1 | 53 | 53 |
| | 31-Oct-12 | 5.9 | 6.9 | 182 | 300 | 9.0 | 78 | 95.9 | 6.6 | 1 | 1 | 68 | 68 |
| | 28-Feb-13 | - | 7.1 | 202 | 190 | 4.9 | 53 | 132 | 6.3 | 1 | 1 | 60 | 60 |
| | 22-May-13 | 5.8 | 6.5 | 222 | 170 | 6.9 | 53 | 134 | 6.1 | 1 | 1 | 53 | 53 |
| **BH05(DP05)** | 22-Apr-12 | 5.9 | - | - | - | - | - | - | - | - | - | - | - |
| | 31-Oct-12 | 5.5 | 6.7 | 138 | 94 | 9.0 | 43 | 252 | 6.4 | 1 | 1 | 32 | 32 |
| | 28-Feb-13 | - | 6.8 | 165 | 111 | 5.0 | 48 | 135 | 6.1 | 1 | 1 | 37 | 37 |
| | 22-May-13 | 5.8 | 6.8 | 153 | 93 | 6.7 | 43 | 115 | 6.4 | 1 | 1 | 35 | 35 |
| **LC12-03YB** | 22-Apr-12 | 6.8 | | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | 7.6 | 7.5 | 262 | 205 | - | 71 | 240 | 7.5 | 1 | 1 | 59 | 59 |
| | 27-Feb-13 | 5.5 | 7.4 | 274 | 176 | 6.5 | 83 | 245 | 6.3 | 1 | 1 | 74 | 74 |
| | 22-May-13 | 6.2 | 7.1 | 247 | 110 | 6.7 | 61 | 147 | 6.7 | 1 | 1 | 57 | 57 |
| **TU-11** | 23-Apr-12 | 6.5 | - | 380 | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | 6.8 | - | 480 | - | 1.2 | - | - | - | - | - | - | - |
| | 28-Feb-13 | 6.6 | - | 356 | 231 | 9.4 | - | - | - | - | - | - | - |
| | 23-May-13 | 6.4 | - | 328 | 213 | 7.7 | - | - | - | - | - | - | - |
| **Golf Course Pond** | 22-Apr-12 | 7.1 | - | 383 | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | 6.5 | - | 425 | - | 5.1 | - | - | - | - | - | - | - |
| | 28-Nov-13 | 7.5 | - | 425 | 276 | 14.7 | - | - | - | - | - | - | - |
| | 23-May-13 | 6.9 | - | 395 | 257 | 7.5 | - | - | - | - | - | - | - |
| **P2** | 22-Apr-12 | 5.2 | - | 767 | - | - | - | - | - | - | - | - | - |
| | 27-Feb-13 | 5.6 | - | 300 | 194 | 10.2 | - | - | - | - | - | - | - |
| | 22-May-13 | 4.2 | - | 733 | 476 | 6.9 | - | - | - | - | - | - | - |
| **Pump Test @ 8am** | 23-Feb-12 | | 7.9 | 498 | 300 | 3.1 | 121 | 106 | 7.6 | 1 | 1 | 122 | 122 |
| **Pump Test @ 2:15pm** | 23-Feb-12 | | 8.2 | 502 | 280 | 3.2 | 134 | 110 | 8.0 | 1 | 1 | 131 | 131 |

**Notes**

"- " Denotes no sample taken

Results that were reported below LOR have been set at the LOR value

Shading indicates relevant trigger value is exceeded

# Water Quality Monitoring Results - Metals and Ions

| | | Dissolved Major Anions | Dissolved Ions | | Dissolved Major Cations | | | | Fluoride | Unionized Hydrogen Sulfide | Ionic Balance | | | Dissolved Metals | | Total Metals | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test Site | Sample Date | Silicon | Sulfate as $SO_4$ | Chloride | Calcium | Magnesium | Sodium | Potassium | | | Total Anions | Total Cations | Ionic Balance | Manganese | Iron | Arsenic | Cadmium | Chromium | Copper | Nickel | Lead | Zinc | Molybdenum | Selenium | Silver | Tin | Iron | Mercury |
| | | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | meq/L | meq/L | % | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* | *mg/L* |
| **Limit of Reporting** | | *0.05* | *1* | *1* | *1* | *1* | *1* | *1* | *0.1* | 0.01 | *0.01* | *0.01* | *0.01* | *0.001* | *0.05* | *0.001* | *0.0001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.005* | *0.001* | *0.01* | *0.001* | *0.001* | *0.05* | 0.0001 |
| **ANZECC Trigger Values - Freshwater Ecosystems** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **99% Level of Species Protection** | | | | | | | | | | <LOR | | | | | | <LOR | <LOR | <LOR | <LOR | 0.008 | <LOR | <LOR | - | <LOR | <LOR | - | - | <LOR |
| **95% Level of Species Protection** | | | | | | | | | | <LOR | | | | | | 0.001 | 0.0002 | 0.001 | 0.001 | 0.011 | 0.003 | 0.008 | - | <LOR | <LOR | - | - | <LOR |
| **90% Level of Species Protection** | | | | | | | | | | <LOR | | | | | | 0.004 | 0.0004 | 0.006 | 0.002 | 0.013 | 0.006 | 0.015 | - | 0.02 | <LOR | - | - | 0.0002 |
| **80% Level of Species Protection** | | | | | | | | | | <LOR | | | | | | 0.014 | 0.0008 | 0.040 | 0.003 | 0.017 | 0.009 | 0.031 | - | 0.03 | <LOR | - | - | 0.0005 |
| **ANZECC Default trigger values for physical & chemical stressors for south-east Australia for slightly disturbed ecosystems** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Estuaries** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Australian Drinking Water Guidelines** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Health** | | | 500 | | | | | | 1.5 | | | | | 0.5 | | 0.01 | 0.002 | 0.05 | 2 | 0.02 | 0.01 | | 0.05 | 0.01 | 0.1 | | | 0.001 |
| **Aesthetic** | | | 250 | 250 | | | 180 | | | 0.05 | | | | 0.1 | 0.3 | | | | 1 | | | 3 | | | | | 0.3 | |
| **MB01** | 13-Mar-10 | - | - | - | - | - | - | - | 0.2 | - | - | - | - | - | - | 0.001 | 0.0002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0002 |
| | 27-May-11 | - | 5 | 42 | 1 | 3 | 17 | 1 | - | - | - | - | - | - | - | 0.009 | 0.0005 | 0.021 | 0.006 | 0.006 | 0.028 | 0.043 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 22-Apr-12 | 2.16 | 3 | 22 | 1 | 2 | 16 | 1 | 0.1 | 0.05 | 0.76 | 0.86 | - | 0.009 | 0.1 | 0.002 | 0.0001 | 0.007 | 0.006 | 0.002 | 0.006 | 0.008 | 0.001 | 0.01 | 0.001 | 0.001 | 2.03 | 0.0001 |
| | 31-Oct-12 | 2.11 | 4 | 26 | 1 | 2 | 15 | 1 | 0.1 | 0.01 | 0.9 | 0.84 | - | 0.005 | 0.08 | 0.001 | 0.0001 | 0.003 | 0.001 | 0.001 | 0.001 | 0.008 | 0.001 | 0.01 | 0.001 | 0.001 | 0.88 | 0.0001 |
| | 27-Feb-13 | 2.19 | 4 | 4 | 1 | 2 | 17 | 1 | 0.1 | 0.01 | 0.9 | 0.9 | - | 0.016 | 0.05 | 0.001 | 0.0001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.007 | 0.001 | 0.01 | 0.001 | 0.001 | 0.66 | 0.0001 |
| | 22-May-13 | 2.24 | 4 | 20 | 1 | 2 | 15 | 1 | 0.1 | 0.01 | 0.73 | 0.82 | - | 0.011 | 0.09 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.33 | 0.0001 |
| **MB02** | 13-Mar-10 | - | - | - | - | - | 1 | - | 0.2 | - | - | - | - | - | - | 0.001 | 0.0002 | - | 0.002 | 0.001 | 0.001 | 0.001 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 27-May-11 | - | 2 | 25 | 25 | 5 | 25 | 2 | - | - | - | - | - | - | - | 0.024 | 0.0005 | 0.069 | 0.023 | 0.028 | 0.062 | 0.110 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0003 |
| | 23-Apr-12 | 4.08 | 13 | 76 | 10 | 2 | 57 | 2 | 0.1 | 0.01 | 3.15 | 3.19 | 0.62 | 0.161 | 0.68 | 0.006 | 0.0001 | 0.008 | 0.003 | 0.006 | 0.010 | 0.016 | 0.001 | 0.01 | 0.001 | 0.001 | 5.01 | 0.0001 |
| | 1-Nov-12 | 3.49 | 17 | 76 | 9 | 1 | 55 | 2 | 0.1 | 0.01 | 3.02 | 2.97 | 0.72 | 0.127 | 1.5 | 0.006 | 0.0001 | 0.006 | 0.003 | 0.008 | 0.008 | 0.017 | 0.001 | 0.01 | 0.001 | 0.001 | 5.59 | 0.0001 |
| | 27-Feb-13 | 3.61 | 15 | 80 | 5 | 1 | 54 | 1 | 0.1 | 0.06 | 2.85 | 2.71 | - | 0.152 | 1.64 | 0.004 | 0.0001 | 0.007 | 0.003 | 0.009 | 0.007 | 0.019 | 0.001 | 0.01 | 0.001 | 0.001 | 7.48 | 0.0001 |
| | 22-May-13 | 3.59 | 8 | 67 | 4 | 2 | 41 | 1 | 0.1 | 0.01 | 2.32 | 2.17 | - | 0.101 | 1.59 | 0.003 | 0.0001 | 0.004 | 0.001 | 0.005 | 0.006 | 0.016 | 0.001 | 0.01 | 0.001 | 0.001 | 5.34 | 0.0001 |
| **MB03** | 13-Mar-10 | - | - | - | - | - | - | - | 0.2 | - | - | - | - | - | - | 0.003 | 0.0002 | 0.003 | 0.003 | 0.001 | 0.004 | 0.001 | 0.012 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| **MB04** | 13-Mar-10 | - | - | 81 | 10 | 7 | 3.3 | 61 | 0.2 | - | - | - | - | - | - | 0.035 | 0.0002 | 0.004 | 0.001 | 0.001 | 0.002 | 0.001 | 0.022 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 23-Feb-12 | 6.62 | 10 | 106 | 3 | 4 | 69 | 6 | 0.1 | 0.10 | 3.5 | 3.63 | 1.89 | 0.058 | 3.54 | 0.008 | 0.0001 | 0.004 | 0.005 | 0.004 | 0.016 | 0.040 | 0.002 | 0.01 | 0.001 | 0.001 | 7.23 | 0.0001 |
| | 22-Apr-12 | 5.31 | 7 | 67 | 2 | 3 | 44 | 4 | 0.1 | 0.09 | 2.28 | 2.36 | 1.87 | 0.03 | 2.22 | 0.006 | 0.0001 | 0.004 | 0.004 | 0.003 | 0.012 | 0.019 | 0.002 | 0.01 | 0.001 | 0.001 | 4.98 | 0.0001 |
| | 31-Oct-12 | 5.55 | 13 | 75 | 2 | 4 | 45 | 4 | 0.1 | 0.02 | 2.55 | 2.49 | - | 0.017 | 1.93 | 0.001 | 0.0001 | 0.002 | 0.001 | 0.002 | 0.002 | 0.009 | 0.001 | 0.01 | 0.001 | 0.001 | 2.34 | 0.0001 |
| | 27-Feb-13 | 5.05 | 6 | 70 | 3 | 4 | 40 | 3 | 0.1 | 0.01 | 2.26 | 2.3 | - | 0.017 | 2.12 | 0.002 | 0.0001 | 0.002 | 0.003 | 0.002 | 0.010 | 0.014 | 0.001 | 0.01 | 0.001 | 0.001 | 3.46 | 0.0001 |
| | 22-May-13 | 6.46 | 5 | 83 | 4 | 6 | 47 | 4 | 0.1 | 0.17 | 2.69 | 2.84 | - | 0.013 | 1.72 | 0.002 | 0.0001 | 0.002 | 0.003 | 0.002 | 0.005 | 0.015 | 0.001 | 0.01 | 0.001 | 0.001 | 2.63 | 0.0001 |
| **MB05** | 13-Mar-10 | - | - | - | - | - | - | - | 0.2 | - | - | - | - | - | - | 0.008 | 0.0002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.012 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 27-May-11 | - | 5 | 42 | 27 | 4 | 52 | 1.2 | - | - | - | - | - | - | - | 0.016 | 0.0005 | 0.020 | 0.008 | 0.005 | 0.022 | 0.052 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 16-Feb-12 | 4.63 | 8 | 99 | 13 | 6 | 58 | 2 | 0.1 | 0.10 | 3.60 | 3.72 | 1.61 | 0.03 | 2.12 | 0.014 | 0.0001 | 0.008 | 0.003 | 0.003 | 0.009 | 0.020 | 0.001 | 0.01 | 0.001 | 0.001 | 4.81 | 0.0001 |
| | 22-Apr-12 | 5.06 | 18 | 116 | 10 | 6 | 71 | 3 | 0.1 | 0.03 | 4.21 | 4.16 | 0.59 | 0.031 | 2.37 | 0.007 | 0.0001 | 0.004 | 0.003 | 0.002 | 0.004 | 0.007 | 0.001 | 0.01 | 0.001 | 0.001 | 3.09 | 0.0001 |
| | 31-Oct-12 | 5.48 | 9 | 122 | 16 | 5 | 70 | 2 | 0.1 | 0.01 | 4.27 | 4.31 | 0.44 | 0.033 | 4.5 | 0.008 | 0.0001 | 0.008 | 0.001 | 0.003 | 0.001 | 0.015 | 0.001 | 0.01 | 0.001 | 0.001 | 5.60 | 0.0001 |
| | 27-Feb-13 | 6.06 | 5 | 98 | 4 | 4 | 56 | 2 | 0.1 | 0.01 | 3.05 | 3.02 | 0.55 | 0.009 | 4.3 | 0.008 | 0.0001 | 0.008 | 0.001 | 0.002 | 0.004 | 0.013 | 0.001 | 0.01 | 0.001 | 0.001 | 5.41 | 0.0001 |
| | 22-May-13 | 5.87 | 6 | 67 | 5 | 5 | 40 | 2 | 0.1 | 0.02 | 2.19 | 2.45 | - | 0.018 | 3.45 | 0.010 | 0.0174 | 0.007 | 0.002 | 0.002 | 0.004 | 0.064 | 0.001 | 0.01 | 0.001 | 0.001 | 5.21 | 0.0001 |
| **MB06** | 13-Mar-10 | - | - | - | - | - | - | - | 0.2 | - | - | - | - | - | - | 0.008 | 0.0002 | 0.003 | 0.001 | 0.001 | 0.001 | 0.012 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0010 |
| | 27-May-11 | - | 6 | 76 | 43 | 6 | 44 | 5 | - | - | - | - | - | - | - | 0.006 | 0.0005 | 0.010 | 0.005 | 0.005 | 0.010 | 0.012 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0001 |
| | 16-Feb-12 | 5.06 | 28 | 180 | 13 | 11 | 92 | 8 | 0.1 | 0.10 | 5.88 | 5.76 | 1.03 | 0.021 | 0.12 | 0.001 | 0.0001 | 0.004 | 0.002 | 0.002 | 0.009 | 0.018 | 0.001 | 0.01 | 0.001 | 0.001 | 0.52 | 0.0001 |
| | 22-Apr-12 | 7.00 | 34 | 123 | 16 | 7 | 72 | 7 | 0.1 | 0.01 | 4.58 | 4.69 | 1.17 | 0.024 | 0.09 | 0.001 | 0.0001 | 0.003 | 0.002 | 0.001 | 0.006 | 0.016 | 0.001 | 0.01 | 0.001 | 0.001 | 0.80 | 0.0001 |
| | 31-Oct-12 | 6.58 | 27 | 87 | 12 | 6 | 52 | 5 | 0.1 | 0.01 | 3.36 | 3.48 | 1.84 | 0.021 | 0.17 | 0.001 | 0.0001 | 0.004 | 0.001 | 0.001 | 0.003 | 0.010 | 0.001 | 0.01 | 0.001 | 0.001 | 0.43 | 0.0001 |
| | 27-Feb-13 | 7.43 | 24 | 66 | 8 | 5 | 44 | 4 | 0.1 | 0.01 | 2.76 | 2.83 | - | 0.021 | 0.31 | 0.001 | 0.0001 | 0.005 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.48 | 0.0001 |
| | 22-May-13 | 7.16 | 12 | 66 | 5 | 5 | 44 | 3 | 0.1 | 0.02 | 2.37 | 2.65 | - | 0.019 | 0.81 | 0.002 | 0.0002 | 0.004 | 0.001 | 0.001 | 0.002 | 0.011 | 0.001 | 0.01 | 0.001 | 0.001 | 1.13 | 0.0001 |
| **MB07** | 13-Mar-10 | - | - | 85 | 26 | 6 | - | 28 | 0.2 | - | - | - | - | - | - | 0.010 | 0.0002 | 0.016 | 0.005 | 0.011 | 0.039 | 0.028 | 0.005 | 0.04 | 0.001 | 0.005 | - | 0.0001 |
| | 27-May-11 | - | 2 | 24 | 61 | 10 | 35 | 8 | - | - | - | - | - | - | - | 0.020 | 0.0005 | 0.012 | 0.016 | 0.008 | 0.082 | 0.140 | 0.005 | 0.01 | 0.001 | 0.005 | - | 0.0003 |
| | 23-Apr-12 | 3.09 | 1 | 32 | 18 | 2 | 25 | 1 | 0.1 | 0.01 | 1.96 | 2.15 | - | 0.065 | 0.24 | 0.022 | 0.0002 | 0.005 | 0.014 | 0.008 | 0.087 | 0.369 | 0.001 | 0.02 | 0.001 | 0.001 | 23.30 | 0.0001 |
| | 31-Oct-12 | 2.80 | 8 | 23 | 28 | 2 | 18 | 1 | 0.1 | 0.01 | 2.17 | 2.34 | - | 0.094 | 0.26 | 0.010 | 0.0003 | 0.006 | 0.009 | 0.008 | 0.050 | 0.234 | 0.001 | 0.01 | 0.001 | 0.001 | 14.50 | 0.0001 |
| | 28-Feb-13 | 2.95 | 8 | 21 | 18 | 2 | 21 | 1 | 0.1 | 0.01 | 1.96 | 1.98 | - | 0.104 | 0.2 | 0.011 | 0.0001 | 0.005 | 0.012 | 0.007 | 0.047 | 1.000 | 0.001 | 0.01 | 0.001 | 0.001 | 16.00 | 0.0001 |
| | 22-May-13 | 3.42 | 13 | 26 | 18 | 2 | 25 | 1 | 0.1 | 0.01 | 2.15 | - | 0.09 | 0.093 | 0.44 | 0.012 | 0.0002 | 0.004 | 0.009 | 0.007 | 0.039 | 2.110 | 0.001 | 0.01 | 0.001 | 0.001 | 13.80 | 0.0001 |
| **BH05(DP05)** | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 31-Oct-12 | 2.72 | 4 | 15 | 14 | 2 | 9 | 1 | 0.1 | 0.01 | 1.28 | - | 0.00 | 0.001 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.006 | 0.012 | 0.001 | 0.01 | 0.001 | 0.001 | 0.32 | 0.0001 |
| | 28-Feb-13 | 2.81 | 4 | 24 | 16 | 2 | 12 | 1 | 0.1 | 0.02 | 1.51 | - | 0.00 | 0.003 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.27 | 0.0001 |
| | 22-May-13 | 3.10 | 2 | 17 | 14 | 2 | 11 | 1 | 0.1 | 0.01 | 1.34 | - | 0.00 | 0.001 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.06 | 0.0001 |
| **LC12-03YB** | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | 2.68 | 4 | 37 | 25 | 2 | 18 | 1 | 0.1 | 0.01 | 2.22 | - | 0.00 | 0.001 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.006 | 0.001 | 0.01 | 0.001 | 0.001 | 0.38 | 0.0001 |
| | 27-Feb-13 | 3.18 | 4 | 30 | 30 | 2 | 20 | 1 | 0.1 | 0.04 | 2.56 | - | 0.00 | 0.001 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.24 | 0.0001 |
| | 22-May-13 | 3.37 | 6 | 29 | 21 | 2 | 21 | 1 | 0.1 | 0.01 | 2.15 | - | 0.00 | 0.001 | 0.05 | 0.001 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.13 | 0.0001 |
| **TU-11** | 23-Apr-12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.006 | 0.38 | 0.006 | 0.0001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.88 | 0.0001 |
| | 28-Feb-13 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.002 | 0.18 | 0.004 | 0.0001 | 0.003 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.92 | 0.0001 |
| | 23-May-13 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.005 | 0.29 | 0.004 | 0.0001 | 0.004 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.55 | 0.0001 |
| **Golf Course Pond** | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.01 | 0.26 | 0.012 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.44 | 0.0001 |
| | 28-Nov-13 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.003 | 0.12 | 0.014 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.88 | 0.0001 |
| | 23-May-13 | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.008 | 0.13 | 0.007 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.001 | 0.01 | 0.001 | 0.001 | 0.32 | 0.0001 |
| **P2** | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - | 0.01 | 0.024 | 6.42 | 0.024 | 0.0001 | 0.007 | 0.002 | 0.001 | 0.020 | 0.011 | 0.001 | 0.01 | 0.001 | 0.001 | 8.99 | 0.0001 |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - | 0.01 | 0.068 | 6.47 | 0.006 | 0.0001 | 0.006 | 0.001 | 0.006 | 0.025 | 0.016 | 0.001 | 0.01 | 0.001 | 0.001 | 7.68 | 0.0001 |
| **Pump Test @ 8am** | 23-Feb-12 | 4.31 | 14 | 79 | 37 | 7 | 59 | 5 | 0.2 | 0.01 | 5.12 | 1.58 | 0.00 | 0.002 | 0.05 | 0.003 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.002 | 0.01 | 0.001 | 0.001 | 0.05 | 0.0001 |
| **Pump Test @ 2:15pm** | 23-Feb-12 | 5.29 | 14 | 82 | 42 | 7 | 60 | 5 | 0.1 | 0.01 | 5.41 | 1.77 | 0.00 | 0.002 | 0.05 | 0.003 | 0.0001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.002 | 0.01 | 0.001 | 0.001 | 0.05 | 0.0001 |

**Notes**

"- " Denotes no sample taken

Results that were reported below LOR have been set at the LOR value

Shading indicates relevant trigger value is exceeded

## Water Quality Monitoring Results - Nutrients, Biological and Oxygen Demand Potential

| Test Site | Sample Date | Ammonia as N | Ammonium as N | Nitrite as N | Nitrate as N | Nitrite + Nitrate as N | Total Kjeldahl Nitrogen as N | Total Nitrogen as N | Total Phosphorus as P | Reactive Phosphorus as P | Chemical Oxygen Demand | Biochemical Oxygen Demand | Faecal Coliforms | Escherichia coli |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | CFU/100mL | CFU/100mL |
| **Limit of Reporting** | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.1 | 0.1 | 0.01 | 0.01 | 5 | 2 | 2 to 10^ | 2 to 10^ |
| **ANZECC Trigger Values - Freshwater Ecosystems** | | | | | | | | | | | | | | |
| **99% Level of Species Protection** | | | | | 0.02 | | | | | | | | | |
| **95% Level of Species Protection** | | | | | 0.70 | | | | | | | | | |
| **90% Level of Species Protection** | | | | | 3.40 | | | | | | | | | |
| **80% Level of Species Protection** | | | | | 17.00 | | | | | | | | | |
| **ANZECC Default trigger values for physical & chemical stressors for south-east Australia for slightly disturbed ecosystems** | | | | | | | | | | | | | | |
| **Estuaries** | | | 0.015 | | | 0.015 | | 0.3 | 0.03 | <LOR | | | | |
| **Australian Drinking Water Guidelines** | | | | | | | | | | | | | | |
| **Health** | | | | 3 | 50 | | | | | | | | Nil | Nil |
| **Aesthetic** | | 0.5 | | | | | | | | | | | | |
| **MB01** | 13-Mar-10 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | 0.01 | - | 0.01 | 0.12 | 0.13 | 0.60 | 0.80 | 0.16 | - | - | - | - | 10 |
| | 22-Apr-12 | 0.03 | 0.03 | 0.01 | 0.05 | 0.05 | 0.30 | 0.40 | 0.11 | 0.01 | 34 | 2 | 10 | 10 |
| | 31-Oct-12 | 0.01 | 0.01 | 0.01 | 0.04 | 0.04 | 0.20 | 0.25 | 0.09 | 0.01 | 19 | 2 | 2 | 2 |
| | 27-Feb-13 | 0.03 | 0.03 | - | - | 0.08 | 0.40 | 0.50 | 0.05 | 0.01 | 18 | 2 | 2 | 2 |
| | 22-May-13 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.10 | 0.10 | 0.18 | 0.01 | 16 | 2 | 2 | 2 |
| **MB02** | 13-Mar-10 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | 0.01 | - | 0.01 | 0.04 | 0.05 | 0.80 | 0.80 | 0.22 | - | - | - | - | 10 |
| | 23-Apr-12 | 0.12 | 0.12 | 0.01 | 0.03 | 0.03 | 0.40 | 0.40 | 0.23 | 0.01 | 54 | 2 | 10 | 10 |
| | 1-Nov-12 | 0.05 | 0.05 | 0.01 | 0.07 | 0.07 | 0.60 | 0.72 | 0.27 | 0.01 | 23 | 2 | 2 | 2 |
| | 27-Feb-13 | 0.06 | 0.06 | - | - | 0.13 | 0.70 | 0.80 | 0.22 | 0.01 | 34 | 2 | 2 | 2 |
| | 22-May-13 | 0.04 | 0.04 | 0.01 | 0.05 | 0.05 | 0.50 | 0.60 | 0.11 | 0.01 | 18 | 2 | 2 | 2 |
| **MB03** | 13-Mar-10 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **MB04** | 13-Mar-10 | - | - | 0.02 | 19.00 | - | - | - | - | - | - | - | - | - |
| | 23-Feb-12 | 0.21 | 0.21 | 0.01 | 0.01 | 0.01 | 0.90 | 0.90 | 0.32 | 0.05 | 145 | 2 | 10 | 10 |
| | 22-Apr-12 | 0.56 | 0.56 | 0.01 | 0.01 | 0.01 | 1.60 | 1.60 | 0.33 | 0.32 | 109 | 26 | 10 | 10 |
| | 31-Oct-12 | 0.91 | 0.91 | 0.01 | 0.01 | 0.01 | 2.80 | 3.72 | 0.48 | 0.31 | 133 | 27 | 2 | 2 |
| | 27-Feb-13 | 0.91 | 0.91 | - | - | 0.04 | 2.50 | 2.50 | 0.44 | 0.20 | 100 | 31 | 2 | 2 |
| | 22-May-13 | 1.17 | 1.17 | 0.01 | 1.33 | 1.33 | 3.30 | 4.60 | 0.46 | 0.15 | 97 | 27 | 2 | 2 |
| **MB05** | 13-Mar-10 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | 0.16 | - | 0.03 | 0.02 | 0.05 | 1.40 | 1.40 | 0.19 | - | - | - | - | 10 |
| | 16-Feb-12 | 0.12 | 0.12 | 0.01 | 0.01 | 0.01 | 0.90 | 0.90 | 0.33 | 0.01 | 67 | 2 | 10 | 10 |
| | 22-Apr-12 | 0.08 | 0.08 | 0.01 | 0.01 | 0.01 | 0.40 | 0.40 | 0.02 | 0.01 | 45 | 2 | 2 | 2 |
| | 31-Oct-12 | 0.05 | 0.05 | 0.01 | 0.01 | 0.01 | 1.00 | 1.06 | 0.14 | 0.03 | 111 | 2 | 2 | 2 |
| | 27-Feb-13 | 0.08 | 0.08 | - | - | 0.01 | 1.00 | 1.00 | 0.10 | 0.02 | 100 | 2 | 2 | 2 |
| | 22-May-13 | 0.10 | 0.10 | 0.01 | 0.01 | 0.01 | 0.70 | 0.70 | 0.04 | 0.01 | 69 | 2 | 2 | 2 |
| **MB06** | 13-Mar-10 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 27-May-11 | 0.10 | - | 3.30 | 0.04 | 3.30 | 1.60 | 4.90 | 0.09 | - | - | - | - | 10 |
| | 16-Feb-12 | 0.18 | 0.18 | 0.01 | 2.89 | 2.89 | 1.60 | 4.50 | 0.07 | 0.06 | 32 | 2 | 2 | 2 |
| | 22-Apr-12 | 0.05 | 0.05 | 0.01 | 0.98 | 0.98 | 1.20 | 2.20 | 0.11 | 0.01 | 59 | 2 | 2 | 2 |
| | 31-Oct-12 | 0.01 | 0.01 | 0.01 | 2.78 | 2.79 | 1.60 | 4.40 | 0.11 | 0.01 | 59 | 2 | 2 | 2 |
| | 27-Feb-13 | 0.04 | 0.04 | - | - | 0.80 | 1.60 | 2.40 | 0.02 | 0.01 | 76 | 2 | 2 | 2 |
| | 22-May-13 | 0.14 | 0.14 | 0.01 | 0.99 | 0.99 | 2.10 | 3.10 | 0.06 | 0.01 | 88 | 2 | 2 | 2 |
| **MB07** | 13-Mar-10 | - | - | 0.02 | 0.02 | 0.04 | - | - | - | - | - | - | - | - |
| | 27-May-11 | 0.02 | - | 0.01 | 0.01 | 0.05 | 0.90 | 0.90 | 0.16 | - | - | - | - | 10 |
| | 23-Apr-12 | 0.20 | 0.20 | 0.01 | 0.09 | 0.09 | 0.40 | 0.50 | 1.02 | 0.03 | 68 | 2 | 60 | 60 |
| | 31-Oct-12 | 0.07 | 0.07 | 0.01 | 0.01 | 0.01 | 0.60 | 0.68 | 0.63 | 0.01 | 76 | 2 | 2 | 2 |
| | 28-Feb-13 | 0.12 | 0.12 | - | - | 0.11 | 0.80 | 0.90 | 0.77 | 0.01 | 67 | 2 | 2 | 2 |
| | 22-May-13 | 0.09 | 0.09 | 0.01 | 0.01 | 0.01 | 1.10 | 1.10 | 0.51 | 0.01 | 81 | 2 | 62 | 62 |
| **BH05(DP05)** | 22-Apr-12 | - | - | - | - | 0.58 | 0.60 | 1.20 | 0.39 | - | - | - | - | - |
| | 31-Oct-12 | 0.01 | 0.01 | 0.01 | 0.62 | 0.62 | 0.40 | 1.03 | 0.08 | 0.01 | 9 | 2 | 2 | 2 |
| | 28-Feb-13 | 0.03 | 0.03 | - | - | 0.37 | 0.20 | 0.60 | 0.01 | 0.01 | 9 | 2 | 2 | 2 |
| | 22-May-13 | 0.02 | 0.02 | 0.01 | 0.23 | 0.23 | 0.30 | 0.50 | 0.02 | 0.01 | 18 | 2 | 2 | 2 |
| **LC12-03YB** | 22-Apr-12 | - | - | - | - | 0.52 | 0.30 | 0.80 | 0.02 | - | | | | |
| | 1-Nov-12 | 0.01 | 0.01 | 0.01 | 0.28 | 0.28 | 0.20 | 0.49 | 0.06 | 0.06 | 5 | 2 | 2 | 2 |
| | 27-Feb-13 | 0.02 | 0.02 | - | - | 0.53 | 0.40 | 0.90 | 0.03 | 0.03 | - | - | - | |
| | 22-May-13 | 0.02 | 0.02 | 0.01 | 0.52 | 0.52 | 1.10 | 1.60 | 0.23 | 0.02 | 18 | 2 | 2 | 2 |
| **TU-11** | 23-Apr-12 | - | - | - | - | 2.96 | 2.30 | 5.30 | 0.07 | - | - | - | - | - |
| | 30-May-12 | - | 0.05 | 4.77 | 0.02 | 4.79 | - | 6.83 | 0.04 | 0.02 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.04 | 10.03 | 0.03 | 10.06 | - | 10.50 | 0.03 | 0.01 | - | - | - | - |
| | 15-Aug-12 | - | 0.01 | 15.50 | 0.05 | 15.60 | - | 17.20 | 0.02 | 0.01 | - | - | - | - |
| | 1-Nov-12 | 0.03 | - | 0.01 | 6.23 | 6.24 | 2.90 | 9.17 | 0.06 | 0.02 | - | 2 | 2 | - |
| | 8-Nov-12 | - | 0.07 | 6.72 | 0.02 | 6.74 | - | 7.92 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.03 | 1.66 | 0.07 | 1.73 | - | 3.26 | 0.04 | 0.04 | - | 2 | 2 | - |
| | 28-Feb-13 | 0.04 | 0.04 | - | - | 1.59 | 1.50 | 3.10 | 0.02 | 0.01 | - | - | - | - |
| | 22-May-13 | - | 0.02 | 3.00 | 0.01 | 3.01 | - | 4.31 | 0.02 | 0.01 | - | - | - | - |
| | 23-May-13 | 0.07 | 0.07 | 0.01 | 2.27 | 2.27 | 1.90 | 4.20 | 0.04 | 0.01 | - | - | - | - |
| **TU -12** | 30-May-12 | - | 0.02 | 0.83 | 0.03 | 0.86 | - | 2.17 | 0.06 | 0.01 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.04 | 5.38 | 0.04 | 5.42 | - | 6.26 | 0.07 | 0.01 | - | 2 | 2 | - |
| | 15-Aug-12 | - | 0.02 | 9.42 | 0.04 | 9.46 | - | 11.40 | 0.05 | 0.01 | - | 2 | 125 | - |
| | 8-Nov-12 | - | 0.01 | 17.67 | 0.05 | 17.72 | - | 18.40 | 0.03 | 0.00 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.01 | 17.10 | 0.04 | 17.10 | - | 20.00 | 0.02 | 0.01 | - | 2 | 2 | - |
| | 22-May-13 | - | 0.02 | 3.29 | 0.02 | 3.31 | - | 4.08 | 0.03 | 0.01 | - | 2 | 2 | - |
| **TU -13** | 30-May-12 | - | 0.01 | 7.51 | 0.05 | 7.56 | - | 9.41 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.01 | 8.01 | 0.03 | 8.04 | - | 8.14 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 15-Oct-12 | - | 0.01 | 5.99 | 0.02 | 6.01 | - | 7.16 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 8-Nov-12 | - | 0.01 | 2.33 | 0.01 | 2.34 | - | 2.81 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.02 | 1.80 | 0.07 | 1.86 | - | 2.60 | 0.03 | 0.02 | - | 2 | 97 | - |
| | 22-May-13 | - | 0.14 | 0.64 | 0.01 | 0.64 | - | 1.22 | 0.03 | 0.02 | - | 2 | 2 | - |
| **TU -14** | 30-May-12 | - | 0.01 | 0.45 | 0.06 | 0.51 | - | 0.74 | 0.04 | 0.02 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.01 | 0.09 | 0.03 | 0.12 | - | 0.38 | 0.03 | 0.02 | - | 2 | 40 | - |
| | 15-Oct-12 | - | 0.01 | 0.12 | 0.03 | 0.15 | - | 0.43 | 0.04 | 0.02 | - | 2 | 2 | - |
| | 8-Nov-12 | - | 0.02 | 0.01 | 0.01 | 0.01 | - | 0.32 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.02 | 0.14 | 0.06 | 0.20 | - | 0.68 | 0.04 | 0.02 | - | 2 | 2 | - |
| | 22-May-13 | - | 0.01 | 2.41 | 0.10 | 2.51 | - | 2.86 | 0.03 | 0.01 | - | 2 | 2 | - |
| **TU -15** | 30-May-12 | - | 0.02 | 0.08 | 0.02 | 0.10 | - | 1.13 | 0.04 | 0.03 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.03 | 0.17 | 0.01 | 0.18 | - | 1.18 | 0.04 | 0.03 | - | 2 | 2 | - |
| | 15-Oct-12 | - | 0.03 | 0.17 | 0.01 | 0.18 | - | 1.08 | 0.05 | 0.03 | - | 2 | 2 | - |
| | 8-Nov-12 | - | 0.05 | 0.82 | 0.03 | 0.85 | - | 1.74 | 0.04 | 0.02 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.07 | 0.11 | 0.01 | 0.12 | - | 1.15 | 0.05 | 0.03 | - | 2 | 2 | - |
| | 22-May-13 | - | 0.05 | 0.70 | 0.02 | 0.72 | - | 1.69 | 0.05 | 0.03 | - | 2 | 2 | - |
| **TU -16** | 30-May-12 | - | 0.01 | 0.62 | 0.04 | 0.66 | - | 1.27 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 11-Jul-12 | - | 0.01 | 0.98 | 0.11 | 1.09 | - | 1.49 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 15-Oct-12 | - | 0.01 | 1.32 | 0.12 | 1.44 | - | 2.05 | 0.02 | 0.02 | - | 2 | 2 | - |
| | 8-Nov-12 | - | 0.01 | 1.72 | 0.22 | 1.94 | - | 1.98 | 0.02 | 0.02 | - | 2 | 2 | - |
| | 13-Feb-13 | - | 0.01 | 1.38 | 0.02 | 1.39 | - | 1.93 | 0.03 | 0.02 | - | 2 | 2 | - |
| | 22-May-13 | - | 0.01 | 2.43 | 0.09 | 2.52 | - | 3.18 | 0.03 | 0.02 | - | 2 | 2 | - |
| **Golf Course Pond** | 22-Apr-12 | - | - | - | - | 0.06 | 0.50 | 0.60 | 0.04 | - | - | - | - | - |
| | 1-Nov-12 | 0.03 | - | 0.01 | 0.04 | 0.04 | 0.40 | 0.47 | 0.13 | 0.09 | - | - | - | - |
| | 28-Nov-13 | 0.01 | 0.01 | - | - | 0.09 | 0.80 | 0.90 | 0.13 | 0.08 | - | - | - | - |
| | 23-May-13 | 0.04 | 0.04 | 0.01 | 0.01 | 0.01 | 0.70 | 0.70 | 0.09 | 0.06 | - | - | - | - |
| **P2** | 22-Apr-12 | - | - | - | - | 0.01 | 1.30 | 1.30 | 0.07 | - | - | - | - | - |
| | 27-Feb-13 | 0.01 | 0.01 | - | - | 0.02 | 1.60 | 1.60 | 0.17 | 0.01 | - | - | - | - |
| | 22-May-13 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 1.20 | 1.20 | 0.05 | 0.01 | - | - | - | - |
| **Pump Test @ 8am** | 23-Feb-12 | 0.68 | 0.65 | 0.01 | 0.04 | 0.04 | 0.60 | 0.60 | 0.26 | 0.20 | 85 | 2 | 1 | 1 |
| **Pump Test @ 2:15pm** | 23-Feb-12 | 0.45 | 0.43 | 0.01 | 0.03 | 0.03 | 0.60 | 0.60 | 0.25 | 0.21 | 87 | 2 | 1 | 1 |

**Notes**

Denotes Data provided by Mid Coast Water

"- " Denotes no sample taken

Results that were reported below LOR have been set at the LOR value

Shading indicates relevant trigger value is exceeded

## Water Quality Monitoring Results - Hydrocarbons

| | | | Total Petroleum Hydrocarbons | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test Site** | **Sample Date** | **Oil & Grease** | **C6 - C9 Fraction** | **C10 - C14 Fraction** | **C15 - C28 Fraction** | **C29 - C36 Fraction** | **C10 - C36 Fraction (sum)** | **C6 - C10 Fraction** | **>C10 - C16 Fraction** | **>C16 - C34 Fraction** | **>C34 - C40 Fraction** | **>C10 - C40 Fraction (sum)** |
| | | *mg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* |
| **Limit of Reporting** | | *5* | *20* | *50* | *100* | *50* | *50* | *20* | *100* | *100* | *100* | *100* |
| **MB01** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | 110 | 800 | 200 | - | - | - | - | - | - |
| | 27-May-11 | - | <20 | <50 | <100 | 100 | 100 | - | - | - | - | - |
| | 22-Apr-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **MB02** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | <LOR | <LOR | <LOR | - | - | - | - | - | - |
| | 27-May-11 | - | <20 | <50 | <100 | <50 | <50 | - | - | - | - | - |
| | 23-Apr-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 1-Nov-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **MB03** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | 90 | 500 | <LOR | - | - | - | - | - | - |
| | | | | | | | | | | | | |
| **MB04** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | 200 | 1200 | 400 | - | - | - | - | - | - |
| | 23-Feb-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 22-Apr-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **MB05** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | 120 | 500 | 200 | - | - | - | - | - | - |
| | 27-May-11 | - | <20 | <50 | <100 | <50 | <50 | - | - | - | - | - |
| | 16-Feb-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 22-Apr-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **MB06** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | <LOR | <LOR | <LOR | - | - | - | - | - | - |
| | 27-May-11 | - | <20 | <50 | <100 | <50 | <50 | - | - | - | - | - |
| | 16-Feb-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 22-Apr-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **MB07** | | | | | | | | | | | | |
| | 13-Mar-10 | - | <LOR | 90 | 500 | 200 | - | - | - | - | - | - |
| | 27-May-11 | - | <20 | <50 | <100 | <50 | <50 | - | - | - | - | - |
| | 23-Apr-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 28-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **BH05(DP05)** | | | | | | | | | | | | |
| | 22-Apr-12 | | | | | | | | | | | |
| | 31-Oct-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 28-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **LC12-03YB** | | | | | | | | | | | | |
| | 22-Apr-12 | | | | | | | | | | | |
| | 1-Nov-12 | - | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **TU-11** | | | | | | | | | | | | |
| | 23-Apr-12 | - | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | - | - | - | - | - | - | - | - | - | - | - |
| | 28-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 23-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **Golf Course Pond** | | | | | | | | | | | | |
| | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - |
| | 1-Nov-12 | - | - | - | - | - | - | - | - | - | - | - |
| | 28-Nov-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 23-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| **P2** | | | | | | | | | | | | |
| | 22-Apr-12 | - | - | - | - | - | - | - | - | - | - | - |
| | 27-Feb-13 | - | - | - | - | - | - | - | - | - | - | - |
| | 22-May-13 | - | - | - | - | - | - | - | - | - | - | - |
| | | | | | | | | | | | | |
| **Pump Test @ 8am** | 23-Feb-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |
| | | | | | | | | | | | | |
| **Pump Test @ 2:15pm** | 23-Feb-12 | <5 | <20 | <50 | <100 | <50 | <50 | <20 | <100 | <100 | <100 | <100 |

**Notes**

"- "  Denotes no sample taken

Results Extracted from WorelyParsons 2010 which applied a higher LOR for some analytes.  Results are reported as <LOR when below LOR.

## Water Quality Results - Pesticides and Herbicides

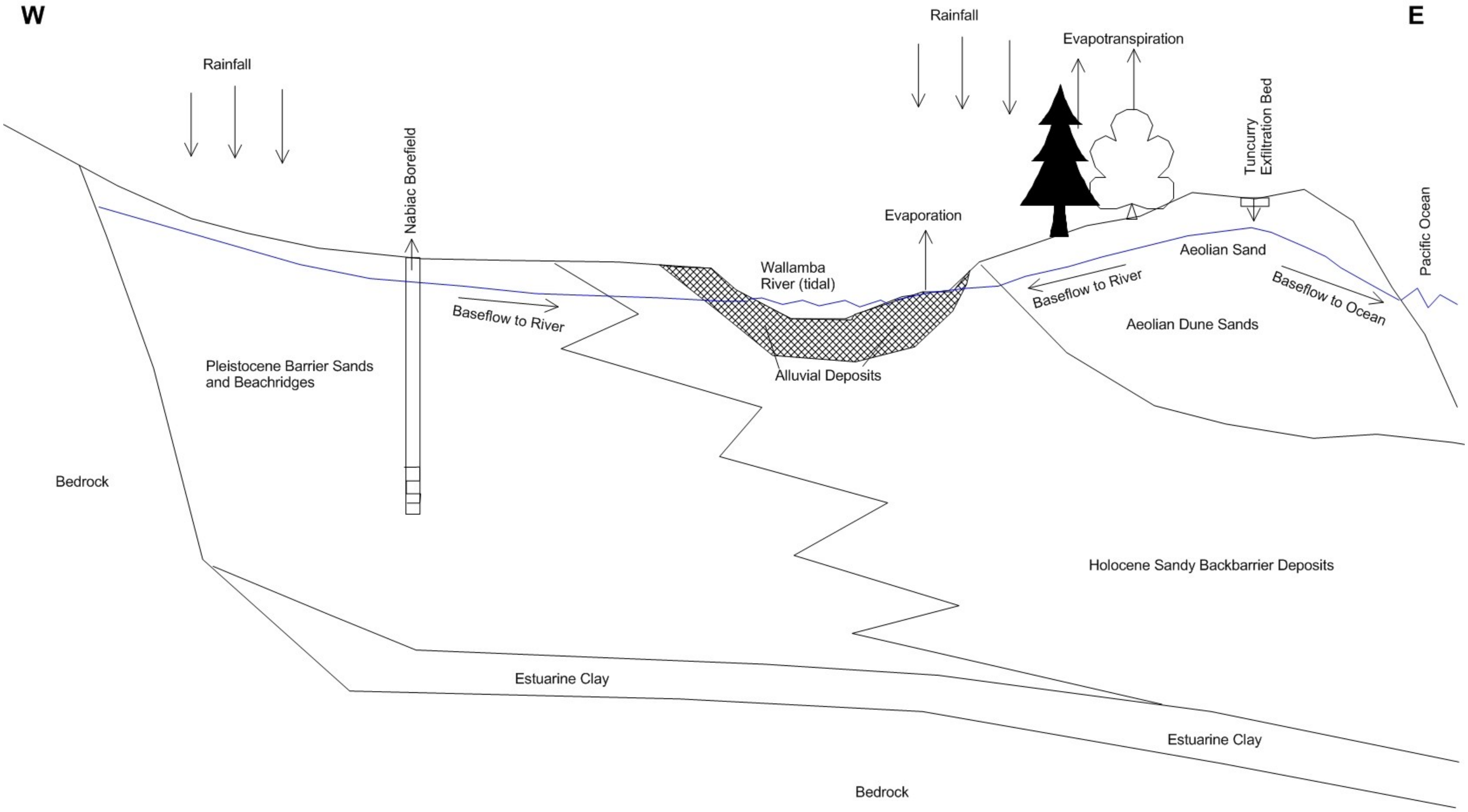
| | | EP068A: Organochlorine Pesticides (OC) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test Site** | **Sample Date** | **alpha-BHC** | **Hexachlorobenzene (HCB)** | **beta-BHC** | **gamma-BHC** | **delta-BHC** | **Heptachlor** | **Aldrin** | **Heptachlor epoxide** | **trans-Chlordane** | **alpha-Endosulfan** | **cis-Chlordane** | **Dieldrin** | **4.4`-DDE** | **Endrin** | **beta-Endosulfan** | **4.4`-DDD** | **Endrin aldehyde** | **Endosulfan sulfate** | **4.4`-DDT** | **Endrin ketone** | **Methoxychlor** | **Total Chlordane (sum)** | **Sum of DDD + DDE + DDT** | **Sum of Aldrin + Dieldrin** |
| | | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| **Limit of Reporting** | | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 0.5 | 2 | 0.5 | 0.5 | 0.5 |
| **TU-11** | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1-Nov-12 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <2 | <0.5 | <0.5 | <0.5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Golf Course Pond** | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1-Nov-12 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <2 | <0.5 | <0.5 | <0.5 |

| | | EP068B: Organophosphorus Pesticides (OP) | | | | | | | | | | | | | | | | | | | EP068S: Organochlorine Pesticide Surrogate | EP068T: Organophosphorus Pesticide Surrogate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test Site** | **Sample Date** | **Dichlorvos** | **Demeton-S-methyl** | **Monocrotophos** | **Dimethoate** | **Diazinon** | **Chlorpyrifos-methyl** | **Parathion-methyl** | **Malathion** | **Fenthion** | **Chlorpyrifos** | **Parathion** | **Pirimphos-ethyl** | **Chlorfenvinphos** | **Bromophos-ethyl** | **Fenamiphos** | **Prothiofos** | **Ethion** | **Carbophenothion** | **Azinphos Methyl** | **Dibromo-DDE** | **DEF** |
| | | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | µg/L | µg/L | µg/L | µg/L | µg/L | % | % |
| **Limit of Reporting** | | *0.5* | *0.5* | *2* | *0.5* | *0.5* | *0.5* | *2* | *0.5* | *0.5* | *0.5* | *2* | *0.5* | *0.5* | *0.5* | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.1 | 0.1 |
| **TU-11** | | | | | | | | | | | | | | | | | | | | | | |
| | 1-Nov-12 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 74.4 | 69.4 |
| | | | | | | | | | | | | | | | | | | | | | | |
| **Golf Course Pond** | | | | | | | | | | | | | | | | | | | | | | |
| | 1-Nov-12 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <2 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 76.8 | 72.1 |

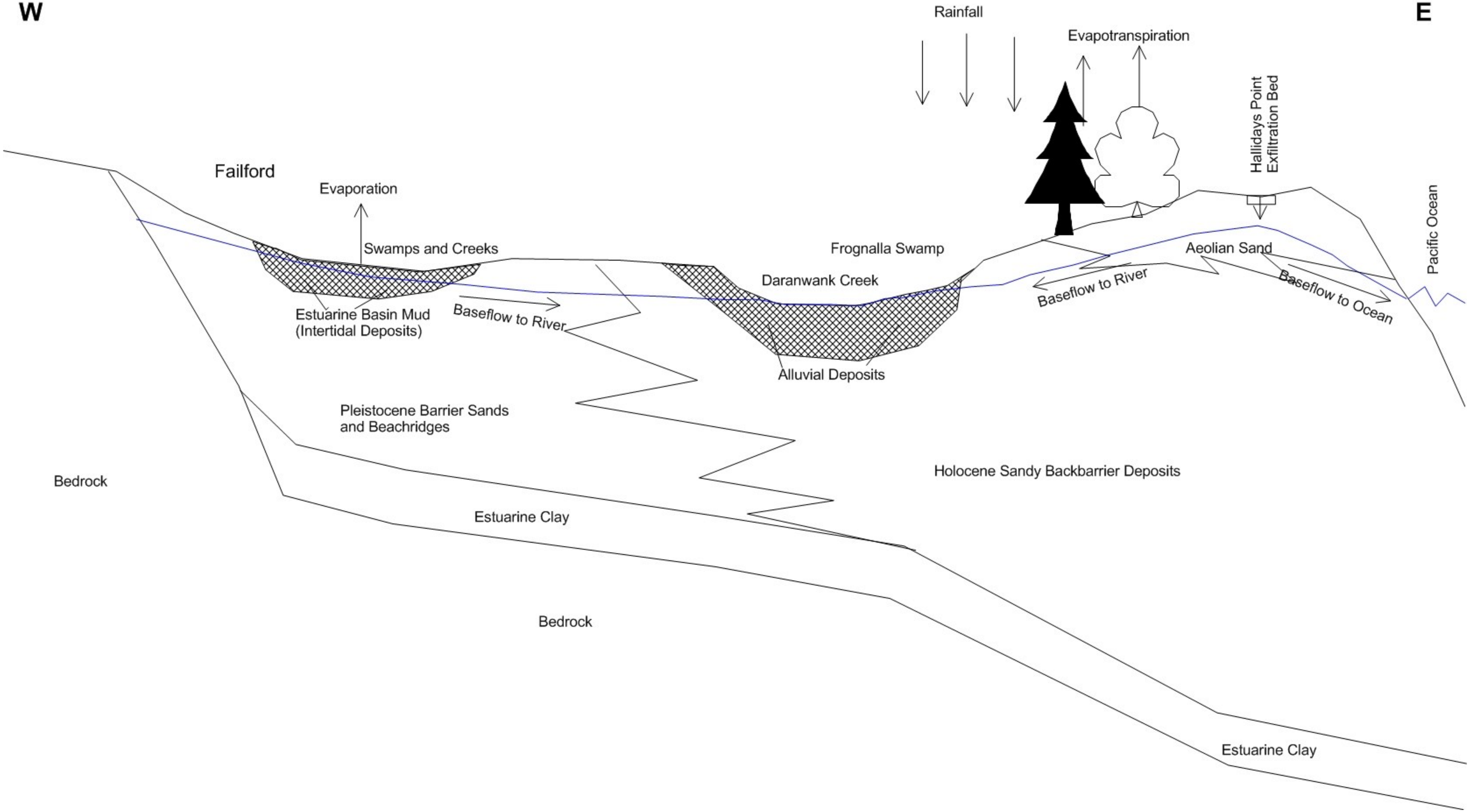
| | | EP202A: Phenoxyacetic Acid Herbicides | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test Site** | **Sample Date** | **4-Chlorophenoxy acetic acid** | **2.4-DB** | **Dicamba** | **Mecoprop** | **MCPA** | **2.4-DP** | **2.4-D** | **Triclopyr** | **2.4.5-TP (Silvex)** | **2.4.5-T** | **MCPB** | **Picloram** | **Clopyralid** | **Fluroxypyr** | **2.6-D** | **2.4.6-T** |
| | | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | *µg/L* | µg/L | µg/L |
| **Limit of Reporting** | | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | *10* | 10 | 10 |
| **TU-11** | | | | | | | | | | | | | | | | | |
| | 28-Feb-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| | 23-May-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| **P2** | | | | | | | | | | | | | | | | | |
| | 27-Feb-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| | 22-May-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| **Golf Course Pond** | | | | | | | | | | | | | | | | | |
| | 28-Feb-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| | 23-May-13 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |

# APPENDIX D – CONCEPTUAL GROUNDWATER MODEL

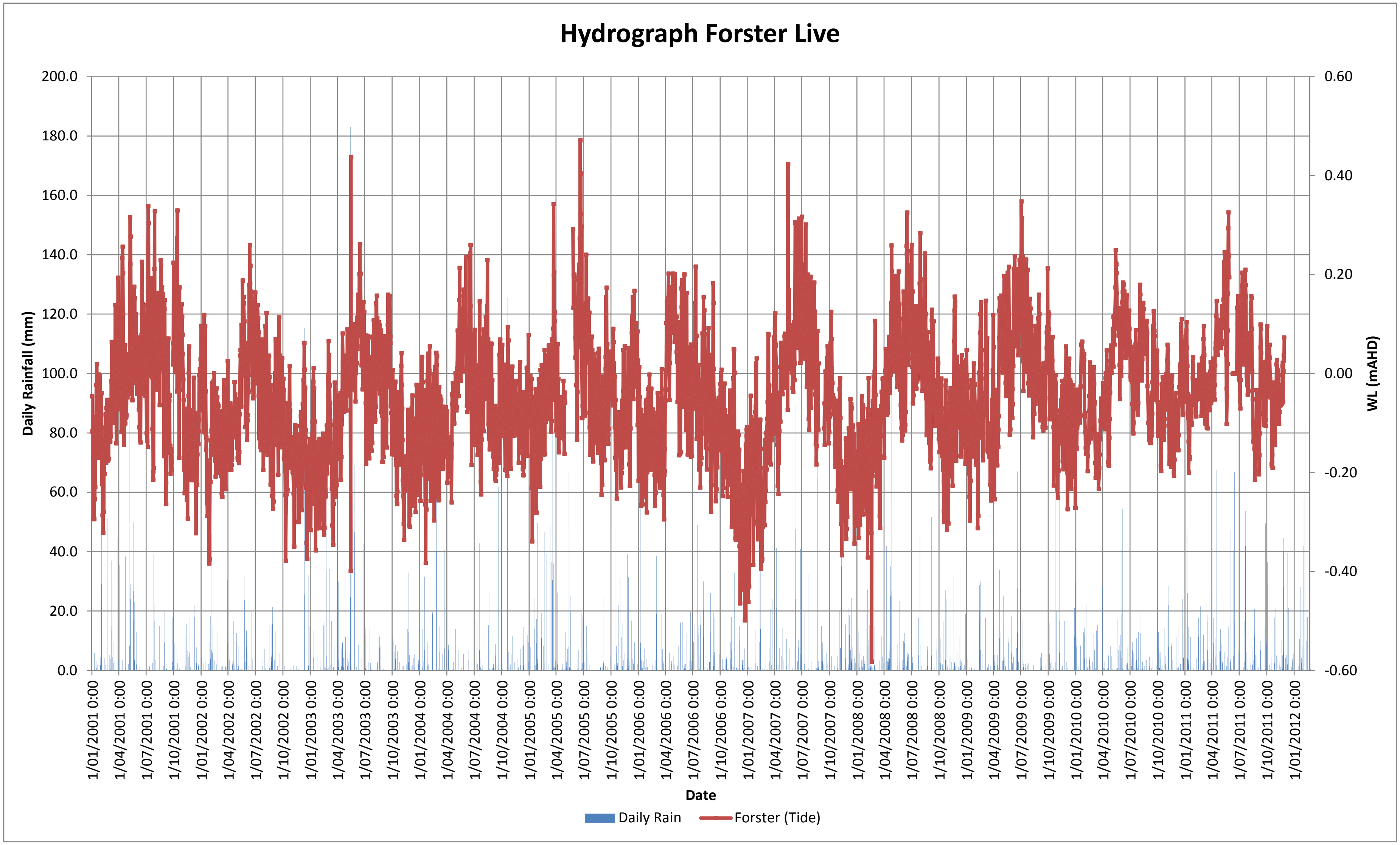
# Conceptual East-West Section through the Project Area

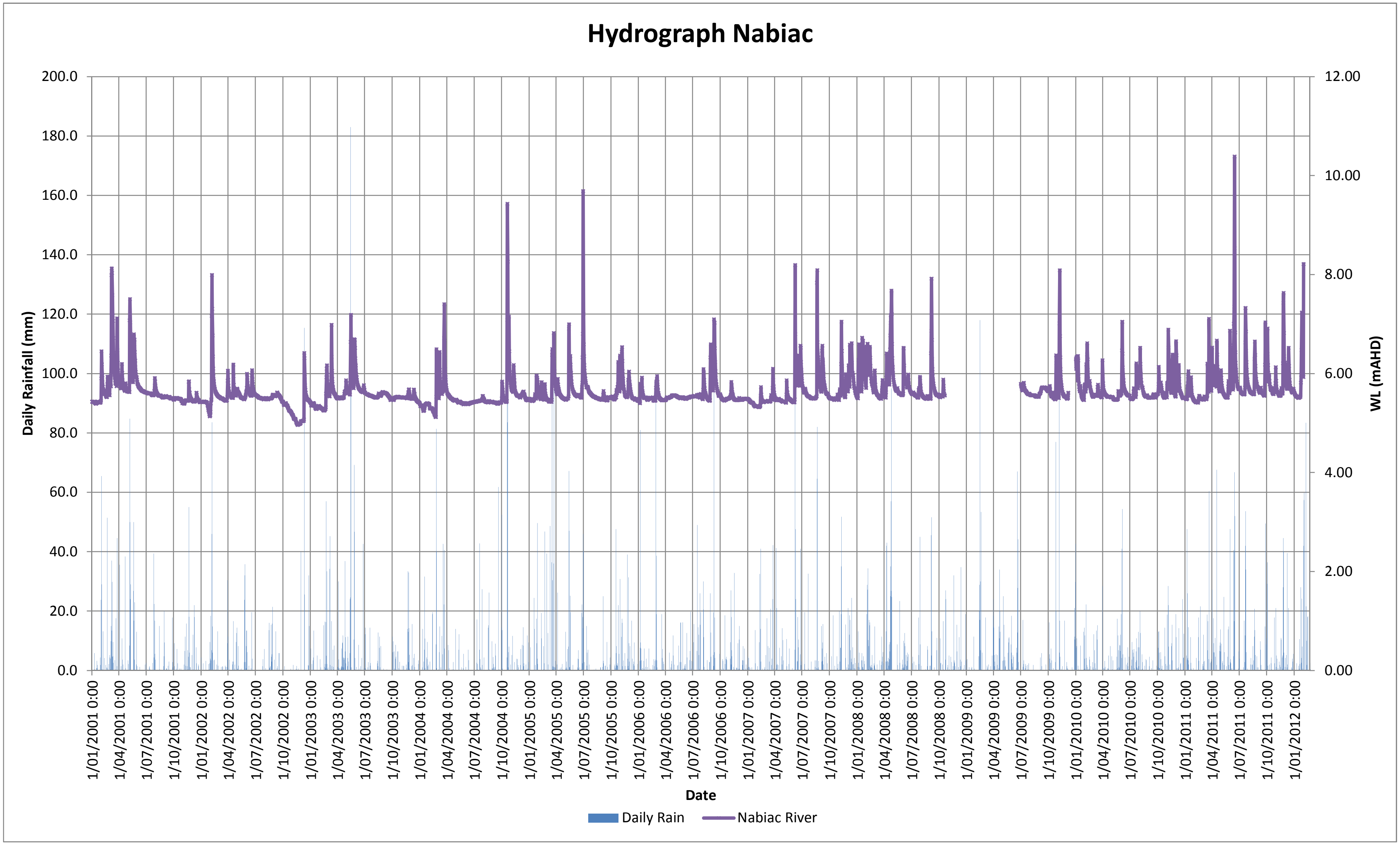


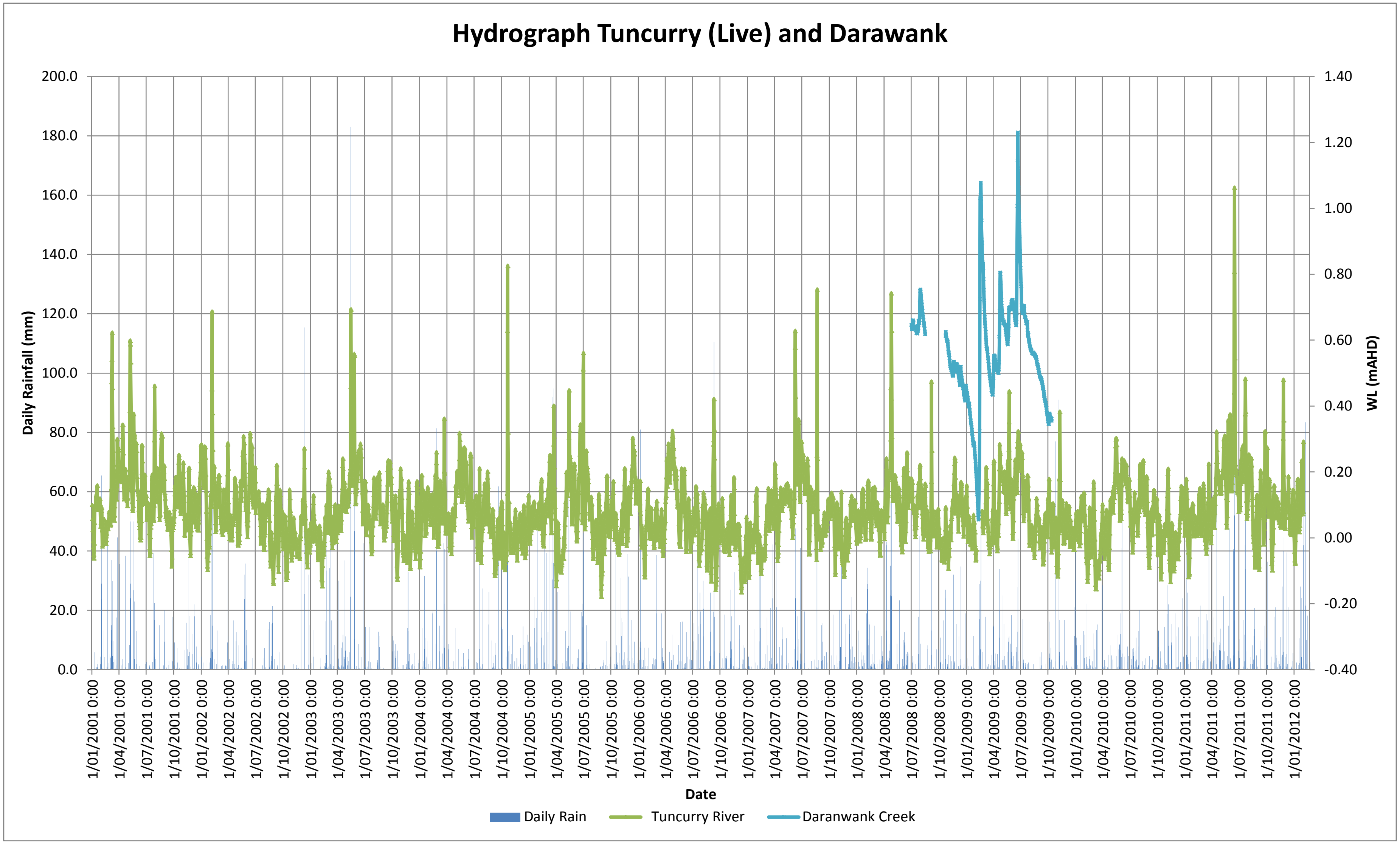
# Conceptual East-West Section to the north of the Project Area

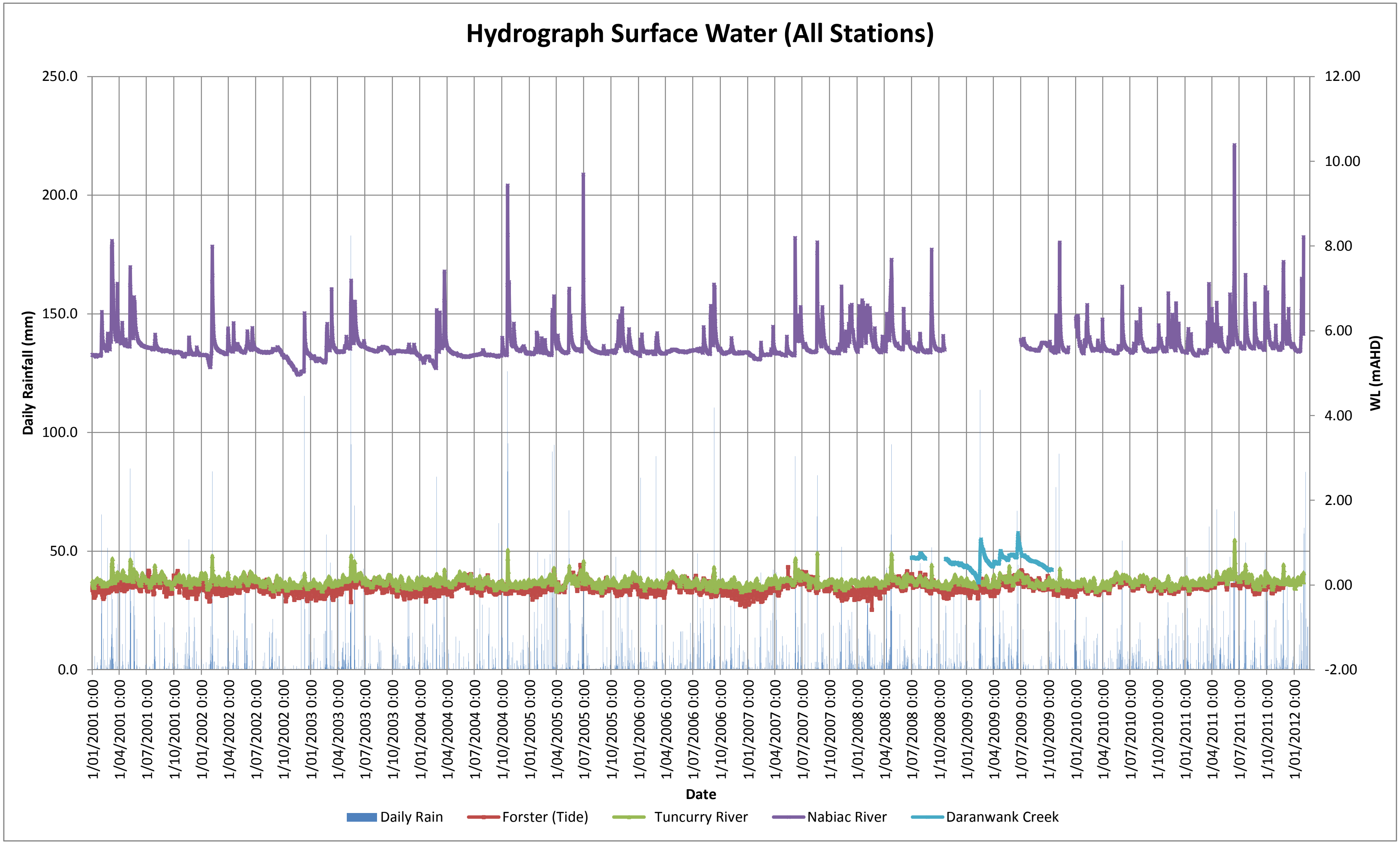


# APPENDIX E – WALLAMBA RIVER WATER LEVEL DATA

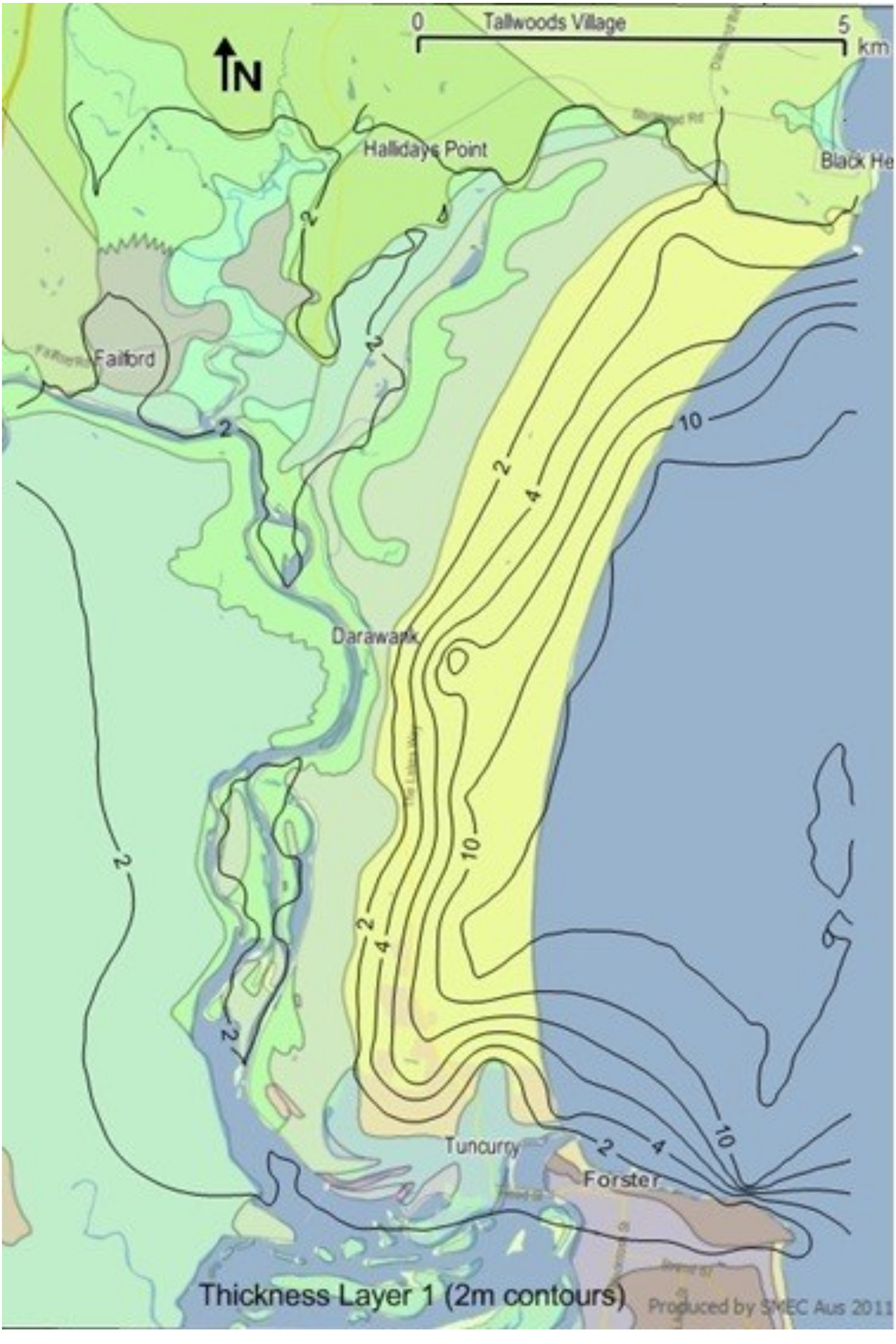

Hydrograph Forster Live
Daily Rainfall (mm)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
WL (mAHD)
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
1/01/2001 0:00
1/04/2001 0:00
1/07/2001 0:00
1/10/2001 0:00
1/01/2002 0:00
1/04/2002 0:00
1/07/2002 0:00
1/10/2002 0:00
1/01/2003 0:00
1/04/2003 0:00
1/07/2003 0:00
1/10/2003 0:00
1/01/2004 0:00
1/04/2004 0:00
1/07/2004 0:00
1/10/2004 0:00
1/01/2005 0:00
1/04/2005 0:00
1/07/2005 0:00
1/10/2005 0:00
1/01/2006 0:00
1/04/2006 0:00
1/07/2006 0:00
1/10/2006 0:00
1/01/2007 0:00
1/04/2007 0:00
1/07/2007 0:00
1/10/2007 0:00
1/01/2008 0:00
1/04/2008 0:00
1/07/2008 0:00
1/10/2008 0:00
1/01/2009 0:00
1/04/2009 0:00
1/07/2009 0:00
1/10/2009 0:00
1/01/2010 0:00
1/04/2010 0:00
1/07/2010 0:00
1/10/2010 0:00
1/01/2011 0:00
1/04/2011 0:00
1/07/2011 0:00
1/10/2011 0:00
1/01/2012 0:00
Date
Daily Rain
Forster (Tide)


Hydrograph Nabiac
Daily Rainfall (mm)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
WL (mAHD)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1/01/2001 0:00
1/04/2001 0:00
1/07/2001 0:00
1/10/2001 0:00
1/01/2002 0:00
1/04/2002 0:00
1/07/2002 0:00
1/10/2002 0:00
1/01/2003 0:00
1/04/2003 0:00
1/07/2003 0:00
1/10/2003 0:00
1/01/2004 0:00
1/04/2004 0:00
1/07/2004 0:00
1/10/2004 0:00
1/01/2005 0:00
1/04/2005 0:00
1/07/2005 0:00
1/10/2005 0:00
1/01/2006 0:00
1/04/2006 0:00
1/07/2006 0:00
1/10/2006 0:00
1/01/2007 0:00
1/04/2007 0:00
1/07/2007 0:00
1/10/2007 0:00
1/01/2008 0:00
1/04/2008 0:00
1/07/2008 0:00
1/10/2008 0:00
1/01/2009 0:00
1/04/2009 0:00
1/07/2009 0:00
1/10/2009 0:00
1/01/2010 0:00
1/04/2010 0:00
1/07/2010 0:00
1/10/2010 0:00
1/01/2011 0:00
1/04/2011 0:00
1/07/2011 0:00
1/10/2011 0:00
1/01/2012 0:00
Date
Daily Rain
Nabiac River


Hydrograph Tuncurry (Live) and Darawank
Daily Rainfall (mm)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
WL (mAHD)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
1/01/2001 0:00
1/04/2001 0:00
1/07/2001 0:00
1/10/2001 0:00
1/01/2002 0:00
1/04/2002 0:00
1/07/2002 0:00
1/10/2002 0:00
1/01/2003 0:00
1/04/2003 0:00
1/07/2003 0:00
1/10/2003 0:00
1/01/2004 0:00
1/04/2004 0:00
1/07/2004 0:00
1/10/2004 0:00
1/01/2005 0:00
1/04/2005 0:00
1/07/2005 0:00
1/10/2005 0:00
1/01/2006 0:00
1/04/2006 0:00
1/07/2006 0:00
1/10/2006 0:00
1/01/2007 0:00
1/04/2007 0:00
1/07/2007 0:00
1/10/2007 0:00
1/01/2008 0:00
1/04/2008 0:00
1/07/2008 0:00
1/10/2008 0:00
1/01/2009 0:00
1/04/2009 0:00
1/07/2009 0:00
1/10/2009 0:00
1/01/2010 0:00
1/04/2010 0:00
1/07/2010 0:00
1/10/2010 0:00
1/01/2011 0:00
1/04/2011 0:00
1/07/2011 0:00
1/10/2011 0:00
1/01/2012 0:00
Date
Daily Rain
Tuncurry River
Daranwank Creek

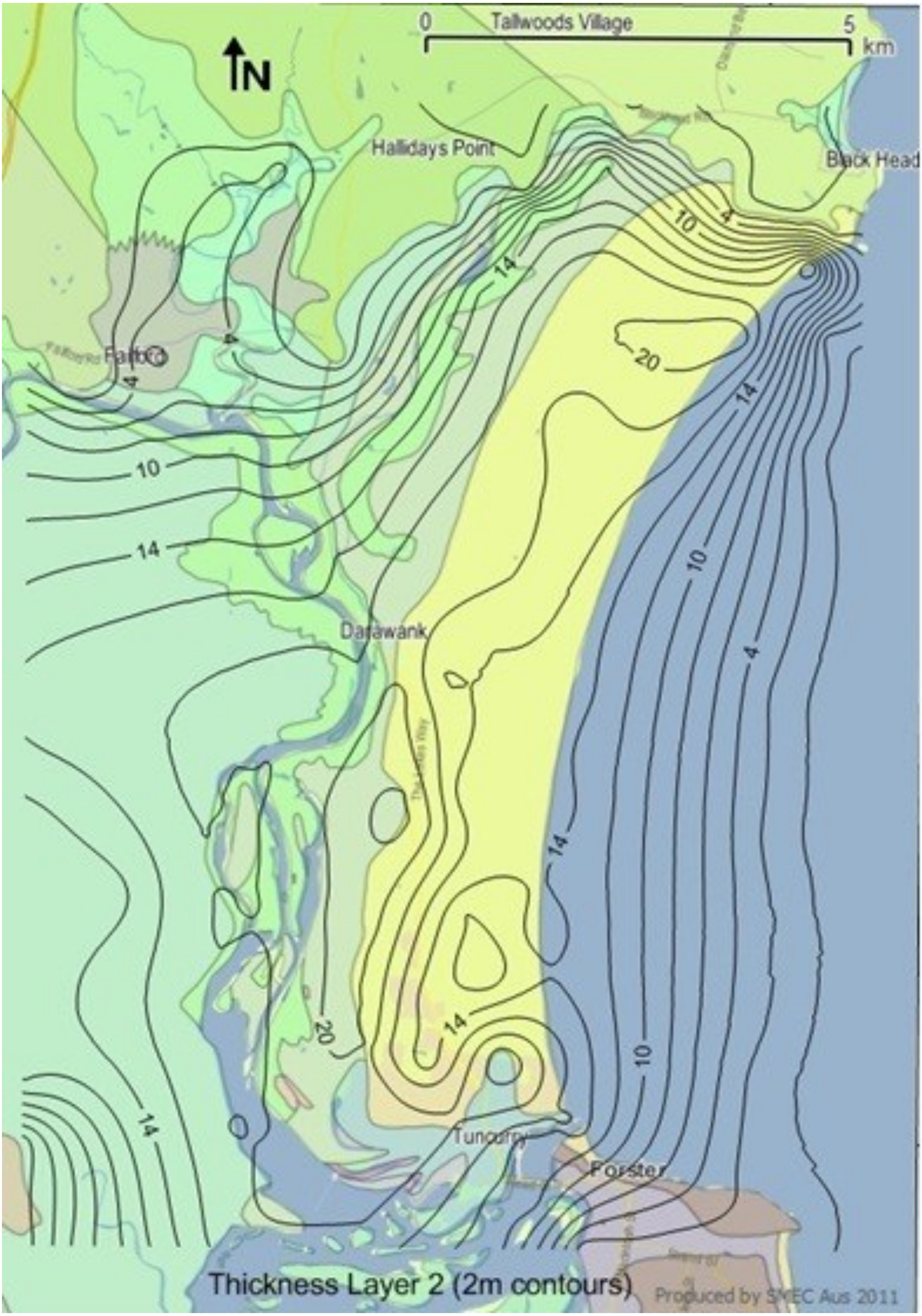

Hydrograph Surface Water (All Stations)
Daily Rainfall (mm)
250.0
200.0
150.0
100.0
50.0
0.0
WL (mAHD)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
Date
1/01/2001 0:00
1/04/2001 0:00
1/07/2001 0:00
1/10/2001 0:00
1/01/2002 0:00
1/04/2002 0:00
1/07/2002 0:00
1/10/2002 0:00
1/01/2003 0:00
1/04/2003 0:00
1/07/2003 0:00
1/10/2003 0:00
1/01/2004 0:00
1/04/2004 0:00
1/07/2004 0:00
1/10/2004 0:00
1/01/2005 0:00
1/04/2005 0:00
1/07/2005 0:00
1/10/2005 0:00
1/01/2006 0:00
1/04/2006 0:00
1/07/2006 0:00
1/10/2006 0:00
1/01/2007 0:00
1/04/2007 0:00
1/07/2007 0:00
1/10/2007 0:00
1/01/2008 0:00
1/04/2008 0:00
1/07/2008 0:00
1/10/2008 0:00
1/01/2009 0:00
1/04/2009 0:00
1/07/2009 0:00
1/10/2009 0:00
1/01/2010 0:00
1/04/2010 0:00
1/07/2010 0:00
1/10/2010 0:00
1/01/2011 0:00
1/04/2011 0:00
1/07/2011 0:00
1/10/2011 0:00
1/01/2012 0:00
Daily Rain
Forster (Tide)
Tuncurry River
Nabiac River
Daranwank Creek

# APPENDIX F – AQUIFER LAYER THICKNESS



Thickness Layer 1 (2m contours)

Produced by SMEC Aus 2011

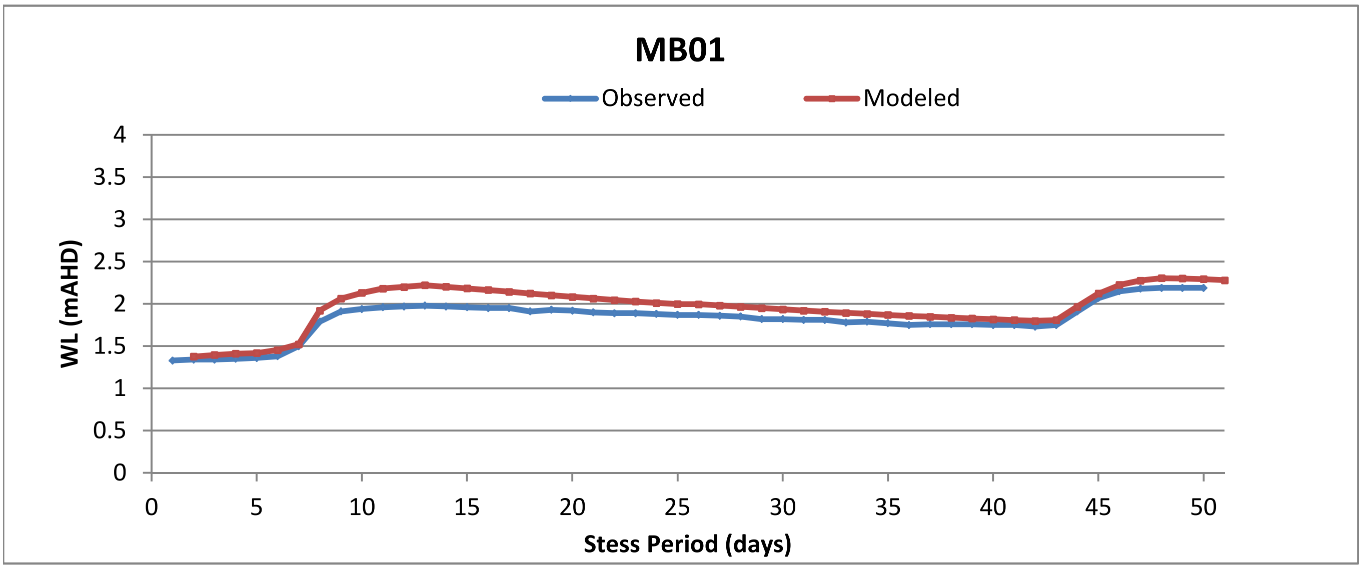


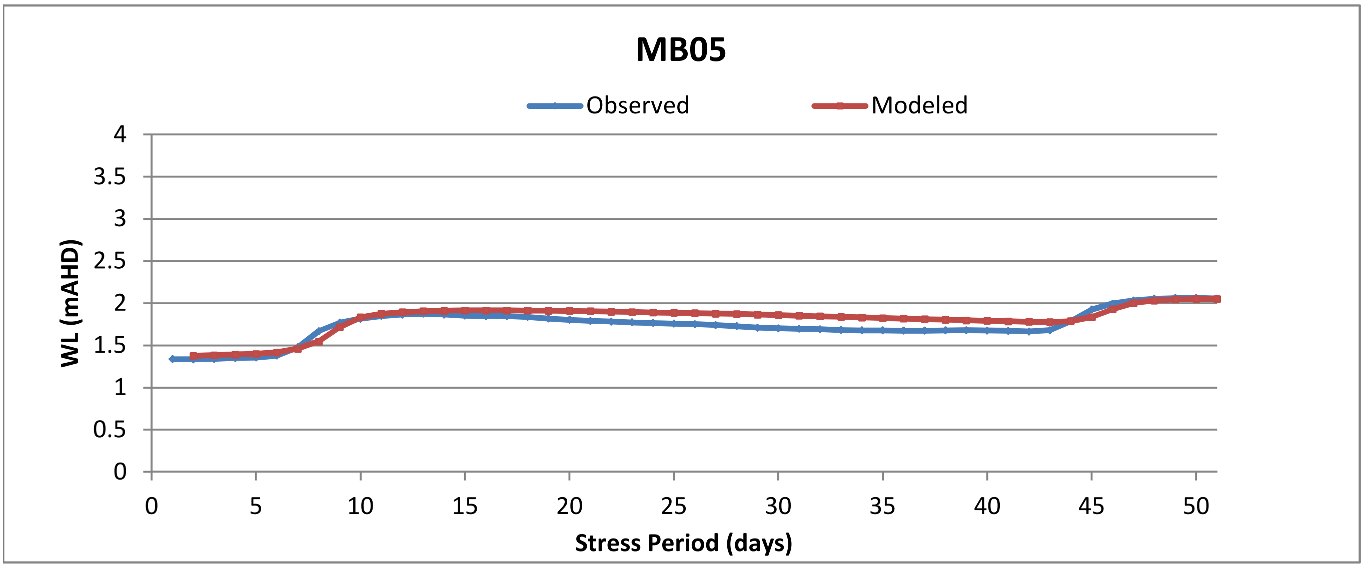
Thickness Layer 2 (2m contours)

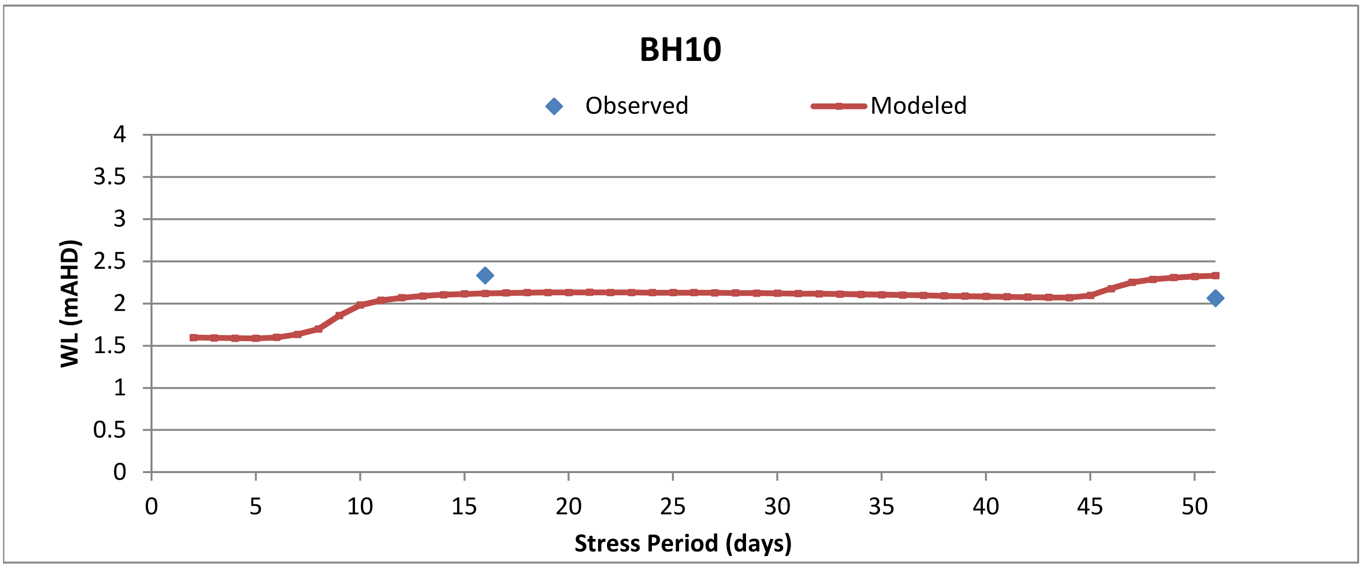
Produced by SMEC Aus 2011

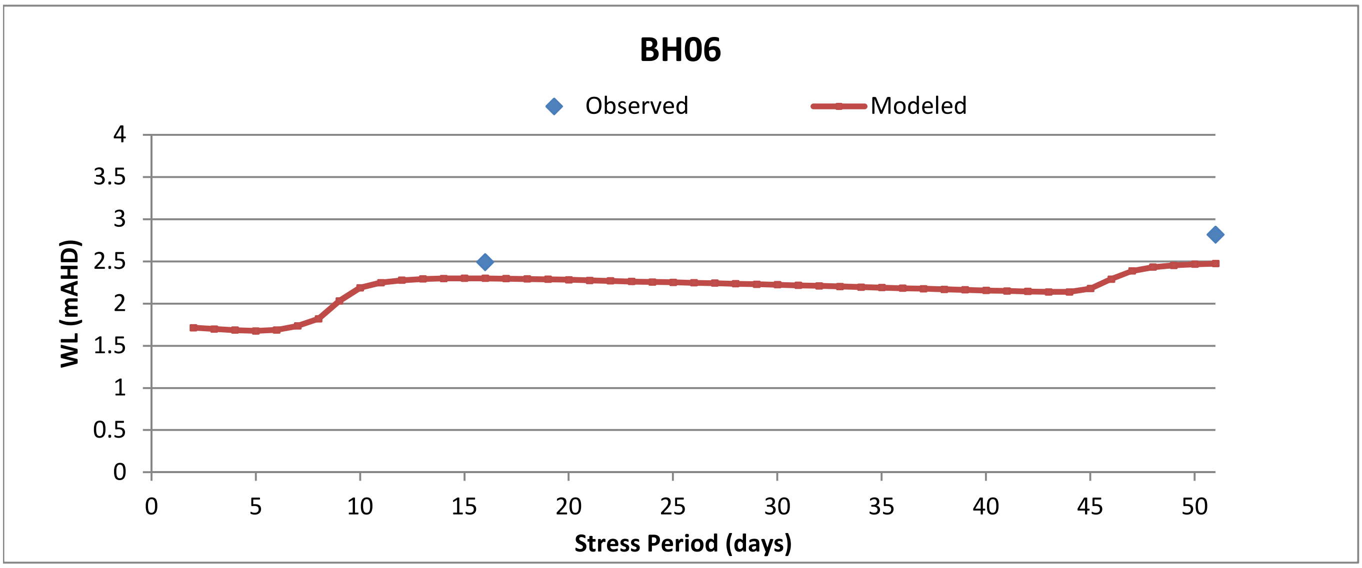
# APPENDIX G – CALIBRATION HYDROGRPAHS

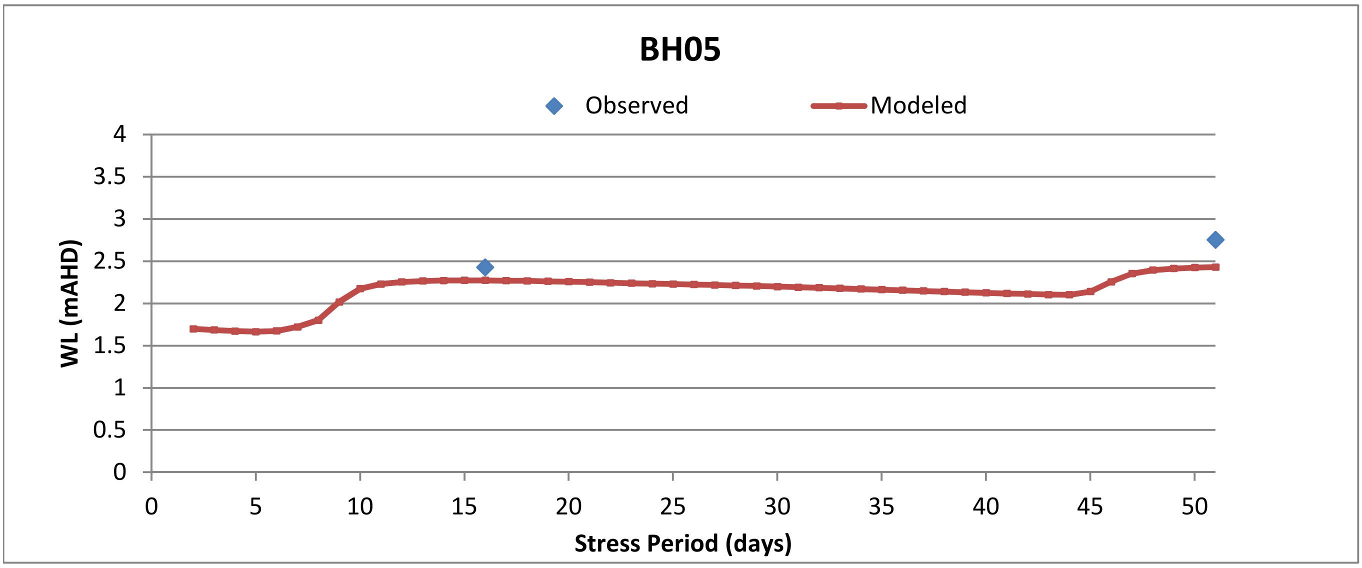
## Development Area

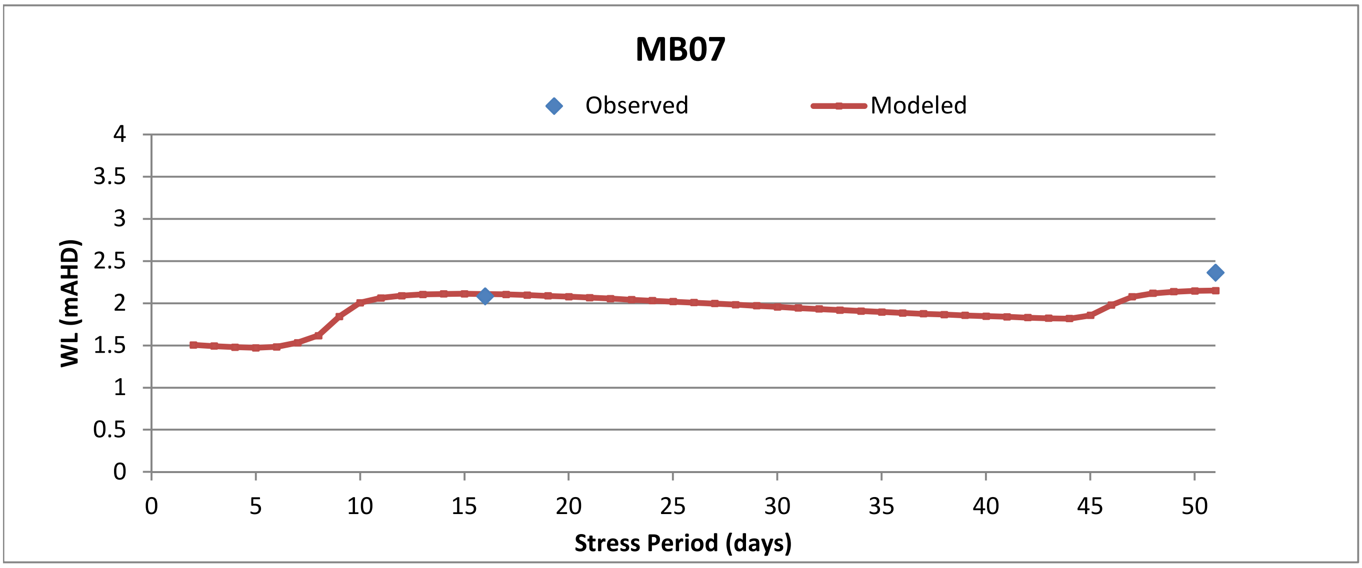


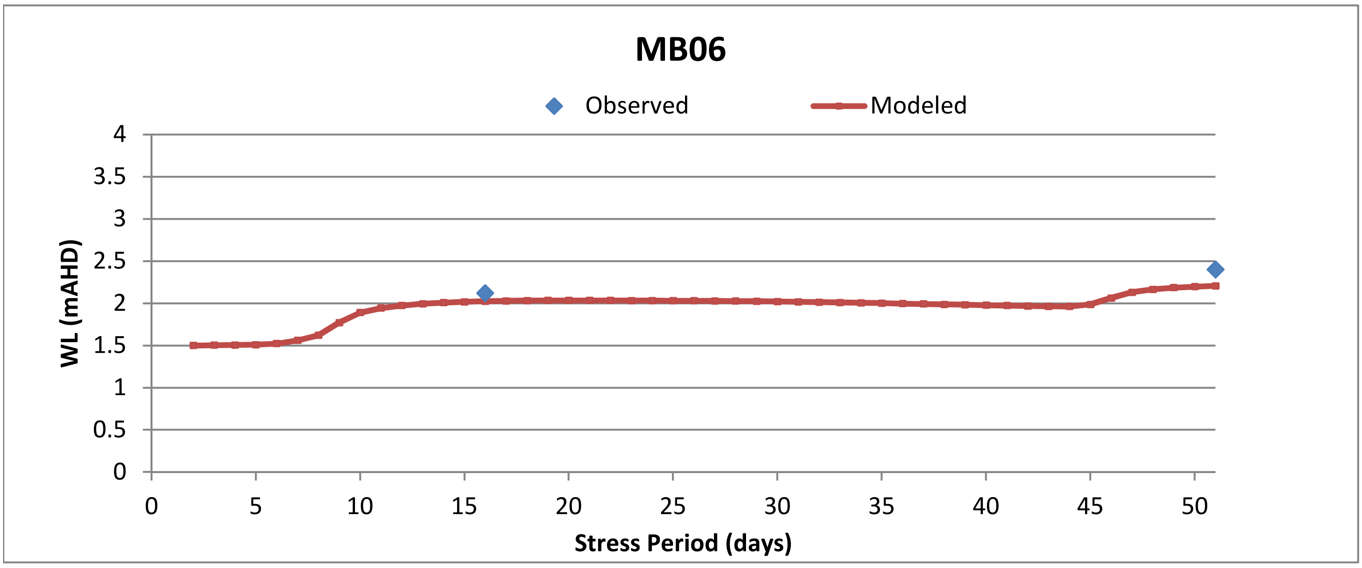


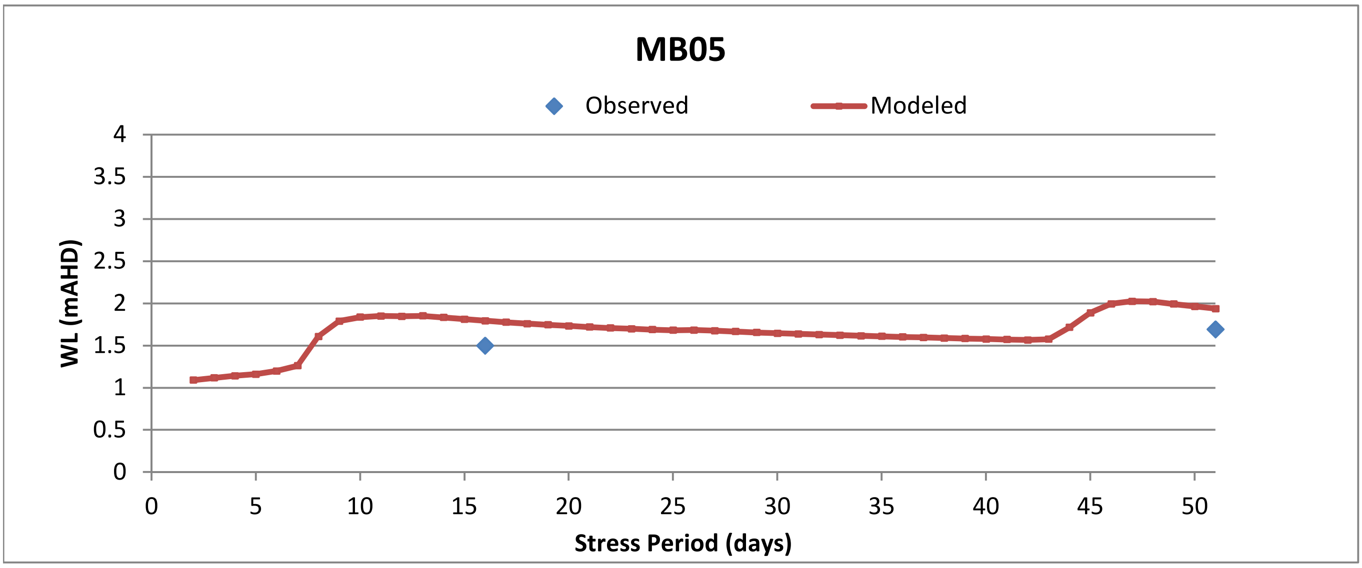

BH10
Observed
Modeled
WL (mAHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

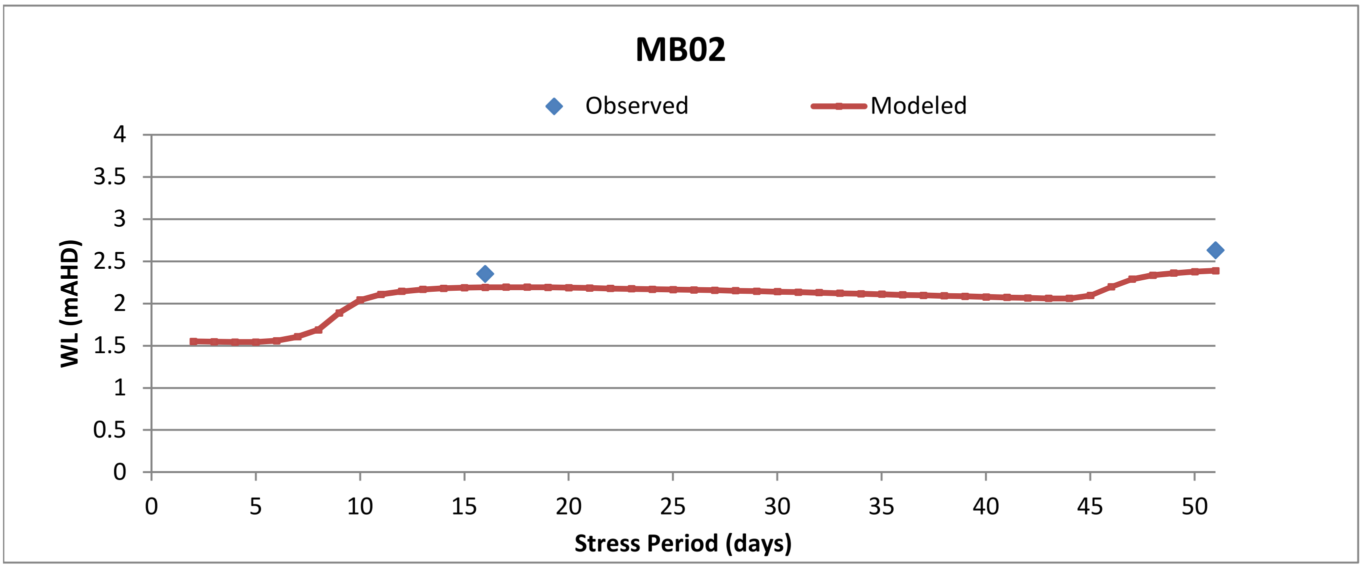

BH06
Observed
Modeled
WL (mAHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)


BH05
Observed
Modeled
WL (mAHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

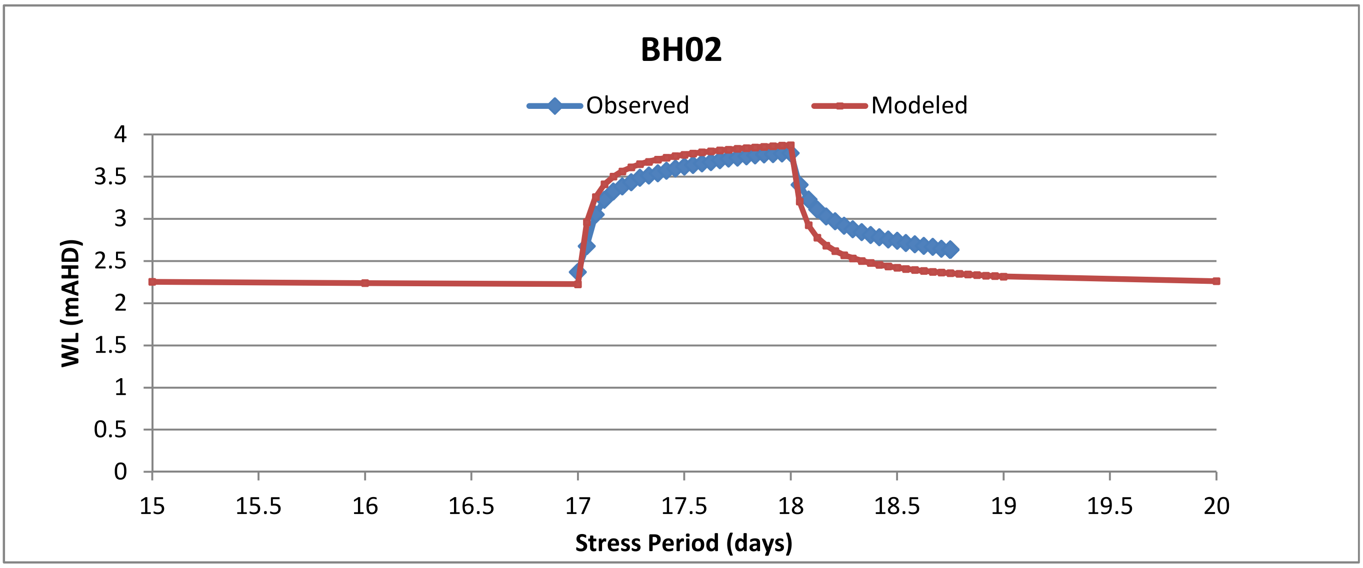

MB07
Observed
Modeled
WL (mAHD)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

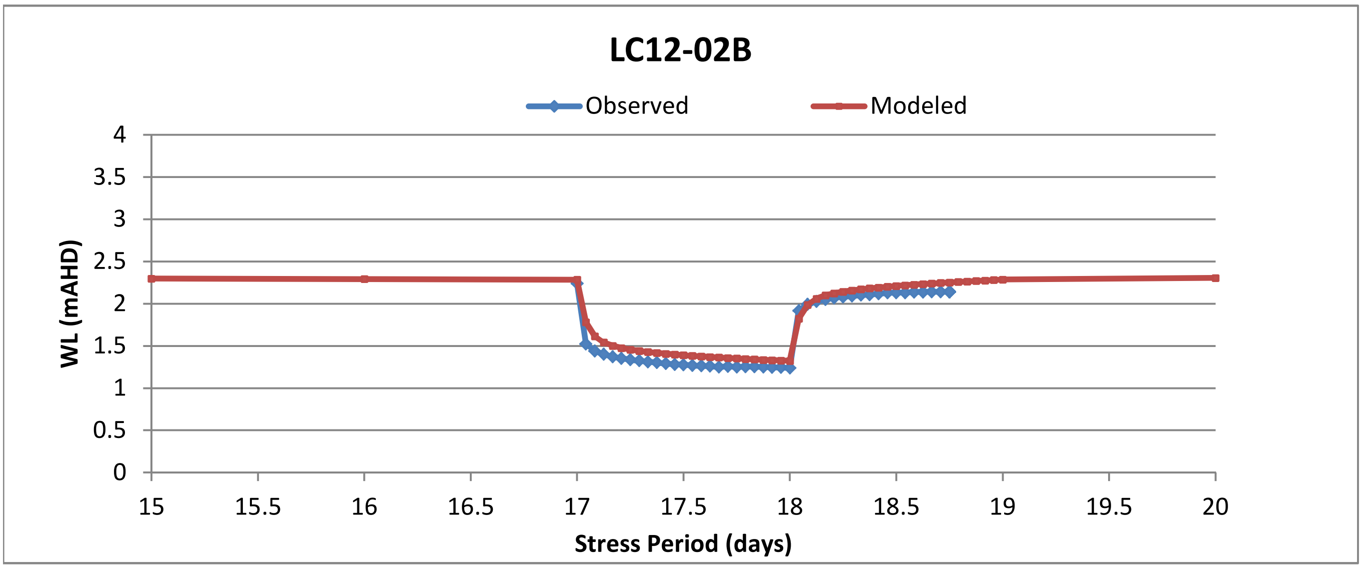

MB06
Observed
Modeled
WL (mAHD)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)


MB05
Observed
Modeled
WL (mAHD)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

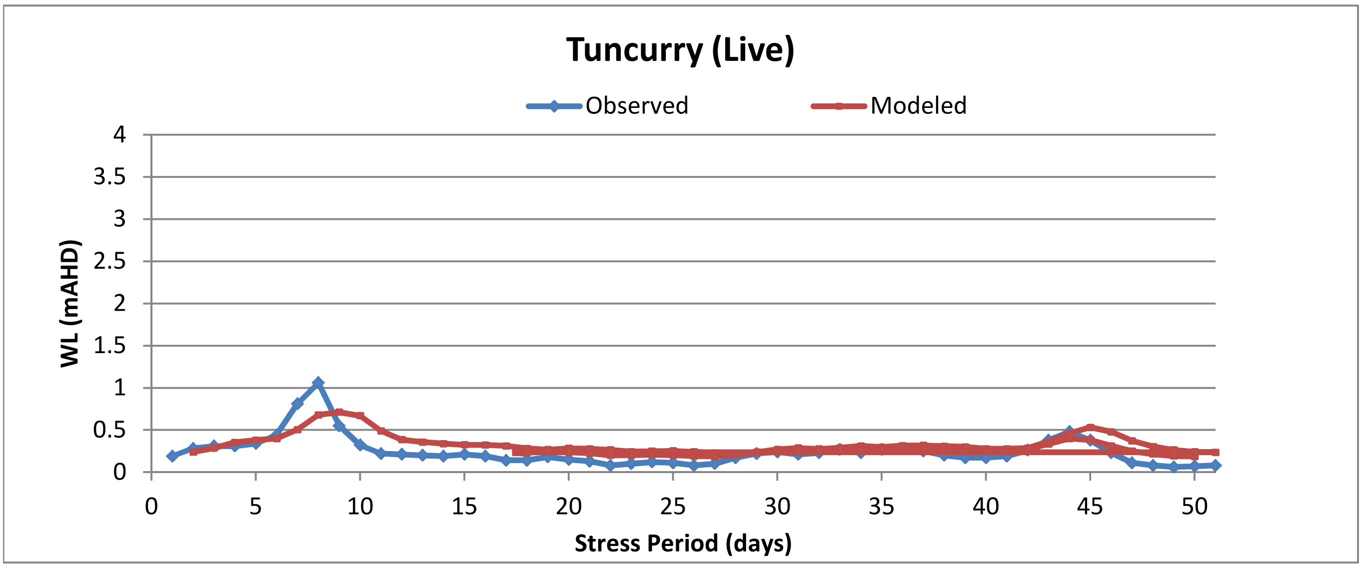

MB02
Observed
Modeled
WL (mAHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

## Aquifer Pump Out Test

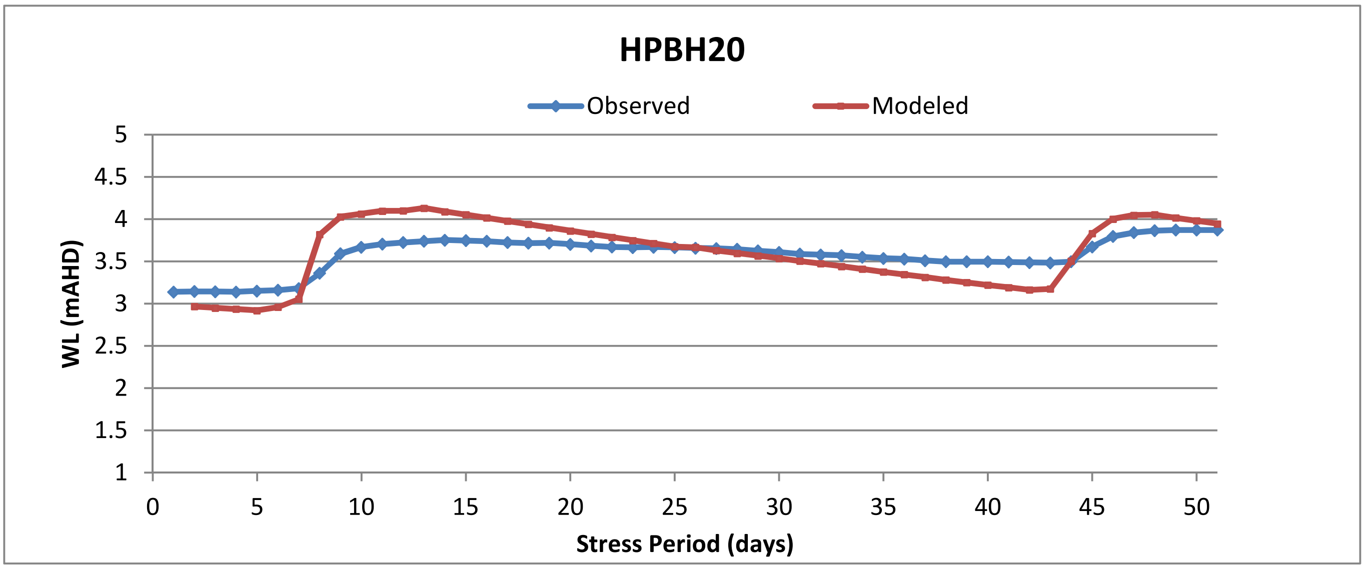


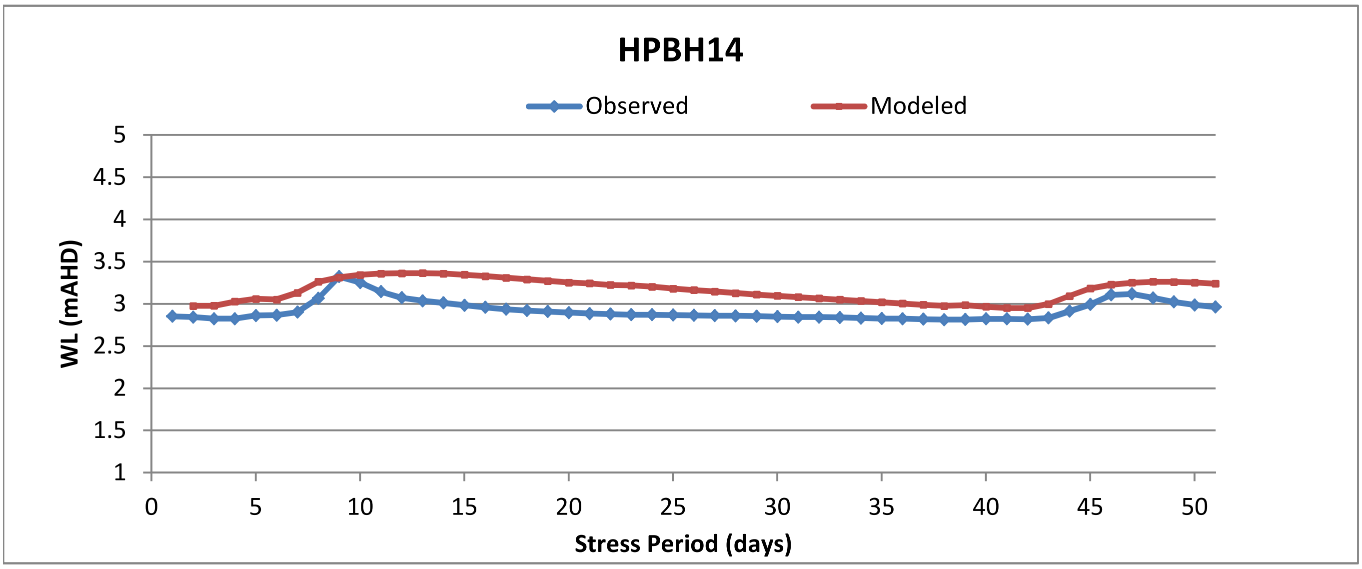


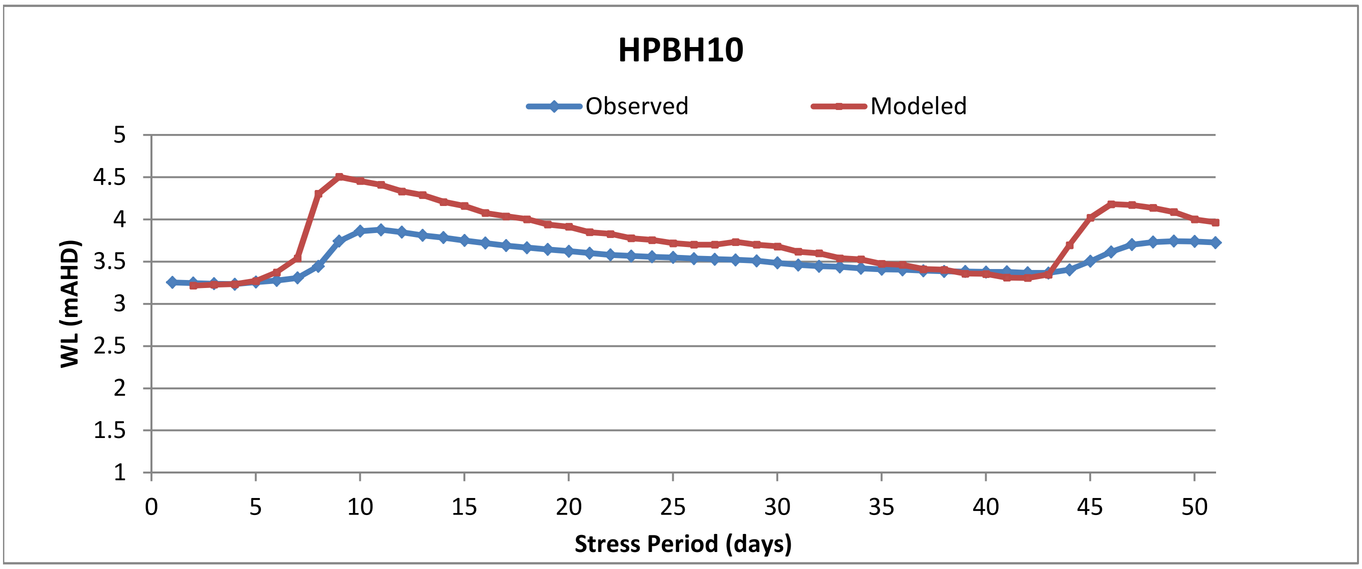
## River

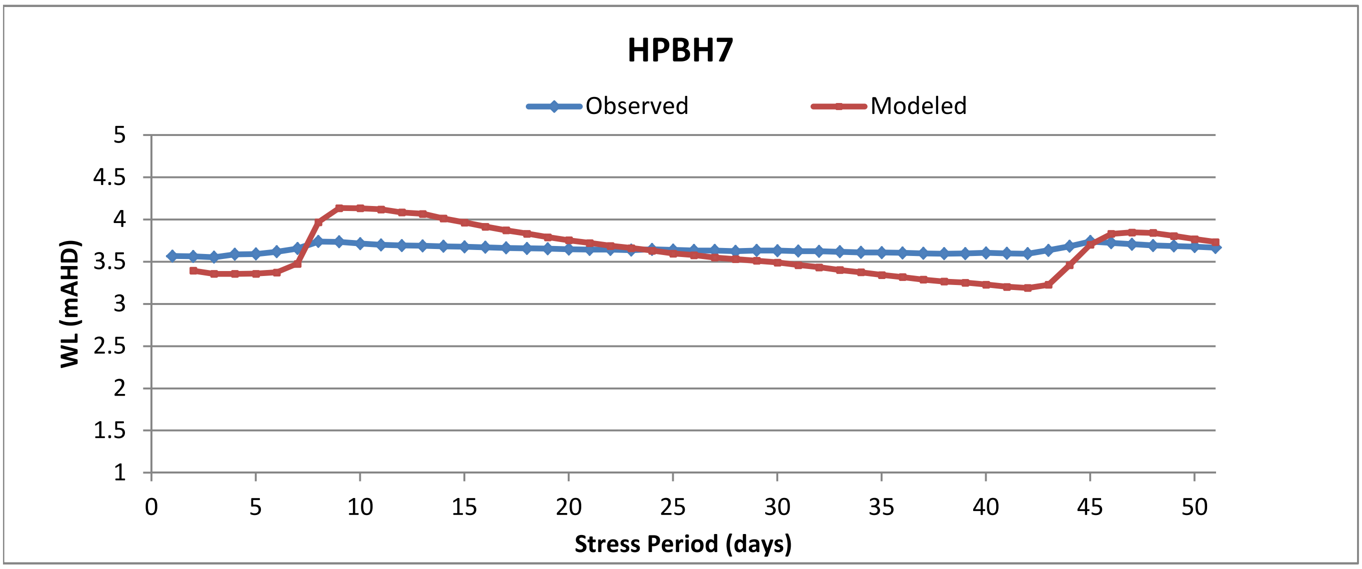

Tuncurry (Live)
Observed
Modeled
4
3.5
3
2.5
2
1.5
1
0.5
0
WL (mAHD)
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

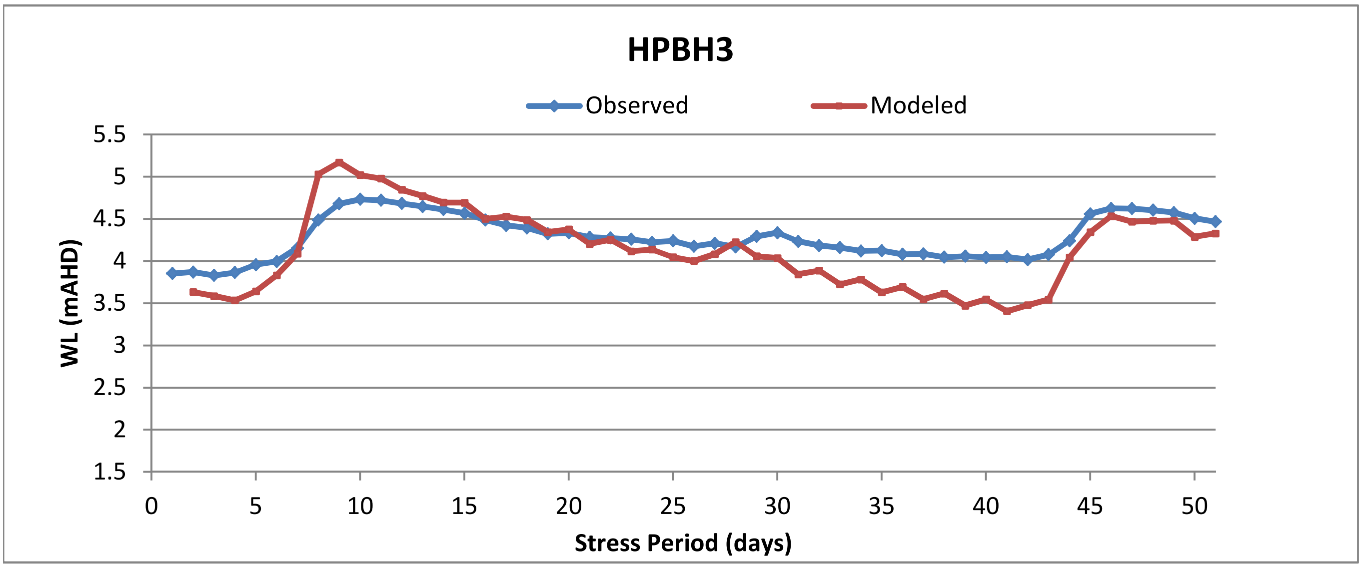
## Hallidays Point



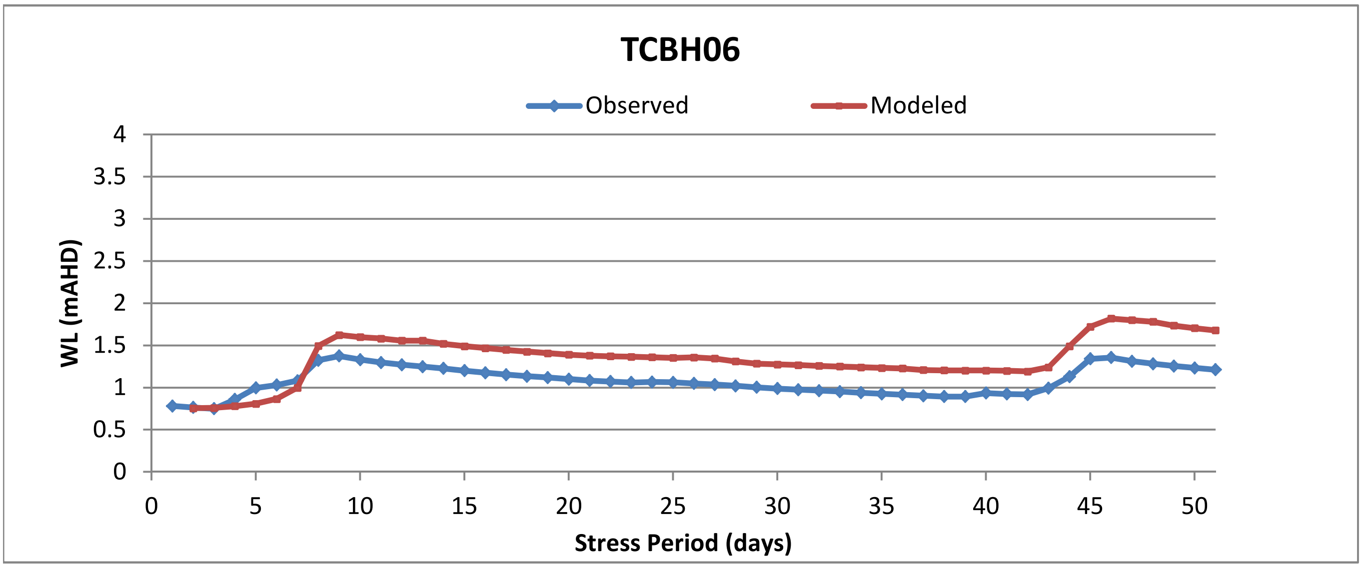




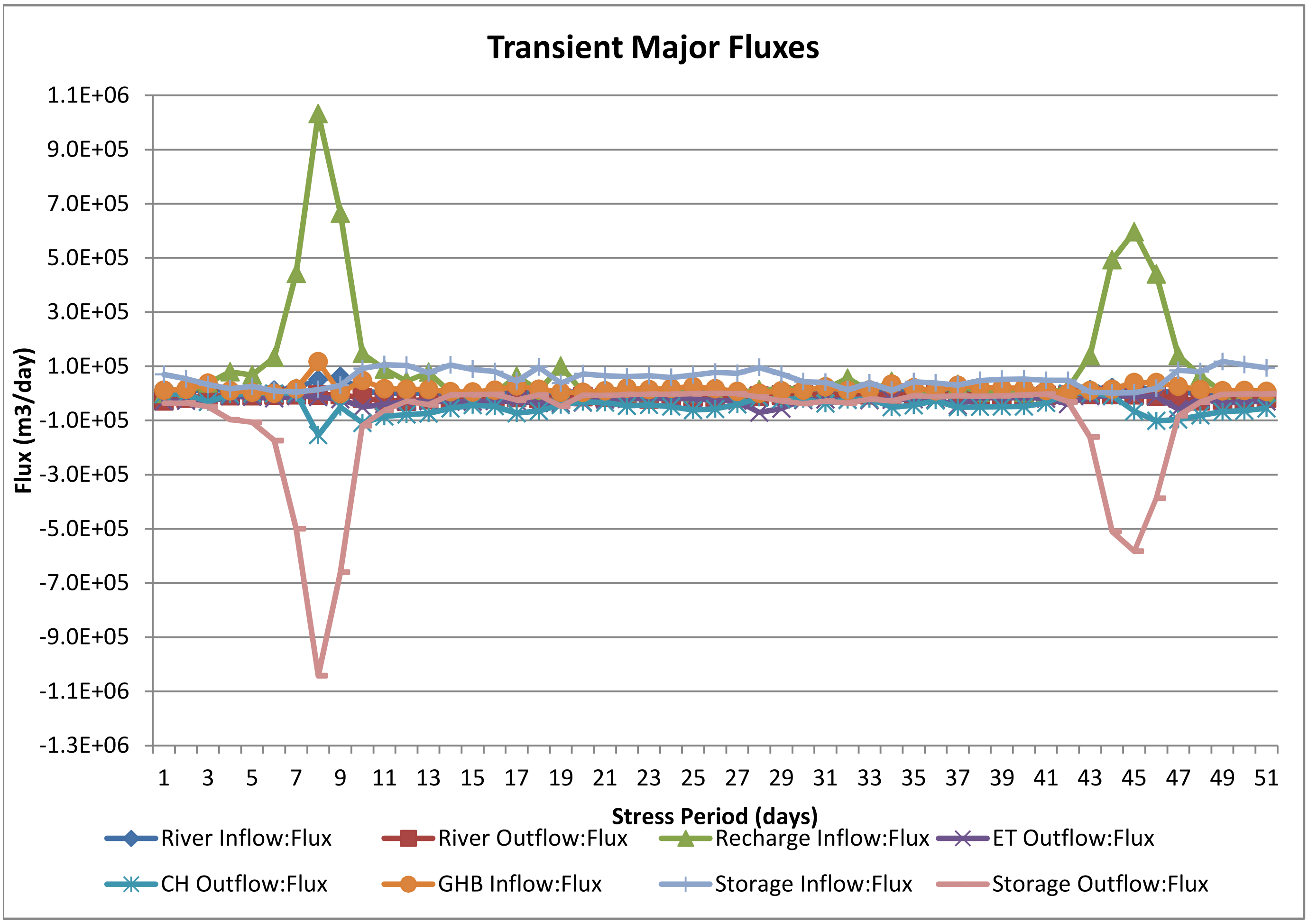

HPBH7
Observed
Modeled
WL (mAHD)
5
4.5
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

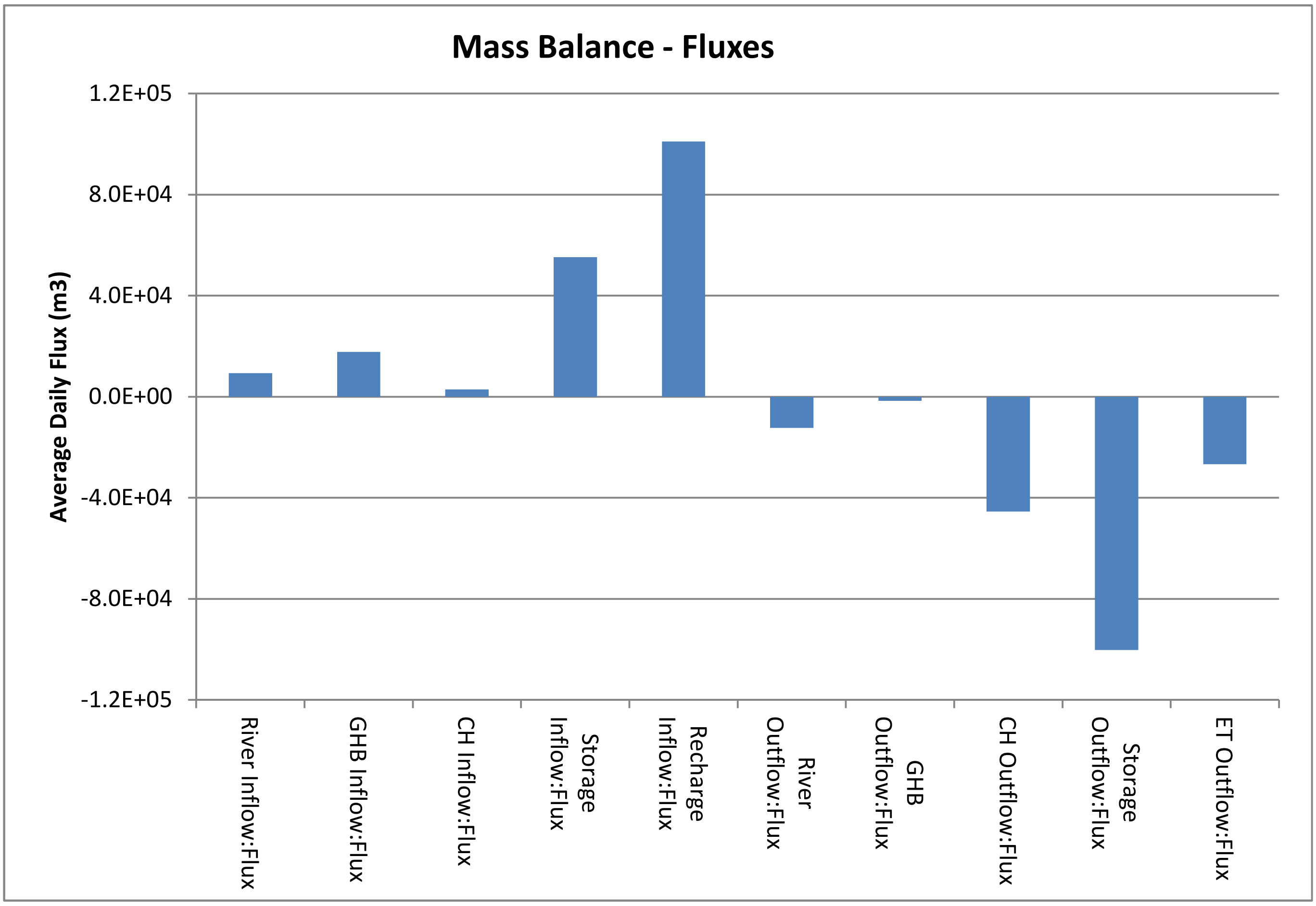

HPBH3
Observed
Modeled
WL (mAHD)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
0
5
10
15
20
25
30
35
40
45
50
Stress Period (days)

## Southwest of Development Area



# APPENDIX H – CALIBRATION WATER BALANCE


Transient Major Fluxes
1.1E+06
9.0E+05
7.0E+05
5.0E+05
3.0E+05
1.0E+05
-1.0E+05
-3.0E+05
-5.0E+05
-7.0E+05
-9.0E+05
-1.1E+06
-1.3E+06
Flux (m3/day)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Stress Period (days)
River Inflow:Flux
River Outflow:Flux
Recharge Inflow:Flux
ET Outflow:Flux
CH Outflow:Flux
GHB Inflow:Flux
Storage Inflow:Flux
Storage Outflow:Flux


Mass Balance - Fluxes
1.2E+05
8.0E+04
4.0E+04
0.0E+00
-4.0E+04
-8.0E+04
-1.2E+05
Average Daily Flux (m3)
River Inflow:Flux
GHB Inflow:Flux
CH Inflow:Flux
Storage Inflow:Flux
Recharge Inflow:Flux
River Outflow:Flux
GHB Outflow:Flux
CH Outflow:Flux
Storage Outflow:Flux
ET Outflow:Flux

# APPENDIX I – DETAILED GROUNDWATER MODEL SENSITIVITY ANALYSIS

## Appendix I – Sensitivity Analysis of Detailed Groundwater Model

Sensitivity analysis was undertaken utilising the auto sensitivity function from Groundwater Vistas. The calibrated transient model was used for this analysis with all 51 stress periods. The parameters, zones and multipliers applied are summarised in **Table I1**.

***Table I1*** *- Parameters, Zones and Multipliers applied to the Sensitivity Analysis*

| Parameter | Zone(s)/ Description | Multipliers |
|---|---|---|
| Horizontal Permeability | Zone 2 to Zone 8 | 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.5 |
| Vertical Permeability | Zone 2 to Zone 8 | 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.5 |
| Specific Storage | Zone 2 to Zone 8 | 0.1, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 2, 10 |
| Specific Yield | Zone 2 to Zone 8 | 0.1, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 2, 10 |
| Recharge | Zone 1 to Zone 6 | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |
| Evapotranspiration Rate | Zone 5 to Zone 8 | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |
| Evapotranspiration Extinction Depth | Zone 5 to Zone 8 | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |
| River Bed Conductance | Wallamba River, Darawank Creek, Frognalla Swamp | 0.1, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 2, 10 |
| General Head Boundary Conductance | Layers 2 and 3 for Ocean Boundary | 0.1, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 2, 10 |
| River Stage Height | Wallamba River, Darawank Creek, Frognalla Swamp | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |
| General Head Boundary | Layers 2 and 3 for Ocean Boundary | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |
| Constant Head Ocean | Layer 1 Ocean Boundary | 0.4, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5 |

For each parameter and each zone/boundary condition, between 9 to 11 simulations were run applying the different multipliers in Table I1. The multipliers were chosen considering both a realistic range for each parameter and the confidence of the applied value (i.e. permeability of the aquifer is unlikely to vary an order of magnitude). A report for each run was automatically produced by Groundwater Vistas including the Multiplier, Sum of Squares, Residual Mean, Residual Standard Deviation, Average Drawdown, Sensitivity Coefficient and Delta Rss. The key outcomes of this output are summarised in the following sections.

## *Sensitivity Results*

The sensitivity analysis provided a means of understanding the simulated groundwater response to changes in the magnitude of the various parameters used in the model calibration. A highly sensitive parameter is defined, for reporting purposes, as one which causes the sum of residual squares to change by 10 or more; a medium sensitivity parameter causes a change between 1 and

10 and a minimal sensitivity parameter causes a change between 0.1 and 1. An insensitive parameter causes changes of less than 0.1 within the multipliers applied.

Based on the abovementioned classification, model results are considered to be insensitive to the following parameters:

- Horizontal Permeability for zones 2, 4, 6 and 8.
- Vertical Permeability for zones 4 and 8.
- Specific Storage for zones 2, 4 and 5.
- Specific Yield for zones 4, 6 and 8.
- River conductance for the western side of the Wallamba River and Wallamba River.
- Recharge of zone 5 (Wetlands). Note: This is due to zero recharge being applied as the multipliers show no effect.
- Evapotranspiration rate and depth for zone 6 which is not active in model.
- River stage height for the western arm of the Wallamba River.
- Constant head of the Ocean boundary (layer 1).

Model results are considered to be minimally sensitive to the following parameters:

- Vertical permeability for zones 2, 3, 5 and 6.
- Specific Storage for zones 3, 6 and 8.
- Specific Yield for zones 2 and 5.
- River conductance for Frognalla Swamp/Darawank Creek and the eastern arm of the Wallamba River.
- General head Ocean Boundary Conductance.
- Evapotranspiration rate for zones 5 and 7.
- Evapotranspiration extinction depth for zones 5, 7 and 8.
- River stage height for the Wallamba River and the eastern arm of the Wallamba River.

Model results are considered to be moderately sensitive to the following parameters:

- Horizontal permeability for zone 5.
- Vertical permeability for zone 7.
- Recharge for zones 2, 3 and 7.
- Evapotranspiration rate for zone 8.
- General head of ocean boundary (Layers 2 and 3).

Model results are considered to be highly sensitive to the following parameters:

- Horizontal permeability for zones 3 and 7.
- Specific storage for zone 7.
- Specific yield for zones 3 and 7.
- Recharge zones 1 and 4.
- River stage height for Darawank Creek.

From the above analysis, it can be seen that the sensitivity tends to be higher for zones where the groundwater flow is higher due to the permeability / transmissivity of the aquifer. This is particularly noticeable in the aquifer in the NTDP area with the following parameters being the most sensitive:

- Recharge.
- Horizontal permeability.
- Specific Yield (Layer 1) and Specific Storage (Layer 2).

It is noted that as the sensitivity analysis has been undertaken as a function of the sum of residual squares for all data points, the analysis is weighted towards zones where there are more observed data points (i.e. within the NTDP area) and for periods of time when most of the data points were recorded (i.e. non recharge periods). Accordingly, the sensitivity analysis understates the model's sensitivity to:

- Recharge, as recharge only occurs on two occasions over the 51 day calibration period. Hence, there are a limited number of observations points associated with periods of recharge.
- Evapotranspiration losses, as the calibration period comprised above average wet weather conditions with seasonally low evaporation rates; and
- Aquifer zones outside of the project area, due to the low number of observed data points available for these areas of the model domain.

These limitations should be considered when assessing the model sensitivity results.

## *Remaining Uncertainty*

The numerical results of the Detailed Groundwater Model have an associated, but not quantified, uncertainty. The analysis to quantify the model prediction uncertainty is possible, but not within the scope of this report. However, the sensitivity analysis showed that the most sensitive parameters are horizontal permeability, specific storage, specific yield and recharge of the Tuncurry Aquifer. Due to the supporting pump test results and data review the permeability and storage information presented in the model for the NTDP area is accepted with a high degree of confidence. Based on the long term groundwater monitoring data and recharge modelling, the confidence for recharge amounts is also considered to be relatively high. However, some uncertainties in the model remain due to the assumed homogeneous nature of the various layers and zones presented in the Detailed Groundwater Model.

As noted in **Section 5.3.5** , the confidence in the parameters applied to calculate evapotranspiration losses from the saturated zone is low due to the calibration being undertaken during an above average wet weather period that comprised seasonally low evaporation rates (due to the calibration period being in the winter months of June and July).

## *Model Limitations*

Mathematical models of groundwater flow are simplified representations of a complex natural system based on limited data and therefore cannot be expected to replicate groundwater behaviour with 100% accuracy. The model is considered to represent the groundwater dynamics within the constraints of the available monitoring data and subsurface investigations that have been conducted within the project's budget and timeframe. The model's specific limitations are:

- The model was designed to represent groundwater flooding occurring after major events. The calibration period was a wetter than an average period, however, the available data does not represent the worst case scenario. Therefore, predictions should be used with caution as they represent a simulated response that cannot be verified with observed data collected to date.

- The groundwater level monitoring at 15 minute intervals has been consolidated to represent daily averaged data. This may have led to slight reductions in peak and minimum levels reached during the calibration period. However, increasing the amount of stress periods (i.e. using a model time step of less than 24 hours) was not considered practical as local rainfall observations are only available in daily time steps.

- The general lack of geological and hydrological data for the Darawank and Frognalla Swamps and river bed.

Refer to **Section 6** of the main report for information on model confidence levels.