Disposal of Effluent from Merimbula Sewage Treatment Plant by Dunal Exfiltration – Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay

Bega Valley Shire Council

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1. Introduction

Bega Valley Shire Council (BVSC) is in the process of devising a revised management strategy for treated effluent from Merimbula Sewage Treatment Plant (STP). The strategy will depend upon the preferred option (or options) selected from the options investigation for the beneficial use of effluent and disposal of the portion of effluent unable to be beneficially used. One of the disposal options under consideration includes discharge to shallow groundwater, via either an exfiltration trench, or a line of shallow well points.

A previous review of disposal options (IGGC, 2006) assessed the potential for shallow disposal in the central area of the dune system and around the existing ponds and focused on impacts on groundwater levels with limited consideration of potential impacts on groundwater quality. This study concluded that discharge to the shallow groundwater system in the central area of the dunes (north of the existing ponds) was a viable disposal method but that further investigation and assessment was required, in particular more detailed assessment of groundwater quality implications and undertaking pump tests to provide reliable estimate of aquifer characteristics.

Ian Grey Groundwater Consulting Pty Ltd (IGGC) has been engaged to undertake further investigation and assessment of the shallow groundwater disposal options, including drilling of additional monitoring wells in the central and northern area of the dunes, drilling of test production wells, test pumping and numerical modelling and assessment for simulation of exfiltration for each of three potential discharge areas. Two test production wells were constructed: one in the central area of the dunes and the other located in the northern area to ensure full understanding of groundwater conditions and prospects for disposal in this area.

Additional numerical modelling and assessment was undertaken for one of the potential exfiltration areas to allow simulation of groundwater discharge from the dunal aquifer system to the lake and ocean, assessment of potential mechanisms of discharge and potential for increased nutrient fluxes to each water body and to the benthic zone sediments through which discharge occurs.

This report presents the results of the assessment.

2. Scope of Work

The scope of work covered in this report was based on Bega Valley Shire Council's (BVSC) request for quotation 11/10 of 13th April 2010 and IGGC's proposal of 13th May 2010 (LT221). A number of additional tasks were added to the original scope of work during the project and the reference to the relevant scope and fee proposals are provided with the task descriptions below.

BVSC's requirements were for investigation of the potential for disposal of effluent into the shallow groundwater system in the peninsula that separates Merimbula Lake from the Pacific Ocean with the following specific objectives:

- Characterise the hydrogeology of the upper part of the Quaternary deposits in the dune system north of the exfiltration ponds;
- Investigate potential options for a shallow dunal exfiltration system north of the exfiltration ponds, including an exfiltration trench or line of injection wells (in combination with or without the existing ocean outfall) and determine viability during future average and peak wet weather flows;
- Identify potential impacts of options investigated for a shallow dunal exfiltration system on groundwater levels, groundwater flow paths, groundwater quality and on the water quality of Merimbula Lake and the ocean;
- Determine infrastructure requirements for sustainable performance.

The work required to achieve these objectives included drilling of monitoring bores and a test production bore and undertaking a pump test to determine the characteristics of the shallow sand aquifer. Additional monitoring bores located in the northern area of the dunes were also required for more comprehensive groundwater quality testing and groundwater level measurement.

A groundwater flow model was required to allow prediction of the effects of shallow exfiltration on groundwater levels, flows, flow paths, chemistry and environmental impact of potential contaminants.

The following is IGGC's scope of work to achieve these objectives.

1. *Project Inception*

- Site meeting/inspection to determine investigation sites and specific requirements for access and prior investigation/supervision;
- Obtain necessary approvals and information, including test bore licence(s), underground service locations and obtaining approval from the Land Property Management Authority.

2. Field Program

2a: Drilling of New Bores – Central Area

A test production/injection bore and two additional monitoring bores to be drilled at agreed locations in the central area (close to PPK1). PPK1 also to be replaced with a new bore drilled immediately adjacent to the existing bore which had been damaged.

A detailed lithological profile to be obtained from one bore location to the full investigation depth prior to drilling to final diameter. This approach provides valuable information on the detailed lithological profile and vertical variations which may affect groundwater behaviour and will allow thorough characterisation of the upper dune sand deposits.

The test production bore to be drilled through the entire thickness of the upper aquifer (or maximum 20m) using a mud rotary drilling technique to allow installation of screen and casing of minimum 100mm nominal diameter. The detailed design of the bore to be based on the exact geological conditions encountered and requirements for pump testing (including placement of the pump intake) with the bore screened throughout the entire saturated thickness of the aquifer if practicable. Monitoring bores to be drilled using a hollow flight auger technique through the entire saturated thickness of the aquifer if the drilling technique allows (or maximum 20m depth), and completed with 50mm diameter screen and casing.

All bores to be completed with gravel packs, bentonite seals and lockable surface monuments cemented into place. All bores to be developed by airlifting, pumping and/or surging to remove drilling mud and fines and ensure a good connection with the aquifer. This is particularly important for the test production bore.

Survey of all bores to provide accurate locations and elevations to be provided by Council.

2b: Drilling Program – Northern Area

Drill up to four monitoring bores in the northern area to provide information on the detailed geology and to allow installation of monitoring wells. At least one to be drilled to the base of the upper sand unit (or to maximum 20m) and the detailed lithological profile logged. All bores to be completed as monitoring bores using 50mm diameter screen and casing, gravel packs, bentonite seals and lockable surface monuments cemented into place. All bores to be developed by airlifting, pumping and/or surging to remove drilling mud and fines and ensure a good connection with the aquifer. An interval of at least two weeks between completion of drilling and commencement of pump testing is recommended to allow breakdown of any residual biodegradable drilling fluids.

2c: Groundwater Level Monitoring

Recovered (static) groundwater levels to be measured in all bores on several occasions including after drilling and before and after test pumping. Continuous groundwater level logging to be undertaken for a minimum 24-hour period in at least one bore in the central area and one bore in the northern area to provide information on tidal fluctuations.

2d: Test Pumping

A 72-hour pump test to be undertaken using the test production bore in the central area to provide accurate data on shallow aquifer parameters in the central area. Pumping to be undertaken at a rate sufficient to stress the surrounding aquifer, with a target rate similar to that required for injection (nominally 5 L/s), with water levels monitored in the test production bore and in nearby monitoring wells during pumping and recovery.

Water level data to be collected during the test from the test bore and from the three nearby monitoring wells. Data analysis to be undertaken using recognised analytical methods to determine parameters for the shallow sand aquifer.

Short-term pump tests or slug tests to be carried out in all new monitoring wells to assist with characterisation of the upper dune sand aquifer.

2e: Water Quality Sampling

Representative water quality samples to be collected from the test production bore and up to five monitoring bores across the study area (central and northern areas). Field readings to be taken (pH, electrical conductivity, redox potential etc.) and samples submitted to a NATA-accredited laboratory for analysis for major ions, ammonia, total Kjeldahl nitrogen, oxidised nitrogen, total nitrogen, orthophosphate, total phosphorous, dissolved organic carbon, dissolved metals (including iron and manganese), dissolved heavy metals (cadmium, chromium, copper, mercury, nickel, lead and zinc) and bacteriological indicators.

Data also to be obtained from Council’s groundwater monitoring program (from existing bores in the dune system) and for treated effluent from Merimbula STP.

2f: Other Investigation

A detailed walkover inspection of the study area to be undertaken and surface features that may indicate groundwater discharge noted. This to include the lake shoreline around Merimbula Airport, subject to access being permitted (Council to arrange access if practicable).

Surveying to be carried out if required to provide additional information on detailed ground surface elevations in key areas of interest, including potential groundwater discharge zones (surveyors to be engaged directly by Council).

3. Numerical Modelling - General

The existing numerical model to be extensively reviewed, extended to cover the entire study area (i.e. to include the northern area) and modifications made as necessary in the light of new data (aquifer parameters, ground surface elevation data, surface features, water levels etc.) and the peer review comments. Model re-calibrated then to be undertaken using all available data.

3a – Numerical Modelling – Central Area

New transient simulations to be run for the central area for both existing and future scheme loadings to an exfiltration trench and to an equivalent line of injection wells. The exact discharge regime, the length of the trench and the number and spacing of injection wells to be agreed with BVSC on the basis of previous modelling results and using revised loading predictions.

This is a detailed modelling exercise to allow full assessment of potential impacts and acceptability of effluent disposal in this area (including potential water quality impacts). Outputs from modelling to include the following:

- Groundwater level predictions under natural conditions and with exfiltration at current and projected future effluent loadings;
- Areas where groundwater may reach the ground surface and the extent and frequency of such events;
- Groundwater travel times from the exfiltration site to Merimbula Lake and the ocean;
- Predicted changes to the local groundwater flow regime.

3b – Numerical Modelling – Northern Area

Transient simulations to be run for the northern area for both existing and future scheme loadings to an exfiltration trench. The exact discharge regime, the length of the trench and the number and spacing of injection wells to be agreed with BVSC on the basis of previous modelling results for the central area and using revised loading predictions, if available.

Numerical modelling for the northern area is intended to provide preliminary assessment of the acceptability of exfiltration at this location and is to include limited sensitivity analysis and assessment of water quality impacts only. Outputs from modelling to be the same as for the central area.

4. Assessment

4a: General

Some preliminary research and assessment to be undertaken to assist with detailed evaluation of the potential impacts of exfiltration on groundwater and associated receptors covering the following areas:

- Fate and transport of phosphorus in groundwater systems. Phosphorus has traditionally been assumed to be largely immobile in groundwater systems. More recently, however, concerns have been raised that under particular conditions mobility in groundwater may be significant. Phosphorus concentrations in the effluent from Merimbula STP are around 8.5 mg/L (as orthophosphate) and this together with the potential for relatively low sorption capacity of much of the sand strata suggests some potential for aqueous-phase migration of phosphorus. A literature review to be undertaken to assist with assessment of this risk and to provide further information on fate and transport processes. In addition, existing data on phosphorus concentrations in groundwater down-gradient of the existing exfiltration ponds to be reviewed to identify whether any such impacts have occurred;

- Clogging of injection systems and surrounding strata. A literature review to be undertaken to provide information on processes associated with clogging of injection systems and surrounding strata during injection of effluent or effluent. This includes disposal systems (exfiltration) and re-use systems (artificial recharge and aquifer storage and recovery (ASR)).

4b: Central Area

Detailed assessment to be undertaken of potential impacts arising from effluent disposal via an exfiltration trench located in the central area on groundwater levels and on groundwater quality, including quality of water discharging to potential receptors. This to include the following:

- Consideration of changes to the groundwater flow regime;
- Fluxes of effluent migrating from the trench towards receptors;
- Groundwater travel times and attenuation mechanisms;
- Final predicted water quality at groundwater discharge zones;
- Potential impacts on receiving waters including groundwater;
- Effluent water quality requirements based on requirements for receiving waters and predicted attenuation processes.

Potential for clogging of exfiltration systems (trenches and wells) and surrounding strata also to be considered based on effluent and groundwater chemistry and likely chemical and biological processes within the groundwater system.

4c: Northern Area

Preliminary assessment to be undertaken of potential impacts arising from effluent disposal via an exfiltration trench located in the northern areas primarily focusing on groundwater levels including travel times and flow paths, with assessment of potential impacts on groundwater quality also provided.

5. Reporting

A detailed and comprehensive technical report to be produced including the following:

- Thorough summaries of the results of previous studies and investigations and of literature and other data reviews undertaken for this study;
- Detailed discussion of the nature and characteristics of the study area;
- Review of NSW State groundwater policy and implications for dunal exfiltration;

- Full results of the proposed investigation and assessment, including additional reporting recommended in the earlier peer review;
- Viability of a dunal exfiltration system in the central area, including potential impacts and monitoring and mitigation requirements;
- Preliminary assessment of the viability of exfiltration in the northern area and recommendations for further investigation and assessment should this be pursued.

The report to be prepared to meet the general requirements of NSW Environment Protection Authority (EPA) with respect to groundwater and receiving waters for dunal exfiltration of effluent, including the recommendations arising from peer review of IGGC's earlier work undertaken by C.M. Jewell Associates.

A draft report to be provided for review by BVSC and EPA, and comments incorporated in the final report.

6. Variations to Original Scope of Work

A number of additional tasks were added to the original scope of work during the project to improve the overall outcomes of the project and assist with decision-making. These are detailed below together with reference to the relevant scope and fee proposal:

- Replacement of monitoring bore BH10 located adjacent to the existing exfiltration ponds which had been damaged beyond repair (email 4/8/12);
- Installation of a test production bore in the northern study area (email 4/8/12);
- Undertaking a 24-hour constant rate pump test in the northern test production bore to provide accurate data on shallow aquifer parameters in this area. The target pump rate to be similar to that required for injection and for the central test production bore (nominally 5 L/s or greater), with water levels monitored in the test production bore and in nearby monitoring wells during pumping and recovery and additional water quality samples collected (email 2/9/10);
- Undertaking additional numerical model runs to simulate the effects of shallow disposal in the area of land currently under Council ownership located between the central and northern study areas (email 29/3/11);
- Analysis of samples of aquifer material for phosphorus retention index and organic carbon (email 14/6/11);
- Further assessment of groundwater discharge and nutrient fluxes to the lake and ocean including extending the groundwater model to include the lake and ocean areas underlain by the shallow aquifer; running one model scenario for 2025 loadings using the revised model and assessing the results of modelling including Zone Budget model outputs for groundwater discharge and nutrient fluxes to the lake and ocean with and without exfiltration (email 24/2/12);
- Additional assessment and reporting of the above items;
- Preparation of this report compiling the results of all phases of investigation and assessment including additional tasks added as variations (email 9/5/12).

3. Review of Previous Work

Detailed investigation of the geology and hydrogeology beneath the dune sand system has been carried out as part of a number of studies. The scope and results of each of these investigations are summarised in this report in order to provide a single, stand-alone reference document. Results of earlier work are included in the data collation and assessment as appropriate.

November/December 1986 (MMA, 1987)

Mackie Martin & Associates (MMA) undertook hydrogeological investigation and numerical modelling of the dune and beach sand system to assess the viability, potential impacts and optimum system for effluent disposal to shallow groundwater based on the predicted 2010 average dry weather flow (ADWF) of 4,856 kL/day. Exfiltration options considered included use of ponds located in a former sand quarry, use of a foredune exfiltration trench located either to the south-east or north of the quarry, use of disposal wells located north of the quarry and a combination of the quarry ponds with the northern trench or wells. The scope of work included the following:

- Drilling of 22 boreholes to depths of 2 to 26 metres (BH1 to BH22);
- Pump testing;
- Water quality assessment;
- Limited water level monitoring;
- Numerical modelling of groundwater flow and impacts of effluent disposal.

Results of the study included the following:

- Demonstrating the lithological profile beneath the dune area including proving the base of the upper aquifer;
- Providing *in situ* hydraulic conductivity results at six locations and flood-compacted permeameter results at eight locations;
- Providing groundwater level data and the groundwater surface across the dune system from c.1 km south to c.1.2 km north of sand quarry at the time of the investigation;
- Providing background groundwater quality data across the study area;
- Numerical model predictions of the effects on groundwater levels for five disposal options.

This study estimated the maximum sustainable exfiltration rate from the ponds to be 600 kL/d compared to the 2010 ADWF of 4,856 kL/d. Trench lengths of 1,950 m and 810 m respectively were required for exfiltration trenches located south and north of the ponds to allow disposal of 2010 ADWF. Composite schemes involving low-volume disposal to the ponds together with pumping of groundwater from adjacent wellpoints and disposal to an exfiltration trench or disposal wells located to the north were also found to be viable.

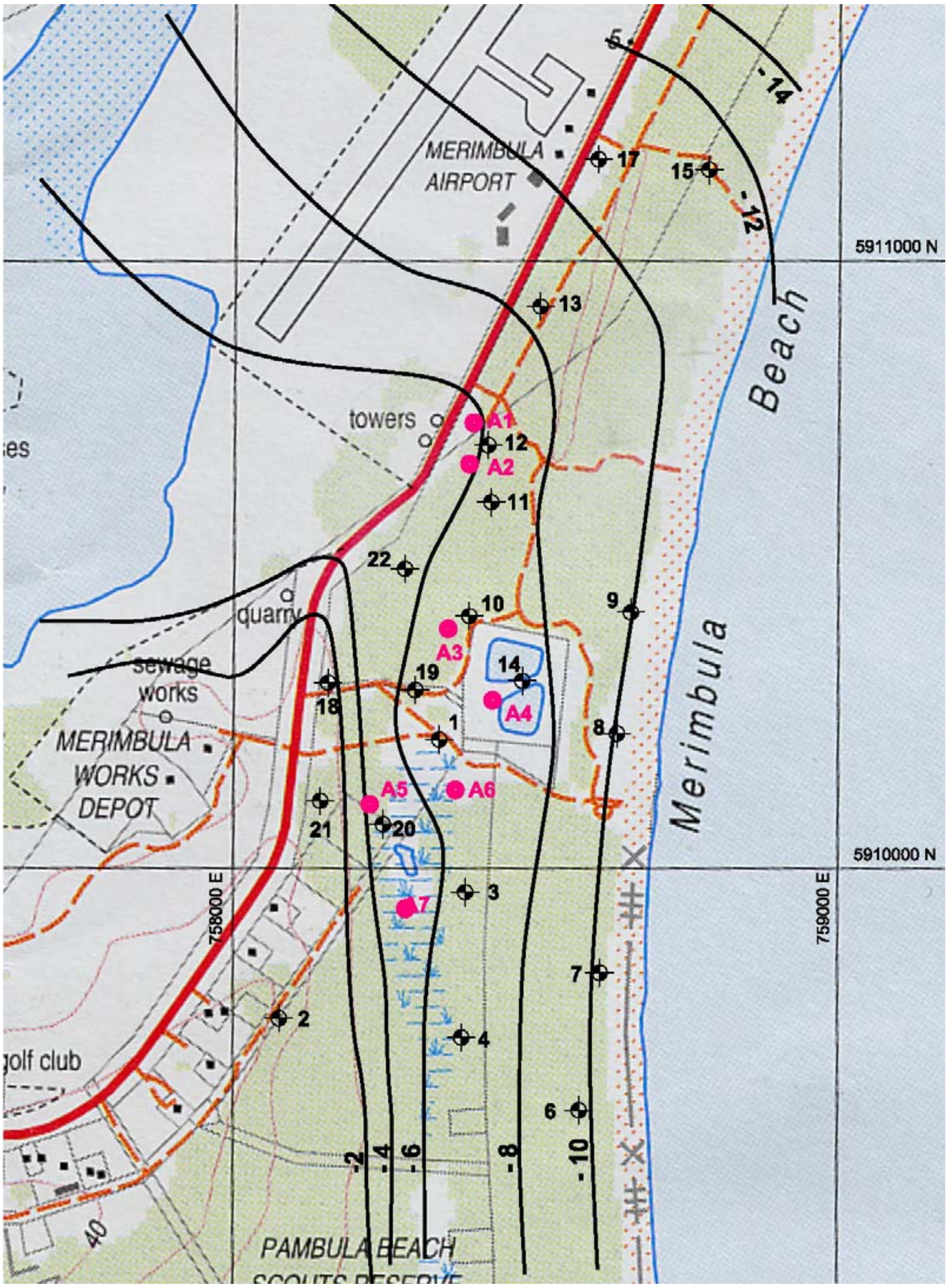
The data collected in the course of this study has been included in the overall dataset for the current study. This includes the base level of the upper aquifer and hydraulic conductivity data. The locations of all bores installed by MMA are shown on *Figure 3.1* below. Interpreted contours of the base of the upper aquifer are also presented in *Figure 3.1* and the full database of hydraulic conductivity values is presented as *Table 8.1*.

All of the MMA bores have either been lost or destroyed.

The locations of bores MM5 and MM16 are not provided in the report. Limited information is provided on the hydraulic conductivity values applied in the numerical model with the report stating that these vary from 47 m/d close to the beach line to less than 12 m/d adjacent to the hill line.

An effective porosity value of 12% was applied but this was a minimum estimate with field values of up to 25% expected. Net rainfall infiltration of 30% of rainfall was applied over most of the model area and evapo-transpiration was not simulated.

Figure 3.1: Previous Bore Locations and Interpreted Base of Upper Aquifer



Key: Mackie Martin Investigation Bores (MMA, 1987) ⊕ *Council Monitoring Bores* ●

September 1987 (Binnie and Partners, 1987)

Binnie and Partners undertook preliminary investigation of effluent disposal options (including exfiltration) for augmentation of Merimbula's sewerage system.

January 1991 to January 1993: Council Monitoring

Installation of monitoring bores A1 to A7, groundwater level monitoring and limited water quality sampling were undertaken by Council to assist in operation of the exfiltration ponds for effluent disposal. These bores were installed to shallow depth with no logs or construction details recorded and therefore do not assist with lithological interpretation; however water quality and water level data are included in the overall dataset for the project and are used in the current study.

The locations of bores A1 to A7 are shown in *Figure 3.1*. Bores A1 to A3 have been lost or destroyed; bores A4 to A6 are still in operation and water level data from these bores has been included in the current study.

March 2000 (PPK, 2000)

This study comprised a preliminary assessment of exfiltration pond performance, including:

- Review of all available data (MMA report, Council monitoring data, effluent loadings);
- Site inspection and collection of additional water level data;
- Assessment of likely causes of tree dieback and poor drainage of the exfiltration ponds;

This assessment concluded that discharge of effluent to the ponds had caused excessive and sustained elevation of groundwater levels, contributing to tree dieback near the ponds. This was likely to be due to excessive loadings, although the sustainable disposal rate identified in earlier work was considered to be too high.

Use of the ponds ceased in June 2000 as a result of these findings.

July 2001 to March 2002 (PPK, April 2002)

This study comprised further investigation of groundwater conditions, including the following:

- Location, surveying, inspection and rehabilitation of all remaining bores;
- Drilling of four additional bores;
- Hydraulic testing;
- Continual groundwater level monitoring for three months;
- Water quality sampling;
- Assessment of options for exfiltration, including identification of potential new sites and conceptual design of the preferred exfiltration scheme, and consideration of other options.

This study confirmed that use of the existing ponds had caused sustained elevation of groundwater levels, resulting in waterlogging in some areas. Groundwater levels had returned to close to pre-exfiltration levels 20 months after cessation of the discharge. No impact on groundwater or surface water quality was identified. However, due to the thin nature of the aquifer, the existing pond site was not considered ideal for long-term exfiltration.

The optimum area for shallow exfiltration was identified as the frontal dune system 400 to 750 metres north of the existing ponds. Deep injection to confined strata was also identified as a potential option, although this was unproven at the time.

The risk to water quality in Merimbula Lake for exfiltration using the existing ponds or the northern site was found to be low, although this was based on a limited assessment.

Water level and water quality data from the PPK bores continues to be collected and have been included in the current study. Lithological data and results of hydraulic testing have also been included. Bore locations are shown in *Figure 4.1*.

July 2004 (PB, 2004a)

Numerical modelling was undertaken for shallow exfiltration from a trench located in the northern preferred area. Exfiltration was found to be viable for current and projected loads, although a trench length greater than the 425 metres assumed in the assessment may be required to meet peak requirements under projected loadings (700m trench recommended).

July 2004 (PB, 2004b)

Geophysical investigation and drilling of a deep borehole located c.120 m north-west of BH10 was undertaken to establish the presence and nature of a deep aquifer, and the viability of deep injection assessed. The deep aquifer suspected to be present was located, and deep disposal found to be potentially viable. Four injection wells were estimated to be required to meet current loads, and up to nine for projected loads. Further investigation was recommended but has not been undertaken.

December 2004 (IGGC, 2004)

Assessment was undertaken of the potential for resuming use of the existing exfiltration ponds for short-term disposal of effluent during the peak loading period of Christmas to Easter. Examination of the groundwater response to historical loading indicated that short-term use was viable without causing unacceptable adverse impacts.

November 2005 (IGGC, 2005a)

Initial review of the potential for continued use of the existing exfiltration ponds in combination with reuse, as part of the ongoing effluent management program. The review concluded that use of the ponds for some effluent disposal would be sustainable, but that the capacity of the ponds was insufficient to meet all disposal requirements.

May 2006 (IGGC, 2006a)

A review of options for disposal of excess effluent was undertaken including disposal to the existing ponds, to an exfiltration trench or line of wellpoints located in the central area of the dunes, and to injection into the deep alluvial aquifer. Assessment included use of each of these options alone and in combination with the existing ponds, and both with and without diversion of some effluent to the ocean outfall during periods of very high flows.

The numerical model used in earlier assessment (PPK, 2004a) was modified, re-calibrated and used as the basis for this assessment. Infrastructure requirements and pros and cons were discussed for each of the options and requirements for further investigation and study identified. These data gaps were used to assist in defining the scope of work required for the current study.

October 2006 (CMJA, 2006)

A detailed peer review of the review of disposal option (IGGC, 2006a) was undertaken by C.M. Jewell & Associates Pty Ltd (CMJA) on behalf of the NSW Environment Protection Authority (EPA). This included a review of the site setting and hydrogeological conditions, summaries of the results of previous investigations and assessment of the adequacy of the options work and reporting standards of the options review (IGGC, 2006a). A number of areas were identified in which further work was considered necessary some of which were acknowledged as being outside of the brief of the options review, such as lack of detailed assessment on groundwater quality. The following additional work was recommended:

- Use of a full zoned water balance to allow changes in groundwater flow to wetlands, the lake and the ocean to be assessed;
- Use of MODPATH (a particle tracking tool used with the MODFLOW numerical modelling software) to establish the fate of effluent;
- Groundwater dependence of wetland ecosystems;
- Consideration of groundwater quality impacts, both qualitatively and using transport modelling;
- A discussion of NSW State Groundwater Protection Policy;
- Provision of a stand-alone report including key findings from all previous studies.

November 2006 (IGGC, 2006b)

IGGC responded to the matters raised in the peer review (CMJA, 2006). It was acknowledged that most of the points raised were valid but that many referred to areas that were outside of the original scope of work. The scope of work for the current study was developed with the assistance of the peer review.

4. Background

4.1 Site Setting

The study area is located on a peninsula separating Merimbula Lake from the ocean (Merimbula Bay). The existing exfiltration ponds and ocean outfall are located east of Merimbula Sewage Treatment Plant (STP).

The area comprises a frontal sand dune system with lower-lying areas behind (west). Wetlands occur behind the frontal dunes south of the existing exfiltration ponds, and extend further north during wet periods. The area west of the highway is flat and low lying in the northern part of the study area but a hill is present south-west of the existing ponds.

The existing exfiltration ponds are located within an area previously used for sand mining, probably during or around the 1970s. There is some anecdotal evidence that the area may have been used for limited waste disposal (PPK, 2002). Many of the eucalyptus trees in the area around the ponds are dead or stressed. Previous assessment concluded that sustained elevation of local groundwater levels due to exfiltration was the likely cause of tree dieback. However, while sustained water table elevation has certainly occurred since the ponds were built and used for effluent disposal from 1991, the Binnie and Partners (1987) report states:

A notable feature of the vegetation in the area is the evidence of dieback in the upper exposed branches of Eucalyptus globoidea. This is due to exposure of the tallest trees to salt spray (S9.3, P35).

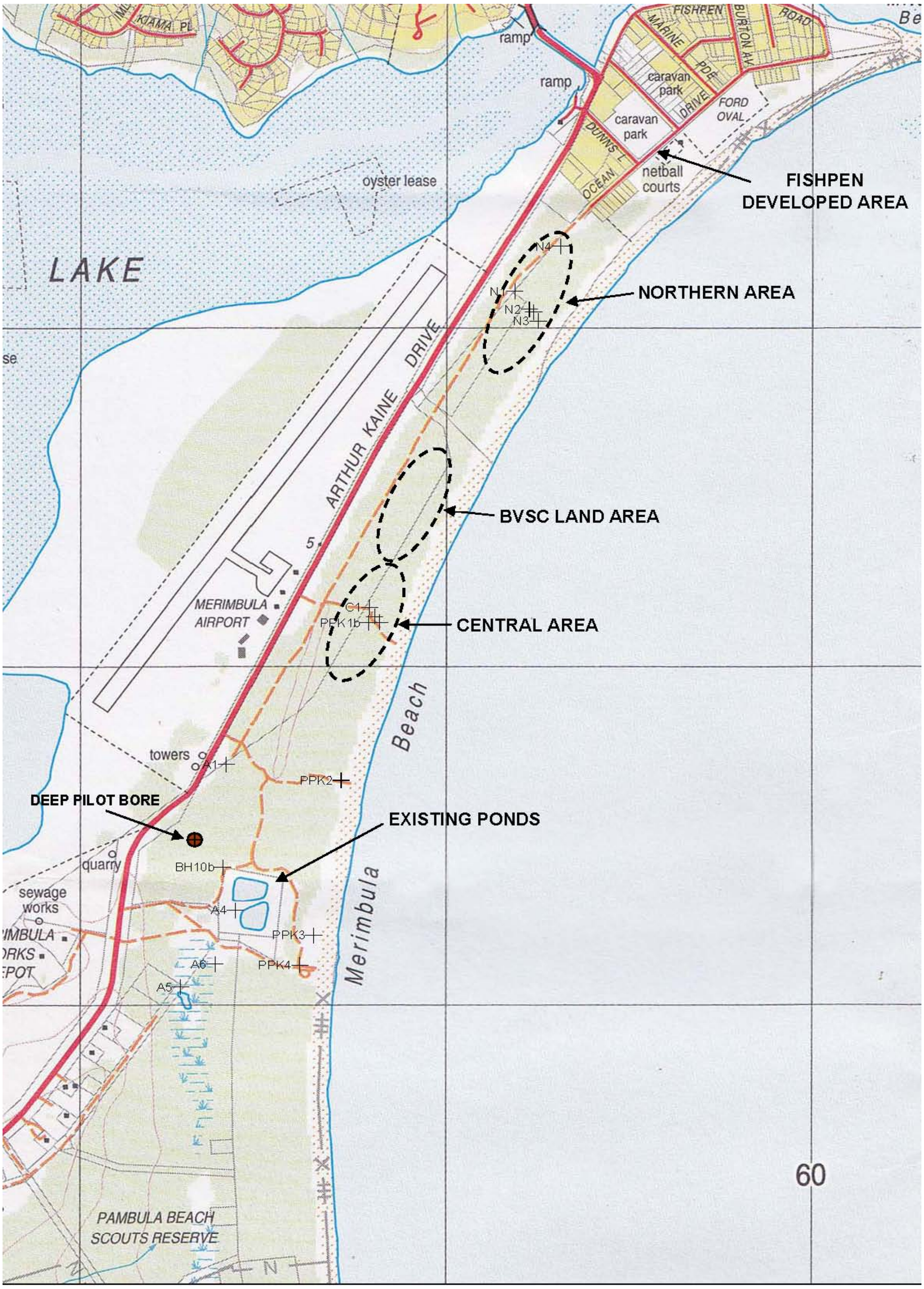
This suggests that the trees were in this condition prior to effluent disposal via the dunal exfiltration ponds and that change due to sand mining or other factors may have been the major cause of stress.

The existing study includes three areas within the foredunes of the Merimbula sand dune system as follows:

- Central Area: this area is located close to existing bore PPK1, approximately 700 m north of the existing ponds;
- Northern Area: this area is located close to the northern limit of the undeveloped dunes, south of the developed area of Fishpen; and,
- Council Land: BVSC already own areas of land east of Arthur Kaine Drive and while ownership does not extend into the highest parts of the dune system an area c.300 m north of the central area is considered prospective and has been included in the assessment.

The dune system and study areas are shown on *Figure 4.1*.

Figure 4.1: Dune System, Study Areas and Bore Locations



Key
+ Groundwater Monitoring Bores
⊕ Deep Pilot Bore (PPK, 2004b)

4.2 Geology and Hydrogeology

A summary of understanding of the geological and hydrogeological setting of the area as provided by published information and previous investigation is as follows.

The published geology map (1:250,000 Bega-Mallacoota Sheet (DMR 1995)), shows the entire peninsula to be underlain by dune and beach sand deposits of Quaternary age, with Tertiary fluvial deposits occurring beneath the low hill to the southwest, close to the golf club. The underlying bedrock consists of sandstones and conglomerates of the Devonian Merimbula Formation, and its outcrop is reflected in steep topography north-west of Pambula and south-east of Pambula Beach.

Boreholes drilled as part of the Mackie Martin investigation (MMA, 1987) proved the presence of the Quaternary sands to depths of 26 metres. A substantial and persistent clay layer was encountered in all bores with effective thickness where proven of 0.7 to 5 m. This clay layer forms an effective base to the upper, unconfined aquifer. The investigated strata beneath this clay layer comprise alternating sands and clays interpreted as being of Tertiary age. Most boreholes were terminated within the Quaternary deposits (usually within the first substantial clay layer), and the underlying Tertiary alluvial sequence was not investigated. The sands wedge out against the hill to the south-east of the existing ponds, and have a thickness of 7 to 10 metres close to the ponds. The thickness of the sands increases to the north and east, reaching 19m in the area of PPK1. The upper sands form a highly transmissive, unconfined aquifer. Groundwater levels are generally around 1m AHD. Groundwater levels are close to surface across parts of the study area, being the low-lying areas around the exfiltration ponds, the wetlands and the southern part of the power line easement. Rainfall recharge results in a groundwater mound along the peninsula, with groundwater flow occurring towards the ocean (east) and Lake Merimbula (west). Results of earlier aquifer testing indicate that hydraulic conductivity of the upper sand aquifer is around 0.5 to 5 metres per day in the area of the existing exfiltration ponds and back-dunes; and 5 to 25 metres per day beneath the frontal dune system and the northern potential exfiltration area.

The presence of a deep Tertiary alluvial sequence was surmised during earlier studies (PPK, 2002), and subsequently investigated using geophysics and by drilling of a pilot bore (PB, 2004b). The interpreted results of geophysical investigation indicate a depth to bedrock of around 30 metres across most of the area, increasing to 50 m or more in three localised areas. The pilot bore was drilled at one of these locations (see *Figure 4.1*), and penetrated layered alluvial strata extending to the full drilled depth of 61.6 m (approx. –58 mAHD). The majority of these strata were clays and silts but coarse sand units were encountered with a total thickness of 8.5 m of the overall thickness of 54 m investigated. Groundwater within the transmissive coarse sand units is confined (i.e. held under pressure) by the overlying clays and the groundwater pressure surface in these confined aquifers is slightly above local ground surface at around 2 mAHD, and is above the local water table in the shallow aquifer and the local ground surface. The casing of the bore extends above ground surface, preventing groundwater from flowing from the bore. Testing of the pilot bore indicated a transmissivity of around 50 m^2/day for the strata intersected. This is equivalent to a hydraulic conductivity of around 4 m/d in the deep, coarse sand sequences located c.35 m below surface and deeper (PPK, 2004b) compared to hydraulic conductivity values of 12 m/d to 47 m./d in the Quaternary sands (MMA, 1987). Hydraulic conductivity is expected to be much lower in the more clay-rich strata and vertical hydraulic conductivity is expected to be very low with limited inter-connection between the shallow sands and the deep aquifer as shown by the pressure surface in the latter.

Groundwater in the deep confined aquifer system is likely to be recharged from rainfall and/or river flow some distance inland along the Pambula River valley. Discharge is likely to occur where the transmissive strata outcrop on the sea bed some distance off-shore, probably where the bed of the bay reaches around 50 m depth (assuming that these strata are approximately horizontal).

4.3 Existing Groundwater Use

A total of ten registered bores (or groundwater works) are recorded on the NSW Office of Water (NoW) database in the vicinity of the study area. The locations of these are shown on *Figure 4.2 (Appendix A)* and details are summarised in *Table 4.1*.

Table 4.1 Summary of Registered Bores

Bore No.	Depth	Construction	Licence?	Use	Comments
GW040589	4.9 m	Unknown	No	Unknown	
GW040590	5.5 m	Spear	No	Unknown	
GW040591	2.5 m	Unknown	No	Unknown	
GW040592	3 m	Excavation	No	Unknown	Airport
GW040593	3 m	Excavation	No	Unknown	Airport
GW047147	14 m	Bore	Yes	Irrigation	SE of Ponds
GW056187	3.1 m	Well	Yes	Domestic	
GW065554	6.7 m	Spear	No	Domestic	
GW105056	79.2 m	Bore	Yes	Industrial	Deep bore
GW105858	u/k	Bore	Yes	Domestic	
GW107944	4 m	Spear	Yes	Domestic	

Most of the registered bores are shallow spears located in the Fishpen area. Some are licensed for domestic use; this is likely to be garden watering and perhaps filling of swimming pools etc. The closest of these is GW107955 which is located approximately 350 m north-east of the northern area.

Bore GW047147 is licensed for irrigation and is constructed into the shallow aquifer but is located close to its south-western limit. GW040592 and GW040593 are excavations on the airport property: the purpose of these is not known.

GW105056 is a deep bore used for abstraction of groundwater from the deeper, Tertiary sedimentary sequence for commercial use (i.e., car wash).

4.4 Surface Water Features

The surface drainage system in the area of the existing exfiltration ponds and surrounding dunes is limited to wetlands and low-lying areas prone to waterlogging and overland flow, with no defined drainage lines. An area of wetlands occurs from a short distance south-west of the exfiltration ponds and extends southwards to Pambula Beach. This includes several permanent ponds, with the closest located around 200m south of the exfiltration ponds.

Overland flow occurs during very wet weather, and tracks in a north-westerly direction from the wetland area along the low-lying area along the power line easement before flowing under the highway via a culvert located immediately south of the transmission towers south of the airport.

The culvert was inspected in August 2010 and comprises two concrete pipes each around 500mm diameter. A surface depression is present at each end of the culvert. There are no clearly defined drainage lines on the eastern side of the highway. On the western side small and poorly defined drainage features are expected to drain to the lake. It is therefore likely that the area of the culvert acts as a source of localised recharge of the shallow aquifer during small to moderate rainfall events, with surface flow towards the lake only occurring during periods of very wet weather, when groundwater levels are effectively at ground surface.

4.5 Climate

Daily rainfall data have been recorded at Merimbula Airport by the Bureau of Meteorology (BoM) since 1969. The station changed in 1998 (from 69093 to 69147), with the period of overlap showing excellent correlation between the two stations.

Average annual rainfall for the record period from 1970 to 2010 is 791 mm, with a 10th percentile of 506 mm and a 90th percentile of 1,105 mm. The annual average for the period 1999 to 2010 is 696 mm. Average monthly rainfall varies from 37.7 mm (August) to 87.1 mm (March) and is highest during summer and early autumn (November to April) and lowest in winter and early spring (July to September).

Evaporation and evapo-transpiration are not measured at the Merimbula BoM station or at any other stations in the area. The closest station for which measurements are available is Orbost, located approximately 170 km to the west-south-west and 10 km from the coast.

Average monthly Areal Potential Evapo-transpiration (APE) has been estimated from maps published by BoM and is provided in *Table 4.2* with monthly average evapo-transpiration values for Orbost and monthly average rainfall for Merimbula.

Table 4.2 Monthly Average Climate Statistics

Month	Average APE (BoM Maps)		Average ET Orbost		Average Rainfall Merimbula
	mm/month	Mm/day	mm/month	mm/d	mm/month
Jan	140	4.52	155	5	70.7
Feb	120	4.29	128.8	4.6	87.1
Mar	110	3.55	108.5	3.5	78.5
Apr	75	2.50	72	2.4	76.9
May	50	1.61	49.6	1.6	61.0
Jun	38	1.27	39	1.3	63.4
Jul	38	1.23	43.4	1.4	46.0
Aug	52	1.68	65.1	2.1	37.7
Sep	80	2.67	81	2.7	54.0
Oct	120	3.87	105.4	3.4	65.8
Nov	142	4.73	123	4.1	83.0
Dec	150	4.84	142.6	4.6	70.9
Annual	1115	3.05	1113.4	3.05	795.0

Notes. ET is evapo-transpiration.

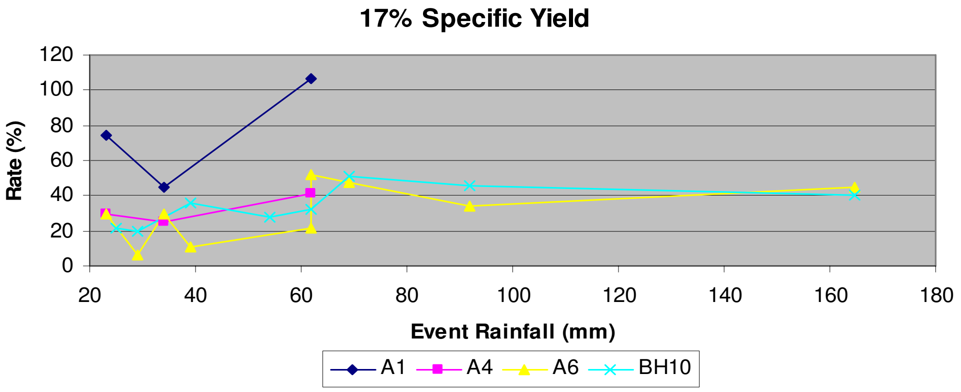
Actual average evapo-transpiration figures from Orbost are similar to those estimated from the BoM maps. APE is the evapo-transpiration that would take place under the condition of unlimited water supply from a large area such as a large wetland or large irrigated area. These values are considered applicable to numerical modelling in the current study.

Table 4.2 shows that average rainfall exceeds AAP from April to July inclusive.

4.6 Rainfall and Recharge

Rainfall recharge was estimated in previous assessments as 30% (MMA, 1987) and 32-40% (PB, 2004). Water level data collected during 2005 includes several rainfall events, and analysis of the groundwater level response to these events allows estimation of rainfall recharge (IGGC, 2006). Estimated rainfall recharge for different events is shown graphically in *Figure 4.3* for assumed aquifer specific yield values of 17% and 22%, the likely mid-range for fine to medium sand based on published values (Fetter, 2001).

Figure 4.3 Estimated Rainfall Recharge



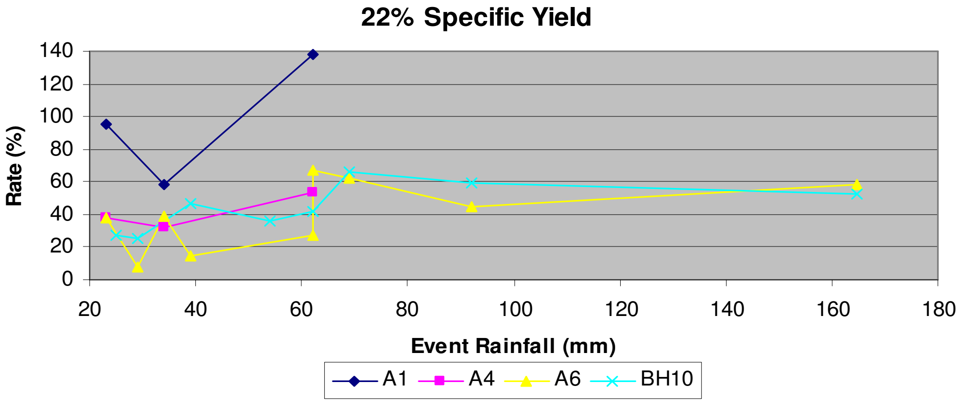


Figure 4.3 shows that the proportion of rainfall infiltrating to groundwater generally increases with the size of rainfall events, from around 20% for smaller events to 40% (17% specific yield) or 60% (22% specific yield) for high rainfall events. The assumed value of specific yield (equivalent to effective porosity) has a strong effect on the estimated recharge value. Some dissipation of recharge probably also occurs, suggesting that recharge may be underestimated by this method, particularly for the larger events.

The actual recharge resulting from a specific rainfall event is dependent on a number of factors, including soil moisture conditions, the intensity and duration of the rainfall event and season.

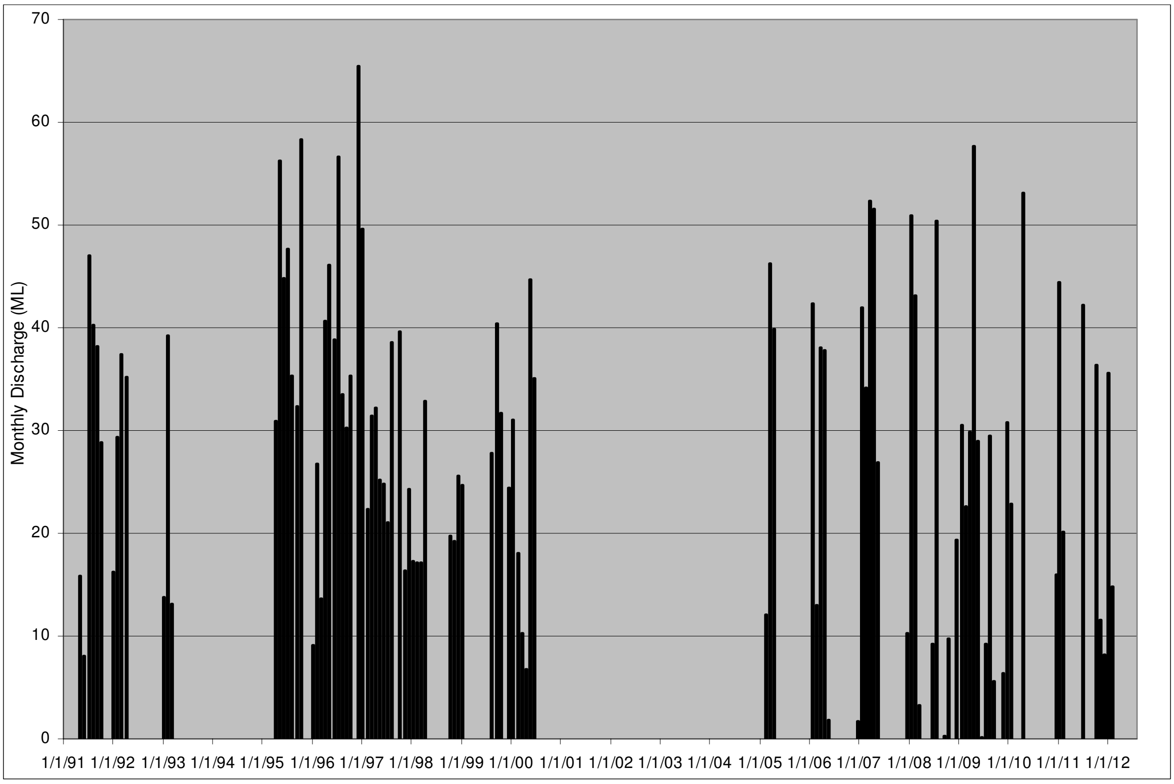
The response to rainfall at bore A1, ranging from 40% to over 100%, indicates much higher recharge than at other locations. This indicates that local conditions are acting to increase recharge. This may be partly due to the topography, with the bore being located in a depression, and run-off from surrounding areas contributing to recharge. Runoff from the adjacent highway may also be contributing to localised recharge close to the highway culvert. The surface soils in this area are also much more clay-rich than beneath the frontal dunes probably leading to increased surface run-off draining to the depression.

Other areas of localised high recharge are expected to occur within the study area including the area immediately south of the southern end of Ocean Drive, the limit of the paved road area of Fishpen. Stormwater runoff from roads in this area has been observed to flow from the paved road into a low-lying area of the northern end of the dunes and most or all of this runoff is expected to infiltrate into the shallow groundwater system. This is expected to result in recharge well in excess of 100% of rainfall falling on this area for moderate to large rainfall events.

4.7 Historical Effluent Disposal to the Existing Exfiltration Ponds

The first recorded discharge of STP effluent to the existing ponds was in May 1991 after assessment of potential impacts (MM, 1987). A histogram showing monthly discharge to the ponds is provided as *Figure 4.4*.

Figure 4.4 Monthly Discharge to Ponds (ML)



Note. Monthly discharge is shown in megalitres (Ml) per month. 1 Ml is 1,000 kilolitre (kL, 1,000 L) or 1,000 m^3.

This shows that the ponds were used initially between 1991 and 1993 and between 1995 and 2000. Use then ceased because of concerns that use of the ponds was elevating groundwater levels and contributing to tree dieback in the area (PPK, 2000). Use of the ponds resumed in 2005 and continues to date but occurs under a management strategy whereby discharge occurs for limited periods only and is suspended if local groundwater levels exceed trigger values (IGGC, 2005).

Average daily discharge rates for the periods in which the ponds have been in use are summarised in *Table 4.3*.

Table 4.3 Average Discharge during Periods of Pond Disposal

Period	May 91 to March 93	Apr 95 to June 2000	Feb 05 to Feb 12
Period Length (months)	23	63	78
Months of Pond Disposal	13	47	45
Average Monthly Discharge (kL)	27,875	31,296	26,498
Average Daily Discharge (kL)	924	1025	876
Overall Average Monthly Discharge (kL)	15,756	23,348	15,287
Overall Average Daily Discharge (kL)	522	765	466

The average discharge is calculated for months in which pond disposal occurred and were similar for all three periods. The overall average discharge is calculated including zero values for months in which no discharge occurred and shows that discharge rates were similar for the initial and recent periods of use (522 kL/d and 466 kL/day respectively) but were considerably higher for the period April 1995 to June 2000 (765 kL/d).

The original Mackie Martin study (MM, 1987) identified 600 kL/day average discharge as the maximum sustainable rate for pond disposal. This was largely adhered to during the initial discharge period but was exceeded during the period April 1995 to June 2000.

Subsequent assessment of periodic pond discharge (IGGC, 2004) assessed potential impacts from discharge to the ponds during the peak summer period only. This concluded that average discharge rates of up to 800 kL/d for maximum periods of 120 days each year should be acceptable, with the 8-9 month period without pond discharge sufficient for groundwater levels to return to close to natural conditions.

4.8 Current and Predicted Effluent Generation

Approximately 20% of the current effluent volume produced from the Merimbula STP in a median year is used to irrigate the Pambula Merimbula Golf Course. The remainder is disposed of either to the ocean via a beach-face ocean outfall or to the existing exfiltration ponds located in the dunes between the STP and the beach.

An effluent irrigation system is currently being commissioned for Oaklands Farm, Pambula. This will potentially increase the volume beneficially used to up to 50% in a median year, once the full 40 hectare area is under irrigation. Investigations are also underway for further beneficial reuse opportunities.

Total estimates of current and projected effluent volumes (i.e. total STP effluent generation) are provided in *Table 4.4*.

Table 4.4 Current and Predicted Total Effluent Volumes

Loading	Average Annual Flow (ML/a)	ADWF (ML/d)	PDWF (ML/d)	PWWF[1] (ML/d)
2010	700	1.9	3.7	14.8
2025	900	2.2	4.1	16.6

Notes. ADWF is average dry weather flow. PDWF is peak dry weather flow. PWWF is peak wet weather flow.
ML/a is megalitres per annum; ML/d is megalitres per day.
1: PWWF = 4 x PDWF.

Modelling of effluent generation and re-use rates (including re-use at Oaklands Farm) has been undertaken by AECOM to provide data on disposal volume requirements. AECOM's modelling simulates the period 1st July 1999 to 30th June 2010 and provides estimates of daily disposal volumes under current (2011) and projected 2025 loadings. Model results have been provided to IGGC for use in this study and are summarised in *Table 4.5*.

Table 4.5 Predicted Effluent Disposal Volumes[1]

Loading	Average Annual Flow (ML/a)	Average Daily Flow (ML/d)	Peak Daily Flow (ML/d)
2011	326	0.89	17
2025	510	1.4	17

Notes. 1: with the Pambula Merimbula Golf Club and Oaklands Irrigation Schemes fully operational.

Average effluent disposal volumes are predicted to be greatest in winter and lowest in summer due to seasonal variations in demand for re-use.

The average annual disposal loadings applied in the previous study (IGGC, 2006a) were 206 ML/a (start-up scheme) and 370 ML/a (interim scheme) compared to 326 ML/a (2011) and 510 ML/a (2025) shown in *Table 4.5*. The predicted disposal increases are due to earlier over-estimation of potential annual re-use volumes at Oaklands. The disposal volumes shown in *Table 4.5* are based on the effluent re-use schemes at the Pambula/Merimbula Golf Course (37 ha) and Oaklands (40 ha) being fully operational and are therefore lower than current volumes disposed.

4.9 Current Effluent Water Quality

Typical effluent water quality characteristics were provided in the tender documents (BCSV, 2010) and are shown in *Table 4.6*.

Table 4.6 Typical Effluent Water Quality

Parameter	Median Value
pH	8
Electrical Conductivity (µS/cm)	710
Suspended Solids (mg/L)	5
Biochemical Oxygen Demand – BOD (mg/L)	4
Ammonia as N (mg/L)	0.5
Total Oxidised Nitrogen as N (mg/L)	2
Total Nitrogen as N (mg/L)	5
Orthophosphate as P (mg/L)	8.5
Total Phosphorus as P (mg/L)	9.5
Faecal Coliforms (cfu/100 mL)	65
Dissolved Sodium (mg/L)	100
Dissolved Calcium (mg/L)	20
Dissolved Magnesium (mg/L)	10
Dissolved Potassium (mg/L)	20

Notes. µS/cm is microSeimens per centimetre; mg/L is milligrams per litre; cfu/100mL is colony forming units per 100 mL.

Results show that effluent quality is generally good with low levels of oxidisable organic matter (as indicated by BOD) and low levels of nitrogen and pathogenic micro-organisms (as indicated by faecal coliforms). Phosphorus levels are fairly high suggesting that phosphorus removal during treatment is limited.

Review of effluent water quality based on all available data (April 2004 to April 2012) indicates similar median values to those given above for the key analytes with respect to groundwater assessment of ammonia, total oxidised nitrogen (TON) and orthophosphate with overall median values of 0.31 mg/L, 1.8 mg/L and 8.4 mg/L respectively. Mean values are similar for orthophosphate (8.6 mg/L) but are slightly higher for TON (3.6 mg/L) and ammonia (0.8 mg/L). These higher mean values are considered to reflect increased TON and ammonia values which typically occur at the end of the summer peak period and are probably due to over-aeration during declining influent flows inhibiting denitrification. IGGC understands that improved STP operation is being sought to reduce this effect.

5. Regulatory Framework

5.1 Licensing of Effluent Discharge

Re-use and disposal of effluent from the Merimbula STP is regulated under Protection of the Environment Operations Act 1997 Environment Protection Licence 1741. This includes requirements for a pollution study and reduction program (PRP) in Condition U1: PRP 6. This requires investigation of beneficial reuse and disposal of treated effluent including consideration and evaluation of “all reasonable and feasible disposal options” for effluent that cannot be beneficially reused.

This investigation and assessment was commissioned to assist BVSC in meeting the requirements of this condition.

5.2 NSW State Groundwater Protection Policy

Consideration of disposal of effluent to the shallow groundwater system is subject to NSW State groundwater policy.

Groundwater policy in NSW is set out in four key documents:

- NSW State Groundwater Policy Framework Document (Department of Natural Resources – now NSW Office of Water - NoW);
- NSW Groundwater Quality Protection Policy (Department of Natural Resources);
- NSW State Groundwater Dependent Ecosystem Policy (Department of Natural Resources);
- NSW Wetlands Management Policy (Department of Natural Resources)

The principles set out in these documents that are relevant to disposal of effluent to the shallow groundwater system at Merimbula are outlined below.

5.2.1 NSW State Groundwater Policy Framework Document

This policy sets out the goal for the management of groundwater in New South Wales as being “t*o manage the State's groundwater resources so that they can sustain environmental, social and economic uses for the people of NSW”.*

The document indicates that State Groundwater Policy objectives will be achieved through application of the following resource management principles:

- An ethos for the ecologically sustainable management of groundwater resources should be encouraged in all agencies, communities and individuals who own, manage or use these resources, and its practical application facilitated;

- Non-sustainable resource uses should be phased out;
- Significant environmental and/or social values dependent on groundwater should be accorded special protection;
- Environmentally degrading processes and practices should be replaced with more efficient and ecologically sustainable alternatives;
- Where possible, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored;
- Where appropriate, the management of surface and groundwater resources should be integrated;
- Groundwater management should be adaptive, to account for both increasing understanding of resource dynamics and changing community attitudes and needs;
- Groundwater management should be integrated with the wider environmental and resource management framework, and also with other policies dealing with human activities and land use, such as urban development, agriculture, industry, mining, energy, transport and tourism.

Principle 2 is particularly relevant and states:

> "Depending on the location, some activities are essentially incompatible with groundwater resource and dependent ecosystem conditions, and will inevitably result in resource depletion or a decline in ecosystem support functions. Strategies are needed to actively discourage these activities and, over time, phase them out. This principle recognises the practical dimensions of sustainable resource management when dealing with existing developments. Any proposed non-sustainable uses, however, will not be permitted.
>
> The disposal of insufficiently treated sewage into permeable coastal sand aquifers is one example of inappropriate use that will be phased out or modified to make the practice ecologically sustainable. Contamination of a good quality groundwater resource is incompatible with the intergenerational equity aspects of ESD. The component policies will identify many of those current uses that are non-sustainable and will detail how they could be phased out".

5.2.2 NSW Groundwater Quality Protection Policy

The focus of this policy is to protect from pollution water below the ground surface and the ecosystems from which these waters are recharged or into which they discharge.

The Groundwater Quality Protection Policy provides a framework for the sustainable management of groundwater quality through:

- Adopting a beneficial use classification system that will be the basis for setting water quality objectives for all groundwater systems in NSW;

- Development of groundwater management plans which include strategies for protecting the quality of water in the State's groundwater systems which are at risk from contamination;
- Providing a comprehensive set of policy principles for groundwater quality protection;
- Establishing a mechanism for co-ordinating the activities of government and the community in relation to protection of groundwater quality;
- Providing guidance for groundwater quality protection to resource managers;
- Establishing reporting and review requirements for groundwater quality protection measures;
- Providing a context for education programs to promote awareness and best practice for groundwater quality protection; and
- Restoring the quality of the State's groundwater.

The policy includes the following nine principles.

1. All groundwater systems should be managed so that the most sensitive identified beneficial use (or environmental value) is maintained.
2. Town water supplies should be afforded special protection against contamination.
3. Groundwater pollution should be prevented so that future remediation is not required.
4. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the resource.
5. A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using ground waters that are incompatible with soil, vegetation or receiving waters.
6. Groundwater dependent ecosystems will be afforded protection.
7. Groundwater quality protection should be integrated with the management of groundwater quantity.
8. The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
9. Where possible and practicable, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.

Principles 1, 3 and 4 are particularly relevant.

Principle 1 states that:

> “Once the beneficial use of a groundwater system has been identified the obligation to protect it lies both with the industry or people involved in the activity which has the potential to contaminate the groundwater, and with the government

> authorities that regulate the activities. Potential dischargers need to either establish that their activity does not contaminate the groundwater system, or show that their proposal will not affect the beneficial use selected. This is consistent with the 'polluter pays' principle, which requires the costs of pollution prevention, or cleaning up pollution, to be met by the polluter.
>
> It must be clearly understood by all members of society that no-one has the right to contaminate groundwater in such a way as to create a significant risk to public health, critical ecosystems or other valued users of water.
>
> As a general rule, degradation of groundwater quality so that the system degrades to a lower beneficial use category, will not be permitted. Any degradation must not result in a substantial change over the natural background quality. If groundwater quality is gradually deteriorating then groundwater management plans will need to set trigger levels to initiate preventative action so that beneficial uses are preserved".

Principle 3 recognises that there are no quick or cheap solutions for groundwater clean-up once contaminated. It states that:

> "In many cases it is unlikely that contaminated groundwater systems can be returned to pre-contamination conditions. This knowledge strengthens the resolve for the prevention or minimisation of further contamination of groundwater systems. Contaminated groundwater can take tens or even hundreds of years to move from the pollution source to the discharge site. Remediation of polluted groundwater can cost millions of dollars to achieve water quality objectives. In the past, the effectiveness of remediation has been poor".

Principle 4 states that new developments that require development consent should be assessed for the risk they pose to a groundwater system. The assessment should be based on three variables:

- The threat factor;
- The vulnerability of the groundwater system; and,
- The beneficial use or environmental values of the groundwater system (e.g. groundwater dependent ecosystems).

The threat factor should consider the nature of the hazard(s) i.e. toxicity, the scale of the development, and the geographical and temporal impacts that may result. Ideally, the vulnerability assessment should be directly related to potential hazards being considered. If this is not possible because of the complex nature of soil/contaminant chemical reactions, then a more general and conservative vulnerability assessment that assumes that the pollutants are non-reactive (and thus more mobile) should be conducted.

Appendix D of the policy sets out groundwater protection levels, and indicates the type of assessment required for each level. The peer review (CMJA, 2006) of the options review (IGGC, 2006a) concluded that the proposed effluent disposal scheme at Merimbula will be Level IV and this is considered reasonable. Level IV requires a Demonstrated Groundwater Protection Plan in areas where the risk to groundwater is demonstrated by Levels II and III assessment, or is otherwise known, and where these effects cannot be tolerated (that is, the beneficial use of the system will be lowered if adequate action is not taken). For comparison, Level III requires site investigation and monitoring while Level V requires development of a demonstrated Remedial Action Plan.

The assessment needed to meet Level IV requirements is as follows:

- Extensive site investigation for baseline soil and water data.
- Definition of groundwater flow system is required.
- Engineering designs for any artificial barriers to be provided.
- An effluent/water management plan is required.
- Calculations or modelling results are to be provided in support of conclusions on level of impact.
- Demonstrated management skills have to be shown.
- A groundwater protection plan is required coupled with a monitoring schedule and an annual report.

The investigation and assessment undertaken to date (including the current assessment) together with recommendations for ongoing management should meet the requirement of Level IV.

5.2.3 NSW State Groundwater Dependent Ecosystems Policy

The NSW Groundwater Dependent Ecosystems Policy is specifically designed to· protect valuable ecosystems which rely on groundwater for survival so that, wherever possible, the ecological processes and biodiversity of these dependent ecosystems are maintained or restored, for the benefit of present and future generations.

This policy provides guidance on how to protect and manage these valuable natural systems in a practical sense. The range of tools that can be used to manage these ecosystems should be adapted to suit local conditions.

The following five principles apply to the management of groundwater-dependent ecosystems in NSW.

1. The scientific, ecological, aesthetic and economic values of groundwater-dependent ecosystems, and how threats to them may be avoided, should be identified and action taken to ensure that the most vulnerable and the most valuable ecosystems are protected.
2. Groundwater extractions should be managed within the sustainable yield of aquifer systems, so that the ecological processes and biodiversity of their dependent ecosystems are maintained and/or restored. Management may involve establishment of threshold levels that are critical for ecosystem health, and controls on extraction in the proximity of groundwater dependent ecosystems.

3. Priority should be given to ensuring that sufficient groundwater of suitable quality is available at the times when it is needed:
    - For protecting ecosystems which are known to be, or are most likely to be, groundwater dependent; and
    - For groundwater dependent ecosystems which are under an immediate or high degree of threat from groundwater-related activities.

4. Where scientific knowledge is lacking, the Precautionary Principle should be applied to protect groundwater dependent ecosystems. The development of adaptive management systems and research to improve understanding of these ecosystems is essential to their management.

5. Planning, approval and management of developments and land use activities should aim to minimise adverse impacts on groundwater dependent ecosystems by:
    - Maintaining, where possible, natural patterns of groundwater flow and not disrupting groundwater levels that are critical for ecosystems;
    - Not polluting or causing adverse changes in groundwater quality; and,
    - Rehabilitating degraded groundwater systems where practical.

Principles 4 and 5 are particularly relevant.

Principle 4 indicates that:

> “The connections between groundwater and its dependent ecosystems are not well known and may change within groundwater systems through variations in weather conditions. In some instances, reducing groundwater availability may cause a proportional decrease in the health, resilience or size of an ecosystem. In cases where ecosystems are entirely dependent on groundwater, if groundwater availability is reduced either below a threshold or if it stops flowing at the surface, an entire ecosystem may collapse.
>
> The level of protection needed depends on the value or significance of the dependent ecosystem, its sensitivity to changes in groundwater quality and availability, and the severity of the threats. The lack of knowledge about groundwater dependent ecosystems and processes that control their existence means that a precautionary approach to management is needed. Action is required as a matter of urgency and should include both protection measures and appropriate research”.

Principle 5 indicates that:

> “Where developments are proposed in sensitive areas (that is, within the zone of influence of a significant groundwater dependent ecosystem and especially in groundwater recharge areas), a risk assessment must be prepared in conjunction with any Environmental Impact Assessment. For existing developments within sensitive areas, a risk assessment must be prepared when seeking to renew

> extraction licences or obtain additional approvals from local and/or State government agencies".

Appendix D of the policy sets out a rapid assessment process for groundwater dependent ecosystems and specifically identifies concerns relating to coastal sand-bed groundwater systems. It states:

> "There are significant sand beds along the coast of NSW which are highly permeable and easily recharged through rainfall. They are also very vulnerable to contamination. The groundwater in these systems mainly supports wetlands, terrestrial vegetation and hypogean ecosystems. These wetlands are often referred to as groundwater windows as they indicate the groundwater levels in the surrounding sandbeds.
>
> It is important that over-extraction from these systems does not occur, as saline water can be drawn into the aquifer from the ocean and nearby estuaries, degrading the quality of the groundwater. Similarly, due to the highly permeable nature of these systems, groundwater can easily become contaminated by sewage, industry and poor land use practices. Water quality can be extremely difficult or impossible to restore once it has been degraded.

5.2.4 NSW Wetlands Management Policy

In NSW, there are about 4.5 million hectares of wetlands, about 6 per cent of the State's geographical area. These range from mangroves and sea grasses to inland billabongs, ephemeral claypans and salt lakes. Wetlands are ecologically, economically and socially important.

The NSW Wetlands Management Policy sets out to:

1. Halt, and where possible, reverse:
   - Loss of wetland vegetation;
   - Declining water quality;
   - Declining natural productivity;
   - Loss of biological diversity; and
   - Declining natural flood mitigation.
2. Encourage projects and activities which will restore the quality of the State's wetlands, such as:
   - Rehabilitating wetlands;
   - Re-establishing vegetation buffer zones around wetlands; and,
   - Ensuring adequate water to restore wetland habitats.

The policy has nine principles, which are:

1. Water regimes needed to maintain or restore the physical, chemical and biological processes of wetlands will have formal recognition in water allocation and management plans.
2. Land use and management practices that maintain or rehabilitate wetland habitats and processes will be encouraged.
3. New developments will require allowance for suitable water distribution to and from wetlands.
4. Water entering natural wetlands will be of sufficient quality so as not to .degrade the wetlands.
5. The construction of purpose-built wetlands on the site of viable natural ones will be discouraged.
6. Natural wetlands should not be destroyed, but when social or economic imperatives require it, the rehabilitation or construction of a wetland should be required.
7. Degraded wetlands and their habitats and processes will be actively rehabilitated as far as is practical.
8. Wetlands of regional or national significance will be conserved.
9. The adoption of a stewardship ethos and co-operative action between land and water owners and managers, government authorities, non-government agencies, and the general community is necessary for effective wetland management.

Principle 4 is particularly relevant:

> "The sources and pathways of pollution will be managed as far as possible to prevent the degradation of wetlands.
>
> Although wetlands are natural filters of water (removing sediments and nutrients), excessive amounts of pollutants or poor quality water will degrade them.
>
> Septic tanks, sewage treatment plants, feedlots, factories, land disposal areas and other point sources of pollution must be designed and managed to minimise the discharge or movement of contaminated water into wetlands. The runoff from towns, cities, logged areas and farms may also contain toxic substances and high levels of nutrients. If these flow or seep into the groundwater feeding into wetlands, they can also cause problems such as eutrophication or excessive plant growth. Increased salinity and turbidity can also alter the composition of vegetation affecting the habitat of many other dependent species".

6. Field Investigation Program

6.1 Drill Program

Site Clearance

The drill program commenced on Monday 26th July 2010. Each of the eight drill sites identified during earlier work and inspected in 2008 was re-inspected by Ian Grey from IGGC; Ken McLeod from BVSC; an archaeologist from **ngh**environmental; two representatives of the local Aboriginal Land Council and the drill crew. Ian Grey provided a Safe Work Method Statement for the fieldwork and inducted all attendees.

Exact drill locations were selected based on hydrogeological requirements, access etc. Initial excavation of the upper two metres of the soil profile was carried out by careful hand-augering with retrieved samples laid out on a tarpaulin to allow detailed inspection. The principal aim of this process was to identify any objects or artefacts with aboriginal cultural or heritage value, and in particular to ensure that no human burial sites were disturbed during drilling.

No artefacts or objects were encountered and all sites were cleared for drilling to proceed. The exact located was marked with a peg at each site.

An underground service check was also undertaken by both IGGC and Council using the “Dial before you Dig” service to ensure that none of the sites were located close to underground services. Hand augering provided a final check that no services were present.

Monitoring Well Drilling

Central Area – Test Production Bore Site

Drilling commenced at the proposed location of the central area test production well. The intention of this was to prove the lithological profile through the full thickness of the upper aquifer or to a maximum depth of 20 m.

Drilling commenced using a push tube technique until refusal at 6.8 m depth. Drilling continued using hollow-flight augers with undisturbed samples obtained at 1 to 1.5 m intervals. Undisturbed sample retrieval was not possible below a depth of c.15 m due to sample loss and logging was undertaken from auger arisings below this depth.

The total depth drilled was c.21 m. The lithological profile comprised clean, medium grained (typically 0.2 mm to 1 mm) sand with no evidence of intermediate clay or other layers. A basal clay layer was encountered at 20 m depth and comprised grey, sandy puggy clay.

Drill rods were pulled from the borehole and the surface covered and clearly marked to allow re-drilling using a mud rotary technique and test production well installation.

Central Area – Monitoring Wells

Drilling and monitoring well installation was carried out at locations C1 (western) and C2 (eastern). Each borehole was drilled to 16 m depth as this was considered sufficiently deep to allow the full aquifer response to pump testing to be recorded. 50 mm Class 18 monitoring wells were installed in each well with a 9 m, machine-slotted screen installed from c.7m to c.16m. A 2 mm sand pack was installed to 1-2 m above the top of the screen followed by a min. 0.5 m bentonite seal. The well annulus was then backfilled to surface and a galvanised steel monument cemented into place.

The existing bore PPK1 had been damaged and was replaced as part of the drill program. The replacement well was installed to c.11.5 m depth a few metres from the original location with a 6 m screen. Construction was otherwise as for MWC1 and MWC2.

Northern Area – Monitoring Wells

Drilling and monitoring well installation was carried out at locations N1 (western), N2 (central), N3 (eastern) and N4 (northern). Each borehole other than N2 was drilled to 11.5 m depth to allow groundwater level and water quality monitoring. 50 mm Class 18 monitoring wells were installed in each well with a 9 m, machine-slotted screen installed from c.7m to c.16m. A 2 mm sand pack was installed to 1-2 m above the top of the screen followed by a min. 0.5 m bentonite seal. The well annulus was then backfilled to surface and a galvanised steel monument cemented into place.

Borehole N2 was drilled to 20.5 m depth to allow the full lithological profile (or the upper 20.5 m) of the upper aquifer to be logged. Drilling was carried out using hollow-flight augers with disturbed samples obtained from the auger arisings. This method was adopted because of the difficulty encountered at location C1 in obtained undisturbed, pushtube samples and considered acceptable based on the good drilling returns and lack of variation observed in the lithological profile.

The total depth drilled was c.20.5 m. The lithological profile comprised clean, medium grained (typically 0.2 mm to 1 mm) sand with no evidence of intermediate clay or other layers. No basal clay was encountered.

A 50 mm Class 18 monitoring well was installed with a 12 m, machine slotted screen installed from 7.7 m to 19.7 m. Construction was otherwise as for the other monitoring wells.

All monitoring wells were developed after construction by pumping of 50 L to 100 L of water using an electro-submersible pump. Typically water was cloudy during initial pumping but ran clear within a few minutes.

Test Production Well Drilling

The original project scope included drilling and construction of a test production well in the central area to allow a 72-hour pump test to be undertaken. This was to be completed with a standard 100 mm diameter PVC screen with 0.8 mm slot aperture.

During drilling of the monitoring wells the sand strata were carefully examined and found to be slightly finer than anticipated with visual inspection indicating a grain size range of 0.2 mm to 1 mm. After discussions between IGGC, Terratest and Council it was concluded that this would lead to an unacceptable risk of well and/or pump test failure due to entry of sand through the screen, particularly given the thickness of the placed sand filter pack would be limited because of the small difference in diameter between the well screen and the drilled borehole. It was therefore decided that a custom made well screen would be required and the delay for manufacture of this meant that a separate mobilisation was needed for test production well drilling. It was also decided that an additional test production bore should be drilled in the northern area to allow pump testing at this location.

Samples of the natural sand strata were collected during drilling of initial test holes in the central area (test production bore site) and the northern area (N2). Samples were collected at one metre intervals and those within the anticipated screened sections of 10 m to 20 m were used to produce a composite sample for each location (note: this was considered appropriate because of the limited variation noted in the grain size). These samples were submitted for sieve analysis to assist in screen design, the results of which are provided in *Appendix B*.

Sieve analysis results show very similar grain size distributions at the two sites with a modal size of 0.3 mm to 0.425 mm for both samples. The sample from the northern area showed a slightly larger grain size distribution overall but the difference was very minor.

On the basis of sieve analysis a screen aperture of 0.4 mm was selected for both sites and stainless steel wire-wound screens ordered. Screen and casing connectors were designed and customised to ensure that the final internal diameter would be at least 100 mm.

The second drill program commenced on Tuesday 10th August 2010. Each drilling location was cleared by hand augering in the presence of Eden Local Aboriginal Land Council representatives as previously prior to drilling. Drilling commenced with replacement of existing monitoring bore BH10 which had been damaged by a vehicle collision. This was drilled to c.5m depth using hollow-flight augers and completed as a monitoring well using 50mm Class 18 screen and casing. The bore was developed by pumping of c.100 L using an electro-submersible pump.

Test production wells were drilled using a mud-rotary drilling technique at PW diameter (c.120 mm OD). The drilling mud was a biodegradable formulation based on guar gum and use was kept to a minimum. The central test production well (CPW) was drilled at precisely the same location as that drilled previously. The borehole was re-drilled to 19.1 m depth and the screen (9 m) and casing installed with the final screen base at 18.9 m depth. A limited volume of sand filter pack (2 mm) was placed due to the small annular space and the drill stem carefully withdrawn.

The northern test production well (NPW) was drilled to 19.2 m depth at the selected location between MWC2 and MWC3. No notable difference in lithology was noted compared to MWC2 other than a slight darkening of colour below 17 m depth. The screen (9 m) and casing was installed with a final screen base at 19.1 m depth and the well completed as above.

Photograph 1 shows installation of the screen in the northern production well.

Photograph 1: NPW Screen Installation

Both wells were extensively developed by air-lifting to remove drilling mud and fine material and to develop the natural filter pack around the screen. CPW produced fine sand during much of development and was developed for 2 hours after drilling and for a further 1.5 hours the following day. A small amount of fine sand was still being produced at the end of development but this was considered acceptable. NPW was developed for two hours and produced a small amount of fine sand during initial air-lifting. NPW showed a higher flow rate of water than CPW during development.

Both test production wells were completed at surface using heavy-duty, galvanised, lockable monuments cemented into place.

Surveying

Surveying of all monitoring and test production bores was undertaken by surveyors engaged directly by Council. A reference point on the top of the PVC casing of all bores was surveyed to Australian Height Datum (AHD) and co-ordinates recorded.

6.2 Single Well Tests

Rising head slug tests were undertaken in the monitoring wells drilled as part of this investigation to assist in characterisation of hydraulic conductivity. A pressure transducer with datalogger was set to record water levels at 1 second intervals and installed in each well following development and recovery. A bailer was then lowered into the well and the water level allowed to re-equilibrate. The bailer was then retrieved rapidly causing an instantaneous lowering of the water level of c.0.5 m. The recovery of the water level is recorded by the datalogger and subsequently analysed to provide an estimation of the hydraulic conductivity of the surrounding strata.

Single well pump and recovery tests were undertaken in some wells by installing a logger, lowering the water level by pumping at a constant rate for c.20 minutes and analysing the recovery data. In general it was found that the achievable drawdown was too small and the recovery too rapid for reliable data to be obtained and this approach was not pursued.

6.3 Pump Testing

The original project scope included a 72-hour constant rate pump test using CPW. The scope was subsequently expanded with the addition of a 24-hour constant rate pump test using NPW to provide information on variations in aquifer transmissivity across the dune area. Pump testing was undertaken between 10th October 2010 and 15th October 2010 by a specialist subcontractor (Taylor Made Pumps Pty Ltd) with supervision provided throughout by IGGC.

CPW 72-hour Test

Pump test equipment was set up at CPW on 9th October including installation of the bore pump and set up of the generator, flow meters and associated equipment. The pump discharge was directed into a stilling tank so that a transfer pump could be used for final discharge if required to achieve a stable, adequate flow rate. After some experimentation the bore pump was set with its base at 17.3 m depth (intake at c.15 m) to allow ample scope for drawdown while ensuring sufficient flow entered the pump from below to provide adequate cooling of the pump motor.

Photograph 2 shows the pump test equipment set-up for the central production well.

Photograph 2: CPW Pump Test

The bore was pumped intermittently for c.2 hours to ensure complete development, to confirm that the target flow rate of 5 L/s was achievable and to remove fine sediment prior to testing. Groundwater levels were then allowed to recover overnight.

Final set up was completed early on 10th October with lay-flat hose run out to a discharge point in the final swale behind the beach at a distance of 110 m from the production well. The discharge was set up carefully to minimise potential for erosion and was considered sufficiently far from CPW to avoid any influence due to recirculation or recharge. The lay-flat hose was then connected directly to the pump riser as the transfer pump was not required. *Photograph 3* shows the discharge arrangement for the CPW pump test.

Photograph 3: CPW Pump Test Discharge

Manual groundwater levels were measured in CPW and the three monitoring wells immediately prior to commencement. Pressure transducers with data loggers were installed in each well to allow continual recording of water levels.

The pump test commenced at 8 am on 10th October. The flow rate was adjusted during the test by means of a gate valve to maintain a constant flow rate of 5 L/s. Field parameters (pH, EC, redox potential and temperature) were measured at intervals during the test. Manual water level measurements were collected throughout the pumping and recovery phases in case any of the water level loggers failed.

The pump was shut off at 8:11 am on 13th October. The logger was removed from CPW to allow removal of the pump, the logger reinstalled and a manual water level measurement taken. Loggers were removed from MW C1 and PPK1b around an hour after cessation of the test to allow their use in the NPW pump test. Manual water level measurements were collected at intervals after removal to provide recovery data.

NPW 24-hour Test

Pump test equipment was set up at NPW at around 9am on 13th October in the same manner as for CPW.

The bore was pumped intermittently for c.20 minutes to ensure complete development and was found to give an excellent yield with little fine sediment produced. Groundwater levels were then allowed to recover.

Final set up was completed including running out the lay-flat hose to a suitable discharge point and the test commenced at 11:03 am on 13th October. The pump test methodology was identical to that for CPW.

The pump was shut off at 8:04 am on 14th October. The logger was removed from NPW to allow removal of the pump, the logger reinstalled and a manual water level measurement taken. All other loggers were left in place to allow continual monitoring of recovery for 21.5 hours after cessation of pumping.

6.4 Water Level Monitoring

Groundwater levels were measured in all new bores during the drilling and pump testing programs. This included individual groundwater level measurements to allow assessment of the water table geometry and groundwater flow directions; and continual measurements to allow assessment of tidal influences on groundwater levels. Individual groundwater levels were measured using an electronic water level meter to an accuracy of c.0.3 mm. Continual measurements were obtained by installing a pressure transducer with data logger in the relevant well and taking manual measurements on installation and removal to allow recorded levels to be converted to absolute levels relative to AHD. Water levels were recorded at 10 minute intervals. A barometric pressure logger was used to remove effects of barometric pressure changes from the data.

Continual water level measurement was undertaken in MW C1 and MW C2 on 27th to 28th July 2010 and in MW N3 on 28th to 29th July 2010.

6.5 Water Quality Sampling

Groundwater quality samples were obtained from two monitoring wells in each of the central and northern study areas and from each of the test production wells on 12th October and 14th October 2010. Monitoring wells were purged of at least three well volumes before sampling and sampled using an electro-submersible pump with the intake located adjacent to the screened section. Test production wells were sampled during the last few hours of the pump test for each well.

Samples were collected in pre-treated sample containers, placed in chilled eskies and then submitted for NATA-accredited laboratory analysis for major ions, nutrients, dissolved metals and bacteriological indicators.

6.6 Inspections

Detailed walkover inspections of the study area were undertaken and surface features that may indicate groundwater discharge noted. This included the following areas:

- The northern end of the power line easement through the dunes where surface water runoff from nearby roads will result in increased recharge;

- The lake shoreline where access was available (note: the shoreline within the boundary of Merimbula Airport could not be inspected;
- The culverts and associated drainage lines crossing Arthur Kaine Drive south of the airport.

The elevation of the culverts and associated footbridge were surveyed by Council to allow surface water levels to be measured relative to AHD.

7. Results of Field Investigation

7.1 Drill Program

Detailed Geology

The results of the drilling program confirm the broad understanding of the nature of the sand deposits present beneath the dune area at Merimbula. The strata encountered comprised fine to medium-grained sand with some shelly material. The basal clay layer reported in earlier investigations (MM, 1987) was encountered at a depth of 20 m (-12.78 mAHD) in the Central Area but was not reached in the Northern Area where the maximum depth drilled was 20.5 m (-14.6 mAHD).

Samples of the natural sand strata were collected at 1m intervals during drilling of initial test holes in the central area (test production bore site) and the northern area (N2). Samples within the anticipated screened sections of 10 m to 20 m were used to produce a composite sample for each location (note: this was considered appropriate because of the limited variation noted in the grain size). These samples were submitted for sieve analysis to assist in screen design, the results of which are provided in *Appendix B*.

Sieve analysis results show very similar grain size distributions at the two sites with a modal size of 0.3 mm to 0.425 mm (medium-grained) for both samples. The sample from the northern area showed a slightly larger grain size distribution overall but the difference was minor.

The geometry of the base of the upper aquifer was interpreted during earlier work (MM, 1987; PPK, 2002) and this interpretation is supported by the additional information obtained during the current investigation. Borehole MM15 was located close to CPW and reported the clay to be at an elevation of -12.2 mAHD, very similar to the -12.78 mAHD level reported in CPW.

Extrapolation from this interpreted surface would suggest a clay elevation of -16 mAHD to -18 mAHD beneath the Northern Area. The results of pump testing showed an increase in aquifer transmissivity of around 35% between the Central and Northern Areas. Grain size analysis did not show an appreciable difference between the Central and Northern Areas. The interpreted clay surface suggests a northward increase in saturated thickness of the upper aquifer of close to 35% consistent with pump test results and grain size analysis.

Well Details

Drilling and well construction logs for all new wells are provided in *Appendix B* and summarised in *Table 7.1*.

Table 7.1 Summary of Well Construction

Well	Easting mMGA	Northing mMGA	Elevation mAHD	Stickup m	Base of Screen mbGL	Top of Screen mbGL	Water Level mbGL	GWL mAHD
CPW	758,804	5,911,149	8	0.78	18.87	9.87	6.66	0.56
C1	758,790	5,911,177	7.77	0.73	15.53	6.53	6.47	0.56
C2	758,818	5,911,133	7.19	0.68	16.06	7.06	5.95	0.56
PPK1b	758,787	5,911,131	7.66	0.73	11.32	5.32	6.37	0.57
NPW	759,238	5,912,048	6.65	0.76	19.1	10.1	5.56	0.34
N1	759,187	5,912,110	6.88	0.67	11.38	5.38	5.87	0.34
N2	759,226	5,912,056	6.78	0.7	19.69	7.69	5.71	0.37
N3	759,251	5,912,022	6.76	0.66	11.36	5.36	5.72	0.39
N4	759,312	5,912,242	6.92	0.61	11.26	5.26	6.04	0.27
BH10b	758,290	5,910,475	2.79	0.66	4.89	1.89	0.89	1.24

Notes. mMGA is metres Map Grid of Australia. mAHD is metres Australian Height Datum. mbGL is metres below ground level. Water levels are those measured before pump testing, i.e. 10/10/10 for the Central Area; 13/10/10 for the Northern Area and 14/10/10 for BH10b.

Groundwater levels are around 0.2 m lower beneath the Northern Area compared to those beneath the Central Area. This is consistent with the general understanding of groundwater behaviour with the groundwater recharge mound being less developed beneath the northern part of the peninsula due to the reduced width resulting in lower overall recharge to the groundwater system and closer proximity to the discharge zones to the lake and ocean.

7.2 Single Well Tests

Rising head slug tests were undertaken in the monitoring wells drilled as part of this investigation to assist in characterisation of the hydraulic conductivity of the sand strata. The data obtained were analysed with the AQUIFERTEST software package using the Hvorslev and the Bouwer and Rice methods.

Single well test analyses are provided in *Appendix C* and are summarised in *Table 7.2.*

Table 7.2 Results of Single Well Tests (Hydraulic Conductivity in m/d)

Bore	Hvorslev	Bouwer & Rice (with R_{eff})	Bouwer & Rice (no R_{eff})
C1	10	**25.2**	5.31
C2	9.95	17	3.6
PPK1b	9.5	**27.1**	5.7
N1	14.8	**43.5**	9.2
N2	8.7	30.8	6.5
N3	15.9	**48.7**	10.3
N4	35	**56.2**	11.8
BH10	13.1	30.8	6.5

Notes: bold values are for wells with screens extending above the water table for which Reff should be applied (see below).

From the table above it is clear that analysis using the Hvorslev method produced reasonably consistent results. Results using the Bouwer and Rice method are heavily dependent upon whether or not the effective well radius (R_{eff}) is applied. This takes account of the relatively high porosity of the gravel pack around the well compared to the surrounding formation and is normally applied where the water level in the well is below the top of the screen for some or all of the tests (those values shown in bold in *Table 7.2*). The gravel pack extends above the top of the screen in all monitoring wells and R_{eff} should probably be applied to all results.

Single well tests influence a very small volume of aquifer and are particularly sensitive to localised effects resulting from natural variation in the strata or from drilling.

The nature of the formation required use of hollow flighted augers for monitoring well installation and this results in a large difference between the size of the drilled hole (200 mm diameter) and that of the piezometer (50 mm diameter). Formation collapse during drilling may increase the effective borehole radius further. Because of this difference in drill hole and piezometer size, results are particularly sensitive to R_{eff} and hydraulic conductivity results derived using the Bower and Rice method with R_{eff} are generally considered to be the most reliable values.

7.3 Pump Testing

Pump testing of NPW (72 hours) and CPW (48 hours) was undertaken successfully. The response of the bores during pumping and recovery is summarised in *Table 7.3*.

Table 7.3 Summary of Water Level Responses to Pump Testing

Bore	Distance m	Initial WL mbTOC	Min. WL mbTOC	Rec. WL mbTOC	Max DD m	Final DD m
CPW	0	7.455	9.705	7.515	2.25	0.06
C1	31	7.207	7.41	7.268	0.203	0.061
C2	22	6.64	6.89	6.7	0.25	0.06
PPK1b	23.9	7.106	7.354	7.17	0.248	0.064
NPW	0	6.315	8.034	6.502	1.719	0.187
N2	14.5	6.411	6.648	6.432	0.237	0.021
N3	28.9	6.376	6.495	6.395	0.119	0.019

Notes. Distance refers to distance from the pumping well. WL is water level; DD is drawdown; mbTOC is metres below top of casing)

For the Central Area, the maximum drawdown in CPW was 2.25 m while that in the monitoring wells was 0.25 in MW C2. Residual drawdown at the end of the 24 hour recovery period was around 0.06 m in all wells.

For the Northern Area, the maximum drawdown in NPW was 1.72 m while that in the monitoring wells was 0.24 in MW N2. Residual drawdown at the end of the 24 hour recovery period was 0.19 m in NPW and around 0.02 m in the monitoring wells. Manual readings collected for MW N1 and MW N4 did not indicate any response to pump testing.

Pump test data were analysed with the AQUIFERTEST software using the Theis recovery method for recovery data in all production wells and the Cooper-Jacob and Theis methods for drawdown data in all monitoring wells. Pump test analyses are provided in *Appendix C* and summarised in *Table 7.4*.

Table 7.4 Summary of Results of Pump Test Analysis

Well	Theis Recovery		Cooper-Jacob		Theis		Average	Average
	T (m^2/d)	k (m/d)	T (m^2/d)	k (m/d)	T (m^2/d)	k (m/d)	T (m^2/d)	k (m/d)
CPW	795	59.7					795	59.7
C1	790	59.3	591	44.4	641	52.5	674	52.1
C2	633	47.5	571	42.9	547	41	584	43.8
PPK1b	868	65.2	527	39.5	509	38.2	635	47.6
Average all wells (Central Area)							**672**	**51**
Geometric mean all wells (Central Area)							**667**	**50**
NPW	1,130	61					1130	61
N2	1,040	56.2	681	36.8	600	32.3	774	41.8
N3	902	48.7	659	35.6	969	52.4	843	45.6
Average all wells (Northern Area)							**972**	**49.4**
Geometric mean all wells (Northern Area)							**965**	**49**

Results of pump testing generally showed consistent results across each area. Transmissivity is approximately 35% higher in the Northern Area, when compared to the Central Area. This is a result of the increase in aquifer thickness due to the deepening of the clay layer to the north and east. Hydraulic conductivity is estimated to be almost identical beneath the two areas.

Results were generally consistent between the different analytical methods indicating a good level of confidence in the results. All monitoring well results displayed delayed yield, with plots of drawdown against log time (e.g. Cooper-Jacob analysis) showing a steepening of the drawdown response during the pump test. This delayed yield reflects the time taken for water stored within the saturated aquifer to drain under the influence of gravity as the water table declines and is a typical response during pump testing of unconfined aquifers. The later part of the response provides the best estimate of aquifer characteristics.

The shallower monitoring wells (PPK1b and N3) showed slightly similar values of transmissivity and hydraulic conductivity compared to the deeper wells showing that any reduction in vertical hydraulic conductivity compared to that for horizontal flow is very small and does not suggest the presence of any significant barriers to vertical groundwater flow such as minor clay layers.

Analysis of pump test results using the Theis method allows estimation of the storage coefficient (specific yield) of the aquifer. Results of this analysis are summarised in *Table 7.5*.

Table 7.5 Estimated Specific Yield Values

Well	Specific Yield (%)
C1	14
C2	20
PPK1b	19
Average	**18**
N2	13
N3	25
Average	**19**

The overall average specific yield value for all wells is 18%, typical for an unconfined aquifer in strata of the type encountered. Estimated values of specific yield are very similar between the Central Area and the Northern Area.

7.4 Comparison of Single Well Test and Pumping Test Results

Results of high-rate (5 L/s) pump testing generally provide significantly higher values of hydraulic conductivity than those resulting from single well tests. Those from the pump tests are more reliable because the test produces greater stresses and influences a much greater volume of the aquifer. Single well tests are also more sensitive to localised effects including variations in strata, disturbance caused by drilling, effective well radius etc.

Values obtained from pump testing and single well tests are provided in *Table 7.6* for comparison.

Table 7.6 Comparison of Hydraulic Conductivity Values

Bore	Single Well Test Hvorslev m/d	Single Well Test B&W (R_{eff}) m/d	Pump Test m/d	Factor Hvorslev	Factor (B&W, R_{eff})
CPW			59.7		
C1	10.0	25.2	52.1	5.2	2.1
C2	10.0	17.0	43.8	4.4	2.6
PPK1b	9.5	27.1	43.0	4.5	1.6
Average	9.8	23.1	49.7	5.1	2.1
NPW			61.0		
N1	14.8	43.5			
N2	8.7	30.8	50.9	5.9	1.7
N3	15.9	48.7	45.6	2.9	0.9
N4	35.0	56.2			
Average	18.6	44.8	52.5	2.8	1.2
Overall Average				3.9	1.7

Comparison of results in *Table 7.6* suggests that hydraulic conductivity results from single well tests should be multiplied by a factor of around 1.2 (Bouwer & Rice using effective bore radius) to 3.9 (Hvorslev) to obtain values representative of aquifer behaviour over a large scale. Care is required, however, as this difference may vary depending on local aquifer conditions. This difference is a phenomenon known as "upscaling" and arises as a result of the heterogeneity of the aquifer material and the scale represented by the various forms of hydraulic testing.

7.5 Water Level Monitoring

Results of continual water level monitoring in MW C2 show some evidence of a minor tidal variation of up to 2 cm between 10 pm on 27th July and 4 pm on 28th July. MW C1 shows a rise of only 6 mm over this period. Both show a relatively sharp rise of around 1 cm around 7 am on 28th July which may reflect a response to localised rainfall although the monitoring period was generally dry with only 0.2 mm of rainfall recorded to 9 am on 28th July. The smaller tidal response in MW C1 reflects its location further from the ocean.

MW N3 shows evidence of a minor tidal variation of up to 2 cm between 9 pm on 28th July and 5 am on 29th July. This is followed by a sharp rise of c.1 cm which is interpreted as a response to rainfall with 12 mm falling in the 24 hours to 9 am on 29th July.

Overall the results of continual water level monitoring indicate that tidal variations have little effect on groundwater levels in the monitoring wells.

7.6 Water Quality Sampling

Results of groundwater quality sampling are presented as *Table 7.7* at the end of this report and laboratory reports are provided in *Appendix D*. These show the following:

- pH is slightly alkaline reflecting the presence of shelly material in the sand strata. Groundwater is generally under slightly oxidising conditions although a strong hydrogen sulphide odour was noted during the early stage of the CPW pump test suggesting reducing conditions in some areas and/or at depth;

- EC varies from 6.4 mS/cm (MW N1) to 37.4 mS/cm (NPW). In general shallow wells are expected to show fresh to brackish water quality as they intercept the upper fresh water lens created by rainfall recharge while the deeper wells partly or wholly intercept the underlying groundwater of higher salinity resulting from saline intrusion. Salinity is generally higher beneath the northern area perhaps because the narrow width of the peninsula limits the development of a recharge mound;

- Major ion chemistry shows sodium and chloride to be the dominant ions, with sulphate, calcium, magnesium and potassium also present;

- Nutrient levels are generally low with inorganic nitrogen present mostly as nitrate with typical values of around 0.3 mg/L and a maximum value of 1.2 mg/L in the northern area. Orthophosphate levels are also low. Some nutrient levels exceed the guideline values for environmental stressors (ANZECC, 2000) however these levels are considered to be largely natural. Parts of the dune system have been affected by bushfires or controlled burns in the last few years and these may give rise to a pulse of recharge water with elevated nutrient concentrations, particularly of nitrate;

- Concentrations of dissolved metals are generally low with the exception of arsenic and zinc which exceed the guideline values for toxicants in all samples. Copper, nickel and cobalt are slightly elevated at times with some values exceeding guidelines. Given the setting of the site the presence of these dissolved metals is considered to be natural;

- Concentrations of dissolved iron are low while those for manganese are slightly elevated;

- Indicators of pathogenic bacteria were only recorded in MW N1. This may reflect minor contamination from faecal matter from wild animals or dogs.

Drinking water guidelines for arsenic are 10 µg/L (World Health Organisation) and 7 µg/L (ANZECC, 2000) and are exceeded in all samples.

7.7 Inspections

Detailed walkover inspections of the study area were undertaken and surface features that may indicate groundwater discharge noted. This included the following areas:

- The northern end of the power line easement through the dunes where surface water runoff from nearby roads will result in increased recharge;

- The lake shoreline where access was available (note: the shoreline within the boundary of Merimbula Airport could not be inspected;

- The culverts and associated drainage line crossing Arthur Kaine Drive south of the airport.

Inspection of the northern end of the power line easement during rain confirmed that a substantial amount of rainfall runoff from the surrounding roads discharges to a hollow in the sands which will act as a localised area of very high recharge.

Inspection of the lake shoreline did not reveal any unusual patterns of groundwater discharge.

The culverts and associated drainage line crossing Arthur Kaine Drive carry surface runoff from the eastern side beneath the road. The culverts comprise two concrete pipes with internal diameters of approximately 700 mm and these discharge to a small surface water channel presumed to discharge to Merimbula Lake. A wooden footbridge crosses the channel immediately west of the western side of the culverts. A survey was arranged by Council to confirm reference elevations at this location and allow water levels to be measured relative to AHD.

The reference elevation of the eastern side rail of the footbridge is 1.36 mAHD and the bed level of the channel at this point is 0.438 mAHD. The minimum culvert invert level on the western side of Arthur Kaine Drive is 0.5 mAHD. The site was inspected and the water level measured by IGGC on 11th August 2010 and was 0.55 m below the reference point, equivalent to 0.81 mAHD. Approximately 21 mm of rain had fallen in the 48 hours preceding. The water level was also measured by Council on 21st December 2010 with a water level of 0.78 mAHD. Approximately 4.2 mm of rain had fallen in the 48 hours preceding.

This surface water feature may act as a control on local groundwater levels during dry weather (i.e. as a drain) but may also produce localised increased recharge to the underlying aquifer during high rainfall periods. The channel becomes indistinct west of the footbridge and collected water is expected to dissipate into the local groundwater system.

8. Data Collation and Review

All available data relating to groundwater conditions beneath the dunes at Merimbula and effluent generation from the STP have been collated to assist with numerical modelling and assessment, including investigation data from past and existing studies. This section collates and reviews these data to provide the best understanding of conditions currently available.

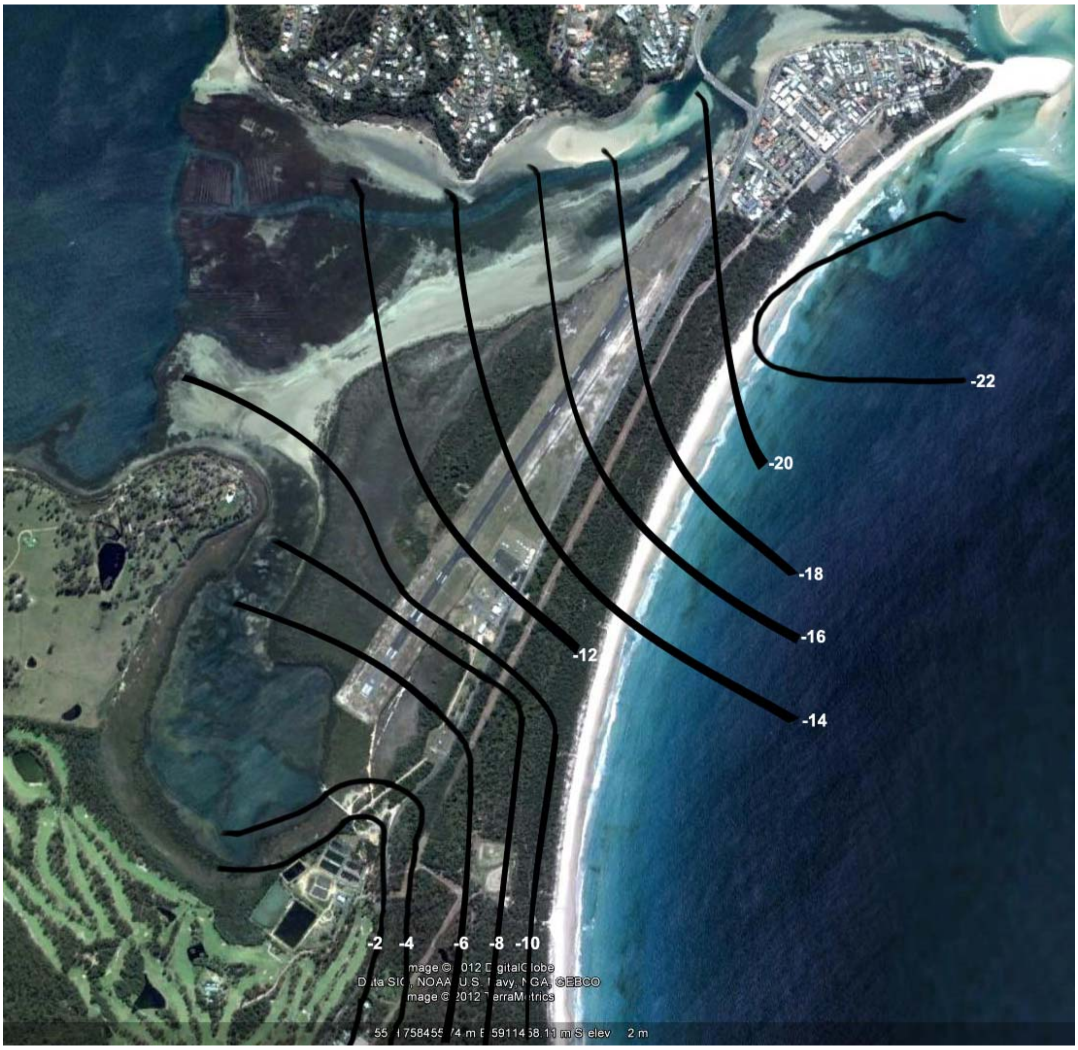
8.1 Aquifer Geometry

The basal profile of the upper transmissive (dune and beach sand) aquifer was well established during early investigations (MMA, 1987). A small amount of additional information was obtained during investigation of the deep aquifer (PPK, 2004a) and from the deeper bores drilled as part of the current investigation. Pump test results for the northern area also assist with understanding.

The basal profile of the upper aquifer is well proven except in the northern part of the study area where drilling did not encounter the underlying clay layer at the maximum drilled depth of 20.5 m (-14.6 mAHD). This compares to the established basal level of -12.77 mAHD beneath the central area. Results of pump testing show an increase in transmissivity of around 45% between the central and northern areas. This may be due in small part to a slight increase in grain size but suggests an increase in saturated thickness of close to 45%, suggesting a basal elevation of around -19 mAHD. This is consistent with the basal profile observed and is considered a reasonable interpretation.

The interpreted basal profile of the upper transmissive sand aquifer is shown in *Figure 8.1*.

Figure 8.1: Interpreted Base of Shallow Aquifer



The basal profile of the deep Tertiary alluvial sequence was interpreted to be at a depth of around 30 metres across most of the area, based on previous geophysical investigations, increasing to 50 m or more in three localised areas (PPK, 2004b). The pilot bore drilled c.120 m north-west of BH10 penetrated layered alluvial strata extending to the full drilled depth of 61.6 m (approx. –58 mAHD). Substantial sand layers were encountered at around 35 m depth and below 50 m depth.

8.2 Aquifer Hydraulic Conductivity and Transmissivity

Hydraulic conductivity is an intrinsic property of a geological material that provides an indication of its ability to transmit water and is generally measured in metres per day (note: this is not a direct indication of the velocity of groundwater through the material). Transmissivity is a measure of the amount of water that can be transmitted horizontally through a unit width of an aquifer and is equivalent to the hydraulic conductivity multiplied by the saturated thickness. Transmissivity is generally measured in units of metres per day per metre (m^2/day).

A large amount of data are available for hydraulic conductivity and/or aquifer transmissivity of the upper aquifer from the current investigation and those undertaken previously as follows:

- MM, 1987. Short-term pump test results from 5 bores and a total of 25 permeameter tests from 8 bores;
- PPK, 2002. Short-term pump test results from 5 bores; slug test results from 9 bores and 3 infiltration test results;
- Current Study. A 72-hour pump test in the Central area with 3 observation wells; a 24-hour pump test in the Northern Area with 2 observation wells; slug test results from 8 wells.

In addition, limited information is available on the interbedded clay and sand strata underlying the upper aquifer based on a single short-term pump test at PB1.

Hydraulic conductivity values for the upper aquifer obtained during the various studies are collated in *Table 8.1* presented at the end of this report. These results show a large degree of variation depending on method of testing and location and sometimes between bores in the same vicinity using the same method.

A suggested value of large scale hydraulic conductivity has been proposed for each area. This value is based on all available data but also takes account of the higher hydraulic conductivity obtained during long-duration pump testing compared to other methods. Consideration is also given to calibration values of hydraulic conductivity obtained during previous modelling studies. Suggested values are summarised in *Table 8.2*.

Table 8.2: Summary of Suggested Hydraulic Conductivity Values

Area	Hydraulic Conductivity (metres per day)
South-west Hill-slope and Wetlands	3 to 8
Existing Exfiltration Ponds	25 to 30
Southern and Western Area – General	30
Southern Foredunes	40
Central and Northern Peninsula	50 to 55

Overall, hydraulic conductivity is considered to be of the order of 30 m/d over the general study area, increasing to 40 to 50 m/d to the north and east beneath the foredunes. Lower values are expected close to the limit of the upper sand aquifer at the south-western hill-slope reflecting the increased presence of finer-grained material, and a gradational increase away from this area is likely.

Transmissivity is given by the hydraulic conductivity of strata multiplied by the saturated aquifer thickness and therefore varies with aquifer base profile and water table elevation as well as hydraulic conductivity.

Testing of the pilot bore drilled into the deep, confined aquifer indicated a transmissivity of around 50 m^2/day for the strata intersected. This is equivalent to a hydraulic conductivity of around 4 m/d in the deep, coarse sand sequences located c.35 m below surface and deeper (PPK, 2004b). Hydraulic conductivity is expected to be much lower in the more clay-rich strata and vertical hydraulic conductivity is expected to be very low with limited inter-connection between the shallow sands and the deep aquifer.

8.3 Specific Yield

The specific yield of an unconfined aquifer is a measure of the volume of water that will drain under gravity and is expressed as a number between 0 and 1 or as a percentage.

Results of pump test analyses indicate values of specific yield ranging from 13% to 25% with an average value of 18%. Assumptions applied during previous work are as follows:

- 15% (MM, 1987);
- 8% to 12% (PPK, 2004a);
- 17% to 22%, calibrated value of 17% applied (IGGC, 2006);

Published values of specific yield give respective minimum, average and maximum values of 10%, 21% and 28% for fine sand and of 20%, 26% and 32% for coarse sand (Fetter, 2001). The measured value and the range of 17% to 22% used previously are both consistent with published data.

The average value from pump testing of 18% is considered to be the best estimate for the local strata and is the suggested starting value for numerical modelling.

8.4 Groundwater Level Variations

8.4.1 Water Table Geometry and Flow Regime

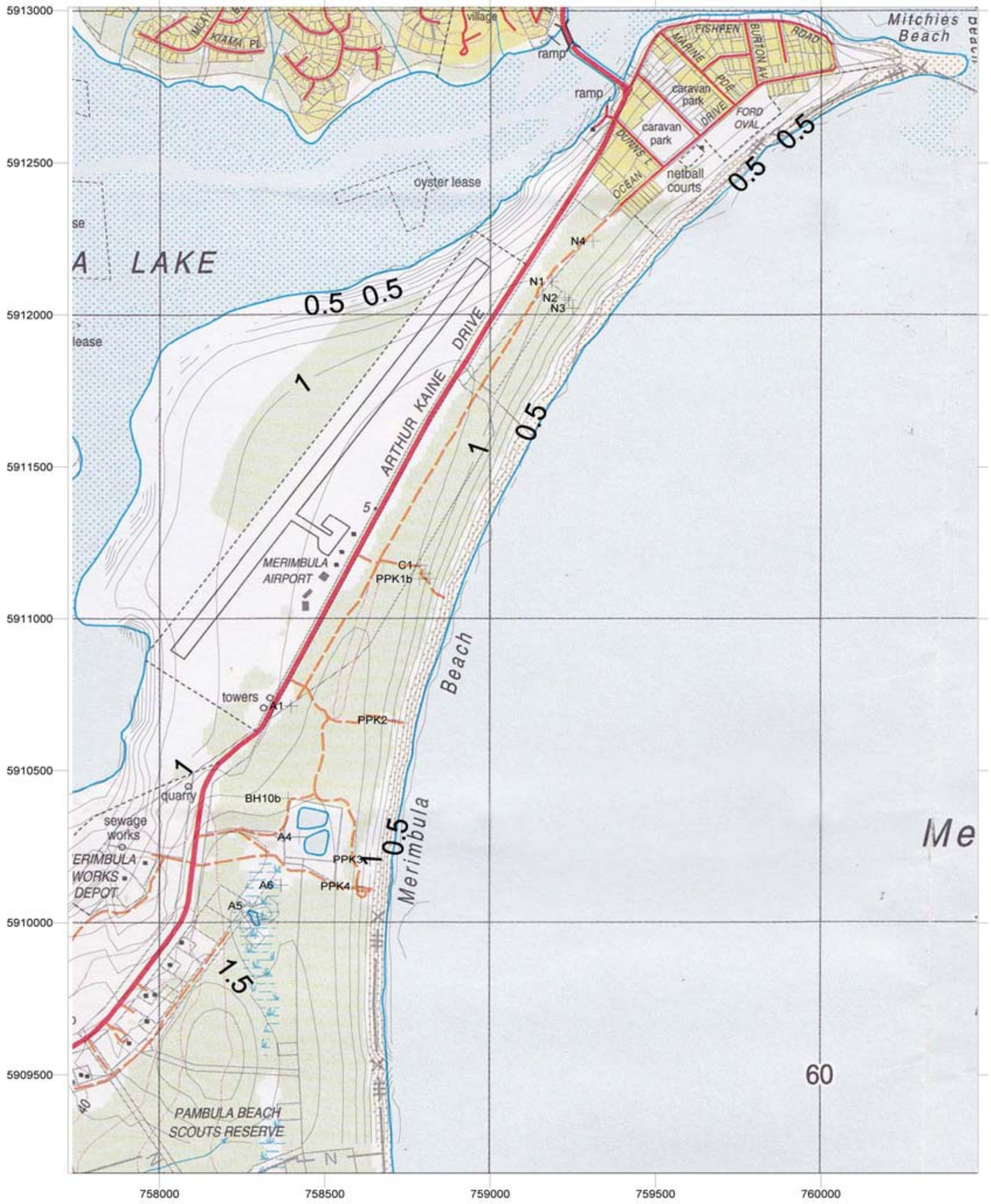
Natural Conditions

The geometry and flow regime of the shallow aquifer varies slightly depending on rainfall conditions. Groundwater contours have been produced for typical conditions and high rainfall conditions and are presented as *Figure 8.2* and *Figure 8.3*.

Figure 8.2: Natural Groundwater Contours, Typical Conditions

Figure 8.3 shows the increased development of the groundwater recharge mound under high rainfall conditions.

Figure 8.3: Natural Groundwater Contours, High Rainfall Conditions



A pilot bore was drilled and constructed around 120 m north-west of BH10 (see *Figure 4.1*) into the deep, confined aquifer as part of an earlier study (PPK, 2004a). This bore penetrated layered alluvial strata extending to the full drilled depth of 61.6 m (approx. –58 mAHD). The majority of these strata were clays and silts but coarse sand units were encountered below 35 m depth with a total thickness of 8.5 m of the overall thickness of 54 m investigated. Groundwater within the transmissive coarse sand units is confined (i.e. held under pressure) by the overlying clays and the groundwater pressure surface in these confined aquifers is slightly above local ground surface at around 2 mAHD, and is above the local water table in the shallow aquifer and the local ground surface. (IGGC, 2006). An upward hydraulic gradient is expected across the study area under most conditions although the degree of connection is likely to be low and the contribution from the deep aquifer to the shallow groundwater system is expected to be negligible because of the depth of the transmissive sand layers of the deep aquifer.

8.4.2 Temporal Variations

Groundwater level responses over time and responses to rainfall and other factors vary across the study area. A good data set of groundwater levels is available for the period 2001 to 2010 and the response in each monitoring well is discussed briefly to assist understanding of groundwater behaviour.

Groundwater level hydrographs are provided as *Figure 8.6a* to *Figure 8.6l* in the relevant sections below. A residual rainfall graph (*Figure 8.4*) and a histogram showing monthly discharge volumes to the existing exfiltration ponds (*Figure 8.5*) are also provided to assist with interpretation. Monthly residual rainfall is the difference between actual rainfall and the long term average for that month. The 12-month moving average residual rainfall can provide a useful indication of likely groundwater level trends in shallow groundwater systems such as the upper aquifer of the Merimbula dunal sands.

Figure 8.4: Residual Rainfall Graph

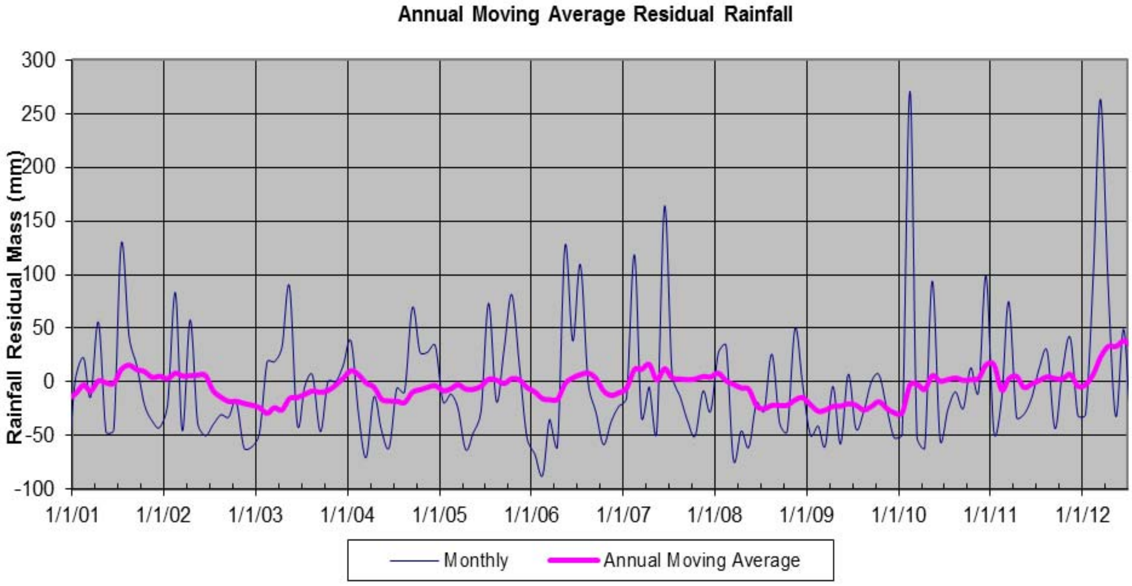
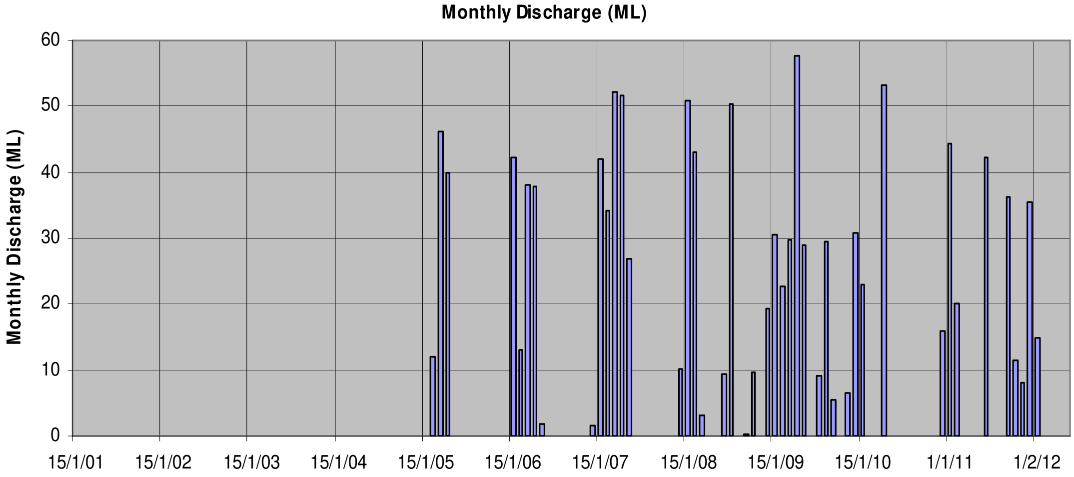


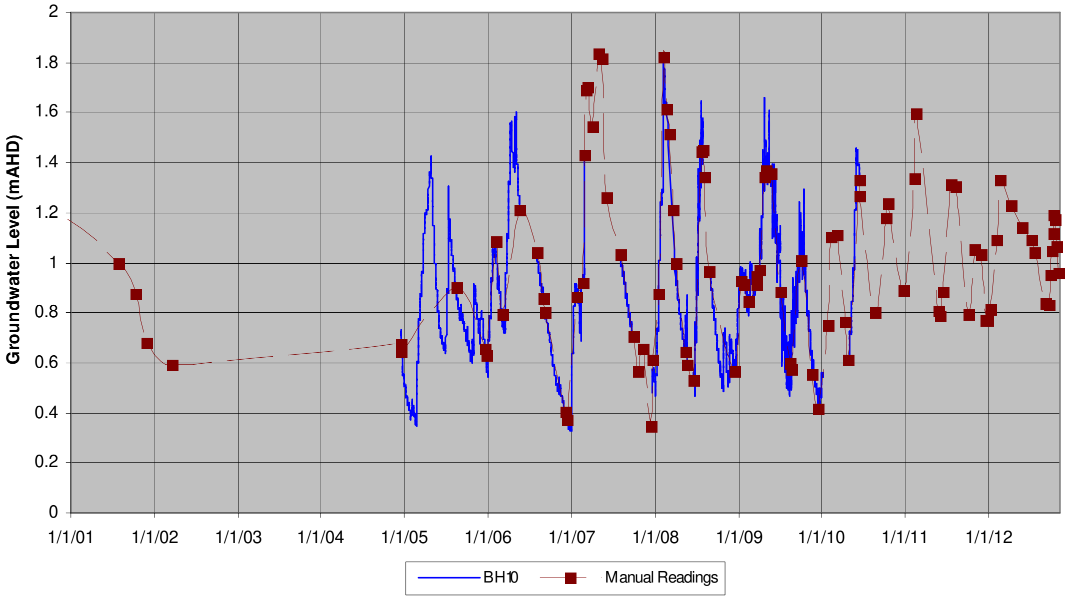
Figure 8.5: Monthly Discharge to Existing Exfiltration Ponds



Wetland and Pond Area Bores

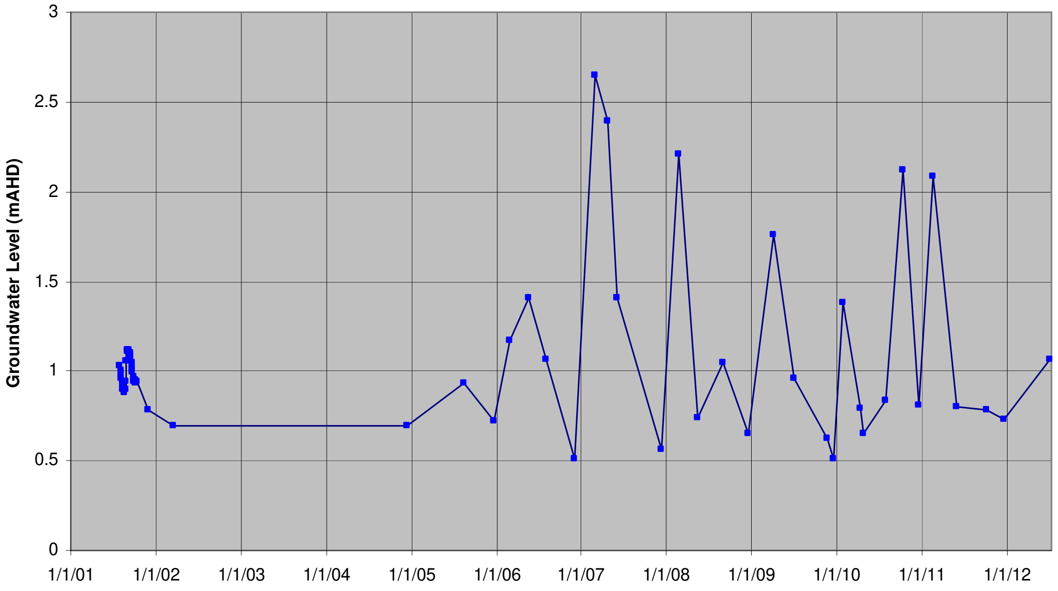
The wells in the area of the wetlands and exfiltration ponds are BH10, A4, A5, A6 and A1 as shown in *Figure 4.1*. Hydrographs are provided as *Figure 8.6a* to *Figure 8.6e*.

Figure 8.6a: Groundwater Hydrograph – BH10



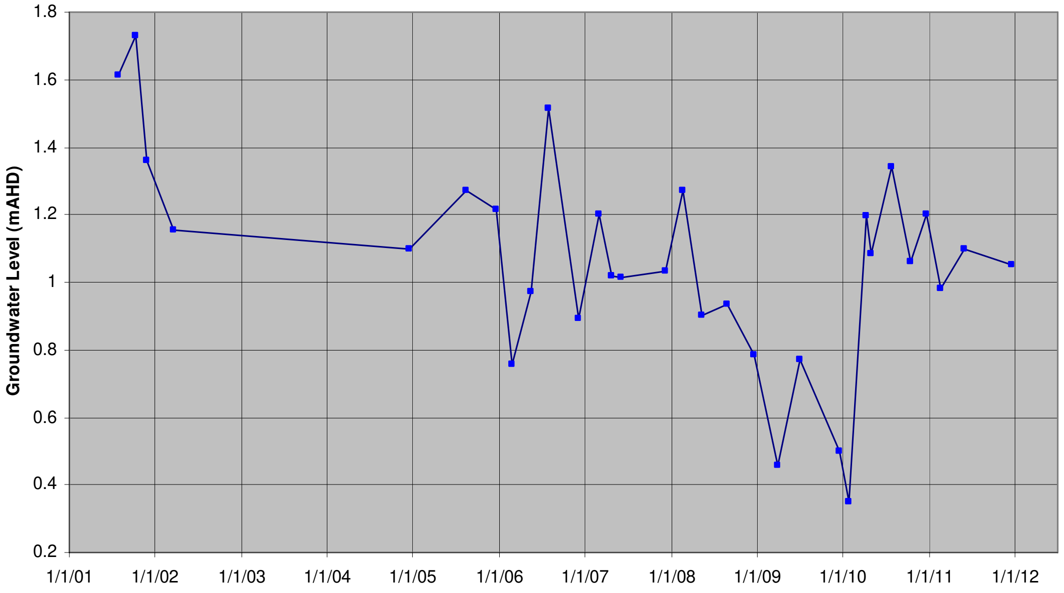
BH10 is strongly responsive to discharge to the ponds as would be expected given their close proximity. Groundwater levels increase steeply when discharge occurs with a maximum observed rise of 1.47 m and recession is also rapid. Limited data are available for prolonged periods with no discharge to the ponds but natural water levels have been measured in the range 0.677 mAHD (15/12/04) to 0.767 mAHD (c.3/12/86, MM, 1987). The minimum groundwater level recorded is 0.344 mAHD.

Figure 8.6b: Groundwater Hydrograph – A4



A4 shows the strongest response to pond discharge as it is located immediately adjacent to the ponds. The maximum rise observed is 2.56 m although only manual measurements are available. Natural groundwater levels have been measured at 0.691 mAHD (19/3/02) and the minimum recorded groundwater level is 0.506 mAHD.

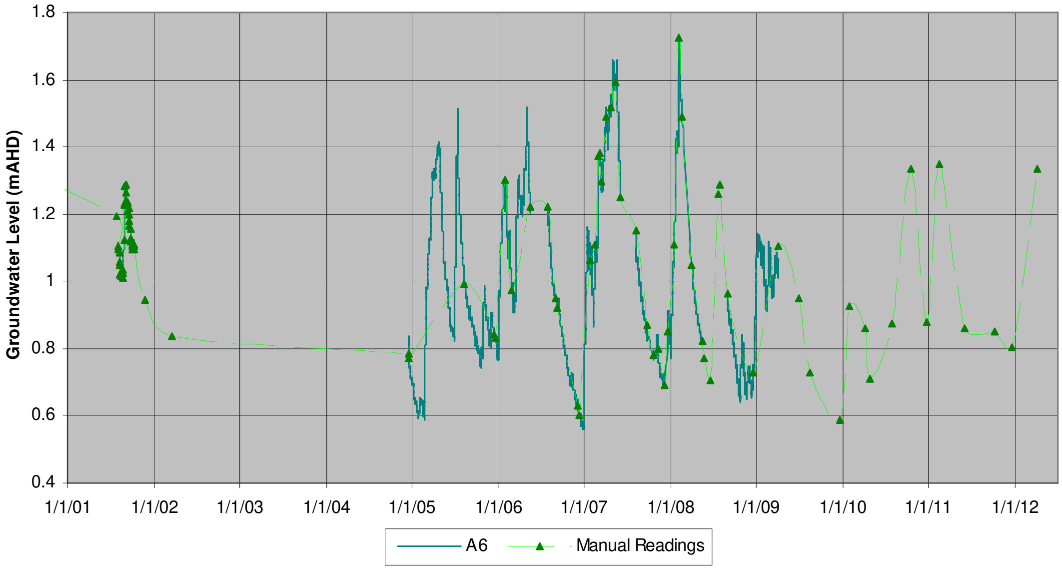
Figure 8.6c: Groundwater Hydrograph – A5



A5 shows a strong rainfall response with steep rises in groundwater levels observed in May 2006 (0.75 m) and April 2010 (1 m) following periods of high rainfall. Groundwater levels declined during a period of below average rainfall between early 2008 and early 2010 despite effluent discharge to the ponds occurring and the minimum level of 0.35 mAHD measured on 28/1/10 is the lowest on record. A5 is located close to wetlands which include areas of natural ponds. Rainfall recharge, evaporation and evapo-transpiration are all expected to be higher than typical across this area resulting in direct response to rainfall but also in reduced groundwater levels after sustained periods of low rainfall. The presence of the ponds may provide additional storage which will reduce the rate of groundwater level recession after wet weather but direct evaporation may also mean that the ponds act as a groundwater sink during dry periods.

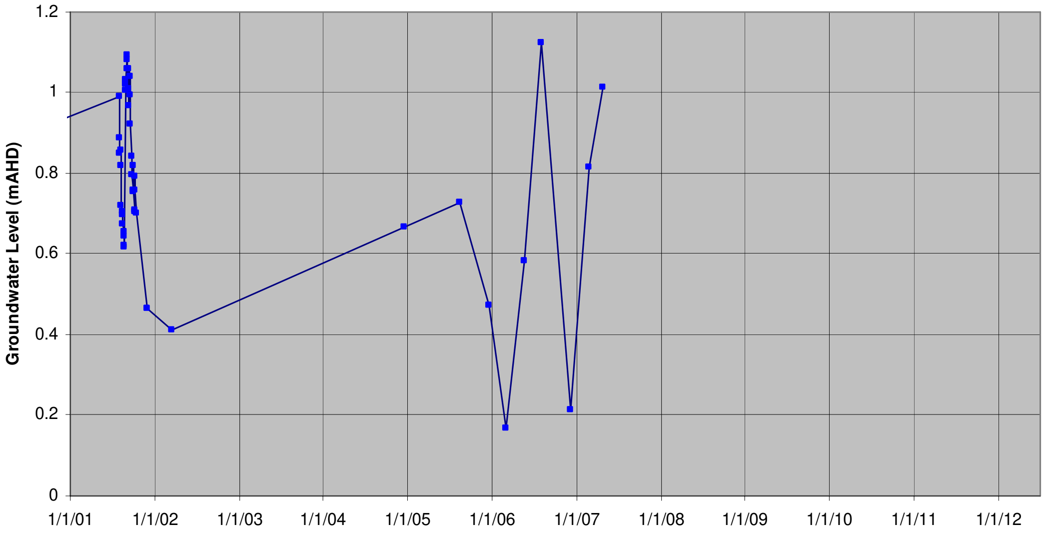
Recorded groundwater levels range from 0.35 mAHD (28/1/10) to 1.73 mAHD (11/10/01) with an average over the period of 1.20 mAHD.

Figure 8.6d: Groundwater Hydrograph – A6



A6 shows a reasonably strong response to pond discharge and a more subdued rainfall response. Groundwater level increase and recession are both rapid, with a maximum observed rise of 1.04 m (February 2008). Natural groundwater levels are expected to be around 0.8 mAHD and the minimum recorded groundwater level during the period is 0.565 mAHD.

Figure 8.6e: Groundwater Hydrograph – A1



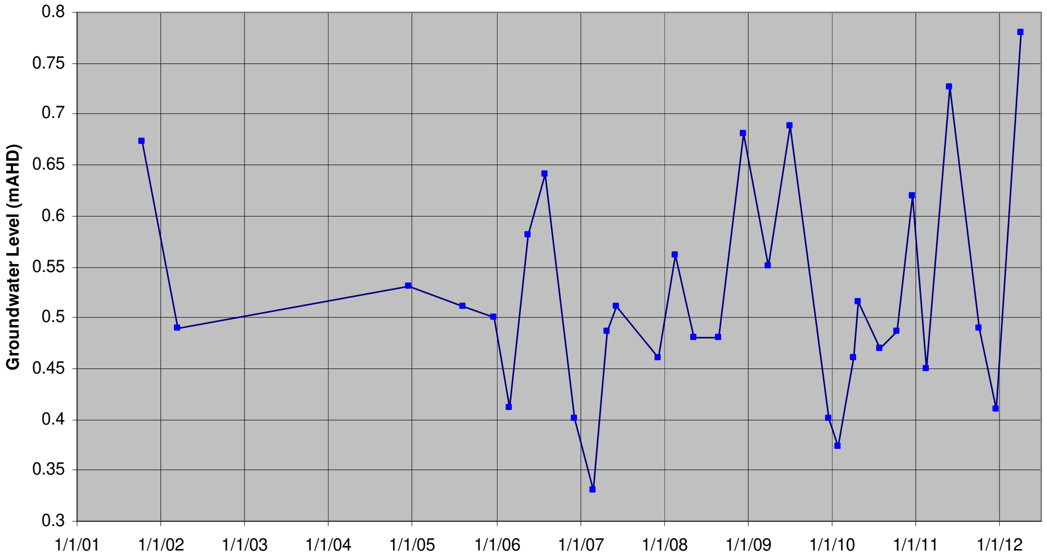
A1 was destroyed in 2007 and no data are available after this time. Continual water level monitoring was undertaken between August and October 2001 (PPK, 2002), during which time no exfiltration took place. Groundwater levels during this period showed a very strong response to rainfall with estimated recharge range from around 40% to over 100% of rainfall. A groundwater level rise of 0.4 m was recorded between 25/8/01 and 27/8/01 in response to 62 mm of rainfall falling over 2 days. The bore is located in a low-lying area and runoff and ponding may both contribute to the high observed recharge rates.

Periods of groundwater level rise coincide with high rainfall and exfiltration pond discharges, while periods of decline coincide with low rainfall and limited or no exfiltration. The minimum groundwater level recorded at A1 is 0.169 mAHD (28/2/06) and the average level is 0.72 mAHD.

Foredune Bores

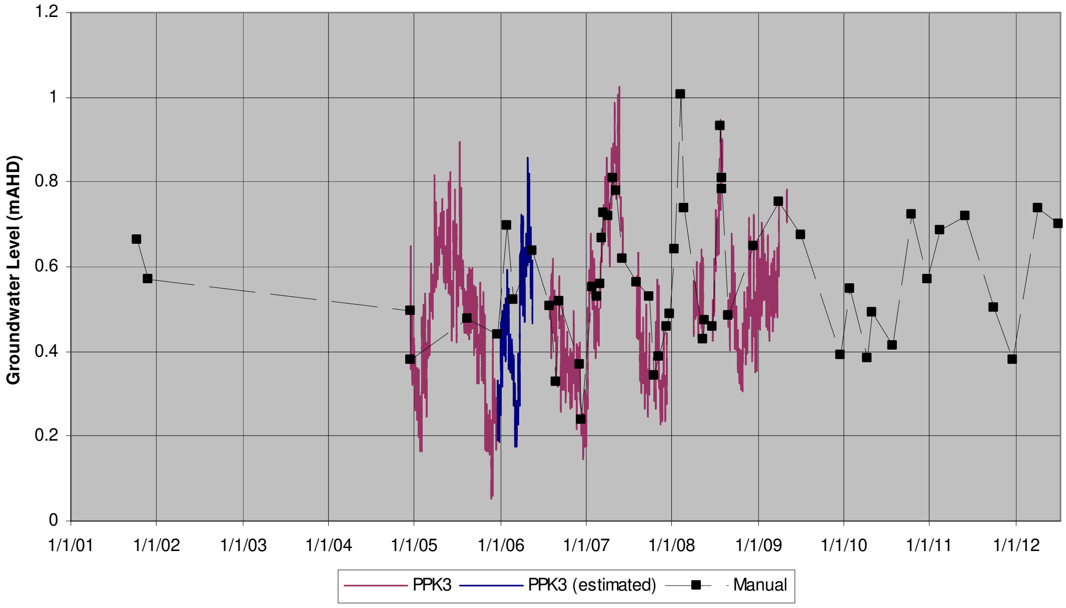
The foredune bores are PPK2, PPK3 and PPK4 as shown in *Figure 4.1*. Hydrographs are provided as *Figure 8.6f* to *Figure 8.6h*.

Figure 8.6f: Groundwater Hydrograph – PPK2



PPK2 is located close to the beach midway between the ponds and the Central Area. Groundwater levels fluctuate from 0.331 mAHD (28/2/07) to 0.78 mAHD (4/4/12) with and average of 0.52 mAHD. There is some evidence of a response to pond discharges with relatively high groundwater levels recorded in mid 2009 during a period of relatively low rainfall. However, it should also be noted that the foredune bores may be influenced by changes in the effective boundary head at the coast due to fluctuations in tides or wave action.

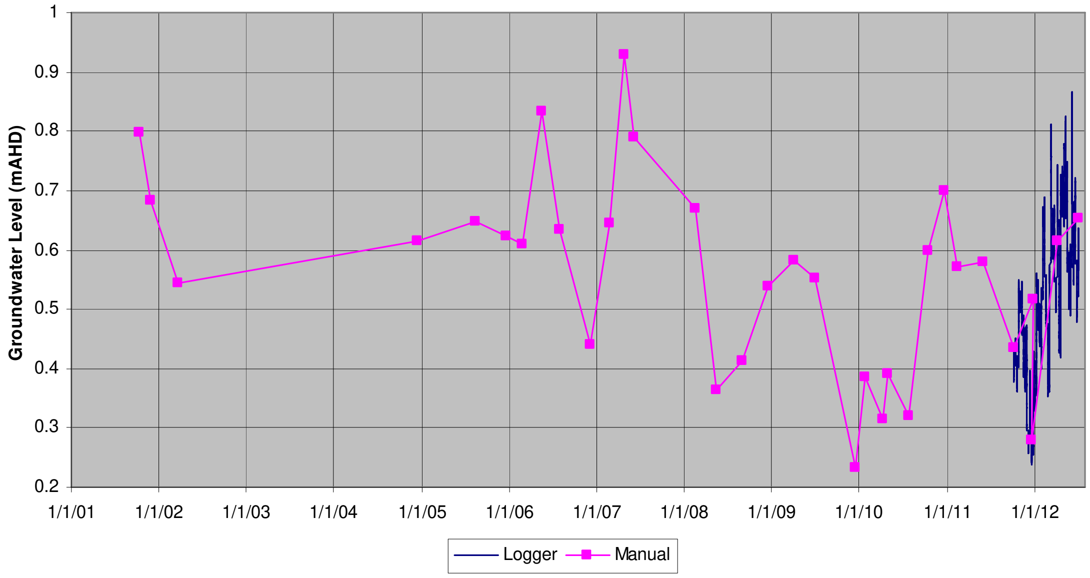
Figure 8.6g: Groundwater Hydrograph – PPK3



PPK3 is located close to the beach, approximately 140 m east of the exfiltration ponds. The groundwater level data include logger data and manual readings. A section of the logger data is based on an estimated datum after the well was damaged between monitoring events and may therefore be slightly inaccurate. Groundwater levels typically exhibit short-term fluctuations of up to 0.1 m and these are considered to be a tidal response. Variations in tides and wave action may also have an influence on longer time scales.

PPK3 shows a response to pond discharges, with a groundwater rise of 0.57 m recorded in early 2008 during period of relatively low rainfall. Natural groundwater levels are expected to be around 0.5 mAHD but will fluctuate based on ocean conditions as well as rainfall.

Figure 8.6h: Groundwater Hydrograph – PPK4

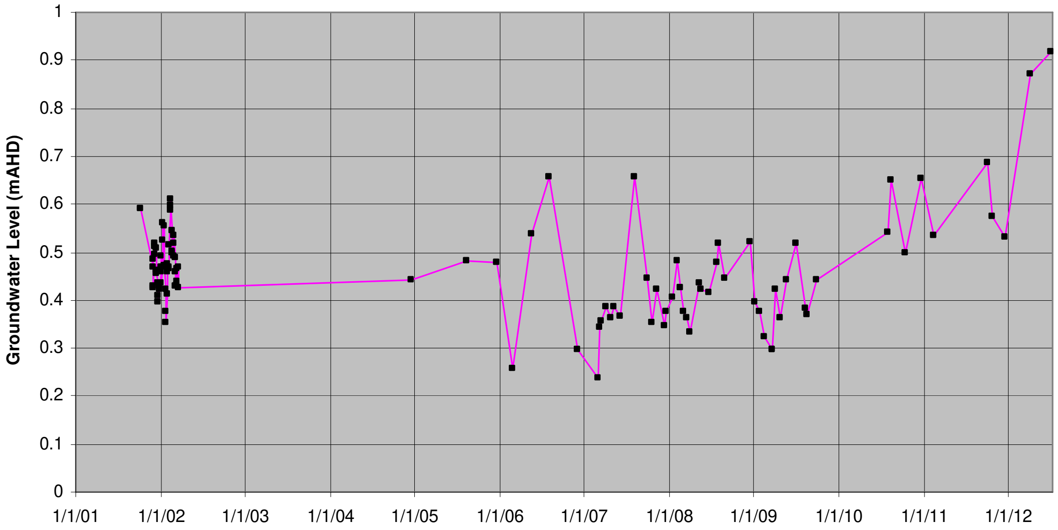


PPK4 is located approximately 140 m south-east of the ponds. Groundwater levels vary from 0.234 mAHD (17/12/09) to 0.929 (26/4/07). PPK4 shows some response to pond discharges, with a rise of 0.168 m recorded between late 2008 and early 2009 during a period of generally low rainfall. Actual rises are expected to be greater but data are limited except for the period late 2011 to mid 2012 during which high rainfall conditions prevailed.

Central Area

The Central Area bores include CPW, C1, C2 and PPK1. All except PPK1 were installed in August 2010 and groundwater level data period for these bores is therefore limited. The bores are located close together and data from PPK1 is considered to be representative of the area. Hydrographs are provided as *Figure 8.6i* to *Figure 8.6k*.

Figure 8.6i: Groundwater Hydrograph – PPK1



Groundwater levels in PPK1 vary from 0.237 (28/2/07) to 0.917 (5/7/12). Groundwater levels generally reflect rainfall, with little evidence of an influence from pond discharges. The average groundwater level during the period was 0.46 mAHD.

Figure 8.6j: Groundwater Hydrograph – C1

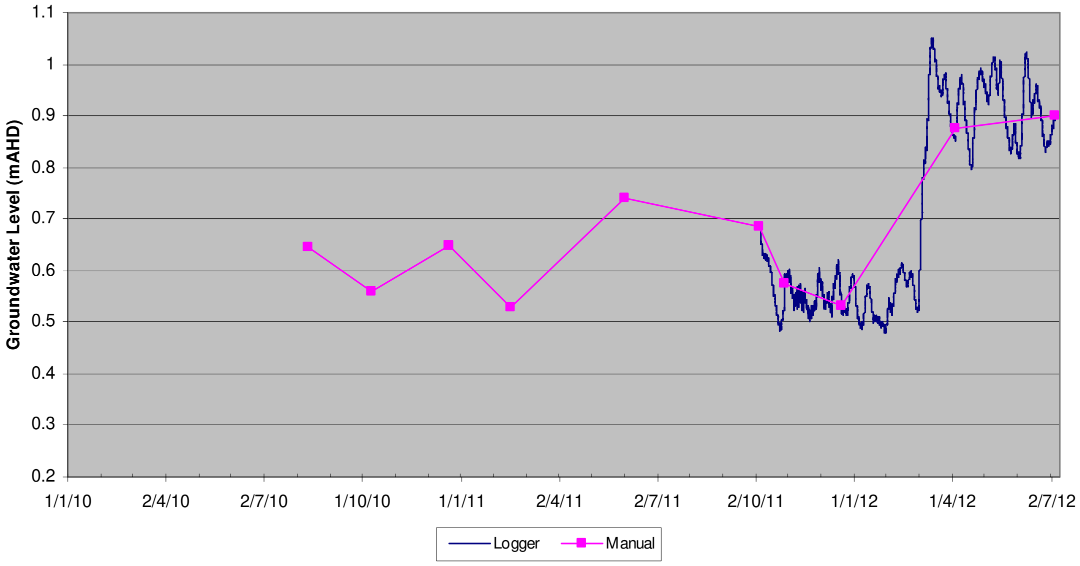
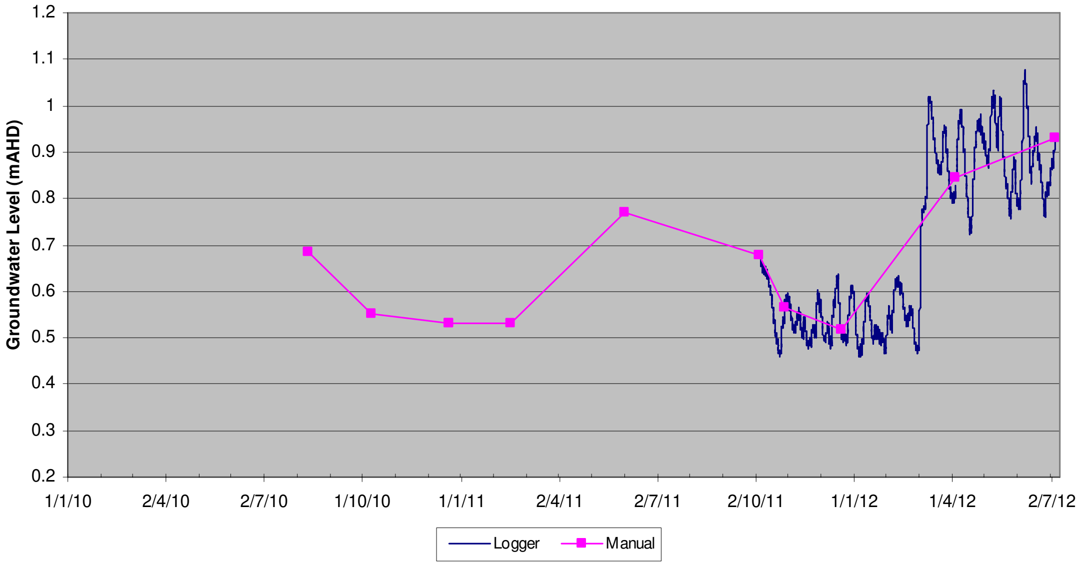


Figure 8.6k: Groundwater Hydrograph – C2



The data available from C1 and C2 show groundwater levels consistent with those of PPK1. The logger data show a steep rise in groundwater levels of 0.5 m between the 1/3/12 and 15/3/12 coinciding with a period of exceptionally high rainfall with 344 mm recorded between 29/2/12 and 9/3/12. Manual data from PPK1 also show a strong rise due to this rainfall event. Groundwater levels are similar in the four Central Area bores.

Northern Area

The Northern Area bores include N1, N2, N3, N4 and NPW. Groundwater levels showed a similar decline to those in the Central Area between August and October 2010. Groundwater levels measured in October 2010 are considered to be close to average (based on rainfall and long-term hydrographs for PPK1 and other bores) and vary from 0.32 to 0.39 mAHD. Hydrographs are provided as *Figure 8.6l* to *Figure 8.6m*.

Figure 8.6l: Groundwater Hydrograph – N1

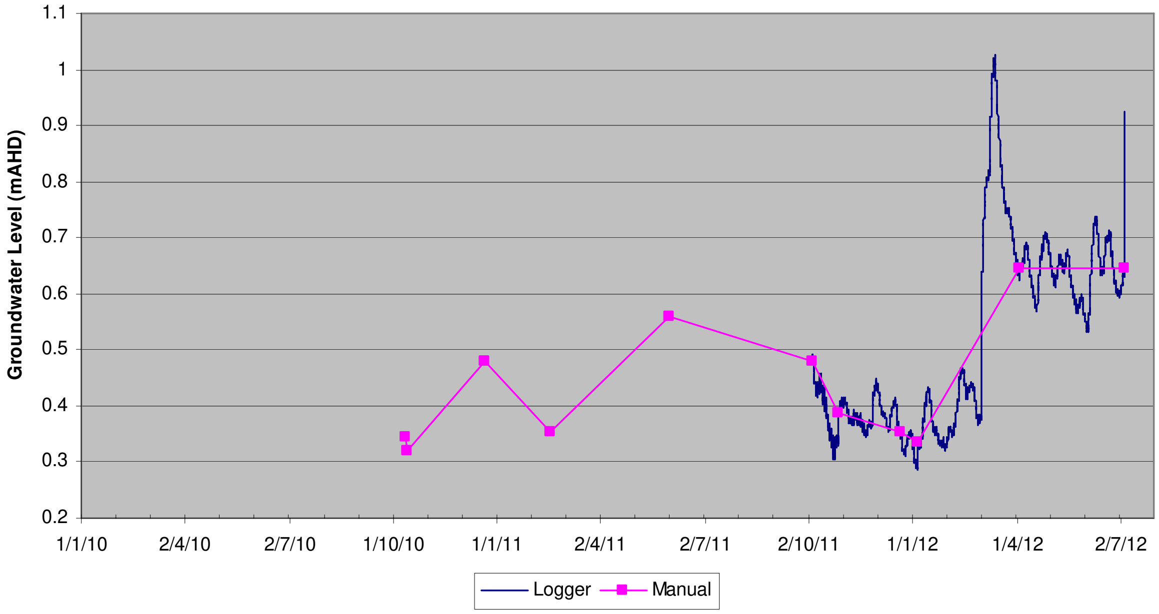
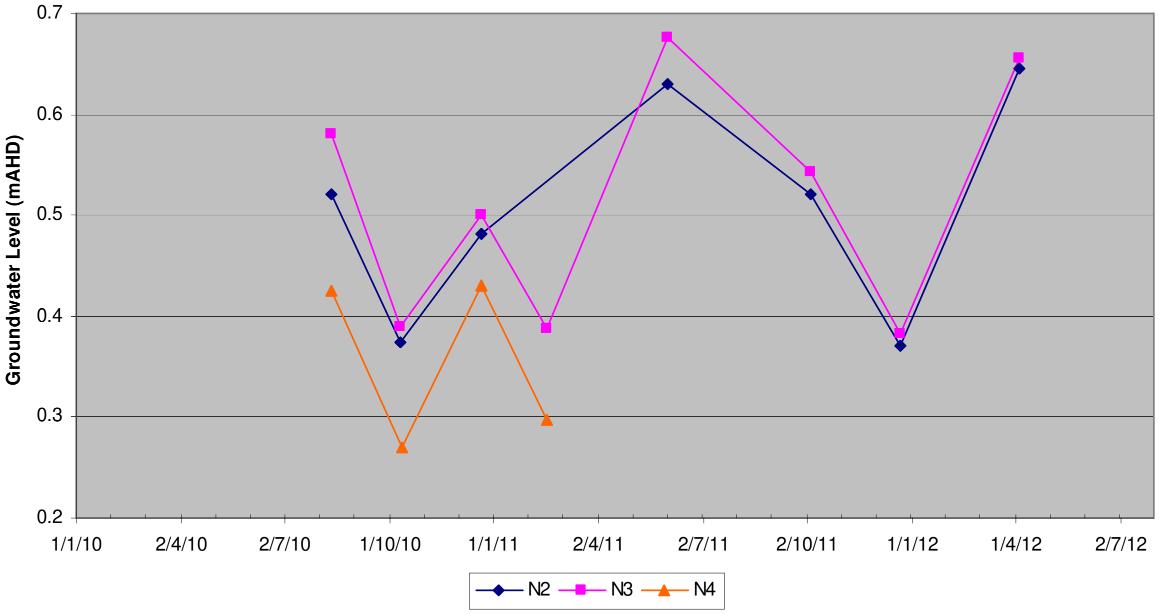


Figure 8.6m: Groundwater Hydrograph – N2, N3 & N4



Groundwater levels in the Northern Area bores are generally very similar. N1, N2 and N3 are arrayed approximately perpendicular to the coast in a north-west to south-easterly arrangement. Groundwater levels increase slightly from N1 to N3 towards the ocean, perhaps reflecting net flow via the groundwater system from the ocean to the lake due to the higher effective ocean head because of the wave set-up factor.

8.5 Groundwater Chemistry

8.5.1 Background Water Quality

Under undisturbed conditions groundwater quality beneath the study area would be expected to be characterised by the following:

- Fresh, neutral pH or slightly alkaline water under slightly oxidising conditions in the upper part of the dune sands, representing the recharge mound produced by rainfall recharge. Water quality would be expected to be good, with low nutrient levels (inorganic nitrogen present largely as nitrate) and perhaps slightly elevated levels of some dissolved metals such as iron, manganese and arsenic. Acidic conditions can develop in dune sand aquifers where calcium carbonate is absent or sparse;

- Brackish and saline water beneath the freshwater lens, becoming increasingly saline and possibly anoxic with depth. Saline groundwater is expected to extend beneath the entire dune system where the dunes form a peninsula between Merimbula Lake and the ocean but will only be present close to the beach beneath the southern part of the study area;

- Fresh, neutral to acidic water under slightly oxidising to reducing conditions in the areas characterised by wetlands, with possible acidic and anoxic conditions resulting from the shallow water table. Nutrient levels are expected to be low (inorganic nitrogen present largely as ammonia) but dissolved metals may be elevated. Groundwater migrating from these areas towards the frontal dune system would be expected to take on the characteristics of the upper dune sands groundwater, with neutral to slightly alkaline pH and more oxidising conditions developing.

8.5.2 Existing Water Quality and Impacts

Regular monitoring of groundwater quality in the bores located in the area of the existing ponds has been undertaken since December 2004. The bores included in this routine monitoring network comprise A6, BH10 and PPK3, with PPK1 added in 2008 to provide a control point and PPK4 added in 2011 for comparison with PPK3. *Ad hoc* monitoring of PPK2 and A4 has also been undertaken from time to time. Regular monitoring of bores C1, C2, N1 and N3 installed as part of this investigation has also been undertaken since October 2010.

The existing exfiltration ponds are located at the inland limit of the frontal dune system. The area east and north of the ponds is characterised by frontal dunes with relatively high surface elevations and deep groundwater levels. South and west of the ponds is characterised by areas of low elevation between the hill to the south-west (formed by relatively impermeable Tertiary-age sediments) and the frontal dune system. The low elevation has led to shallow water tables and development of wetlands, particularly to the south where wetlands are extensive and include small areas of open water.

A summary of existing average groundwater quality for key analytes in the area of the existing exfiltration ponds is presented as *Table 8.3*.

Table 8.3: Summary of Existing Groundwater Quality, Existing Exfiltration Pond Area (Mean Values)

Analyte	**BH10** Closest/W	**A6** South	**PPK3** East	**PPK1** Control	**A4** Ponds	**PPK4** SE	**PPK2** NE
No. Samples (post Dec 2004)	22	20	26	13	3	9	5
EC (mS/cm)	0.79	0.21	0.85	1.33	0.94	0.81	1.48
pH	6.75	5.03	7.97	7.68	6.865	7.88	7.71
Redox Potential (mV)	-55	64	58	109	-107	-108	86
Chloride (mg/L)	145	47	136	253	129	123	312
Total Alkalinity (mg/L)	131	3	170	253	280	180	254
Ammonia (mg/L)	**1.13**	0.12	**0.55**	0.03	0.29	**1.15**	0.03
Oxidised Nitrogen (mg/L)	0.01	0.01	0.36	0.40	0.01	0.08	0.59
Total Inorganic Nitrogen (mg/L)	**1.14**	0.13	**0.91**	0.43	0.29	**1.22**	0.62
Orthophosphate (mg/L)	**0.3**	0.03	**3.84**	0.07	0.06	**0.44**	0.06
Bacterial indicators	occ.minor	occ.minor	occ high	none	none	none	none

For comparison, STP effluent typically has slightly alkaline pH, EC of 0.7 mS/cm, ammonia of 0.5 mg/L, oxidised nitrogen of 2 mg/L (although mean oxidised nitrogen levels are currently higher) and orthophosphate of 8.5 mg/L.

Times series water quality graphs are provided for key bores as *Figure 8.7a* to *Figure 8.7f* (in *Appendix A)*.

Results for each monitoring bore are as follows:

- BH10. Very slightly acidic pH, EC close to that of effluent and slightly reducing conditions. Elevated ammonia and slightly elevated orthophosphate probably indicate minor impacts from exfiltration. The level of ammonia is higher than that in the effluent. Time series data do not indicate any significant trends other than increasing sulphate concentrations which may reflect the higher average sulphate concentration in effluent (40 mg/L) or indicate oxidation of sulphide minerals during to denitrification. Given the proximity of this bore to the ponds and the strong observed water level response to loading, results appear to indicate the release of ammonia during anaerobic decomposition of organic matter in the effluent or aquifer material and significant attenuation of orthophosphate and denitrification of oxidised inorganic nitrogen;

- A6. Low salinity with acidic and slightly oxidising to slightly reducing conditions considered typical of the wetland area of the sand aquifer. Some inorganic nitrogen is present as ammonia: this may reflect a very minor impact from exfiltration or may be natural. Phosphorus levels are consistently low. Time series data do not indicate any trends other than a slight increase in salinity during a period of low rainfall in 2009. Water quality at A6 is considered to reflect natural conditions with no appreciable impact from exfiltration, despite a strong water level response. This may indicate effective attenuation mechanisms including nitrogen reduction due to denitrification and perhaps ammonia adsorption and orthophosphate removal;

- PPK3. Fresh to slightly brackish water, slightly alkaline pH and slightly reducing to oxidising conditions. Ammonia and oxidised nitrogen are both slightly elevated. Phosphorus is present at strongly elevated levels, mostly as the soluble form orthophosphate with the average concentration close to 50% of that of the effluent. Time series data show a strong, consistent increasing trend in phosphorus as orthophosphate, rising from 0.67 mg/L in December 2004 to a peak of 6.4 mg/L in January 2010, 75% of the effluent concentration. This peak occurred approximately one year after the period of greatest discharge to the exfiltration ponds.

  Oxidised nitrogen shows some indication of an initial rise then a decline to close to or less than December 2004 levels with some more elevated levels occurring after December 2010. Ammonia levels are somewhat variable with some indication of an increasing trend between December 2006 and June 2010. The graph of NO_x plus ammonia (total inorganic nitrogen or TIN) is also somewhat variable although effluent discharge to the existing ponds does appear to have resulted in slightly increased TIN concentrations in groundwater at PPK3. This increase is small: the average concentration is 0.91 mg/L, just 20% of the average effluent concentration of 4.4 mg/L during the period of discharge to the ponds. A single, unusually high concentration of 2.75 mg/L (i.e. slightly over 50% of the effluent concentration) was recorded in February 2011;.

  Groundwater in the area of PPK3 is clearly impacted by effluent disposal with peak orthophosphate levels around 75% of those in the effluent occurring over a period of less than five years since disposal of effluent to the ponds re-commenced and indicating limited attenuation of phosphate in the local groundwater system. Mean inorganic nitrogen concentrations in groundwater are less than 20% of those in effluent concentrations indicating considerable nitrate removal, probably by nitrification;

- PPK1. Slightly brackish, slightly alkaline pH, mildly oxidising conditions. Oxidised nitrogen appears slightly elevated (average 0.4 mg/L) as does orthophosphate on occasion (maximum 0.23 mg/L). This area is unlikely to have been impacted by effluent discharge and these results may be natural. Parts of the dune system have been affected by bushfires or controlled burns in the last few years and these may have given rise to pulses of recharge water with elevated nitrogen concentrations;

- A4 (three samples). Very slightly acidic pH, EC slightly higher than that of effluent and strongly reducing conditions. Slightly elevated ammonia appears to indicate a surprisingly minor impact from exfiltration given the proximity of the bore to the ponds. The acidic pH and highly reducing conditions may be enhancing attenuation of nutrients.;

- PPK4 (nine samples). Fresh to slightly brackish, alkaline pH and consistently reducing conditions. Elevated ammonia levels (up to 2.1 mg/L) were recorded during 2010 and 2011, probably in response to relatively high rates of exfiltration during 2009 and formation of ammonia during anaerobic composition of organic material (or reduction of nitrate to ammonia rather than N_2). This was followed by a decline after June 2011 continuing to date. Oxidised nitrogen is low reflecting the reducing conditions. These data suggest that use of the ponds causes some elevation of TIN in PPK4 with a recorded maximum concentration of 2.1 mg/L, close to 50% that of effluent. The mean TIN concentration is around 25% of that in effluent. Impacts lag one to two years behind peak exfiltration periods.

- Orthophosphate is low other than a minor rise from 2011 onwards with a peak level of 0.96 mg/L. This is 10% of the effluent concentration and indicates phosphorus removal from groundwater probably due to sorption or precipitation reactions. It should also be noted that PPK4 is located close to the ocean outfall (c.30 m) and discharge from the outfall may cause localised reversal of groundwater flow and thereby impact on local groundwater quality;

- PPK2 (five samples only). Slightly brackish, slightly alkaline, oxidising to slightly reducing conditions. Oxidised nitrogen appears slightly elevated (average 0.59 mg/L); this probably reflects background water quality as at PPK1.

Impacts on groundwater quality from the existing exfiltration ponds are present in PPK3 and PPK4. These comprise slightly elevated inorganic nitrogen levels in both bores with evidence of substantial attenuation, probably due to denitrification. Phosphorus impacts differ markedly between the two bores with PPK3 showing peak concentrations approaching those in effluent and limited evidence of attenuation while PPK4 shows only very minor impacts. This difference probably reflects the more strongly reducing conditions prevailing in groundwater in the area of PPK4.

A summary of existing average groundwater quality for key analytes for the central and northern study areas is provided in *Table 8.4*.

Table 8.4: Summary of Existing Groundwater Quality, Central and Northern Study Areas (Mean Values)

Analyte	PPK1	C1	C2	N1	N3
No. Samples	13	5	5	6	5
EC (mS/cm)	1.33	5.96	12.78	4.23	15.38
pH	7.68	7.83	7.72	7.57	7.56
Redox (mV)	109	43	52	-62	91
Chloride (mg/L)	253	1,790	3,940	1,163	4,820
Total Alkalinity (mg/L)	253	215	225	296	259
Ammonia (mg/L)	0.03	0.04	0.04	0.04	0.03
Oxidised Nitrogen (mg/L)	0.40	0.05	0.24	0.08	0.72
Orthophosphate (mg/L)	0.07	0.05	0.06	0.06	0.07
Bacterial indicators	none	none	none	occ.minor	none

Results for each monitoring bore are as follows:

- C1. Brackish, alkaline pH, slightly oxidising of slightly reducing conditions with low nutrient levels. The initial sample was collected shortly after pump testing of CPW and shows much higher salinity than later samples, probably indicating that pumping caused the saline interface to be drawn upwards. Salinity is higher than for PPK1 probably C1 is slightly deeper and therefore closer to the saline interface;

- C2. Brackish, alkaline pH, slightly oxidising conditions. Salinity is higher than for C1 or PPK1 probably because C2 is closer to the coast. Oxidised nitrogen appears to be slightly elevated (average 0.24 mg/L) but this is probably natural. Ammonia and orthophosphate are low;

- N1. Brackish, slightly alkaline pH and generally reducing conditions. Nutrient levels are low;

- N3. Brackish, slightly alkaline pH and slightly oxidising conditions. Salinity is higher than for N1 probably reflecting relative proximity to the coastline. Ammonia and orthophosphate are low but oxidised nitrogen appears to be slightly elevated, perhaps reflecting nutrient release by bushfires.

Results of monitoring indicate generally consistent groundwater quality beneath the frontal dunes with slightly alkaline pH, slightly oxidising to slightly reducing conditions and salinity varying with bore depth and proximity to the coast. Nutrient levels are generally low but oxidised nitrogen appears slightly elevated in some areas, probably due to bushfires or controlled burns.

Limited data on groundwater quality in the deep aquifer indicate brackish water with low pH (4.1) and reducing conditions. Analytical results (PPK, 2004b) show a sodium/magnesium chloride water type with high magnesium levels (137 mg/L). Magnesium levels in the upper aquifer are generally around 10 mg/L or less except in areas affected by saline intrusion where concentrations of up to 910 mg/L have been measured (NPW). The magnesium concentration in seawater is around 1,300 mg/L.

8.6 Ocean and Lake Water Level Data

Effective Ocean Water Levels

The mean ocean water level is 0 mAHD with a typical tidal range of up to 1.5 m. The effective ocean head is higher than the mean water level, principally because ocean processes result in net super-elevation of the water table in an unconfined aquifer discharging to the ocean (Turner *et al*, 1996). This super-elevation results from the effects of wave action (referred to as the wave set-up factor) and ocean tides because of a sloping beach face is able to "fill" with water through vertical infiltration more quickly than it can drain through horizontal seepage. The overall effect on the water table elevation at the land-ocean boundary will depend on a number of factors including beach morphology, local wave and tide conditions and on the nature of the aquifer. The effective coastal head will vary over time due to changes in tidal and wave action.

Examination of hydrographs for monitoring bores located close to the beach (PPK2, PPK3 and PPK4) indicates typical base groundwater level (i.e. with limited influence from high rainfall events or exfiltration) of 0.3 to 0.5 mAHD for PPK2 and 0.25 to 0.6 mAHD for PPK3 and PPK4. The greater range at PPK3 and PPK4 may be due to the presence of the channel in the beach created by discharge from the outfall. During periods without discharge this may allow groundwater discharge at a lower elevation and during discharge or high tides may allow tides to reach further up the beach than they would otherwise do.

Effective Lake Water Levels

Water levels in Merimbula Lake are monitored at two sites, Merimbula Jetty (in the lower estuary downstream of the road bridge) and in the north-western part of the inner estuary.

Water level data for Merimbula Lake for the monitoring station located in the north-west area of the lake have been obtained from NSW Department of Finance and Services for the entire period available, 30th May 1991 to 30th April 2011. Transient numerical modelling in this study uses a transient calibration period of 15th December 2004 to 21st December 2005 and a transient simulation period of 1st January 2007 to 30th June 2010.

Summary lake water level are also available for Merimbula Jetty located downstream of the road bridge (WorleyParsons, 2011).

Lake water levels for the relevant periods are summarised in *Table 8.5*.

Table 8.5: Summary of Lake Water Levels

Period	Mean (mAHD)	Minimum (mAHD)	Maximum (mAHD)	Range (m)
Merimbula Lake NW				
Full Record	0.0652	-0.33	1.09	1.42
Transient Cal. Period	0.091	-0.26	0.92	1.18
Transient Sim. Period	0.07	-0.33	0.94	1.27
Merimbula Jetty				
1991 to 2010	0.0068	-0.94	1.22	2.16

Water level variations in the inner estuary (Merimbula Lake NW) are attenuated compared to the outer estuary (Merimbula Jetty) and the ocean mainly due to higher low tides (WorleyParsons, 2011). This is likely to be due to incomplete ebb-tide emptying through the narrow channel beneath the road bridge which divides the inner and outer estuary. Lake water levels in the inner estuary will exert the greatest control on the water table elevation in the areas of interest.

Some super-elevation of groundwater levels at the land-lake boundary is expected. This will be due to tidal effects as the wave set-up factor will be very small.

On the basis of the lake water level data available, the lake shoreline hydraulic head for the inner estuary is considered to be around 0.1 mAHD and this is consistent with the interpretation of a hydraulic gradient in the shallow aquifer from the ocean to the lake. Effective water levels in the main water body of the inner estuary (i.e. away from the shoreline) will be closer to the average water level of 0.065 mAHD due to absence of super-elevation effects..

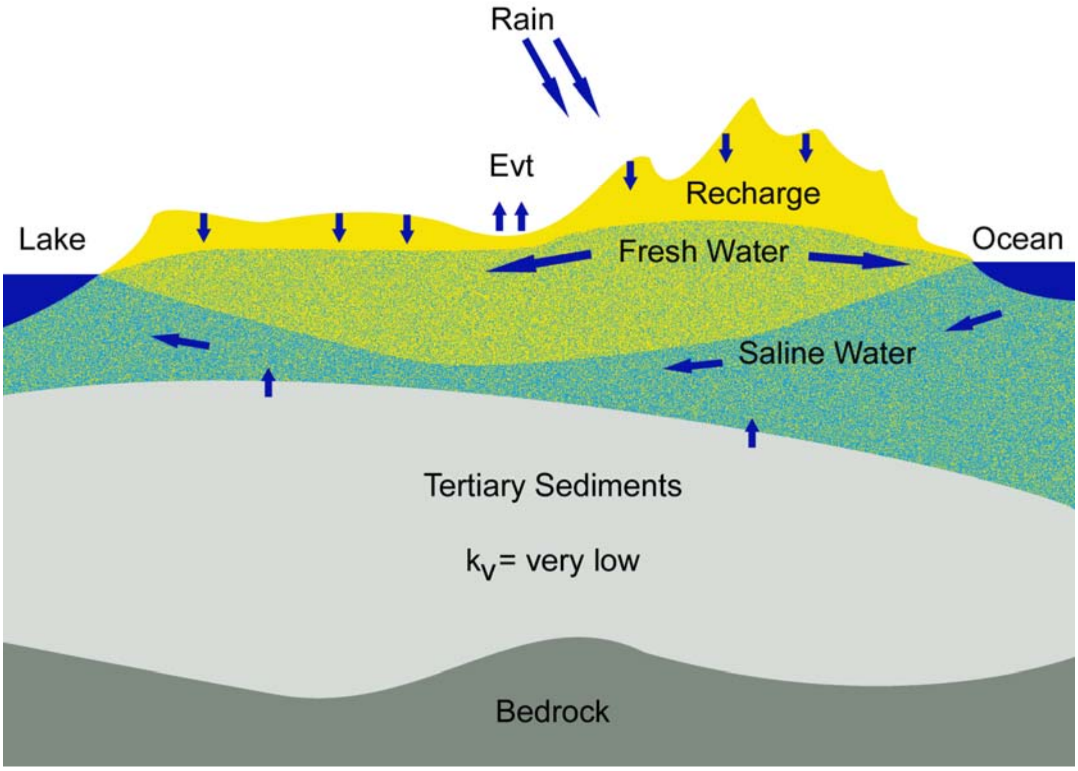
9. Conceptual Groundwater Model

Development of a conceptual model of the groundwater system assists with understanding of groundwater processes, including those associated with effluent disposal, and with construction of the numerical model.

The peninsula between Merimbula Lake and Merimbula Bay is underlain by a shallow, highly transmissive sand aquifer comprising dune and beach sands. The effective base of this aquifer comprises a persistent clay horizon which forms the upper part of a thick sequence of Tertiary-age alluvial deposits. The aquifer base deepens from south to north from around -8 mAHD beneath the existing ponds to around -19 mAHD beneath the northern area. The lateral limit of the upper aquifer is the hill in the southern part of the study area close to Merimbula STP.

Figure 9.1a shows the conceptual groundwater model of the shallow groundwater system beneath the main, central area of the peninsula.

Figure 9.1a: Conceptual Model of the Shallow Groundwater System, Central Area



The following summarises the inputs and outputs to the natural groundwater system:

INPUTS

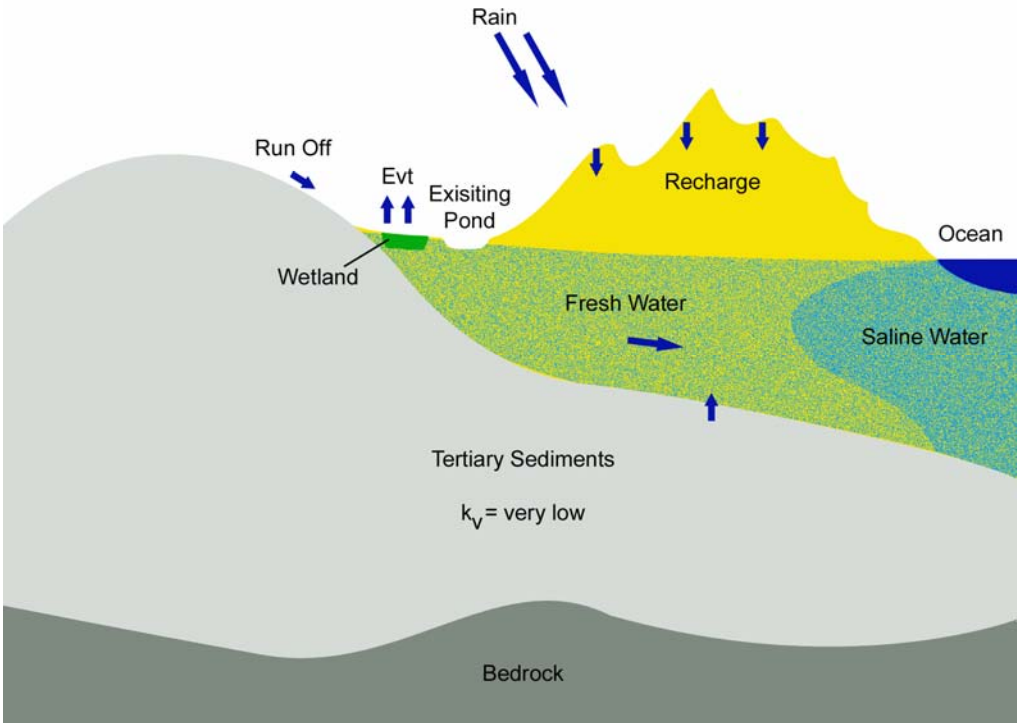
- Rainfall recharge (major input);
- Ingress of ocean waters and lake waters;
- Upward flow of groundwater from the underlying Tertiary sediments (negligible).

OUTPUTS

- Groundwater discharge to the ocean;
- Groundwater discharge to the lake;
- Evapo-transpiration in areas of shallow groundwater;
- Direct evaporation from areas of open water in the wetlands located south of the existing ponds;
- Surface discharge and possible overland flow from low-lying areas during periods of very high rainfall.

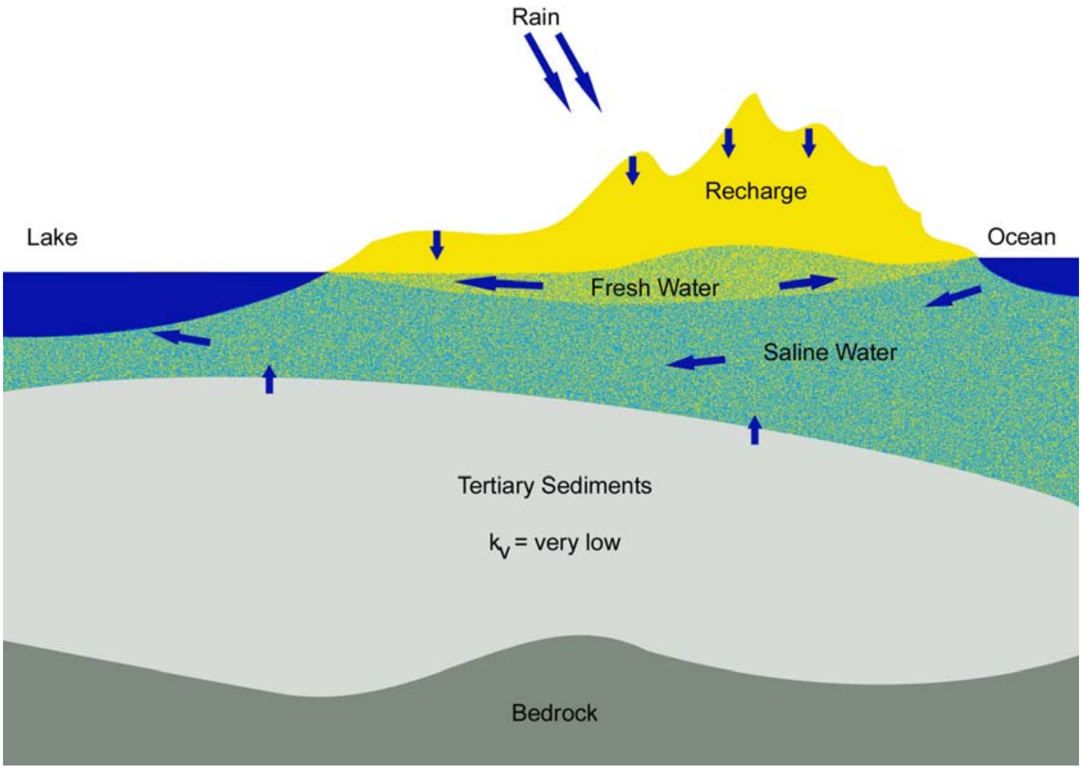
The groundwater flow regime varies across the study area. South of the existing ponds there is no direct connection to the lake and groundwater flows eastwards from the limit of the shallow aquifer in the west to the ocean. The conceptual groundwater model for this area is shown on *Figure 9.1b*.

Figure 9.1b: Conceptual Model of the Shallow Groundwater System, Southern Area



Beneath the main peninsula area there is a component of saline groundwater flow westwards from the ocean to the lake due to the higher effective hydraulic head of the ocean. A recharge mound of fresh groundwater is present on top of the deep saline groundwater due to rainfall recharge. This recharge mound forms a groundwater divide, from which groundwater flows both west to the lake and east to the ocean. Both of these Features are shown in *Figure 9.1a*. Development of the recharge mound will vary depending on rainfall conditions and will be greatest during sustained periods of high rainfall. The size of the groundwater mound and of the freshwater lens will generally decrease from south to north due to the narrowing of the peninsula reducing overall rainfall recharge and due to the effective increase in the hydraulic gradient from the ocean to the lake. The conceptual groundwater model for the northern area is shown in *Figure 9.1c*.

Figure 9.1c: Conceptual Model of the Shallow Groundwater System, Northern Area



The effect of effluent disposal will be to enhance the groundwater recharge mound and increase groundwater flow to the lake and particularly to the ocean.

10. Numerical Modelling

10.1 Model Description

The numerical groundwater model used during the previous study (IGGC, 2006) was used as the starting point for this study. An updated numerical groundwater model was developed using the latest version of the modelling software (VISUAL MODFLOW Pro 4.4.0.146) and incorporates more recent data obtained from the study area.

The study area for the current investigation and assessment extends further to the north than previous work, and the model was extended and both actual and interpolated aquifer base levels imported for the new area. Model boundaries were also extended to represent lake and ocean water levels and rainfall recharge.

Ground surface levels (2 m contours) were provided by BVSC and imported into the model. This provides ground surface levels of sufficient resolution to allow evapo-transpiration to be simulated and this was applied based on average monthly Areal Potential Evaporation (APE) as described in *Section 4.5*.

10.1.1 Layering

The model represents the upper aquifer only and as such represents a single layer. The underlying, persistent clay layer is treated as a no-flow boundary. The base of the upper aquifer deepens to the north and east and is represented in the model. The upper sand pinches out against the surface outcrop of the underlying clay in the area around the hill in the south-western part of the model domain.

10.1.2 Model Grid

The extended model domain covers an area of c.4 km (N-S) and 3 km (E-W). The model grid has been designed to provide suitable level of refinement in the area of the existing exfiltration ponds (for model calibration) and around the potential new exfiltration areas. Grid spacing varies from 50 m around the model edge to 5 m or smaller in the areas of interest. The grid size variation was smoothed to prevent variation by a factor of more than 2 from cell to cell as this is important in achieving model convergence and obtaining accurate results. The model grid was altered for the various simulations to provide greater refinement in the areas of interest and a courser grid in other areas to prevent excessively long model run times.

Areas of the model domain located outside of the model boundaries were made inactive. The active model is estimated to cover an area of around 2.7 square kilometres.

10.1.3 Boundary Conditions

The following boundary conditions are represented:

- No-flow boundaries set at the base of the upper aquifer and at the lateral limit around the south-west hill. A no-flow boundary is also applied at the southern end of the model parallel to the expected groundwater flow direction;

- Constant head boundaries are applied to represent the Pacific Ocean with an applied head of 0.4 mAHD to take account of superelevation due to wave set-up and tidal effects; and around the shoreline of Merimbula Lake with an applied head of 0.1 mAHD, slightly higher than the average water level in the inner estuary to reflect minor super-elevation due to tidal effects;

- Rainfall recharge was applied to the model on an initial basis of 32% of rainfall over most of the model area, 40% across the frontal dunes and 60% in the localised area around bore A1. A recharge factor of 500% was applied to a small area at the southern limit of the paved roads of the Fishpen area to represent road runoff that is directed to a depression in the dune sands;

- Evapo-transpiration is applied to the model based on average monthly Areal Potential Evaporation (APE) as described in *Section 4.5*. The extinction depth was set at 2.5 m, a value considered typical for well-vegetated sandy strata.

10.1.4 Initial Aquifer Parameters

Changes were made to the hydraulic conductivity applied to the model, with additional zones added and values changed from those used previously. In general higher values of hydraulic conductivity were applied based on the results of recent pump testing as described in *Section 8.2*.

10.2 Steady State Recalibration

During review of groundwater level data undertaken during this assessment, difficulty was found in identifying true average groundwater levels for many of the bores as much of the data were collected during periods affected by effluent discharge to the ponds. Groundwater levels for December 2004 were therefore selected for steady-state calibration. This date was prior to re-commencement of effluent exfiltration and 2004 was a year of close to average rainfall.

The model was run in steady state with the revised parameters and calibration data. The initial predicted head distribution was found to be unsatisfactory. Review of the rainfall data showed that while the overall yearly rainfall was close to average, the few months preceding the calibration date had been wet. An equivalent average annual rainfall of 1,075 mm was calculated to represent this period.

The model was run more times and minor adjustments made to the hydraulic conductivity and rainfall recharge for the various zones until a satisfactory hydraulic head distribution was obtained. The final steady-state model parameters are as follows:

- Recharge of 32% total rainfall in the main model area, 40% over the frontal zones and the exfiltration ponds and recharge of 50% rainfall applied to the area around A1.

Additional recharge zones were assigned to represent the open water area with the wetlands close to A5 (95%) and road run-off from the paved roads at the southern end of the Fishpen area (500%);

- Hydraulic conductivity values of 3 m/d (adjacent to hill), 8 m/d (transition zone), 25 m/d (2nd transition zone) and 30 m/d (main model area). The frontal dunes were assigned values transitioning from 40 m/d (PPK2 area) to 50 m/d (Northern Area) across two zones.

The model domain and hydraulic conductivity zones are shown in *Figure 10.1* and recharge zones are shown in *Figure 10.2*.

Figure 10.1: Numerical Model Domain and Hydraulic Conductivity Zones

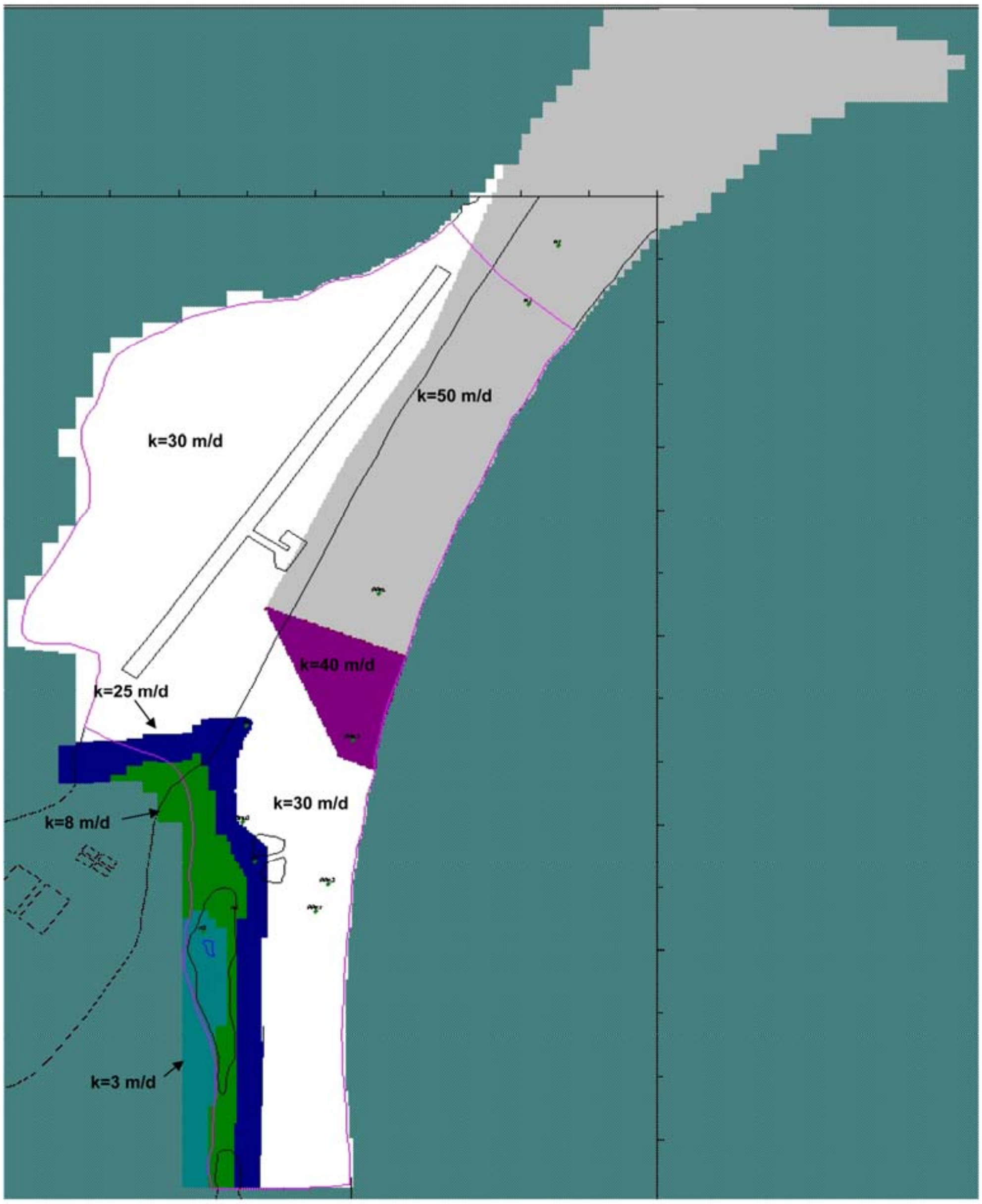
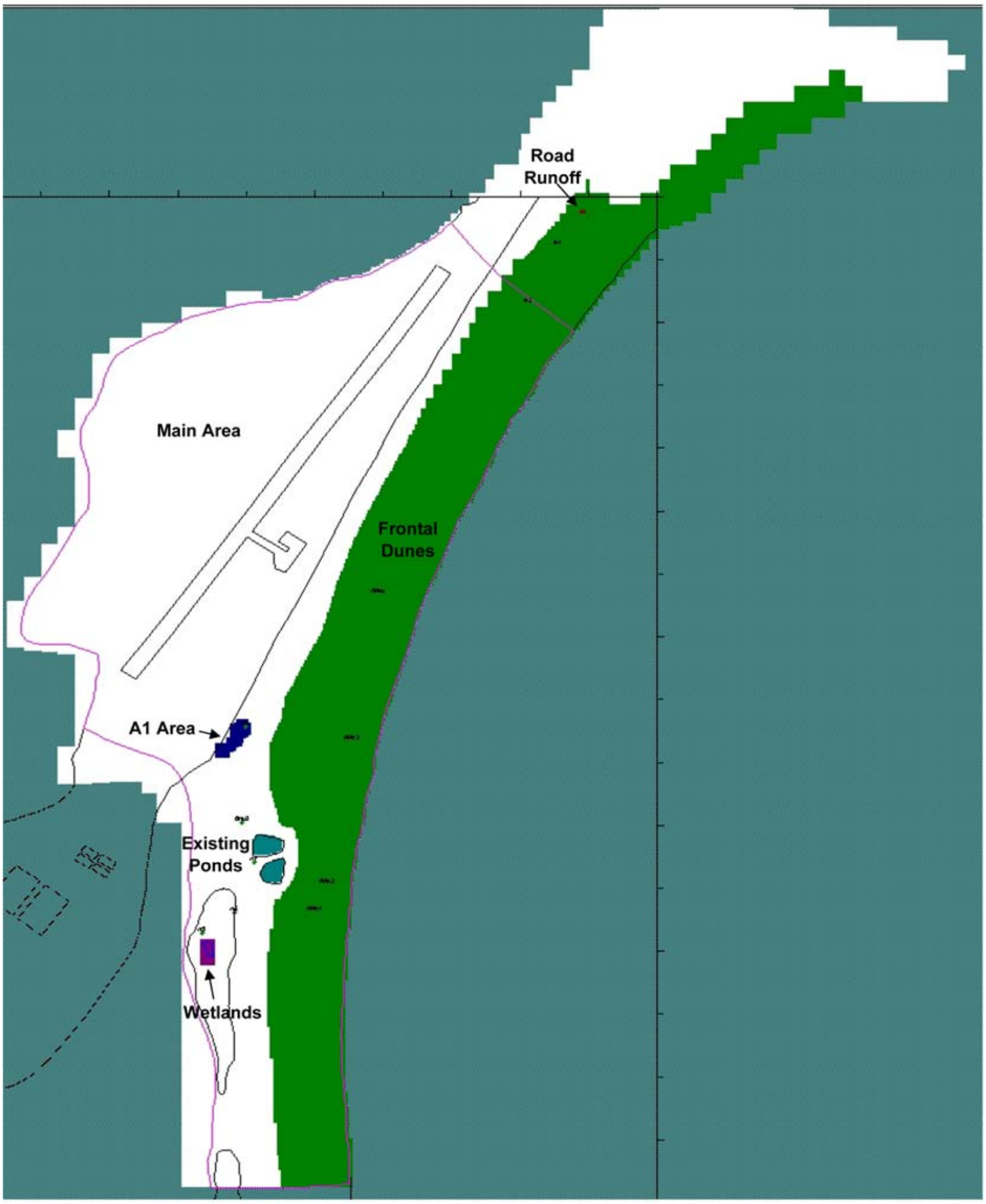
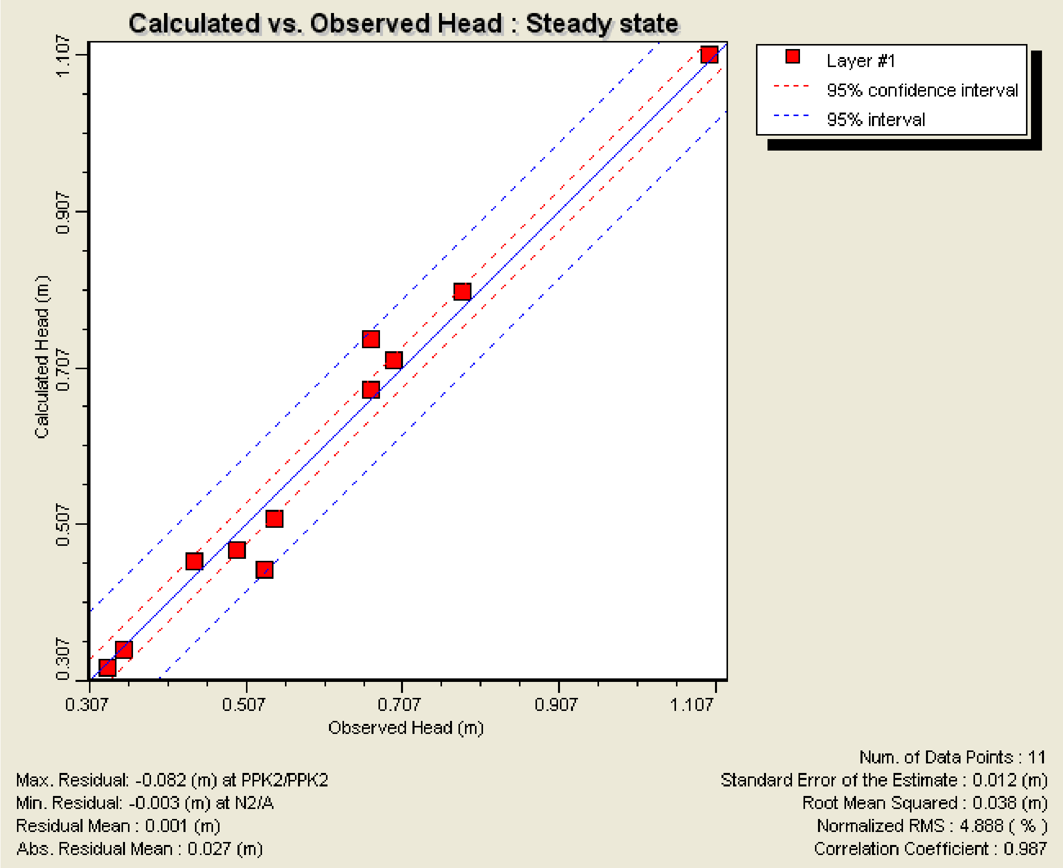


Figure 10.2: Numerical Model Recharge Zones



Final steady-state model calibration has a normalised root mean square error of 4.9% and is considered to show good agreement with observed water levels. A graph showing model calibration is provided as *Figure 10.3*.

Figure 10.3 Steady State Model Calibration



Max. Residual: -0.082 (m) at PPK2/PPK2
Min. Residual: -0.003 (m) at N2/A
Residual Mean : 0.001 (m)
Abs. Residual Mean : 0.027 (m)

Num. of Data Points : 11
Standard Error of the Estimate : 0.012 (m)
Root Mean Squared : 0.038 (m)
Normalized RMS : 4.888 (%)
Correlation Coefficient : 0.987

10.3 Water Balance

The steady-state numerical model converged well and is considered to provide a realistic simulation of groundwater behaviour. The water balance for the model is summarised in *Table 10.1*, and an effective error of 0%.

Table 10.1 Steady State Model Mass Balance

Source/Sink	In (m^3/day)	Out (m3/day)
Constant Head	484.1	3,486.3
Recharge	3,016.1	0
Evapo-transpiration	0	13.8
TOTAL	3,500.2	3,500.21
Error		+0.01

10.4 Transient Recalibration

Recalibration Period

Detailed groundwater level monitoring has been undertaken from December 2004, and data are available for the period from 15th December 2004 to 21st December 2005. Discharge of effluent to the existing ponds occurred from 23rd February to 26th April 2004, and major wet weather events occurred in July, October and December 2005. The combination of good groundwater level data and substantial stresses on the groundwater system provide an excellent situation for transient model calibration.

Recalibration

Daily rainfall recharge was imported into the model for the various zones based on the recharge percentages estimated during steady state calibration. Observation data for the period for the monitoring bores were also imported. Data for the bores with loggers were processed to provide average daily groundwater levels prior to being imported. Average lake water levels for the transient period were 0.091 mAHD with a maximum tidal range of 1.18 m.

The revised model was run in transient mode, and the predicted groundwater level behaviour based on observed data. Initial model runs showed the following:

- The predicted groundwater level rise due to exfiltration at the ponds was greater than that observed, particularly at BH10;
- The predicted rise due to the major rainfall event in July 2005 was less than that observed.

The model was run several times and the following changes made iteratively:

- Specific yield was increased to 20% across the model. This is consistent with pump test results and published values and gives model results more consistent with the observed water level response to rainfall and exfiltration;
- Hydraulic conductivity was kept the same as for the steady state model;
- The percentage of rainfall recharging the aquifer was increased to 60% for the major rainfall events to the values observed (>10 mm). This allows these events to be simulated without requiring an unrealistically high level of rainfall recharge during drier periods.

Hydrographs of predicted groundwater level behaviour are shown as *Figure 10.4a* and *Figure 10.4b*, (*Appendix A*) together with observed water levels. The simulated groundwater response closely matches that observed. There are some discrepancies in absolute water levels, most of which are considered to be due to changes in the boundary conditions due to tidal and wave variations. These are not simulated in the model, with average lake and ocean water levels being applied as constant head boundaries.

The exfiltration response is over-predicted in BH10 and under-predicted slightly in A6: this may reflect uneven loading between the northern and southern ponds. Overall the magnitude of the water level response to both exfiltration and rainfall recharge is simulated very well and the model calibration is considered acceptable.

Water level residuals (the water levels calculated by the model minus those observed) for the transient calibration must be treated with some care. Simply plotting all would mean that the result would be dominated by residuals for A6, BH10 and PPK3 because of the much greater number of observations and therefore residuals available for these bores. Residual statistics have therefore been calculated separately for these bores and only then included in the overall dataset.

The average residual water level is -0.02 m meaning that groundwater levels are typically under-predicted by just 2 cm. The average absolute residual provides a measure of the scatter of the residuals and is 0.073 m.

Calibrated Model Parameters

The calibrated model parameters used for simulations are as follows:

- Specific yield of 20%;
- Hydraulic conductivity values of 5 m/d (adjacent to hill), 8 m/d and 25 m/d (transition zones), 30 m/d (main model area) and 40 m/d to 50 m/d (frontal dunes). These are generally slightly higher than those used in the previous assessment;
- Recharge of 32% total rainfall over the main model area, increased to 40% over the frontal dunes, 50% in a localised area around bore A1 and 500% for the small area located immediately south of the limit of the paved roads at Fishpen (north of N4);
- Evapo-transpiration of 1.23 mm/d to 4.84 mm/d based on estimated monthly average Areal Potential evapo-transpiration. The extinction depth is set at 2.5 m;
- Constant heads of 0.104 mAHD (Merimbula Lake) and 0.4 m (ocean), the latter including allowance for a wave set-up factor.

10.5 Selection of the Simulation Period

Limitations of the software impose a practical restriction on transient simulation of 1000 stress periods (periods within which model conditions remain constant). Selection of a maximum simulation period of 3 to 5 years is therefore required in order to allow peak rainfall and effluent discharge to be represented, and therefore to allow prediction of peak groundwater levels and associated dissipation rates.

Predicted excess effluent generation rates were provided to IGGC for the period 1st July 1999 to 30th June 2010 and the simulation period of 1989 to 1993 used in the previous study (IGGC, 2006) therefore could not be used. Rainfall and predicted excess effluent generation rates were examined for the period available.

The period 1st January 2007 to 30th June 2010 was selected for simulation of potential effects on groundwater and is summarised in *Table 10.2*.

Table 10.2 Rainfall and Discharge Volumes for Simulation Period

Loading Scenario	2007	2008	2009	2010[1] (to 30th June)	2010 equiv annual[2]
Rain (mm/a)	849	617	447	587[1]	1,174[2]
Effluent Discharge – 2011 Loadings (ML/a)	331	242	180	216[1]	432[2]
Effluent Loadings – 2025 Loadings (ML/a)	533	468	325	258[1]	516[2]

Notes. 1. Values are for the six month period 1st January 2010 to 30th June 2010 only. 2. 2010 equivalent annual is based on 2-times the January to June rainfall or effluent discharge/loading. Average annual rainfall is 791 mm (1970-2010) and 696 mm (1999-2010).

Predicted average annual discharge rates are 326 ML (2011) and 510 ML (2025) for the entire period for which predicted excess effluent generation rates have been provided to IGGC (1999 to mid-2010) and 277 ML (2011) and 453 ML (2025) for the simulation period used for groundwater assessment. These rates are based on modelling of effluent generation and re-use rates undertaken by AECOM which assumes that the Pambula Merimbula Golf Club and Oaklands effluent re-use schemes are fully operational.

Rainfall graphs of the groundwater simulation period are provided as *Figure 10.5 (*see *Appendix A)*. The period includes a wet interval between February 2007 and July 2007 and extremely high rainfall in February 2010. The rainfall in February 2010 was 358 mm, above the 99th percentile monthly rainfall for the entire rainfall record period (1969 to 2010). The period between these events generally shows average or below average rainfall with 2009 being a particularly dry year. Peak daily discharge rates for the period are 17 ML for both current loadings and 2025 predictions. The median daily discharge is 0 ML for current loadings (discharge is predicted to occur on slightly fewer than half the days) and 2.0 ML for 2025 loadings. Average daily discharge is 0.84 ML (2011) and 1.4 ML (2025). The 95th percentile daily discharge is 1.85 ML (2010) and 2.9 ML (2025) and the 99th percentile loadings are 3.9 ML/day and 7.2 ML/day respectively.

The simulation period is therefore considered to provide a good range of conditions, including some exceptionally wet months.

Average lake water levels for the simulation period were 0.07 mAHD with a maximum tidal range of 1.27 m.

10.6 Natural Groundwater Level Behaviour

Rainfall recharge data were imported into the calibrated transient model for the selected simulation period and the model run to provide predicted baseline conditions without effluent exfiltration including no discharge to the existing exfiltration ponds. Hydrographs of predicted groundwater levels are provided as *Figure 10.6a* and *Figure 10.6b in Appendix A*.

Groundwater levels show a general variation of around 0.5m with slightly greater fluctuations in the area of the existing ponds reflecting the lower transmissivity in this area. Peak groundwater levels occur after major rainfall events, with peaks rising sharply and recession occurring more slowly. The major rainfall event in February 2010 results in a predicted natural groundwater level rise of up to 1 m in the area of the ponds and around 0.6 m beneath the frontal dunes.

Groundwater levels are predicted to remain below ground level at all bores except A1 where the groundwater level is predicted to rise very slightly above ground level on model day 1143 (16th February 2010, coinciding with rainfall of around 200 mm over three days. This is consistent with waterlogging observed to occur in this area during wet periods. A plot of depth to groundwater for this period (*Figure 10.7 – Appendix A*) indicate that groundwater levels at or close to ground surface are predicted to occur along the low-lying area around A1 and close to the wetlands located to the south of the existing ponds, consistent with observed behaviour.

11. Results of Numerical Modelling

The numerical model was used to assess the impacts on groundwater levels and flow regimes for exfiltration trenches and lines of well points located in the central area, the northern area and in the area of land under existing Council ownership. The key outcomes required were as follows:

- Capacity of exfiltration trench and injection well systems in the three areas under predicted loadings (2011 and 2025);
- Any volumetric or discharge period limitations required to prevent unacceptable groundwater impacts;
- Predicted changes in groundwater level behaviour, particularly prediction of areas of waterlogging due to excessive groundwater level rise;
- Predicted changes to the groundwater flow regime for each area, including changes to groundwater travel times and fluxes to the ocean and to Merimbula Lake;
- Implications for groundwater quality in the shallow aquifer and for groundwater discharging to the ocean and the lake.

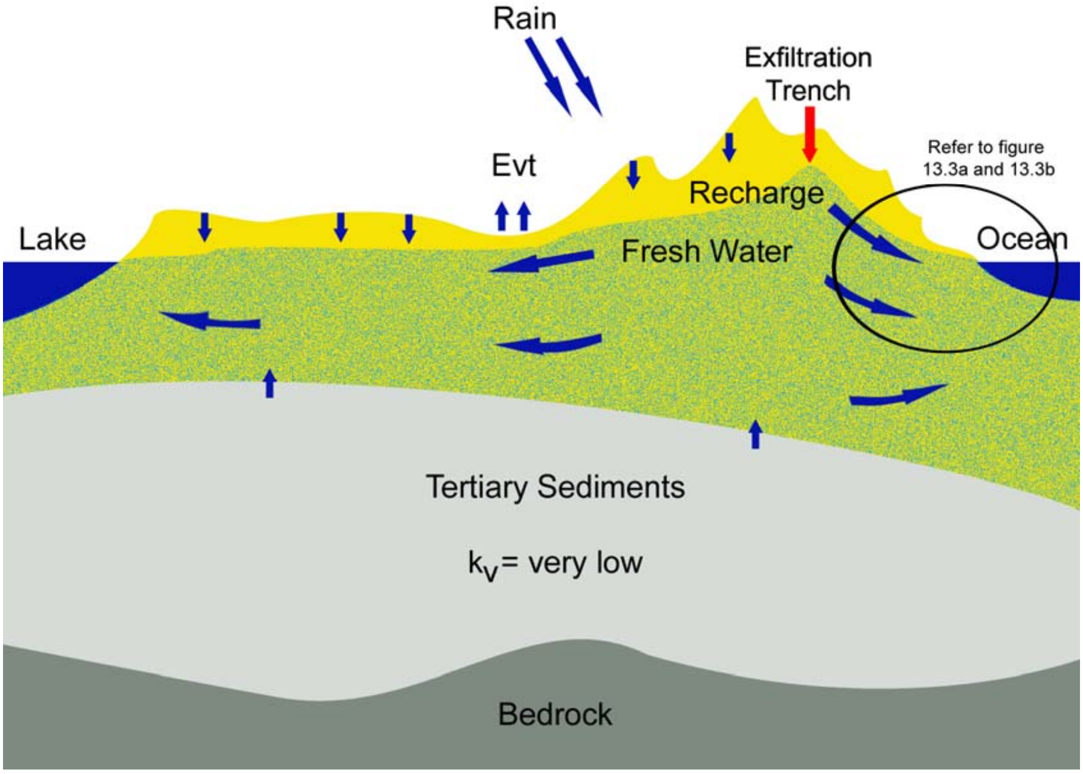
The numerical model was run for the selected simulation period without any effluent discharge. Hydrographs for selected wells are provided as *Figure 10.6 (Appendix A)* and maps showing groundwater level contours for typical conditions (model day 226, 14th August 2007) and wet conditions (model day 1,143, 16th February 2010) are provided in *Figure 8.2* and *Figure 8.3* respectively.

For each of the three areas the transient simulation model was modified as follows:

- Refinement of the model grid in the area of interest;
- Addition of imaginary monitoring wells to allow prediction of groundwater level fluctuations at key locations;
- Addition of model budget zones to allow changes in groundwater fluxes to the ocean and the lake to be assessed using MODFLOW's ZONEBUDGET package;
- Addition of tracking particles adjacent to the discharge areas to allow use of VISUAL MODFLOW's MODPATH package to allow assessment of the fate and transport of discharged effluent and travel times within the groundwater system;
- Assignment of recharge zones to represent exfiltration trenches or discharge wells and importing of recharge/discharge rates. For the exfiltration trenches the model area occupied by each was estimated and effluent discharge assigned accordingly. ZONEBUDGET was then used during initial model runs to refine the area and ensure that the discharge was an accurate reflection of the predicted effluent volume.

A diagram showing the conceptual groundwater model including the effects of exfiltration is included as *Figure 11.1*.

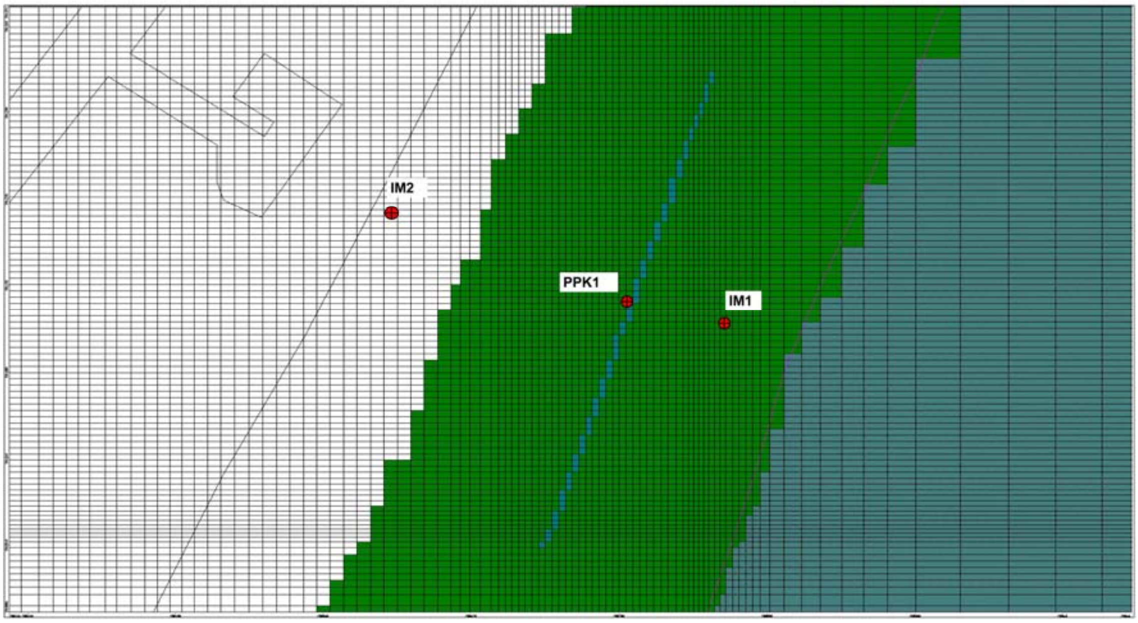
Figure 11.1: Conceptual Model of the Shallow Groundwater System with Exfiltration



11.1 Central Area

The transient simulation model was run with predicted effluent loadings for 2011 and 2025 directed to a 400 m exfiltration trench and a 400 m line of nine injection wells at 50 m spacings, both centred on PPK1 and oriented parallel with the coastline. The location of the exfiltration trench and image wells is shown on *Figure 11.2*.

Figure 11.2: Central Area Trench and Image Well Locations

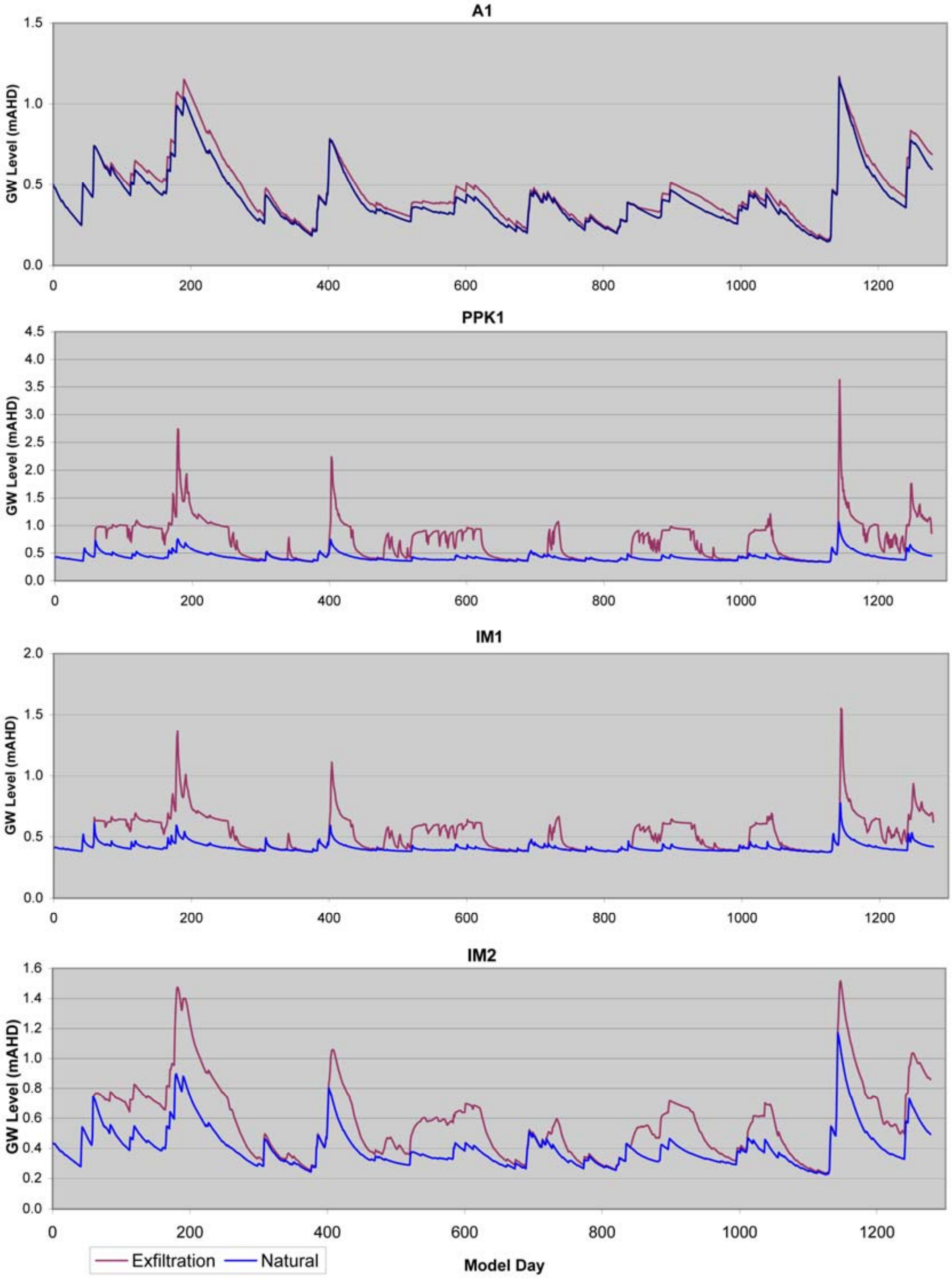


Predicted effects on groundwater are detailed below.

11.1.1 400 m Trench - 2011 Loadings

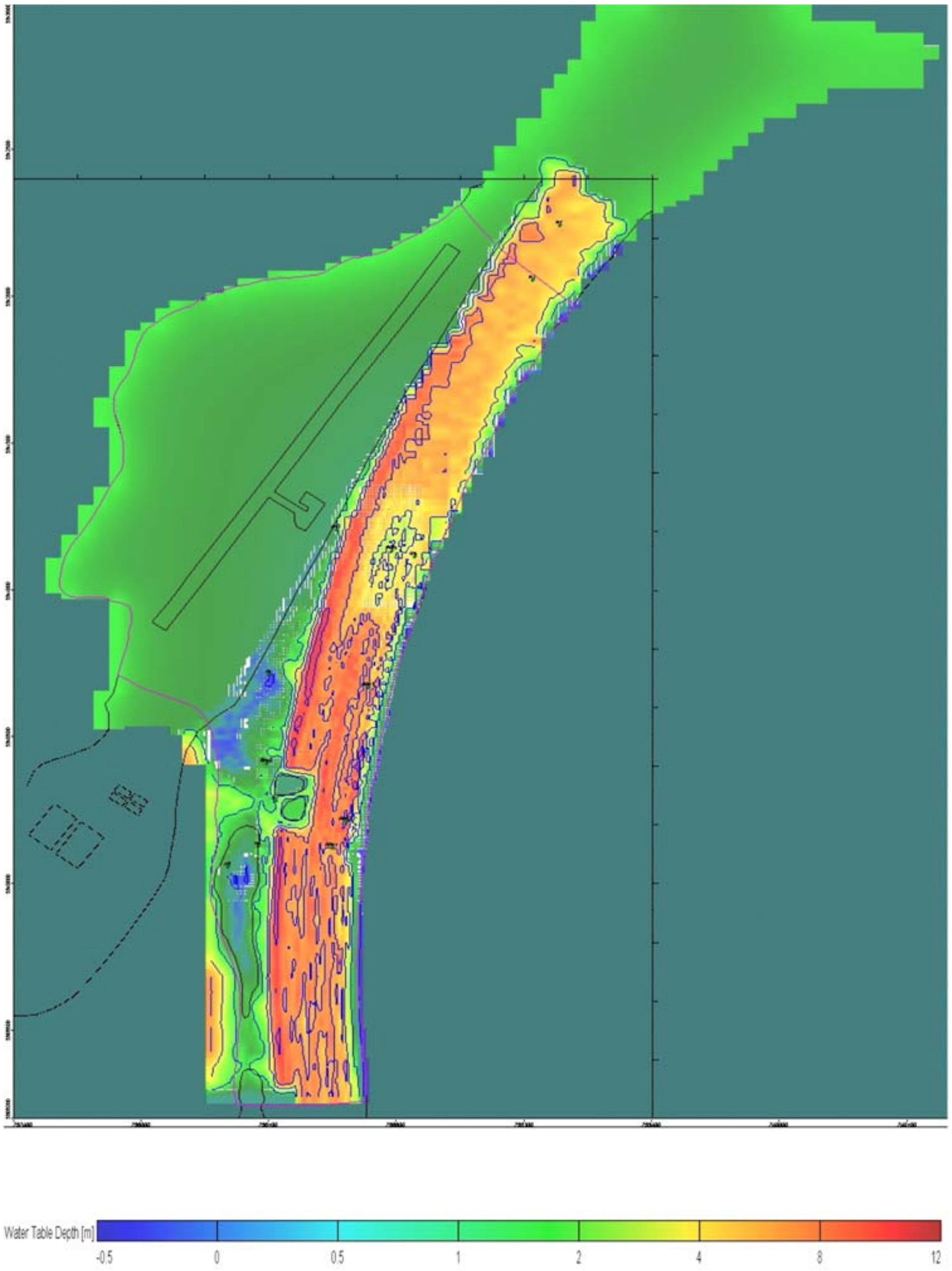
Hydrographs of groundwater levels at bores A1, PPK1 and the imaginary wells are provided in *Figure 11.3 (Appendix A)*. These show that groundwater levels are typically increased by around 0.5 m at PPK1 (located within one of the middle trench cells) during periods of effluent discharge with peak levels up to 2.6 m higher than natural peaks (model days 1,143/4, 16/17th February 2011). Groundwater levels are typically increased by c.0.25 m at IM1 and c.0.35 m at IM2, with peak increases of up to 0.78 m at IM1 and 0.35 m at IM2. The difference in responses is due to IM1 being around 70 m from the trench compared to 200 m for IM2 and because IM1 shows less response to natural rainfall recharge due to its proximity to the ocean which acts as a constant head boundary.

Figure 11.3: Central Area 400m Trench, 2011 Loading



Predicted groundwater level increases at A1 are very small and are less than 0.1 m during both peak and non-peak conditions. A map showing predicted depth to groundwater on model day 1,144 is provided as *Figure 11.4*.

Figure 11.4: Depth to Groundwater, Central Area, 2011 Loading, Day 1,144

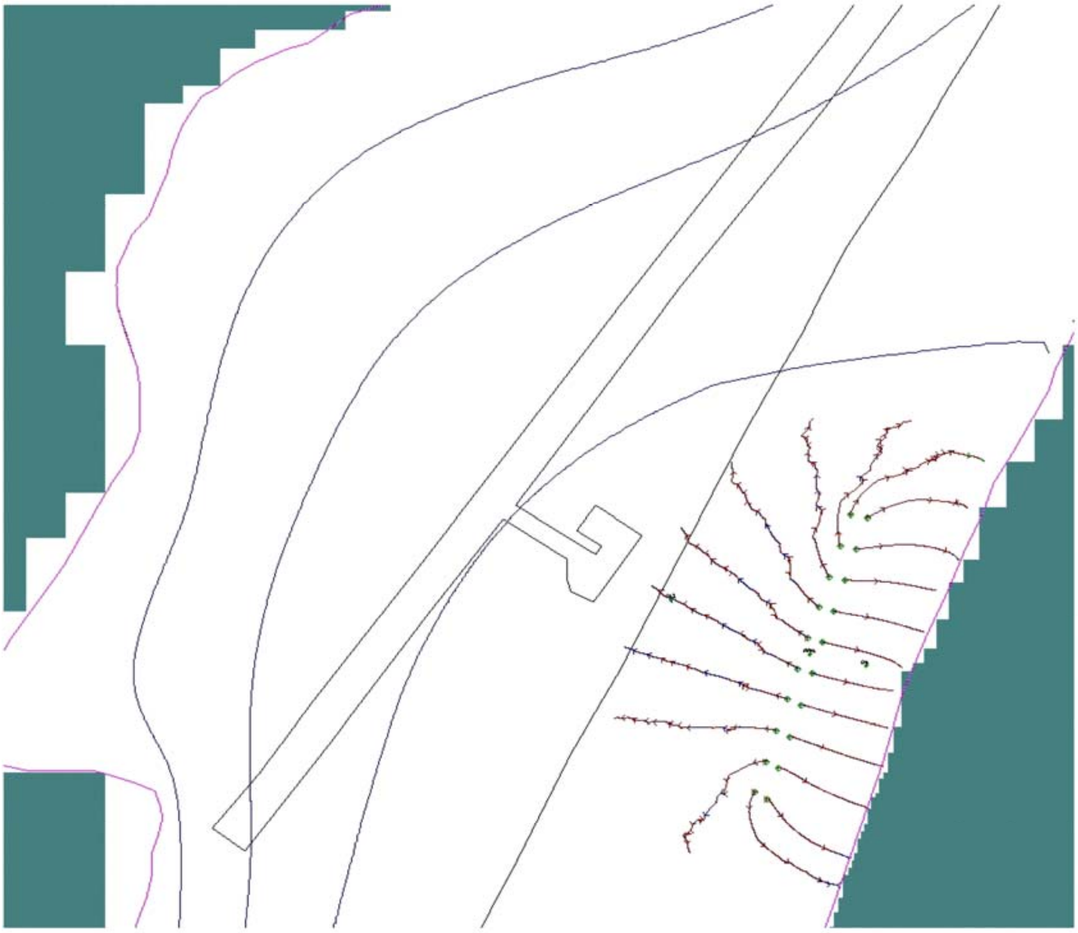


The area in which groundwater is predicted to rise to or close to ground surface level (shown as blue on *Figure 11.4*) is very similar to that under natural conditions and is localised in the low-lying area around A1 and the existing wetlands.

Exfiltration has an effect on the groundwater flow regime. Under natural conditions a groundwater recharge mound forms beneath the peninsula with groundwater levels highest close to half-way between the lake and the ocean. During extended dry periods this mound dissipates entirely and during these times net groundwater flow from the ocean to the lake may occur. Under typical conditions groundwater flows from the trench area towards the ocean. The hydraulic gradient is low and reverses during very dry periods and travel times are therefore long (over 1000 days). Exfiltration results in the highest area of the groundwater mound being beneath the trench and therefore closer to the ocean. Groundwater flow is from the trench area both towards the lake and towards the ocean with hydraulic gradients considerably higher than those that would occur naturally. Travel times are predicted to be at least 120 days for groundwater from the trench area to reach the ocean. Groundwater from the trench is not predicted to reach the lake within the model period. Extrapolation of MODPATH outputs suggests that the travel time would be expected to be at least of the order of 5,000 days.

Particle pathlines predicted by MODPATH are shown in *Figure 11.5*.

Figure 11.5: Model Pathlines, Central Area, 2011 Loading



Tickmarks at 100 Day Intervals

Examination of the ZONEBUDGET outputs shows that under natural conditions net average groundwater discharge to the ocean over the simulation period is -373 m^3/d or kL/d (i.e. overall net recharge from the ocean to the groundwater system) while that to the lake is 1,512 m^3/d. *Table 11.1* summarises the effects of exfiltration on the groundwater discharge regime.

Table 11.1: Effect of Exfiltration on Groundwater Discharge Regime, Central Area, 2011 Load (Average 840 m^3/d)

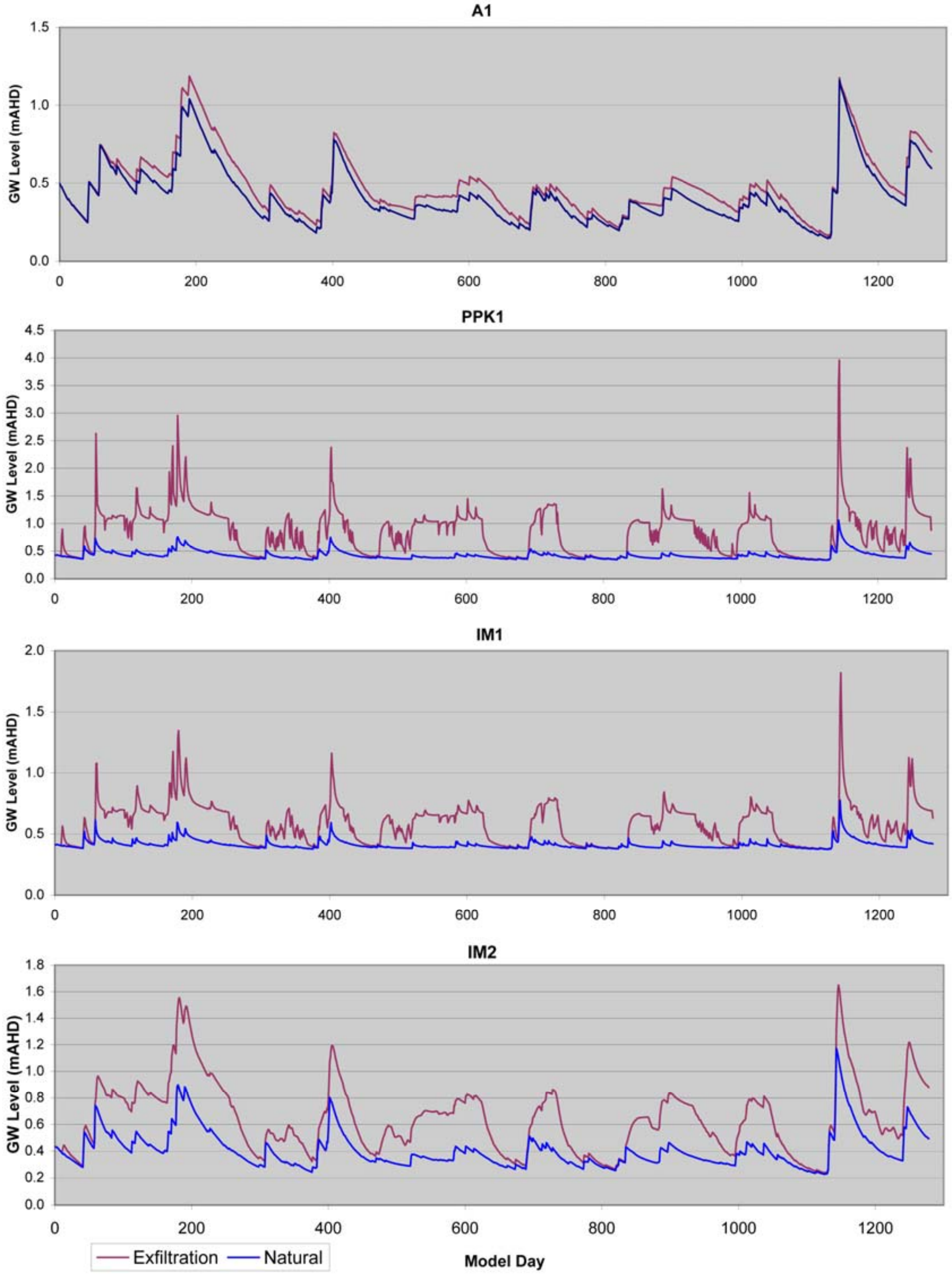
	Ocean	Lake
Natural Groundwater Discharge (m^3/d)	-373	1,512
Net Groundwater Discharge with Exfiltration (m^3/d)	309	1,647
Increase in Groundwater Discharge (m^3/d)	682	135
Percentage of Effluent Reaching Water Body	81%	16%
Travel Times (days)	120	>5,000

Average exfiltration discharge over the simulation period is 840 m^3/day (0.84 ML/d) of which 81% is expected to discharge to the ocean and 16% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.1.2 400 m Trench - 2025 Loadings

Hydrographs of groundwater levels at bores A1, PPK1 and the imaginary wells are provided as *Figure 11.6*.

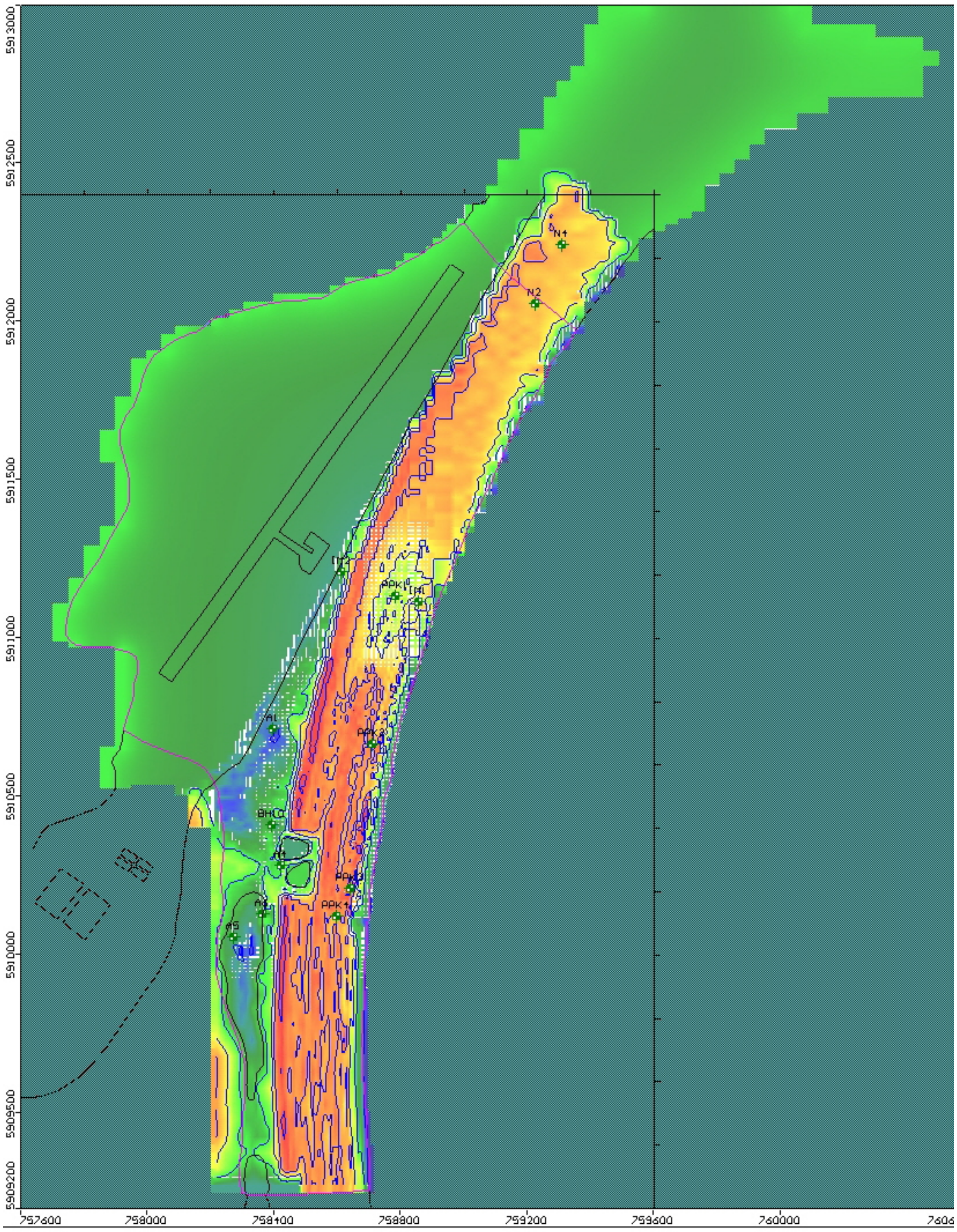
Figure 11.6: Central Area 400m Trench, 2025 Loading



These show that groundwater levels are typically increased by 0.5 m to 1 m at PPK1 (located within one of the middle trench cells) during periods of effluent discharge with peak levels up to 2.9 m higher than natural peaks (model days 1,143/4, 16th/17th February 2011). Groundwater levels are typically increased by c.0.3 m at IM1 and c.0.4 m at IM2, with peak increases of up to 1 m at IM1 and 0.48 m at IM2. The difference in responses is mostly due to IM1 being around 70 m from the trench compared to 200 m for IM2. IM1 also shows less response to natural rainfall recharge because of its proximity to the ocean which acts as a constant head boundary.

Predicted groundwater level increases at A1 are very small, typically less than 0.1 m during both peak and non-peak conditions. A map showing predicted depth to groundwater is provided as *Figure 11.7*.

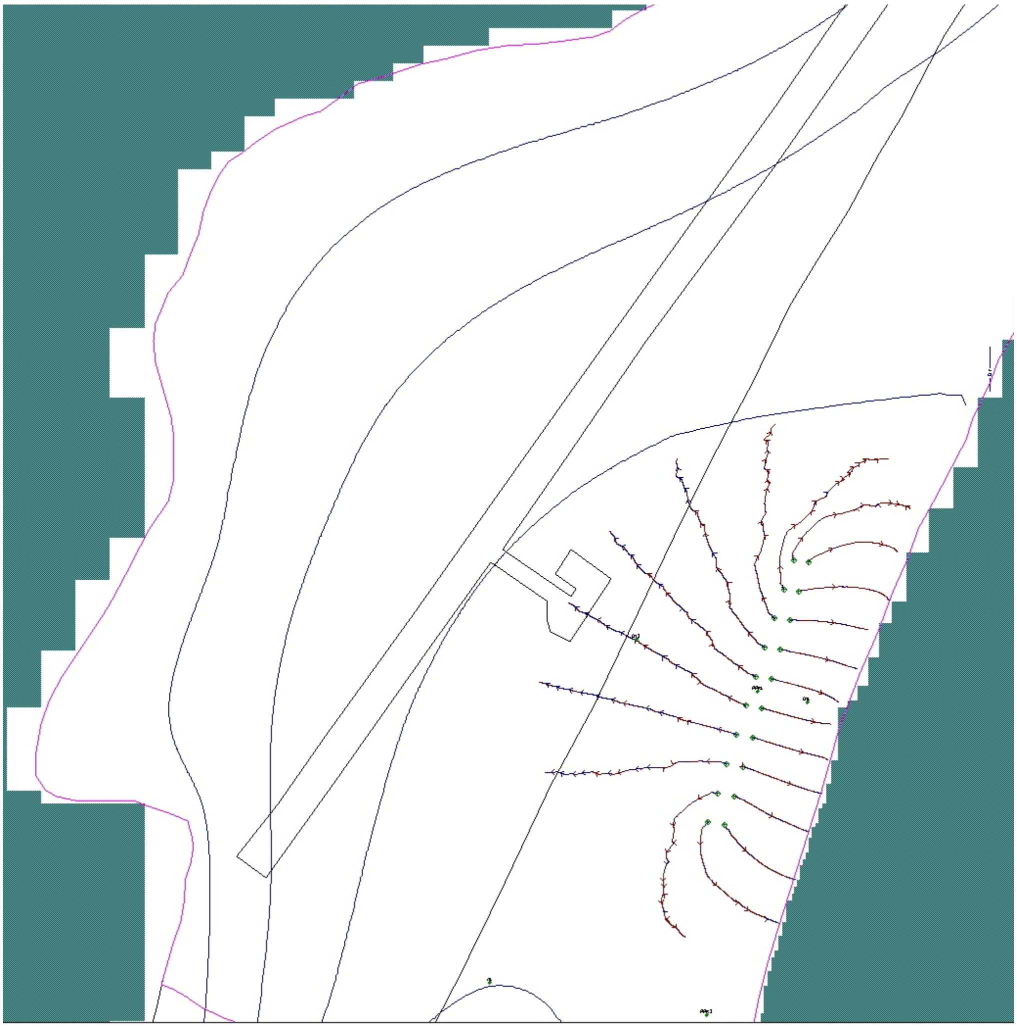
Figure 11.7: Depth to Groundwater, Central Area, 2025 Loading, Day 1,144



The area in which groundwater is predicted to rise to or close to ground surface level is very similar to that under natural conditions and is localised in the low-lying area around A1 and the existing wetlands.

Exfiltration has an effect on the groundwater flow regime. Under natural conditions a groundwater recharge mound forms beneath the peninsula with groundwater levels highest close to half-way between the lake and the ocean. Only during very dry periods does this mound dissipate entirely and during these times net groundwater flow from the ocean to the lake may occur. Groundwater generally flows from the trench area towards the ocean. The hydraulic gradient is low and reverses during very dry periods and travel times area therefore long (over 1000 days). Exfiltration results in the highest area of the groundwater mound being beneath the trench and therefore closer to the ocean. Groundwater flow is from the trench area both towards the lake and towards the ocean with hydraulic gradients considerably higher than those that would occur naturally. Travel times are predicted to be at least 110 days for groundwater from the trench area to reach the ocean. Groundwater from the trench is not predicted to reach the lake within the model period. Extrapolation of MODPATH outputs suggests that the travel time would be expected to be of the order of 4,000 days. Particle pathlines predicted by MODPATH are shown as *Figure 11.8*.

Figure 11.8: Model Pathlines, Central Area, 2025 Loading



The predicted effects of exfiltration on the groundwater discharge regime based on the numerical model ZONEBUDGET outputs are summarised in *Table 11.2*.

Table 11.2: Effect of Exfiltration on Groundwater Discharge Regime, Central Area, 2025 Load (Average 1,240 m^3/d)

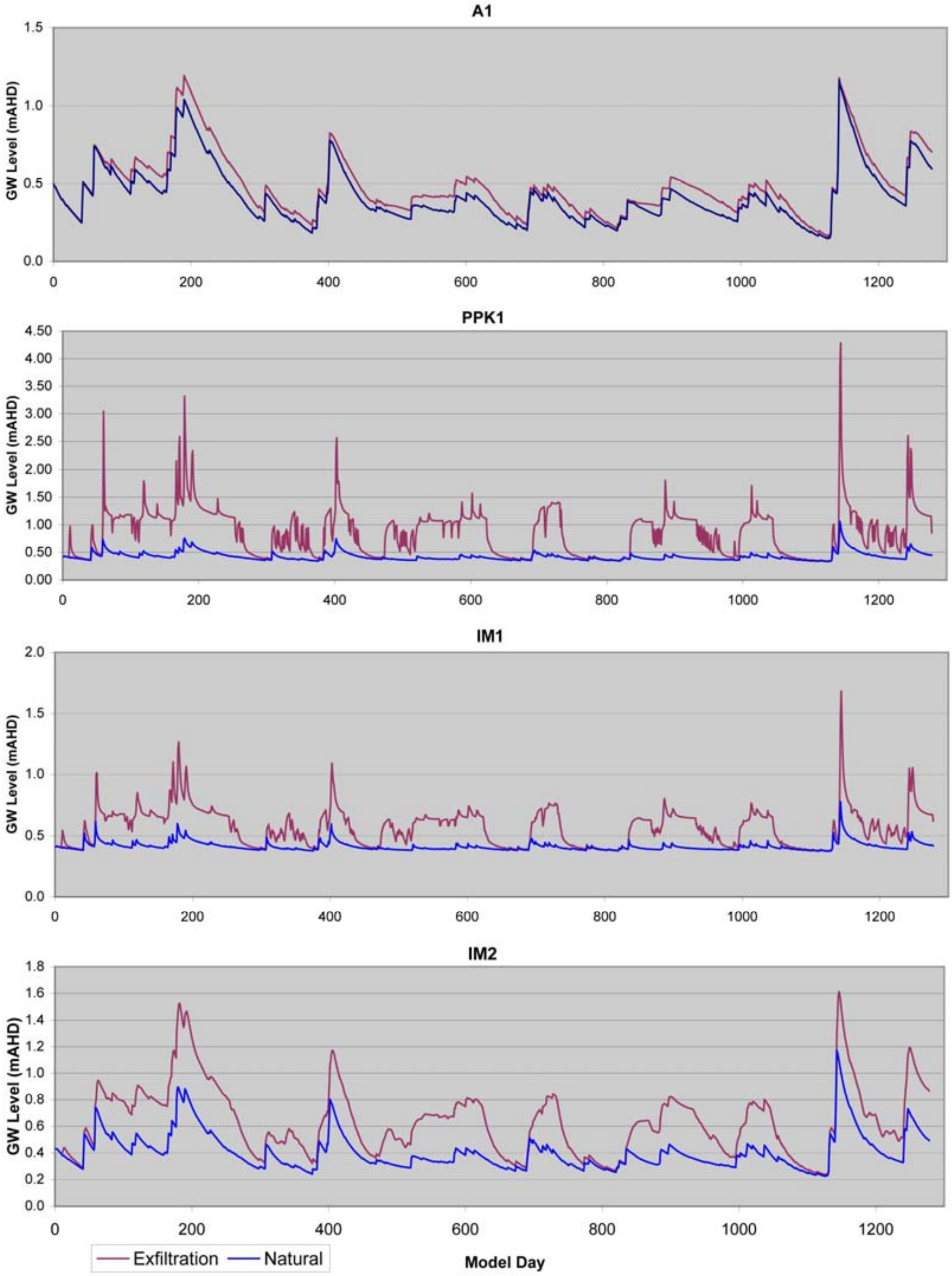
	Ocean	**Lake**
Natural Groundwater Discharge (m^3/d)	-373	1,512
Net Groundwater Discharge with Exfiltration (m^3/d)	397	1,697
Increase in Groundwater Discharge (m^3/d)	1,070	185
Percentage of Effluent Reaching Water Body	76%	13%
Travel Times (days)	110	4,000

Average exfiltration discharge over the period is 1,200 m^3/day (1.2 ML/d) of which 85% is expected to discharge to the ocean and 12% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.1.3 Injection Wells – 2025 Loading

Hydrographs of groundwater levels at bores A1, PPK1 and the imaginary wells are provided as *Figure 11.9*.

Figure 11.9: Central Area Injection Wells, 2025 Loading



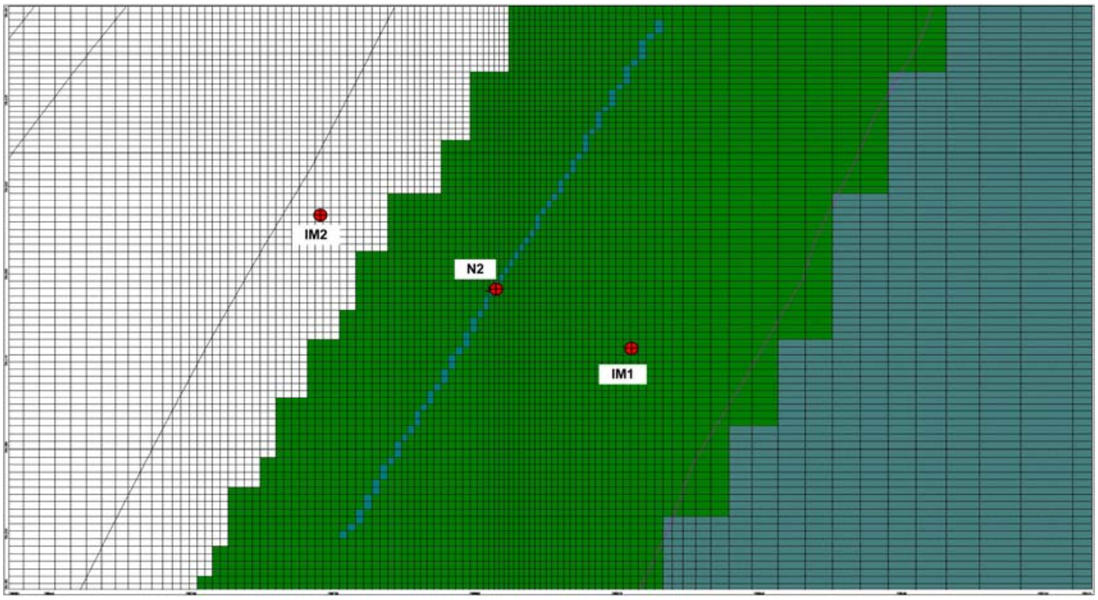
These show that groundwater levels are typically increased by 0.72 m in the central injection well model cell during periods of effluent discharge with peak levels of up to 4.28 mAHD, up to 3.22 m higher than natural peaks. Groundwater levels are typically increased by 0.25 m at IM1 and 0.41 m at IM2, with peak increases of up to 0.91 m at IM1 and 0.26 m at IM2. The groundwater level response to injection of effluent is very similar to that predicted for an exfiltration trench except for increased peak levels in the model injection well cells by up to 0.32 m). It should be noted that this is based on the assumption within MODFLOW that the injection well occupies the entire cell (c.5 m x 5 m) and the response at a real injection well will be greater, although this effect will be very localised. An indication of this is provided by the drawdown response in CPW during the pump test which showed a maximum drawdown of 2.25 m of which perhaps 1.8 m is estimated to be from well losses, i.e. well effects will produce localised additional peaks several metres higher than those predicted. This is not expected to result in adverse impacts on the groundwater system but may limit injection rates.

The effects of effluent injection using wells are otherwise very similar to equivalent disposal by exfiltration using a trench.

11.2 Northern Area

The transient simulation model was run with predicted effluent loadings for 2011 and 2025 directed to a 400 m exfiltration trench and a 400 m line of nine injection wells at 50 m spacings, both centred on NPW and oriented parallel with the coastline. The location of the exfiltration trench and image wells is shown on *Figure 11.10*.

Figure 11.10 Northern Area Trench and Image Well Locations

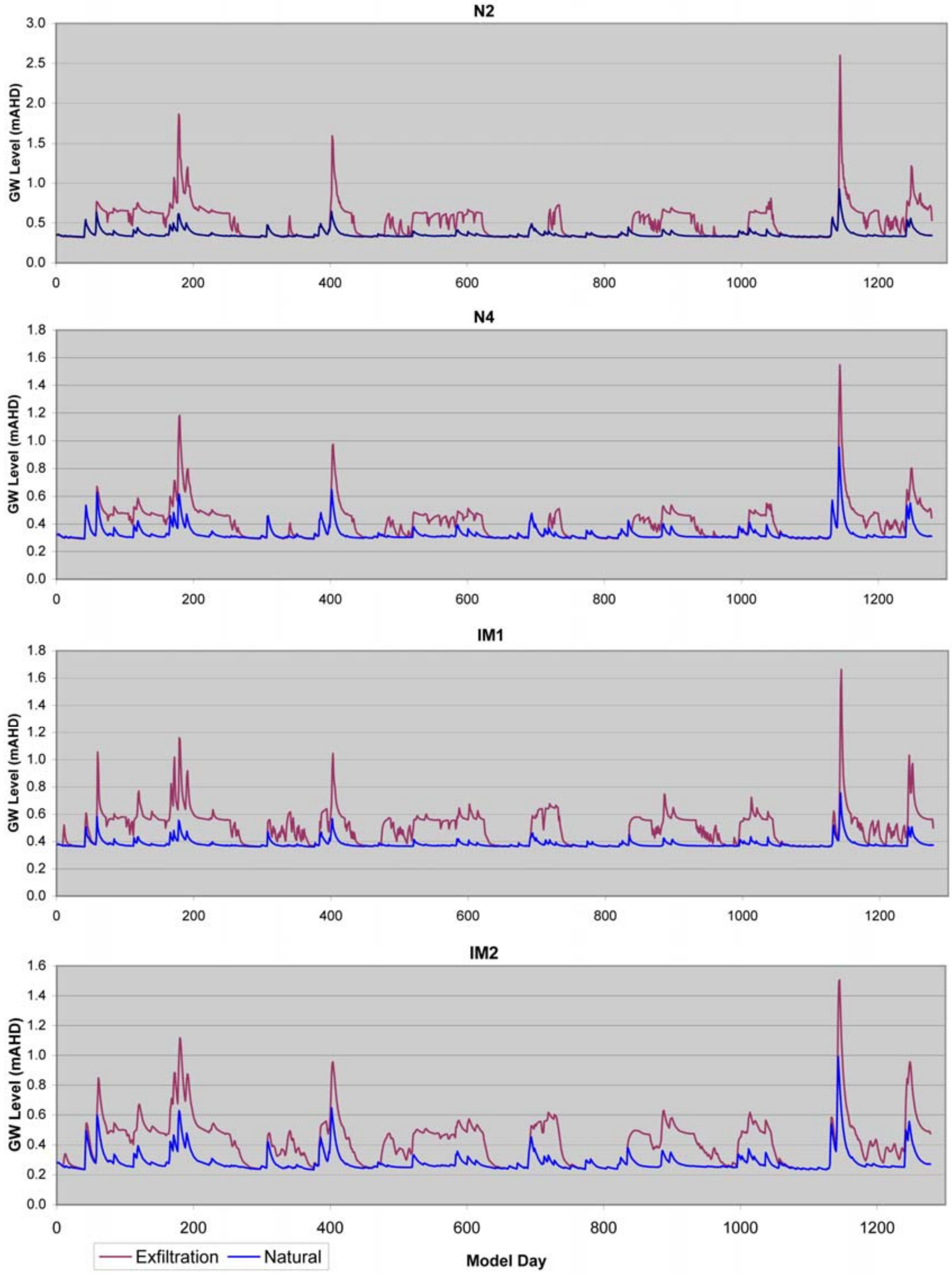


Predicted effects on groundwater are detailed below.

11.2.1 400 m Trench - 2011 Loadings

Hydrographs of groundwater levels at bores N2, N4 and the imaginary wells are provided in *Figure 11.11*.

Figure 11.11: Northern Area 400m Trench, 2011 Loading



These show that groundwater levels are typically increased by around 0.3 m immediately beneath the middle trench cells during periods of effluent discharge with peak levels up to 1.8 m higher than natural peaks. Groundwater levels are typically increased by 0.14 m at IM1 and 0.16 m at IM2, with peak increases of up to 0.69 m at IM1 and 0.23 m at IM2. The difference in responses is mostly due to IM1 being around 65 m from the trench compared to 150 m for IM2. IM1 also shows less response to natural rainfall recharge because of its proximity to the ocean which acts as a constant head boundary.

Exfiltration results in smaller groundwater level rises than for the central area largely because of the greater aquifer transmissivity.

Exfiltration has an effect on the groundwater flow regime. Under natural conditions net groundwater flow is typically from the ocean to the lake due to the higher effective head at the ocean boundary resulting from wave set-up factors. The groundwater recharge mound that occurs beneath the central area is only expected to develop beneath the northern area during high rainfall conditions. Groundwater generally flows from the trench area towards the lake with a low hydraulic gradient and reversal during wet periods. Exfiltration results in increased development of the groundwater mound with being beneath the trench and therefore closer to the ocean. Groundwater flow is from the trench area both towards the lake and towards the ocean with hydraulic gradients considerably higher than those that would occur naturally. Travel times are predicted to be 1,200 days for groundwater from the trench area to reach the lake and 350 days for it to reach the ocean.

Examination of the ZONEBUDGET outputs shows that under natural conditions net average groundwater discharge to the ocean over the simulation period is -383 m^3/d or kL/d (i.e. overall net recharge from the ocean to the groundwater system) while that to the lake is 1,654 m^3/d. *Table 11.1* summarises the effects of exfiltration on the groundwater discharge regime.

The predicted effects of exfiltration on the groundwater discharge regime are summarised in *Table 11.3*.

Table 11.3: Effect of Exfiltration on Groundwater Discharge Regime, Northern Area, 2011 Load (Average 840 m^3/d)

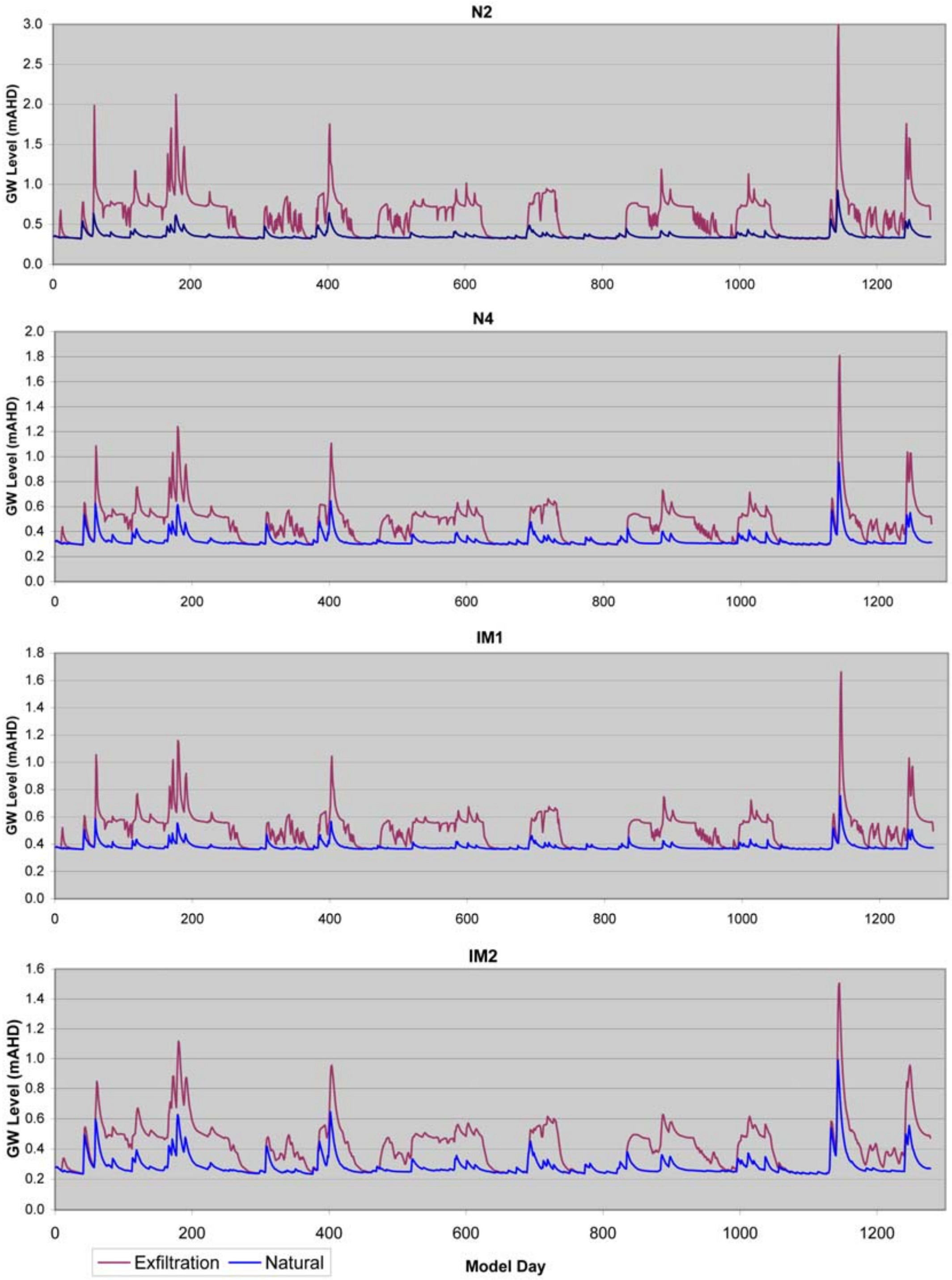
	Ocean	Lake
Natural Groundwater Discharge (m^3/d)	-383	1,654
Net Groundwater Discharge (m^3/d)	186	1,824
Increase in Groundwater Discharge (m^3/d)	569	260
Percentage of Effluent Reaching Water Body	66%	20%
Travel Times (days)	350	1,200

Average exfiltration discharge over the period is 840 m^3/day (0.84 ML/d) of which 66% is expected to discharge to the ocean and 20% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.2.2 400 m Trench - 2025 Loadings

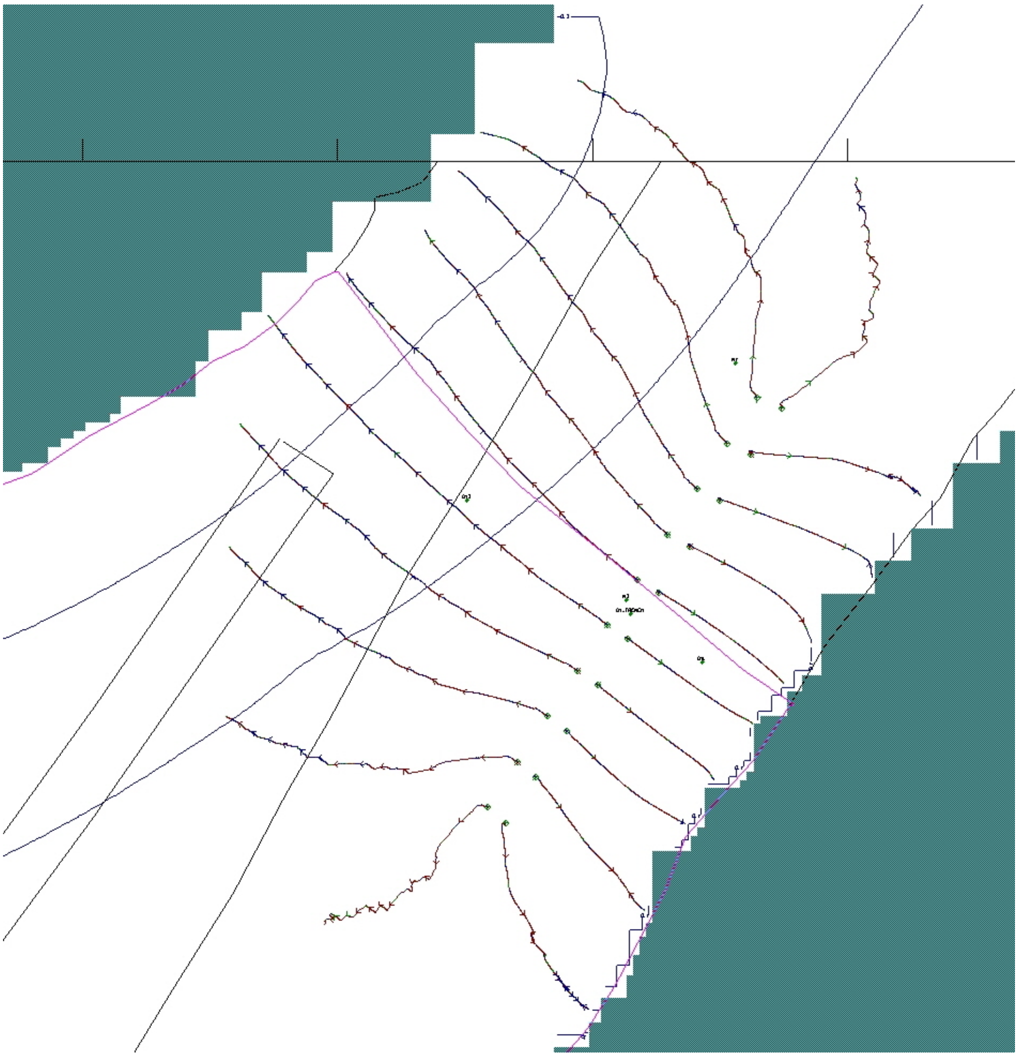
Hydrographs of groundwater levels at bores N2, N4 and the imaginary wells are provided in *Figure 11.12*.

Figure 11.12: Northern Area 400 m Trench, 2025 Loading



These show that groundwater levels are typically increased by around 0.4 m immediately beneath the middle trench cells during periods of effluent discharge with peak levels up to 2.14 m higher than natural peaks. Groundwater levels are typically increased by 0.18 m at IM1 and c.0.21 m at IM2, with peak increases of up to 0.81 m at IM1 and 0.5 m at IM2. Exfiltration is predicted to alter the groundwater flow regime as noted for the 2011 discharge but to a greater extent, i.e. with development of a larger and more persistent recharge mound. Groundwater flow is from the trench area both towards the lake and towards the ocean with hydraulic gradients considerably higher than those that would occur naturally. Travel times are predicted to be around 850 days for groundwater from the trench area to reach the lake and 190 days for it to reach the ocean. Particle pathlines predicted by MODPATH are shown in *Figure 11.13*.

Figure 11.13: Model Pathlines, Northern Area, 2025 Loading



The predicted effects of exfiltration on the groundwater discharge regime are summarised in *Table 11.4*.

Table 11.4: Effect of Exfiltration on Groundwater Discharge Regime, Northern Area, 2025 Load (Average 1,400 m^3/d)

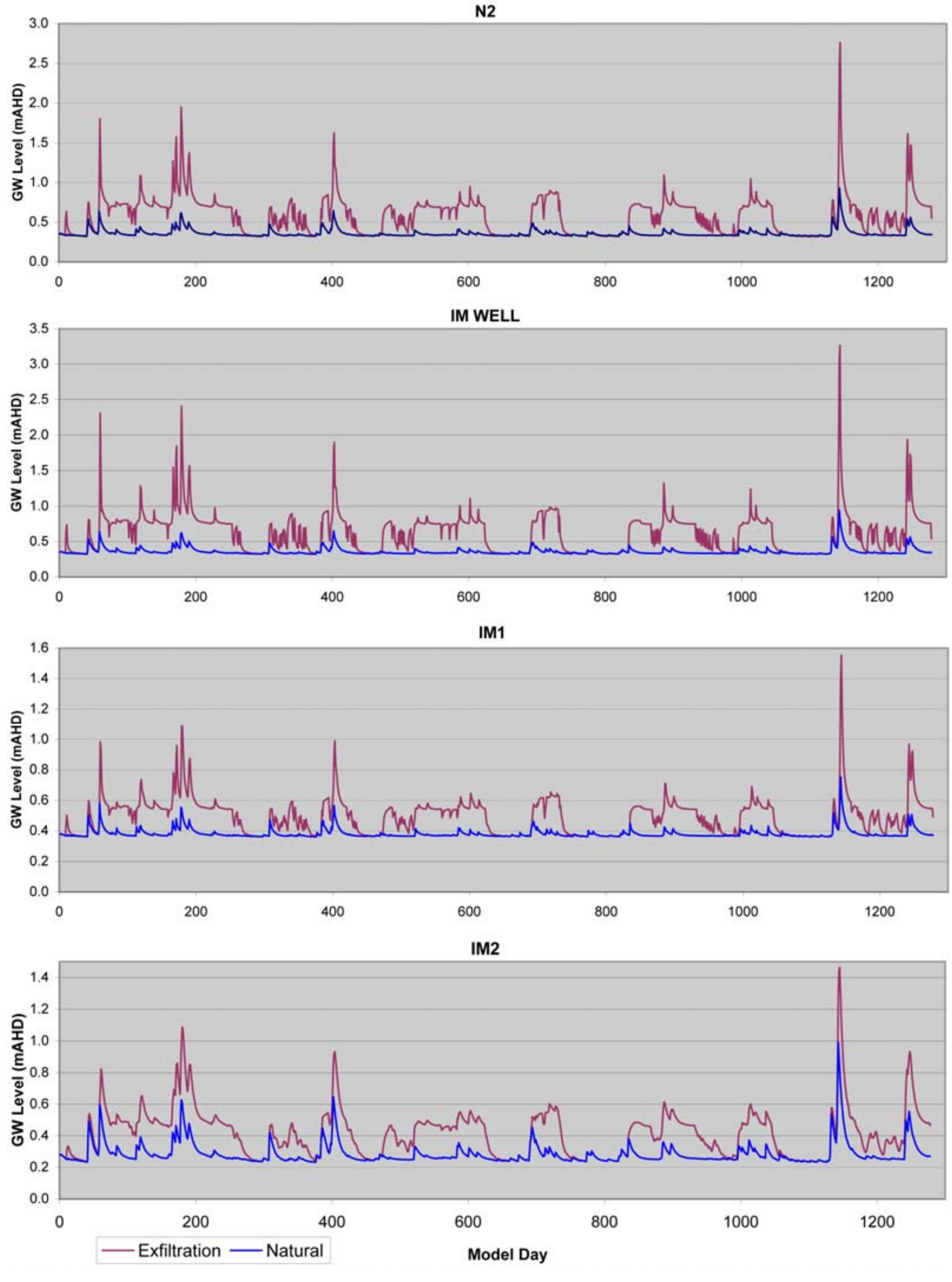
	Ocean	Lake
Natural Groundwater Discharge (m^3/d)	-383	1,654
Net Groundwater Discharge with Exfiltration (m^3/d)	551	1,933
Increase in Groundwater Discharge (m^3/d)	924	421
Percentage of Effluent Reaching Water Body	67%	20%
Travels Times (days)	190	850

Average exfiltration discharge over the period is 1,400 m^3/day (1.4 ML/d) of which 67% is expected to discharge to the ocean and 20% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.2.3 Northern Area Injection Wells – 2025 Loading

Hydrographs of groundwater levels at bores N2 and the imaginary wells (including one located in the same model cell as the central injection well) are provided in *Figure 11.14*.

Figure 11.14: Northern Area Injection Wells, 2025 Loading



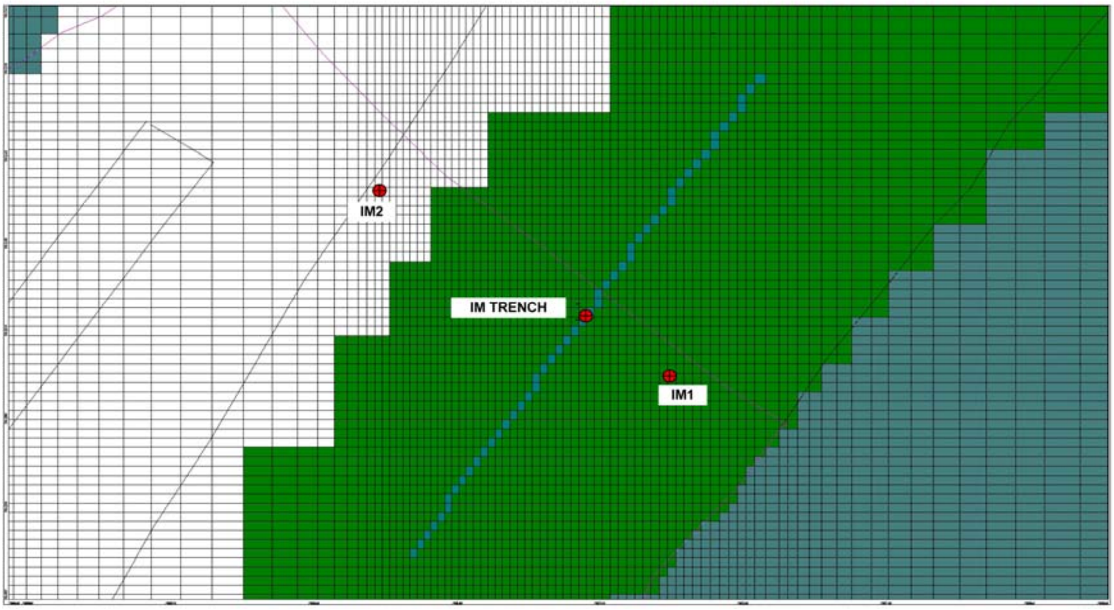
These show that groundwater levels are typically increased by 0.42 m in the central injection well model cell during periods of effluent discharge with peak levels up to 2.34 m higher than natural peaks. Groundwater levels are typically increased by 0.17 m at IM1 and 0.21 m at IM2, with peak increases of up to 0.84 m at IM1 and 0.46 m at IM2. The groundwater level response to injection of effluent is very similar to that predicted for an exfiltration trench except for slightly increased peak levels in the model injection well cells (by up to 0.13 m). It should be noted that this is based on the assumption within MODFLOW that the injection well occupies the entire cell (c.5 m x 5 m) and the response at a real injection well will be greater, although this effect will be very localised.

The effects of effluent injection using wells are otherwise very similar to equivalent disposal by an exfiltration trench.

11.3 BVSC Land Area

The transient simulation model was run with predicted effluent loadings for 2011 and 2025 directed to a 400 m exfiltration trench and a 400 m line of nine injection wells at 50 m spacings, both located close to the eastern limit of land currently under BVSC ownership. The location of the exfiltration trench and image wells is shown in *Figure 11.15*.

Figure 11.15 BVSC Land Area Exfiltration Trench and Image Well Locations

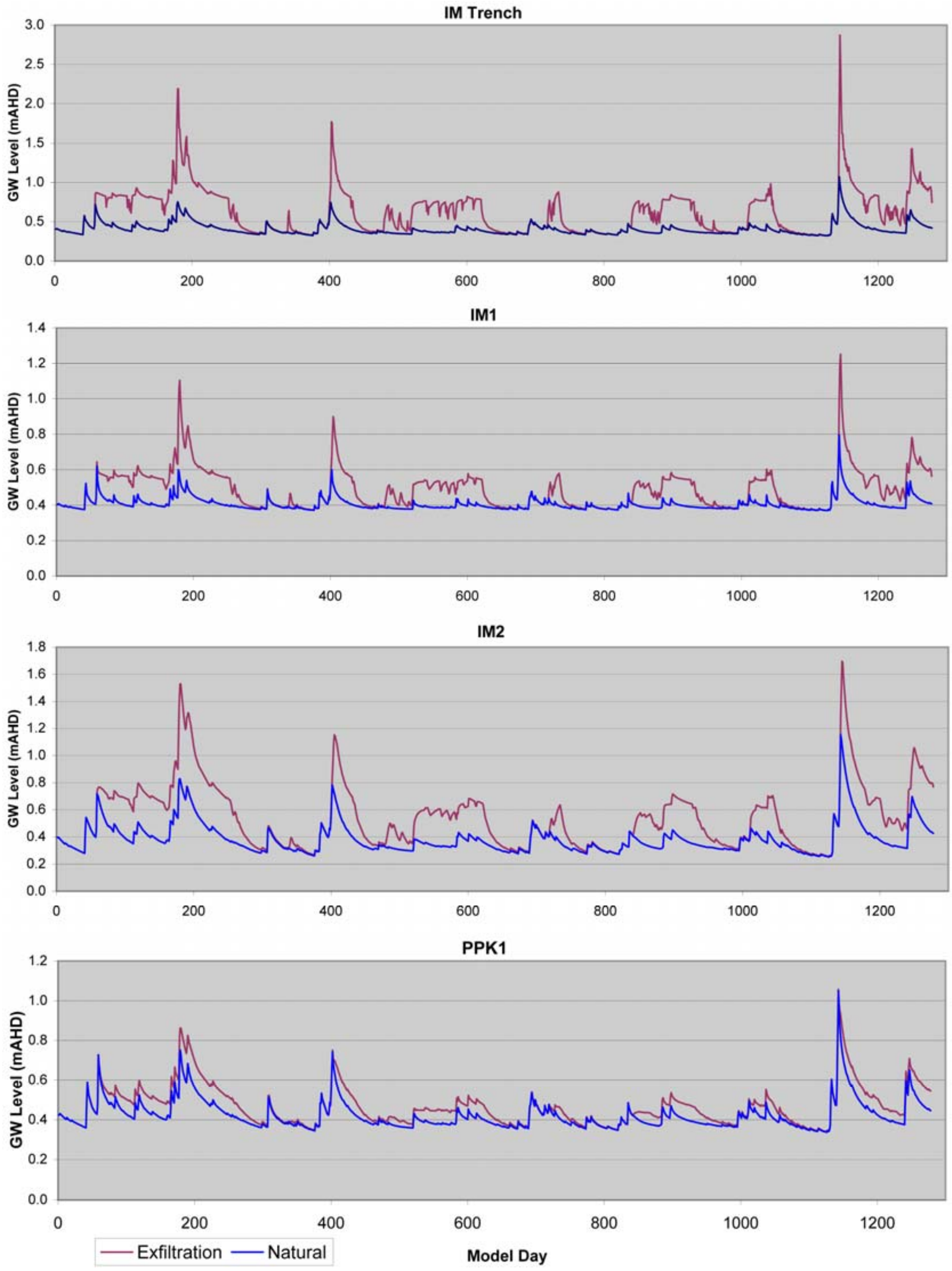


Predicted effects on groundwater are detailed below.

11.3.1 400 m Trench - 2011 Loadings

Hydrographs of groundwater levels at bore PPK1 and the imaginary wells IM1, IM2 and IM3 located in the centre of the exfiltration trench are provided in *Figure 11.16*.

Figure 11.16: BVSC Land Area 400 m Trench, 2011 Loading



These show that groundwater levels are typically increased by 0.42 m immediately beneath the middle trench cells during periods of effluent discharge with peak levels up to 1.8 m higher than natural peaks. Groundwater levels are typically increased by 0.16 m at IM1 and 0.32 m at IM2, with peak increases of up to 0.38 m at IM1 and 0.36 m at IM2. IM1 is located c.95 m east of the trench and IM2 c.115 m west, the lesser typical response at IM1 reflecting proximity to the ocean which act as a constant head boundary.

Exfiltration results in slightly smaller groundwater level rises than for the central area largely because of the increase in aquifer transmissivity because of deepening of the aquifer base and perhaps also as a result of the area being further from the limit of the shallow aquifer where it meets the hill to the south.

Exfiltration has a similar effect on the groundwater flow regime to that noted for the other sites, with increased development of the groundwater recharge mound and increases in hydraulic gradients and in groundwater flow, particularly towards the ocean. Travel times are predicted to be over 3,000 days for groundwater from the trench area to reach the lake and 200 days for it to reach the ocean.

The predicted effects of exfiltration on the groundwater discharge regime are summarised in *Table 11.5*.

Table 11.5: Effect of Exfiltration on Groundwater Discharge Regime, BVSC Land, 2011 Load (Average 840 m^3/d)

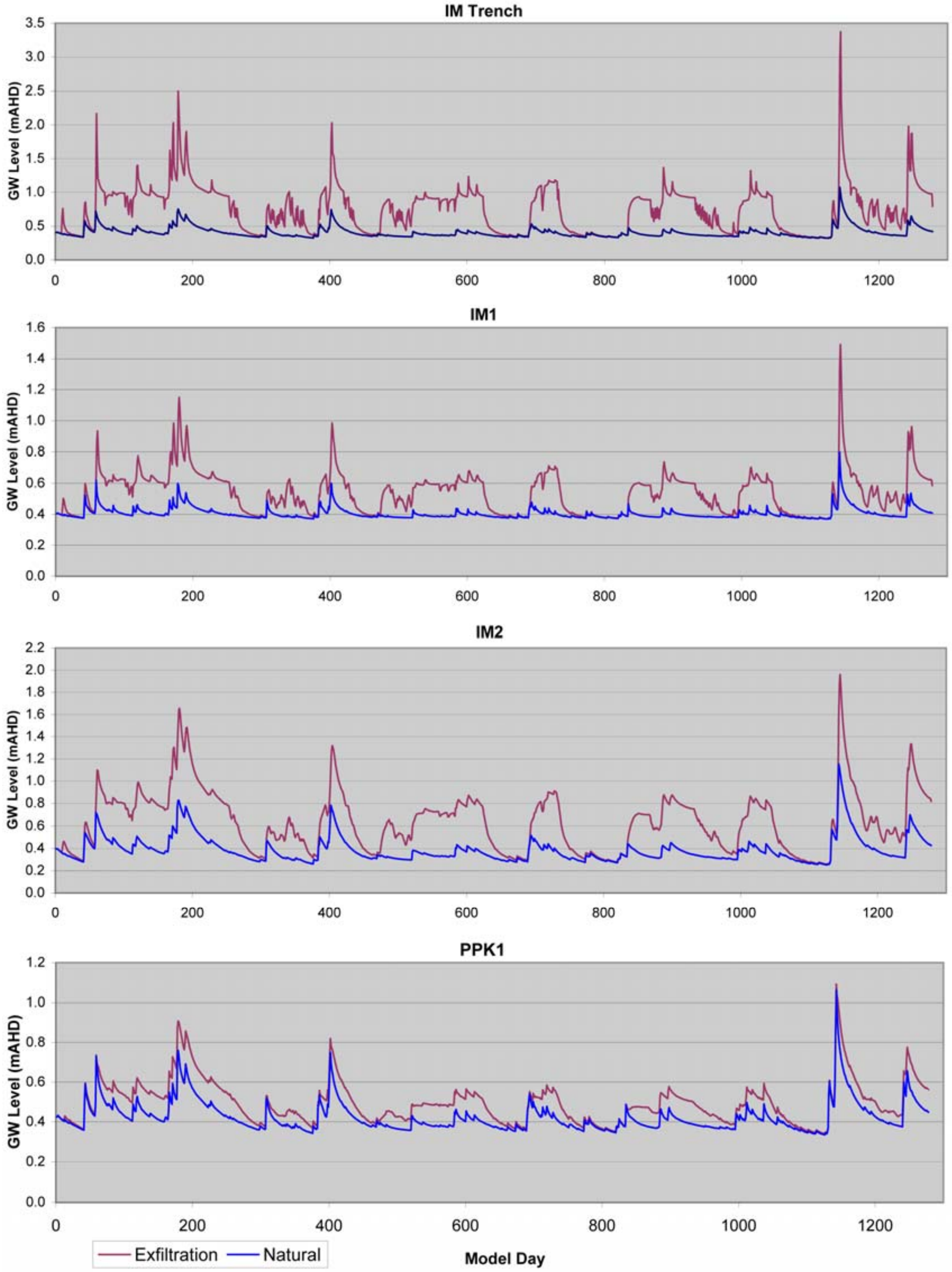
	Ocean	Lake
Natural Groundwater Discharge (m^3/d)	-373	1,512
Net Groundwater Discharge (m^3/d)	239	1,717
Increase in Groundwater Discharge (m^3/d)	612	205
Percentage of Effluent Reaching Water Body	73%	24%
Travels Times (days)	200	>3,000

Average exfiltration discharge over the period is 840 m^3/day (0.84 ML/d) of which 73% is expected to discharge to the ocean and 24% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.3.2 400 m Trench - 2025 Loadings

Hydrographs of groundwater levels at bore PPK1 and the imaginary wells IM1, IM2 and IM3 located in the centre of the exfiltration trench are provided in *Figure 11.17*.

Figure 11.17: BVSC Land Area 400 m Trench, 2025 Loading

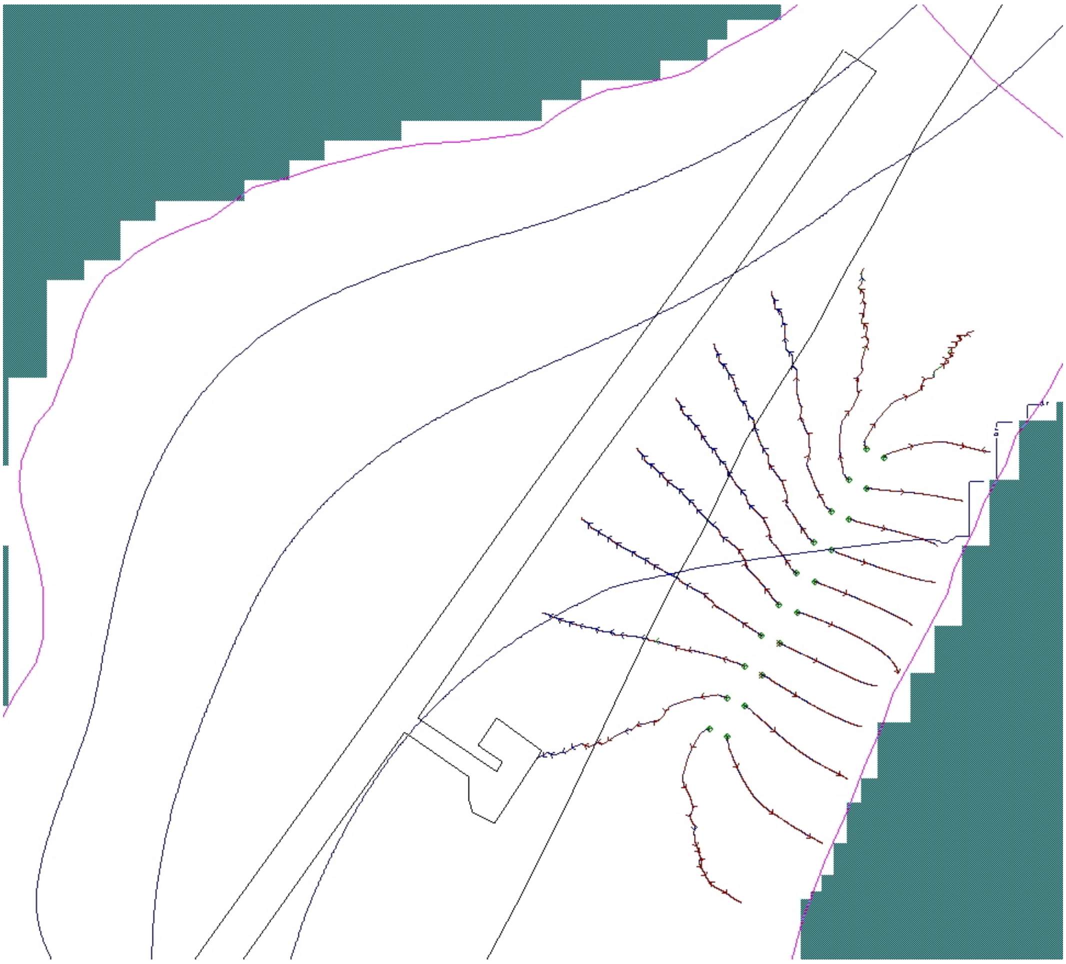


These show that groundwater levels are typically increased by 0.56 m immediately beneath the middle trench cells during periods of effluent discharge with peak levels up to 2.3 m higher than natural peaks. Groundwater levels are typically increased by 0.21 m at IM1 and 0.42 m at IM2, with peak increases of up to 0.67 m at IM1 and 0.72 m at IM2. IM1 is located c.95 east of the trench and IM2 c.115 m west, the lesser typical response at IM1 reflecting proximity to the ocean which act as a constant head boundary.

Exfiltration results in slightly smaller groundwater level rises than for the central area largely because of the increase in aquifer transmissivity both in general and as a result of the area being further from the limit of the shallow aquifer where it meets the hill to the south.

Exfiltration has a similar effect on the groundwater flow regime to that noted for the other sites, with increased development of the groundwater recharge mound and increases in hydraulic gradients and in groundwater flow, particularly towards the ocean. Travel times are predicted to be over 2,000 days for groundwater from the trench area to reach the lake and 180 days for it to reach the ocean. Particle pathlines predicted by MODPATH are shown in *Figure 11.18*.

Figure 11.18: Model Pathlines, BVSC Land Area, 2025 Loading



The predicted effects of exfiltration on the groundwater discharge regime are summarised in *Table 11.6*.

Table 11.6: Effect of Exfiltration on Groundwater Discharge Regime, BVSC Land, 2025 Load (Average 1,400 m^3/d)

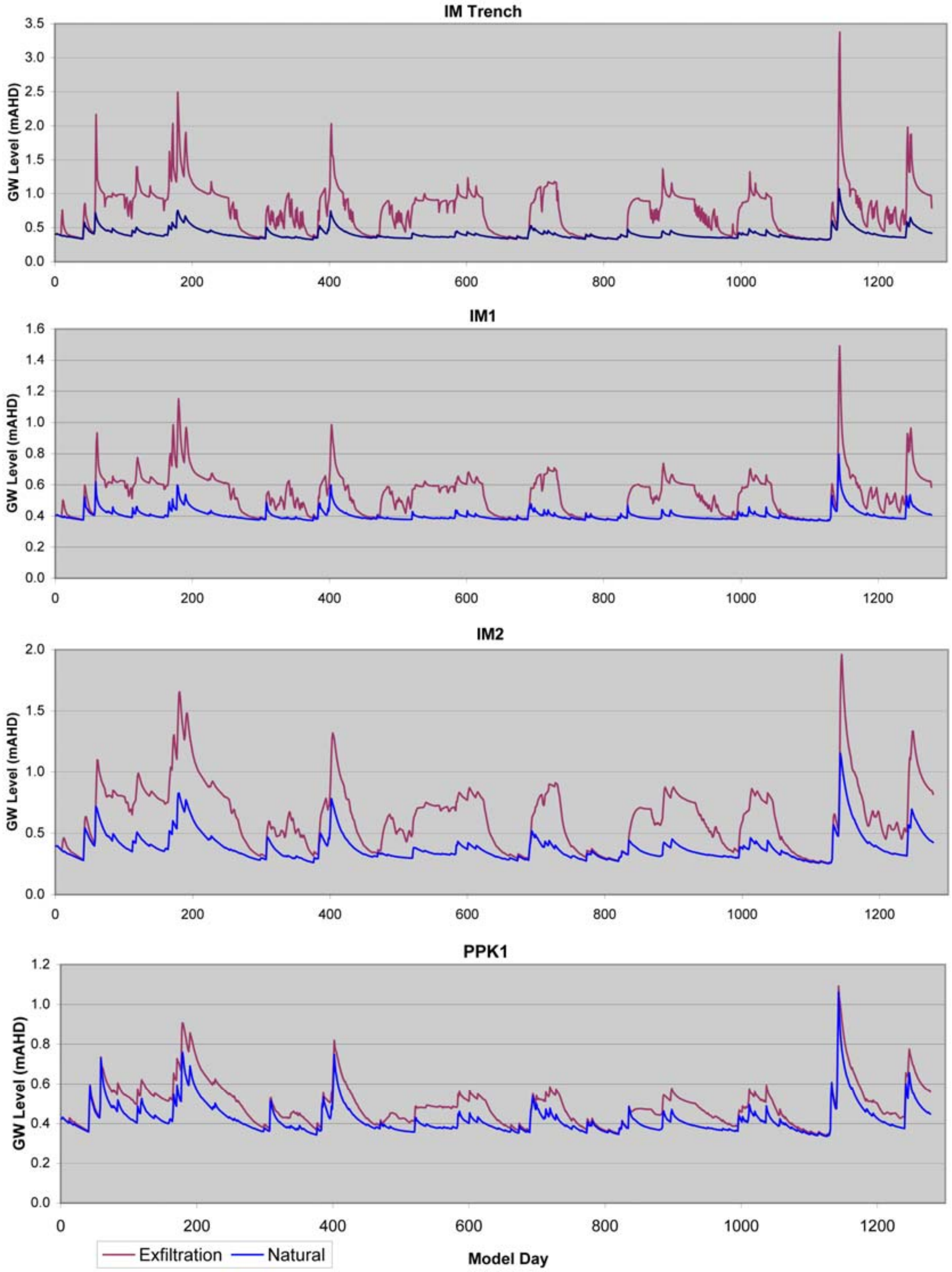
	Ocean	Lake
Natural Groundwater Discharge (m^3/d)	-373	1,512
Net Groundwater Discharge (m^3/d)	640	1,769
Increase in Groundwater Discharge (m^3/d)	1,013	257
Percentage of Effluent Reaching Water Body	72%	18%
Travel Times (days)	180	>2,000

Average exfiltration discharge over the period is 1,400 m^3/day (1.4 ML/d) of which 72% is expected to discharge to the ocean and 18% to the lake, with the remainder reflecting changes in the stored volume or increased evapo-transpiration.

11.3.3 BVSC Land Area Injection Wells – 2025 Loading

Hydrographs of groundwater levels at bore PPK1 and the imaginary wells IM1, IM2 and IM3 located in the centre of the exfiltration trench are provided in *Figure 11.19*.

Figure 11.19: BVSC Land Area Injection Wells, 2025 Loading



These show that groundwater levels are typically increased by 0.64 m in the central injection well model cell during periods of effluent discharge with peak levels of up to 4.03 mAHD, up to 2.95 m higher than natural peaks. Groundwater levels are typically increased by 0.21 m at IM1 and 0.41 m at IM2, with peak increases of up to 0.64 m at IM1 and 0.69 m at IM2. The groundwater level response to injection of effluent is very similar to that predicted for an exfiltration trench except for increased peak levels in the model injection well cells (by up to 0.64 m). It should be noted that this is based on the assumption within MODFLOW that the injection well occupies the entire model cell (c.5 m x 5 m) and the response at a real injection well will be greater (although this effect will be very localised).

The effects of effluent injection using wells are otherwise very similar to equivalent disposal by an exfiltration trench.

12. Assessment and Review of Disposal Options

12.1 Impact on Groundwater Levels

The predicted rise in groundwater levels resulting from effluent discharge from an exfiltration trench located in each of the three areas is summarised in *Table 12.1*.

Table 12.1 Summary of Predicted Groundwater Level Rise (m)

Location	Central Area		Northern Area		BVSC Area	
	2011	2025	2011	2025	2011	2025
Typical Groundwater Level Rise (Model Day 226)						
Trench	0.56	0.68	0.30	0.39	0.42	0.56
IM1	0.23	0.27	0.14	0.18	0.16	0.21
IM2	0.35	0.42	0.16	0.21	0.32	0.42
Peak Groundwater Level Rise (Model Day 1,144)						
Trench	2.6	2.9	1.77	2.14	1.79	2.29
IM1	0.78	1.04	0.55	0.81	0.38	0.67
IM2	0.35	0.48	0.22	0.50	0.36	0.72

The greatest groundwater level rise is predicted for the central area and the smallest for the northern area, reflecting the increase in aquifer transmissivity that occurs from south to north. The northward narrowing of the peninsula is also likely to have an effect as closer proximity to the ocean and lake boundaries will reduce development of a recharge mound and therefore limit groundwater levels under natural conditions and with effluent discharge.

The potential impacts of groundwater level rise are limited for all locations, particularly the northern area and BVSC land as neither of these are close to low-lying areas or existing wetlands. No substantial increase in the area of waterlogging associated with the low-lying areas around bore A1 or the wetlands located south of the existing ponds is predicted for effluent discharge in the central area although some may occur under sustained, high rainfall conditions.

Discharge of effluent via wells is not predicted to result in appreciably greater groundwater level rise than that resulting from an exfiltration trench along an equivalent area except for localised effects close to the wells and during periods of high discharge. An injection well arrangement of 9 wells at 50 m spacings was assumed during this study and local groundwater level rises will be greater if fewer wells are used. It should also be noted that the predicted groundwater levels are based on the assumption within MODFLOW that the injection well occupies the entire cell (c.5 m x 5 m) and an increased response will occur in and immediately around a real injection. An indication of this is provided by the drawdown responses in the production wells during pump testing which showed maximum drawdowns of 2.25 m and 1.72 m for CPW and NPW respectively, of which around 1.8 m and 1.4 m are considered to be due to localised well effects. These effects may produce localised additional peaks several metres higher than those predicted. This is not expected to result in adverse impacts on the groundwater system but may limit injection rates.

The effects of effluent injection using wells are otherwise very similar to equivalent disposal by exfiltration.

12.2 Influence on the Groundwater Flow Regime

Discharge of effluent to the sand aquifer will alter the natural groundwater flow regime to varying extents depending on the discharge location and climatic/discharge conditions. The greatest change occurs with discharge at the northern area as the prevailing natural conditions are of net flow from the ocean to the lake via the groundwater system in this area, and discharge of effluent will result in increased development of a groundwater recharge mound and flow divide. It does not appear likely that this will have any noticeable impact as its effect will be to cause a small decrease in the flux of saline water from the ocean discharging to an estuarine water body, i.e. Merimbula Lake. This flux is expected to be negligible compared to the daily volume of tidal water exchange.

Changes to the flow regime will be less noticeable beneath the central and BVSC land areas.

The effects of discharge from the three sites on the groundwater flow regime can be compared by considering the relative changes to groundwater discharge to Merimbula Lake and to the Ocean. It should be noted that small changes are predicted to these fluxes between the three model scenarios under natural conditions because of changes made to the model grids to ensure accurate representation in the key area of interest for each.

The average daily discharges predicted by the transient simulation model runs are summarised in *Table 12.2*.

Table 12.2 Summary of Groundwater Discharge Regimes (average m^3/day)

Scenario	Net Groundwater Discharge to Lake	Net Groundwater Discharge to Ocean	Effluent Discharge[1]	Effluent to Lake	Effluent to Ocean
	m^3/day	m^3/day	m^3/day	%	%
Central Natural	1,512	-373	0	NA	NA
Central 2011	1,647	309	840	16	81
Central 2025	1,697	697	1,400	13	76
Northern Natural	1,654	-383	0	NA	NA
Northern 2011	1,824	186	840	20	66
Northern 2025	1,933	551	1,400	20	67
BVSC Natural	1,512	-373	0	NA	NA
BVSC 2011	1,717	239	840	24	73
BVSC 2025	1,769	640	1,400	18	72

Notes. 1: Average daily effluent discharge for simulation period (m^3/day is equivalent to kL/day).

This shows that under natural conditions the model shows net movement of groundwater towards the lake with a net average discharge of groundwater to Merimbula Lake of 1,512 m^3/d to 1,654 m^3/d and net recharge of groundwater <u>from</u> the ocean of 373 m^3/d to

383 m^3/d. It should be noted that this applies to the model area as a whole and it is expected that net discharge of groundwater to the ocean will be the prevailing condition beneath the southern part of the model area (including the central area).

Effluent disposal results in increased groundwater discharge to the lake and particularly to the ocean. Disposal to the northern area results in the greatest proportion of effluent discharging to the lake. Discharge to the central and BVSC land areas result in similar proportions discharging to the lake although the proportions are slightly higher for the BVSC area.

The totals of the predicted proportions of effluent discharging to the lake and ocean are close to 100% for all areas with minor discrepancies probably due to two factors: changes in the volume of groundwater stored within the aquifer due to increased groundwater levels; and, increased evapo-transpiration where groundwater levels are closer to the ground surface. The latter is expected to be a small factor, particularly for the Northern and BVSC areas which are not located close to low-lying areas. Given a sufficiently long simulation period the change in aquifer storage would be expected to become negligible.

12.3 Consideration of Areas of Impact

Additional model runs have been undertaken to assist with understanding and assessment of the likely main areas of the groundwater system impacted by effluent discharged at three locations under consideration. These comprise steady state models based on average conditions including average projected 2025 effluent loads with MODPATH used to track particles and indicate the area of impact from each location. Effluent is expected to influence a wider area than that indicated using this approach but it will provide a useful indication of the areas of greatest likely impact.

Central Area

The groundwater flow regime under average conditions with effluent discharge is such that the groundwater divide is located west of the discharge location with groundwater levels of around 1 mAHD beneath the line of discharge. As a result, particle tracking indicates that groundwater from the trench area all discharges to the ocean, with travel times varying from around 100 days for particles from the ocean side of the trench to over 5,000 for particles commencing from the middle of the western side of the trench which follow a semi-circular pathway travelling first west then gradually being diverted either north or south and eventually following an easterly path.

Northern Area

The groundwater flow regime under average conditions is such that a groundwater divide with a water table elevation of up to 0.7 mAHD is formed beneath the line of discharge. Groundwater travels both to the ocean with travel times of at least 220 days and to the lake with travel times of at least 780 days.

BVSC Land Area

The groundwater flow regime under average conditions with effluent discharge is such that a local groundwater divide develops beneath the line of discharge with groundwater levels of up to 0.9 mAHD. Particle tracking indicates that groundwater from the eastern side of the line of discharge travels to the ocean with travel times of at least 150 days. Groundwater from west of the line of discharge generally travels to the lake with travel times of at least 3,500 days. Groundwater from west of the very southern end of the line of discharge predicted to travel to the ocean in the same manner as that noted for the central area, with travel times of at least 450 days.

12.4 Estimated Groundwater Travel Times

Travel times for discharged effluent to reach Merimbula Lake and the Ocean have been estimated based on transient conditions (i.e. from MODPATH outputs from the transient simulations with extrapolation where required) and under average steady-state conditions. The former are more representative of actual groundwater behaviour. Estimated travel times are summarised in *Table 12.3*.

Table 12.3 Summary of Predicted Groundwater Travel Times (Days)

Receptor	**Central Area**		**Northern Area**		**BVSC Area**	
	2011	**2025**	**2011**	**2025**	**2011**	**2025**
Transient Simulation Model						
Ocean (transient)	120	110	350	190	200	180
Lake (transient)	5000+[1]	4000[1]	1200	850	3000+[1]	2000+[1]
Steady State Simulation Model[2]						
Ocean	-	100	-	220	-	150
Lake	-	NA[3]	-	780	-	3500

Notes. 1: travel times exceed the model period (c.1,300 days) and are therefore estimated. 2: steady state simulations were only run for average 2025 loadings. 3: under steady state conditions all groundwater from the exfiltration/injection system is predicted to discharge to the ocean.

Groundwater travel times provide an indication of the potential for attenuation of contaminants. As a very general guide, well head protection zones for town supply bores are typically based on travel times of at least 50 days for inner zones (for die-off of most pathogenic micro-organisms) and at least 400 days for out zones to allow attenuation of other contaminants (DLWC, 1998).

Predicted travel times to the ocean under 2025 loadings are 110 days for the central area and 180 to 190 days for the northern and BVSC land areas.

13. Assessment of Potential Water Quality Impacts

Disposal of treated sewage effluent to the shallow groundwater system has the potential to result in adverse impacts on water quality of the groundwater resource itself and on the quality of groundwater discharging to environmental receptors.

13.1 Beneficial Use of the Shallow Groundwater System

Assessment of potential impacts requires identification of the beneficial uses of the shallow groundwater system. This requires consideration of groundwater quality and of the volume of groundwater which may be available.

Groundwater quality is somewhat variable and can be characterised into three types:

- Fresh water under acidic and sometimes reducing conditions in the area south of the existing ponds and close to the wetlands;
- Fresh to brackish water under mildly oxidising conditions and neutral or slightly alkaline pH forming a freshwater lens beneath the central part of the peninsula and extending to the northern part under high rainfall conditions;
- Saline water in the deeper parts of the shallow aquifer, occupying much of the aquifer thickness beneath the northern part of the peninsula.

Otherwise, groundwater quality is generally reasonable with fairly low levels of iron, manganese and nutrients. Some dissolved metal concentrations exceed the ANZECC 2000 default trigger levels for protection of aquatic ecosystems for toxicants including arsenic, copper and zinc. Arsenic levels exceeded ANZECC and WHO drinking water guidelines in all samples collected and one sample exceeded the ANZECC guideline for recreation. These concentrations are considered to represent background water quality and limit the beneficial use for which shallow groundwater is suitable.

The beneficial uses for groundwater from the shallow aquifer are as follows:

- Small-scale domestic use such as garden watering, car-washing etc; and perhaps limited irrigation of parks etc. Excessive pumping would be likely to draw in saline groundwater and great care would be needed with use of anything other than shallow wells for small-scale supply;
- Maintenance of aquatic ecosystems through groundwater discharge to wetlands and groundwater dependent ecosystems;
- Groundwater discharge to Merimbula Lake and the ocean and associated aquatic ecosystems.

The wetlands located south of the existing ponds are considered to be Groundwater Dependent Ecosystems and include open water bodies with water levels reflecting the local water table. Some vegetation in the low-lying parts of the dune system (such as around A1) may also have some reliance on groundwater given its shallow occurrence in these areas. Wetlands also occur around Merimbula Lake and these will receive some groundwater flow; however, they are likely to comprise salt marshes and proximity to the lake means that they are unlikely to be reliant on groundwater.

Protection of aquatic ecosystems is considered to be the most sensitive beneficial use of groundwater in the study area.

13.2 Potential Contaminants

The key potential contaminants in treated sewage effluent are as follows:

Nutrients

Nitrogen and phosphorus are present at elevated levels in treated effluent compared to those generally occurring in the aquatic environment. Effluent from the Merimbula STP (BVSC, 2010) shows a median nitrogen concentration of 0.5 mg/L as ammonia, 2 mg/L as oxidised nitrogen (nitrate and nitrite) and total nitrogen of 5 mg/L. Median nitrogen levels in treated effluent are considered to be low. Examination of the full dataset shows that mean nitrogen concentrations are slightly higher due to regular peaks in concentration occurring over 3 to 4 months in the earlier part of each year, giving rise to a mean TIN concentration of 4.4 mg/L. It is understood that these periods of elevated nitrogen concentrations are likely to arise as a result of over-aeration as influent loads decline at the end of the holiday period and it is anticipated that improved plant management will rectify this situation.

Phosphorus is present at median concentrations of 8.5 mg/L as orthophosphate and 9.5 mg/L as total phosphorus. These levels show little variation and are similar to those found in raw sewage indicating that limited phosphorus removal occurs during treatment. There is the potential to reduce phosphorus concentrations in treated effluent to around 1.5 mg/L with additional treatment.

Organic Carbon

A measure of the amount of organic carbon is provided by the biochemical oxygen demand (BOD) which has a median value of 4 mg/L, a low value for treated sewage effluent. The presence of organic carbon exerts an oxygen demand during biological degradation which can result on reduced levels of dissolved oxygen in receiving waters.

Pathogenic Micro-organisms

Sewage contains micro-organisms that can be harmful to humans, including bacteria and viruses. The majority of these are removed during the treatment process but some remain in the treated effluent. Analysis for faecal coliforms is provided and gives an indication of the general load of pathogenic micro-organisms. The median value used in this report is 65 colony forming units per 100 mL (cfu/100 mL) based on data collected from August 2009 to April 2010, after the commissioning of the STP chlorinator. Inclusion of data collected to February 2011 gives a lower median faecal coliform value of 35 cfu/100mL.

Other Contaminants

Industrial Contaminants

Industrial contaminants in sewage effluent can include heavy metals, organic solvents, etc. Industrial activity in the Merimbula area is limited and the presence of such compounds at elevated levels is considered very unlikely.

Surfactants

Surfactants are found in detergents and similar compounds and can increase the mobility of organic compounds. Typical domestic surfactants are generally broken down during the sewage treatment process with any remainder unlikely to be persistent in groundwater.

Biologically Active Compounds

A number of compounds are found in sewage effluent that are biological active including endocrine-disrupting compounds and pharmaceuticals. The behaviour of these substances in the environment is complex and poorly understood and while concentrations are typically very low, adverse impacts on aquatic ecosystems have been shown from direct discharge of effluent to surface waters. Some studies suggest that mobility in groundwater is low (Sonzogni *et al*, 2006) but there have been reports of persistence of some compounds in groundwater (Musolff, 2009).

13.2.1 Review of Potential for Phosphorus Migration

The traditional view of the behaviour of phosphorus in relation to groundwater has been that it is generally of low mobility because dissolved phosphorus is readily adsorbed onto soil and rock particles (Fetter, 1999). In addition, the soluble form, orthophosphate, readily forms mineral precipitates (IGGC, 2005a).

This is certainly the case in most hydrogeological settings, with phosphorus rarely showing significant potential for migration in groundwater. Evidence of elevated orthophosphate levels and rising trends at PPK3 challenges this view and a brief internet-based literature review has been undertaken to assist with understanding of the fate and transport processes. The following section summarises the key publications identified during this review and their findings.

Literature Review

Impacts on a Sand Aquifer from an Old Septic System: Nitrate and Phosphate (Harman *et al*, 1996).

Phosphorus attenuation is controlled by soil adsorption and mineral precipitation reactions. Adsorption sites are principally provided by calcium carbonate, metal hydroxide coatings and solid organic carbon. Precipitation may provide unlimited capacity to fix phosphorus provided that solution and soil chemistry is conducive. Adsorption capacity can be exhausted with long-term loading.

Investigation of a 44 year-old septic system located on a homogenous, calcareous, fine to medium-grained sand aquifer low in organic carbon showed dissolved phosphate concentrations decreasing from 9 mg/L at outlet to 1.5 mg/L at the water table c.1.5 m below. It was concluded that this attenuation in the unsaturated zone was controlled by precipitation with all available adsorption sites already utilised. It is suggested that lowered pH in parts of the unsaturated zone may cause dissolution of aluminium or iron, the increased dissolved concentrations of which may result in precipitation of aluminium or iron phosphate minerals.

Little phosphate attenuation was observed in the first 60 m of the saturated zone plume. Phosphate attenuation occurred between 60 m and 70 m distance, apparently due to sorption. Precipitation does not appear to be occurring in the saturated zone with data suggesting that mineral phases are in equilibrium. The phosphate plume front is advancing with an effective retardation factor of 60.

Phosphate Plume Persistence at Two Decommissioned Septic System Sites (Robertson and Harman, 1999).

Long-term monitoring of two well-characterised, oxidising septic system plumes over periods of two to four years after decommissioning revealed that ground water orthophosphate concentrations of 0.4 to 5 mg/L persisted at levels virtually unchanged from those observed during active sewage loading, with the phosphate plume continuing to advance during this period at one of the sites. This evidence suggests that phosphate behaviour in the groundwater zone at these sites is dominated by sorption reactions which are both rapid and reversible. In these settings, phosphorus has the potential to be both persistent and mobile. In addition, where sorption is the key attenuation mechanism, there is evidence that de-sorption can mean that impacts continue for some time after decommissioning.

Enhanced Attenuation of Septic System Phosphate in Non-Calcareous Sediments (Robertson, 2003).

Review of phosphate behaviour in groundwater plumes from four mature septic systems on sand aquifers revealed a strong correlation between carbonate mineral content and phosphate concentrations. A plume on calcareous sand showed average proximal groundwater phosphate concentrations of 4.8 mg/L, c.75% of the septic tank effluent value. Three plumes on non-calcareous sand showed proximal groundwater phosphate concentrations consistently less than 2% of effluent concentrations. Phosphate attenuation at the non-calcareous sites appears to be an indirect result of the development of acidic conditions with average pH values of 3.5 to 5.9 and elevated aluminium concentrations (up to 24 mg/L), which subsequently causes the precipitation of Al-P minerals. This is supported by scanning electron microscope analyses, which show the widespread occurrence of (Al-P)-rich secondary mineral coatings on sand grains below the infiltration beds. All of these septic systems are more than 10 years old, indicating that these attenuation reactions have substantial longevity. A field lysimeter experiment demonstrated that this reaction sequence can be incorporated into engineered wastewater treatment systems.

Phosphorus Transport in Sewage-Contaminated Ground Water, Massachusetts Military Reservation, Cape Cod, Massachusetts (Walter et al, 1999).

Disposal of treated sewage effluent at the Massachusetts Military Reservation between 1936 and 1995 has created a plume of contaminated groundwater in the underlying sand and gravel aquifer in which dissolved phosphorus concentrations can exceed 10 mg/L, with concentrations as high as 2 mg/L at the point of discharge into nearby Ashumet Pond. Phosphorus is transported in two geochemical environments in the plume: an anoxic environment in which phosphorus is closely associated with dissolved iron and no dissolved oxygen, and a more extensive suboxic environment in which there is low, but detectable, dissolved oxygen and no dissolved iron. Adsorption of phosphorus onto iron and aluminium oxides has greatly retarded the movement of phosphorus relative to groundwater velocities but continued loading has created a large reservoir of sorbed phosphorus and allowed for the breakthrough and significant transport of dissolved phosphorus. High concentrations of dissolved phosphorus along the edges of the plume may result from desorption in response to an influx of clean water. It is concluded that dissolved phosphorus could remain at elevated levels for long periods of time after other plume constituents have been flushed from the aquifer.

Interpretation of Phosphorus Behaviour at Merimbula

The sand strata of the upper aquifer at Merimbula comprise fine to medium-grained sand with rounded grains. The strata beneath the frontal dunes are generally moderately to well sorted and commonly include shell fragments; groundwater is typically slightly alkaline. Strata beneath the back-dunes are similar but perhaps slightly finer and less well sorted; shell fragments sometimes occur at depth. Groundwater generally appears to be neutral or slightly alkaline based on limited data from the original investigation (MM, 1987) but becomes acidic but still with some alkalinity as the water table becomes shallower in the area of A1. BH10 shows neutral or slightly acidic conditions with moderate alkalinity.

Strata beneath the wetlands are of similar composition although shell fragments are absent (possibly due to dissolution) and organic matter occurs. Groundwater is acidic and alkalinity low.

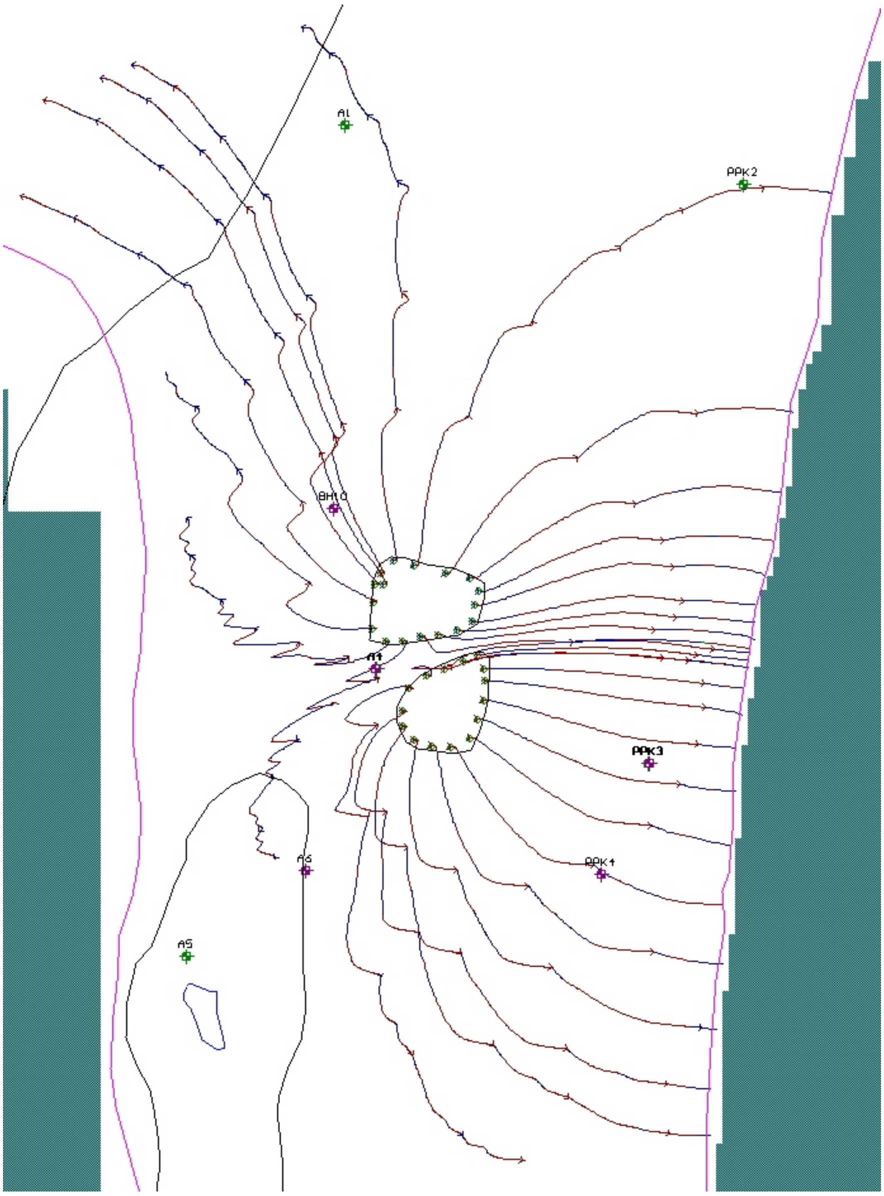
Groundwater conditions in the upper aquifer with respect to phosphorus are as follows:

- Potential for retardation due to sorption is limited by absence of clay particles. There is potential for sorption on metal hydroxides coating the sand grains and by calcium carbonate where shell fragments are present. Some adsorption by organic carbon may occur, where present;

- Potential for precipitation occurs where groundwater conditions are, or may become, acidic and reducing. This is likely around the wetlands located in the low-lying back-dune area south of the ponds. Redox conditions across the majority of the shallow aquifer are mildly oxidising although biodegradation of additional organic carbon from effluent has the potential to encourage development of reducing conditions. These may already occur in the deeper part of the aquifer and beneath the low-lying back-dune areas further north and around Merimbula Lake.

Further assessment of existing phosphorus impacts has been undertaken using the numerical groundwater model described in *Section 10*. A variant of the model was developed to allow simulation, in a relatively simple manner, of groundwater behaviour since use of the exfiltration ponds re-commenced in 2005. The hydraulic model uses monthly stress periods to represent rainfall and STP pond loadings and thereby generate average monthly groundwater flow conditions. The MODPATH package was then used to show the movement and eventual fate of effluent discharged to the ponds and the area potentially impacted. They also provide travel times along each pathline. A plot of the modelled pathlines with tick marks at 365 day intervals is provided as *Figure 13.1*.

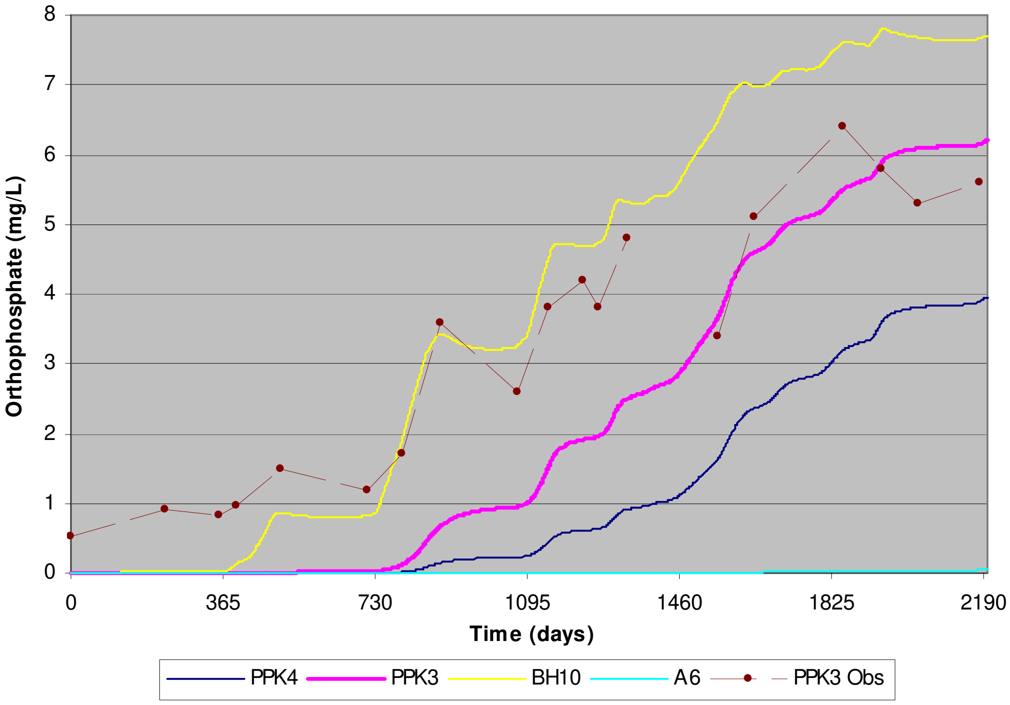
Figure 13.1. Predicted Pathlines from Exfiltration Ponds, 2005 to 2010



This shows the area potentially impacted by effluent and the effect on groundwater movement of periodic discharge to the ponds. Impacts on groundwater will generally decrease with travel time due to a range of attenuation processes including dilution. Travel time from the ponds to PPK3 and PPK4 is predicted to be around one year while that to BH10 is around 3 months. PPK2 and A6 have predicted travel times of 5 years or more.

The contaminant transport package MT3D was then used to predict impacts assuming uniform conditions. A simple retardation factor was applied to represent sorption and this factor was adjusted by trial and error until breakthrough and final concentration were similar to those observed at PPK3. This was achieved using a retardation factor (K_d) of 0.1 mL/g. A graph of model results is presented as *Figure 13.2*.

Figure 13.2. Predicted Contaminant Transport Model Results for Bore PPK4, PPK3, BH10 & A6 for Orthophosphate Calibrated on and Compared with PPK3 Observed Concentrations



This graph shows predicted orthophosphate breakthrough time (c.2 years) and final concentration at PPK3 being similar to that observed. Assuming the same conditions, concentrations at BH10 would be expected to reach a peak of around 7.5 mg/L compared to the observed peak level of 0.88 mg/L. Breakthrough is also predicted at PPK4 with a peak level of nearly 4 mg/L and there is little evidence of this occurring except for some indication of slightly increasing concentrations during 2011 and 2012 (maximum value 0.96 mg/L).

The implication from this is that groundwater conditions with respect to orthophosphate are different at PPK3 to those at BH10 and at PPK4. With regard to BH10 this is not altogether surprising as, although some alkalinity is present in groundwater, conditions are typically slightly acidic and this may be sufficient for release of aluminium or iron and precipitation of phosphorus minerals. Breakdown of the organic carbon present in the effluent and/or strata may be sufficient to produce the slight acidity seen at BH10. The reason for the difference in results between PPK3 and PPK4 is less clear as groundwater conditions would be expected to be similar. Examination of the bore logs (PPK, 2002) indicates the presence of peaty organic matter at PPK4 (note: this was originally recorded as PPK1 due to an error in the original bore numbering). This would provide greater sorption capacity than that of the cleaner sands recorded at PPK3 and may be a factor in the greatly reduced phosphorus impact at PPK4. In addition, while dissolved oxygen levels are reasonably low at both sites, groundwater is under slightly oxidising to slightly reducing conditions at PPK3 but consistently reducing at PPK4, perhaps due to decomposition of the organic matter in the strata. Further investigation and assessment of the potential for phosphorus attenuation in the dunal groundwater system has been undertaken to determine whether the conditions at PPK3 are unusual or are representative of those typically found beneath the frontal dune system.

Results of Analysis of Aquifer Material

Analysis of aquifer material was undertaken for speciated carbon and phosphorus retention index to provide additional information on the potential for phosphorus sorption and retardation. Four samples collected during the drilling and test production well installation program were submitted for laboratory analysis for Phosphorus Retention Index (PRI) and speciated carbon.

PRI is a simple and robust qualitative test for phosphorus retention that provides an indication of the ability of a material to retain phosphorus by sorption. PRI test results generally under-estimate actual phosphorous sorption potential as the high concentration in the test solution rapidly exhausts sorption sites (Patterson, 2001).

PRI testing allows estimation of the distribution or partition co-efficient (K_d) for phosphorus. The distribution co-efficient describes how a solute is distributed between dissolved-phase and adsorbed-phase for a particular aquifer matrix and allows sorption and retardation of the solute to be calculated and modelled.

Speciated carbon includes total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC). When present in an aquifer matrix, organic carbon provides sorption sites for phosphorus and other contaminants and its measurement provides insight into the processes responsible for sorption.

Laboratory reports are attached and results are summarised in *Table 13.1*.

Table 13.1: Summary of Aquifer Material Analysis

Sample	**PRI** %	**PRI** mg/kg	**Classification**	**TC** %	**TOC** %	**TIC** %	K_d mL/g
C1(10m to 12m)	89.6	5,279	High	1.04	0.01	1.03	43.1
C1 (16.5m)	79.8	4,707	High	0.87	0.02	0.85	19.8
N2 (11m)	74	4,362	High	0.74	0.01	0.73	14.2
N2 (18m)	36	2,121	Medium	0.44	0.1	0.43	2.8
Average	66.9	4,117		0.8	0.04	0.8	11.6
Geometric Mean	66.1	3,894		0.7	0.02	0.7	13.6

Results show that all samples show substantial ability to retain phosphorus with three samples showing high PRI and one medium PRI. All samples show low to very low values of TOC, with the great majority of carbon present in inorganic form (probably as carbonate).

The likely distribution co-efficient (K_d) for phosphorus has been estimated based on the PRI results. The K_d values shown in *Table 13.1* are substantially higher than the 0.1 mL/g value estimated for the area between the existing exfiltration ponds and PPK3 obtained from calibration of a numerical model against observed impacts at PPK3. This indicates that phosphorus sorption on aquifer material will be much greater in the areas considered for a future exfiltration system than that estimated for the area around PPK3 and therefore the potential for phosphorus migration across the study area as a whole is expected to be substantially lower.

The differences in PRI results and equivalent K_d values are likely to reflect differences in the nature of the strata between the areas. Given the absence of organic carbon, phosphorus sorption is expected to be due largely to metal hydroxides and/or carbonate minerals. These are expected to be present at greater levels in the strata beneath the central and northern areas than in those beneath the area between the existing exfiltration ponds and PPK3. It should be noted that PPK3 is the only monitoring bore that has showed appreciable phosphorus impacts from the existing exfiltration ponds. PPK4 also lies within the groundwater plume and has shown no significant impact from phosphorus other than perhaps a minor recent rise indicating that the effective K_d value is substantially higher between the ponds and PPK4 than it is between the ponds and PPK3.

13.2.2 Potential for Migration of Nitrogen Species

Inorganic nitrogen is generally one of greatest concerns with respect to groundwater-related impacts from nutrients from sources including effluent disposal. It is present in the effluent at median levels of around 0.5 mg/L N as ammonia and 2 mg/L N as NO_x (oxidised nitrogen - almost all will be present as nitrate as nitrite is very unstable). Current mean concentrations of TIN (NO_x plus ammonia) are around 4.4 mg/L because of seasonal spikes in concentration.

Nitrate is not removed significantly by sorption or precipitation reactions and is generally stable in solution in groundwater systems when oxidising conditions prevail. Under reducing conditions it can readily be reduced to nitrogen gas, a process known as denitrification (generally mediated by bacterial activity), although this process can be limited by availability of suitable electron donors such as organic carbon or sulphide. Less commonly nitrate can be reduced to ammonia.

The key mechanism for inorganic nitrogen removal is usually denitrification through nitrate reduction by oxidation of organic matter. This process is bacterially mediated: it can occur at dissolved oxygen concentrations up to half of air saturation (i.e. 50% saturation or around 6 mg/L for fresh water) and is accompanied by increases in molecular nitrogen gas, bicarbonate, pH and inorganic carbon (Appelo & Postma, 1999). The process is generally limited by availability of organic matter rather than of nitrate and this can lead to decreasing rates of denitrification as organic carbon in the substrate become exhausted (Chapelle, 2000). Denitrification can be accompanied by generation of ammonia during anaerobic decomposition of organic matter (Fetter, 1999).

Sulphide minerals such as pyrite can act as electron donors for denitrification, generally in the absence of organic carbon. The resulting pyrite oxidation is often incomplete as denitrification using iron(II) takes place at a much slower rate than that using sulphur, giving rise to increases in ferrous iron as well as sulphate in groundwater. This process can also give rise to increases in arsenic concentrations in groundwater where arsenopyrite minerals (FeAsS) are present.

Groundwater in the shallow dunal system at Merimbula is generally under slightly oxidising conditions although reducing conditions occur in some areas, particularly around the wetlands and in the deeper parts of the shallow aquifer. Discharge of effluent by exfiltration will provide an additional source of organic carbon into the groundwater system, degradation of which will reduce dissolved oxygen levels, tending to make groundwater conditions more reducing and therefore encouraging denitrification processes. Examination of groundwater quality data for bores PPK3 and PPK4 shows mean groundwater concentrations of inorganic nitrogen of around 20% to 25% of those in effluent with peak concentrations occasionally approaching 50% of mean effluent concentrations. This indicates substantial removal of inorganic nitrogen from the groundwater system and is likely to be typical for the shallow groundwater system. In fact groundwater conditions in areas closer to the lake would be expected to be more reducing and to show increasing occurrence of organic material.

Data from PPK3 and PPK4 have been used to calibrate a simple numerical model of groundwater flow and TIN behaviour around the existing exfiltration ponds. Removal of nitrate by denitrification is a biodegradation process and is therefore treated as an irreversible first-order decay reaction. The contaminant transport package MT3D was then used in a similar manner to that described for orthophosphate in *Section 3.2.1* using the same transient groundwater flow model to predict inorganic nitrogen impacts assuming uniform conditions. A simple first-order rate constant was applied to represent removal of nitrate and this constant was adjusted by trial and error until predicted TIN concentrations were similar to those observed at PPK3 and PPK4. This was achieved using a rate constant of 0.004 days^{-1} (equivalent to a half-life of 250 days) and graphs of model results are presented as *Figure 13.3* and *Figure 13.4*.

Figure 13.3. **Predicted Contaminant Transport Model Results for PPK3 for Nitrate Calibrated on and Compared with Observed Concentrations**

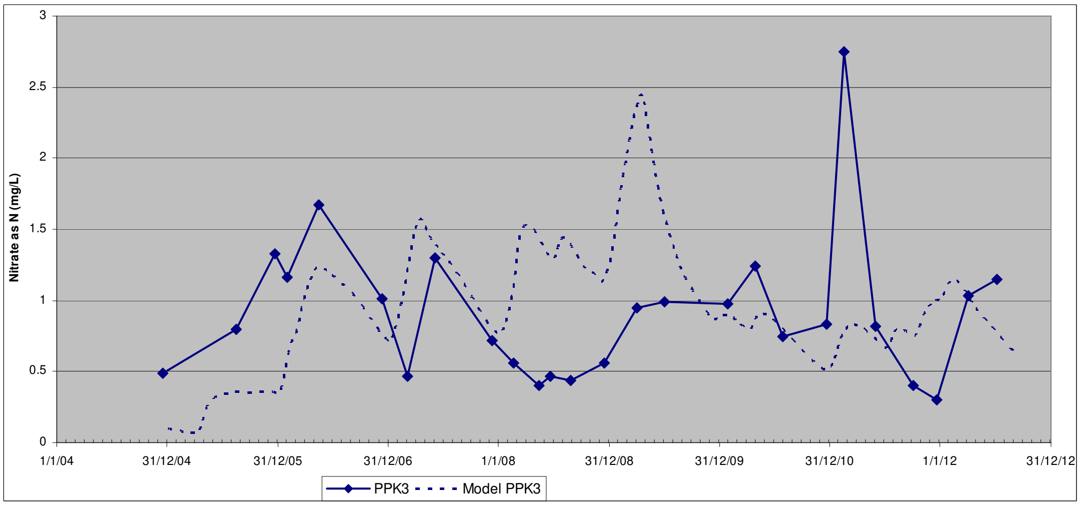
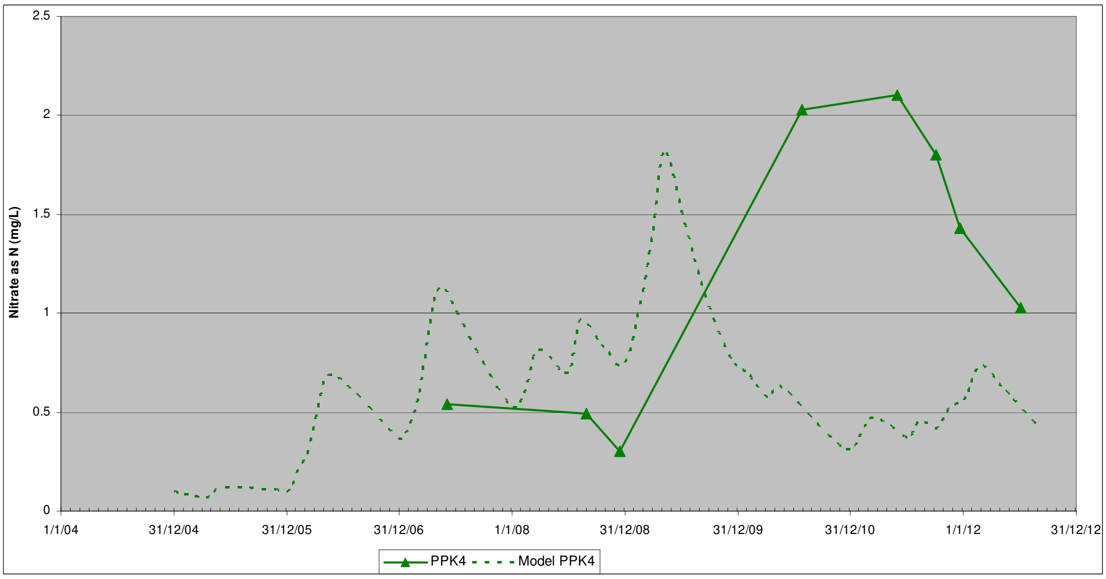


Figure 13.4. **Predicted Contaminant Transport Model Results for PPK4 for Nitrate Calibrated on and Compared with Observed Concentrations**



This simplified approach to nitrate removal does not take account of rate-limiting factors such as presence of dissolved oxygen, absence of organic carbon etc., or of potential generation of ammonia from organic matter; however the model provides a reasonable approximation to observed nitrate behaviour and provides further support for nitrate removal being a result of denitrification. A rate constant of 0.002 was selected for use in simulation of potential impacts from exfiltration. This is 50% of the value predicted from observational data to provide a conservative assessment.

Background nitrate levels in groundwater in SE Australia are generally below 2 mg/L (LWRRDC, 1999). Levels would be expected to be low beneath a low-nutrient, largely undisturbed area such as the Merimbula dunes and this is generally the case, with very low levels (around 0.1 mg/L) seen in the wetland and back-dune areas. Nitrate levels beneath the foredunes are slightly higher, with a range of 0.2 to 0.5 mg/L beneath the Central Area (including PPK2) and variable but sometimes higher levels beneath the Northern Area (low levels of around 0.1 mg/L at N1 but up to 1.2 mg/L at N3 and NPW. Water quality from beach sampling of the waters of Merimbula Bay show mean total nitrogen levels of 0.27 mg/L and nitrate from ocean water ingress into the groundwater system is unlikely to contribute substantially to the observed elevated groundwater concentrations. Parts of the dune system have been affected by bushfires or controlled burns in the last few years and these may give rise to pulses of recharge water with elevated nitrogen concentrations.

Ammonia is present in effluent and is also produced by decomposition of organic matter (including that in effluent) under anaerobic conditions. Ammonia is subject to sorption; mostly through cation exchange reactions with clay minerals. These processes are generally reversible and are likely to be limited by the absence of material in the sand strata offering suitable sites for cation exchange (i.e. clays or organic matter). Ammonia can also be converted to nitrate under a process known as nitrification which generally occurs under oxidising conditions.

Overall, there is considerable potential for attenuation of inorganic nitrogen from effluent during migration in groundwater providing that reducing condition are present along some or all of the flow path or are induced by the addition of organic material in the effluent. In addition the median total concentration in effluent from Merimbula STP is fairly low at 2.5 mg/L (ammonia plus NO_x). This compares to existing background concentrations of up to 1.2 mg/L beneath the northern area and c.0.3 mg/L for the central area.

13.3 Receptors

The key potential receptors for treated effluent discharged to the shallow groundwater system are as follows:

- Groundwater quality, i.e. water quality in the shallow groundwater resource and any adverse impacts which may restrict beneficial use of the resource;
- Merimbula Lake due to discharge of groundwater containing effluent. Merimbula Lake is used for oyster farming, fishing and recreation and is therefore a highly sensitive receptor;
- Ocean water in Merimbula Bay due to discharge of groundwater containing effluent;
- Groundwater Dependent Ecosystems such as wetlands;
- Groundwater users, such as property owners using shallow bores for domestic irrigation.

13.4 Prediction of Impacts on Groundwater Quality - Nutrients

The assessment detailed above suggests that there is considerable potential for attenuation of inorganic nitrogen in the sand aquifer unless oxidising conditions prevail along the entire flow path. The potential for attenuation of orthophosphate is high but may be limited in some parts of the groundwater system.

The potential mechanisms of groundwater discharge to Merimbula Lake and Merimbula Bay and potential for increased nutrient fluxes to each water body and to the lake and ocean bed sediments through which discharge occurs is a major issue of stakeholder concern and further refinement of the numerical model has been undertaken to allow simulation of these processes and estimation of potential nutrient fluxes.

Conceptual Model

Refinement of the conceptual model of the groundwater system discussed in *Section 9* assists with understanding of groundwater discharge processes, and with refinement of the numerical model.

Wave action and tidal variations acting on the sloping face of the ocean beach result in super-elevation of groundwater levels along the ocean shore (Turner et al, 1996) with an effective hydraulic head of around 0.35 mAHD. This has implications for the groundwater flow regime. Super-elevation of groundwater levels at the ocean shore will result in a downward hydraulic gradient which will force groundwater flowing towards the ocean downwards into deeper parts of the aquifer. Groundwater discharge will therefore occur slightly off-shore, beyond the main effects of super-elevation, although some discharge is expected to occur via beach-face seepage during low tide.

Development of the rainfall recharge mound will vary depending on rainfall conditions and will be greatest during sustained periods of high rainfall. The size of the groundwater mound will generally decrease from south to north due to the narrowing of the peninsula reducing overall rainfall recharge. Beneath the northern part of main peninsula area the height of the natural recharge mound is generally less than the hydraulic head at the ocean shore and intrusion of ocean water occurs, with a component of the ocean water intrusion resulting in saline groundwater flowing westwards from the ocean to the lake due to the higher effective hydraulic head of the ocean. A lens of fresh water from rainfall recharge will generally be present above the saline water.

The effect of effluent disposal will be to enhance the groundwater recharge mound and increase groundwater flow to the lake and particularly to the ocean.

Figure 9.1 shows the overall conceptual groundwater model with no exfiltration. *Figure 11.1* shows the groundwater flow regime with effluent exfiltration taking place. Diagrams showing refinements of the conceptual groundwater model with respect to beach zone hydraulics are provided as *Figure 13.5a and Figure 13.5b*.

Figure 13.5a: Conceptual Model: Beach Zone Hydraulics – No Exfiltration

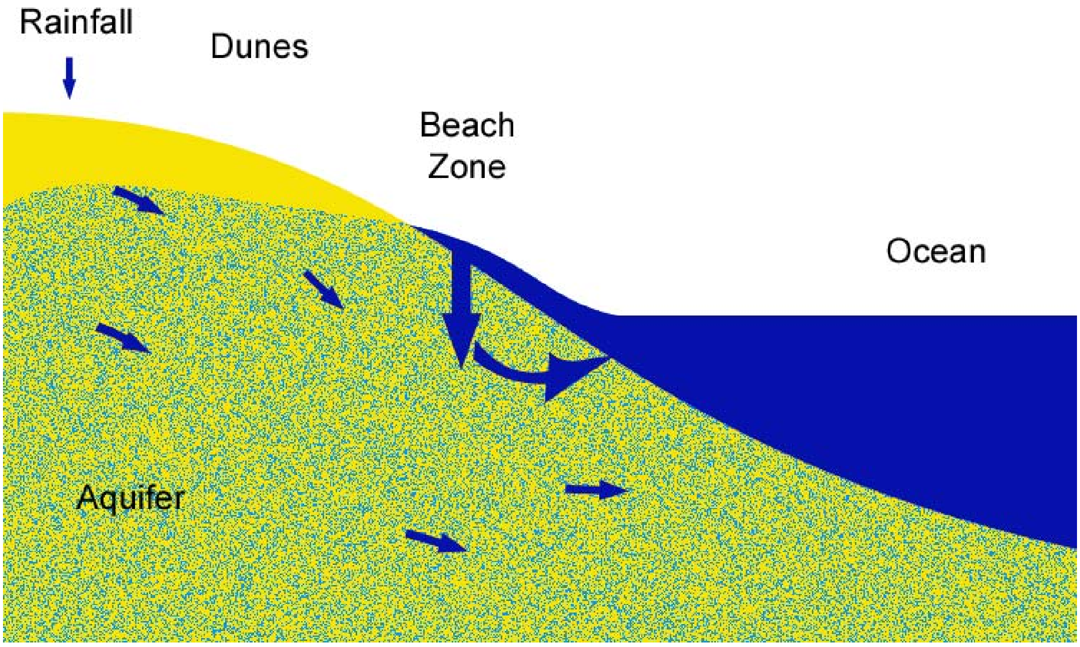


Figure 13.5b: Conceptual Model: Beach Zone Hydraulics with Exfiltration

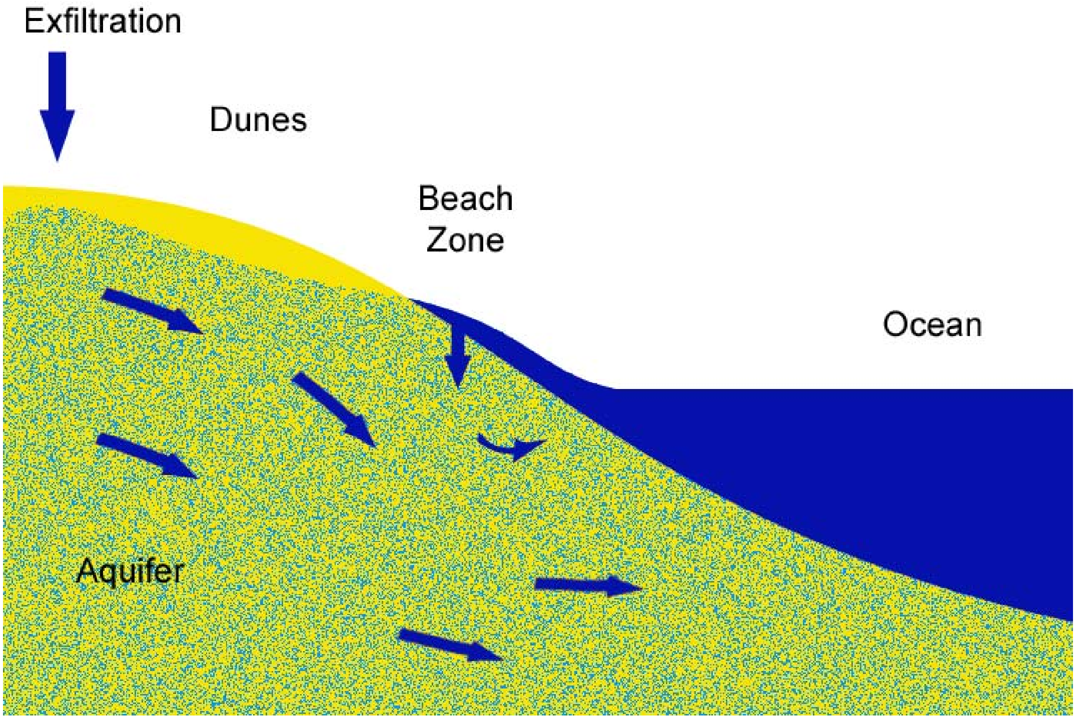
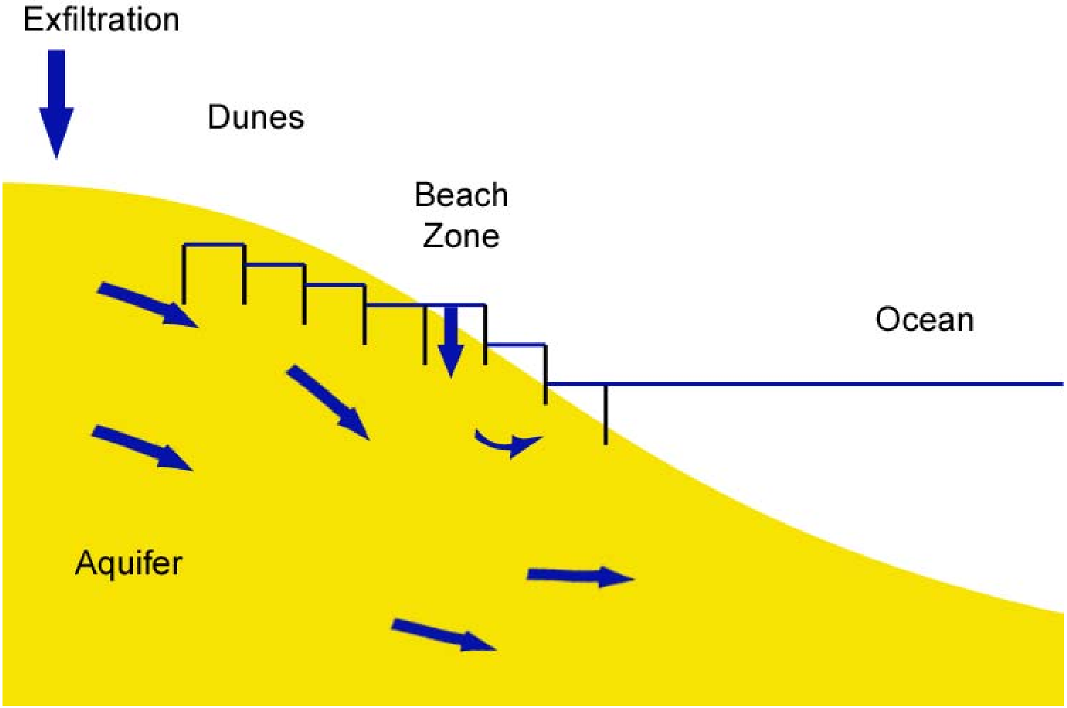


Figure 13.5c shows the numerical model representation of the beach zone hydraulic processes.

Figure 13.5c: Beach Zone Hydraulics: Model Representation



Refinement of the Numerical Model – BVSC Land Area

The steady-state version of the model used for simulation of a 400 m exfiltration trench located on BVSC land was used as the basis for model refinement. Bathymetric data have been provided by AECOM and show the following:

- The ocean bed in Merimbula Bay deepens at a gradient of around 1 in 85. The ocean floor outcrop of the base of the upper aquifer (c.-16 mAHD) is expected to occur at a distance of around 1,050 m from the shore;
- The bed of Merimbula Lake is generally fairly shallow except for the relatively narrow main channel. The inner estuary north-west of the airport typically has bed elevations of 0 mAHD to -2 mAHD. The north-western area of the lake is deeper with bed levels of -2 mAHD to -8 mAHD.

The raw bathymetric data supplied by AECOM was imported into the surface contouring package SURFER to allow ocean and lake bed elevations to be generated in a form that could be imported into the numerical model.

The numerical model was modified as follows:

- Lateral model extents were extended to include the lake and ocean areas underlain by the shallow aquifer including the whole of Merimbula Lake (inner and outer estuary) and Merimbula Bay to the expected extent of the sea floor outcrop of the aquifer (within the area of interest);

- The lateral extent of the shallow aquifer was estimated based on published geological maps, topography and aerial photographs and the limit of the aquifer represented in the model by setting cells outside this area as inactive. This limit acts as a no-flow boundary;

- Three vertical model layers replaced the single layer of the original model to improve representation of vertical groundwater movement. The three new model layers include:

    - Addition of an upper model layer to allow the ocean and lake water columns to be represented. Ocean and lake bathymetry were imported from SURFER as the basal elevation of this layer. The storage coefficient was set to close to 1 to represent 100% effective porosity/specific yield;

    - Splitting of the shallow aquifer into two layers to improve representation of vertical groundwater movement;

- The exfiltration trench located on BVSC land was represented as a recharge zone based on the average daily effluent discharge rate of 1.4 ML/d. Effluent was represented as a recharge concentration zone occupying the same area;

- Constant head boundaries were set in Layer 1 along the lake shore with an effective head of 0.1 mAHD for the inner estuary, 0.05 mAHD for the outer estuary and 0.35 mAHD along the ocean shore. The latter represents the super-elevation effect produced by wave action;

- Constant head boundaries were set in Layer 1 to represent the lake and ocean water columns away from the shore with effective heads of 0.065 mAHD for the inner estuary, 0.01 mAHD for the outer estuary and 0 mAHD for the ocean;

The model was run with exfiltration simulated and using particle tracking to identify the predicted groundwater discharge zones for the lake shore, open lake, ocean shore and open ocean. Initial zone budget zones were assigned to allow groundwater discharge fluxes to be examined for different areas of the model, including the lake shore, open lake, ocean shore and open ocean.

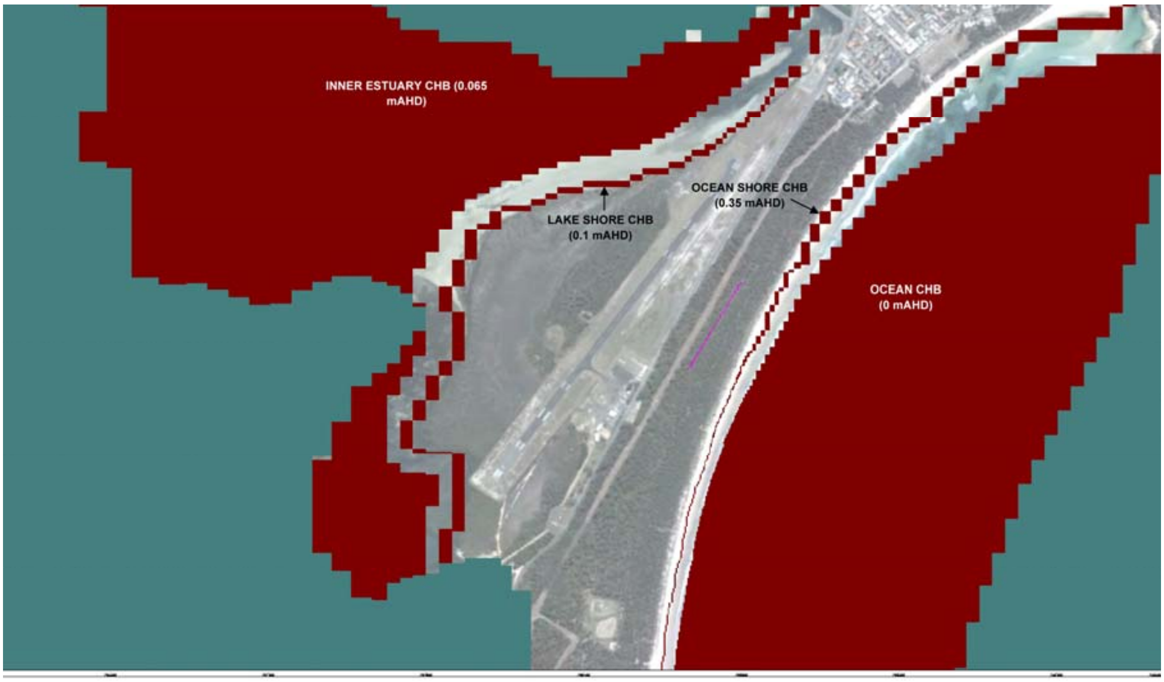
Zone budget zones were later refined during the predictive modelling process to provide additional data for assessment.

The extended model domain is shown in *Figure 13.6*.

Figure 13.6: Extended Model Domain

Layer 1 constant head boundaries in the area of interest are shown in *Figure 13.5*.

Figure 13.7: Constant Head Boundaries



Model zone budget zones for Layer 1 and Layer 2 are shown in *Figures 13.8a and 13.8b* (note: budget zones are not required for Layer 3 as no direct groundwater discharge takes place from this layer).

Figure 13.8a: Zone Budget Zones – Layer 1

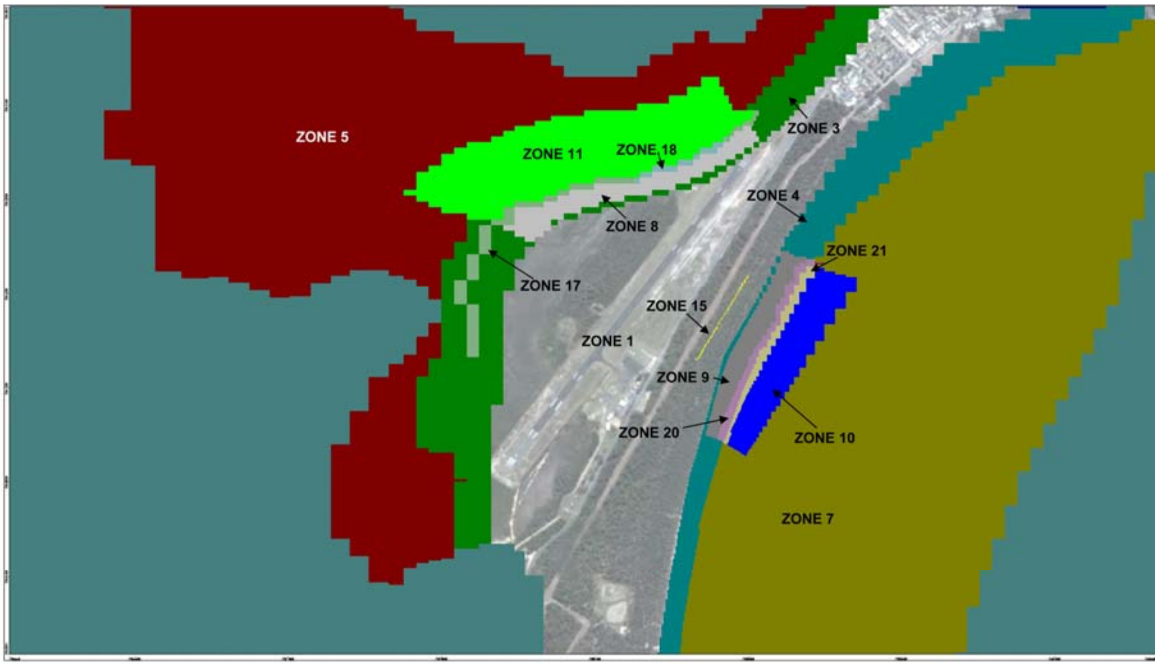
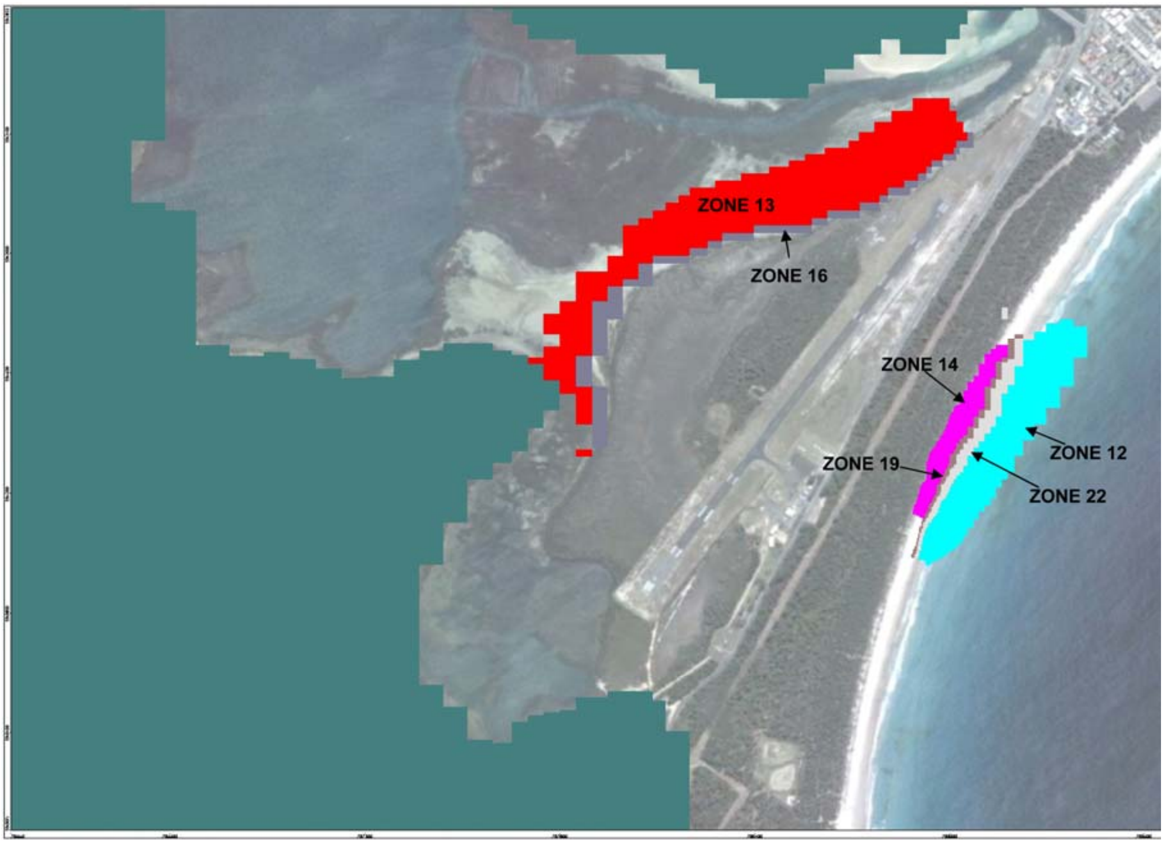
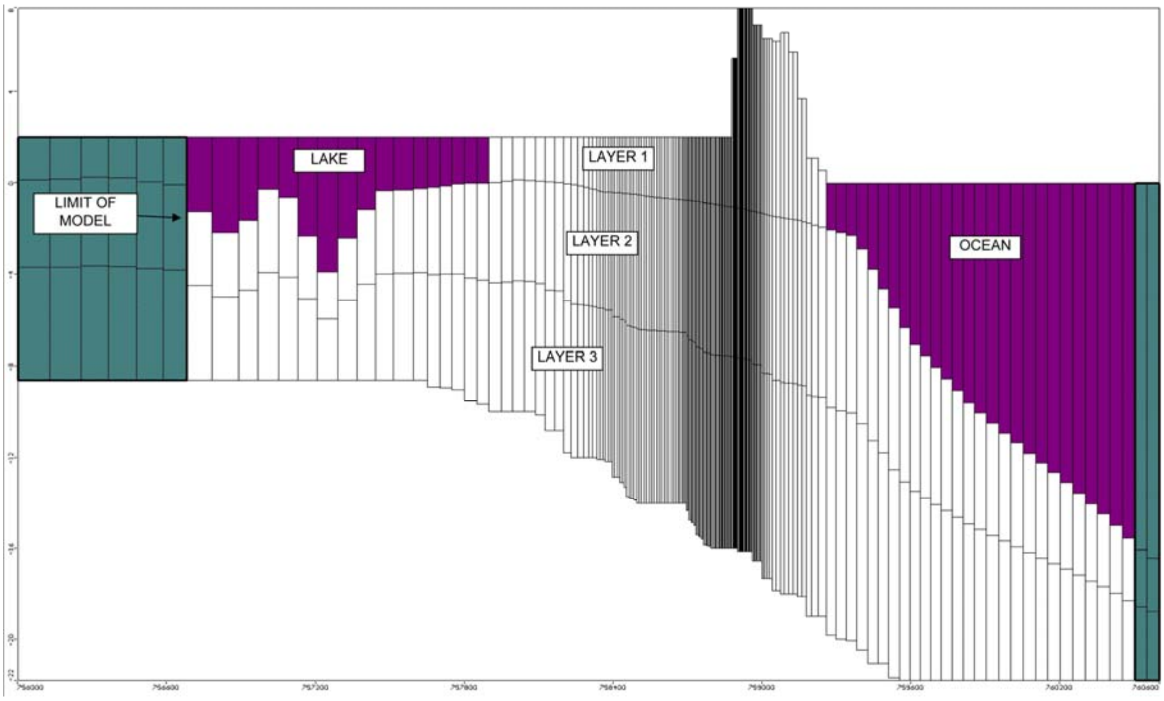


Figure 13.8b: Zone Budget Zones – Layer 2



A cross-section through the model is shown in *Figure 13.9*.

Figure 13.9: Cross Section through Model Domain



Results of the Refined Groundwater Flow Model – BVSC Land Area

The groundwater flow model was run without exfiltration for average rainfall conditions to provide baseline Zone Budget data. It was then re-run with exfiltration (from a 400 m trench located on BVSC land) simulated based on the average daily discharge of 1.4 ML/d. MODPATH was used to allow particle tracking to predict groundwater flow pathlines, discharge zones and travel times.

Simulation of natural groundwater flow conditions shows the presence of a groundwater divide (recharge mound) in the southern area extending to close to the northern end of the modelled exfiltration trench location. The maximum groundwater level is around 0.4 mAHD (Layer 1) and 0.45 mAHD (Layers 2 and 3) at the divide.

Simulation of groundwater flow conditions with average exfiltration rates of 1.4 ML/d causes the groundwater divide to become centred on the exfiltration trench with maximum groundwater levels of 0.9 mAHD (Layer 1) and 0.8 mAHD (Layers 2 and 3). Groundwater from the BVSC land trench area flows directly towards the ocean (east-south-east) and towards the lake at its closest point (north-west).

The mass balance for the groundwater flow model for the entire area modelled is summarised in *Table 13.2*.

Table 13.2: Groundwater Flow Model Mass Balance

Source/Sink	In (m^3/d)	Out (m^3/d)	Net (m^3/d)
No Exfiltration			
Constant Head	13,762	15,564	-1,802
Recharge	2,775	0	2,775
Evapo-transpiration	0	975	-975
TOTAL	16,537	16,539	-2
With Exfiltration (BVSC Land Area)			
Constant Head	12,770	15,967	-3,197
Recharge	4,173		4,173
Evapo-transpiration		975	-975
TOTAL	16,943	16,942	1

Notes: Positive values indicate are sources of groundwater; negative values represent groundwater sinks.

The mass balance indicates a substantial influx of ocean water into the shallow aquifer; i.e. ocean water entering the groundwater system. This is a real phenomenon rather than being an artefact of the modelling process and occurs along the ocean shore beach zone where wave and tidal action cause super-elevation of the hydraulic head; i.e. the effective ocean water level along the beach zone is slightly higher than sea level. Beneath the southern part of the model area this is a localised effect occurring only immediately adjacent to the beach zone with net groundwater flow still being from the land towards the ocean. Beneath the northern area, the narrow width of the peninsula limits rainfall recharge and therefore development of a recharge mound causing lower groundwater levels. Beneath this area, net groundwater flow is therefore from the ocean to the lake because of the higher effective hydraulic head at the ocean boundary compared to that at the lake boundary; i.e. ocean water enters the aquifer and eventually discharges through the lake bed via the groundwater system (although a large component of the beach zone ingress discharges to the ocean floor). This effect is shown diagrammatically in *Figure 13.5a* to *Figure 13.5c*

The steady-state model with no exfiltration predicts overall groundwater flow from the ocean to the lake in the aquifer beneath the northern part of the potential exfiltration trench location (on BVSC land) and northwards. With exfiltration simulated, net flow from the ocean to the lake occurs from around 300 m north of the exfiltration trench northwards. Exfiltration results in decreased beach zone ingress of ocean water, with recharge from exfiltration replacing a component of groundwater discharge that would otherwise be derived from this ingress as well as adding to ocean bed groundwater discharge.

The overall effect of exfiltration on the mass balance is as expected with an increase in recharge inputs of c.1,400 m^3/d. This additional groundwater flux leaves the groundwater model via the constant head boundaries associated with the ocean and the lake.

The Zone Budget Zones defined across the model area allow greater insight into the detailed flow and discharge processes. Additional Zone Budget Zones were assigned in Layer 2 of the model to allow better understanding of groundwater discharges via the lake and ocean bed (near shore zones). These coincide with the areas of the predicted nitrate and phosphate plumes and were adjusted for each model run to allow the groundwater flux between model Layer 2 (the top of the shallow aquifer) and model Layer 1 (the lake or ocean water column) to be determined. In addition, constant concentration zones were defined in Layer 1 of zero phosphate and nitrate concentration to represent the lake and ocean water columns and to allow opportunity for dilution of groundwater by interchange of water between groundwater and surface water systems. This is considered to give a more realistic prediction of nutrient concentrations in benthic sediments.

A full list and brief description of all Zones is provided in *Table 13.3* (end of report). Results of Zone Budget outputs for zones through which groundwater discharges to the lake or ocean in the areas of the predicted contaminant plumes are summarised in *Table 13.4* (with and without exfiltration).

Table 13.4: Summary of Zone Budget Results

Zone	Description	Natural Net Discharge (m^3/d)	Exfiltration Net Discharge (m^3/d)	Increased Flux m^3/d	%
	Model Zones Outside of Exfiltration Discharge Plume Area				
1	Gen	0	0	0	0%
2	Lake Shore, Outer Estuary	1,146	1,146	0	0%
3	Lake Shore, Inner Estuary	510	553	43	8%
4	Ocean Shore	-10,477	-10,354	123	1%
5	Lake, Inner Estuary	369	370	1	0%
6	Lake, Outer Estuary	676	676	0	0%
7	Ocean	8,584	8,594	10	0%
	Potential Exfiltration Impacted Discharge Area Zones				
8	Lake Shore	0	0	0	0%
9	Ocean Shore	-3,174	-2,283	891	28%
10	Ocean, Near Shore	3,392	3,499	107	3%
11	Lake, Near Shore	257	266	9	4%
17	Lake Shore CHB	324	441	117	36%
18	Lake Shore CHB, High Flow	216	310	94	44%
	Overall Totals, Entire Model				
	Total Ocean	-1,674	-544	1,130	73%
	Total Lake	3498	3762	264	7.5%
	TOTAL	1,823	3,218	1,394	77%
	Totals for Exfiltration Discharge Area Zones				
	Total Ocean	218	1,216	998	458%
	Total Lake	797	1,017	220	28%
	TOTAL	1,015	2,233	1,218	120%

Notes. Groundwater from Zone 8 discharges via other Layer 1 zones. Layer 2 zones also discharge via Layer 1 zones shown above.

The greatest increase in overall net groundwater discharge occurs to the ocean with a total net increase of 1,130 m^3/d; 73% higher than under natural conditions. The total net increased discharge to the lake is 264 m^3/d; 7.5% higher than under natural conditions. It should be noted that the net increased groundwater discharge flux does not necessarily directly represent exfiltration due to the effects on beach-zone ingress discussed above.

The proportion of effluent discharged to the exfiltration trench that discharges to the ocean and to the lake is estimated by dividing the increases in groundwater discharge to each by the total increase in groundwater of 1,394 m^3/d (reoresenting the effluent exfiltration discharge of 1,400 m^3/d). On the basis of the zone budget results approximately 81% of effluent discharges to the ocean (increased net groundwater discharge of 1,130 m^3/d) and 19% to the lake (increased groundwater discharge of 264 m^3/d).

The groundwater discharge area zones and areas of groundwater quality impacts from exfiltration are of greatest importance for this assessment. The discharge area zones have been refined during the modelling process to coincide with the areas of the predicted nutrient plumes in groundwater and additional sub-zones added to assist interpretation of groundwater discharge regimes.

The greatest net increase within the discharge area zones is shown for the ocean shore (891 m^3/d, 28%) while the greatest percentage increase is for the lake shore (211 m^3/d or 39% for the total of both lake shore zones). The increases in discharge to the near-shore areas are small for both ocean and lake; however this is partly due to replacement of natural groundwater discharge derived from beach-zone ingress with recharge from exfiltration.

The concept of ocean water ingress into the shallow aquifer along the shoreline can be difficult and makes the mass balance tables more complex then they would be otherwise, particularly where exfiltration reverses the local groundwater flow direction so that areas that were subject to groundwater recharge from the ocean become discharge zones or at least reduce ocean water entry. The overall concept of ocean water entering the shallow groundwater system, flowing through it and discharging to the lake bed can itself also be challenging, These concepts are, however, supported by the field evidence and have been well researched at other locations (Ang et al, 2004). The conceptual model figures presented earlier in the report (*Figure 9.1*, *Figure 11.1* and *Figure 13.3a* to *13.3c*) are intended to assist with understanding of this process,

Predicted Groundwater Pathlines – 400 m Exfitration Trench, BVSC Land Area

The MODPATH package included in VISUAL MODFLOW has been used to track the predicted pathlines and fate of groundwater particles migrating from an exfiltration trench located on BVSC land. Particles were placed in model cells adjacent to the exfiltration trench on both sides of the trench and in each of the three model layers and tracked to their discharge points to the lake or to the ocean.

Particles released in Layer 1 discharge to the lake and ocean via Layer 2 and Layer 3. Groundwater travel times to the ocean shore are around 250 days, with typical travel times of 300 to 375 days prior to ocean floor discharge.

Groundwater travel times to the lake shore are around 7 years, with typical travel times of 12 years or more prior to lake bed discharge. There is a clear decrease in groundwater velocity once the lake shore is reached reflecting the low hydraulic gradient in the shallow aquifer beneath the lake.

Groundwater pathlines and groundwater level contours with exfiltration for the refined flow model are shown in *Figure 13.10*.

Figure 13.10: Hydraulic Head Contours and Pathlines

Notes. Pathline tickmarks show 100-day intervals.
Groundwater contours are for Layer 2 and are at 0.1 m AHD intervals

Phosphate and Nitrate Contaminant Transport Simulations

Contaminant transport in groundwater has been simulated for the key nutrients of oxidised nitrogen (nitrate) and orthophosphate (phosphate) using the MT3DMS modelling package with the MODFLOW groundwater flow model. Four scenarios have been simulated and these are summarised in *Table 13.5*.

Table 13.5: Contaminant Transport Simulation Scenarios

Scenario	**Effluent Concentration**		**K_d PO$_4$**	**R (NO$_x$)**
	Phosphate as P	**Nitrate as N**[1]	(mL/g)	1/day
Phosphate				
1	8.5 mg/L	-	2	-
2	8.5 mg/L	-	0.1	-
3	1.5 mg/L	-	2	-
4	1.5 mg/L	-	0.1	-
Nitrate				
1	-	2.5 mg/L	-	0.002
2	-	2.5 mg/L	-	0
3	-	2.5 mg/L	-	0.002
4	-	2.5 mg/L	-	0

Notes. 1: nitrate concentration in effluent is based on the median value for total inorganic nitrogen and assumes nitrification of ammonia to nitrate.

2: K_d PO$_4$ is the distribution or partition coefficient discussed in *Section 13.2.1* and below.

3: R is the first order decay constant for nitrate discussed in *Section 13.2.2* and below.

Simulations have been run for two distribution coefficients (K_d) for phosphorus sorption. The first is nearly one order of magnitude below the geometric mean of values estimated from the PRI results to provide a conservative assessment based on the measured values in the area of the proposed exfiltration trench and is equivalent to a "low" PRI classifcation. The second is based on the very low value previously estimated for the area around PPK3 and is considered to represent conditions with the greatest potential for phosphate migration in groundwater that could realistically occur. This values is equivalent to a PRI at the lower end of the “vey low” classification.

No sorption of nitrate or ammonia is included in the model. Nitrate is not removed significantly by sorption or precipitation reactions and is generally stable in solution in groundwater systems when under oxidising conditions with little attenuation occurring. Removal can occur due to microbial activity and denitrification under reducing conditions. No data are available on the detailed nature of strata or groundwater around Merimbula Lake. It is anticipated that sediments relatively high in organic matter and perhaps clay minerals may be present close to the lake. Migration of groundwater through such strata would be expected to result in development of increasingly reducing conditions and substantial attenuation of contaminants, particularly through denitrification of nitrate, sorption of ammonia and sorption/precipitation of phosphorus. Substantial removal of nitrate due to denitrification is taking place around the existing exfiltration ponds and this is represented in the simulation for Scenarios 1 and 3 using first-order irreversible decay of TIN with a rate constant of 0.002 day^{-1}, This is about half of the rate estimated from calibration of the numerical model of the existing ponds to provide a conservative assessment, particularly as groundwater conditions in the areas closer to the lake are expected to me more conducive to development of reducing conditions . A rate constant for nitrate of 0 d^{-1} is applied in Scenarios 2 and 4 to provide an indication of increases in nitrogen fluxes that could if occur if redox conditions are uniformly oxidising along the entire groundwater flow path which would greatly limit the potential for denitrification.

Scenarios 1 and 3 are considered to provide conservative “best estimate” cases and are likely to best reflect actual conditions for phosphate and nitrate migration, while Scenarios 2 and 4 are considered as “worst case” excluding conditions which could not conceivably apply.

Contaminant transport has been simulated for a period of 21,000 days (57 years) for all scenarios. The realistic lifespan of an exfiltration discharge system is likely to be 20 to 50 years (7,300 to 18,250 days).

The predicted extent and concentrations of the phosphate plumes for the four phosphate scenarios and for the nitrate plume with and without denitrification in the shallow aquifer after 21,000 days (c.57 years) were used to refine Zone Budget areas for each scenario individually so that the zones approximate to the areas over which contaminant discharge is predicted to occur. This allows the predicted groundwater fluxes for the discharge zones to be determined for each scenario. Calculation of nutrient fluxes can then be undertaken.

The predicted phosphate and nitrate concentration distributions are shown in *Figure 13.11a* to *Figure 13.11f*.

Figure 13.11a: **Phosphate Concentrations in Groundwater, Scenario 1 (High Effluent PO_4=8.5 mg/L; Low P Sorption Capacity, K_d=2.0 mL/g)**

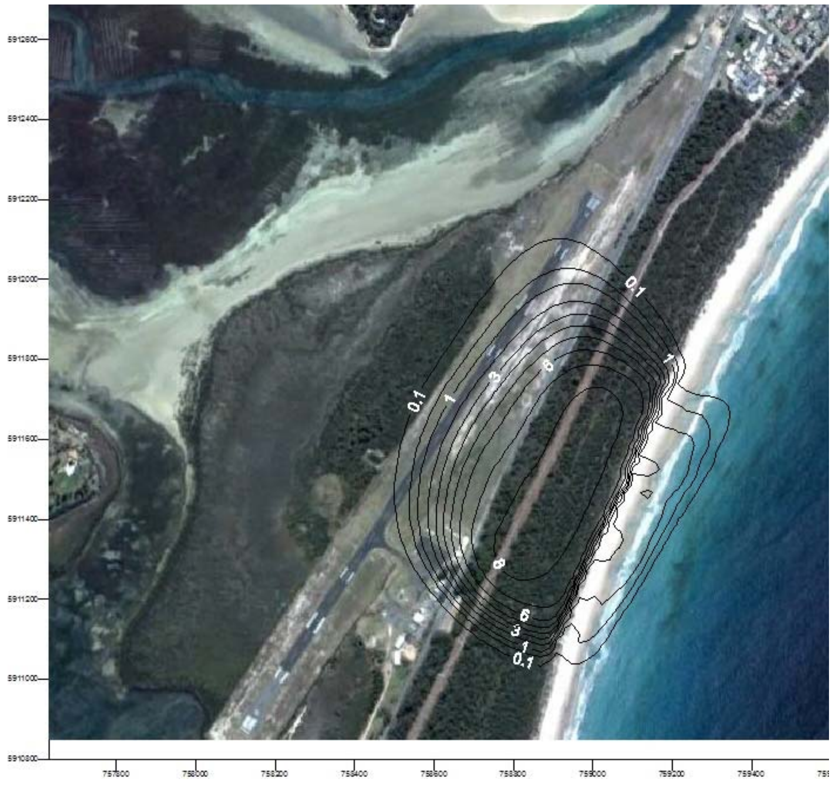


Figure 13.11b: **Phosphate Concentrations in Groundwater, Scenario 2 (High Effluent PO_4=8.5 mg/L; Very Low P Sorption Capacity, K_d=0.1 mL/g)**

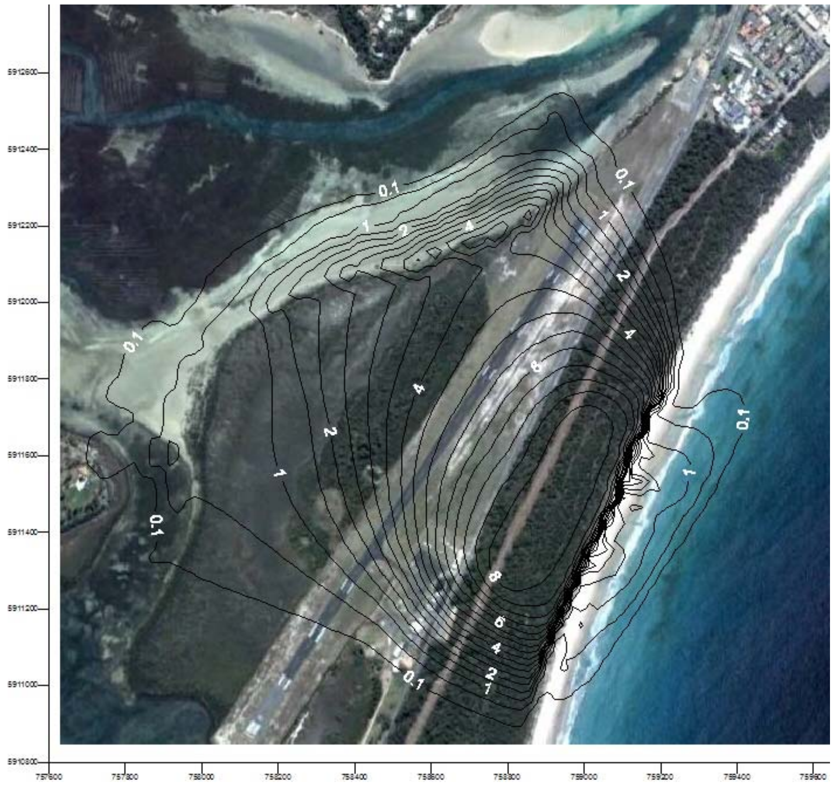


Figure 13.11c: **Phosphate Concentrations in Groundwater, Scenario 3 (Low Effluent PO_4=1.5 mg/L; Low P Sorption Capacity, *Kd*=2.0 mL/g)**

Figure 13.11d: **Phosphate Concentrations in Groundwater, Scenario 4 (Low Effluent PO_4=1.5 mg/L; Very Low P Sorption Capacity, K_d=0.1 mL/g)**

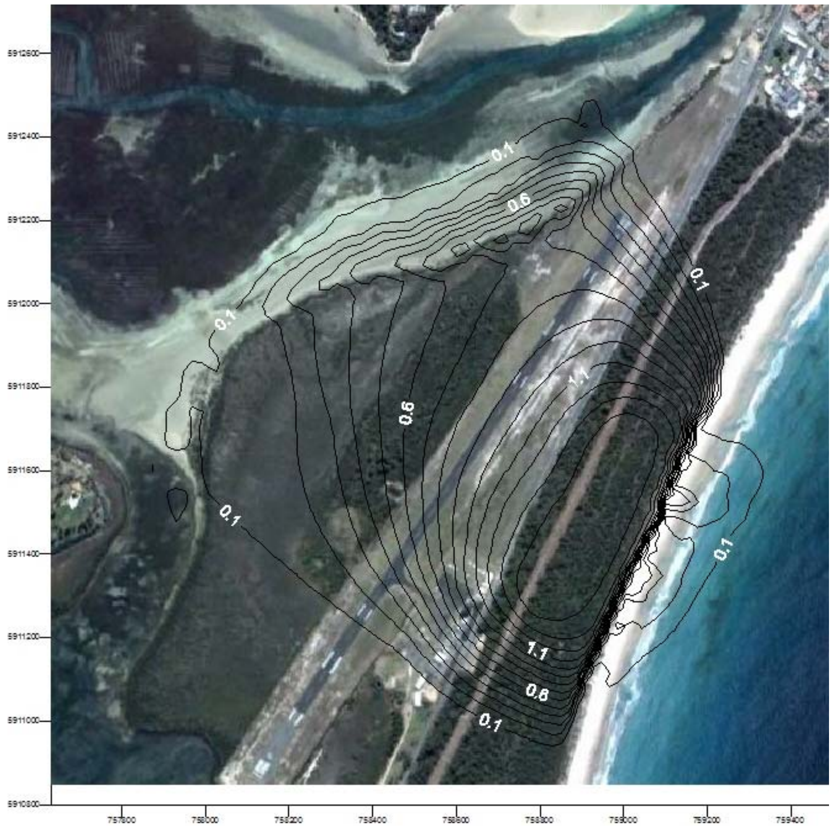


Figure 13.11e: **Nitrate Concentrations in Groundwater, Scenarios 1 and 3 (Moderate N Decay Rate Constant R=0.002 day^{-1})**

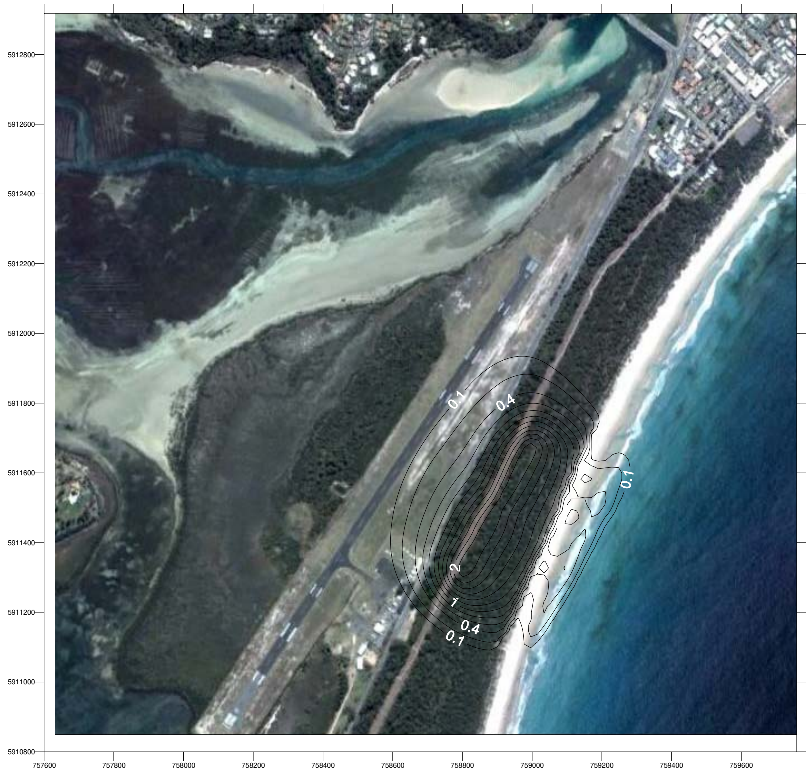
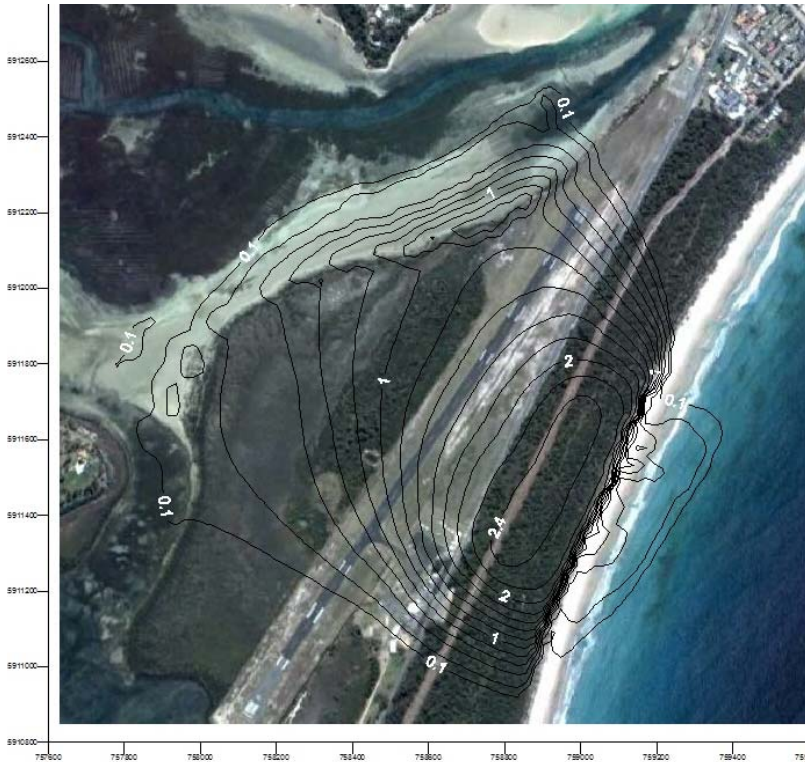


Figure 13.11f: **Nitrate Concentrations in Groundwater, Scenarios 2 and 4 (Zero N Decay Rate Constant R=0 day^{-1})**



Typical nutrient concentrations and the predicted extent of the impacted groundwater discharge zones are summarised in *Table 13.6* and *Table 13.7*.

Table 13.6: Typical Lake Discharge Zone Concentrations and Areas

Scenario	Lake Shore Central	Lake Shore Central	Lake Shore Outer	Lake Shore Outer	Lake Near Shore	Lake Near Shore
	Concentration (mg/L)	Length (m)	Concentration (mg/L)	Length (m)	Concentration (mg/L)	Area (m^2)
Phosphate						
1	0	0	0	0	0	0
2	5	400	1.5	1,400	2.5	287,400
3	0	0	0	0	0	0
4	0.8	400	0.4	1,200	0.3	153,100
Nitrate						
1	0	0	0	0	0	0
2	1.4	400	0.6	1,300	0.8	242,400
3	0	0	0	0	0	0
4	1.4	400	0.6	1,300	0.8	242,400

Notes. Lake shore values include the two zones coinciding with the constant head boundary (the central area with greatest flow and highest concentration) and the remainder, and indicate the linear distance along which increased nutrient flux is expected.

Table 13.7: Typical Ocean Discharge Zone Concentrations and Areas

Scenario	Ocean Shore Concentration	Ocean Shore Area	Ocean Near Shore Concentration	Ocean Near Shore Area
	(mg/L)	(m^2)	(mg/L)	(m^2)
Phosphate				
1	1.5	22,080	1.0	53,000
2	1.5	24,340	1.2	83,430
3	0.3	19,630	0.2	31,140
4	0.3	23,720	0.2	56,690
Nitrate				
1	0.8	15,600	0.4	35,500
2	1.5	21,675	0.4	70,750
3	0.8	15,600	0.4	35,500
4	1.5	21,675	0.4	70,750

Notes. Ocean shore values are discharge from Layer 1 Zone 20 to Zone 21. Ocean Near Shore values are discharge from Layer 2 Zone 12 to Layer 1 Zones 12 & 21 and from Layer 2 Zone 22 to Layer 1 Zone 10.

Groundwater discharge fluxes for the budget zones coinciding with the groundwater discharge zones within the plume areas are summarised in *Table 13.8* and *Table 13.9*.

Table 13.8: Groundwater Discharge Fluxes to Lake

Scenario	Lake Shore Central (m^3/d)	Lake Shore Outer (m^3/d)	Lake Near Shore (m^3/d)
Phosphate			
1	0	0	0
2	310	518	384
3	0	0	0
4	310	444	300
Nitrate			
1	0	0	0
2	310	483	246
3	0	0	0
4	310	483	246

Notes. 1. Lake shore values include the two zones coinciding with the constant head boundary (the central area with greatest flow and highest concentration and the remainder).

Table 13.9: Groundwater Discharge Fluxes to Ocean

Scenario	Ocean Shore (m^3/day)	Ocean Near Shore (m^3/day)
Phosphate		
1	422	2,703
2	513	2,973
3	422	2,194
4	475	2,703
Nitrate		
1	258	2,073
2	475	2,884
3	258	2,073
4	475	2,884

Notes. 1. Ocean shore values are for Layer 1, Zone 20 to Zone 21. Ocean Near Shore values are for Layer 2 Zone 12 to Layer 1 Zone 10 and Zone 21 and Layer 2 Zone 22 to Layer 1 Zone 10.

Nutrient fluxes are provided in *Table 13.10*.

Table 13.10: Nutrient Fluxes from Groundwater

Scenario	Lake Shore	Lake Near Shore	Ocean Shore	Ocean Near Shore	Total
Phosphate Flux (grams per day)					
1	0	0	633	2,744	3,377
2	2,326	961	770	3,526	7,556
3	0	0	169	459	628
4	426	90	238	561	1,315
Nitrate Flux (grams per day)					
1	0	0	207	829	1,036
2	724	200	713	1,154	2,791
3	0	0	207	829	1,036
4	724	200	713	1,154	2,791

Results for phosphorus (low K_d) Scenario 2 and nitrate (zero rate constant) represent 64% and 80% respectively of the respective nutrient input flux from exfiltration and results are considered to be reliable. The remainder of the input flux discharges from the groundwater system outside of the zones representing the plume areas at concentrations below 0.1 mg/L. The concentrations provided in *Table 13.6* and *Table 13.7* are those expected to be typical for groundwater discharging through the benthic zone of the lake and of the ocean for the areas lying within the nutrient plumes.

Nutrient fluxes have also been calculated in units of micromoles per square metre per hour (µmol/m^2/hr) to assist with assessment of potential impacts on benthic ecosystems. This was undertaken by dividing the typical concentration by the area affected for each case and converting the units. The assumed nutrient concentrations in effluent and in the numerical model are expressed in units of milligrams per litre of orthophosphate as P or of nitrate as N, so the respective atomic masses are used in the conversions rather than the molecular mass of orthophosphate or nitrate. Results of these calculations are summarised in *Table 13.11*.

Table 13.11: Nutrient Fluxes from Groundwater (µmol/m^2/hr)

Scenario	Lake Shore (central)	Lake Shore (outer)	Lake Shore (all)	Lake Near Shore	Ocean Shore	Ocean Near Shore
Phosphate Flux (µmol P/m^2/hr)						
1	0	0	0	0	85	154
2	2,307	330	769	10	94	126
3	0	0	0	0	26	44
4	369	88	158	2	30	29
Nitrate Flux (µmol N/m^2/hr)						
1	0	0	0	0	39	70
2	646	133	253	3	98	49
3	0	0	0	0	39	70
4	646	133	253	3	98	49

Notes. Lake shore values are calculated using based on an assumed shore zone groundwater discharge width of 5 metres, approximately representing the intertidal zone.

Time series graphs of concentration of phosphate and nitrate in groundwater have been produced for simulated monitoring wells located at the ocean and lake shore and at the closest point of each of the lake bed and ocean bed discharge zones. The locations of the simulated wells are shown in *Figure 13.12.*

Figure 13.12: Location of Simulated Discharge Zone Monitoring Wells

Time series graphs of concentration are provided as *Figure 13.11a* to *Figure 13.11e.* Concentrations are for model layer 2 unless stated otherwise.

Figure 13.13a: **Predicted Phosphate Concentrations in Groundwater over Time (Scenario 1)**

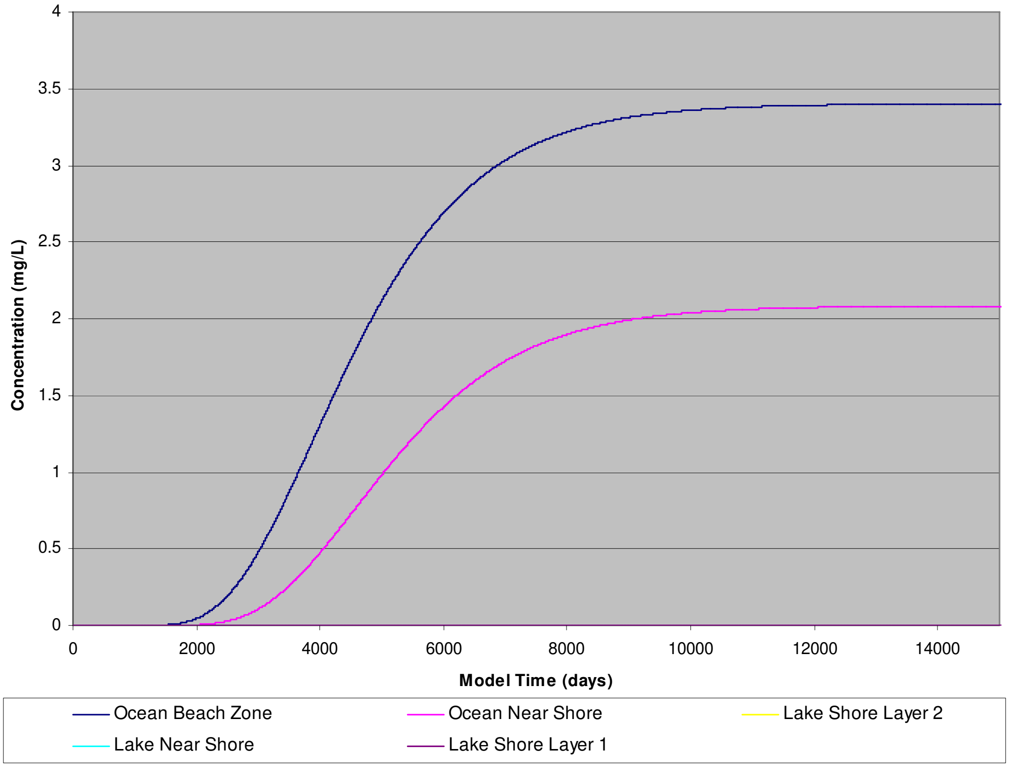


Figure 13.13b: **Predicted Phosphate Concentrations in Groundwater over Time (Scenario 2)**

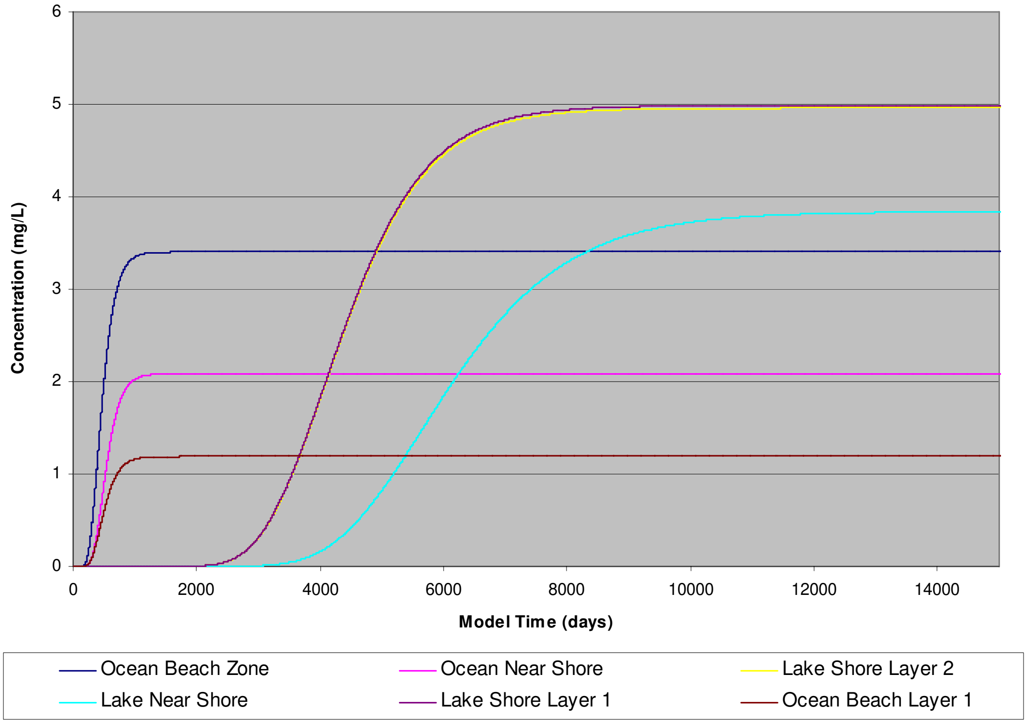


Figure 13.13c: **Predicted Phosphate Concentrations in Groundwater over Time (Scenario 3)**

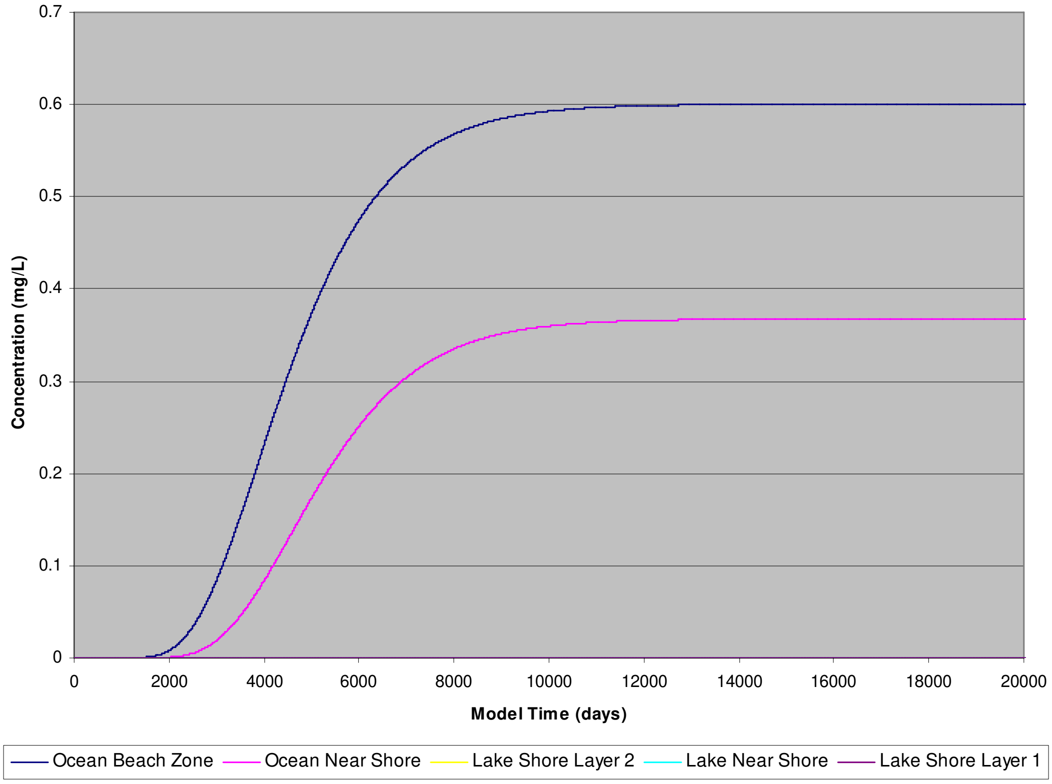


Figure 13.13d: **Predicted Phosphate Concentrations in Groundwater over Time (Scenario 4)**

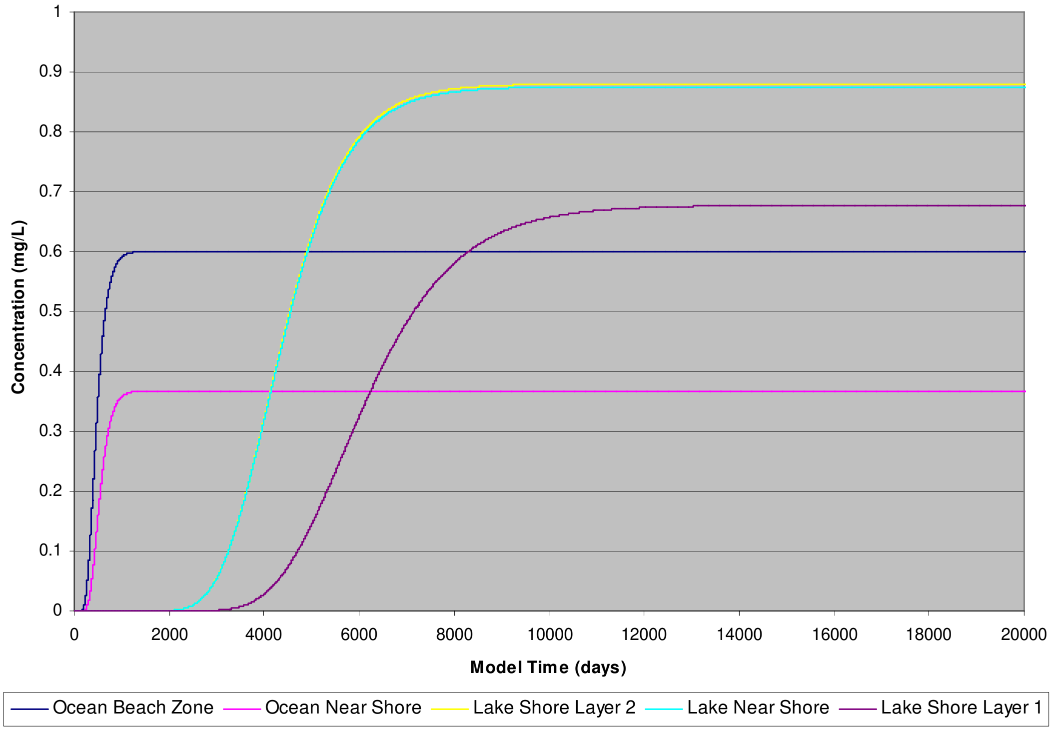


Figure 13.13e: **Predicted Nitrate Concentrations in Groundwater over Time, Scenario 1 (Rate Constant 0.002 day^{-1})**

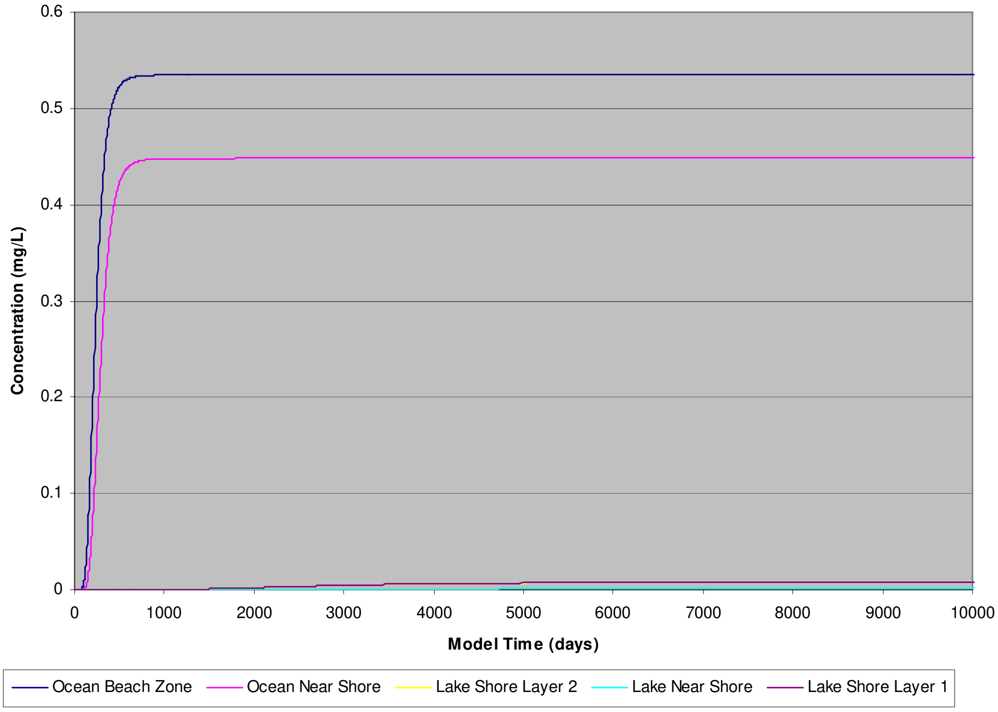
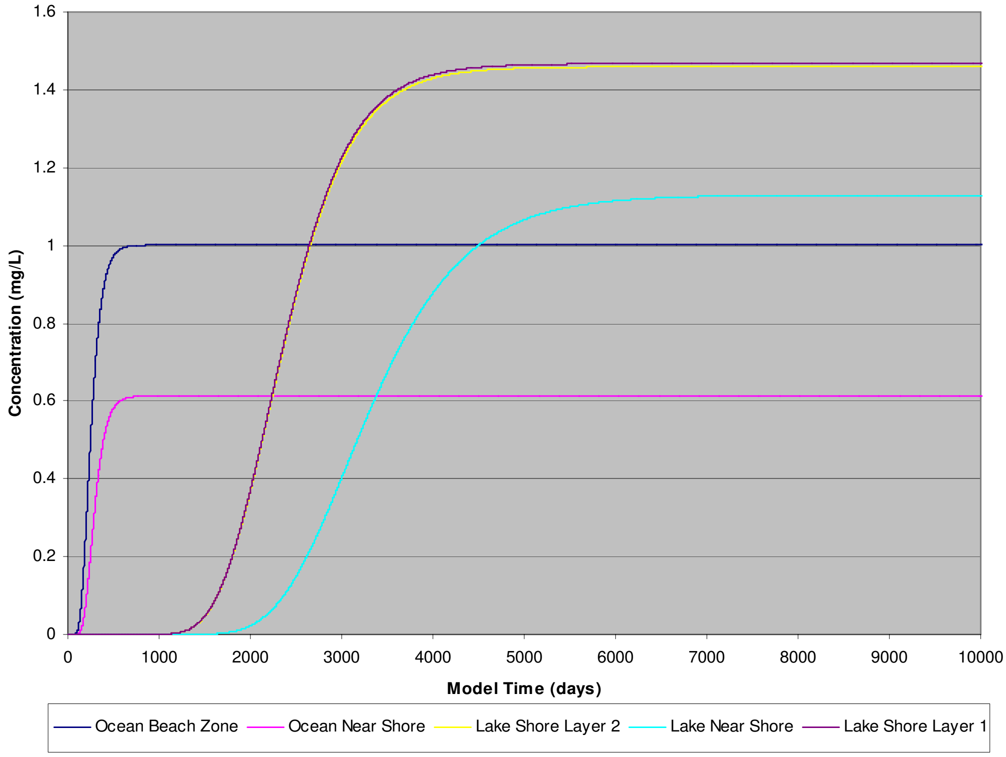


Figure 13.13f: **Predicted Nitrate Concentrations in Groundwater over Time, Scenario 2, (Zero Rate Constant)**



The following summarises the predicted nutrient impacts on the lake and ocean resulting from effluent discharge to an exfiltration trench located on BVSC land for the period of 57 years:

- Phosphate from effluent is not predicted to discharge to the lake under the conservative best-estimate scenarios (Scenarios 1 and 3) using existing or reduced effluent concentrations;

- Under worst-case Scenario 2 with existing effluent concentrations, phosphate is predicted to reach the lake bed along 1,800 m of shoreline with the discharge plume extending 220 m from the shore. Phosphate breakthrough is predicted to occur after over 2,000 days (5.5 years) with groundwater concentrations reaching steady state after 10,000 days (27 years). The typical concentration in groundwater discharging to the lake bed is predicted to be 2.5 mg/L with concentrations of up to 5 mg/L in groundwater discharging along the shoreline in the central area of the plume.

- Reducing the effluent phosphate concentration to 1.5 mg/L (Scenario 4) reduces the area of discharge and reduces predicted the typical concentration to 0.3 mg/L for groundwater discharging to the lake bed;

- Phosphate in groundwater is predicted to reach the ocean under all scenarios along 600 m to 800 m of shoreline and extending 100 m to 210 m from the shore. Typical conservative best-estimate concentrations (Scenarios 1 and 3) are predicted to be 1.2 mg/L to 1.5 mg/L with existing effluent concentrations and 0.2 mg/L to 0.3 mg/L with reduced effluent concentrations. Predicted impacts are only slightly greater for the worst case scenarios because of the short migration path;

- Nitrate from effluent is not predicted to discharge to the lake under the conservative best-estimate scenarios (Secanios 1 and 3);

- Under worst-case Scenario 2, nitrate in groundwater is predicted to reach the lake along 1,700 m of shoreline with the discharge plume extending up to 250m from the shore. Typical concentrations in groundwater discharging to the lake are predicted to be 0.6 to 1.4 mg/L;

- Nitrate in groundwater is predicted to reach the ocean under all scenarios 600 m to 800 m of shoreline with the discharge plume extending up to 180 m from the shore. Typical concentrations in groundwater discharging to the ocean are predicted to be 0.4 mg/L to 0.8 mg/L (Scenario 1) and 0.4 mg/L to 1.5 mg/L (Scenario 2).

The actual groundwater discharge regime and effective nutrient concentrations in the benthic layer will be more complex than this as they will vary with daily and longer-term tidal fluctuations. Under low tide water level conditions, groundwater discharge will occur at similar or slightly greater rates than those applied. During high tide water level conditions, however, the hydraulic gradient will be temporarily reversed, with lake or ocean water expected to be pushed into the shallow aquifer via benthic sediments. This means that the concentrations within these sediments will be lower than those predicted by the steady state model and an assumption of actual concentrations being half of those predicted is considered reasonable.

Summary of Nutrient Impact Assessment

The numerical model has been expanded and refined to allow simulation and prediction of impacts from exfiltration on groundwater discharge through the off-shore benthic zones of Merimbula Lake and Merimbula Bay. Four model scenarios have been run, using existing (8.5 mg/L) and reduced (1.5 mg/L) phosphate concentrations and based on conservative best-estimate and worst-case parameters for phosphate and nitrate attenuation.

Results of conservative best-estimate modelling show that phosphate from exfiltration is not predicted to reach the lake. Results of worst-case modelling show predicted phosphate concentrations of around 2.5 mg/L with the area affected by higher concentrations being 800 m along the shoreline and within 220 m of the lake shore. This represents a small fraction of the overall lake area.

Phosphate from effluent is predicted to reach the ocean under all scenarios but is limited to an area of 900 m or less along the shoreline and within 210 m from the shore. Concentrations are predicted to be up to 1.5 mg/L along the ocean shore and 1.2 mg/L beneath the near shore area for Scenario 2, slightly less under Scenario 1 and between 0.2 mg/L and 0.3 mg/L under Scenario 3 and Scenario 4.

Results of conservative best-estimate modelling show that nitrate from exfiltration is not predicted to reach the lake. Results of worst-case modelling show predicted nitrate concentrations of around 0.6 mg/L to 1.4 mg/L with the area affected by higher concentrations being 800 m along the shoreline and within 220 m of the lake shore. This represents a small fraction of the overall lake area.

Nitrate from effluent is predicted to reach the ocean under all scenarios but is limited to an area of 800 m or less along the shoreline and within 210 m from the shore. Concentrations are predicted to be around 0.8 mg/L along the ocean shore and 0.4 mg/L beneath the near shore area for Scenario 1 and around 1.5 mg/L along the ocean shore and 0.4 mg/L beneath the near shore area for Scenario 2.

Some impacts on benthic biota may occur within the affected areas depending on the tolerance of the organisms present to the predicted increases in phosphate and nitrate concentrations and fluxes. Actual impacts are expected to be less than those predicted under all scenarios as the assessment includes conservative assumptions and the realistic worst case scenarios are considered very pessimistic. In addition, interchange between groundwater and surface waters due to tidal effects will reduce concentrations in the benthic sediments further.

Finally, assessment of the predicted impact from groundwater discharge of phosphate and nitrate on overall lake or ocean water quality is beyond the scope of this report; however the estimated nutrient fluxes provided can be used for this assessment.

Other Receptors

Existing Wetlands

There is some risk of effluent discharged to shallow groundwater migrating to wetland areas. The only known natural wetlands, however, are those located south of the existing ponds. These are located a considerable distance from all of the potential effluent disposal areas being around 800 m south of the southern end of the central area. Results of numerical modelling show little potential for groundwater from the central area migrating to the wetlands and even less from the BVSC land or northern area. In addition, existing groundwater quality data suggest that active mechanisms for phosphorus and nitrogen attenuation exist in the area of the wetlands, with concentration of both contaminants in groundwater remaining low despite a long period of discharge to the existing ponds which are located much closer than the disposal areas currently being assessed.

Other wetland-type areas may exist, such as around the shore of Merimbula Lake. Predicted groundwater level changes in this area are negligible and groundwater travel times from the potential disposal areas are long. The nutrient flux estimates provided above will allow assessment of potential impacts, if required. If wetland areas are present they would be expected to show characteristics and groundwater conditions that would encourage nutrient attenuation, such as presence of organic matter, reducing conditions, etc.

Existing Groundwater Users

A small number of registered bores are present in the area, mostly comprising shallow spearpoints in the Fishpen area for domestic use. Predicted groundwater pathlines from numerical modelling results indicate that even with exfiltration from the northern disposal area, groundwater is unlikely to reach the closest existing groundwater users located c.350 m north-east of the simulated exfiltration trench. Should such migration occur, the proportion of groundwater travelling in this direction is low and travel times would be long and, hence, no detectible effect on groundwater quality is expected.

Groundwater Resource

Discharge of treated effluent to the shallow groundwater system has limited potential to affect the resource value of the aquifer and any potential future development of this resource. Areas of the aquifer located beneath and around disposal areas would be impacted by effluent, most notably by increased concentrations of phosphorus and nitrogen.

Other than maintenance of environmental values, beneficial use of the shallow groundwater resource is limited to small-scale domestic use such as garden watering, car-washing etc; and perhaps limited irrigation of parks etc. Excessive pumping would be likely to draw in saline groundwater and great care would be needed with use of anything other than shallow wells for small-scale supply. The expected increases in nutrient levels would not impact on these uses.

Future development of the groundwater resource is highly unlikely unless residential or commercial development is permitted across the dunal system, and even then it would be limited to small-scale domestic use. Natural groundwater quality is not suitable for development of drinking water supplies and any sustained pumping of groundwater at high rates would be expected to induce saline intrusion or upwelling. Disposal of effluent will increase the amount of low-salinity water in the aquifer and may therefore increase groundwater availability for some uses.

13.5 Prediction of Impacts on Groundwater Quality – Other Contaminants

Pathogenic Micro-organisms

Groundwater travel times provide a good indication of the potential for viable pathogenic micro-organisms in discharge waters to reach receptors. A minimum 50-day travel time has been used as a general guideline for protection of groundwater quality (DLWC, 1998) although a number of studies have shown that some pathogens can survive for longer periods under favourable conditions. Travel times for groundwater from the disposal areas to reach the lake are very long and the potential for pathogens to reach lake waters is considered negligible. Travel times to the ocean are relatively short and there is some risk of pathogen contamination being present in groundwater discharging to the ocean from all three sites, particularly for the Central Area. Any such impacts would be expected to be small given that travel times are at least twice the 50-day guideline and the great majority of pathogens present in the effluent would be expected to die or be filtered out during groundwater migration. Any impacts would certainly be far less than from a direct ocean discharge.

Other

The potential for impacts from other contaminants (industrial compounds, surfactants and biologically active compounds) are considered to be negligible for Merimbula Lake because of the long travel times and highly diffused nature of discharge of potentially contaminated groundwater. There is some risk of impacts on groundwater discharging to the ocean but this risk is considered to be low, particularly compared to that from direct ocean discharge.

14. Consideration of Construction and Infrastructure Requirements and Potential Limitations

14.1 Potential for Clogging of the Disposal System

Clogging occurs to some extent with most effluent disposal systems and can result in reduced achievable discharge rates over time or even surface overflow at the disposal point(s). Clogging can affect one or all of the disposal pipes of exfiltration systems, the screen of injection wells, the surface layer of the strata and the aquifer around the exfiltration site. There are a number of mechanisms by which clogging can occur.

Physical Clogging due to Filtration of Suspended Solids in the Effluent

Suspended solids in the effluent can clog discharge pipes, well apertures or surrounding strata. This is a simple physical effect and will generally be localised. Effluent from Merimbula STP is low in suspended solids (median value 5 mg/L) and the potential for physical clogging is limited.

Air Entrainment

Presence of air bubbles in the injected water can force these bubbles into the aquifer formation, effectively causing clogging. This can also occur due to gasses coming out of solution if the effluent is substantially cooler than native groundwater or is supersaturated with dissolved gasses. These conditions are unlikely to apply at Merimbula.

Development of Bacterial Growths

Bacterial growths can occur on disposal system surfaces or within the aquifer. The most common is growth of iron bacteria. These organisms colonise the transition zone between anaerobic and aerobic zones and their metabolism is based on oxidation of dissolved ferrous iron, converting it into insoluble ferric iron which forms slimes and filamentous growth, clogging pore spaces.

Levels of dissolved iron in the shallow groundwater system are very low, with the highest value recorded being 0.24 mg/L in CPW and all other wells showing concentrations below 0.1 mg/L. This greatly limits the potential for clogging due to development of iron bacteria. Manganese (which can be metabolised in a similar way) levels are also low.

Growth of most other types of clogging bacteria relies upon the presence of organic carbon as a food source. The low BOD of the effluent from Merimbula STP is expected to limit such growth.

While the risk of clogging due to bacterial growth is considered low, disinfection of effluent prior to injection is common practice in such systems and should be considered.

Mineral Precipitation due to Geochemical Reactions

Clogging of injections systems and surrounding strata can occur due to precipitation of insoluble minerals caused by chemical interaction between the injected effluent and the aquifer formation. This generally arises when injection causes substantial changes in redox conditions by introduction of highly oxygenated effluent into a groundwater system where reducing conditions apply. This situation does not apply at Merimbula. Low levels of dissolved minerals in the effluent and in groundwater, and low levels of soluble minerals in the geologic formation greatly limit the potential for clogging due to chemical precipitation.

Dispersal and/or Swelling of Clay Particles due to Ion Exchange Processes

This can occur when water containing high amounts of sodium is introduced into an aquifer formation containing clay minerals. Deflocculation of the clay results and can cause clay minerals to swell or to disperse into the aquifer material, effectively reducing the hydraulic conductivity of the formation. This is not expected to occur at Merimbula because of the very low clay content of the shallow aquifer.

Conclusions

Excessive clogging of disposal systems and surrounding formation is unlikely to occur at Merimbula because of the following factors:

- Low suspended solids;
- Low iron levels in the aquifer;
- Low BOD in the effluent;
- Low dissolved solids levels in the groundwater and the effluent.

BVSC's experience with disposal of treated effluent to the existing ponds at Merimbula shows that clogging is both limited and manageable. The demonstrated performance of the exfiltration ponds in terms of lack of serious clogging over a total period of 20 years is valuable in providing confidence that clogging will not unduly affect future disposal system performance.

14.2 Exfiltration Trench Considerations

An exfiltration trench consists of an excavated trench, typically at least 1m deep, containing a slotted pipe, and backfilled with gravel or sand if required. Effluent is directed through the slotted pipe to ensure that the hydraulic load is spread along the length of the trench. Pressure discharge is not required, and pumps and delivery pipe requirements should be based on the peak discharge requirements. The delivery pipe is sealed and burial is only required to meet aesthetic requirement or where crossing roads and tracks.

The rate of clogging of the slotted pipe and surrounding strata is likely to be low. However, some clogging will occur and the effects of this will need to be monitored and maintenance undertaken periodically to remediate its effects. This may involve jetting or physical cleaning of the discharge pipe, periodic disinfection or excavation and re-laying of pipe sections. The system design should allow for isolation of parts of the exfiltration discharge system for maintenance

Additional groundwater monitoring wells will be required around any exfiltration trench, with a minimum of 4 to 5 monitoring wells likely to be required.

14.3 Disposal Well Considerations

Disposal wells should comprise boreholes drilled to the full depth of the upper sand aquifer (around 20m). Mud rotary drilling is likely to be required to provide support for the formation during drilling and well construction.

Disposal wells should be completed with stainless steel screens with apertures sized according to the grain size distribution to optimise the achievable injection rates and provide wells that are sufficiently robust to meet operation and maintenance requirements. The 0.4 mm screen aperture used in the central and northern area test production wells is expected to be suitable at all sites. Final well diameters should be the largest that can readily be achieved to minimise well losses. Boreholes should be screened from the base to c.5m below ground surface. Installation of a sump should also be considered. The annulus of each bore should be filled with a carefully placed and properly sized gravel filter pack if practicable.

Results of numerical modelling indicate that the use of wells may result in a small localised increase in peak groundwater levels compared to use of an exfiltration trench. However this is based on the assumption within MODFLOW that the injection well occupies the entire cell (c.5 m x 5 m). The local response at a real injection well will be greater (i.e. higher localised groundwater levels) due to well losses. This may place limitations of the injection rates that can be achieved, particularly during times of peak effluent loads. In addition, this increase in head compared to the theoretical requirement is typically greater for injection than the additional head loss experienced during pumping of groundwater out of the aquifer.

The average daily discharge rate to each of the assumed nine injection wells is 156 m^3/day (2025 loadings). This is equivalent to 1.8 L/s and results of pump testing at 5 L/s shows that this is readily achievable. The peak 2025 discharge rate is 1,889 m3/d, equivalent to 21.9 L/s. During the major rainfall event of 14-16th February 2010 predicted loadings per well are equivalent to 11.2 L/s, 21.9 L/s and 21.9 L/s on consecutive days followed by a sustained period of discharge at 2.5 L/s. The peak groundwater level increase at an injection well during the major rainfall event is predicted to be 3.22 m for the central area, with the actual peak groundwater level predicted to be 4.28 mAHD.

The drawdown responses during pump testing showed a maximum drawdown of 2.25 m at CPW, of which perhaps 1.8 m is estimated to be from well losses (0.45 m is drawdown in the aquifer), and 1.72 m at NPW of which c.1.4 m represents well losses.

Based on the observed drawdown response which shows well losses to be around four times the actual drawdown for a pumping rate of 5 L/s, well losses during injection at rates of over 20 L/s are expected to in excess of 12 m. Well losses do not follow a linear relationship with flow rate. The actual well loss cannot be calculated but is expected to be greater than that extrapolated from pump test results assuming identical well design. Improved well efficiency and reduced well losses can be achieved by use of larger diameter wells.

This suggests that discharge of peak rates to an array of nine wells will not be achievable as water levels within the wells are expected to rise above ground surface level (around 6.8 mAHD for the central area) by over 10 m. This does not necessarily mean groundwater levels will rise above ground surface as well loss is a very localised effect and provided that sealed headworks are provided then surface discharge may not occur. It is clear that over-elevation to this extent is not acceptable and the peak discharge rate would have to be reduced for injection wells to be practicable. This could be achieved by the following:

- Temporary storage of effluent during periods of peak flow;
- Diversion of effluent during peak flow periods to an alternative disposal method (such as an ocean outfall);
- Use of a greater number of disposal wells. At least double the number assessed would be required to keep well water levels within acceptable limits.

Pressure discharge may be required for an injection well disposal system to overcome well losses and the delivery infrastructure should reflect this.

The rate of clogging of injection wells and surrounding strata is likely to be low and excessive clogging is not anticipated. Clogging is generally a greater problem for injection wells than for exfiltration systems largely because of the smaller surface area through which injection occurs when wells are used.

The effects of clogging should be carefully monitored by measurement of changes in head loss through the discharge well system. Maintenance to remediate the effects of clogging is likely to be required from time to time. This may involve jetting or physical cleaning of the well screen, periodic disinfection or replacement of wells. The injection system design should allow for wells to be isolated from the disposal system as needed for maintenance. Cycling of wells can also assist in reducing the effects of clogging. This involves installation of more wells than are needed such that only a proportion are in use at any one time, with discharge cycled through the system so that each well or group of wells is “rested” periodically.

Additional groundwater monitoring wells will also be required around any shallow disposal wellfield, with at least 4 to 5 monitoring wells likely to be required.

15. Review of Options

Each of the three potential disposal areas has been evaluated for disposal of excess treated effluent to the shallow groundwater system, including use of a 400 m exfiltration trench or an equivalent line of 9 injection wells at 50 m spacings at each.

The advantages and disadvantages of the three areas are summarised in *Table 15.1.*

Table 15.1 Advantages and Disadvantages of Main Disposal Options

Disposal Area	Advantages	Disadvantages
Central Area	Closest to STP. Long travel times to lake.	Proximity to wetland areas. Greatest groundwater level rise predicted. Short travel time to ocean.
Northern Area	Least groundwater level rise predicted.	Relatively short travel time to lake. Furthest from STP.
BVSC Land Area	Long travel times to lake. Distant from wetland areas.	Closer to western limit of frontal dunes and areas of lower surface elevation.

Disposal of treated effluent is considered to be viable at all three sites. The northern site is considered to be the least favourable because of the relatively short travel times to the lake.

The relative merits of these options should be considered by BVSC and other stakeholders as part of the process of assessment of the overall preferred disposal option.

16. Conclusions

Bega Valley Shire Council is currently assessing options for disposal of excess effluent from Merimbula STP. IGGC was engaged to undertake investigations of the shallow groundwater system in the dune and beach sand deposits of the peninsula separating Merimbula Lake from the ocean and to provide detailed assessment of the potential for effluent disposal to the central and northern areas of the dunes and to a site located on land owned by BVSC. The scope of work included drilling of monitoring wells and test production wells, test pumping, numerical modelling and detailed assessment of the effects of effluent disposal on groundwater levels and water quality, including the potential for increased nutrient fluxes to Merimbula Lake and the bay.

Results of investigation confirm the broad understanding of the conceptual model for the shallow groundwater system but show that hydraulic conductivity of the aquifer beneath the study areas is slightly higher than assumed previously and that net flow of water from the ocean to the lake is likely to occur under dry conditions, particularly beneath the northern part of the peninsula. Assessment of the hydrochemical characteristics of the groundwater system indicates that potential for attenuation of inorganic nitrogen may be substantial unless oxidising conditions prevail along the entire groundwater flow path, with results from monitoring bores PPK3 and PPK4 showing removal rates of nitrogen in effluent from the existing ponds of around 80%, probably through denitrification. The potential for migration of orthophosphate in groundwater identified in recent research appears to be present in the area of PPK3 but not at PPK4 and results of sampling of aquifer material suggest that potential for migration is likely to be limited in the areas north of the existing ponds.

Results of numerical groundwater flow modelling indicate that disposal of excess effluent at projected 2025 loading rates can be carried out at any of the three potential disposal areas using a 400 m exfiltration trench without causing unacceptably high groundwater levels. The smallest rises are predicted beneath the northern area and the greatest beneath the central area reflecting the increase in aquifer thickness that occurs from south to north. Disposal of effluent using a line of nine injection wells at each location was also assessed. Results of modelling indicate that this should be acceptable, with only small additional increases to peak groundwater levels predicted around each well and overall effects on groundwater level behaviour to be similar to those resulting from use of exfiltration trenches. Consideration and assessment of the effects of well losses, however, suggest that excessive over-elevation of water levels within, and perhaps immediately around, the injection wells is likely to occur during peak loadings. Reduction of the peak loading to each well would be required such as by use of a greater number of wells, diversion of part of the peak flow or temporary storage.

Predicted travel times for groundwater from disposal areas to reach the ocean are relatively short (110 to 350 days), offering little opportunity for attenuation of nutrient loads although removal of most pathogens would be expected. The shortest travel times to the ocean are predicted for the central area.

Predicted travel times for groundwater to reach Merimbula Lake are considerably longer and range from 850 days from the northern area to 4,000 days (over 10 years) for the central area (2025 loadings).

Assessment of potential impacts on groundwater quality and that of groundwater reaching receptors was also undertaken. This included expansion and refinement of the numerical model to allow simulation and prediction of impacts from exfiltration on groundwater discharge through the off-shore benthic zones of Merimbula Lake and Merimbula Bay. Four model scenarios were run, using existing (8.5 mg/L) and reduced (1.5 mg/L) phosphate concentrations and based on conservative best-estimate and worst-case parameters for phosphate and nitrate attenuation.

Results of conservative best-estimate modelling show that neither phosphate nor nitrate is predicted to reach the lake. Results of worst-case modelling show predicted phosphate concentrations of around 2.5 mg/L with the area affected by higher concentrations being 800 m along the shoreline and within 220 m of the lake shore. Worst-case nitrate concentrations are predicted to be around 0.6 mg/L to 1.4 mg/L across the same area. This represents a small fraction of the overall lake area.

Phosphate from effluent is predicted to reach the ocean under all scenarios but is limited to an area of 900 m or less along the shoreline and within 210 m from the shore. Concentrations are predicted to be up to 1.5 mg/L along the ocean shore and 1.2 mg/L beneath the near shore area for Scenario 2, slightly less under Scenario 1 and between 0.2 mg/L and 0.3 mg/L under Scenario 3 and Scenario 4.

Nitrate from effluent is predicted to reach the ocean under all scenarios but is limited to an area of 800 m or less along the shoreline and within 210 m from the shore. Concentrations are predicted to be around 0.8 mg/L along the ocean shore and 0.4 mg/L beneath the near shore area for Scenario 1 and around 1.5 mg/L along the ocean shore and 0.4 mg/L beneath the near shore area for Scenario 2.

Some impacts on benthic biota may occur within the affected areas depending on the tolerance of the organisms present to the predicted increases in phosphate and nitrate concentrations and fluxes. Actual impacts are expected to be less than those predicted under all scenarios as the assessment includes conservative assumptions and the realistic worst case scenarios are considered very pessimistic. In addition, interchange between groundwater and surface waters due to tidal effects will reduce concentrations in the benthic sediments further.

Finally, assessment of the predicted impact from groundwater discharge of phosphate and nitrate on overall lake or ocean water quality is beyond the scope of this report; however the estimated nutrient fluxes provided can be used for this assessment. The numerical model results for Scenario 1 and Scenario 3 are considered to represent conservative “best estimate” predictions and it is recommended that these be applied.

Consideration has been given to potential mechanisms by which clogging of the disposal system might occur. Based on the characteristics of the effluent and the receiving groundwater system potential for clogging is considered to be low and is expected to be acceptable subject to appropriate management.

17. Recommendations

The results of investigation, numerical modelling and assessment indicate that the three potential disposal areas are all expected to be viable. The northern area is considered the least favourable site because of relatively short travel time for groundwater to reach Merimbula Lake. The relative merits of the options for disposal of excess treated effluent to shallow groundwater will be considered by BVSC and other stakeholders together with other disposal options. Should disposal to shallow groundwater be identified as the preferred option, then the preferred disposal area and method (i.e. an exfiltration trench or injection wells) should be confirmed. Some further assessment may be needed to assist with the detailed design of the final system. Additional monitoring wells will be required to allow monitoring of changes in groundwater levels and groundwater quality in response to effluent disposal with a total of at least five new wells likely to be needed. These should be installed as soon as possible after the preferred option has been finalised to allow collection of background data.

A management plan should be developed for the shallow groundwater disposal system to ensure effective, long-term operation. This should include the following:

- Discharge strategy including maximum peak and average discharge rates;
- A groundwater level and groundwater quality monitoring program with data review requirements;
- Trigger levels for key aspects of the monitoring program to provide early indication of possible adverse impacts and require review of discharge system performance and groundwater processes. The purpose of such a review would be to assess the potential for adverse impacts and to identify any requirements for modifications to the disposal system design or operation, including maintenance to manage clogging of the discharge system;
- Further modelling and assessment if groundwater level behaviour or groundwater quality is substantially different to that predicted or if loadings rates change from those used in the current assessment.

The numerical modelling and assessment undertaken did not indicate a clear need for use of the ocean outfall for emergency discharges for the period simulated. It is recommended, however, that this option be retained as it may be required during periods of very high rainfall; in the event of unforeseen adverse impacts from shallow groundwater disposal or during maintenance of the shallow groundwater disposal system(s).

Further Investigation Requirements

Evaluation of the performance of the three areas and two disposal options for disposal of excess effluent volumes to shallow groundwater has been undertaken based on the available data and various assumptions, and the reliability of the assessments are dependent on the reliability of data and validity of the assumptions. In general terms the groundwater system and implications of effluent disposal are considered to be well understood. There are some remaining areas of uncertainty and the following additional investigation should be undertaken should dunal exfiltration be identified as a preferred disposal option:

- Groundwater Chemistry. Recent research suggests that precipitation of aluminium-phosphate minerals may be an important mechanism in phosphorus attenuation. Redox conditions and presence of organic carbon are likely to the primary factors for removal of nitrate by denitrification and reducing conditions are also important for phosphorus removal. The existing groundwater quality monitoring program should be reviewed to ensure that the data collected assists with assessment of the potential for these processes to occur and perhaps to be enhanced. Analysis of aquifer material should also be considered, including in the areas of PPK3 and PPK4 where phosphate attenuation varies markedly.

- Geological and Groundwater Conditions near Merimbula Lake. Limited information is available on the detailed nature of sub-surface strata around Merimbula Lake or on detailed groundwater conditions. Investigation of conditions between the proposed disposal system location and the lake should be undertaken as part of the groundwater monitoring network installation, including collection of samples of the aquifer material and analysis of phosphorus adsorption capacity, cation exchange capacity, organic carbon etc. Groundwater quality sampling should include assessment of redox conditions and analysis for indicators of existing denitrification processes.

- Surface drainage systems around Merimbula Lake on the airport land remain poorly understood and should be investigated if possible in order to identify any potential unknown groundwater discharge zones.

Finally, discharge of treated effluent to the shallow aquifer will increase development of the freshwater lens within the groundwater system and will effectively provide storage for treated effluent. Consideration should be given as to whether periodic shortages of effluent for re-use would be sufficient that re-extraction from the groundwater system would be justified and if so whether such a system to increase beneficial effluent re-use would be practicable. Development of an artificial recharge scheme in this manner would increase availability of effluent for re-use and would also reduce any potential impacts associated with disposal by exfiltration.

18. References

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19. Glossary

Aquifer: water-bearing underground strata with sufficient hydraulic conductivity to allow groundwater to flow to bores, springs etc. in quantities sufficient to allow extraction.

Confined Aquifer: an aquifer overlain by strata of significantly lower hydraulic conductivity than that of the aquifer material.

Constant Head Boundary: a cell in a numerical model of fixed hydraulic head regardless of conditions in surrounding cells which acts as an infinite source or sink for water entering or leaving the system.

Distribution or Partition Coefficient (K_d): a coefficient describing the relationship between the amount of a solute adsorbed onto a soil surface with concentration.

Finite Element Numerical Model: a digital groundwater flow model based on a rectangular grid with the model equation solved at each grid node.

First Order Decay Reaction: a decay reaction the rate of which depends on the concentration of one reactant, with decay following an exponential pattern determined by the rate constant.

Hydraulic Conductivity (k): a coefficient of proportionality describing the rate at which water can move through a permeable medium.

MODFLOW: a modular finite-difference model which solves the groundwater flow equation developed by the U.S. Geological Survey (USGS).

MODPATH: a computer program developed by the USGS to calculate three-dimensional particle tracking pathlines from MODFLOW flow simulation outputs.

MT3D: a computer program which solves a range of mass transport equations to allow prediction of the fate and transport of chemical species.

Specific Yield: the specific yield of an unconfined aquifer is a measure of the volume of water that will drain under gravity and is expressed as a number between 0 and 1 or as a percentage.

Storage Coefficient: the volume of water a unit area of aquifer releases or takes into storage per unit change in hydraulic head. Equivalent to specific yield for unconfined aquifers.

Transmissivity: the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient, equivalent to the hydraulic conductivity multiplied by the saturated thickness of the aquifer.

Unconfined Aquifer: an aquifer with no confining beds between the saturated zone and the ground surface.

VISUAL MODFLOW: a graphical user interface for MODFLOW to assist with pre- and post-processing of data.

Zone Budget: a computer program which calculates sub-regional water budgets from MODFLOW simulations based on user-defined zone budget zones, allowing groundwater flow into or out of the model over specific areas and/or layers to be obtained.

Zone Budget Zone: a user-defined zone within a MODFLOW flow model for which Zone Budget calculates groundwater flows from sources, to sinks and between different zone budget zones.

Appendix A

Additional Tables and Figures

TABLE 7.7: GROUNDWATER QUALITY RESULTS

Well		MW N1	MW N3	NPW	MW C1	MW C2	CPW	ANZECC 2000 Guideline Values		
Well Depth (m)		11.4	19.7	19.1	15.5	16.1	18.9	Env Stressors	Toxicants	
Date Sampled		12/10/10	12/10/10	14/10/10	14/10/10	14/10/10	12/10/10	(Lowland Rivers)	Fresh	Marine
Field Readings										
pH		7.48	7.31	7.64	7.71	7.61	7.44	6.5 to 8		
Electrical Conductivity	mS/cm	6.41	26.71	37.43	11.84	18.98	19.9			
Redox Potential	mV	73	96	73	63	67	69			
Temperature	C	17.8	17.4	17.2	17.2	17.3	17.1			
Major Ions										
Calcium	mg/L	160	270	330	160	220	220			
Magnesium	mg/L	110	610	910	250	420	450			
Sodium	mg/L	1100	5300	7800	2100	3500	3700			
Potassium	mg/L	61	280	430	90	160	200			
Chloride	mg/L	1900	8600	13000	3800	6300	6700			
Fluoride	mg/L	0.22	0.52	0.89	0.17	0.4	0.3			
Bromide	mg/L	6	31	46	13	21	23			
Sulphate	mg/L	220	1300	1800	530	880	870			
Nutrients										
Ammonia	mg/L N	0.01	<0.01	0.13	0.07	0.08	0.05	0.02	0.9	0.91
Nitrate/NOx	mg/L N	0.15	1.2	0.95	0.2	0.25	0.33	0.04	0.7	
Nitrite	mg/L N	<0.05	<0.05	-	<0.05	<0.05	<0.05			
Organic Nitrogen	mg/L N	0.3	<0.1	<0.1	0.3	<0.1	0.2			
Total Nitrogen	mg/L N	0.49	1.4	1	0.42	0.47	0.57	0.5		
Orthophosphate	mg/L P	0.05	0.09	0.04	0.05	0.07	0.03	0.02		
DOC	mg/L	11	8	1	2	2	5			
Dissolved Metals										
Aluminium	ug/L	5	6	<5	<5	<5	<5		55	
Antimony	ug/L	<3	<3	<3	<3	<3	<3			
Arsenic	ug/L	17	**44**	**59**	18	**28**	**35**		24	
Barium	ug/L	62	25	26	48	44	33			
Beryllium	ug/L	<0.1	<0.1	0.2	<0.1	<0.1	<0.1			
Cadmium	ug/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		0.2	0.7
Cobalt	ug/L	0.5	1	**1.2**	0.4	0.7	0.7			1
Chromium	ug/L	<2	2	2	2	3	<2			27.4
Copper	ug/L	**1.5**	**5.4**	**6.3**	**2.2**	**3.5**	**3.3**		1.4	1.3
Iron	mg/L	0.04	0.02	0.02	<0.01	<0.01	0.24			
Manganese	ug/L	8.8	3.6	0.7	3.6	7.7	2		1900	
Mercury	ug/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		0.06	0.1
Molybdenum	ug/L	1.1	5.2	7.7	2.1	3.6	3.5			
Nickel	ug/L	6	**11**	**12**	5	7	<5		11	7
Lead	ug/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		3.4	4.4
Selenium	ug/L	<2	<2	<2	<2	<2	<2		5	
Silver	ug/L	<1	<1	<1	<1	<1	<1		0.05	1.4
Zinc	ug/L	**41**	**17**	**25**	**21**	**22**	**26**		8	15
Bacto										
Enterococci	CFU/100mL	48	<2	<1	<2	<1	<2			
Faecal Coliforms	CFU/100mL	<2	<2	<1	<10	<1	<2			

Notes.

DOC is dissolved organic carbon.
Where no guideline value is given none is available
Bold values exceed the ANZECC 2000 guideline values for toxicants

Bore	Area	Previous Investigations				Current Investigation				Suggested Value
		Permeameter (MM, 87)	Infiltration (MM, 87)	Short-term Pump (MM, 87; PPK, 02)	Slug (PPK 02)	Slug Hv	B&W	B&W (Eff r)	Pump Test	
MA5	South	8.42		11.49						
MA6	South	17.69								N/A
MA3	Wetlands			4.91						3 to 8
A5	Wetlands			1.38	1.47					
A6	Wetlands			1.84	4.95					
MA1	Ponds	8.50		6.81						25 to 30
MA14	Ponds	35.00								
A4	Ponds			3.7	3.62					
BH10	Ponds				4.33	13.1	6.5	30.8		
A1	A1				1.47					30
MA11	A1	27.33		6.10						
MA13	A1	38.00								
MA9	Pond Foredunes	21.52								
PPK3	Pond Foredunes				22.3					30
PPK4	Pond Foredunes			6.17	14					
PPK2	A1 Foredunes				24.2					
Inf 3	A1 Foredunes		58							40
Inf 4	A1 Foredunes		140							
C1	Central					10	5.31	25.2	52.1	50
C2	Central					9.95	3.6	17	43.8	
CPW	Central								59.7	
PPK1/1b	Central			5.6	13.1	9.5	5.7	27.1	47.6	
Inf 1	Central		7.61							
Inf 2	Central		4.38							
MA16	Central	8.93								
MA17	Central (road)			3.44						
N1	Northern					14.8	9.2	43.5		
N2	Northern					8.7	6.5	30.8	54.5	55
N3	Northern					15.9	10.3	48.7	48.6	
N4	Northern					35	11.8	56.2		
NPW	Northern								65.1	

Table 8.1: Collated Hydraulic Conductivity Values by Area (metres per day)

Project: Investigation and Assessment of Impacts on Groundwater and Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

Table 13.3: Zone Budget Zone Descriptions

Zone	Layer	Description	Notes
1	All	General	
2	1	Outer estuary lake shore	
3	1	Inner estuary lake shore	
4	1	Ocean shore	
5	1	Inner estuary	
6	1	Outer estuary	
7	1	Ocean	
8	1	Lake shore - discharge area	Outflow via other L1 zones
9	1	Ocean shore - discharge area	Beach zone ocean infiltration
10	1	Ocean near shore	
11	1	Lake near shore	
12	**2**	**L2 ocean near shore**	
13	**2**	**L2 lake near shore**	
14	2	L2 ocean shore	
15	1	Exfiltration trench	
16	2	L2 lake shore	
17	**1**	**L1 lake shore Constant Head Boundary**	
18	**1**	**L1 lake shore Constant Head Boundary - high flow**	Highest GW flow and concentrations
19	2	L2 beach inner	
20	1	Beach discharge inner	Outflow via other L1 zones
21	1	Beach discharge outer	Outflow via other L1 zones
22	**2**	**L2 beach outer**	

Notes. Bold zones indicate the key groundwater and nutrient flux areas

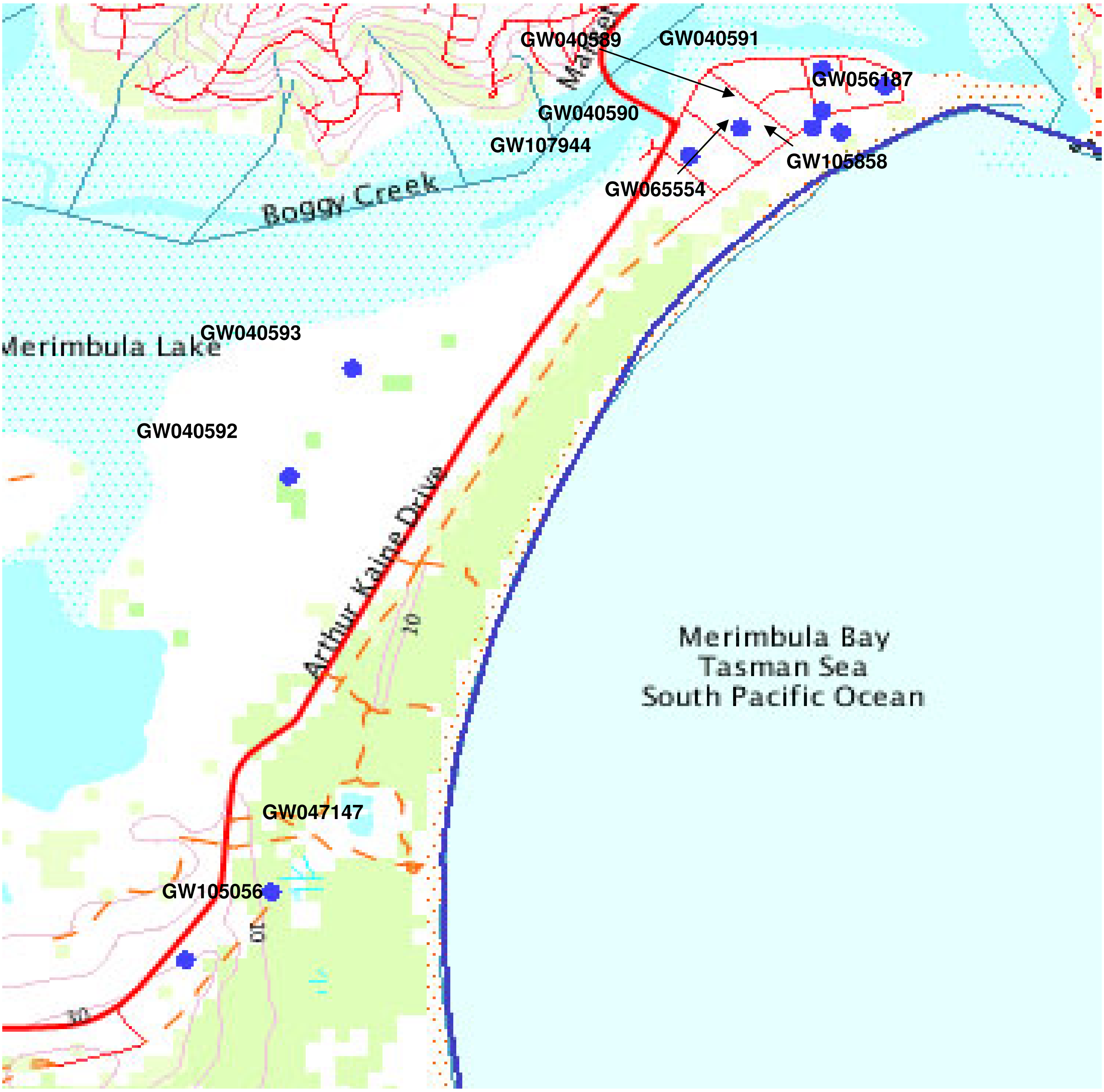


Figure 4.2: Locations of Registered Bores

Project: Investigation and Assessment of Impacts: Groundwater, Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

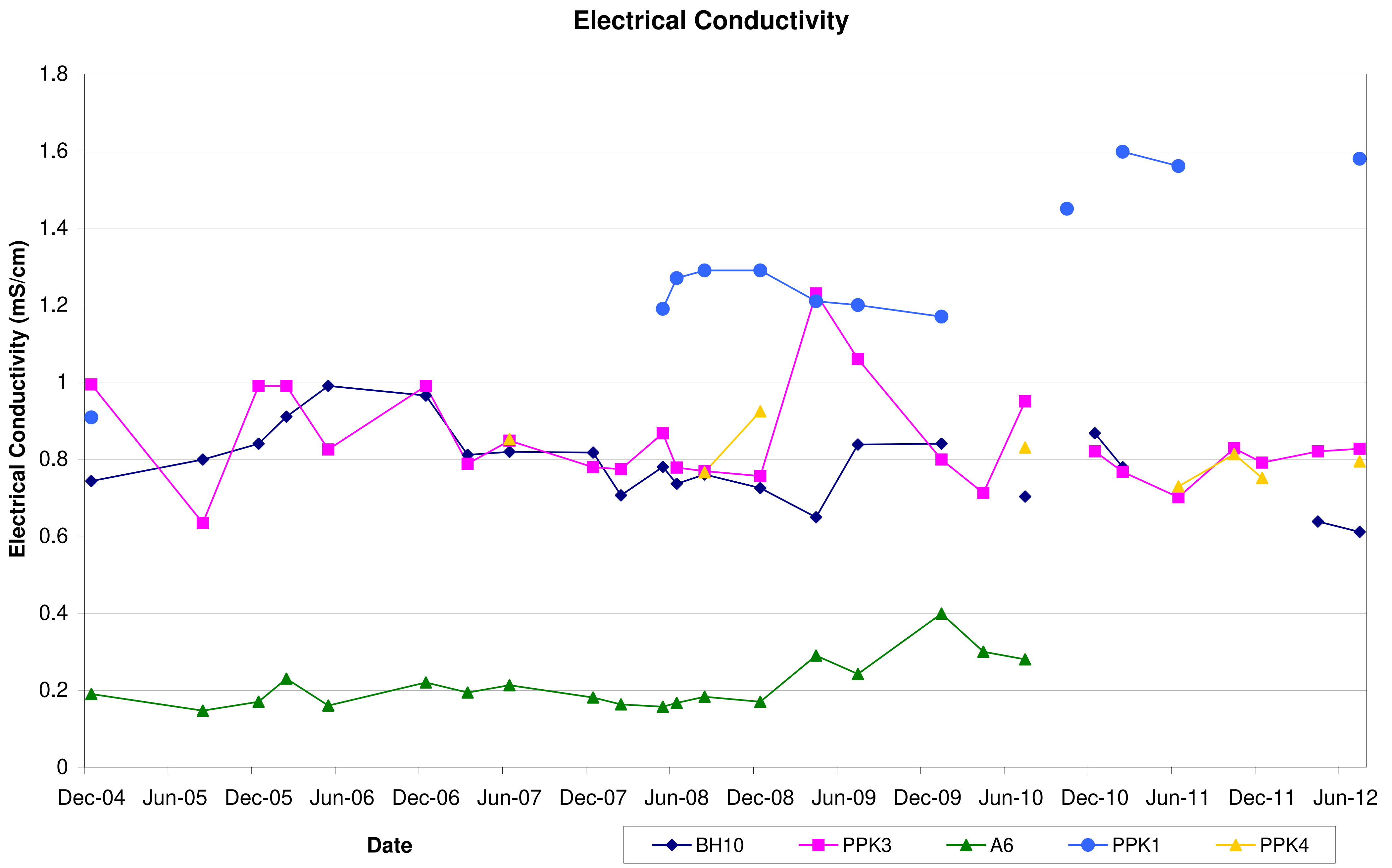


Figure 8.7a: Groundwater Quality, Electrical Conductivity

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

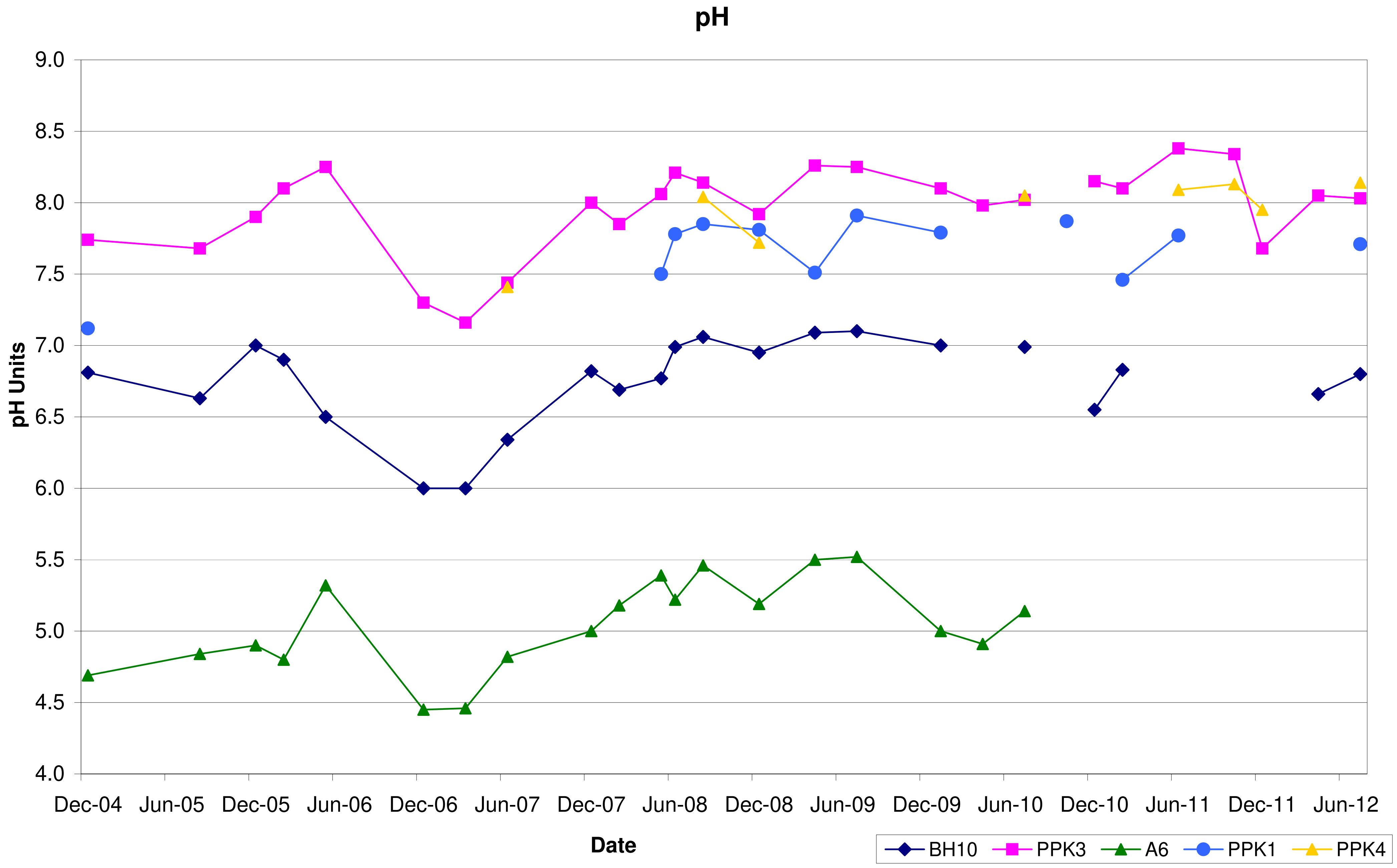


Figure 8.7b: Groundwater Quality, pH

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

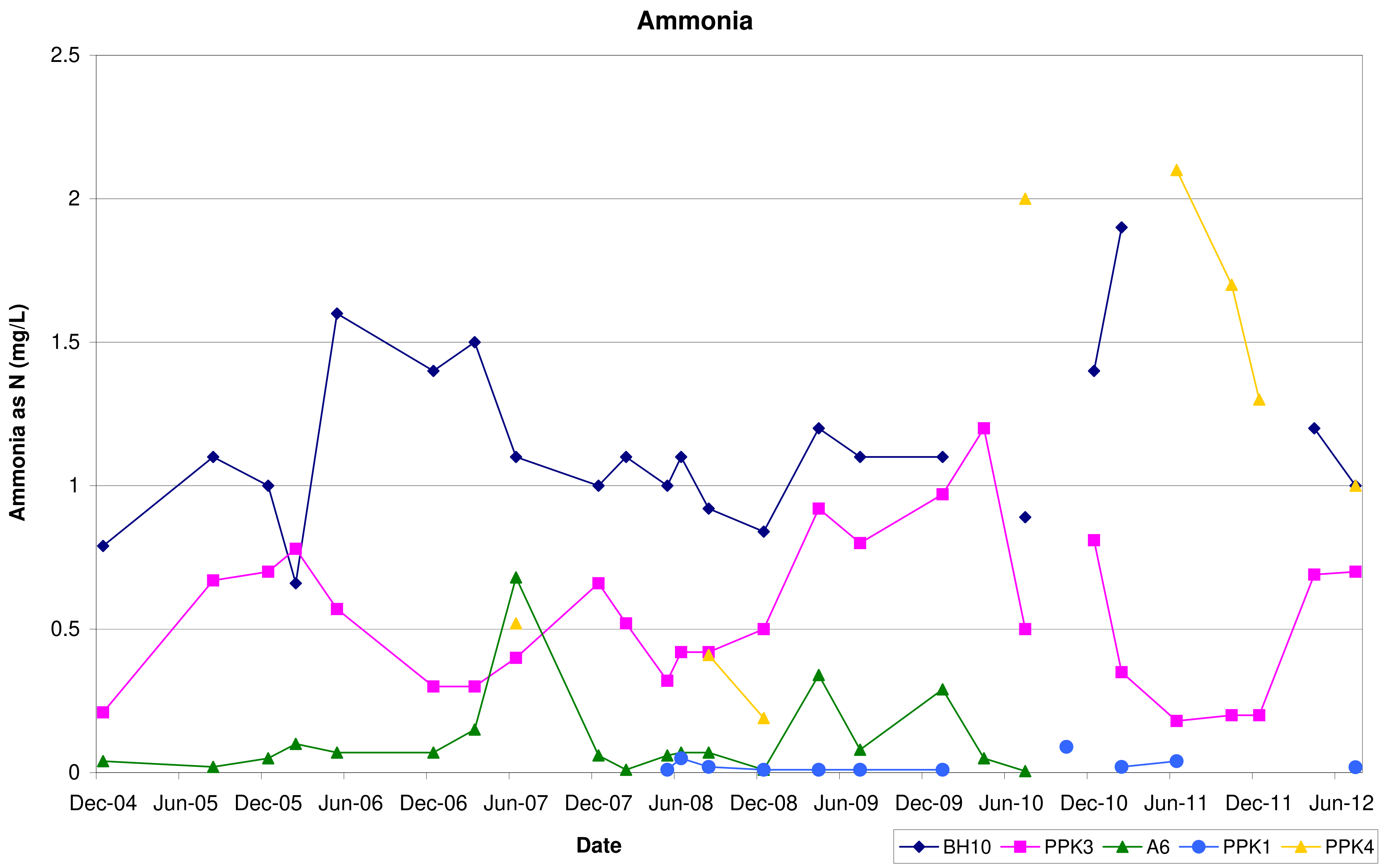


Figure 8.7c: Groundwater Quality, Ammonia

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

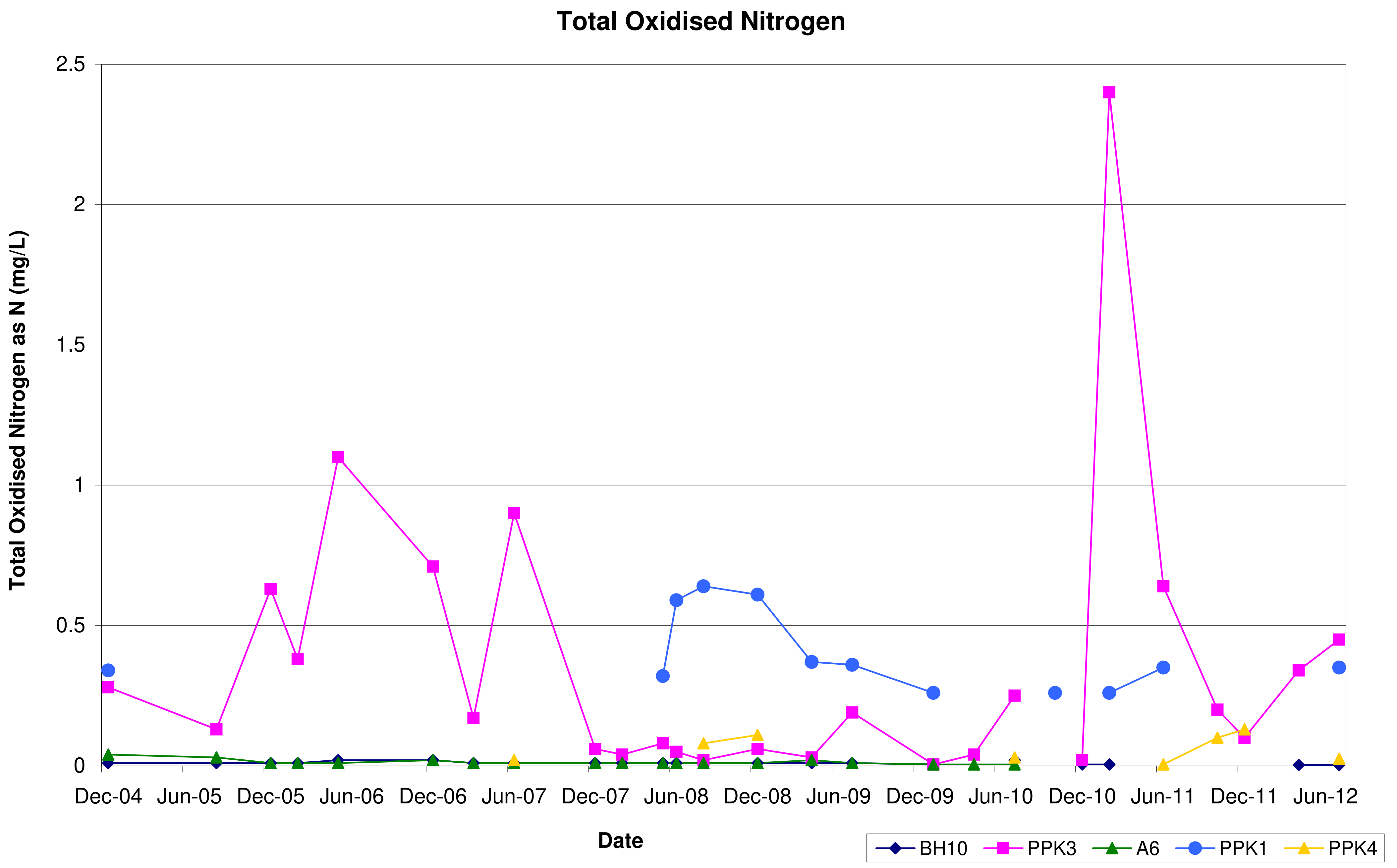


Figure 8.7d: Groundwater Quality, Total Oxidised Nitrogen

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

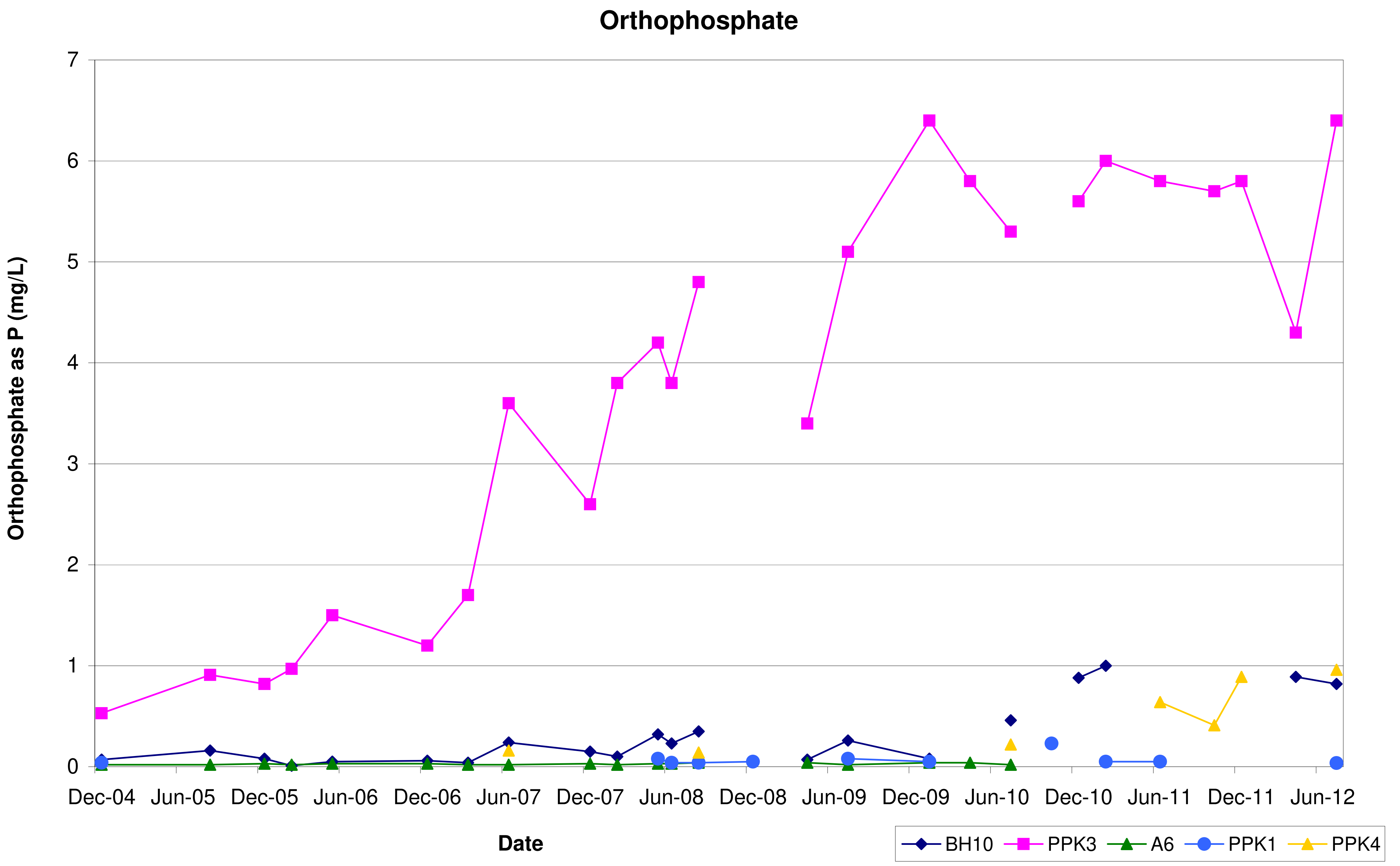


Figure 8.7e: Groundwater Quality, Orthophosphate

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

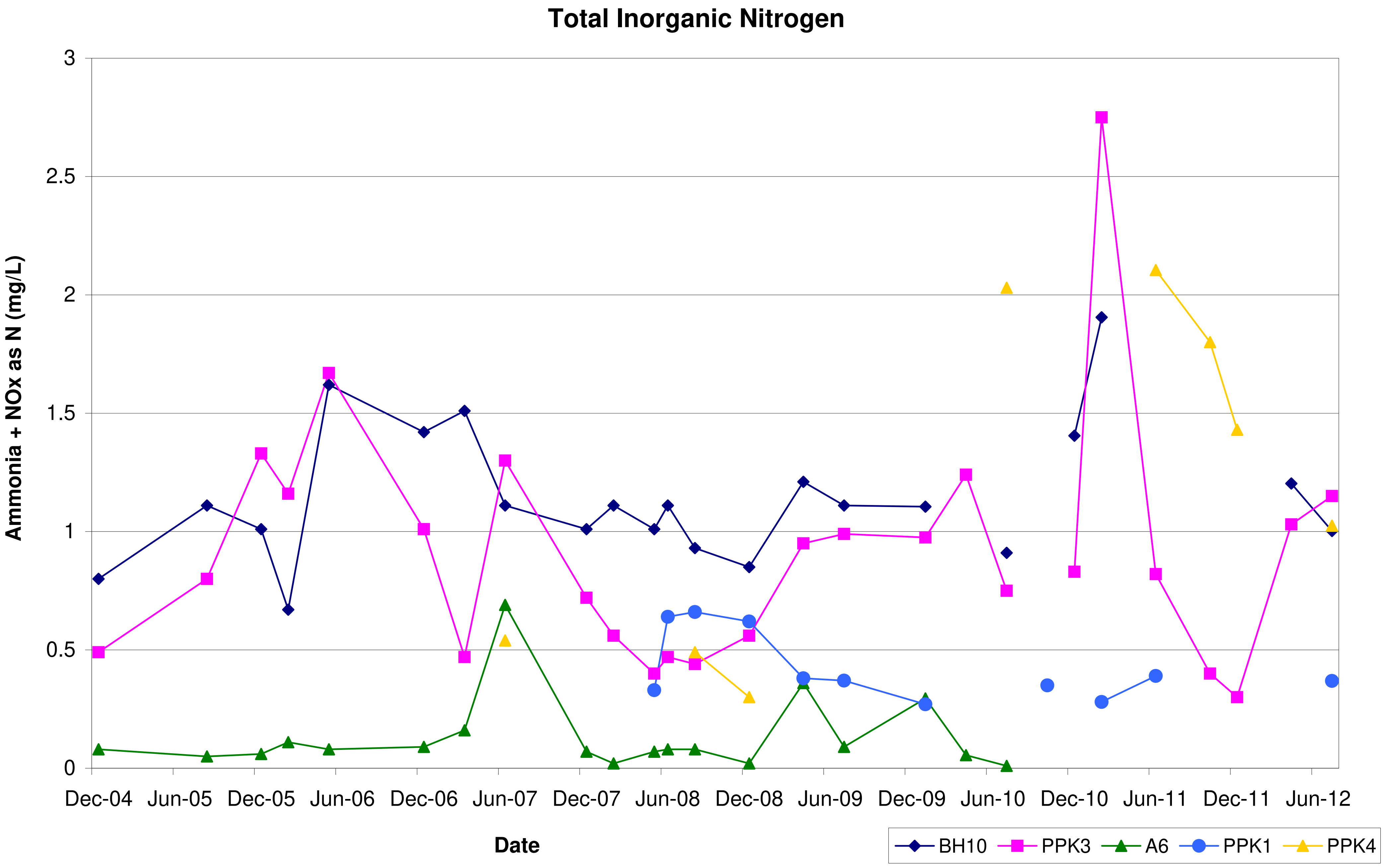


Figure 8.7f: Groundwater Quality, Total Inorganic Nitrogen (Ammonia plus NOx)

Project: Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client: Bega Valley Shire Council
Project No: FJ06

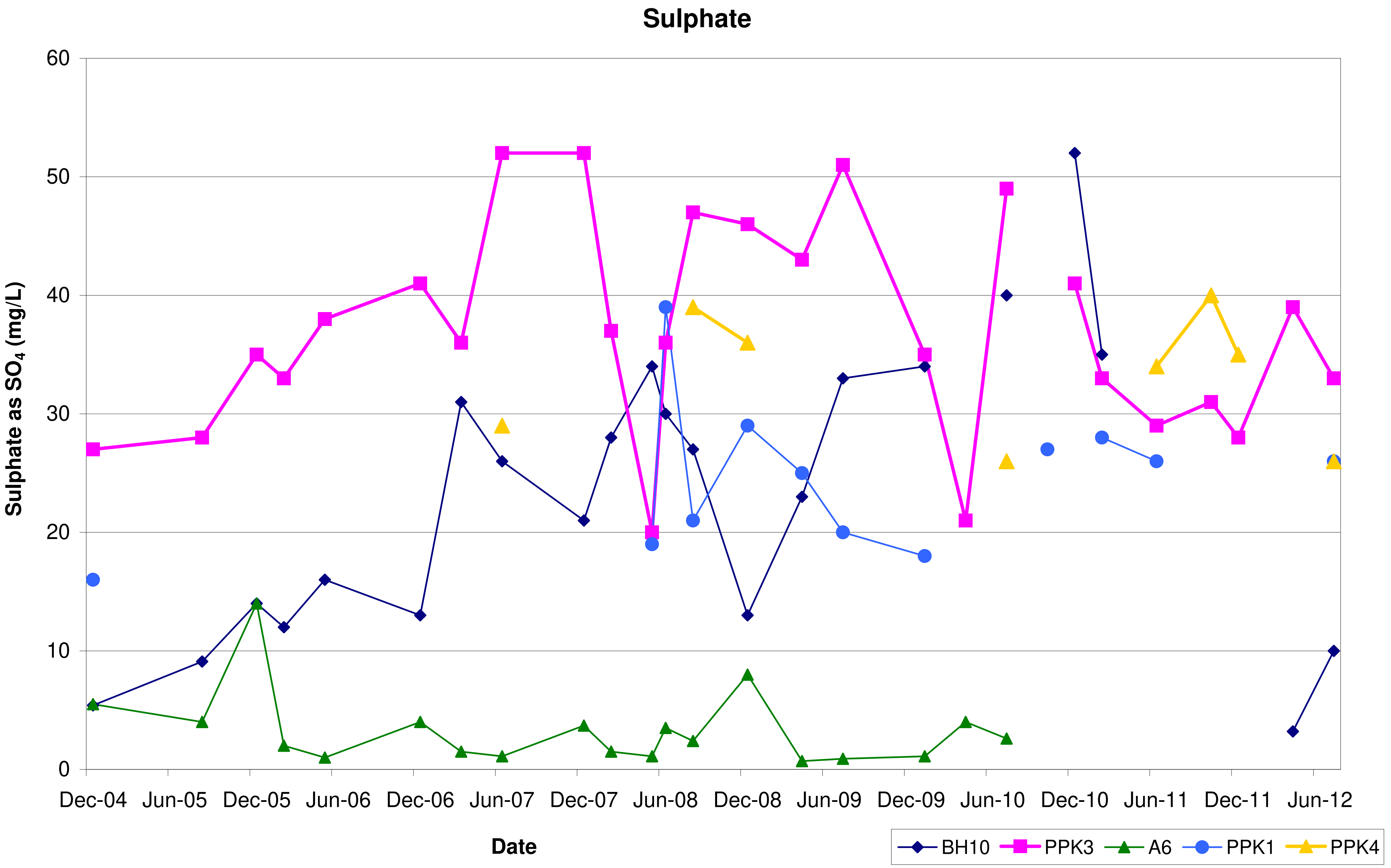


Figure 8.7g: Groundwater Quality, Sulphate as SO_4

Project:	Investigation and Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Client:	Bega Valley Shire Council
Project No:	FJ06

IGGC

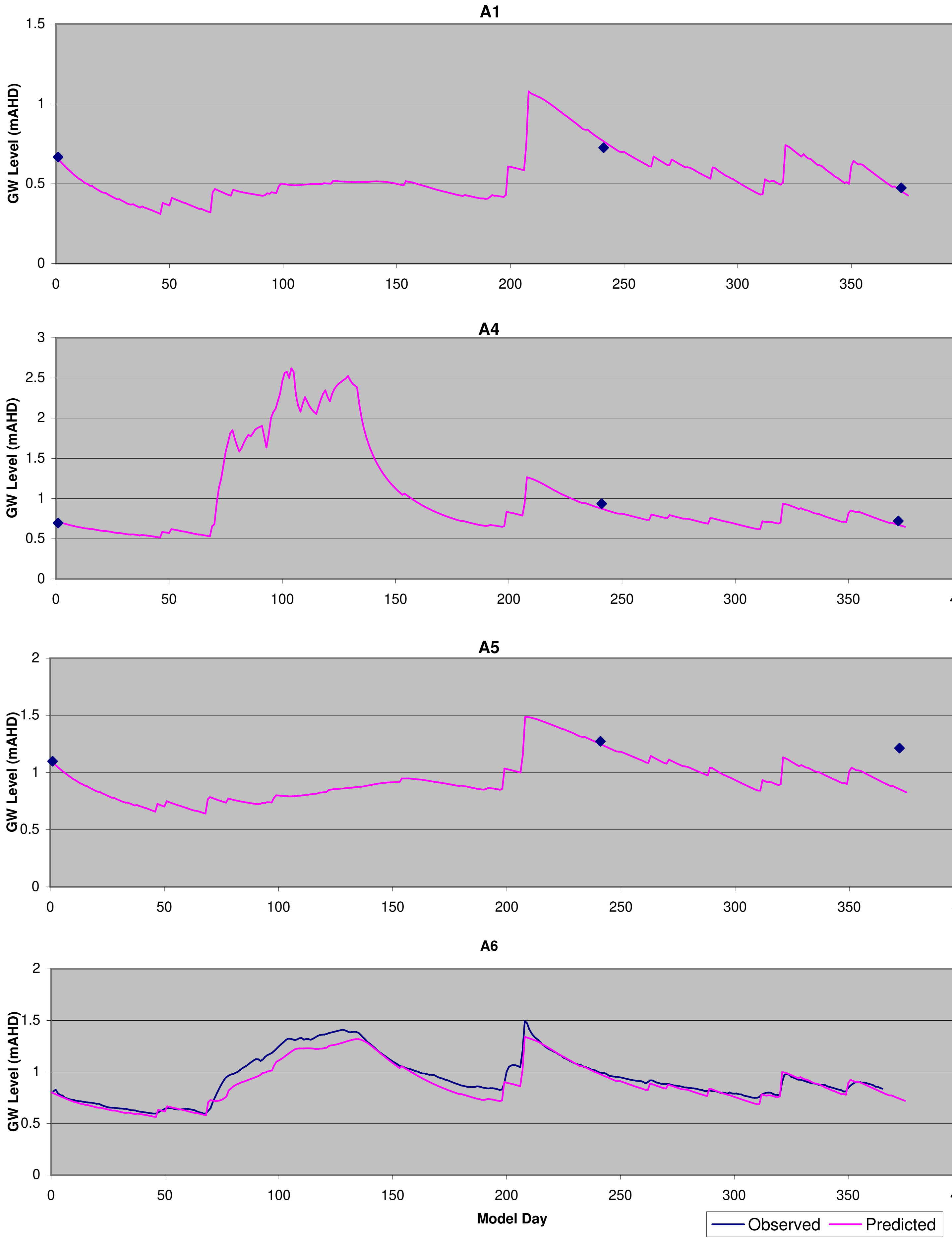


FIGURE 10.4a: Transient Calibration Hydrographs

Project: Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Location: Merimbula
Client: Bega Valley Shire Council
Project No: FJ06

IGGC

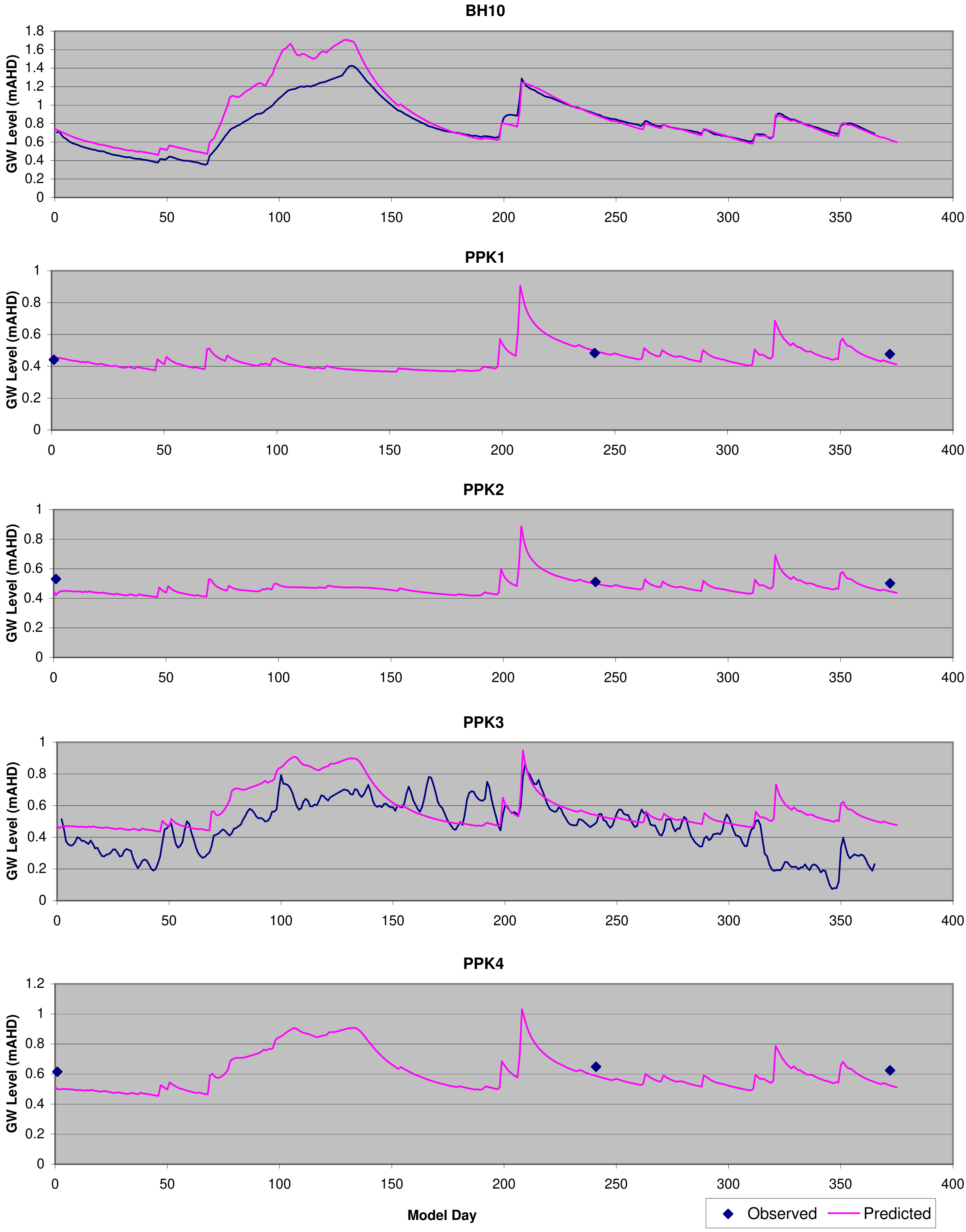
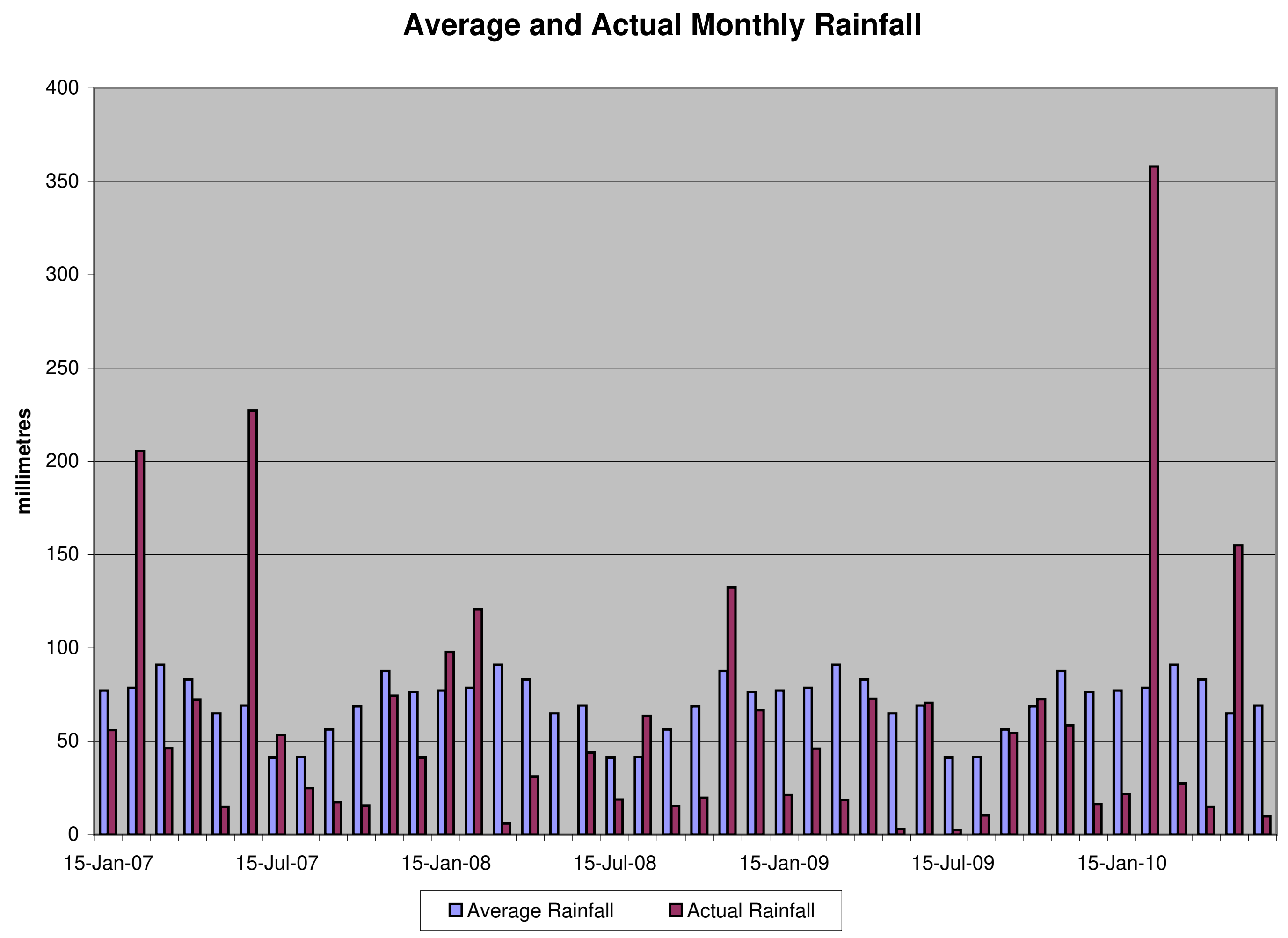


FIGURE 10.4b: Transient Calibration Hydrographs

Project: Assessment of Impacts on Groundwater Levels and Water Quality of Merimbula Lake and Bay
Location: Merimbula
Client: Bega Valley Shire Council
Project No: FJ06



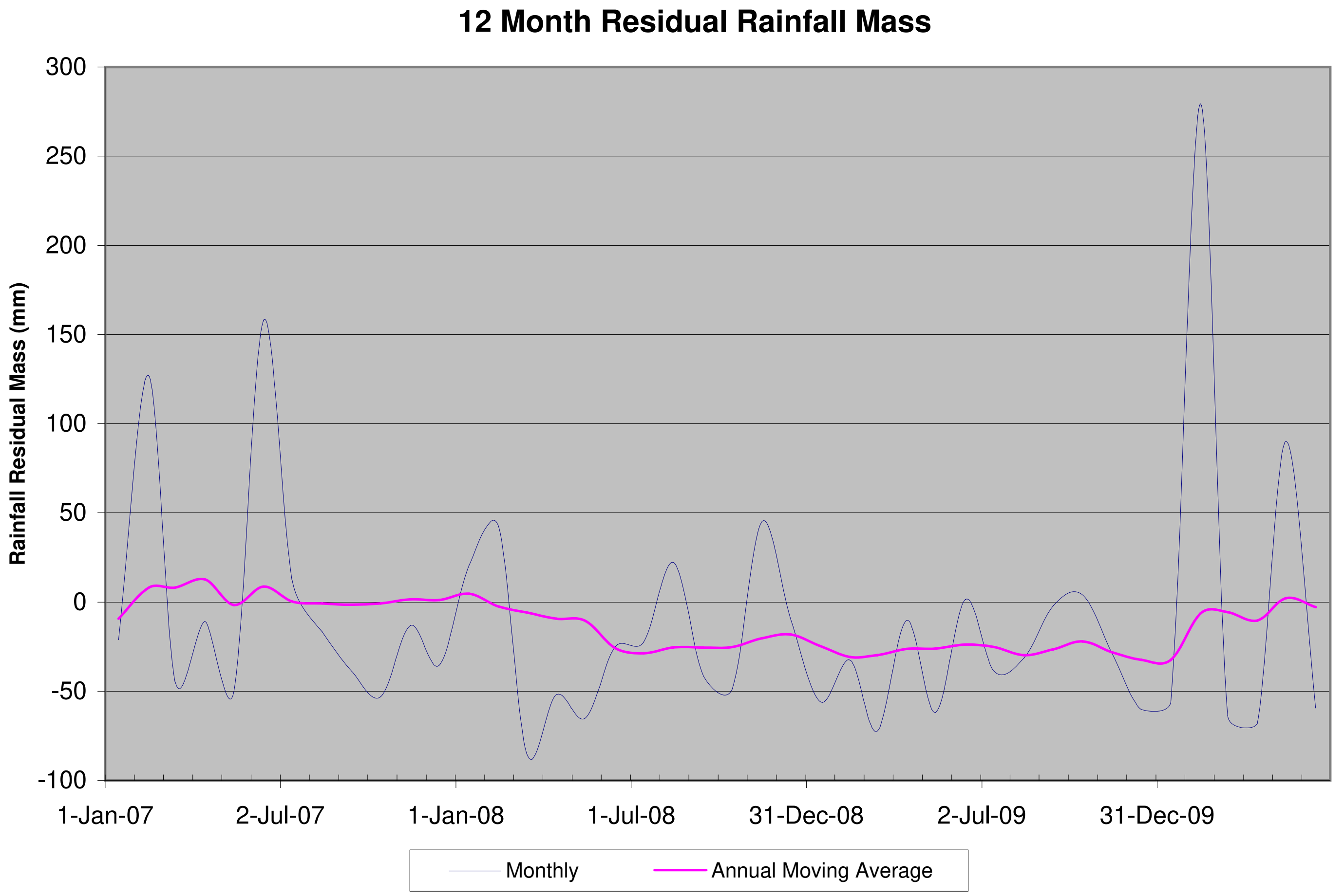


Figure 10.5: Rainfall Graphs - Simulation Period

Project: Investigation and Assessment of Impacts: Groundwater, Merimbula Lake and Bay

Client: Bega Valley Shire Council

Project: FJ06

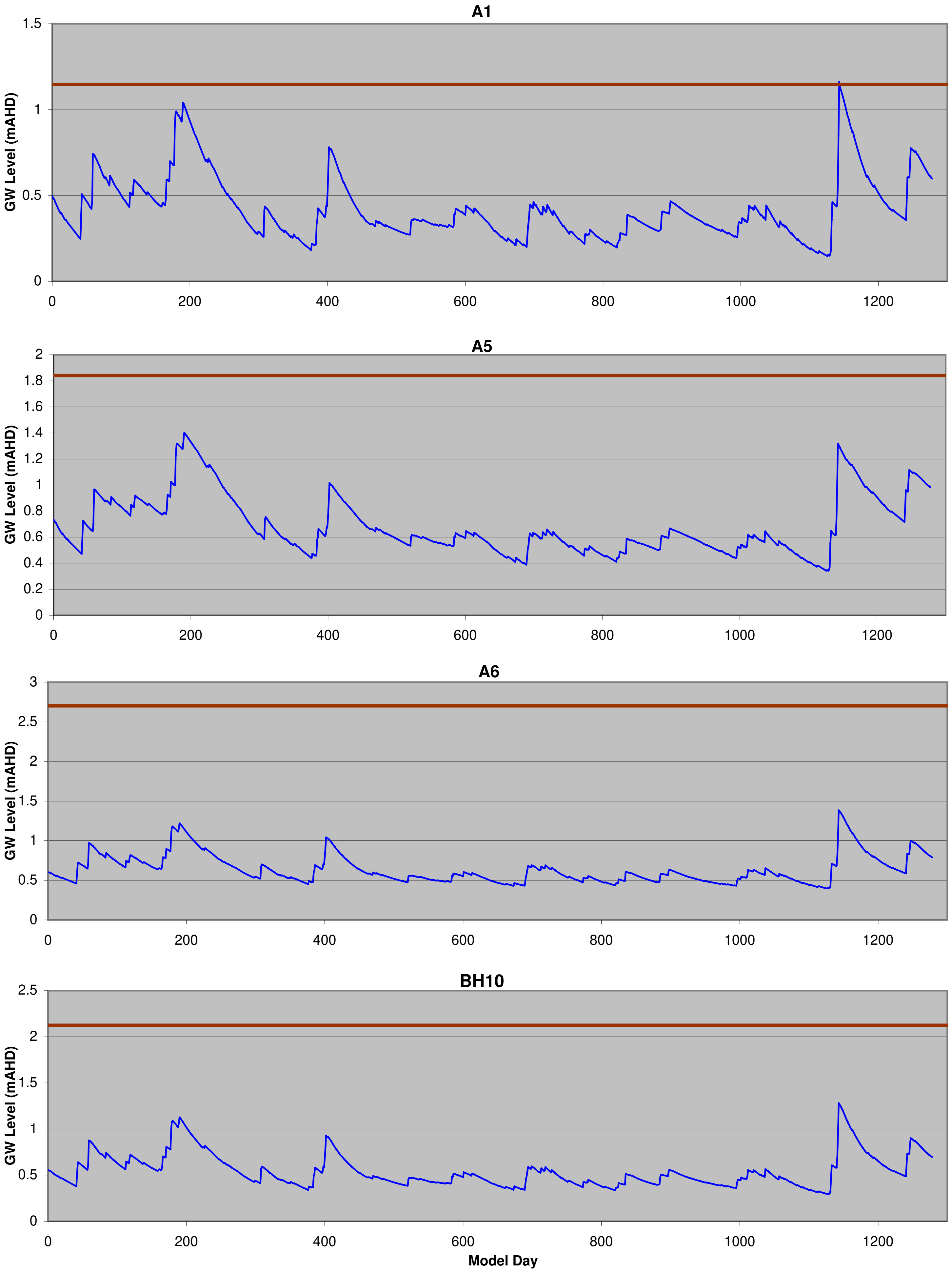


Figure 10.6a: Hydrographs for Simulation Period, No Effluent Discharge

Project:	Investigation and Assessment of Impacts: Groundwater, Merimbula Lake and Bay
Location:	Merimbula
Client:	Bega Valley Shire Council
Project No:	FJ06

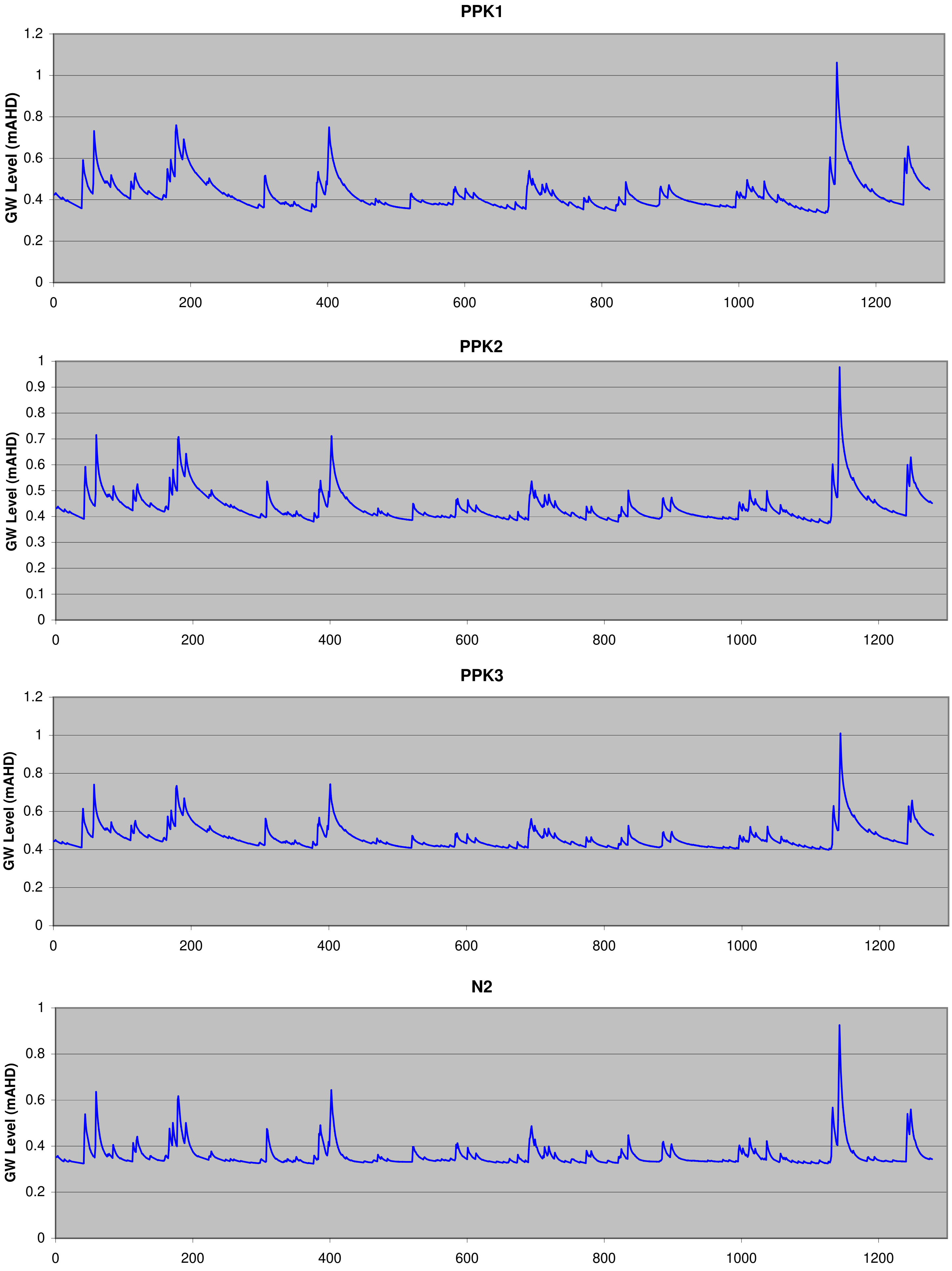


Figure 10.6b: Hydrographs for Simulation Period, No Effluent Discharge

Project: Investigation and Assessment of Impacts: Groundwater, Merimbula Lake and Bay
Location: Merimbula
Client: Bega Valley Shire Council
Project No: FJ06

IGGC

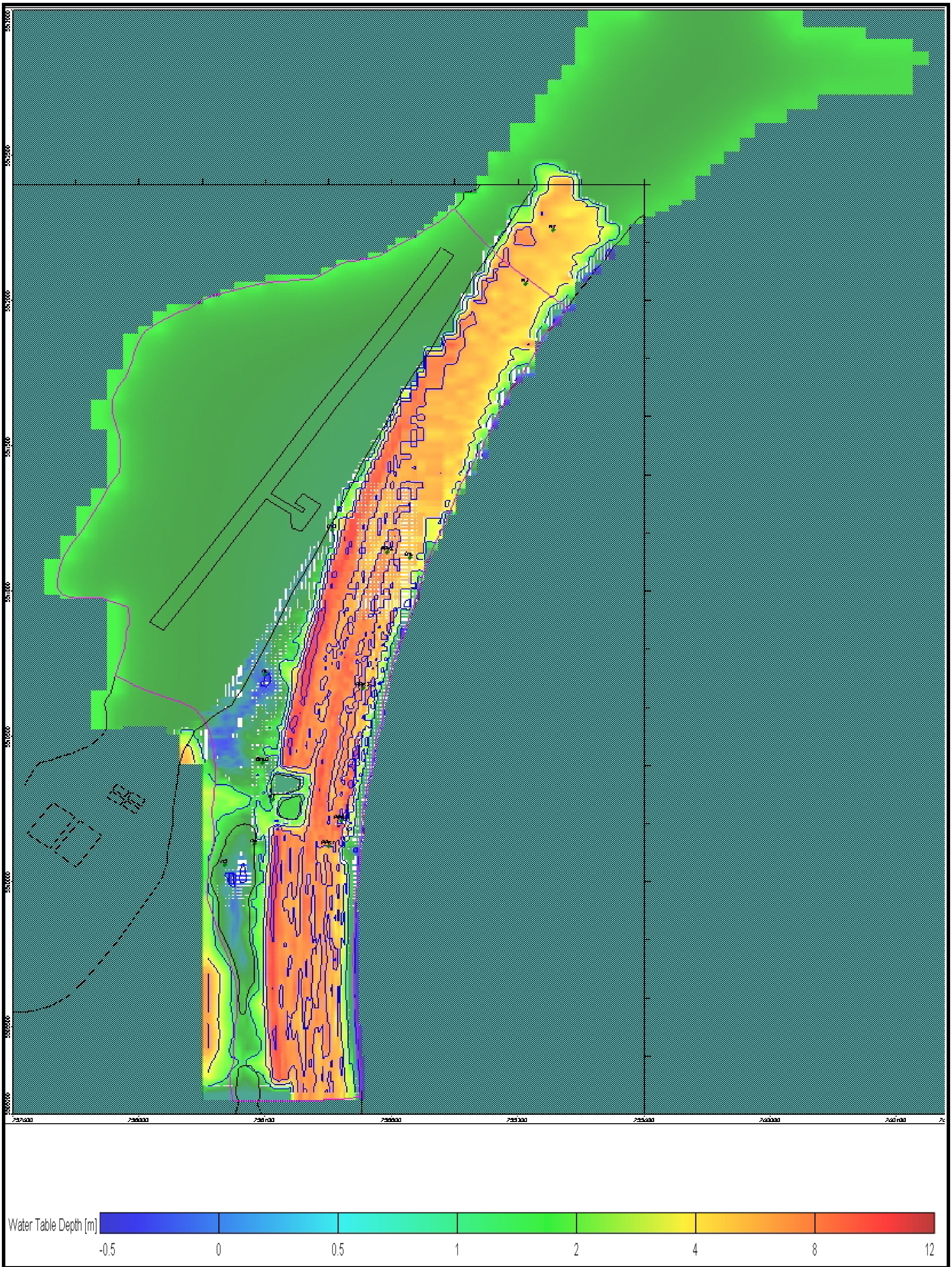


Figure 10.7: Depth to Groundwater, 16th February 2010, No Exfiltration

Project:	Investigation and Assessment of Impacts: Groundwater, Merimbula Lake and Bay
Client:	Bega Valley Shire Council
Project No:	FJ06

Appendix B

Sieve Analyses and Bore Logs

Resource Laboratories

ABN: 25 131 532 020

Sydney: 32/6 Abbott Road Seven Hills NSW 2147 | PO Box 45 Pendle Hill NSW 2145

Ph: (02) 9674 7711 | **Fax**: (02) 9674 7755 | **Email**: info@resourcelab.com.au

Test Report

Customer: Terratest Environmental

Project: Materials Testing

Location: Merimbula

Job number: 10-0020

Report number: 1

Page: 1 of 1

Particle Size Distribution

Sampling method: Sample tested as received

Date sampled: Not known

Test method(s): AS1289.1.1, 3.6.1 (Dry sieved)

Date tested: 29/07/2010

	Results				
Laboratory sample no.	331				
Customer sample no.	C1 10.5 - 20m				
Material description	Medium sand, pale brown				
% Passing AS Sieve 75.0mm					
63.0mm					
53.0mm					
37.5mm					
26.5mm					
19.0mm					
13.2mm					
9.5mm					
6.7mm					
4.75mm	100				
2.36mm	99				
1.18mm	98				
600µm	89				
425µm	71				
300µm	35				
150µm	2				
75µm	1				

Approved Signatory: **E. Maldonado** **Date:** 29/07/2010

Resource Laboratories

ABN: 25 131 532 020

Sydney: 32/6 Abbott Road Seven Hills NSW 2147 | PO Box 45 Pendle Hill NSW 2145
Ph: (02) 9674 7711 | **Fax**: (02) 9674 7755 | **Email**: info@resourcelab.com.au

Test Report

Customer: Terratest Environmental
Project: Materials Testing
Location: Merimbula

Job number: 10-0020
Report number: 2
Page: 1 of 1

Particle Size Distribution

Sampling method: Sample tested as received
Date sampled: Not known

Test method(s): AS1289.1.1, 3.6.1 (Dry sieved)
Date tested: 2/08/2010

	Results				
Laboratory sample no.	340				
Customer sample no.	C2 10 - 20m				
Material description	Medium sand, pale brown				
% Passing AS Sieve					
75.0mm					
63.0mm					
53.0mm					
37.5mm					
26.5mm					
19.0mm					
13.2mm					
9.5mm					
6.7mm					
4.75mm					
2.36mm	100				
1.18mm	99				
600µm	86				
425µm	65				
300µm	31				
150µm	2				
75µm	0				

Approved Signatory: **E. Maldonado** **Date:** 2/08/2010

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Fax: (+61) (02) 9519 0905

COMPOSITE WELL LOG

Well No: MW PPK1 Rep

Client: BVSC
Project: Merimbula Dunes Investigation

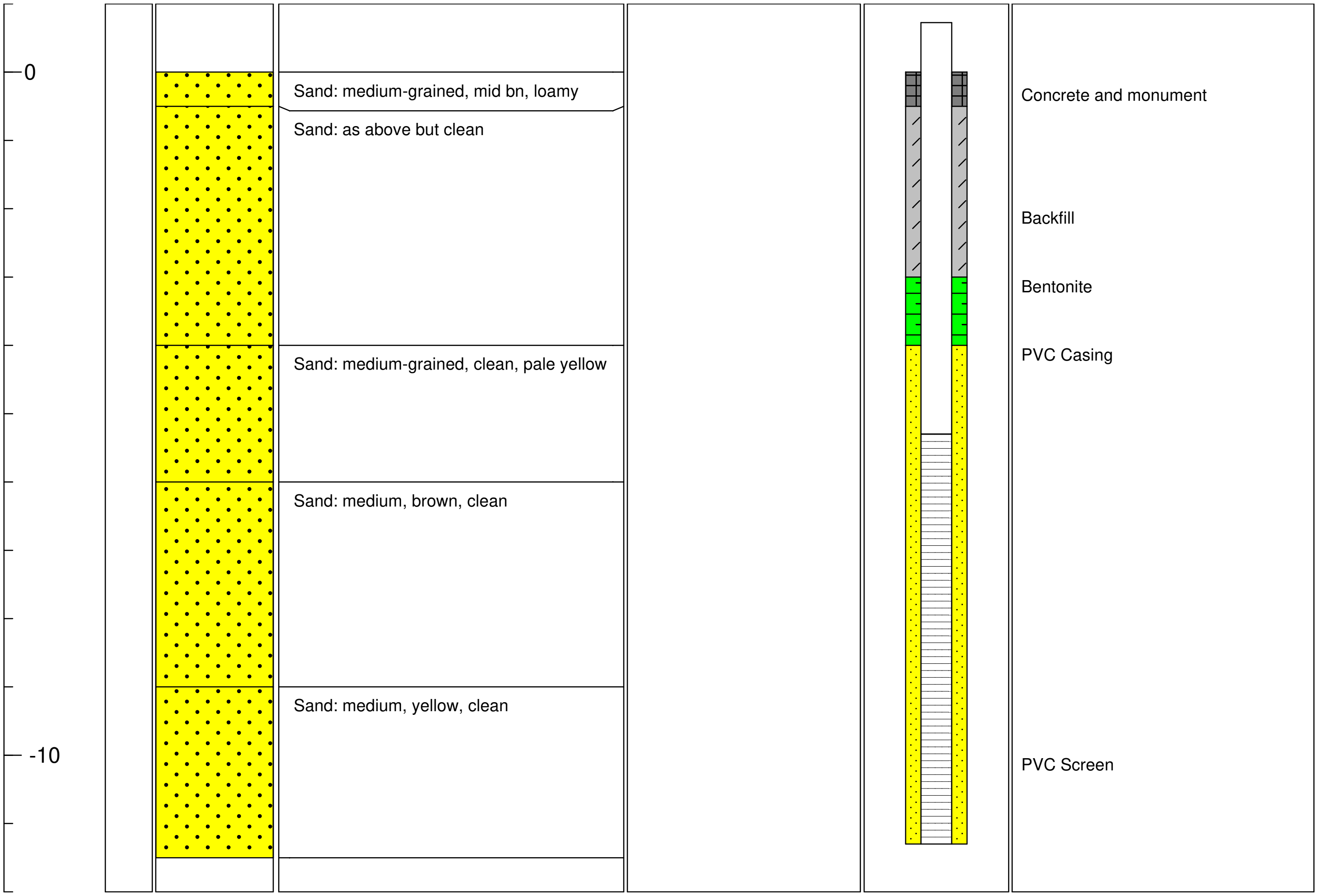
Commenced: 28/7/10
Completed: 28/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Augers
Fluid: Water
Bit: 225 mm

Area: Central
East: 758787.445
North: 5911131.49
Elevation: 7.66

Static Water Level: 7.16
Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



Sand: medium-grained, mid bn, loamy

Sand: as above but clean

Sand: medium-grained, clean, pale yellow

Sand: medium, brown, clean

Sand: medium, yellow, clean

Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: MW C1

Client: BVSC
Project: Merimbula Dunes Investigation

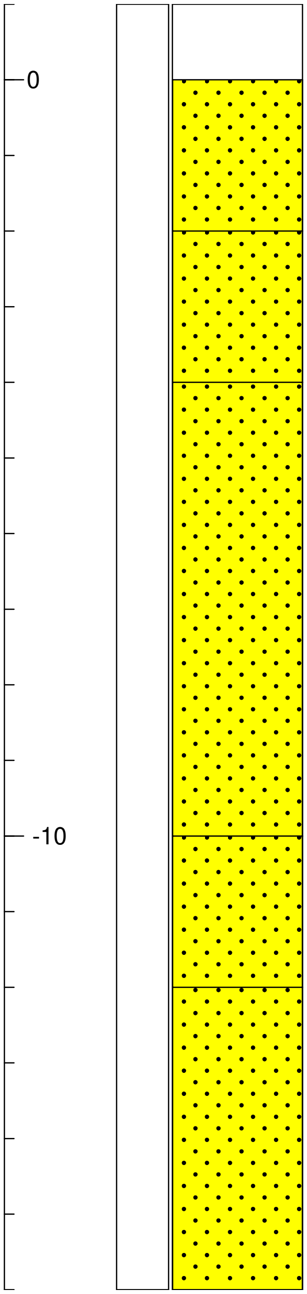
Commenced: 27/7/10
Completed: 27/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Auger
Fluid: Water
Bit: 225 mm

Area: Central
East: 758789.96
North: 5911176.76
Elevation: 7.765

Static Water Level: 7.26
Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



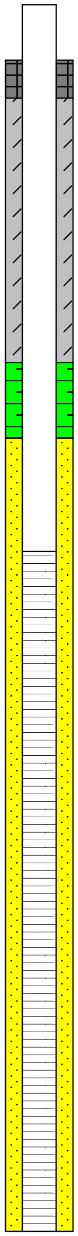
Sand: medium-grained, brown, loamy

Sand: medium, lt bn, clean

Sand: medium-grained, pale yellow, clean

Sand: slightly coarser

Sand: as above with shell fragments



Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: MW C2

Client: BVSC
Project: Merimbula Dune Investigation

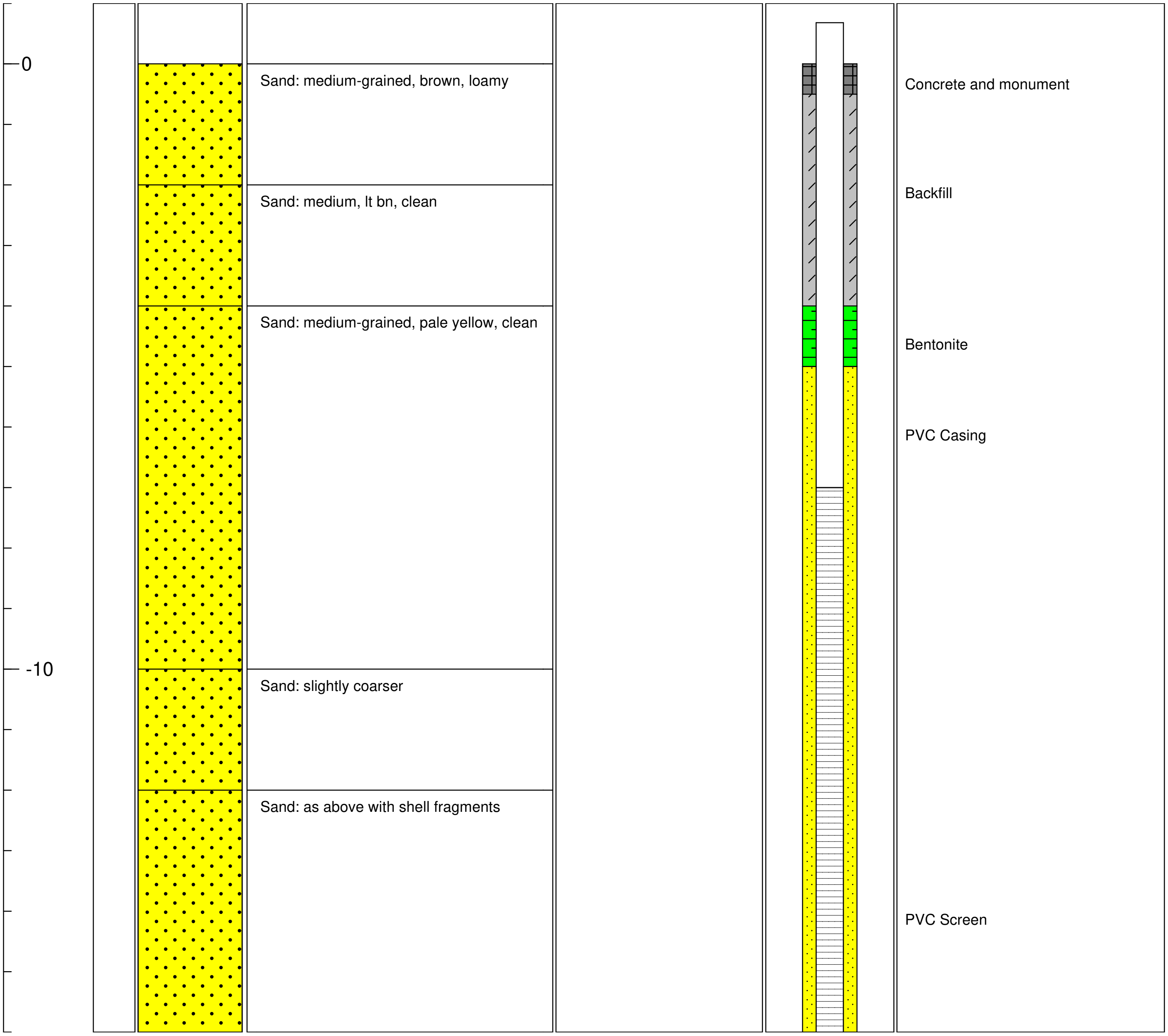
Commenced: 27/7/10
Completed: 27/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Augers
Fluid: Water
Bit: 225 mm

Area: Central
East: 758818.34
North: 5911132.56
Elevation: 7.19

Static Water Level: 6.69
Date: 14/10/10

Depth (mbgl)	**Geology**	**Graphic Log**	**Lithological Description**	**Field Notes**	**Well Completion** Diagram	**Well Completion** Notes



Sand: medium-grained, brown, loamy

Sand: medium, lt bn, clean

Sand: medium-grained, pale yellow, clean

Sand: slightly coarser

Sand: as above with shell fragments

Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: Central Test Bore

Client: BVSC
Project: Merimbula Dune Investigation

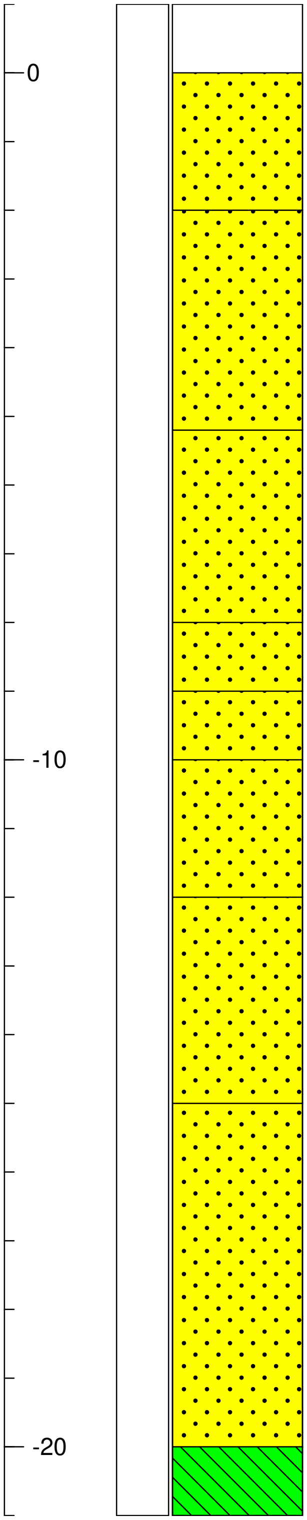
Commenced: 26/7/10
Completed: 11/8/10
Drilled: Terratest
Logged By: IG

Method: Hollows & Mud Rotary
Fluid: Water, guar gum
Bit: 125 mm

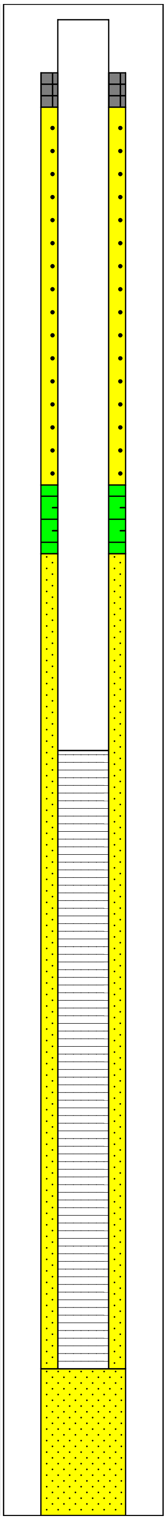
Area: Central
East: 758803.7
North: 5911149.03
Elevation: 8.0

Static Water Level: 7.503 m
Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



Lithological Description	Field Notes
Sand: fine-med, brown, roots	
Sand: fine-med, brown	
Sand: fine-med, yellow/brown, sub-rounded	
Sand: fine-med, lt brown, occ. carb, occ. shelly	
Sand: fine-med, lt bn/yellow, (sub)rounded	
Sand: fine-med, yellow, shell frags common	
Sand: fine-med, yellow/grey, silcrete frags to 20mm	
Sand: fine-med	
Clay: sandy, grey, puggy	



Concrete

PVC Casing

Bentonite Seal

S/S Screen

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COMPOSITE WELL LOG

Well No: MW N1

Client: BVSC
Project: Merimbula Dunes Investigation

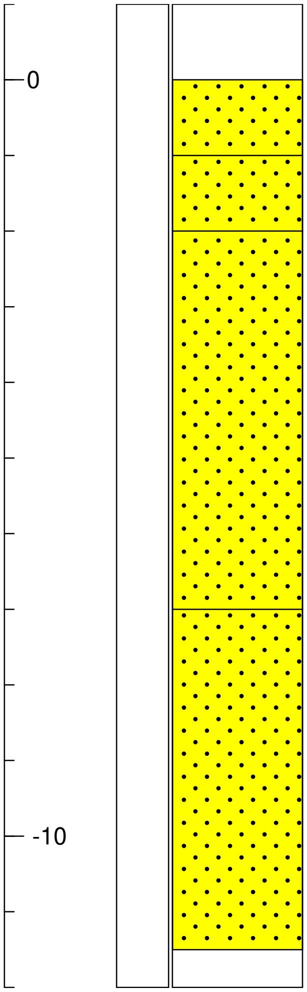
Commenced: 28/7/10
Completed: 28/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Augers
Fluid: Water
Bit: 225 mm

Area: Northern
East: 759187.11
North: 5912110.05
Elevation: 6.88

Static Water Level: 6.56
Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes

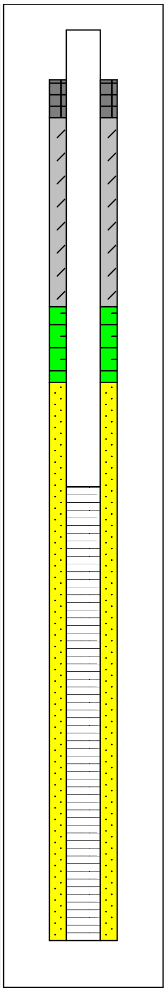


Sand: medium-grained, mid bn, loamy, s. carb

Sand: medium-grained, brown, occ carb

Sand: medium-grained, clean, yellow

Sand: medium, yellow, clean, shell frags increasing with depth



Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: MW N2

Client: BVSC
Project: Merimbula Dunes Investigation

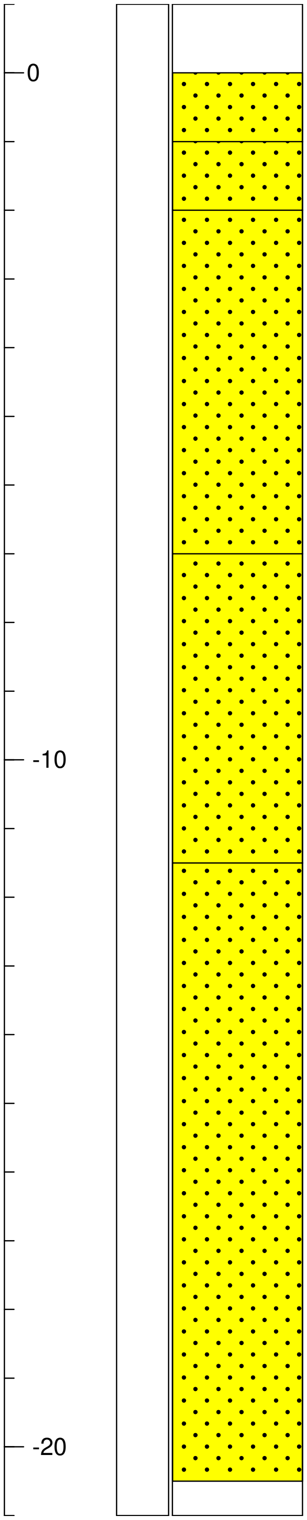
Commenced: 29/7/10
Completed: 29/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Augers
Fluid: Water
Bit: 225 mm

Area: Northern
East: 759226.42
North: 5912056.49
Elevation: 6.78

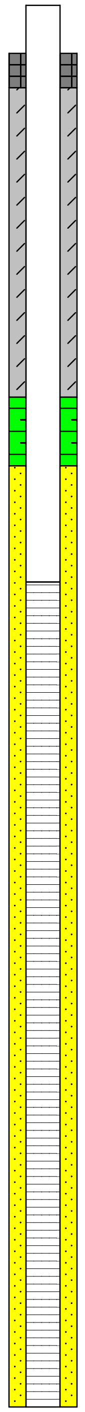
Static Water Level: 6.48
Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



Lithological Description

- Sand: medium-grained, mid bn, loamy
- Sand: medium-grained, yellow
- Sand: medium-grained, clean, yellow
- Sand: medium, yellow, clean
- Sand: medium, becoming s.coarser



Notes

- Concrete and monument
- Backfill
- Bentonite
- PVC Casing
- PVC Screen

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COMPOSITE WELL LOG

Well No: MW N3

Client: BVSC
Project: Merimbula Dunes Investigation

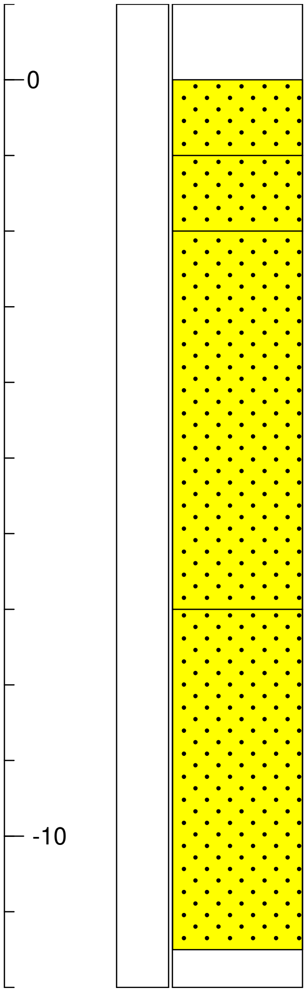
Commenced: 28/7/10
Completed: 28/7/10
Drilled: Terratest
Logged By: IG

Method: Hollow Flight Augers
Fluid: Water
Bit: 225 mm

Area: Northern
East: 759250.71
North: 5912022.26
Elevation: 6.76

Static Water Level: 6.43
Date: 14/10/10

Depth (mbgl) | **Geology** | **Graphic Log** | **Lithological Description** | **Field Notes** | **Well Completion: Diagram** | **Notes**

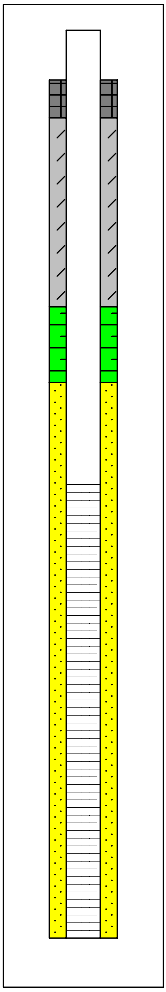


Sand: medium-grained, mid bn, loamy, s. carb

Sand: medium-grained, brown, occ carb

Sand: medium-grained, clean, yellow

Sand: medium, yellow, clean, shell frags increasing with depth



Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: MW N4

Client: BVSC

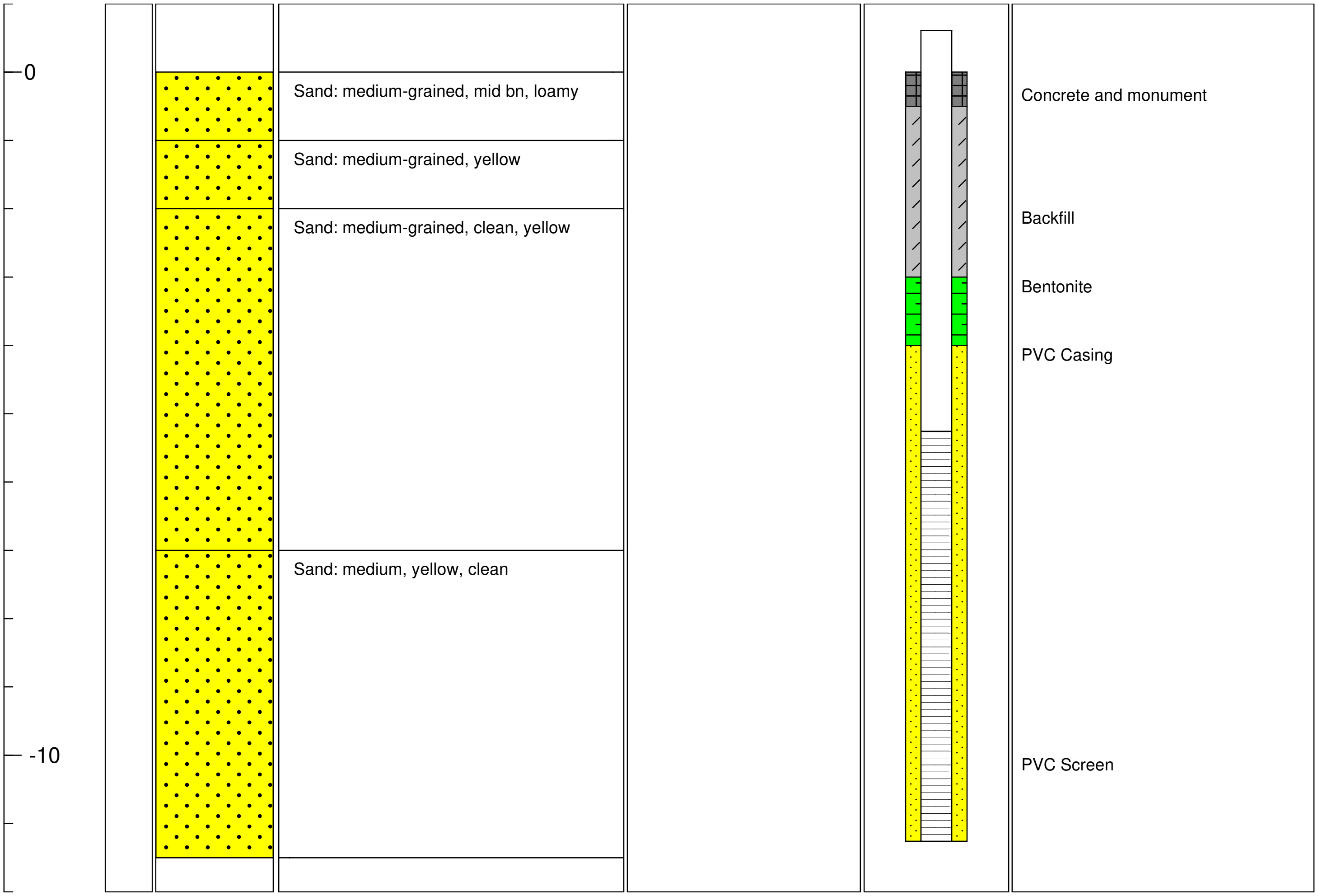
Project: Merimbula Dunes Investigation

Commenced:	29/7/10	**Method:**	Hollow Flight Augers	**Area:**	Northern
Completed:	29/7/10	**Fluid:**	Water	**East:**	759311.86
Drilled:	Terratest	**Bit:**	225 mm	**North:**	5912242.28
Logged By:	IG			**Elevation:**	6.92

Static Water Level: 6.64

Date: 14/10/10

Depth (mbgl)	Geology	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes



Sand: medium-grained, mid bn, loamy

Sand: medium-grained, yellow

Sand: medium-grained, clean, yellow

Sand: medium, yellow, clean

Concrete and monument

Backfill

Bentonite

PVC Casing

PVC Screen

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COMPOSITE WELL LOG

Well No: Northern Test Bore

Client: BVSC
Project: Merimbula Dunes Investigation

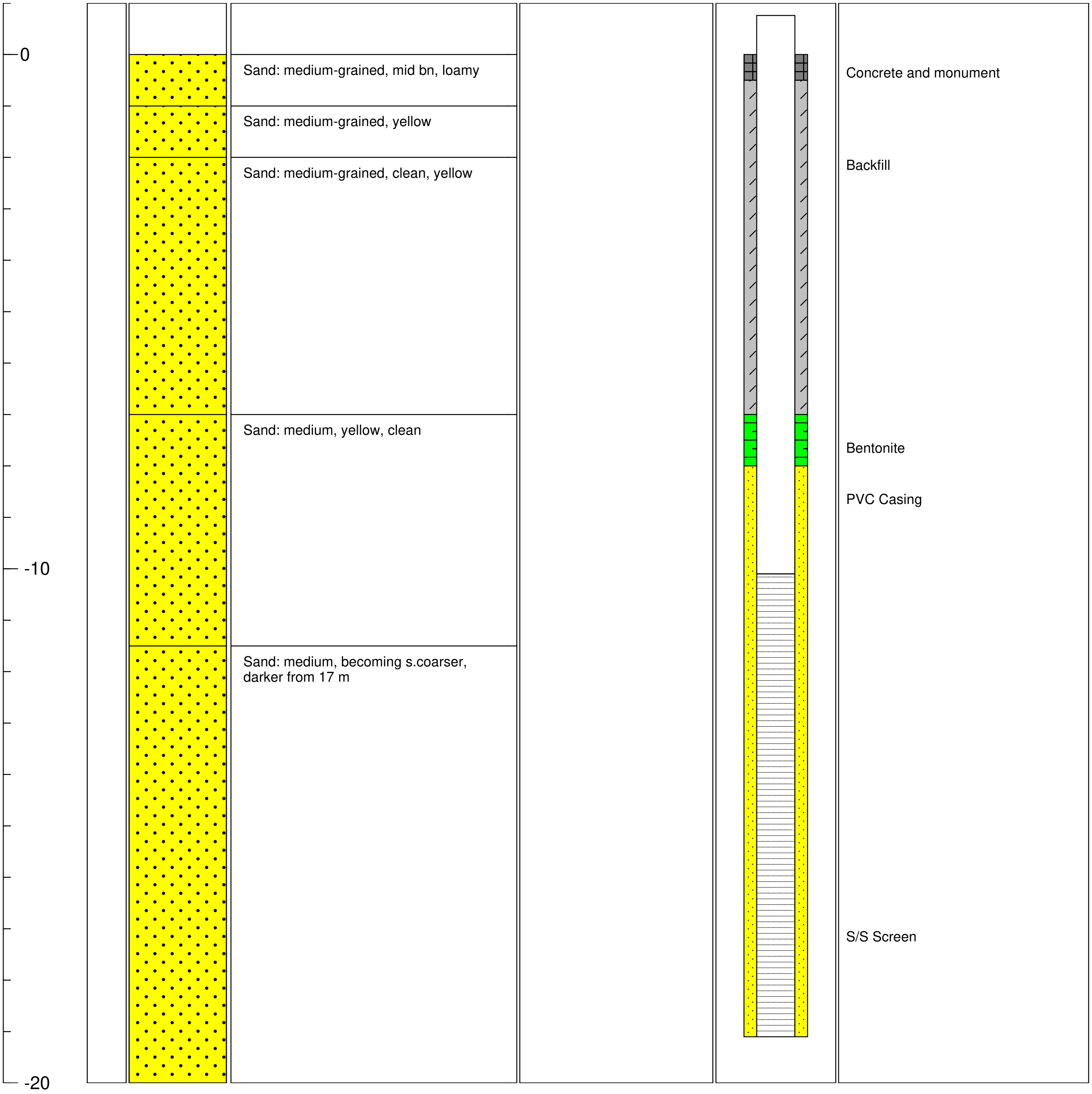
Commenced: 12/8/10
Completed: 12/8/10
Drilled: Terratest
Logged By: IG

Method: Mud Rotary
Fluid: Water , guar gum
Bit: 125 mm

Area: Northern
East: 759238.44
North: 5912048.45
Elevation: 6.65

Static Water Level: 6.31
Date: 15/10/10

Depth (mbgl)	**Geology**	**Graphic Log**	**Lithological Description**	**Field Notes**	**Well Completion** Diagram	**Well Completion** Notes



Sand: medium-grained, mid bn, loamy

Sand: medium-grained, yellow

Sand: medium-grained, clean, yellow

Sand: medium, yellow, clean

Sand: medium, becoming s.coarser, darker from 17 m

Concrete and monument

Backfill

Bentonite

PVC Casing

S/S Screen

Appendix C

Pump Test Analyses

IGGC P/L
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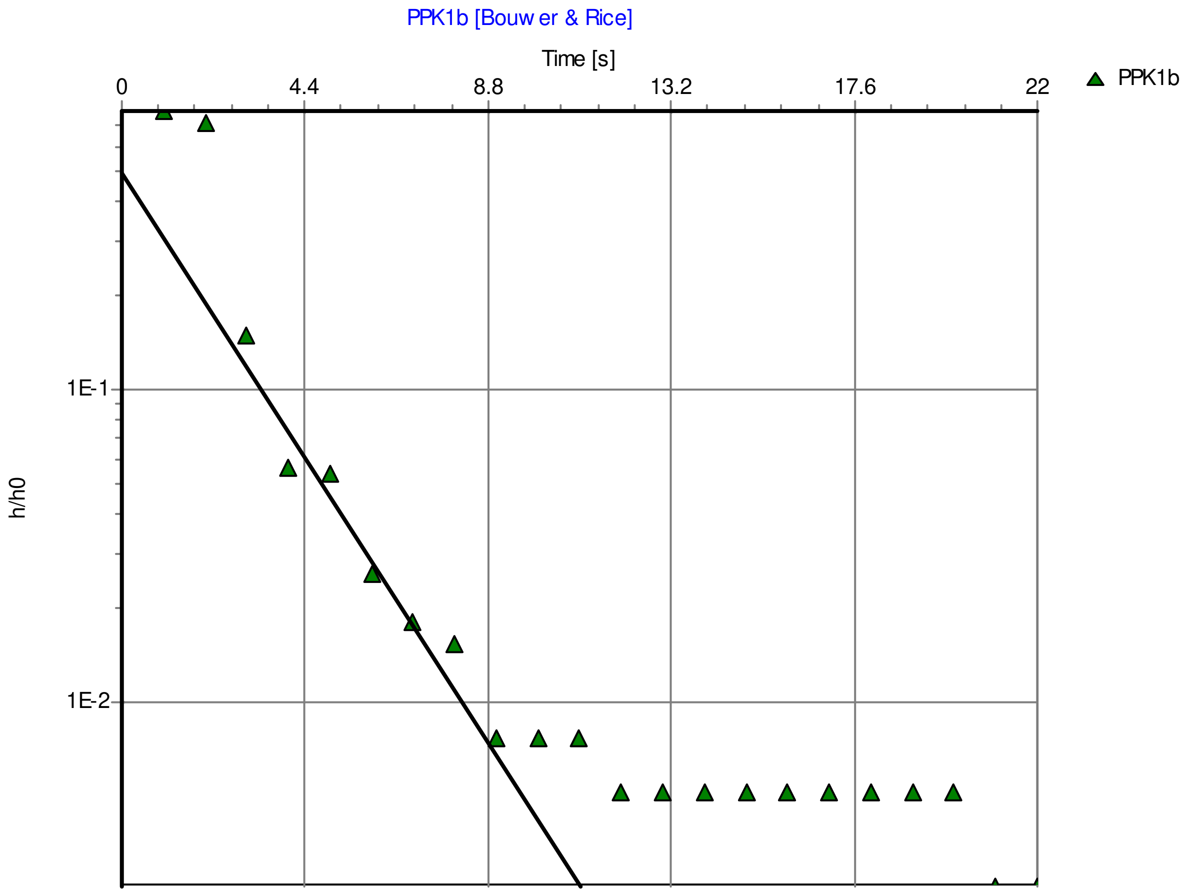
Phone: 02 9029 2995

Slug Test Analysis Report

Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



<u>Slug Test:</u> **PPK1b**

<u>Analysis Method:</u> **Bouwer & Rice**

<u>Analysis Results:</u>

Conductivity: 2.71E+1 [m/d]

<u>Test parameters:</u>

	Test Well:	PPK1b	Aquifer Thickness:	13.6 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	6 [m]		
	Boring radius:	0.1 [m]		
	r(eff):	0.054 [m]		

<u>Comments:</u>

Evaluated by: IG

Evaluation Date: 16/01/2011

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Newtown NSW 2042
Phone: 02 9029 2995

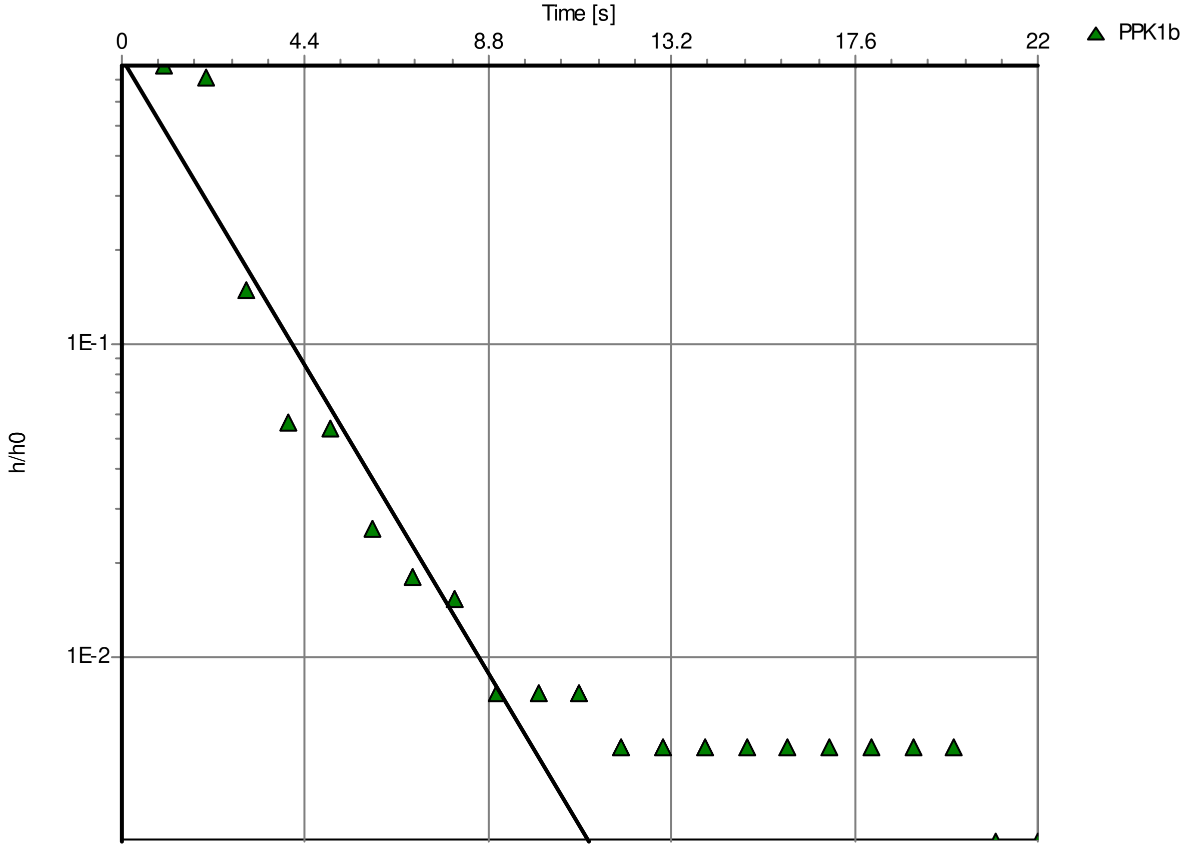
Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC

PPK1b [Hvorslev]



Slug Test: **PPK1b**

Analysis Method: **Hvorslev**

Analysis Results: Conductivity: 9.52E+0 [m/d]

Test parameters:	Test Well:	PPK1b	Aquifer Thickness:	13.6 [m]
	Casing radius:	0.025 [m]		
	Screen length:	6 [m]		
	Boring radius:	0.1 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 29/07/2010

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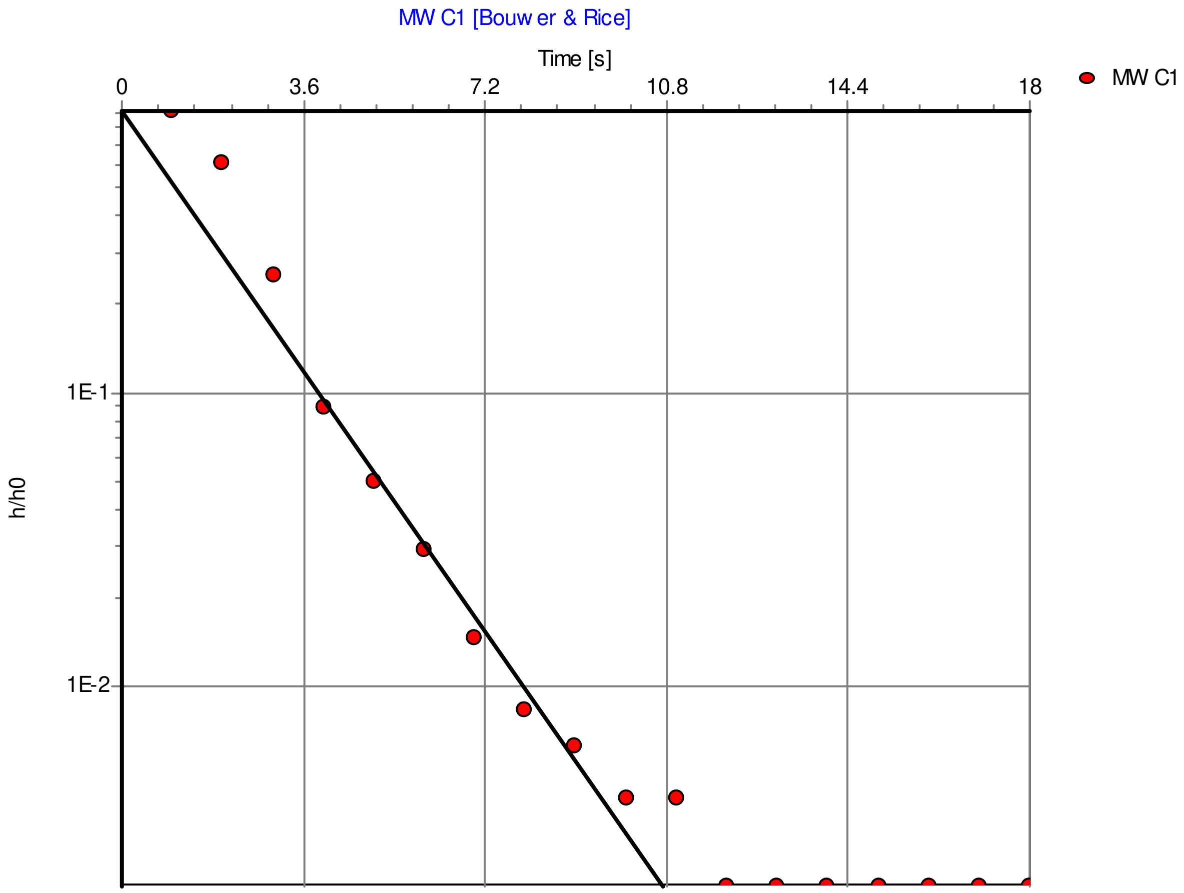
Newtown NSW 2042
Phone: 02 9029 2995

Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Slug Test: **MW C1**

Analysis Method: **Bouwer & Rice**

Analysis Results:			Conductivity:	5.31E+0 [m/d]
Test parameters:	Test Well:	MW C1	Aquifer Thickness:	13.5 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	9 [m]		
	Boring radius:	0.1 [m]		
	r(eff):	0.054 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011

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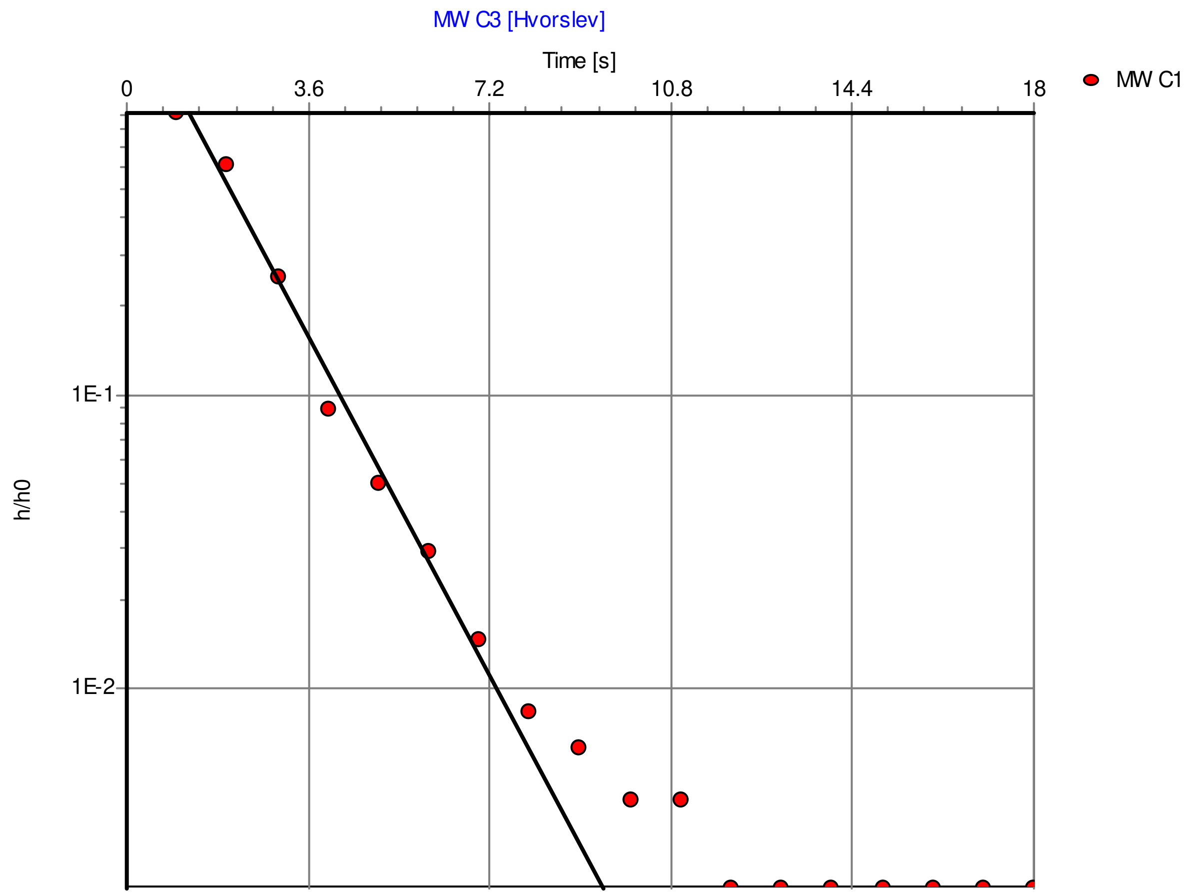
Slug Test Analysis Report

Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Slug Test: **MW C1**

Analysis Method: **Hvorslev**

Analysis Results: Conductivity: 1.00E+1 [m/d]

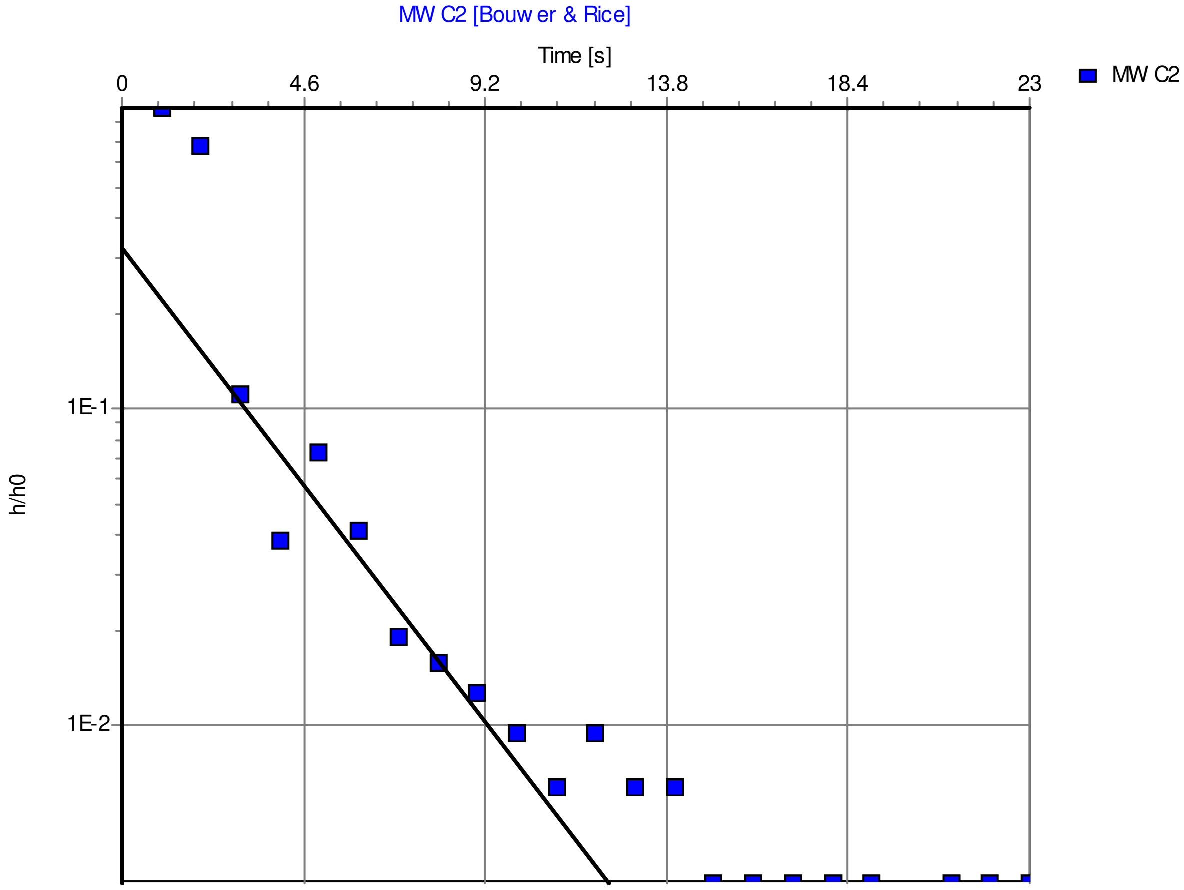
Test parameters:				
	Test Well:	MW C1	Aquifer Thickness:	13.5 [m]
	Casing radius:	0.025 [m]		
	Screen length:	9 [m]		
	Boring radius:	0.1 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 29/07/2010

Slug Test Analysis Report	
Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Slug Test: **MW C2**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 1.70E+1 [m/d]

Test parameters:				
Test Well:	MW C2		Aquifer Thickness:	14 [m]
Casing radius:	0.025 [m]		Gravel Pack Porosity (%)	25
Screen length:	9 [m]			
Boring radius:	0.1 [m]			
r(eff):	0.054 [m]			

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011

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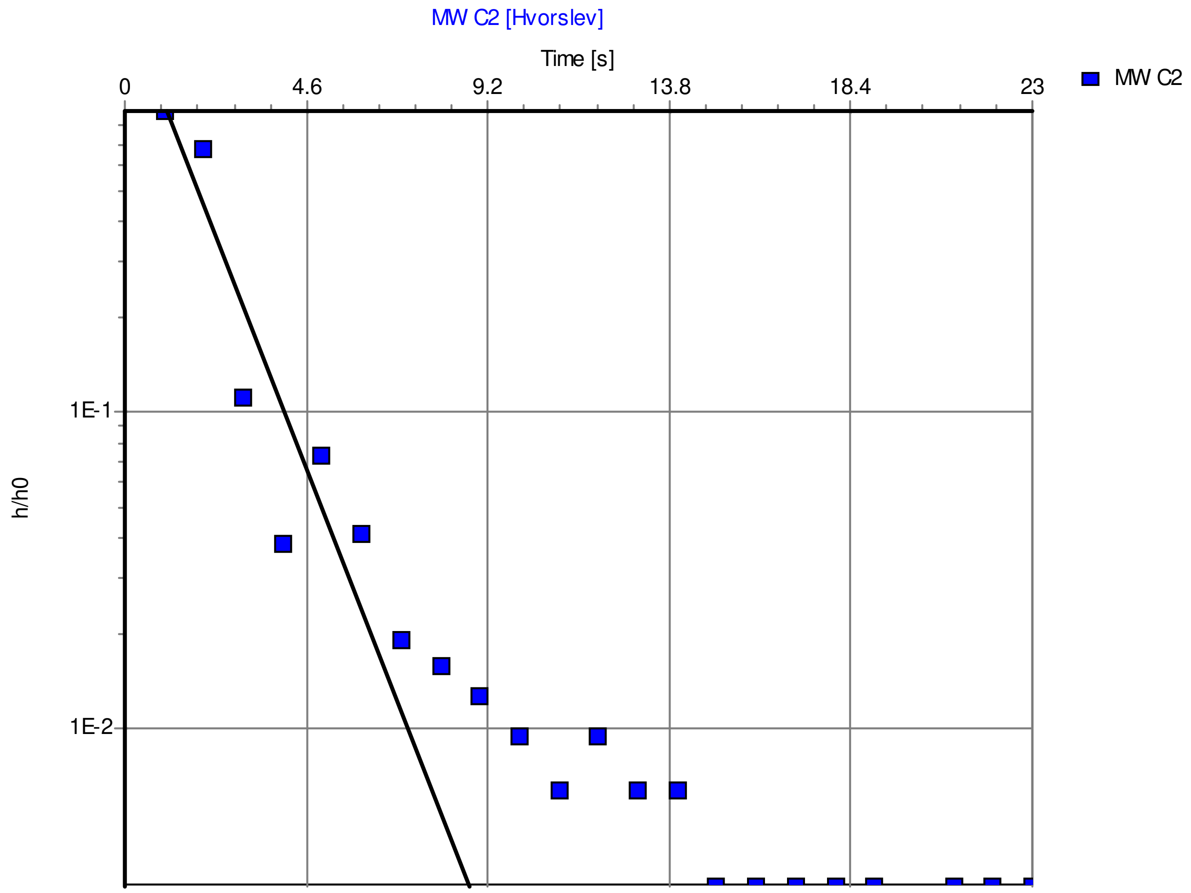
Slug Test Analysis Report

Project: Merimbula Detailed Investigation
Number: FJ06
Client: BVSC



Slug Test: **MW C2**

Analysis Method: **Hvorslev**

Analysis Results:

Conductivity: 9.95E+0 [m/d]

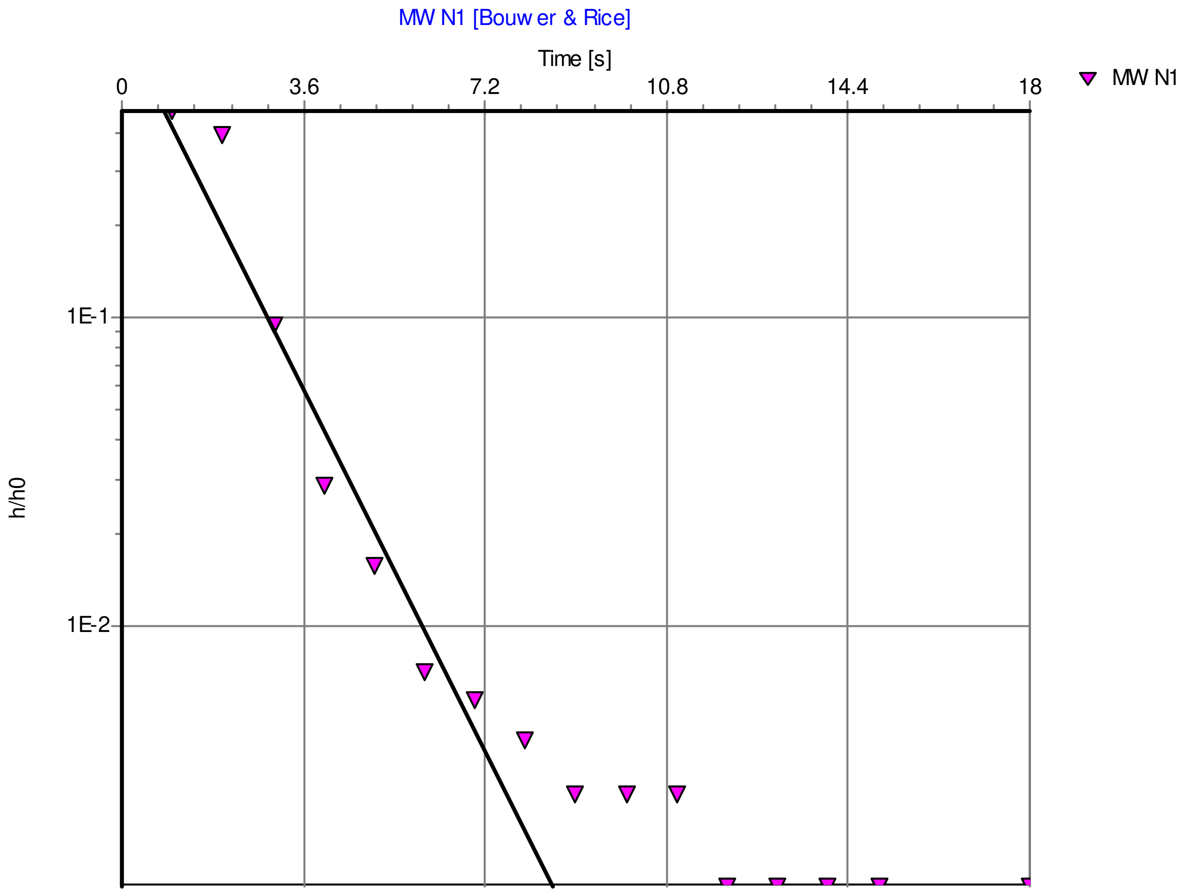
Test parameters:

Test parameters:	Test Well:	MW C2	Aquifer Thickness:	14 [m]
	Casing radius:	0.025 [m]		
	Screen length:	9 [m]		
	Boring radius:	0.1 [m]		

Comments:

Evaluated by: IG
Evaluation Date: 29/07/2010

IGGC P/L PO Box 247 Newtown NSW 2042 Phone: 02 9029 2995	**Slug Test Analysis Report** Project: Merimbula Detailed Investigation Number: FJ06 Client: BVSC



Slug Test: **MW N1**

Analysis Method: **Bouwer & Rice**

Analysis Results:	Conductivity:	4.35E+1 [m/d]

Test parameters:	Test Well:	MW N1	Aquifer Thickness:	14.17 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	6 [m]		
	Boring radius:	0.1 [m]		
	r(eff):	0.054 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011

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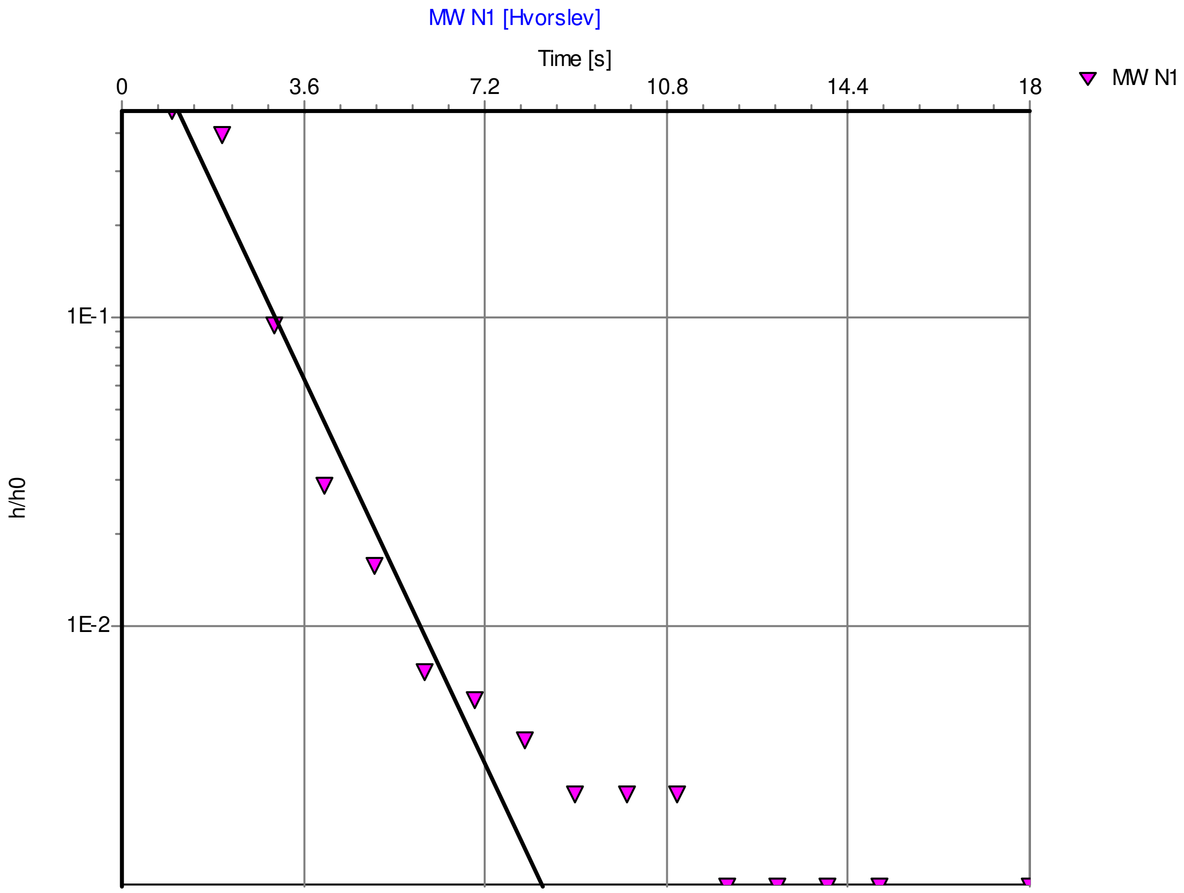
Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



<u>Slug Test:</u> **MW N1**

<u>Analysis Method:</u> **Hvorslev**

<u>Analysis Results:</u>

Conductivity: 1.48E+1 [m/d]

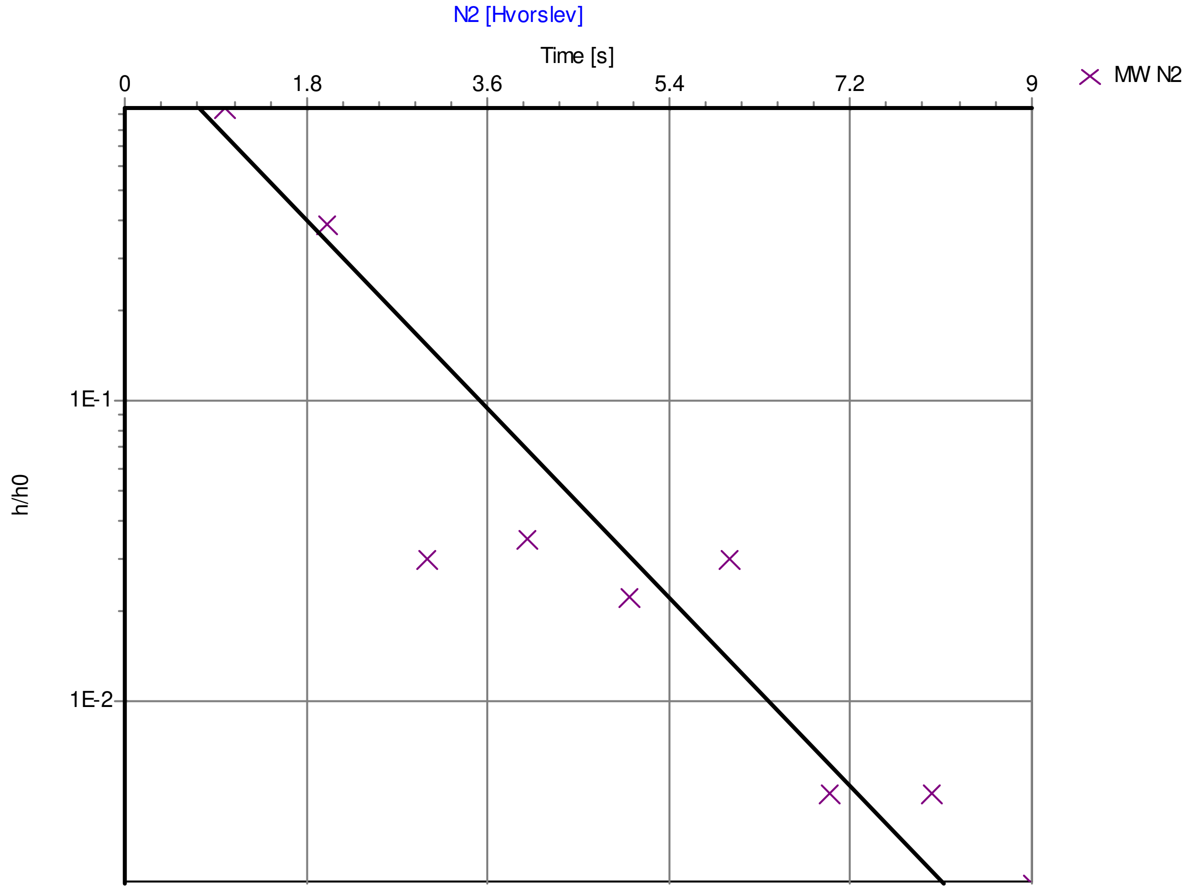
<u>Test parameters:</u>

Test Well:	MW N1		Aquifer Thickness:	14.17 [m]
Casing radius:	0.025 [m]			
Screen length:	6 [m]			
Boring radius:	0.1 [m]			

<u>Comments:</u>

Evaluated by: IG

Evaluation Date: 29/07/2010



Slug Test: **N2**

Analysis Method: **Hvorslev**

Analysis Results: Conductivity: 8.71E+0 [m/d]

Test parameters:

Test Well: MW N2

Casing radius: 0.025 [m]

Screen length: 12 [m]

Boring radius: 0.1 [m]

Aquifer Thickness: 17.3 [m]

Comments:

Evaluated by: IG

Evaluation Date: 3/08/2010

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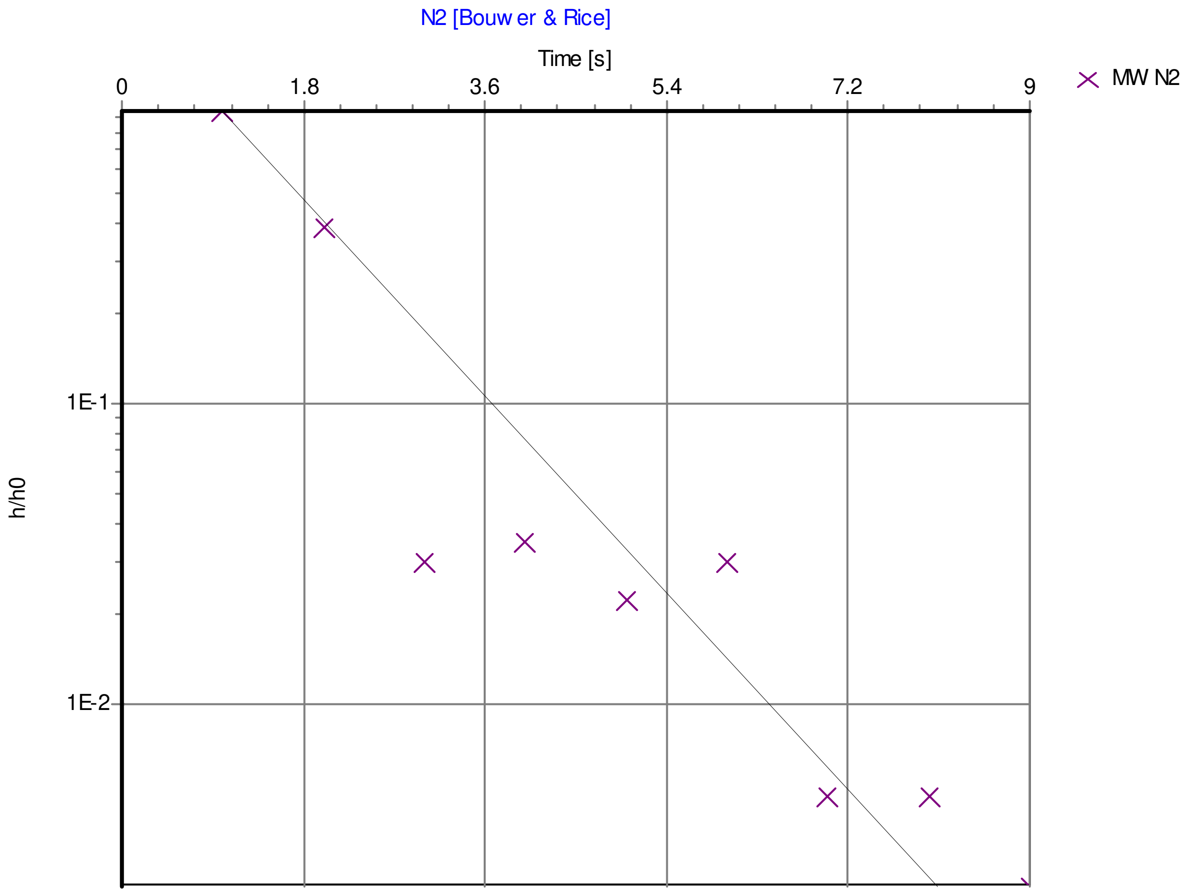
Slug Test Analysis Report

Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Slug Test: **N2**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity: 6.49E+0 [m/d]

Test parameters:

Test Well:	MW N2	Aquifer Thickness:	17.3 [m]
Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
Screen length:	12 [m]		
Boring radius:	0.1 [m]		
r(eff):	0.054 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011

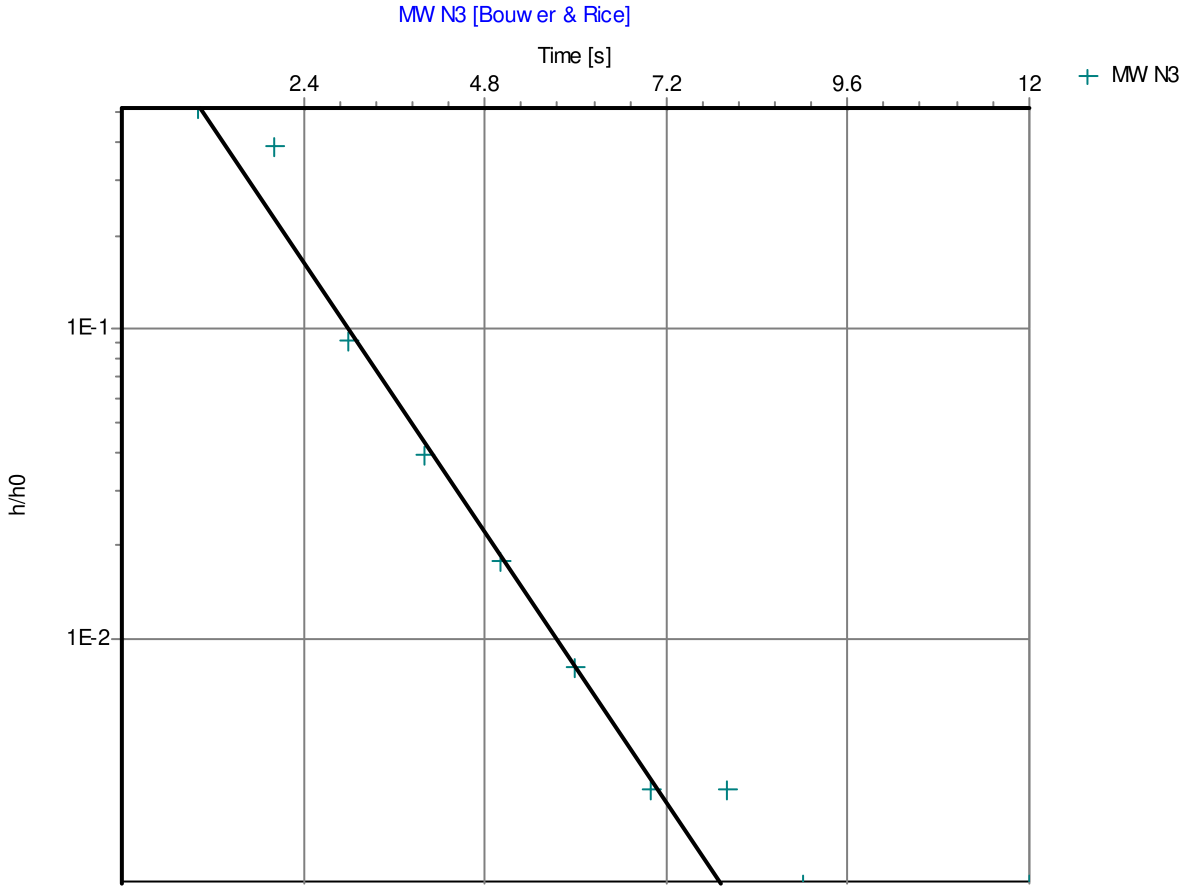
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Slug Test: **MW N3**

Analysis Method: **Bouwer & Rice**

Analysis Results:		Conductivity:	4.87E+1 [m/d]
Test parameters: Test Well:	MW N3	Aquifer Thickness:	14.293 [m]
Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
Screen length:	6 [m]		
Boring radius:	0.1 [m]		
r(eff):	0.054 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011

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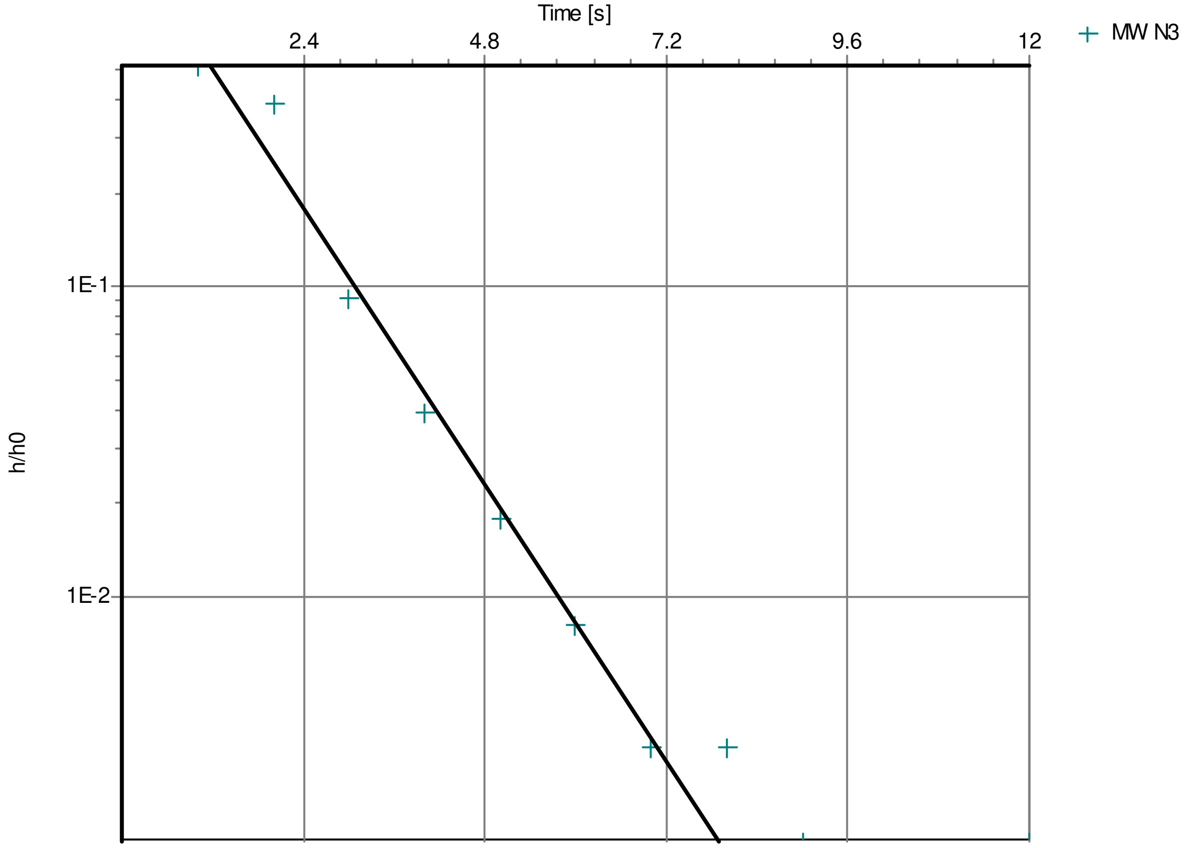
Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC

MW N3 [Hvorslev]



Slug Test: **MW N3**

Analysis Method: **Hvorslev**

Analysis Results:

Conductivity: 1.59E+1 [m/d]

Test parameters:

Test Well: MW N3

Casing radius: 0.025 [m]

Screen length: 6 [m]

Boring radius: 0.1 [m]

Aquifer Thickness: 14.293 [m]

Comments:

Evaluated by: IG

Evaluation Date: 29/07/2010

IGGC P/L
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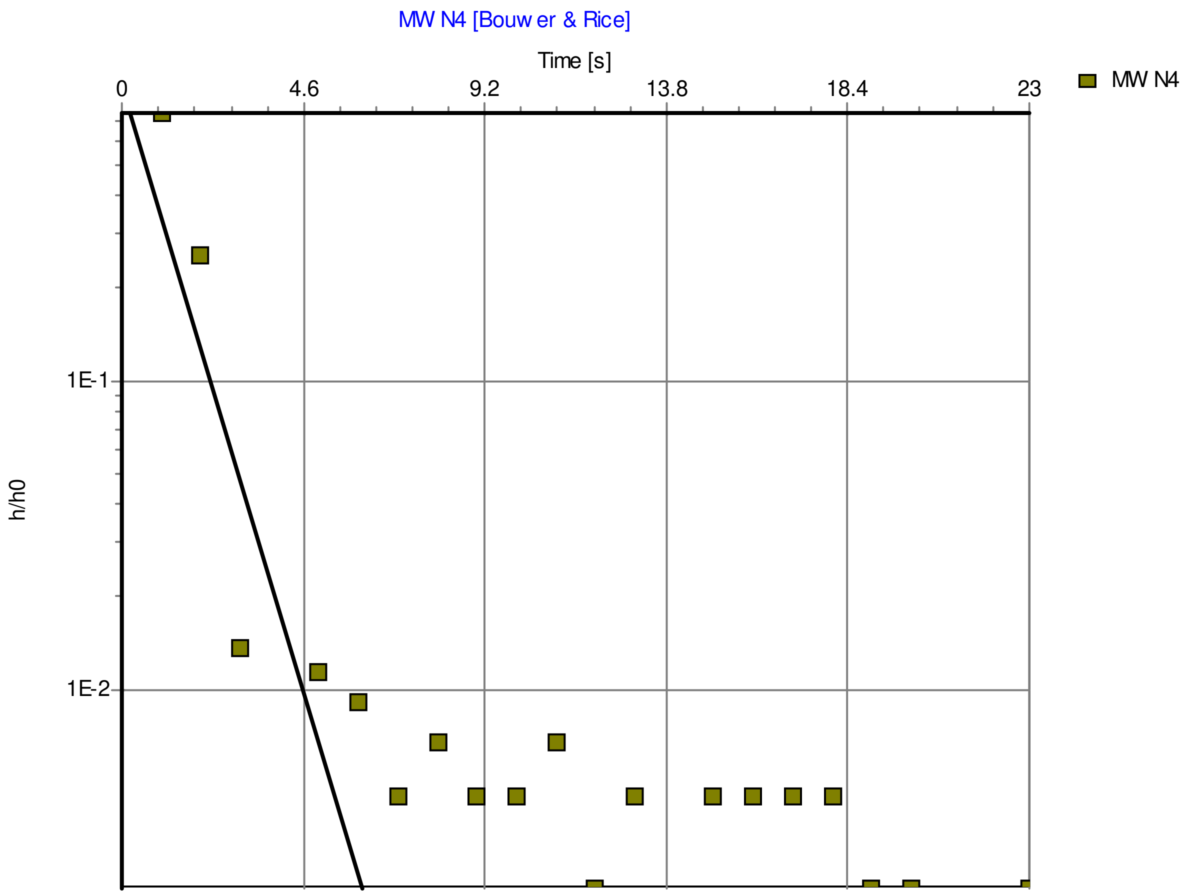
Newtown NSW 2042
Phone: 02 9029 2995

Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Slug Test:	**MW N4**
Analysis Method:	**Bouwer & Rice**

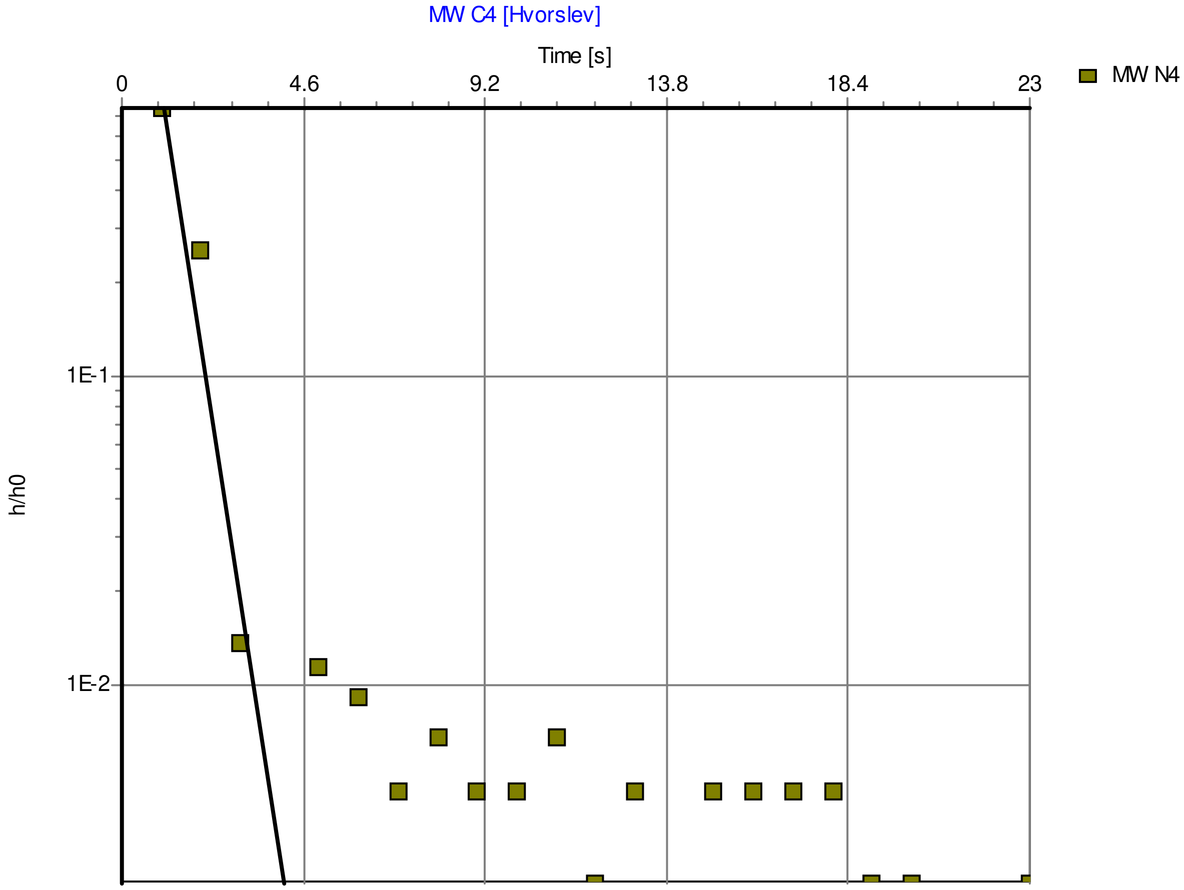
Analysis Results:	Conductivity:	5.62E+1 [m/d]

Test parameters:	Test Well:	MW N4	Aquifer Thickness:	17.1 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	6 [m]		
	Boring radius:	0.1 [m]		
	r(eff):	0.054 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 16/01/2011



Slug Test: **MW N4**

Analysis Method: **Hvorslev**

Analysis Results: Conductivity: 3.50E+1 [m/d]

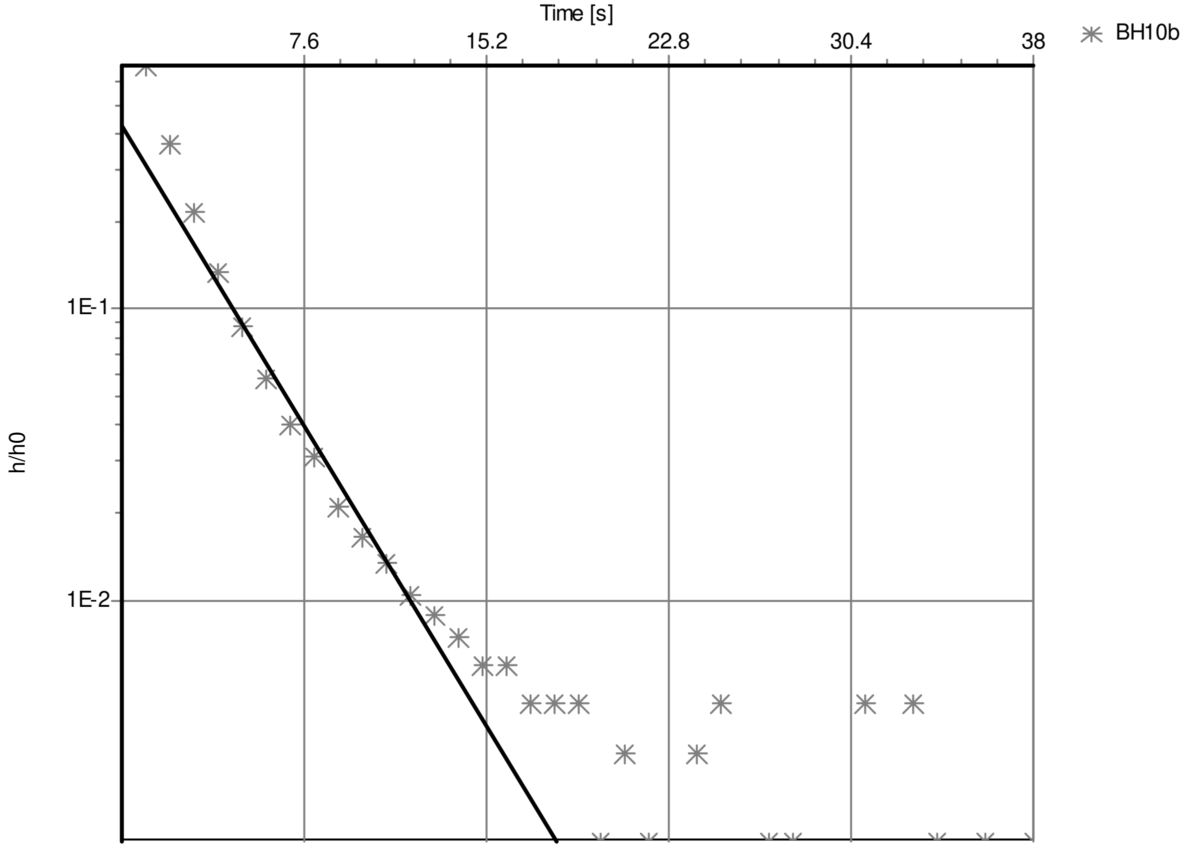
Test parameters:				
	Test Well:	MW N4	Aquifer Thickness:	17.1 [m]
	Casing radius:	0.025 [m]		
	Screen length:	6 [m]		
	Boring radius:	0.1 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 11/08/2010

BH10b [Bouwer & Rice]



Slug Test: **BH10b**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity: 6.48E+0 [m/d]

Test parameters:

Test Well: BH10b
Casing radius: 0.025 [m]
Screen length: 3 [m]
Boring radius: 0.1 [m]
r(eff): 0.054 [m]
Aquifer Thickness: 8.192 [m]
Gravel Pack Porosity (%) 25

Comments:

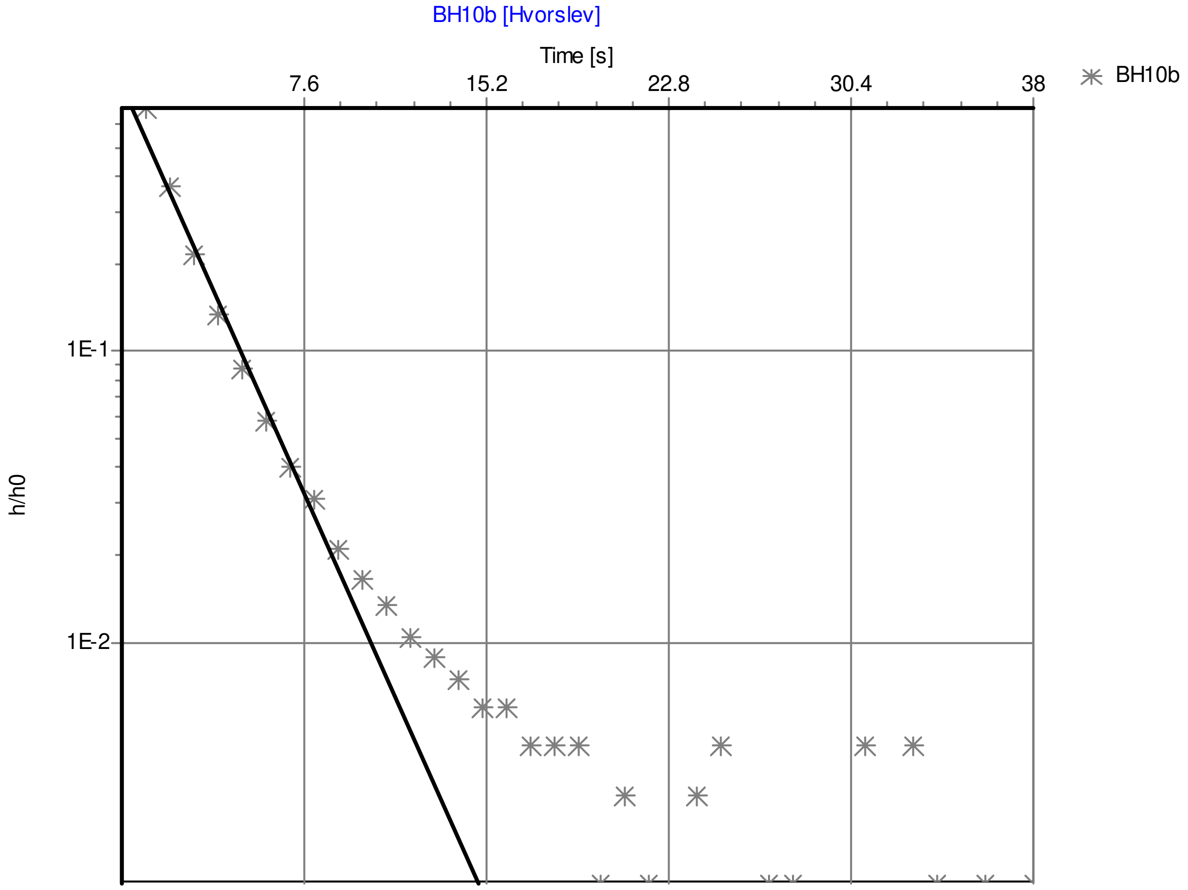
Evaluated by: IG
Evaluation Date: 16/01/2011

Slug Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC

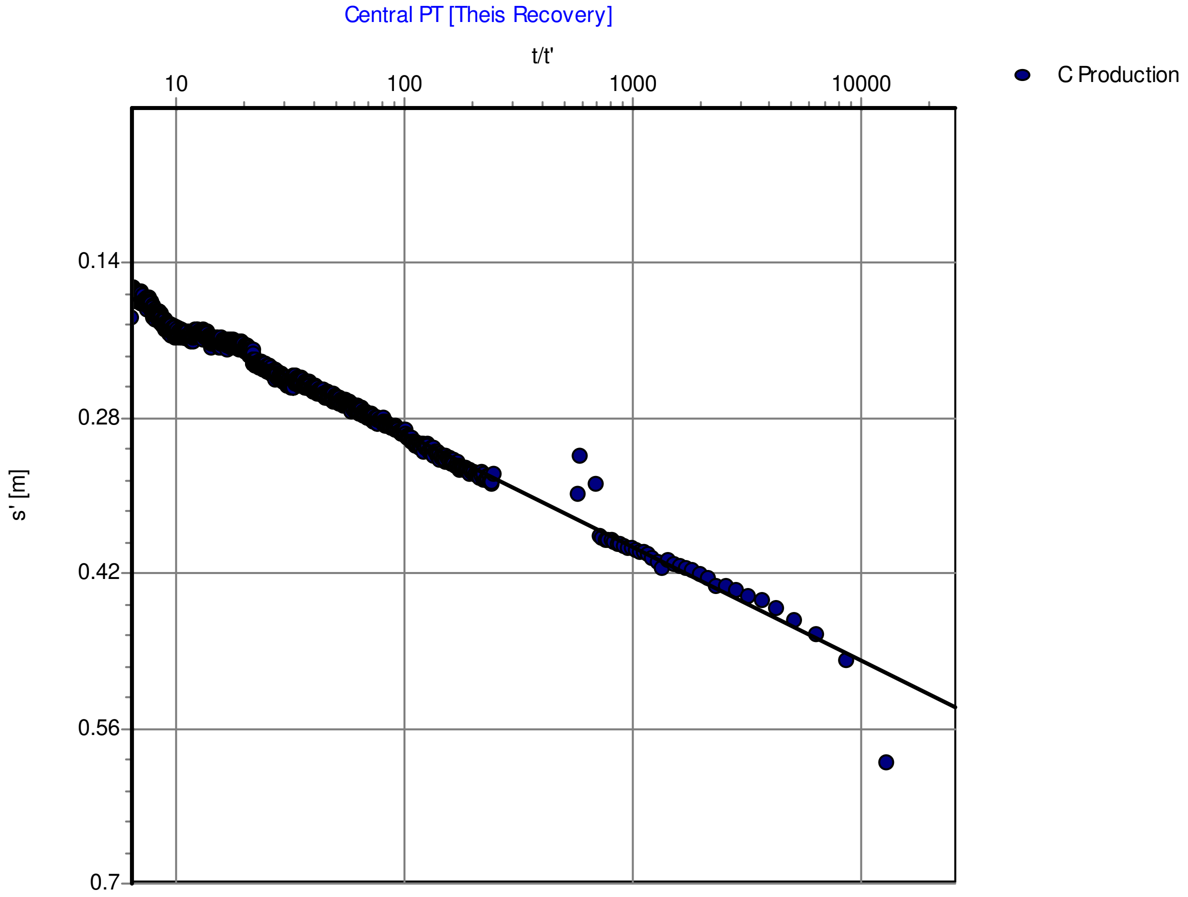


Slug Test:	**BH10b**			
Analysis Method:	**Hvorslev**			
Analysis Results:			Conductivity:	1.31E+1 [m/d]
Test parameters:	Test Well:	BH10b	Aquifer Thickness:	8.192 [m]
	Casing radius:	0.025 [m]		
	Screen length:	3 [m]		
	Boring radius:	0.1 [m]		

Comments:

Evaluated by: IG

Evaluation Date: 10/08/2010



Pumping Test: **CPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	7.95E+2 [m²/d]	Conductivity:	5.97E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		
	Pumping Time	259920 [s]		

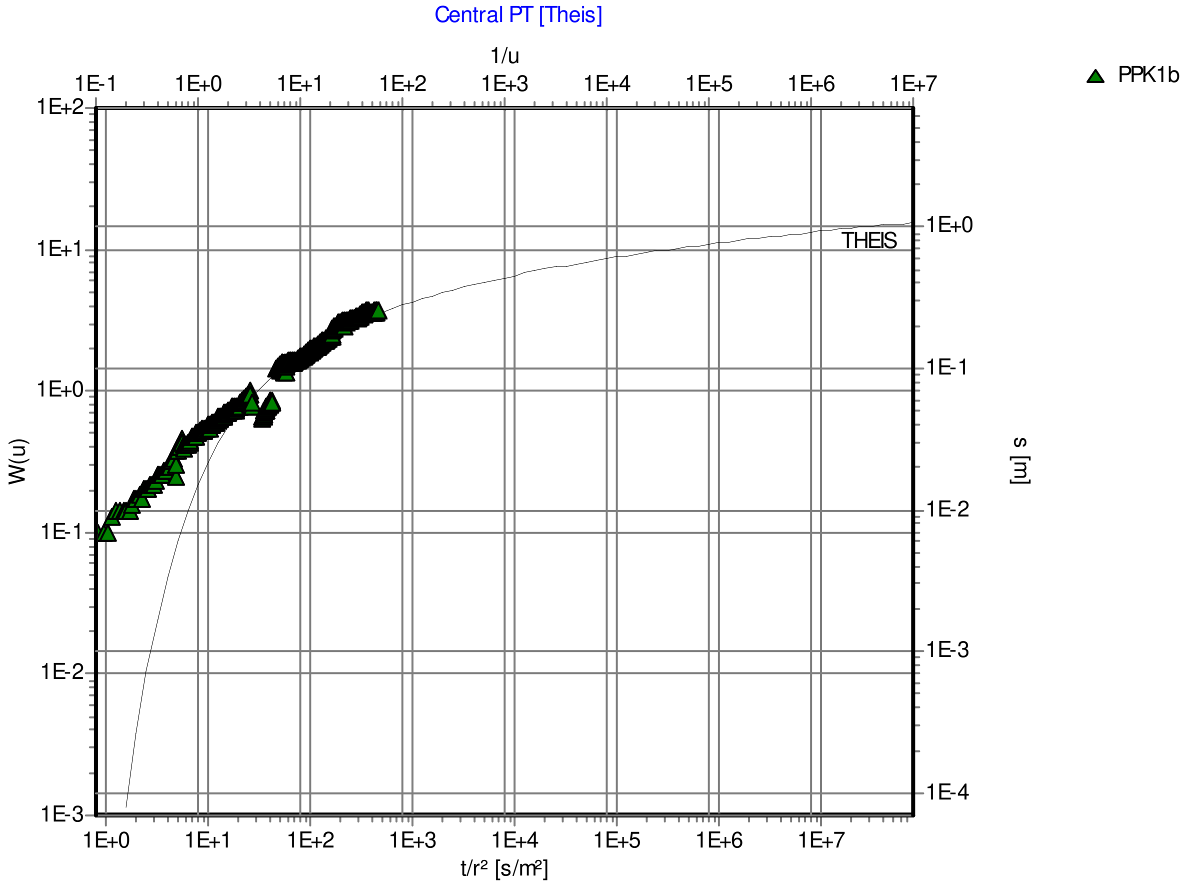
Comments:

Evaluated by: IG

Evaluation Date: 13/01/2011

IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report	
Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Pumping Test:	**CPW**			
Analysis Method:	**Theis**			
Analysis Results:	Transmissivity:	5.09E+2 [m²/d]	Conductivity:	3.82E+1 [m/d]
Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		

Comments:

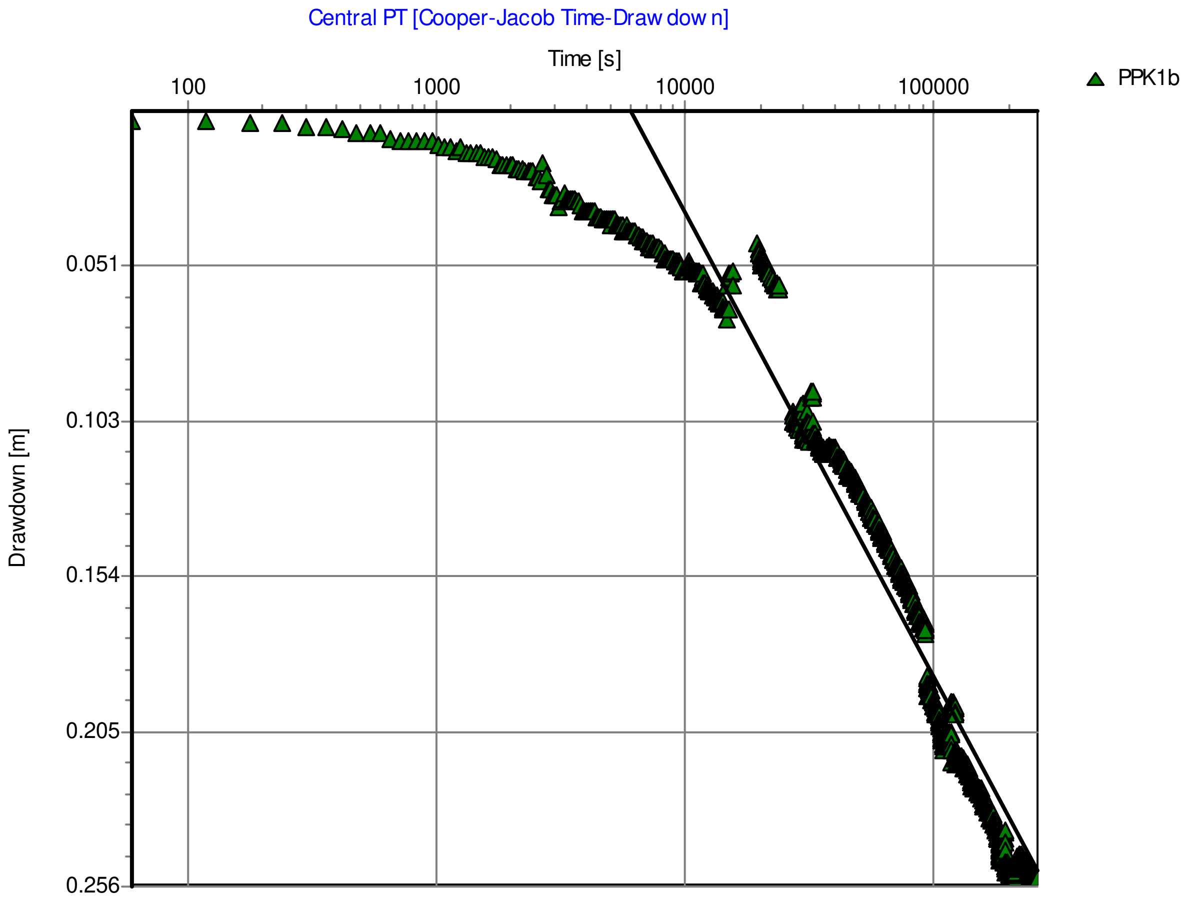
Evaluated by: IG

Evaluation Date: 21/10/2010

IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation
Number: FJ06
Client: BVSC



Pumping Test: **CPW**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results: Transmissivity: 5.27E+2 [m²/d] Conductivity: 3.95E+1 [m/d]

Test parameters:

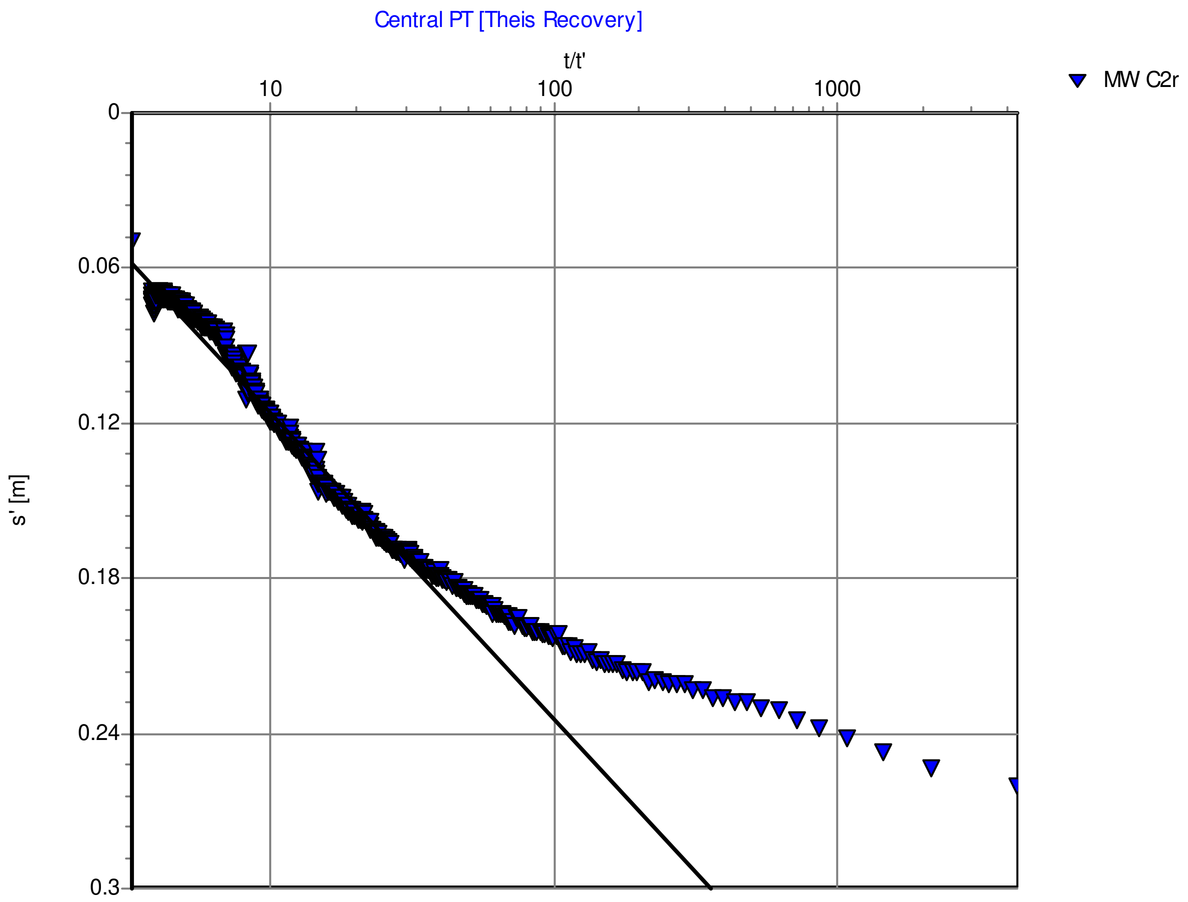
Pumping Well: C Production
Casing radius: 0.05 [m]
Screen length: 9 [m]
Boring radius: 0.065 [m]
Discharge Rate: 0.005134 [m³/s]
Aquifer Thickness: 13.32 [m]
Unconfined Aquifer

Comments:

Evaluated by: IG
Evaluation Date: 13/01/2011

IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report	
Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Pumping Test: **CPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	6.86E+2 [m²/d]	Conductivity:	5.15E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		
	Pumping Time	259900 [s]		

Comments:

Evaluated by:

Evaluation Date: 21/10/2010

IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

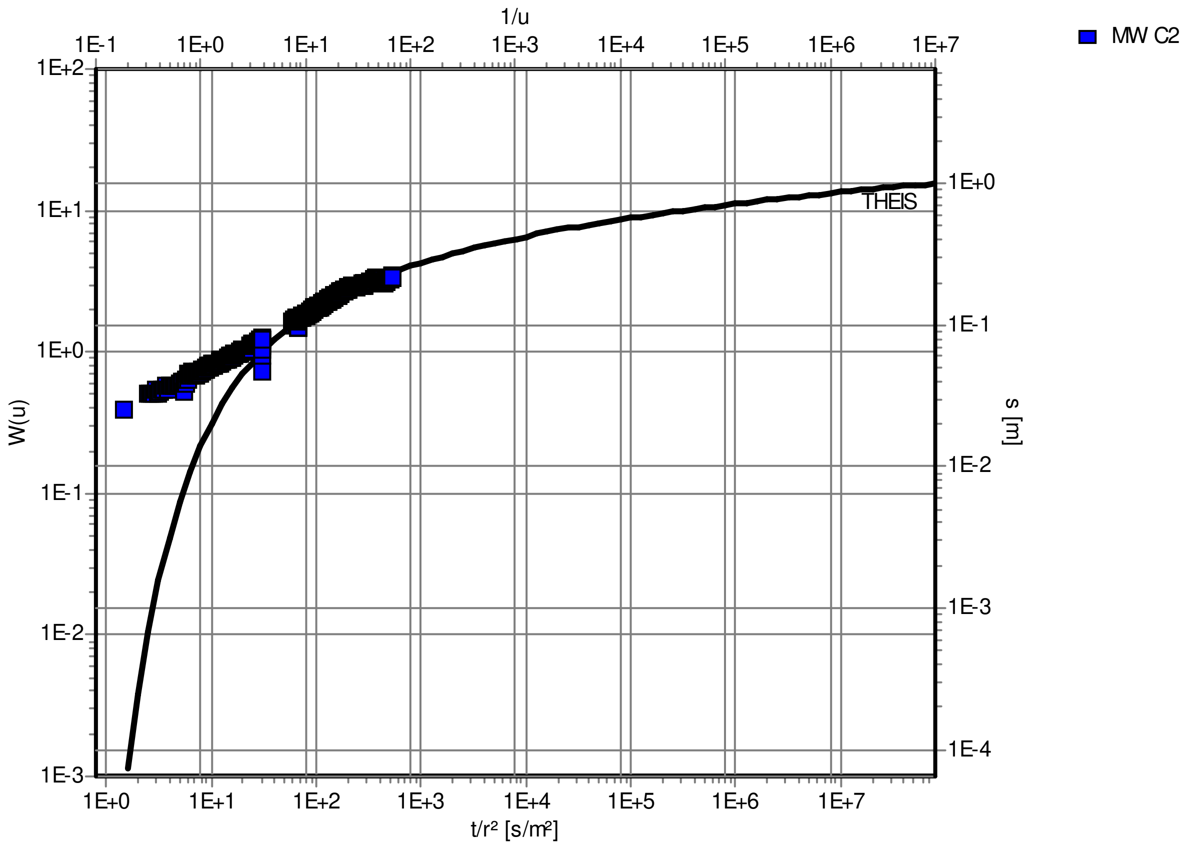
Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC

Central PT [Theis]



Pumping Test: **CPW**

Analysis Method: **Theis**

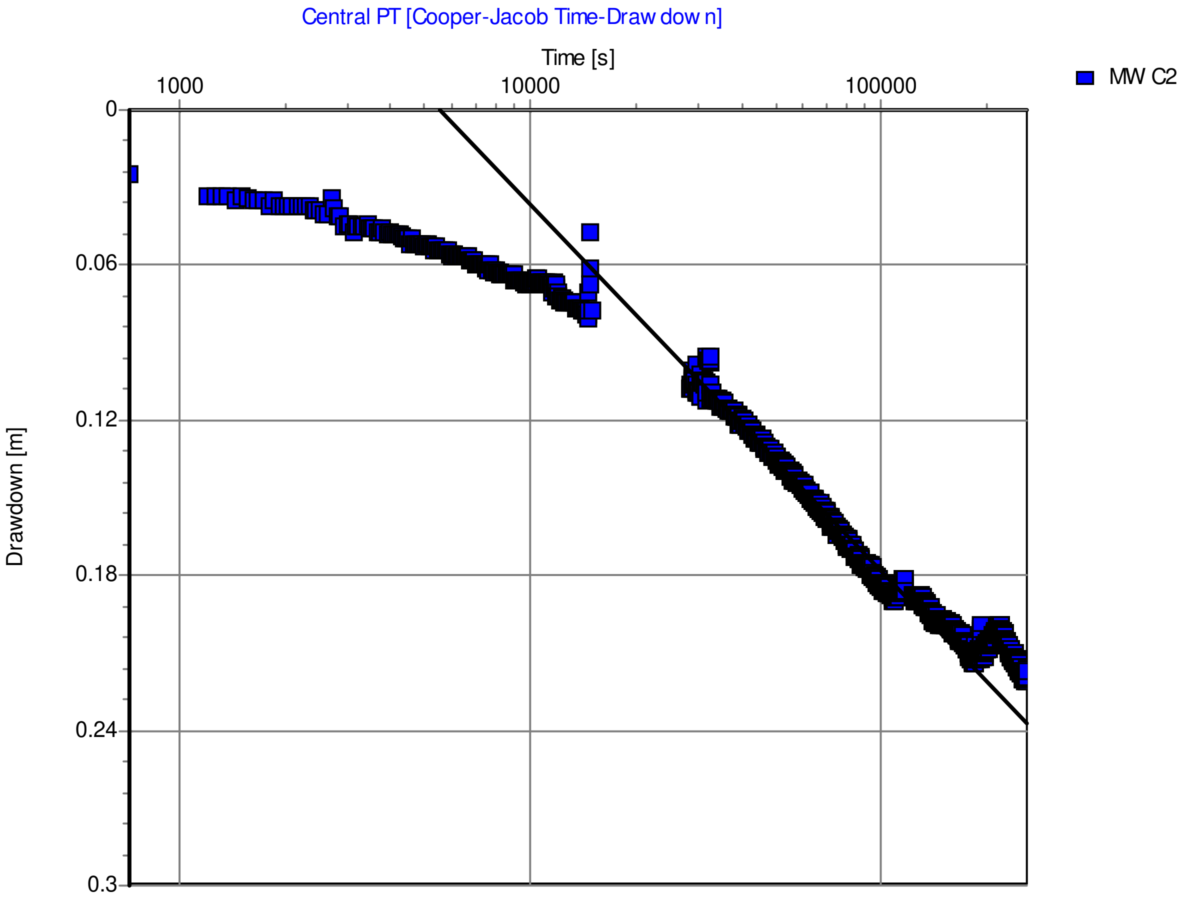
Analysis Results:	Transmissivity:	5.47E+2 [m^2/d]	Conductivity:	4.10E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m^3/s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010



Pumping Test: **CPW**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	5.71E+2 [m²/d]	Conductivity:	4.29E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010

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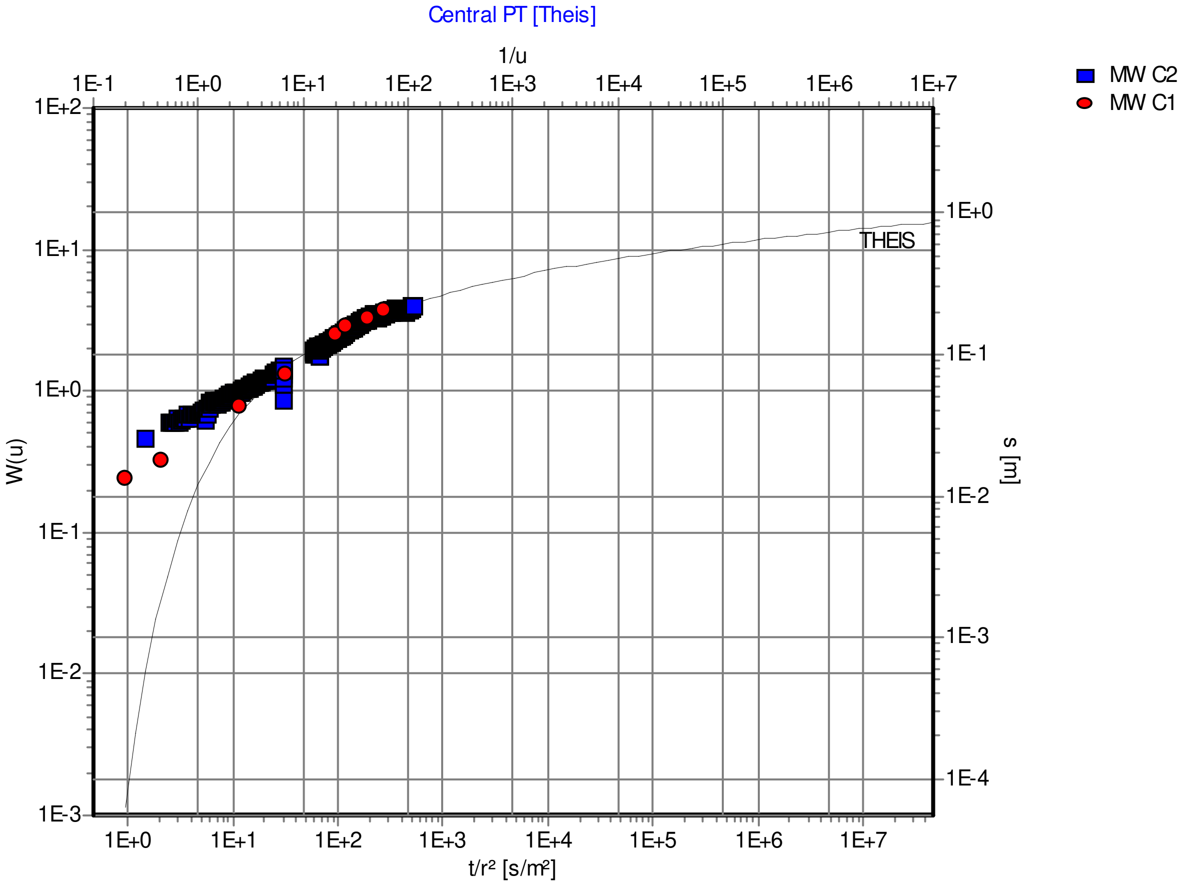
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test: **CPW**

Analysis Method: **Theis**

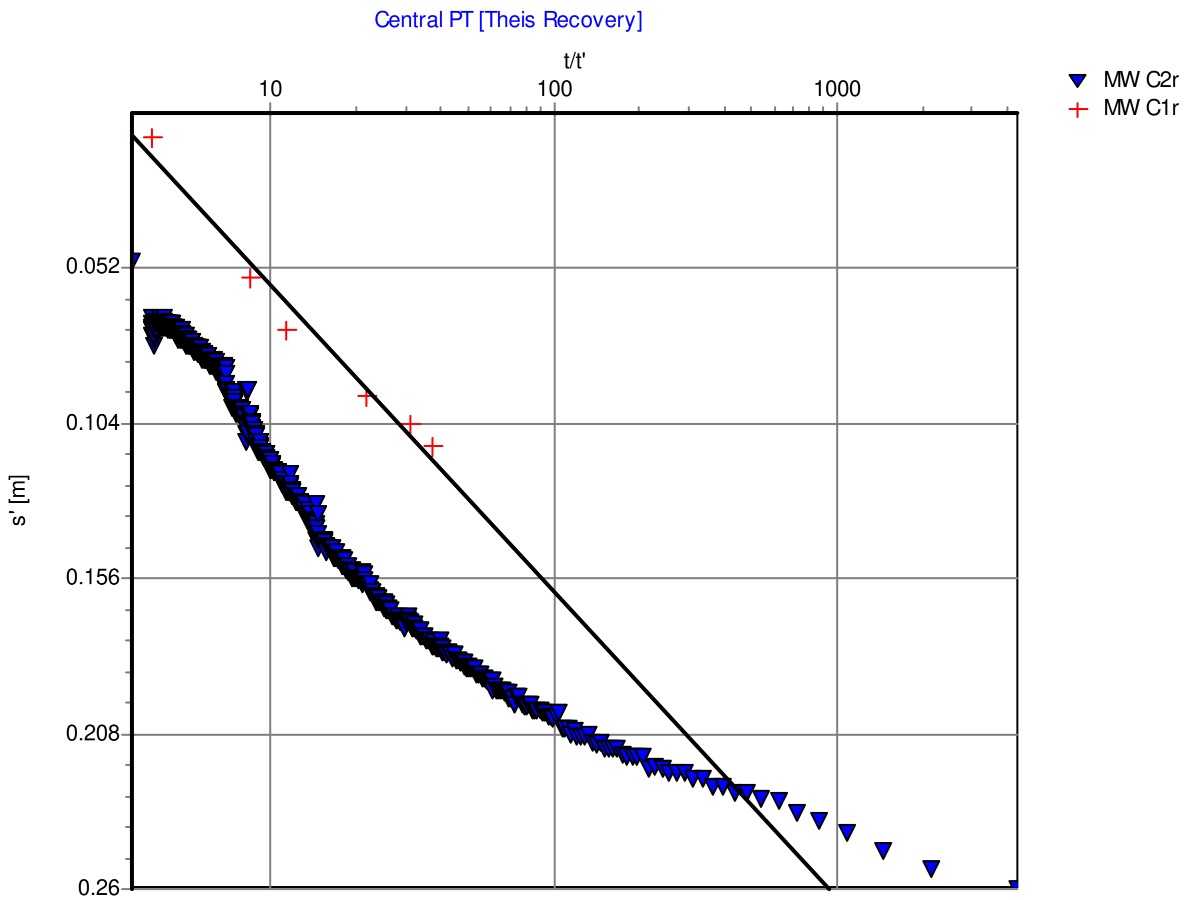
Analysis Results:	Transmissivity:	6.41E+2 [m²/d]	Conductivity:	4.81E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		

Comments:

Evaluated by:

Evaluation Date: 21/10/2010



Pumping Test: **CPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	7.90E+2 [m²/d]	Conductivity:	5.93E+1 [m/d]

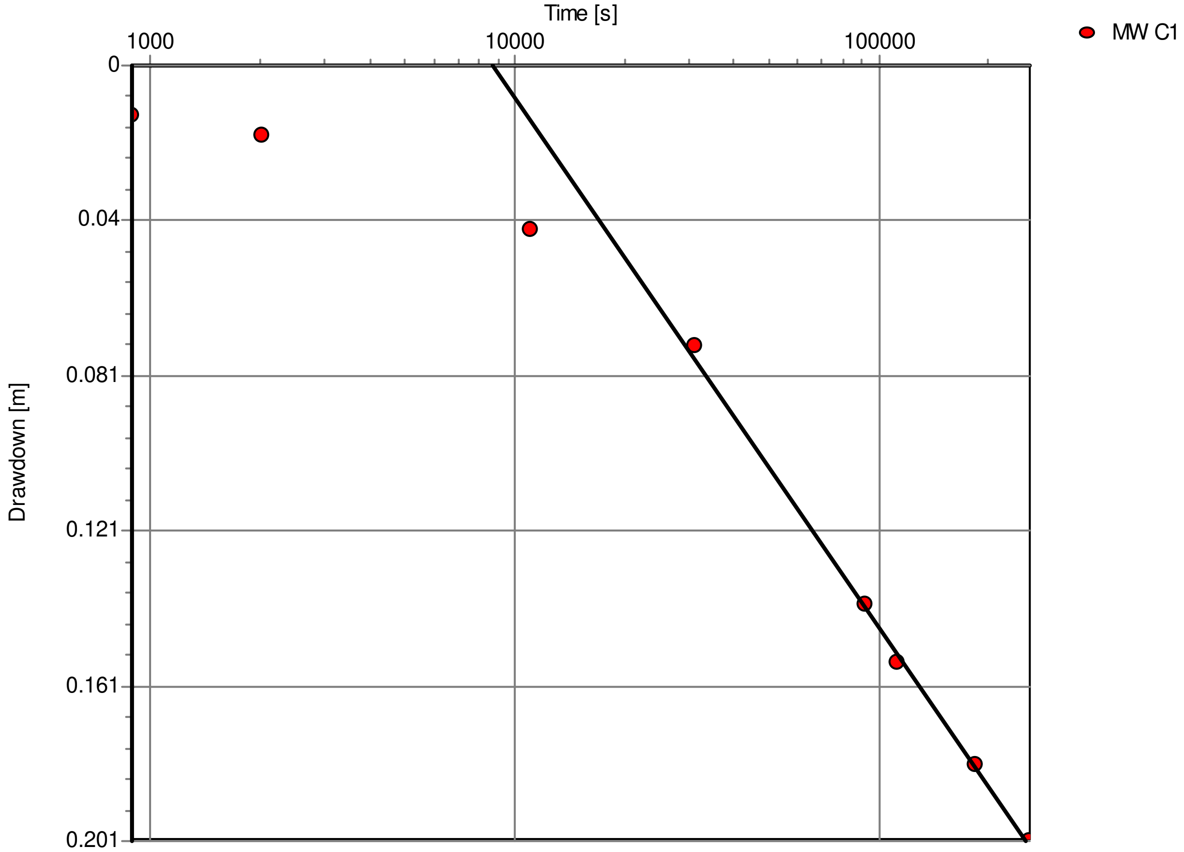
Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		
	Pumping Time	259900 [s]		

Comments:

Evaluated by: IG
Evaluation Date: 21/10/2010

Pumping Test Analysis Report	
Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC

Central PT [Cooper-Jacob Time-Draw dow n]



Pumping Test: **CPW**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	5.91E+2 [m²/d]	Conductivity:	4.44E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		

Comments:

Evaluated by: IG
Evaluation Date: 21/10/2010

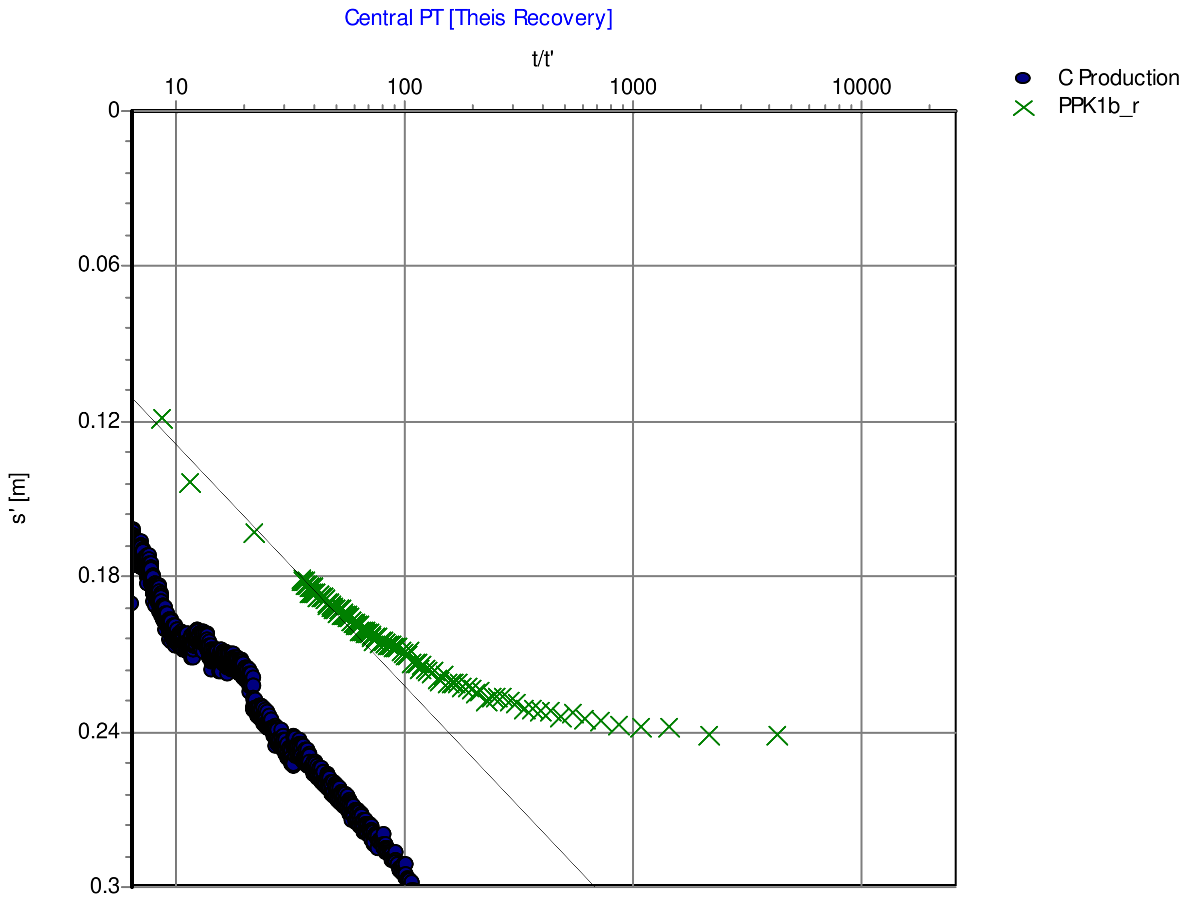
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test:	**CPW**
Analysis Method:	**Theis Recovery**

Analysis Results:	Transmissivity:	8.68E+2 [m²/d]	Conductivity:	6.52E+1 [m/d]

Test parameters:	Pumping Well:	C Production	Aquifer Thickness:	13.32 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005134 [m³/s]		
	Pumping Time	259920 [s]		

Comments:

Evaluated by: IG

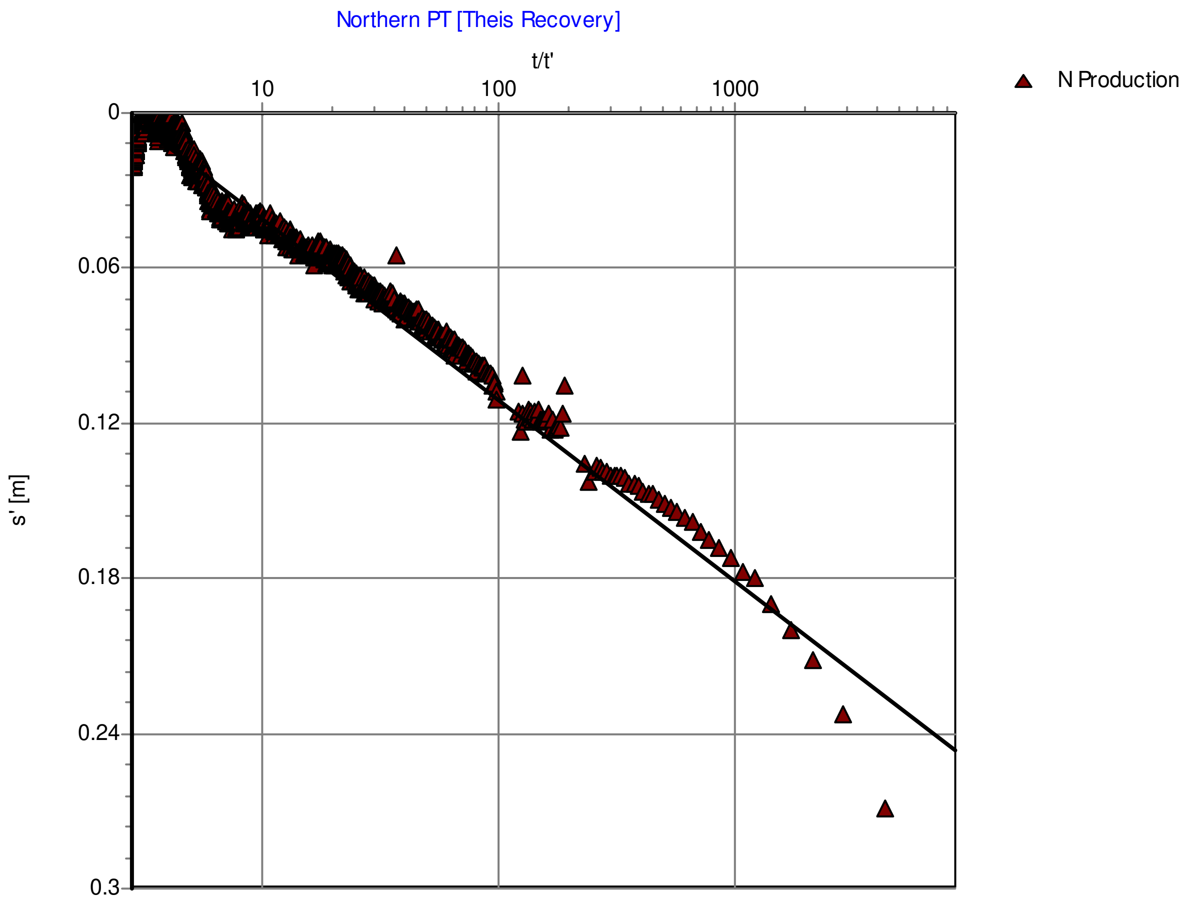
Evaluation Date: 13/01/2011

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test: **NPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	1.13E+3 [m²/d]	Conductivity:	6.10E+1 [m/d]

Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		
	Pumping Time	86460 [s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010

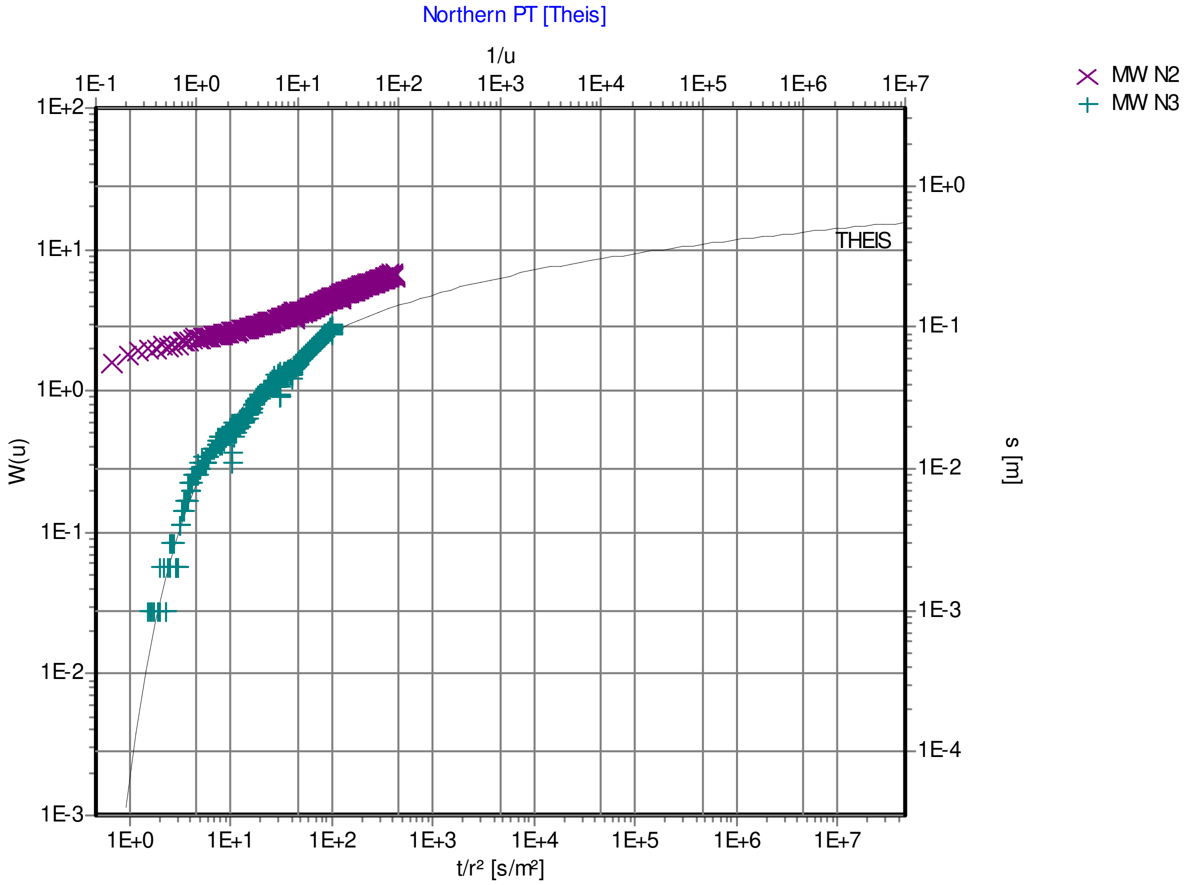
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC

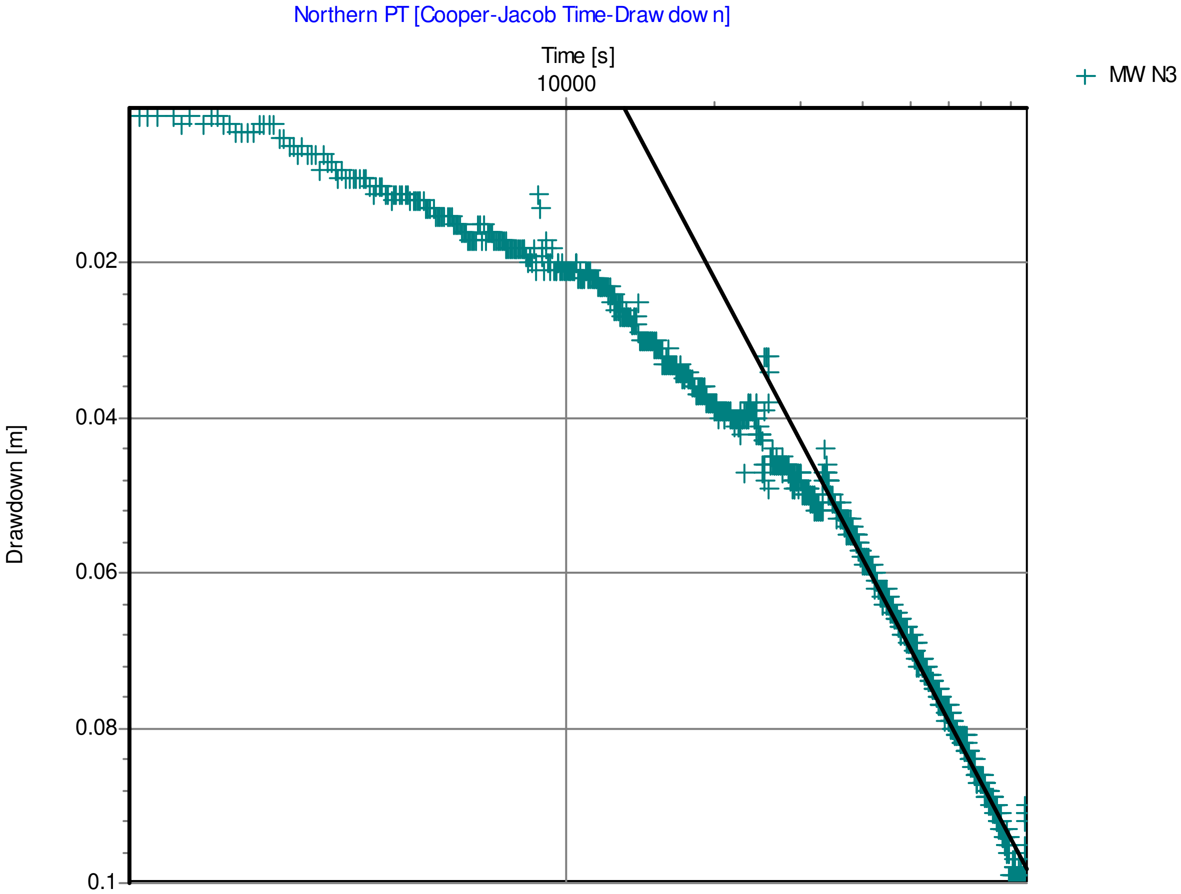


Pumping Test:	**NPW**			
Analysis Method:	**Theis**			
Analysis Results:	Transmissivity:	9.69E+2 [m²/d]	Conductivity:	5.24E+1 [m/d]
Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010



Pumping Test: **NPW**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	6.59E+2 [m²/d]	Conductivity:	3.56E+1 [m/d]

Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Confined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		

Comments:

Evaluated by: IG
Evaluation Date: 21/10/2010

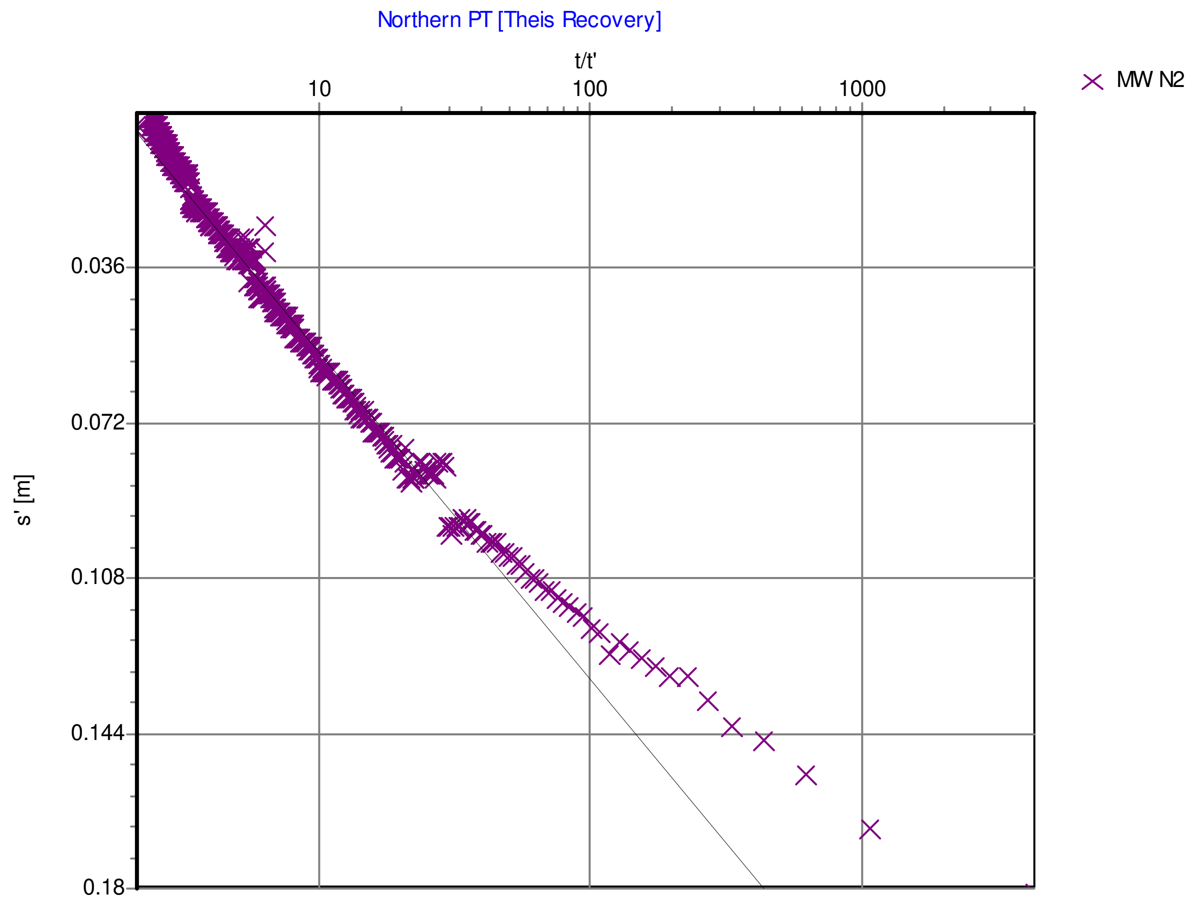
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test: **NPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	1.04E+3 [m²/d]	Conductivity:	5.62E+1 [m/d]
Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		
	Pumping Time	86480 [s]		

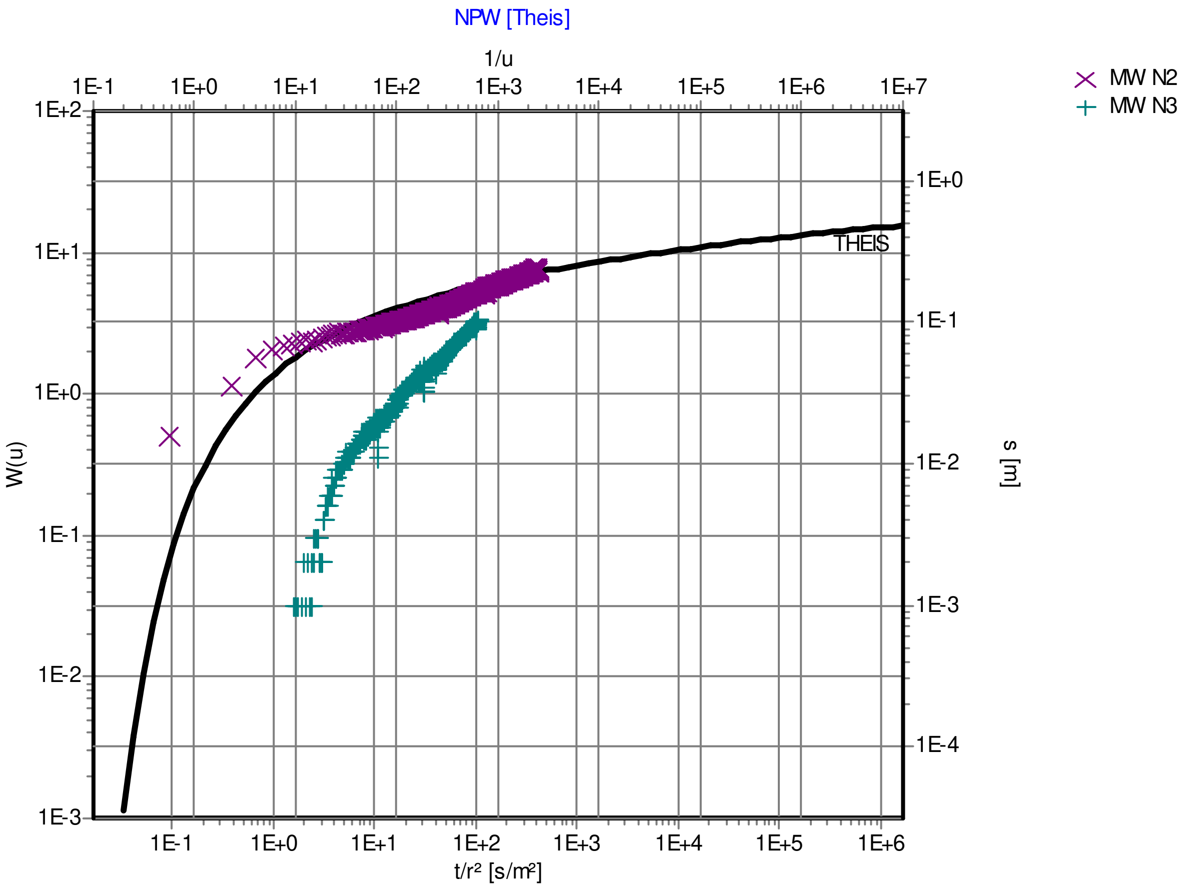
Comments:

Evaluated by: IG

Evaluation Date: 17/01/2011

IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report	
Project:	Merimbula Detailed Investigation
Number:	FJ06
Client:	BVSC



Pumping Test: **NPW**

Analysis Method: **Theis**

Analysis Results:	Transmissivity:	1.11E+3 [m²/d]	Conductivity:	5.98E+1 [m/d]

Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		

Comments:

Evaluated by:

Evaluation Date: 27/01/2011

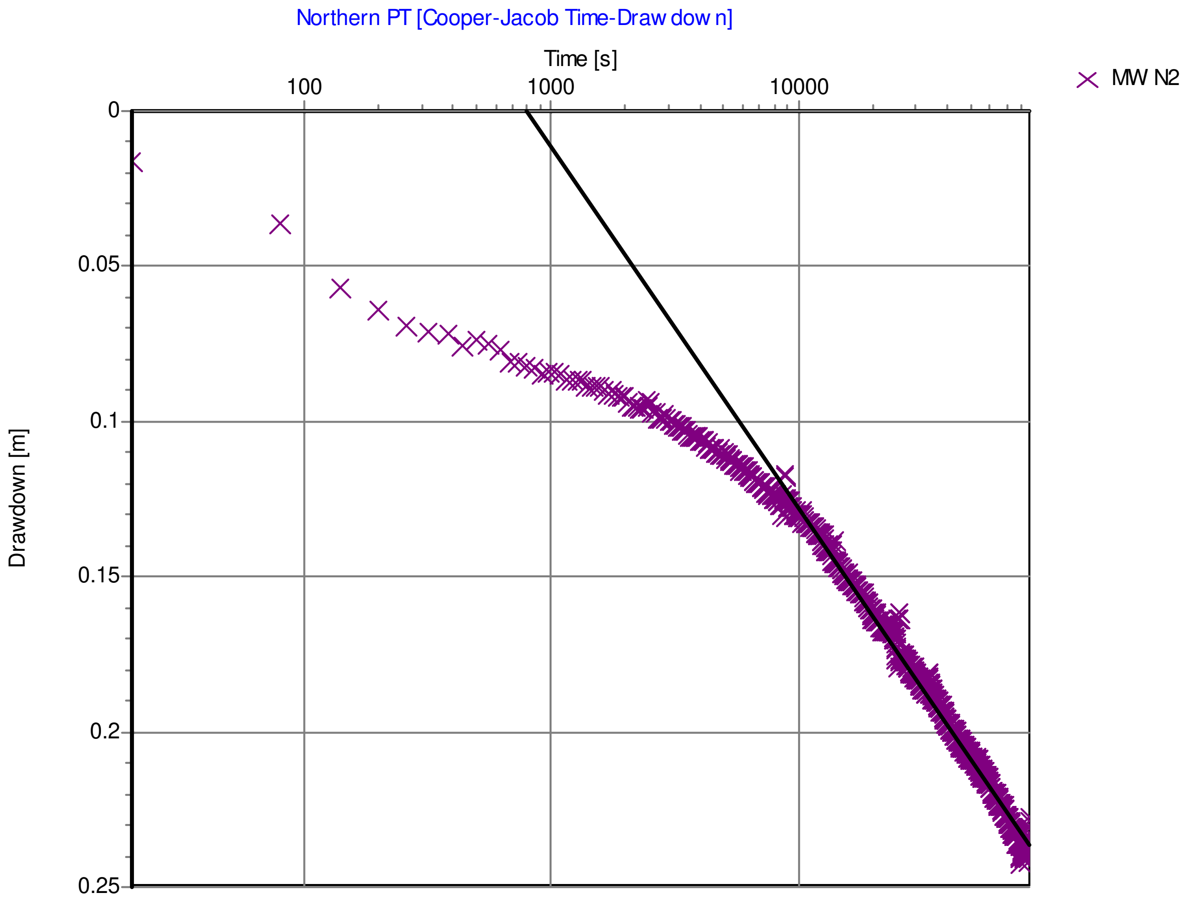
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test: **NPW**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results: Transmissivity: 6.81E+2 [m²/d] Conductivity: 3.68E+1 [m/d]

Test parameters:				
	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010

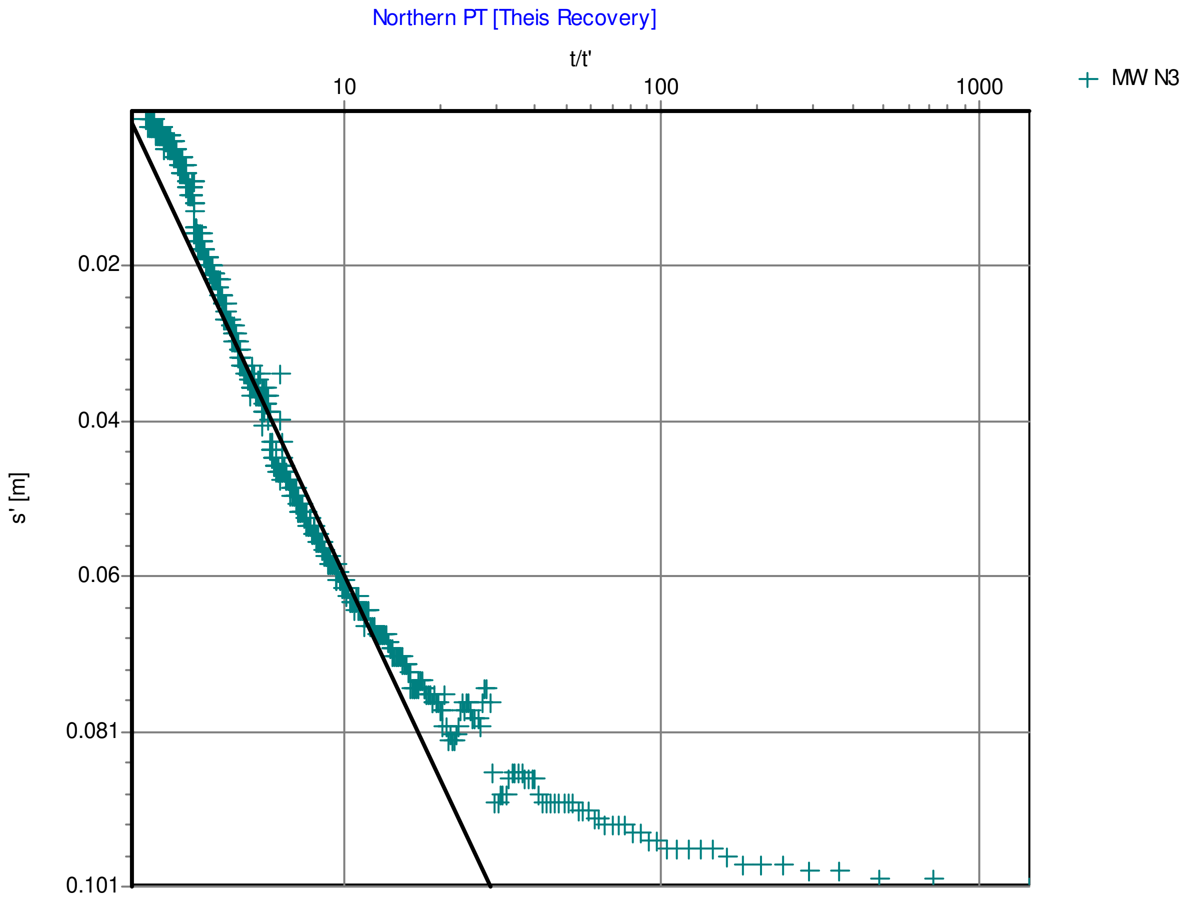
IGGC P/L
PO Box 247
Newtown NSW 2042
Phone: 02 9029 2995

Pumping Test Analysis Report

Project: Merimbula Detailed Investigation

Number: FJ06

Client: BVSC



Pumping Test: **NPW**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	9.02E+2 [m²/d]	Conductivity:	4.87E+1 [m/d]

Test parameters:	Pumping Well:	N Production	Aquifer Thickness:	18.5 [m]
	Casing radius:	0.05 [m]	Unconfined Aquifer	
	Screen length:	9 [m]		
	Boring radius:	0.065 [m]		
	Discharge Rate:	0.005 [m³/s]		
	Pumping Time	86480 [s]		

Comments:

Evaluated by: IG

Evaluation Date: 21/10/2010

Appendix D

Laboratory Reports

Environmental Division (Water Resources Group)

Certificate of Analysis

Batch No: **XIGGC_18908**

Final Report: XIGGC_18908_JKWK14

Client: **Ian Grey Groundwater Consulting PTY LTD**

Contact: **Ian Grey**

Address:
62 Darley St
Newtown NSW 2042

Client Ref: **Merimbua Dunes**

Client PO: Quote IGGWC-061010, P#. FJ06-1, ON# FJ06

Page Page 1 of 3

Laboratory Canberra Laboratory

Address PO Box 1834, Fyshwick, Canberra. ACT 2609.

Phone 02 6202 5427

Fax 02 6202 5452

Contact: Carmel Boatwright
Manager
carmel.boatwright@alsglobal.com

Date Sampled: 12-Oct-2010

Date Samples Received: 13-Oct-2010

Date Issued: **23-Nov-2010**

Date Testing Commenced: 13-Oct-2010

The sample(s) referred to in this report were analysed by the following method(s):
\# - NATA accreditation does not cover the performance of this service

Analysis	*Method*	*Laboratory*	*NATA No.*	*Analysis*	*Method*	*Laboratory*	*NATA No.*	*Analysis*	*Method*	*Laboratory*	*NATA No.*
Anions Screen	35	CANBERRA	992	**Enterococci**	561	CANBERRA	992	**Faecal Coliform Env.**	550	CANBERRA	992
DOC (as NPOC)	290	CANBERRA	992	**Diss. Calcium**	120	CANBERRA	992	**Diss. Iron**	120	CANBERRA	992
Diss. Magnesium	120	CANBERRA	992	**Diss. Mercury**	122	CANBERRA	992	**Diss. Metals**	121	CANBERRA	992
Diss. Nickel	120	CANBERRA	992	**Diss. Potassium**	120	CANBERRA	992	**Diss. Sodium**	120	CANBERRA	992
Ammonia (asN)	32	CANBERRA	992	**Organic N(calc)**		CANBERRA	992	**Orth.Phosp(asP)**	220	CANBERRA	992
T.Kjel.N (calc)		CANBERRA	992	**T.Oxid Nit(asN)**	150	CANBERRA	992	**Total Nitrogen**	114	CANBERRA	992

Temperature on receipt at Lab: 8.3

This document is issued in accordance with NATA's accreditation requirements.

Accredited for compliance with ISO/IEC 17025.

No. 992

Signatories

These results have been electronically signed by the authorised signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11

Name	*Title*	*Name*	*Title*
Carmel Boatwright	**Manager**	**Martin Radic**	**Supervisor Microbiology**
Terry Obrien	**Supervisor Nutrients**	**Titus Vimalasiri**	**Supervisor Metals**

			Sample No.	**805673**	**805674**	**805675**
			Client Sample ID.	MER N3	MER N1	MER C PROD
			Sample Point.	XSITE	XSITE	XSITE
			Sample Date.	12-Oct-2010 12:15:00PM	12-Oct-2010 12:30:00PM	12-Oct-2010 12:45:00PM
Analysis	**Analyte**	**LOR**	**Units**			
Ammonia (asN)	Ammonia	<0.01	mg/L N	<0.01	0.01	0.05
Anions Screen	Chloride	<0.05	mg/L	8600	1900	6700
	Bromide	<0.2	mg/L	31	6	23
	Sulphate	<0.4	mg/L SO4	1300	220	870
	Fluoride	<0.1	mg/L	0.52	0.22	0.30
	Nitrate	<0.1	mg/L N	1.2	0.15	0.33
	Nitrite	<0.05	mg/L N	<0.05	<0.05	<0.05
	Phosphate	<0.2	mg/L P	<0.20	<0.20	<0.20
Diss. Calcium	Diss_Ca	<0.05	mg/L	270	160	220
Diss. Iron	Diss_Fe	<0.01	mg/L	0.02	0.04	0.24
Diss. Magnesium	Diss_Mg	<0.05	mg/L	610	110	450
Diss. Mercury	Diss_Hg	<0.1	ug/L	<0.1	<0.1	<0.1
Diss. Metals	Silver	<1	ug/L	<1	<1	<1
	Aluminium	N/A	ug/L	6	5	<5
	Arsenic	N/A	ug/L	44	17	35
	Barium	N/A	ug/L	25	62	33
	Beryllium	<0.1	ug/L	<0.1	<0.1	<0.1
	Cadmium	N/A	ug/L	<0.05	<0.05	<0.05
	Cobalt	N/A	ug/L	1.0	0.5	0.7
	Chromium	N/A	ug/L	2	<2	<2
	Copper	N/A	ug/L	5.4	1.5	3.3
	Manganese	N/A	ug/L	3.6	8.8	2.0
	Molybdenum	N/A	ug/L	5.2	1.1	3.5
	Nickel	N/A	ug/L	11	6	<5
	Lead	N/A	ug/L	<0.05	<0.05	<0.05
	Antimony	<3	ug/L	<3	<3	<3
	Selenium	N/A	ug/L	<2	<2	<2
	Zinc	N/A	ug/L	17	41	26
Diss. Nickel	Diss_Ni	<0.005	mg/L	<0.005	<0.005	<0.005
Diss. Potassium	Diss_K	<0.1	mg/L	280	61	200
Diss. Sodium	Diss_Na	<0.1	mg/L	5300	1100	3700
DOC (as NPOC)	DOC	<1	mg/L	8	11	5
Enterococci	Pres_Count	<1	CFU/100mL	<2	48	<2

Page: **Page 3 of 3**

Batch No: **XIGGC_18908**

Report Number: **XIGGC_18908_JKWK14**

Client: **Ian Grey Groundwater Consulting PTY LTD**

Client Ref: **Merimbua Dunes**

				805673	**805674**	**805675**
				MER N3	MER N1	MER C PROD
				XSITE	XSITE	XSITE
				12-Oct-2010 12:15:00PM	12-Oct-2010 12:30:00PM	12-Oct-2010 12:45:00PM
Enterococci	Conf_Count	<1	CFU/100mL	<2	48	<2
Faecal Coliform Env.	Pres_Count	<1	CFU/100mL	<2	<2	<2
	Conf_Count	<1	CFU/100mL	<2	<2	<2
Organic N(calc)	Org_Nitrogen	N/A	mg/L N	<0.1	0.3	0.2
Orth.Phosp(asP)	Ortho_P	<0.01	mg/L P	0.09	0.05	0.03
T.Kjel.N (calc)	TKN_calc	N/A	mg/L N	<0.1	0.3	0.2
T.Oxid Nit(asN)	Oxidised_N	<0.01	mg/L N	1.4	0.20	0.37
Total Nitrogen	Total_N	<0.05	mg/L N	1.4	0.49	0.57

These samples were analysed as received into the Laboratory.
Tests marked # are not NATA accredited.
A blank space indicates no test performed. A 'P' indicates results are pending authorisation
Soil results expressed in mg/kg dry weight unless specified otherwise

LOR = Limit of reporting. When a reported LOR is higher than the standard LOR, this may due to high moisture content, insufficient sample or matrix interference.

The analytical procedures in this report (including house methods) are developed from internationally recognised procedures such as those published by USEPA, APHA and NEPM

Results listed as Total Metals are actually Total Recoverable Metals

Multiple Analysis Profile

CLIENT: **IGGC Pty Limited**
PO Box 247
NEWTOWN NSW 2042
Attn: Ian Grey

PROJECT: Name: **Merimbula**
Location:
SESL Quote N°: Client Job N°: **FJ06**
Order N°: Date Received: **30/06/2011**

SAMPLE: Batch N°: **18905** Sample N°: **1**
Name: **C1/10-12**
Test Type: **PRI, (TC,TOC,TIC)**

Certified System
Quality
ISO 9001

Sydney Environmental and Soil Laboratory

Specialists in Soil Chemistry, Agronomy and Contamination Assessments

Tests are performed under a quality system certified as complying with ISO 9001: 2000. Results and conclusions assume that sampling is representative. This document shall not be reproduced except in full.

Sydney Environmental & Soil Laboratory Pty Ltd
ABN 70 106 810 708
16 Chilvers Road
Thornleigh NSW 2120
Australia
Address mail to:
PO Box 357
Pennant Hills NSW 1715
Tel: 02 9980 6554
Fax: 02 9484 2427
Em: info@sesl.com.au
Web: www.sesl.com.au

Total No Pages: 1 of 1

Analysis	Unit	Result
Total Carbon	%	1.04
Total Organic Carbon	%	0.01
Total Inorganic Carbon	%	1.03
Phosphate Retention Index	%	89.6
Phosphate Retention Index	mg/kg	5279

Commentary from SESL not requested.

Consultant:
Scott Fraser

Authorised Signatory:
Murray Fraser

Date of Report
08/07/2011

END OF REPORT

Multiple Analysis Profile

CLIENT: **IGGC Pty Limited**
PO Box 247
NEWTOWN NSW 2042
Attn: Ian Grey

PROJECT: Name: **Merimbula**
Location:
SESL Quote N°: Client Job N°: **FJ06**
Order N°: Date Received: **30/06/2011**

Certified System™
Quality
ISO 9001

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SAMPLE: Batch N°: **18905** Sample N°: **2**
Name: **C1/16.5**
Test Type: **PRI, (TC,TOC,TIC)**

Tests are performed under a quality system certified as complying with ISO 9001: 2000. Results and conclusions assume that sampling is representative. This document shall not be reproduced except in full.

Total No Pages: 1 of 1

Analysis	Unit	Result
Total Carbon	%	0.87
Total Organic Carbon	%	0.02
Total Inorganic Carbon	%	0.85
Phosphate Retention Index	%	79.8
Phosphate Retention Index	mg/kg	4707

Commentary from SESL not requested.

Consultant: Scott Fraser

Authorised Signatory: Murray Fraser

Date of Report 08/07/2011

END OF REPORT

Multiple Analysis Profile

CLIENT: **IGGC Pty Limited**
PO Box 247
NEWTOWN NSW 2042
Attn: Ian Grey

PROJECT: Name: **Merimbula**
Location:
SESL Quote N°: Client Job N°: **FJ06**
Order N°: Date Received: **30/06/2011**

SAMPLE: Batch N°: **18905** Sample N°: **3**
Name: **N2/11**
Test Type: **PRI, (TC,TOC,TIC)**

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Total No Pages: 1 of 1

Analysis	Unit	Result
Total Carbon	%	0.74
Total Organic Carbon	%	0.01
Total Inorganic Carbon	%	0.73
Phosphate Retention Index	%	74.0
Phosphate Retention Index	mg/kg	4362

Commentary from SESL not requested.

Consultant:
Scott Fraser

Authorised Signatory:
Murray Fraser

Date of Report
08/07/2011

END OF REPORT

Multiple Analysis Profile

CLIENT: **IGGC Pty Limited**
PO Box 247
NEWTOWN NSW 2042
Attn: Ian Grey

PROJECT: Name: **Merimbula**
Location:
SESL Quote N°: Client Job N°: **FJ06**
Order N°: Date Received: **30/06/2011**

SAMPLE: Batch N°: **18905** Sample N°: **4**
Name: **N2/18**
Test Type: **PRI, (TC,TOC,TIC)**

Certified System™
Quality
ISO 9001

Sydney Environmental and Soil Laboratory

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Total No Pages: 1 of 1

Analysis	**Unit**	**Result**
Total Carbon	%	0.44
Total Organic Carbon	%	0.1
Total Inorganic Carbon	%	0.43
Phosphate Retention Index	%	36.0
Phosphate Retention Index	mg/kg	2121

Commentary from SESL not requested.

Consultant: Fraser
Scott Fraser

Authorised Signatory:
Murray Fraser

Date of Report
08/07/2011

END OF REPORT