Gales-Kingscliff Pty Ltd

ABN: 75 093 540 080

Cudgen Lakes Sand Extraction Project

Groundwater Assessment

Prepared by

Australasian Groundwater & Environmental Consultants Pty Ltd

April, 2008

Specialist Consultant Studies Compendium

Part 1

Gales-Kingscliff Pty Ltd

ABN: 75 093 540 080

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Groundwater Assessment

Prepared for: R.W. Corkery & Co. Pty Limited
1st Floor, 12 Dangar Road
PO Box 239
BROOKLYN NSW 2083

Telephone: (02) 9985 8511
Facsimile: (02) 9985 8208
Email: admin@rwcorkery.com

On behalf of: Gales-Kingscliff Pty Ltd
20 Ginahgulla Road
BELLEVUE HILL NSW 2023

Tel: (02) 9327 2481
Fax: (02) 9387 8230
Email: segals@galesgroup.com.au

Prepared by: Australasian Groundwater & Environmental Consultants Pty Ltd
36 Jeays Street
BOWEN HILLS QLD 4006

Tel: (07) 3257 2005
Fax: (07) 3257 2088
Email: errol.briese@ageconsultants.com.au

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EXECUTIVE SUMMARY

Gales-Kingscliff Pty Ltd ("the Proponent") proposes to establish a sand extraction operation on land which it owns on the floodplain of the Tweed River at Cudgen. The sand would be extracted from two extraction sites using a dredge and excavators and would be used as fill material to raise nearby low-lying land for commercial and residential development, and as raw material for the construction industry. The sand used as fill material would be hydraulically pumped to the fill sites and the tailwater returned to the southern extraction pond. Sand to be sold to the construction industry would be processed on site and transported to markets by road trucks.

The Proponent also proposes to establish the operation as a Virgin Excavated Natural Materials (VENM) receival and treatment facility. VENM would be either processed, used as backfill or interned below the water level within the extraction sites.

This report has been prepared for the *Environmental Assessment* (EA) which is required in order to obtain Project Approval. It describes a hydrogeological assessment of the Project Site and surrounds based on historic data and data obtained from investigations undertaken as part of the assessment, and provides a response to the Director-General's Requirements and issues raised by government agencies and the local community relating to groundwater.

The review of existing data and reports and the investigation undertaken as part of the study indicate that the hydrogeological regime of the Project Site and surrounds consists of:

- a Quaternary alluvial sand aquifer system with a maximum thickness of about 22.5m; and
- a basalt aquifer which forms the Cudgen Plateau and is located just beyond the southern boundary of the Project Site.

The sand aquifer contains fresh water in the near surface but the water quality becomes progressively more brackish with depth, whereas the basalt aquifer generally contains good quality groundwater. A census of bores and groundwater use in the area indicates that there is some use from shallow spears in the sand aquifer for garden watering in residential areas away from the site, and that there are deeper bores in the basalt aquifer used for irrigation of vegetable crops.

An assessment of the proposed methods of sand extraction through mechanical excavation, dredging and hydraulic pumping indicated that there may be a lowering of the water table in the areas surrounding the extraction ponds. Lowering of the water table presents the following potential risks and constraints which are a focus of the groundwater impact assessment.

- Oxidation of potential acid sulfate soils and sediments in the area of drawdown of the water table.
- Saline intrusion from the base of the aquifer impacting pond water and groundwater quality.
- Increased flow from the Cudgen Plateau and impact on yield from bores in the area.

There are 21 groundwater monitoring bores that have been established within or around the Project Site, the majority of which were installed as part of previous investigations. Some of these bores are nested and monitor shallow, mid depth and the base of the sand aquifer. Water quality and water level monitoring has been undertaken regularly (4 to 6 times per year) since May 2002. This monitoring has shown:

- generally fresh to slightly brackish water in the upper part of the aquifer becoming increasingly saline with depth; and
- a water table fluctuation range of about 1.5m with the minimum water level being -0.75m AHD and the upper level about 0.75m AHD.

Water level data loggers have been installed in three shallow monitoring bores within the Project Site to monitor daily fluctuations and the response of the aquifer to rainfall. The hydrographs were used to calibrate the numerical groundwater model.

An assessment of the potential impact of sand extraction on the groundwater regime was undertaken using the three-dimensional flow model, MODFLOW. The conceptual model of the groundwater regime that was developed through the course of the study was used to define the extent of the model and the model boundaries. The model grid covers the whole of the floodplain to the Tweed River and to the Pacific Ocean, and incorporated in Cudgen Ridge to the south. The adjoining operating Hanson Tweed Sand Quarry to the west, and drains in the floodplain constructed to lower groundwater levels, were incorporated into the model to provide a cumulative impact. A water balance for the sand extraction operation lake was developed for the stages of extraction and for different extraction rates. The water balance took into consideration:

- the volume and rate at which sand would be extracted and hence the make-up of groundwater required to fill the void created when removing the sand;
- rainfall;
- open water body evaporation; and
- return of tailwater to the pond following the hydraulic placement of sand in the fill areas.

A similar water balance was also developed for the western adjoining Hanson Tweed Sand Quarry assuming extraction of 150,000m^3 of sand per annum. Importantly, the water balance accounted for the water required to replace the volume of sand removed from beneath the water table. This accounting was not included within the 2005 hydrological assessment completed for the extension to the Hanson Tweed Sand Quarry operation.

The model was calibrated by adjustment of rainfall recharge and hydraulic parameters until a match between observed and simulated groundwater levels was achieved for both steady state and transient conditions. Modelling indicates that the greatest drawdown in the water table level would occur in the early years of sand extraction when the southern extraction pond size and hence the area of sand aquifer and direct rainfall contributing to make-up water is relatively small. As the pond size increases, the:

- volume of water in storage increases relative to that being removed;

- area of aquifer exposed in the sides of the pond through which groundwater inflow occurs progressively increases; and
- relative contribution of direct rainfall onto the pond increases and exceeds open water body evaporation rates on an annual basis.

Therefore, as the operation progresses and the size of the southern extraction pond increases, the drawdown in the water table around the southern extraction pond would decrease.

Modelling initially indicated that, for a maximum sand extraction rate of 650,000m^3 per year, there would be a drawdown to about -2.5m AHD in the dredge pond at Year 1, and that this would decrease to about -1.0m AHD at full development of the dredge pond in about 7.5 years. Following cessation of sand extraction, the groundwater level in the pond would fully recover to generally between 0.0 to 0.25m AHD, that is, within the pre-sand extraction water table fluctuation range.

In order to reduce the drawdown during the early years of operation, it was proposed to reduce the extraction rate to 450,000m^3 year for the first two years, increasing to 650,000m^3 in subsequent years. Modelling for this scenario indicated a drawdown within the southern extraction pond to approximately -1.5m AHD decreasing to -1.0m AHD in subsequent years. It is also important to note that, during the first year of operations, extraction within the southern extraction pond would commence at an equivalent rate of 100 000m^3 per year and progressively ramp up in increments of 100 000m^3 per year. During this ramp up period (and throughout the life of the operation), the level of extraction would be adjusted to ensure that groundwater drawdown levels remain within the limits predicted. It is noted that the current Development Consent DA 96/518, which requires that 400 000m^3 of sand is extracted within 26 weeks, would be surrendered should project approval be granted. Therefore, the likely groundwater drawdown from this equivalent extraction rate of 800 000m^3 would be avoided.

Predictive modelling also indicates that groundwater levels along the southern boundary of the Project Site, that is, near the toe of Cudgen Plateau, may decrease to -1.0m AHD to -1.5m AHD during the early stages of sand extraction, but that this drawdown would gradually reduce as the pond size increases. At completion of sand extraction, the water levels would fully recover. Should the landowners on the southern boundary of the Project Site water supply be adversely impacted, the Proponent would provide an alternate supply of water and/or compensation.

Acid sulfate soil and sediment investigations for the Project (refer HMC 2008 - Part 3 of the Specialist Consultant Studies Compendium) indicate that no impacts relating to potentially acid sulfate soils and sediments (PASS) would be expected where groundwater drawdown remains within the range of previously observed groundwater fluctuations. The groundwater model predicts that drawdown below the lowest recorded water levels generally remains within the Project Site. Therefore PASS external to the Project Site would not likely be impacted by dewatering. Furthermore, PASS has also been recorded above the observed groundwater fluctuations without any adverse impacts upon water quality. Hence, it is expected that exposure of PASS below the observed fluctuations would be unlikely to cause adverse impacts.

It is important to note that, during sand extraction operations, the pond would always remain a sink to groundwater flow and therefore, in the event that any acidic groundwater is generated from oxidised PASS, it would flow to the pond and would not flow off site. A management plan has been developed as part of the Acid Sulfate Soils and Sediment Assessment component of this study outlining a pond water monitoring program and mitigation strategies should the pH of the pond water decrease. However, based upon the water quality monitoring at the adjoining Hanson Tweed Sand Quarry, monitoring data collected during the creation of the initial dredge pond and data for the acid sulfate soils and sediments assessment, the pH of the water within the extraction ponds is expected to be near neutral to slightly alkaline.

Furthermore, monitoring of pond water quality at the adjoining Hanson Tweed Sand Quarry, which extracts to the base of the aquifer (20m depth), has indicated a slightly brackish lake water quality (electrical conductivity ~2,500µS/cm). Similarly, monitoring of groundwater quality in the surrounding aquifer has indicated no impact around the pond. A report on the monitoring concluded that the monitoring demonstrates *"satisfactory environmental performance"* of the operation and it is concluded, based on this working example, that the performance of the Cudgen Lakes Sand Extraction Project would be similar with regards to pond water quality.

In order to assess the potential groundwater impacts of sand extraction operations within the northern extraction site, analytical equations were used based on the previously developed conceptual model. Extraction within the northern extraction site was assumed to occur at an annual rate of 200 000m^3 for the first two years of the operation. It was also assumed that the extraction pond would be progressively backfilled with VENM starting at the end of the first year. The analytical assessment indicated that the drawdown in the northern extraction pond would be minimal at about 0.25m below the static water level. The cone of depression would also be relatively limited with 0.1m drawdown at a radius of about 60m from the excavation. Given the limited drawdown associated with the northern sand extraction site, the cumulative interaction between the northern and southern extraction sites is not considered to be significant.

In summary, it is concluded that there would be drawdown of the groundwater table around the southern extraction site, particularly in the first few years of extraction, and that this could lead to exposure of PASS and lowering of water level in bores on adjoining properties to the south and lowering of the dredge pond at the adjoining Hanson Tweed Sand Quarry to the west. Management plans and mitigation measures have been prepared to address any adverse impacts. At cessation of sand extraction, annual rainfall inputs to the pond would exceed evaporation and resultant drawdown in groundwater levels would be very limited.

1 INTRODUCTION

Gales-Kingscliff Pty Ltd ("the Proponent") proposes to establish a sand extraction operation ("the Project") at Cudgen to extract the recoverable sand resource for use as fill material to raise the level of nearby low-lying land for commercial and residential development, and as raw material for the local construction industry. Sand would be extracted from the extraction sites by both mechanical and hydraulic (dredging) methods. Sand for use as fill material would be hydraulically pumped to the fill sites using groundwater from within the extraction pond. It is proposed that tailwater would be collected and returned to the extraction pond. Sand to be sold to the construction industry would be processed on site and transported by road trucks.

Development approval has been obtained to extract 400,000m^3 of sand over a six-month period to raise the elevation of low-lying land at Cudgen. The conditional development consent provides for extraction within a 7ha area to a depth of 8.5m, well above the limit of the base of the resource. The Proponent is now seeking Project Approval to extend the currently approved extraction limit to enable the long-term provision of sand for land development purposes and for the local construction industry.

The maximum combined annual extraction rate throughout the life of the Project would be in the order of 650,000m^3. This would comprise a regular component of up to approximately 200,000m^3 per year for the supply of construction material with the remaining 450,000m^3 per year being intermittently extracted for fill sand.

In order to obtain the required Project Approval for the proposed extension, the Proponent needs to submit an *Environmental Assessment* (EA) to the Department of Planning (DoP), formerly the Department of Infrastructure, Planning and Natural Resources (DIPNR). Subsequent to the Planning Focus Meeting held on the 17 October 2004, the initial set of Director-General's Requirements for preparation of an Environmental Impact Statement were outlined in a letter received from DIPNR, dated 6 December 2004. The DoP has subsequently issued a new set of Director-General's requirements in accordance with Part 3A of the *Environmental Planning & Assessment Act 1979* which came into effect on 1 August 2006. This report provides a response to both sets of requirements in relation to groundwater. It identifies the risks and constraints, addresses the assessed impact of the proposed development on the hydrogeological regime of the sand extraction area, and describes groundwater impact mitigation options where adverse impacts may occur. The report was prepared by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) at the request of R.W. Corkery and Co. Pty Ltd (RWC) on behalf of Gales-Kingscliff Pty Ltd.

2 DESCRIPTION OF THE PROJECT

The Proponent proposes to develop and operate a sand extraction operation to supply fill sand to a number of nominated fill sites via two pipeline corridors and to produce a range of sand products for sale to the local construction industry. The Project would also be appropriately licensed to accept virgin excavated natural material (VENM) which would be used in production of saleable sand products, used to backfill the northern extraction pond or interned at or near the base of the southern extraction pond. The Project would involve the removal of approximately 5 000 000m^3 of sand over a period of 15 to 20 years. The Project Site covers an area of 67ha which includes:

- a 9ha extraction site north of Altona Drive ('northern extraction site');

- a 37ha extraction site south of Altona Drive ('southern extraction site'); and
- a processing area north of Altona Drive covering an area of 3.7ha.

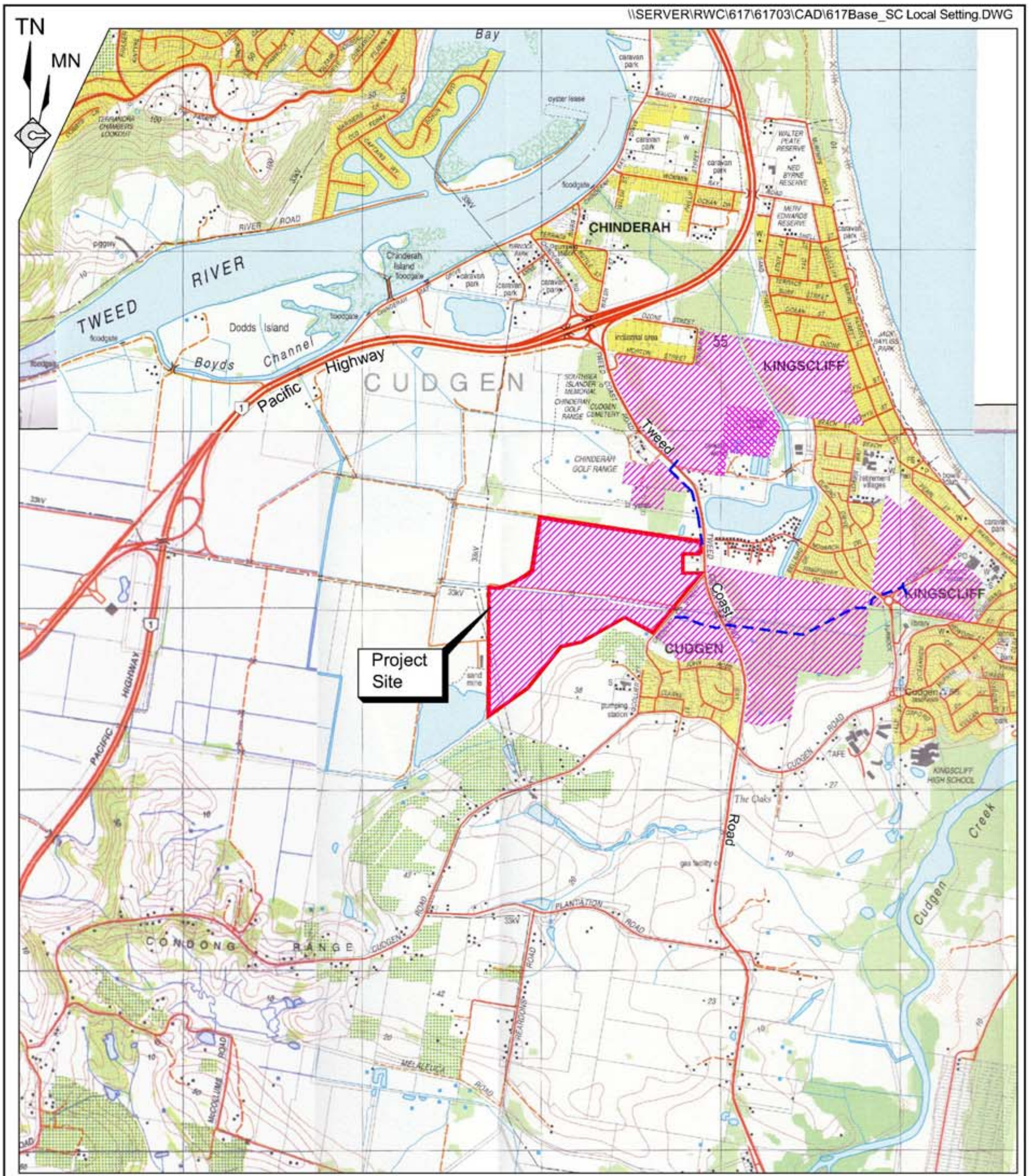
Figure 1 shows the location of the Project Site while **Figure 2** shows the layout of the Project Site and proposed fill sites.

Two pipeline corridors are also proposed extending north and east from the southern extraction site (see **Figure 2**). These are referred to as the "northern pipeline corridor" (0.8km in length) and the "eastern pipeline corridor" (1.5km in length). The proposed northern pipeline corridor would be located in the road reserve on the western side of Tweed Coast Road. The proposed eastern pipeline corridor would be located within the road reserve for a proposed road within land owned by the Proponent. It is acknowledged that the proposed road has not yet been approved. Therefore, an alternative eastern pipeline corridor (see **Figure 2**) has been proposed in the event that the proposed road is not approved within a suitable timeframe. An alternative northern pipeline has also been proposed in the event that suitable agreements are reached with an adjoining landholder.

The extraction sequence would involve: stripping of topsoil; formation of bunds; and extraction of the sand resource (loamy sand and fine grained sand). Extraction of all material within the northern extraction site would be undertaken over four stages (see **Figure 3**) progressing east to west to a depth of approximately 5m using mechanical methods (ie. an excavator and trucks). Within the southern extraction site, extraction would occur over 10 stages (see **Figure 3**), generally progressing west to east. Extraction would commence within the 0.5ha initial dredge pond created within the existing approved extraction area, using a cutter-suction dredge, and occur to the depth of the resource, typically 20m below current ground level. The upper loamy sand material over the remainder of the site would be progressively extracted using mechanical methods prior to dredging of the underlying fine grained sand material.

The upper loamy sand material would be treated using alkaline amendments, such as agricultural lime, prior to being transferred to the processing area for production of various construction materials, such as mortar sand. The fine grained sand material would either be trucked or pumped to the processing area and washed to remove oversize and undersize materials, producing construction grade sand, or be pumped to a nominated fill site for use as fill material. All fines separated during processing or returned from the fill sites would be returned at or near the base of either the northern or southern extraction pond. An estimated 2,500,000m^3 of sand would be required to raise the level of the proposed fill sites.

The Project has been designed to optimise the recovery of sand whilst at the same time addressing and managing the environmental constraints within and surrounding the Project Site. In order to reduce groundwater drawdown during the early years of operation, an extraction rate of 450,000m^3 per year would be adopted for the first two years, increasing to 650,000m^3 in subsequent years. Furthermore, during the first year of operations, extraction within the southern extraction pond would commence at an equivalent rate of 100 000m^3 per year and progressively ramp up in increments of 100 000m^3 per year to the nominated rate of 450 000m^3 per year.

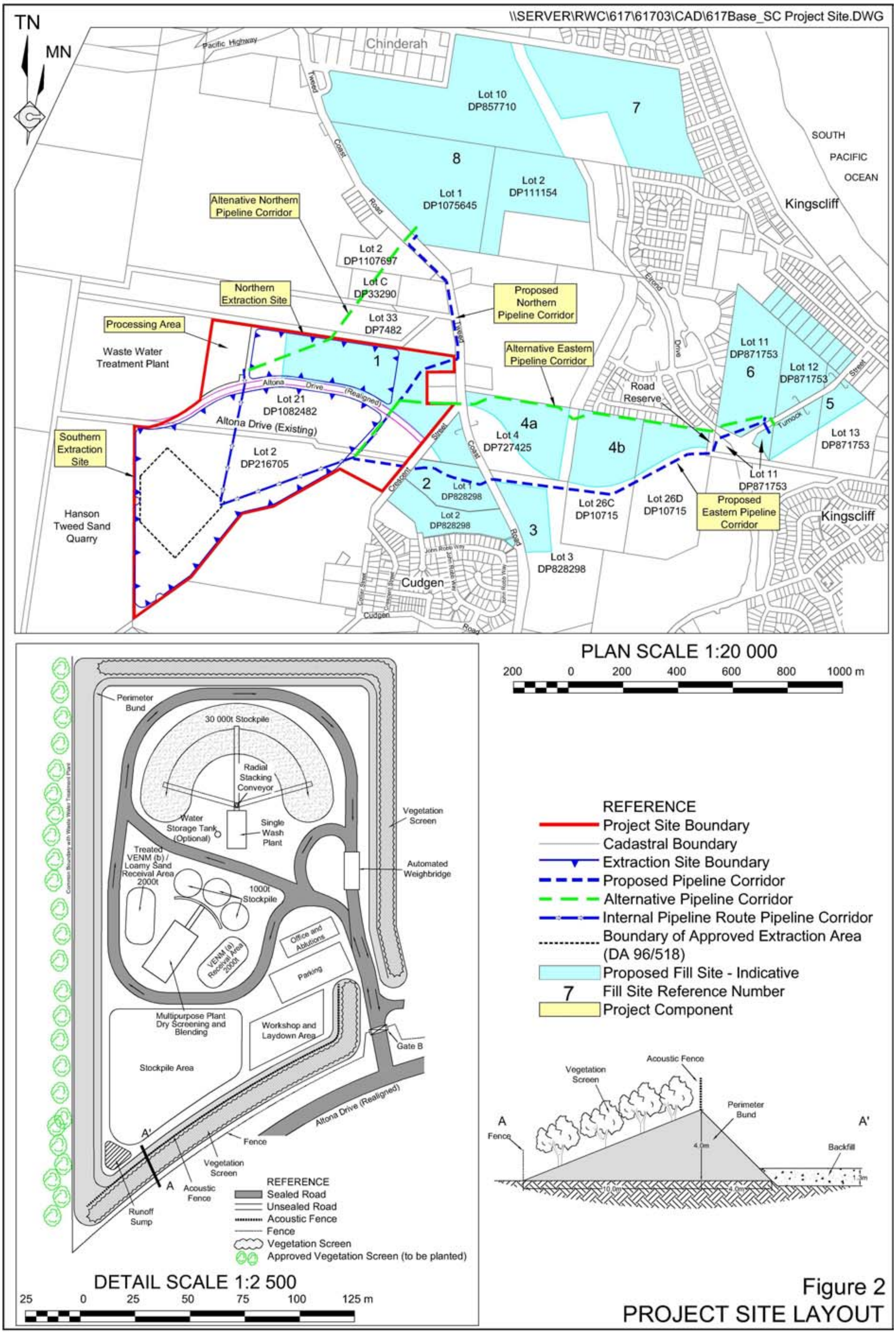


REFERENCE
Project Site Boundary
Gales-Kingscliff (and associated companies) Landholdings
Gales-Kingscliff (and associated companies) Option to Purchase
Proposed Pipeline Corridors

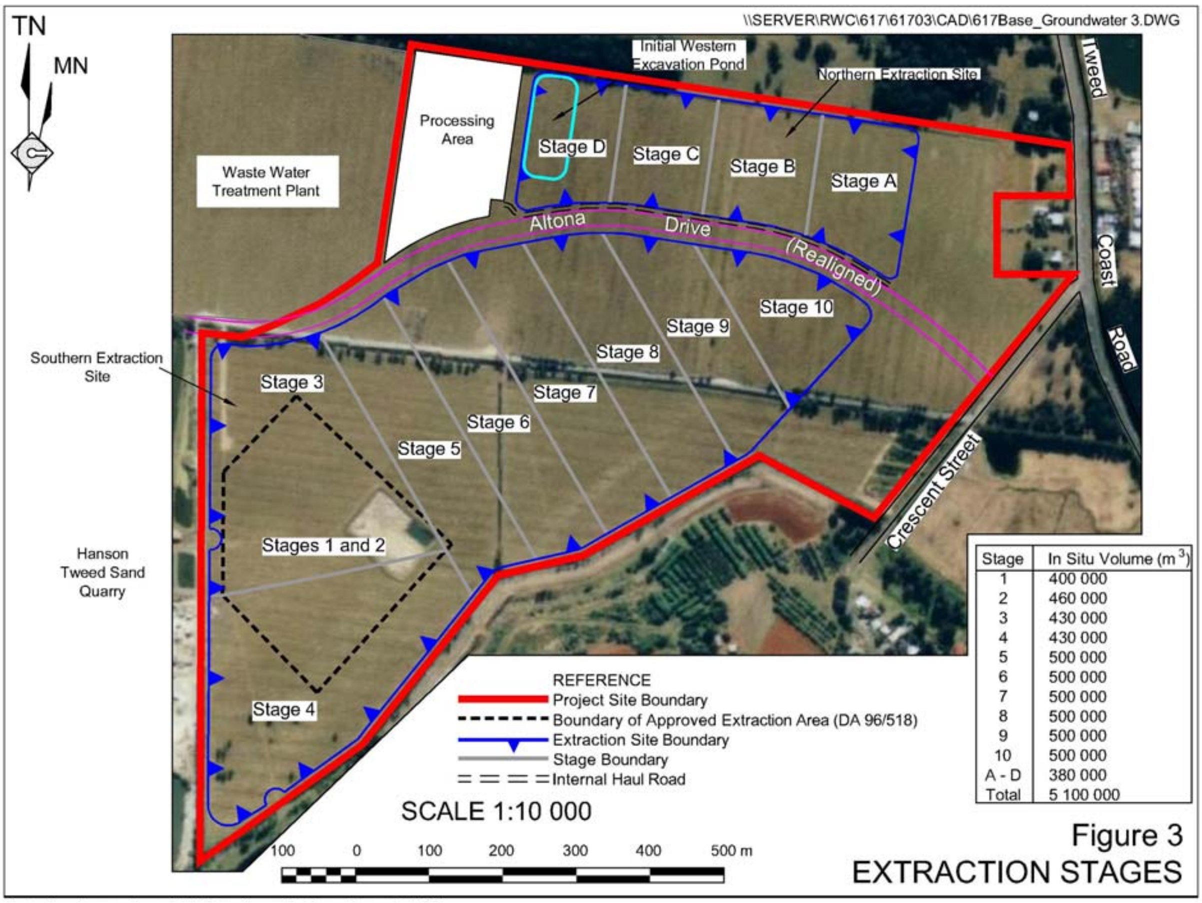
SCALE 1:35 000
500 0 500 1000 1500m
Source: Tweed Heads & Cudgen 1:25 000 Topographic Maps

Figure 1
LOCAL SETTING

Note: A colour version of this figure is available on the Project CD.



Note: A colour version of this figure is available on the Project CD.



Note: A colour version of this figure is available on the Project CD.

During this ramp up period (and throughout the life of the operation), the rate of extraction would be adjusted to ensure that groundwater drawdown levels remain within acceptable limits. It is noted that Development Consent DA 96/518, which requires the removal of 400 000m^3 of sand over a 7ha area (see **Figure 3**) within 6 months (equivalent to a rate of 800 000m^3 per year) would be surrendered following the issue of project approval. Hence the likely drawdowns associated with this approved operation would not occur.

Both non-acid generating VENM - VENM(a) and acid producing VENM – VENM(b) would be received at the Project Site via road trucks, appropriate details recorded and the material classification verified. VENM(a) would either be processed to produce saleable products or used to backfill the northern extraction pond or finalised edges of the southern extraction pond. VENM(b) which is suitable for processing would be placed adjacent to the southern extraction pond for treatment, as for the loamy sand material, prior to processing. VENM(b) not suitable for processing would be either used to backfill the northern extraction pond or interned at or near the base of finalised sections of the southern extraction pond.

All VENM delivered to the Project Site and processed materials despatched from the processing area would be transported via Altona Drive and Tweed Coast Road. Access to the Project Site would be provided via three entrances off Altona Drive, one to the processing area and northern extraction site and two to the southern extraction site.

The Proponent would adopt a progressive approach to site landscaping and rehabilitation to ensure that, wherever possible, disturbed areas are either temporarily or permanently stabilised to limit erosion and adverse visual impacts. An important component of the rehabilitation of the Project Site would be the progressive backfilling of selected finalised sections of the shore of the southern extraction pond and introduction of native vegetation to create wetland areas and parklands. The construction of recreational facilities such as walking and equestrian tracks would occur following completion of sand extraction activities. The final lake would have a depth of up to 20m and cover an area of approximately 37ha.

3 ENVIRONMENTAL ASSESSMENT REQUIREMENTS AND ISSUES RAISED BY GOVERNMENT AGENCIES

The general requirements of DIPNR, North Coast Region for the groundwater impact assessment as outlined in their letter dated 6 December 2004 are as follows.

> *"The information required by the Department with respect to potential groundwater impacts from this development will be used to assess if the site is deemed appropriate for sand extraction.*
>
> *The Department's Policy is aimed at preventing the degradation of the State's aquifers where by each aquifer system is evaluated for its beneficial use. Developers are required to establish that their activity will not contaminate the groundwater quality or impact on groundwater dependent ecosystems.*
>
> *The Department will not allow dewatering of the proposed sand excavation to allow dry mining, because of acid sulfate soils being present at the site. The impacts on the existing groundwater tables and close proximity to tidal areas should be assessed with respect to the mining proposal. Limited low volume groundwater extraction for dust suppression or other industrial uses may be permitted, provided adequate environmental assessment is undertaken and this justifies granting of an extraction licence.*
>
> *Monitoring bores would need to be installed to measure any potential impacts on the aquifer. All bores must be licenced with the Department and this must be obtained prior to any drilling on site.*
>
> *In addition to the above recommendations to adequately assess the feasibility of the Project, the following aquifer investigations will be expected as a minimum requirement to be undertaken by a qualified groundwater consultant.*
>
> 1. *A detailed map showing the location of all drill holes and monitoring bores.*
> 2. *Installation of monitoring bores at key locations to measure both shallow and deep groundwater quality across the site.*
> 3. *Monitoring bores should be installed based on geology/depth of proposed excavation, with relatively short screens intervals, installed at multiple depths.*
> 4. *An assessment of the discrete groundwater hydrogeochemistry is required by a qualified consultant to determine the impact and mixing of groundwater through the aquifers water column (from the near surface to the base of the excavation proposed).*

5. *Groundwater quality parameters for pH/EC/DO/EH from each of the bores should be measured.*
6. *Analysis of shallow and deep groundwater for the following: cations/anions, (Ca, Mg, Na, K, HCO_3, SO_4, Cl), iron (Fe), arsenic (As), manganese (Mn) and aluminium (Al).*
7. *Groundwater levels measures to define flow contours (relative to AHD) to show the groundwater flow directions.*
8. *Test results detailing the percentage of pyritic material and its size present in the acid sulfate (pyritic) fines (Microscopic examination to describe the morphology of iron sulfide fragments and their range of sizes: visual estimation of the abundance of iron sulfide).*
9. *A visual estimation by microscopic examination of the percentage of shell material and other calcareous components within unconsolidated sediments.*
10. *Extraction of groundwater requires the determination of aquifer hydraulic parameters and surrounding impacts based on the proposed extraction volume.*
11. *A management plan for the disposal/storage of acid sulfate fines. Consideration of the fact that the fines may undergo oxidation when exposed to air for long periods and produce acidic by products.*
12. *An interpreted Hydrogeological report detailing the impacts that the development may have with respect to water quality, quantity and groundwater dependent ecosystems. The development should be considered with respect to the NSW State Groundwater Quality Protection Policy (1998) and The NSW State Groundwater Dependent Ecosystem Policy (2002).*
13. *A proposed groundwater management plan for the site and progressive rehabilitation plan must be detailed in the EIS report.*

Water Licences

Licences under Part V of the Water Act 1912 will be required for the following:

1. *A monitoring bore licence.*
2. *An industrial groundwater licence (aquifer interference licence) to carry out sand extraction.*
3. *A licence to pump water from the pit or bores to carry out washing of the extracted material and dust suppression (Low volume – no lowering of the water table will be permitted)".*

Points 8, 9 and 11 are addressed in a separate Acid Sulfate Soils Assessment prepared by HMC Environmental Pty Ltd (HMC, 2008).

This assessment has also been prepared with reference to the *EIS Guidelines Extractive Industries – Dredging and other extraction in riparian and coastal areas* (DUAP, 1996).

Appendix 1 provides a summary of the *Environmental Assessment* Requirements relating to groundwater raised by the Director General and various government agencies and indicates where each requirement is addressed (covered) in this report.

4 LEGISLATION, GUIDELINES AND POLICIES

4.1 Groundwater Quality Protection

The NSW Groundwater Quality Protection Policy (1998), states that the objectives of the policy will be achieved by applying the management principles listed below.

1. *All groundwater systems should be managed such that their 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 groundwater resource.*
5. *A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation and receiving waters.*
6. *Groundwater dependent ecosystems will be afforded protection.*
7. *Groundwater quality protection should be integrated with the management of groundwater quality.*
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 practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.*

4.2 Groundwater Dependent Ecosystems

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. The policy defines Groundwater Dependent Ecosystems as *"communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater".*

4.3 Aquifer Risk

The Tweed Coastal Sands aquifer is classified as a medium risk aquifer based on potential for over extraction and from contamination, (Department of Land and Water Conservation, 1998).

5 SITE SETTING

5.1 Topography

The Project Site lies on a broad, flat, floodplain, (the Cudgen Flood Plain), of the lower reaches of the Tweed River. The elevation across the Project Site varies between 0.8m Australian Height Datum (AHD) and 1.2m AHD. The southern boundary of the Project Site abuts the Cudgen Plateau, which rises steeply to an elevation of 38m AHD, to the immediate south.

5.2 Land Use

The Project Site is located on the Cudgen Flood Plain, which was cleared and drained in the early 1900's by a network of shallow open drains, excavated to lower the water table and discharge the water to the Tweed River. The Project Site is traversed by several of these drains running east / west located adjacent to the northern and southern boundaries and adjacent to the existing Altona Drive. The Project Site has been used in the past as a wet grazing block, and subsequent to draining, a tropical grass and legume seed nursery and as a sugar cane farm up until 1984. Due to ongoing drainage problems, the land has only been used for cattle grazing since that time.

An operational sand extraction operation known as Hanson Tweed Sand (formerly Tweed Turf and Sand) is located adjacent to the western boundary of the Project Site and currently consists of two open water bodies that cover an area of about 10ha. The new Kingscliff Waste Water Treatment Plant is under construction within the western part of Lot 20 on DP 1082482 and is due to commence operation in December 2007.

The southern boundary of the Project Site is marked by the base of the Cudgen Plateau which is productive agricultural land with a variety of crops grown, including mangoes, sweet potato and taro. The land rises steeply upwards from the southern boundary to the top of the Plateau. The eastern end of the Cudgen Plateau is occupied by the residential suburb of Cudgen.

5.3 Climate

The Cudgen area experiences a subtropical climate with dominant summer rainfall. The rainfall totals in the region are relatively high with an average of 1720mm measured between 1887 and 1972 at the Condong Sugar Mill, about 13km west-southwest of the Project Site. Average rainfall at Murwillumbah (17km west-south-west) was 1584mm between 1972 and 2004.

The closest station measuring pan evaporation is at Alstonville 62km south-south-west of the Project Site, and the annual average evaporation recorded between 1963 and 2004 was 1560mm.

Average monthly rainfall and evaporation for each of the stations are presented in **Table 1**.

Table 1
Climate Averages[1] (mm)

	Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall Condong Stn 058013	1887-1972	219.8	249.7	264.2	147.9	138.5	122.8	93.5	73.4	66	87.9	105.5	150.9
Rainfall Murwullimbah Stn 058158	1972-2004	189.7	234.7	223.9	170	150.4	88	70.7	50	39.3	84.9	124.4	158.6
Evaporation Alstonville 058131	1963-2004	179.8	141.25	133.3	105	83.7	75	83.7	108.5	138	158.1	165	189.1

[1]Source: Bureau of Meteorology http://www.bom.gov.au/climate/averages/tables/ca_nsw_names.shtml

6 ISSUES, POTENTIAL RISKS AND CONSTRAINTS

With respect to the groundwater regime and the proposed methods of sand extraction, the main potential for impacts would be as a result of, lowering the water table through mechanical extraction, normal dredging operations and hydraulic pumping of sand to the fill sites. Lowering of the water table could potentially result in:

- oxidation of potential acid sulfate soils and sediments within the area of the “cone of depression” in the water table;
- intrusion of the saline groundwater identified at the base of the aquifer at CNP1 in the northwest corner of the new WWTP; and
- increased flow from the Cudgen Plateau and impact of groundwater levels and yields of bores in this area.

It is important to note that it is proposed that the tailwater resulting from the pumping of sand would be captured and pumped back to the extraction ponds. It is estimated that up to 90% of the tailwater would be captured and returned, hence minimising the impact on the water table around the extraction ponds.

7 METHODOLOGY OF STUDY

The groundwater impact assessment for the Cudgen Lakes Sand Extraction Project was undertaken in four stages as follows.

- Stage 1 – Assessment of the existing environment.
- Stage 2 – Data analysis and predictive modelling.
- Stage 3 – Assessment of environmental impacts and reporting.
- Stage 4 – Review of modelling assumptions and impact assessment.

The main objectives of Stage 1 were to assess and define the existing environment at the site and to identify any significant Project environmental risks and/or constraints.

Work undertaken as part of Stage 1 included:

(i) a review of all previous relevant studies undertaken at the Project Site and in surrounding areas;

(ii) installation of additional monitoring bores around the Project Site;

(iii) a census of existing bores in the area to establish the current use of groundwater and to obtain baseline data;

(iv) a review of baseline data on groundwater levels, yields, quality and flow in the aquifer or aquifers held by government departments and consultants;

(v) formulation of a conceptual hydrogeological model for the area based on the available existing data; and

(vi) a preliminary assessment of the potential impacts of the Project on groundwater users in the surrounding areas.

During Stage 2, the potential impacts of the Project were assessed using numerical modelling. Work undertaken in Stage 2 included:

- development of a conceptual model based on the available data;
- construction of a numerical model based on the conceptual model;
- model testing and calibration;
- predictive simulations; and
- data extraction and analysis.

During Stage 3, all data collected and generated during Stage 1 and Stage 2 was used to assess the potential impacts of the Project, recommend mitigation options, where necessary, and to present all data in this final report.

During Stage 4, additional data collected following the modelling was reviewed and the assumptions within the model and impact assessment confirmed.

8 PREVIOUS STUDIES

The first hydrogeological investigation at the sand extraction site was undertaken in 1986 by Coffey & Partners Pty Ltd (C&P). The purpose of the investigation was to assess subsurface conditions for a proposed 56ha sand pit to be excavated to a depth of 10m to 15m. Six boreholes were drilled as part of the investigation and were backfilled after drilling without installation of casing to establish groundwater monitoring bores. The logs for these boreholes and a location map are included in **Appendix 2**.

An Environmental Impact Statement (EIS) for sand extraction from the site was prepared by Woodward-Clyde (WC) in 1996. Two clusters of groundwater monitoring bores (CNP1-3 and CSP1-3) were drilled at the sand extraction site as part of an acid sulfate soil and water quality investigation. Each cluster of bores consisted of three monitoring bores (shallow, intermediate and deep) constructed using hollow flight augers. The logs of these monitoring bores are given in **Appendix 2** and the bore locations are shown on **Figure 4**. Conclusions from the report relevant to this study are:

- groundwater quality ranges from near fresh near the Cudgen Plateau to slightly brackish near to northern boundary of the Project Site, and is of near neutral pH; and
- it is considered that lake water quality during construction would be slightly brackish with a pH value of between 5.0 to 7.0, and of elevated turbidity.

Coffey Geosciences Pty Ltd (CG) installed five shallow monitoring bores around the perimeter of Lot 2 on DP 216705 in 1999 as part of the approval process for a sand extraction operation of about 400,000m^3. The bores, MB1 to MB5, shown on **Figure 4**, were installed to depths of between 5.3m and 5.8m. Conclusions reached from the study were:

- the unconfined Quaternary sediments host a significant aquifer beneath the site;
- groundwater levels across the Project Site are generally around 0.6m below ground level and although not evident from the initial monitoring, groundwater is assumed to flow north and northwest across the site at a very low gradient;
- groundwater quality is generally good, although variable across the site; and
- water loss by evaporation from the dredge pond is unlikely to be sufficient to create a significant impact on the groundwater system.

Geotechnical drilling, cone penetration tests (CPTs) and vibro coring for acid sulfate soil (ASS) testing was undertaken at six sites of the new Kingscliff WWTP by Gutteridge Haskins & Davey Pty Ltd (GHD) in 1994. The holes were drilled to provide coverage of Lot 20 DP 1082482 (previously the western part of Lot 2 on DP 611021). The geotechnical boreholes (BH1 to 6), and CPTs were extended to depths of between 28m and 40m, whereas the ASS holes were drilled to about 5m depth. Subsurface conditions encountered in the boreholes and CPTs were relatively similar across the site, and logs of two bores selected as representative of the strata encountered are given in **Appendix 2**.

CG also undertook a geotechnical investigation of the WWTP site in 2004 for Tweed Shire Council. The 2004 study consisted of:

- thirty (30) geotechnical holes (BH1 to BH30) to between about 4.0m and 6.5m depth, on an approximate 15m grid at the WWTP;
- seven (7) boreholes (BH31 to BH37) to a similar depth, along the pipeline route, that is along Tweed Coast Road to the Tweed River;
- six (6) groundwater holes (GW1 to GW6) to about 6m depth around the WWTP site which were converted to monitoring bores; and
- particle size distributions analysis on five (5) of the bores.

The groundwater monitoring bore locations are shown on **Figure 4**.

An EIS was prepared by Jim Glazebrook and Associates Pty Ltd (JGA) in 2005 for the proposed expansion of the Tweed Turf and Sand (now Hanson Tweed Sand) sand extraction operation on the western boundary of the Project Site. The EIS reported on groundwater regime, monitoring of water quality in monitoring bores and in the dredge pond and impact of the existing operation as well as the predicted impact of the proposed extension. The report provides real data from a working operation and can be used to assess the likely impact of the Cudgen Lakes Sand Extraction Project.

9 INSTALLATION OF MONITORING BORES AND BORE CENSUS

As part of the field investigations undertaken for the Project, additional monitoring bores were installed on the Project Site and a census of existing bores in the surrounding area was undertaken. The following subsections describe the work undertaken.

9.1 Installation of Monitoring Bores

Sixteen new boreholes were drilled on the Project Site to provide additional stratigraphic, groundwater and ASS information. The program was managed by HMC with drilling undertaken by Border-Tech and Maiden Geotechnics. Of the sixteen new boreholes, ten were cased and completed as monitoring bores. The bores are summarised in **Table 2** and their locations shown in **Figure 4**. Borehole logs for bores drilled by Border-Tech are included in **Appendix 2**. Maiden Geotechnics were unable to supply borehole logs.

Table 2
Summary of New Bores Drilled

Borehole ID	Date Drilled	Depth (m)	Monitoring Bore Constructed	Drilling Company	Borehole Logs
BH1	16-May-05	20	No	Border-Tech	Yes
BH2	17-May-05	18.5	No	Border-Tech	Yes
BH3	18-May-05	18.5	No	Border-Tech	Yes
BH4	19-May-05	20.5	No	Border-Tech	Yes
BH5	2-Jun-05	6.0	No	Border-Tech	Yes
BH6	6-Jun-05	11.2	No	Border-Tech	Yes
MB6		12.8	Yes	Maiden Geotechnics	No
MB6A	8-Nov-05	12.0	Yes	Border-Tech	Yes
MB7		16.2	Yes	Maiden Geotechnics	No
MB8		17.7	Yes	Maiden Geotechnics	No
MB8A	8-Nov-05	10.9	Yes	Border-Tech	Yes
MB9		12.1	Yes	Maiden Geotechnics	No
MB10		21.0	Yes	Maiden Geotechnics	No
MB11		5.5	Yes	Maiden Geotechnics	No
MB12		9.7	Yes	Maiden Geotechnics	No
MB13		20.6	Yes	Maiden Geotechnics	No

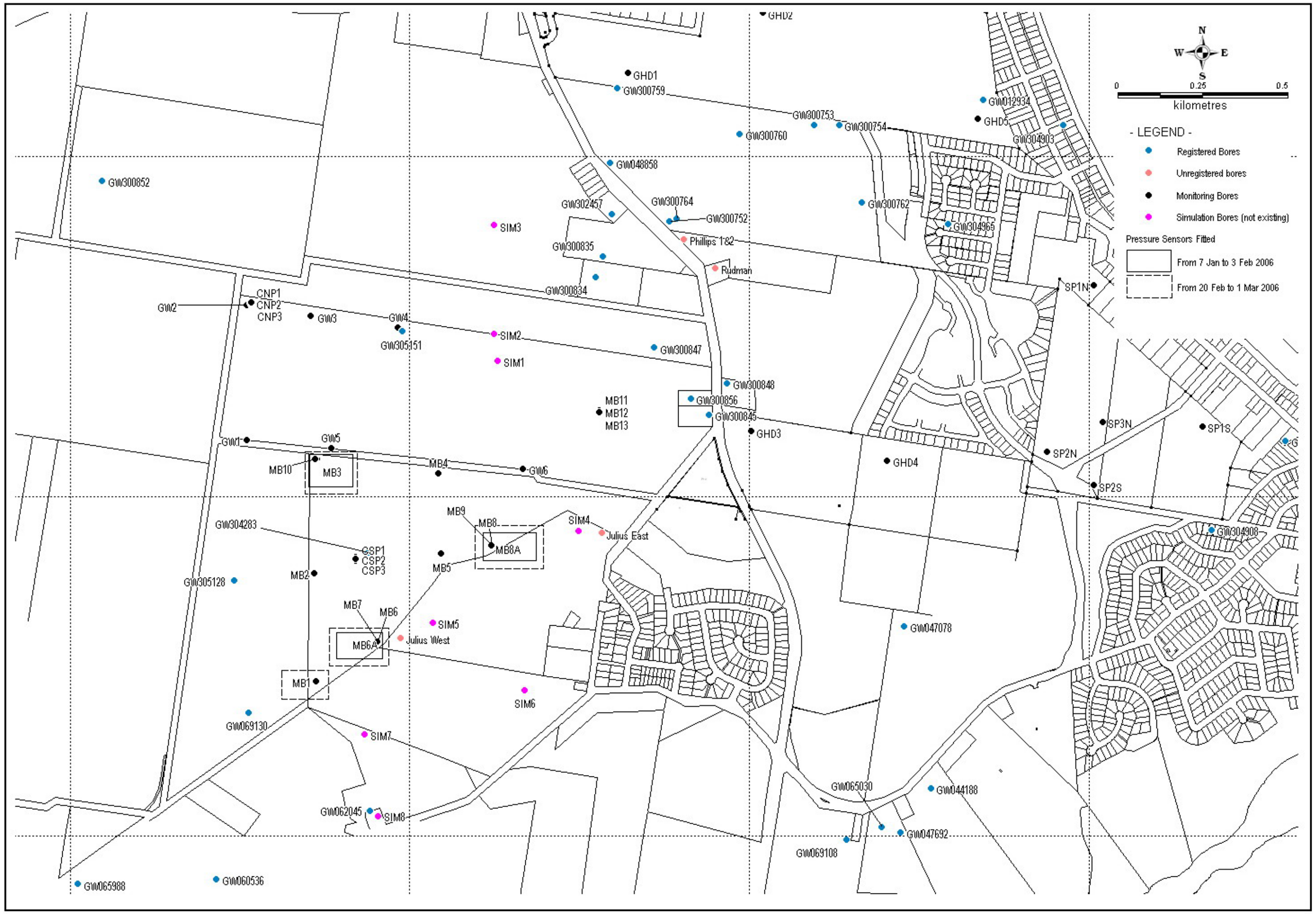


Figure 4 Bore Locations

The monitoring bore network established across the Project Site includes the above mentioned bores drilled as part of the current investigation and some of the bores that were installed during previous investigations, discussed in Section 8.0. A summary of the existing monitoring bore network including location and construction details are summarised in **Table 3**.

9.2 Bore Census

A census of existing registered and unregistered bores on properties surrounding the Project Site was undertaken by HMC during the community consultation process. The objective of the bore census was to record background data such as bore depth, yield, use, water quality and aquifer intersected so that potential impacts could be predicted through modelling. In the event the Project is approved, this data could again be monitored, actual impacts assessed, and if appropriate, replacement water supplied or compensation negotiated from a known starting point.

The results of the bore census are summarised in **Appendix 3**. Registered bores examined in the census and unregistered bores discovered are shown in **Figure 4**. Registered bores within a 1.5km radius of the site are shown in **Figure 5**.

The bore census indicated that a number of properties on Tweed Coast Road to the northeast of the Project Site have shallow spears. The spears are typically between 4.0m and 5.5m deep and are constructed of 32mm diameter galvanised pipe. The bore census indicated that the spears yield relatively fresh groundwater indicated by an electrical conductivity ranging between 77µS/cm and about 400µS/cm. The dominant use of the spears is for irrigation of household gardens. Several of the groundwater users in this area report that during the construction of Noble Lake, the groundwater quality in their bores deteriorated producing a sulfide odour and iron discolouration. It is understood that Noble Lake was dewatered during construction and it is possible some oxidation of sulfides occurred at this time.

A number of registered bores (GW300764, GW300752, GW300759, GW300760 and GW048858), to the northeast of the Project Site were installed as monitoring bores for a proposed turf farm and have since been removed.

Two unregistered spears were identified at the base of Cudgen Plateau on the property adjacent to the southern boundary of the proposed Project Site. The locations of these spears, referred to as Julius East and Julius West, are shown on **Figure 4**. The spears are used in dry periods to fill small dams on the property which in turn are used for irrigating a variety of agricultural crops. The property owner indicated that the property was irrigated on a rotational basis in dry periods but did not know the volumes of water used or pumping rates at the time the groundwater modelling for the Project was undertaken. Subsequent monitoring indicates that the equivalent continuous pumping rates from Julius East and Julius West between December 2006 and March 2007 were 0.3L/s and 1.4L/s respectively (see Section 13.3.3).

Table 3
Summary of Existing Groundwater Monitoring Bores – Sand Extraction and Fill Areas

Property Description	Bore	Location (ISG) mE	Location (ISG) mN	Ground Level (mAHD)	Top of Casing (mAHD)	Depth (m)	Screen/Slotted (from-to) mbns	Standing Water Level (mbns)	Standing Water Level (mAHD)	Water Quality EC (uS/cm)	Water Quality pH	Casing Type
South of Altona Drive (Realigned) Lot 2 DP216705	CSP1	353758	1872562	1.17	1.51	15.2	13.2 – 15.2	0.96	0.55	1438	7.37	Class18, 50mm diameter uPVC 400 micron screen
	CSP2	353759	1872567	1.24	1.39	9.6	7.6 – 9.6	0.84	0.55	866	7.12	
	CSP3	353758	1872562	1.14	1.36	5.4	3.4 – 5.4	0.81	0.55	763	7.07	
	MB1	353642	1872206	0.89	1.20	5.6	2.6 – 5.6	0.89	0.31	1214	7.12	40mm diameter uPVC slotted and wrapped in geofabric
	MB2	353635	1872523	1.65	1.95	5.8	2.3 – 5.3	1.53	0.42	182	5.49	
	MB3	353643	1872861	1.13	1.43	5.6	2.8 – 5.8	0.91	0.24	1193	7.19	
	MB10	353640	1872860	1.12	1.62	21.0	18 – 21	1.3	0.32	43800	7.34	Class 18, 50mm diam.
	MB4	354002	1872818	0.85	1.22	5.7	2.6 – 5.6	-	-	2778	7.11	40mm diameter uPVC slotted and wrapped in geofabric
	MB5	354009	1872581	0.85	1.15	5.7	2.7 – 5.7	0.88	0.24	2319	7.25	
	MB6	353821	1872323	0.86	1.26	12.8	NR	0.79	0.47	6800	7.62	Class 18, 50mm diameter uPVC, 400 micron screen
	MB6A	353820	1872326	0.87	1.39	12	NR	1.01	0.38	4040	7.47	
	MB7	353822	1872321	0.84	1.12	16.2	NR	0.74	0.38	-	-	
	MB8	354159	1872608	0.94	1.69	17.7	NR	1.2	0.49	-	-	
	MB8A	354160	1872610	0.93	1.68	10.9	NR	1.18	0.50	5500	7.27	
	MB9	354159	1872606	0.88	1.55	12.1	NR	1.1	0.45	-	-	
North of Altona Drive (Realigned) Lot 20 & 21 DP 1082482	CNP1	353449	1873317	0.85	1.02	15.08	13 -15	0.47	0.55	22120	7.15	
	CNP2	353448	1873318	0.87	0.97	10.08	8 - 10	0.41	0.56	15250	7.27	
	CNP3	353443	1873317	0.87	1.21	4.01	2 - 4	0.66	0.55	1096	7.14	
	MB11	354477	1873003	0.85	1.59	5.5	2.5 - 5.5	0.86	0.73	1743	7.25	
	MB12	354476	1873001	0.85	1.37	9.68	6.5 - 9.5	0.63	0.74	1818	7.11	
	MB13	354476	1872999	0.85	1.71	20.60	17.5 - 20.5	1.21	0.50	35400	6.77	

Notes: TOC – Top of Casing mbns = metres below natural surface water level and water quality data measured on 12 January 2006 NR – not recorded

Two registered bores in the Cudgen Plateau to the south of the Project Site were inspected as part of the bore census. These are bore GW062045, located 500m to the south, and bore GW060536 located 600m to the southwest. Bore GW062045 yields about 1L/s of fresh water (electrical conductivity 133µS/cm) and is reportedly used for irrigation. Bore GW060536 also yields about 1L/sec of fresh water (electrical conductivity 137µS/cm) and is used for washing vegetables several times a week.

Figure 5 Registered Groundwater Bores

10 HYDROGEOLOGICAL REGIME – EXISTING ENVIRONMENT

10.1 Introduction

Based on a review of existing data and a site inspection, a conceptual model of the hydrogeological regime of the area has been developed. This section of the report discusses the conceptualisation of the hydrogeological regime – existing environment and the data used.

10.2 Geological Setting and Aquifers

The geology in the vicinity of the Project Site is shown in **Figure 6**. Roy (1973) described the Tweed River floodplain as a drowned river valley formed following sea level rise at the beginning of the Holocene, about 18,000 years ago. The sea level rise resulted in the landward movement of offshore marine sands and clays into the prior valley and the formation of a sand barrier. The basins behind these sand barriers progressively in-filled with estuarine material and today are relative mature floodplains. The depositional environment of the Quaternary sands is described as tidal deltaic, with the presence of shell and organic fragments throughout the sequence indicative of alternating marine and terrestrial influence during deposition.

In the area of the Project Site, fine to medium grained sand extends from the surface to a depth of about 20m. The sand deposits are underlain by finer grained marine silts and organic clays to about 38m depth. Basement is the Neranleigh-Fernvale Group which outcrops to the north of the Tweed River and to the southwest as shown on **Figure 6**. The Neranleigh-Fernvale Group is comprised of greywacke, slate, phyllite and quartzite. Tertiary basalt of the Lamington Volcanics overly the Neranleigh-Fernvale beds immediately to the south of the Project Site and form the Cudgen Plateau. The basalt is fine grained and black as fresh rock, but weathers to form deep red-brown good quality agricultural soils over the Cudgen Plateau. A thin band of beach and dune sands occurs adjacent to the coastline.

Within and surrounding the Project Site, the Quaternary sands of the Tweed River flood plain and the Tertiary basalt of the Cudgen Plateau are considered to be significant aquifers. An aquifer is defined as a groundwater-bearing formation sufficiently permeable to yield water in useable quantities. The deeper marine silts/clays that underlie the alluvial sands and the rocks of the basement Neranleigh-Fernvale Group are not considered significant aquifers due to their low permeability. The sand and basalt aquifers are discussed further below. An indicative section showing the relationship of these geological units is presented in **Figure 7**.

10.3 Quaternary Sand Aquifer

10.3.1 Extent and Thickness

The six boreholes drilled on the Project Site by C&P (1986) intersected fine to medium grained quartzose sand with some coarse material. C&P (1986) concluded that *"the sand has a maximum thickness of 22.5 metres and a minimum thickness of 20.5 metres. Over the total area of investigation of 84 hectares, there is a relatively uniform thickness of approx. 21 metres of sand. The sand is underlain by dark to black organic clay or grey to dark grey clay. Both types of clay appear to represent an abrupt alteration of depositional environments from swamp and estuarine to deltaic. Shells and organic fragments within the alluvial sand throughout the sequence indicate continuous marine and terrestrial influence throughout deposition…..The groundwater table on the site is approximately 1m below the ground surface."*

The logs for boreholes 1 to 6 and the location map are given in **Appendix 2**.

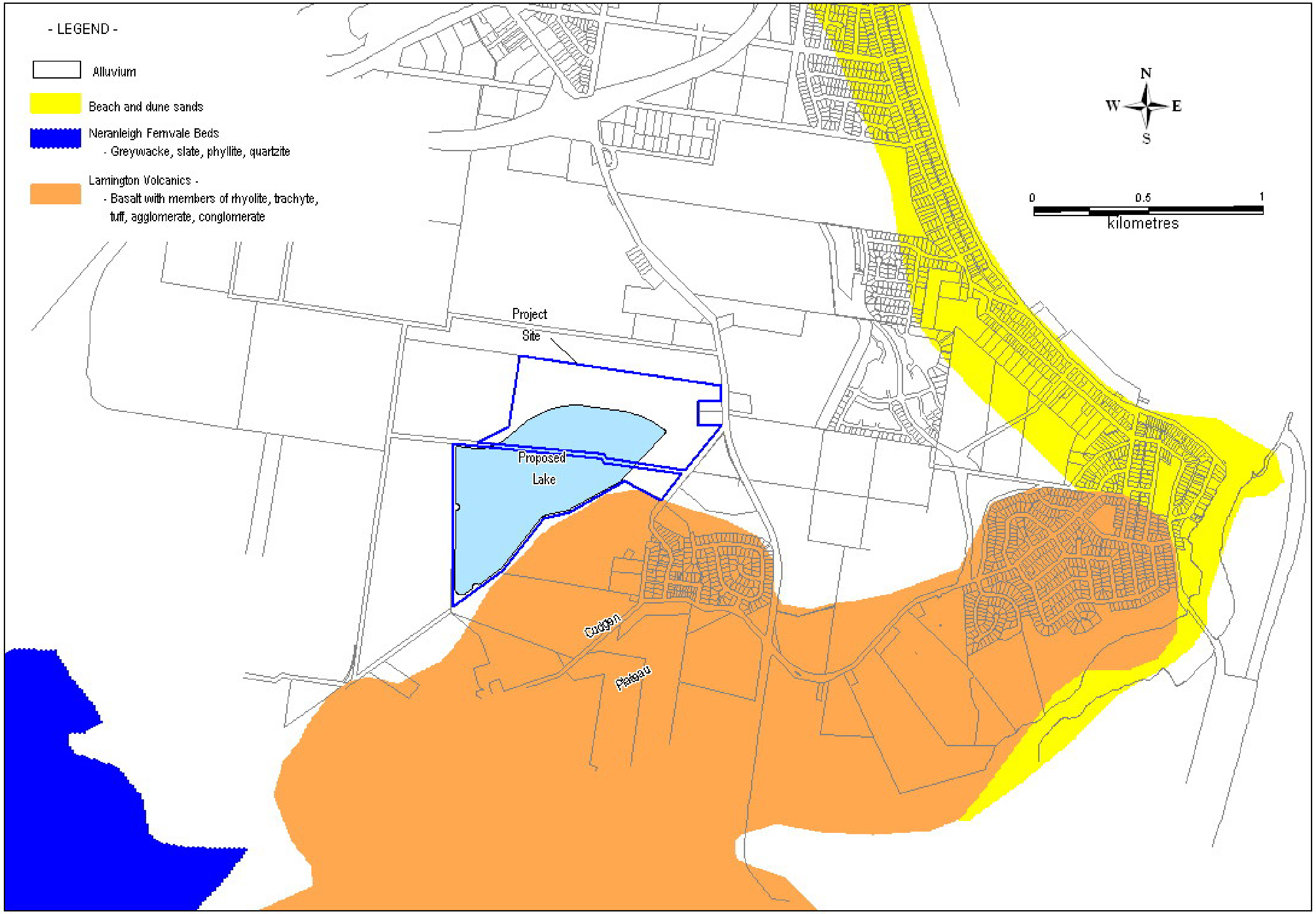
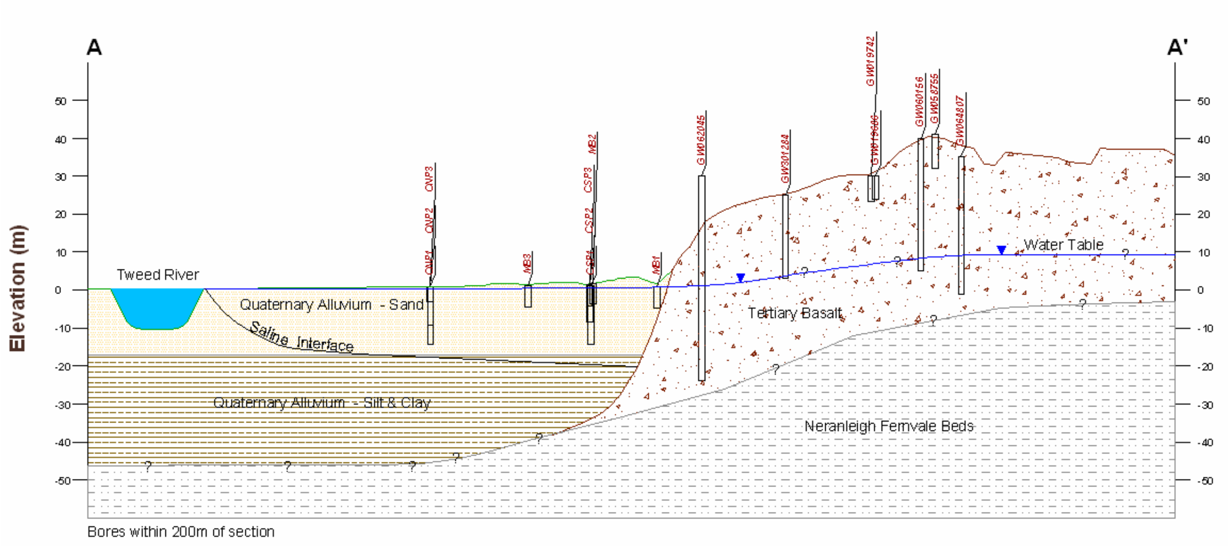


Figure 6 Geology



Note: A colour version of this figure is available on the Project CD.

Figure 7 Conceptual Cross Section

The two clusters of groundwater monitoring bores (CNP1 to 3, CSP1 to 3) installed within and adjacent to the Project Site by WC (1996) intersected fine to medium grained sand to depths of 19.5m and 23m in boreholes CNP1 and CSP1 respectively. Drilling was terminated in grey, silty clay underlying the sands, and no attempt was made to determine the depth to the bedrock.

Similarly, the geotechnical drilling and CPTs undertaken by GHD (2004) encountered loose sand with occasional lenses of silty sand to depths of between 23m and 24m below ground level. The sand was underlain by alluvial clay and silt to a depth of about 38m, which in turn was underlain by residual clay. This indicates that about 15m of low permeability marine sediments are present, underlying the sands.

Monitoring bores have been installed up to a depth of 20m around the existing sand extraction operation to the immediate west of the Project Site, as reported by JGA (2005). The thickness and lithology of the Quaternary sands in this area is similar to that of the Project Site, and it is considered that the alluvium is relatively uniform across the floodplain, with a possible increase in thickness towards the Tweed River.

In summary, the Project Site is underlain by silt grading into fine to medium sand with a maximum depth of about 24m. The upper profile is similar at the fill sites and the profile at depth is likely to be similar. The sand is underlain by marine clays which in turn are underlain by residual clay of the weathered profile of the basement rock, that is, the Neranleigh-Fernvale Beds.

10.3.2 Grain Size and Hydraulic Conductivity

Particle size analyses undertaken on one sample collected from the Project Site (sample ID Wallarah) and five samples collected from the proposed waste water treatment plant site were reviewed and are summarised in **Table 4**.

Table 4
Summary of Grain Size Analyses

Sample ID	Wallarah	BHAS3-1m	BHAS3-3m	BHAS4-4m	BHAS5-4.25m	GS04/709
Sample Location	Project Site	Tweed Shire New WWTP*				
Date	6/12/2004	6/01/2005				20/12/2004
Sample Type	Unimodal, Well Sorted	Unimodal, Very Well Sorted	Unimodal, Very Well Sorted	Bimodal, Very Well Sorted	Bimodal, Very Well Sorted	Bimodal, Well Sorted
Lithology	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand
d10 (µm)	153.2	153.5	153.6	154.4	153.6	152.7
d50 (µm)	217.1	180.3	180.6	183.3	182.1	182.1
d90 (µm)	296.9	211.8	305.9	348.6	335.0	342.9
% Gravel	0	0	0	0	0	0
% V Coarse Sand	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% Coarse Sand	0.4%	0.6%	0.6%	1.6%	0.6%	0.6%
% Medium Sand	31.5%	9.2%	10.0%	14.3%	13.6%	14.8%
% Fine Sand	64.2%	85.9%	85.3%	80.9%	81.5%	78.6%
% V Fine Sand	3.8%	4.3%	4.2%	3.2%	4.3%	6.0%
* Source: GHD						

The grain size analyses indicate that the material is typically very well sorted fine sand with about 80% of the grains in the range 0.15mm to 3.0mm. Based on the mean grain size of 0.18mm, the method presented by Shepard (1989) indicates the hydraulic conductivity of the sand is likely to be about 10m/day.

No insitu permeability testing is known to have been undertaken on the Quaternary sands, however, collection of water samples by CG (1999) indicated that "*the groundwater purging had virtually no effect on groundwater levels with recovery to within 20mm or better of pre-purge levels occurring almost immediately".*

Experience in similar sand deposits on the east coast suggests that the hydraulic conductivity of the fine to medium sand would be in the range of 5m/day to 15m/day. Therefore a value of 10m/day from grain size analysis is considered to be a reasonable value. Assuming an average saturated thickness of 20m, the transmissivity is about 200m^2/day.

10.3.3 Recharge and Groundwater Flow

Recharge to the Quaternary sands occurs by direct rainfall infiltration through the sandy soils and by inflow from the Tertiary basalt aquifer that forms the Cudgen Plateau to the south. Rainfall recharge to the sand aquifer is expected to be relatively high at between 20% and 35% of annual rainfall.

Groundwater levels in bores MB1 to MB5 have been monitored intermittently since May 2002. The hydrographs for these bores are presented in **Figure 8**. The Cumulative Rainfall Departure (CRD) is also plotted. The CRD is the cumulative difference between average monthly and actual observed rainfall and can be used to assess recharge to an aquifer.

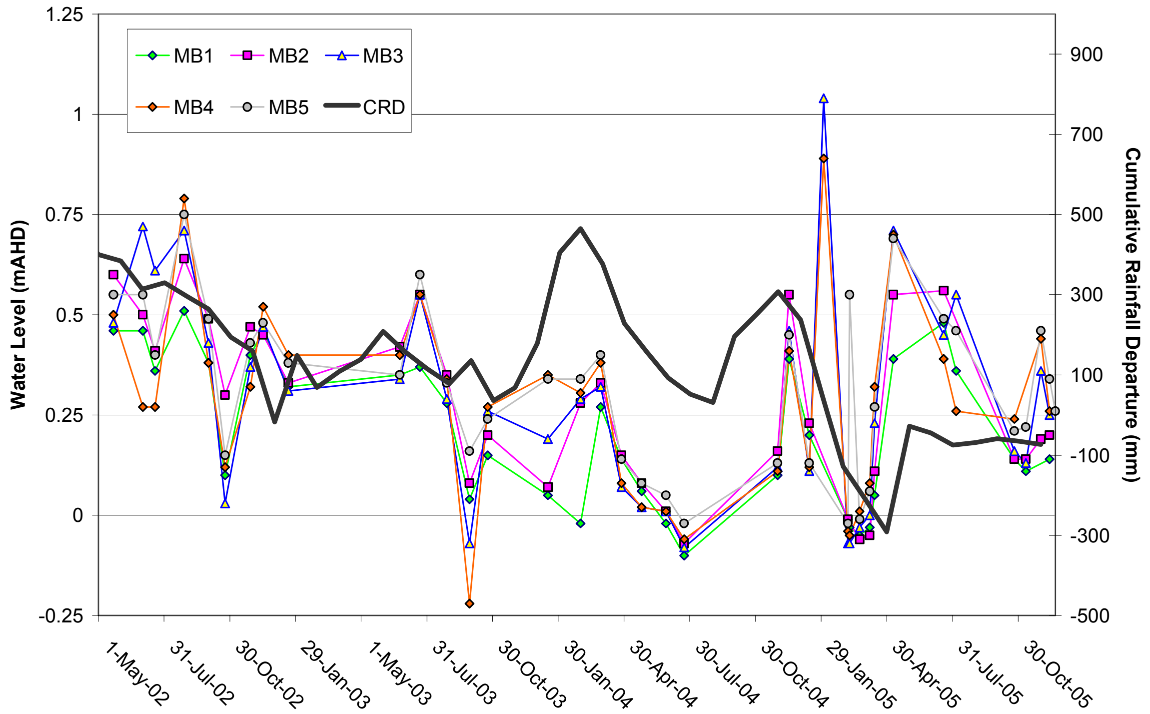


Figure 8 Hydrographs Monitoring Bores MB1 to MB5

The hydrographs for MB1 to 5 indicate that the water table beneath the Project Site has a fluctuation range from -0.25m to 0.75m AHD, with a seasonal fluctuation of about ±0.5m and an average level of about 0.25m AHD.

Water levels at the Project Site show a gradual decline during the winter of 2003, which was an exceptionally dry year to about -0.25m AHD. The fact that water levels in the aquifer fell below 0m AHD suggests that pumping by adjoining sand extraction operation, or evaporation from the drains and the adjacent sand pit lakes may be having some influence on the aquifer.

In January 2006, three pressure sensors were installed within bores within the Project Site to provide a continuous record of groundwater levels. The pressure sensors were installed in monitoring bores MB3, MB6A and MB8A between 7 January and 3 February 2006. The loggers were removed on 3 February and the data examined. The loggers were then reinstalled in MB1, MB3 and MB6A between 20 February and 1 March 2006. The hydrographs along with recorded atmospheric pressure and daily rainfall over the period are presented in **Figure 9**.

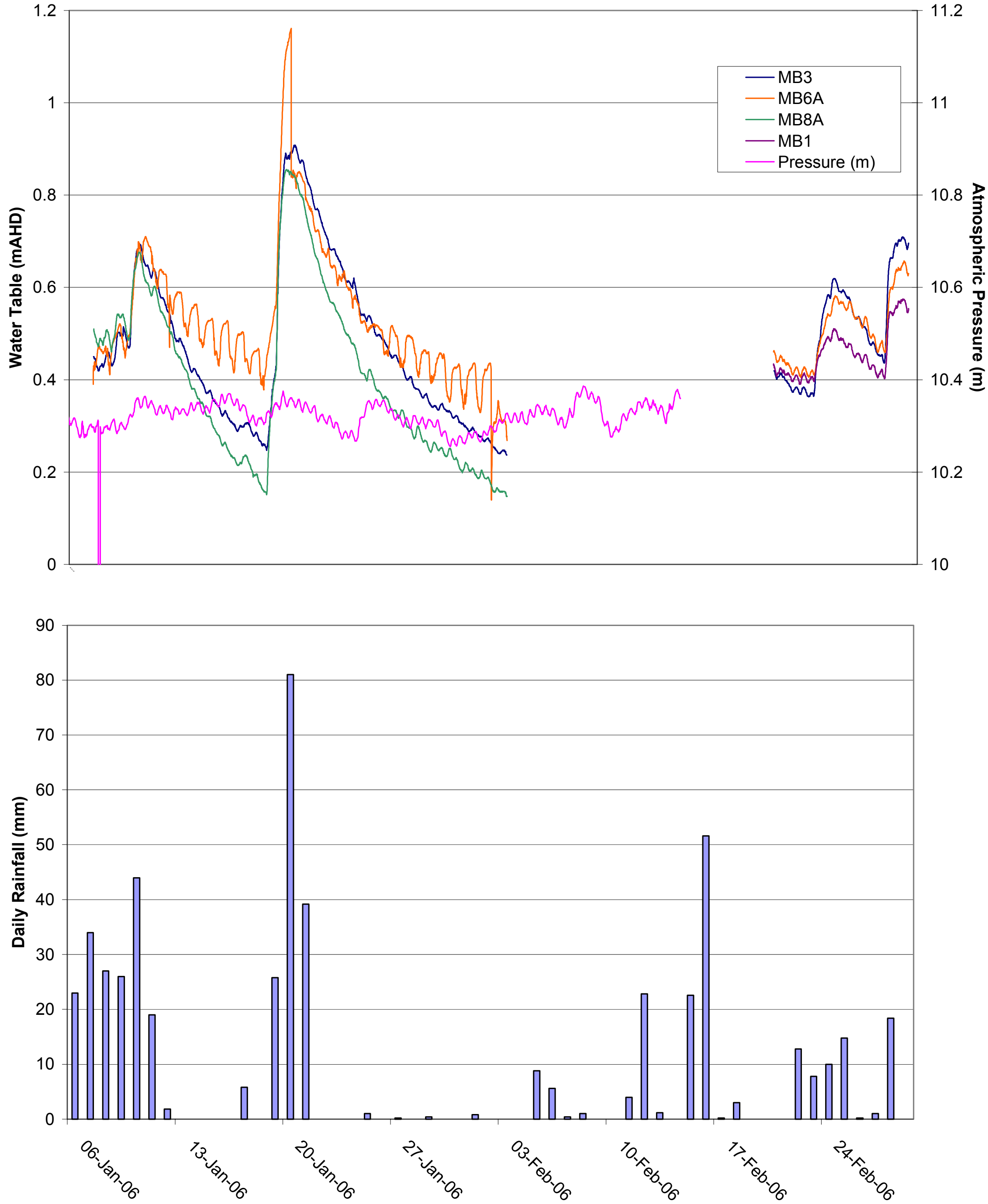


Figure 9 Hydrographs Monitoring Bores MB1, MB3, MB6A, MB8A

Recharge from two rainfall events is clearly evident in the hydrographs that show groundwater levels rising rapidly in response to recharge and then gradually receding over a period of about 8 to 12 days. A very small continuous fluctuation in water levels is also evident in the hydrographs due to atmospheric pressure effects. In addition to the small fluctuations, larger diurnal fluctuations are also evident for monitoring bore MB6A with a daily cycle in groundwater levels of about 0.1m. Monitoring bore MB6A is located on the southern boundary of the Project Site and is estimated to be about 70m from the dam and spear pumps on the property adjoining the southern boundary of the Project Site (R. Julius property) that are used for irrigation. The hydrographs indicate that pumping from the dam and spear on the property are drawing down the water table within the Project Site with the cone of depression extending beyond MB6A.

The water levels indicate a very slight gradient to the north of the Project Site of between 1 in 10,000 to 1 in 20,000. It is likely that there is a slight depression of the water table adjacent to the drains that surround or bisect the Project Site, however, the monitoring network is not sufficient to detect this.

Work by IGC and Associates (1996) at the current waste water treatment plant site, which is about 750m from the coast, (**Figure 1**), found that, in this area, tidal fluctuation did not allow clear hydraulic gradients to be plotted. No tidal fluctuation is evident in monitoring data collected at the Project Site.

Work at the Project Site by CG (1999) concluded that *"no firm conclusion can be drawn in regard to groundwater flow directions, however it is assumed that groundwater is likely to flow from elevated regions south of the site in a northerly/north-easterly direction towards the Tweed River".*

It is concluded that discharge from the sand aquifer occurs through 'windows' in the aquifer created by existing and past sand pits, ornamental lakes and open drains, by discharge to the Tweed River and by evapotranspiration where there is a shallow water table and dense vegetation cover.

10.3.4 Water Quality

<u>Groundwater</u>

Analysis of groundwater samples indicates that water quality in the Quaternary sands aquifer is dependent on depth. Nested monitoring bores installed by WC (1996) and more recently as part of the current Project provide a vertical profile of groundwater quality. Groundwater samples collected from the nested bores CSP1 to 3, MB3 and MB10 which are located within the southern extraction site (**Figure 4**) and CNP1 to 3 to the northwest of the Project Site and MB11 to 13 located within the northern extraction site show that the groundwater is fresh to a depth of at least 15m, but that towards the base of the aquifer at around 20m depth it becomes saline. Nested bores CNP1 to 3 to the northwest of the Project Site indicate brackish water at 10m to 15m depth, suggesting that the groundwater becomes more saline to the north towards the Tweed River. The water quality monitoring data from about 15 monitoring rounds taken from May 2002 to the present are summarised in **Table 5**.

Based on monitoring between 1991 and 1992, WC (1996) concluded that "*Groundwater quality ranges from fresh near Cudgen Ridge to weakly saline in bores CNP1 approximately 1km northwest of Cudgen Ridge…The data suggests that a wedge of fresh water thins northwards from the presumed recharge area of Cudgen Ridge…..the groundwater quality is largely controlled by the degree of mixing between fresh waters from (Cudgen Ridge) and deep, saline waters originally derived from estuarine and marine infiltration.*

IGC and Associates (1996) collected and analysed groundwater samples from the site of the existing waste water treatment plant which is located on the Quaternary sands aquifer about 1.3km northeast of the Project Site (referred to as "Sewage Works" on **Figure 1**). The work was undertaken in Nov/Dec 1995 to assess the impact of effluent irrigation on land to the north of Noble Lake. It was noted that groundwater samples contained very high concentrations of total iron but were not acidic. Analysis of samples collected from monitoring bores MB1 to 5, CSP1 to 3 and CNP1 to 3 also indicated high concentrations of iron and neutral pH.

Monitoring bores MB1 to MB5 which are relatively shallow, at depths of between 5.3m to 5.8m, were installed by CG (1999) using sludge bailing techniques. Groundwater quality has been monitored in these bores intermittently since 2002 by Gilbert and Sutherland Pty Ltd (G&S) and more recently by HMC. Groundwater in these bores is generally fresh, however, bores MB3, MB4 and MB5 which are next to drains which are influenced by tides during dry periods, indicate that the groundwater next to the drains can become slightly brackish as a result. The data is shown on **Table 5**.

All data on **Table 5** is compared to ANZECC 2000 guideline trigger values for aquatic ecosystems for estuaries in southeast Australia. The data indicates that the groundwater, both shallow and deep, is generally more acidic than the trigger value.

In summary, the data indicates that groundwater quality beneath the Project Site is essentially fresh to a depth of 15.2m, that is, to about 5m above the base of the proposed final lake, but that the drainage network which is tidally influenced during dry periods, can locally influence upper groundwater quality.

Table 5
Summary of Baseline Groundwater Quality Data

Location	Bore	Screens (mbns)	pH	EC (μS/cm)	Ca	Mg	Na	K	SO_4	Fe	Al	Mn	Cl	HCO_3
ANZECC Guideline Trigger Values			7.0-8.5	-	-	-	-	-	-	ID	ID	1.2	-	-
South of Altona Drive (Realigned) Lot 2 DP216705	**MB1**	2.6-5.6	6.54-7.32	872-1866	137-193	23-36	23-61	5-6	179-528	0.01-26	0.01-0.1	0.22-0.34	35-154	142-283
	MB2	2.3-5.3	4.62-7.72	115-2394	0.4-1.7	0.33-2.5	12-19	8-17	11-27	2.26-17	0.42-12	0.01-0.05	10-40	6-146
	MB3	2.8-5.8	6.56-7.46	874-3140	14.9-219	33-60	19-43	6-10	175-259	0.24-3.35	0.01-0.11	0.14-0.29	35-53	165-311
	MB10	19.0-21.0	7.09-8.75	29400-43800	205-233	1070-1150	7330-7440	290-290	1740-2490	0.81-1.90	0.09-0.34	0.14	3500-12828	72-302
	MB4	2.6-5.6	6.38-7.37	1056-6930	83-163	38-82	186-449	11-21	46-117	2.52-9.44	0.01-0.34	0.15-0.33	290-650	193-351
	MB5	2.7-5.7	5.77-7.8	171-4850	82-153	36-78	155-285	11-40	185-291	0.06-6.43	0.01-0.09	0.16-0.34	217-328	190-315
	MB6	NR	7.62-7.89	4310-6800	89-121	87-126	879-1080	34-52	234-657	0.65-2.67	0.12-0.23	0.15-0.31	1700-4062	177-199
	MB6A	NR	7.47-8.03	4040	39-63	23-43	369-508	10-18	175-178	0.49-2.74	0.09-3.91	0.04-0.11	625-941	180-187
	MB7	NR	7.61-7.80	15060-15800	-	-	-	-	-	-	-	-	-	-
	MB8	NR	6.40	21070	-	-	-	-	-	-	-	-	-	-
	MB8A	NR	7.27-7.66	5500	52-87	51-87	523-832	23-34	257-340	3.34-6.59	1.2-2.7	0.06-0.08	810-1227	202-223
	MB9	NR	7.51	5820	-	-	-	-	-	-	-	-	-	-
	CSP3	3.4-5.4	6.5-7.8	300-901	50-157	5-17	9-22	5-28	7.44	3-15	0.04-0.26	0.21-0.43	8-67	161-201
	CSP2	7.6-9.6	6.8-7.9	350-757	61-251	4-427	12-2570	1-234	7.7-764	3-17	0.05-0.2	0.52-0.64	13-70	190-250
	CSP1	13.2-15.2	6.9-8.0	320-1179	67-321	6-36	12-105	1-312	32-329	0.9-3	0.06-0.51	0.24-0.61	13-70	190-250
North of Altona Drive (Realigned) Lot 20 & 21 DP 1082482	**CNP3**	2.0-4.0	6.2-7.3	897-1500	75-123	18-108	58-769	5-5	5.2-313	8-17	0.1-0.48	0.16-0.33	105-1230	202-214
	CNP2	8.0-10.0	6.3-7.5	10200-16700	134-251	316-601	2320-3410	9-51	537-888	3-25	0.07-0.6	0.24-0.52	4200-5850	353-415
	CNP1	13.0-15.0	6.6-7.6	12500-22300	188-344	427-1060	3110-4380	12-85	1050-1560	3-25	0.15-0.8	0.18-0.39	5100-7500	563-670
	MB11	2.5-3.5	6.81-7.54	1492-1625	211-289	65-72	127-220	11.19	456-484	3.57-11	0.64-3.13	0.20-0.33	300-311	23-302
	MB12	6.7-9.7	6.84-7.46	1587-1619	322-433	54-59	43-66	12-13	528-706	1.61-2.98	0.12-0.74	0.28-0.35	87-147	24-223
	MB13	17.6-20.6	6.36-7.18	32200-36800	559-1170	1050-2040	6870-6940	215-217	2260-4000	1.8-19	0.17-0.75	0.81-0.83	247-15198	33-304

Notes:
- i) mbns = metres below natural surface
- ii) ID = insufficient data to derive reliable trigger value
- iii) ANZECC guidelines are trigger values for aquatic ecosystems for estuaries in south-east Australia
- iv) NR – not recorded

The percentage composition of the major ions for MB1 to MB5 are presented as a Piper Diagram in **Figure 10** for a round of samples collected on 13 January 2005.

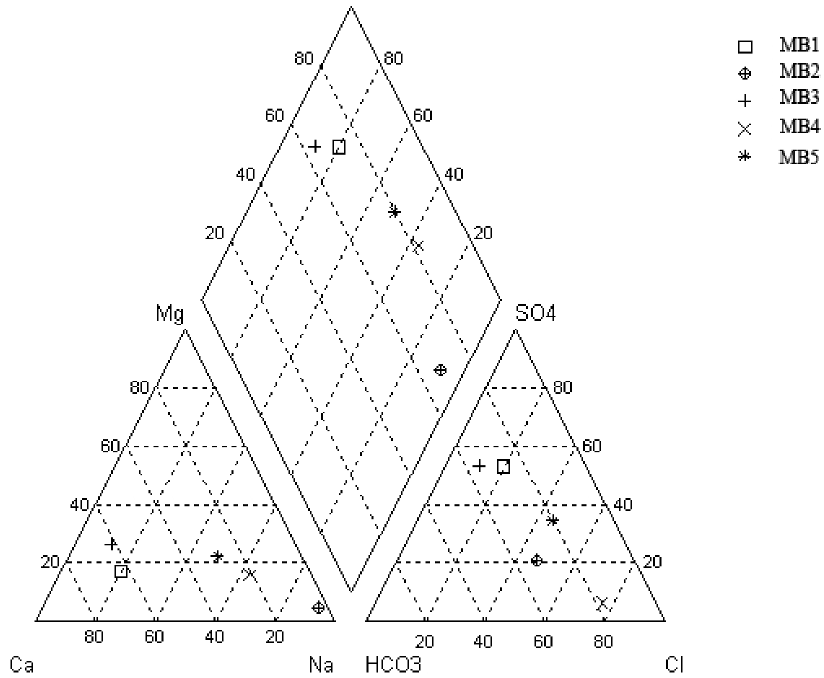


Figure 10 Piper Diagram - 13 Jan 2005 - Monitoring Bores MB1 - MB5

The diamond part of the Piper diagram can be used to characterise different water types. Two different water types are evident. Water samples collected from MB1 and MB3 are high in Ca, Mg, Cl, SO_4 and are relatively hard water. The water samples collected from MB2 and MB4, have a more saline water composition with dominance of Na, K, Cl and SO_4 whereas the sample from MB5 appears to in between the hard and saline water types.

It should also be noted that there is a poor charge balance between the major cations and anions of between 6% and 13% for the samples, which may indicate a poor analysis. However, Hounslow (1995) indicates that a poor balance can occur when organic ions are present in significant quantities which is often indicated by coloured water. The presence of tannin stained water was noted by CG (1999)[3] and may explain the poor charge balance.

A range of groundwater samples were collected by HMC Environmental Consulting during the bore census and submitted to Tweed Laboratory Centre for analysis. In addition, a round of samples was collected from monitoring bores GW1 to GW6. Of interest in the dataset are the relatively high concentrations of iron in bores to the northeast of the Project Site that reported increased iron concentrations during the construction of Nobel Lake. The concentrations of iron reported in registered bores GW300834, 300845, 300856 and the unregistered bores on the Phillips and Rudman properties (see **Figure 4**) were relatively high being between 8.4mg/L and 17mg/L. In comparison, iron concentrations in samples collected from the R. Julius and Kettle properties that adjoin the Project Site to the south, reported concentrations of iron typically less than 1mg/L. The source of the high iron concentrations in selected bores to the northwest is uncertain but the presence of iron together with dissolved aluminium in these water samples suggests some interaction with acid sulfate soils and sediments. The concentrations of iron make the water unsuitable for drinking and problematic for irrigation.

<u>Window Lakes and Drains</u>

Excavations below the water table in the Quaternary sand aquifer have created several 'window lakes' in the vicinity of the proposed extraction site. These include the Hanson Tweed Sand extraction operation to the west of the Project Site, Noble Lake about 1km to the northwest and the lake created by the Action Sands' sand quarry about 1.4km to the north (**Figure 1**).

Recent analysis of samples from the small excavation (start-up dredge pond) created within the Project Site for the approved sand extraction operation indicates that the water in the pit is relatively fresh (EC-721-819µS/cm) and neutral to slightly alkaline (pH 6.67 to 9.01). That is, it is similar in quality to that recorded in the monitoring bore cluster CSP1 to 3.

Vertical profile monitoring has been undertaken of the adjoining operating sand extraction pond as part of their licence requirements. Gilbert and Sutherland Pty Ltd (2005), report that profile monitoring of EC undertaken between April and October 2003 at depths of between 6m and 13m indicated that the EC varied between about 1500µS/cm and 3000µS/cm. They also state that "v*ertical profile monitoring was also undertaken in situ at one metre intervals for pH, EC, DO, REDOX potential and temperature within the expansion area on a quarterly basis to assess the degree of stratification occurring within the on-site lakes.*

The variation in pH, EC, DO and ORP of groundwater at various depths within the extraction pit was negligible, and no consistent trend with depth was identified for any of the monitored parameters. Dredging activities in the lake are likely to circulate waters thus eliminating any depth zonation or stratification that may occur……..Furthermore, there was no variation in EC with depth in the Phase 2 expansion area detected during the quarterly vertical profile monitoring program.

Analysis of surface water samples collected from the drains in the area of the Project Site between 2003-2004, indicate that water in these drains is fresh (EC 100-450µS/cm) with a slightly acid to neutral pH.

10.3.5 Licensed Bores – Groundwater Use

There are about 30 registered bores recorded on the Department of Water and Environment (DWE) (formerly Department of Natural Resources) groundwater database within the Quaternary sand aquifer within a 4km radius of the site as summarised on **Table 6** and shown on **Figures 4** and **5**. The bores have been constructed for various uses; monitoring, domestic, stock, irrigation. Three water bores are located to the west of the Project Site, namely bores GW300852, 300853 and 300003. Bores GW300852 and GW300853 are relatively shallow at 6m deep and the records do not contain information on strata encountered. Bore GW300003 was drilled to a depth of 122m and reports that quartzite was intersected over the entire depth. The location of bore GW300003 is shown on the floodplain, however, given the lithological log, it is considered unlikely that the recorded position of this bore is correct, and it is more likely to be located to the south where the Neranleigh-Fernvale Beds outcrop.

Twenty of the bores on the DWE groundwater database are to the east of the Project Site. Drillers' logs are not available for any of these bores and therefore an assessment of the thickness of the Quaternary sands in this area is not possible.

Water bores installed in the Quaternary sand aquifer appear to have relatively low yields, typically less than 1L/s (refer **Table 6**). The low yields are probably due to most of the bores being relatively shallow, installed at depths of less than 6m, and therefore not tapping the full thickness of the aquifer. The depth of most of the bores in the area has probably been restricted to the upper section of the sand aquifer due to the presence of saline groundwater at depth and due to the fact that 1L/s is sufficient for irrigation of gardens, and therefore they do not need to go deeper.

Five unregistered spears in the sand aquifer were also identified during the bore census. The location of these spears is shown on **Figure 4**.

Table 6
Water Bores – Quaternary Sands

Bore Number	Date	Lot and DP	Land Owner	Purposes	Construct. Method	Final Depth (m)	SWL (mbns)	Salinity (mg/L)	Yield (L/s)
GW047078	1978	L2 DP568845	N/A	Domestic Irrigation Stock	Excavation	2.5	-	-	-
GW062045	-	L1 DP547984	-	Irrigation	Rotary	54	-	-	-
GW069130	1991	L2 DP777905	Hanson	Sand & Gravel Irrigation	Excavation	0	-	-	-
GW300003	1993	L1 DP 780237	Christiansen	Farming Irrigation	Rotary	122	17.1	-	0.63
GW300752	1995	L32 DP847319	Tweed Council	Monitoring Bore	RC	2	1.4	300	0.1
GW300753	1995	L32 DP847319	Tweed Council	Monitoring Bore	Open Hole	2	1.5	370	0.1
GW300754	1995	L32 DP847319	Tweed Council	Monitoring Bore	Open Hole - Water	6	1.5	280	0.1
GW300756	1995	L32 DP847319	Tweed Council	Monitoring Bore	Rotary	2	1.5	-	0.1
GW300759	1995	L32 DP847319	Tweed Council	Monitoring Bore	RC	6	1.5	-	0.1
GW300760	1995	L32 DP847319	Tweed Council	Monitoring Bore	RC	2.5	2.5	-	
GW300762	1995	L32 DP847319	Tweed Council	Monitoring Bore	RC	2	1.4	180	0.1
GW300764	1995	L32 DP847319	Tweed Council	Monitoring Bore	(Unknown)	6	1.4	108	0.1
GW300834	1980	C DP33290	Rudman	Domestic Stock	-	6	-	-	0.57
GW300835	1980	L1 DP781709	Rudman	Domestic Stock	-	6	-	-	0.57
GW300845	1968	L1 DP105009	Hermann	Domestic	-	-	-	-	-
GW300846	1979	L7 DP249122	Harrison	Domestic	-	6	-	-	-
GW300847	-	L33 DP755701	Cooper	Domestic	-	-	-	-	-
GW300848	1962	L1 DP348858	Mye	Domestic	-	-	-	-	-
GW300852	1996	L57 DP755701	Brinsmead	Stock	Hand Dug	6	1	-	1
GW300853	1990	L3 DP755701	Brinsmead	Domestic Stock	-	6	1.5	-	1
GW300856	-	L1 DP611021	Martins	Domestic	-	-	-	-	-
GW300857	-	L109 DP755701	Mackay	Domestic	-	-	-	-	-

Table 6
Water Bores – Quaternary Sands (Cont'd)

Bore Number	Date	Lot on DP	Land Owner	Purposes	Construct. Method	Final Depth (m)	SWL (mbns)	Salinity (mg/L)	Yield (L/s)
GW300858		L109 DP755701	Mackay	Domestic	-	-	-	-	-
GW302457	1996	L1 DP771798	Brinsmead	Domestic	Hand Dug	6	2	-	2
GW304283	2003	L2 DP216705	Kareena Dev	Industrial - Sand & Gravel	-	-	-	-	-
GW304965	2004	L93 DP867769	Varela	Domestic	Hollow Flight Auger	6	3.5	200	0.5
GW304979	2004	L13 DP246190	Wilson	Domestic	Hollow Flight Auger	6	2	200	0.5
GW305057	2005	L9 DP830659	Action Sands Pty Ltd	Industrial – Sand & Gravel	-	-	-	-	-
GW305128	2000	L2 DP777905	Hanson	Monitoring Bore	-	12	-	-	-
GW305151	2004	L2 DP611021	Tweed Council	Monitoring Bore	Rotary	6	0.9	-	-
Phillips 1	2005	L1 DP227034	Phillips	Domestic	-	5.5	~1-1.5	-	0.8
Phillips 2	2001	L1 DP227034	Phillips	Monitoring	-	5.1	1.08	-	-
Rudman	1958	L1 DP397479	Rudmann	Domestic	-	4.1	-	-	-
Julius East	-	L1 DP598073	R. Julius	Irrigation	-	-	-	-	-
Julius West	-	L1 DP598073	R. Julius	Irrigation	-	-	-	-	-

Note: - mbns = metres below natural surface * See Figure 3

In summary, a review of information from the DWE database indicates that groundwater use from the Quaternary sands aquifer in the vicinity of the Project Site is relatively limited. The primary user in proximity to the Project Site appears to be the adjacent property (R. Julius) to the south that uses dams which form windows into the Quaternary sand aquifer and spears for irrigating crops on the adjacent Cudgen Plateau in dry periods.

10.4 Tertiary Basalt Aquifer

10.4.1 Extent and Thickness

The Tertiary basalt aquifer covers an area of about 8.4km^2, the extent of which is defined by the Cudgen Plateau (**Figure 6**). The Tertiary basalt is essentially broken into two surface water catchments with the catchment divide corresponding approximately to Cudgen Road, that runs along the ridge of the plateau. To the north of Cudgen Road, surface flows are to the north and to the Tweed River, whereas to the south of Cudgen Road, flows are to the east into Cudgen Creek. The groundwater divide and groundwater levels generally form a subdued reflection of the topography.

A review of the strata logs on the DWE database was undertaken to assess the thickness of the Tertiary basalt aquifer. Most bores drilled in the area intersected basalt inter-bedded with layers of clay. The thickness of the basalt is highly variable and dependent on the ground elevation and depth of the underlying Neranleigh-Fernvale Group.

Only two bores are present to the north of Cudgen Road, that is, north of the groundwater divide beneath Cudgen Plateau. The closest bore to the Project Site, that intersects the basalt aquifer located about 300m to the south, is GW62045 (**Figure 4**). Drilling of this bore intersected weathered basalt to a depth of 18m, followed by 3m of grey clay, which was inturn underlain by black, water-bearing basalt from 21m to 54m (-24m AHD based on an assumed elevation of the bore of 30m AHD from the topographic map).

10.4.2 Hydraulic Conductivity

No information on hydraulic conductivity of the Tertiary basalt is available, however, experience in other areas suggests that the hydraulic conductivity is highly variable and depends on whether the basalt is massive, fractured or vesicular.

10.4.3 Recharge and Groundwater Flow

Recharge to the Tertiary basalt aquifer occurs by direct infiltration through the well drained krasnozem soils that cover the Cudgen Plateau and which have a relatively high permeability. Water level records for bores in the Tertiary basalt aquifer are limited. Measurements in selected bores on the DWE database indicate water levels between 2m and 13m below ground level. The available data indicates that water levels in the Tertiary basalt are significantly above those in the Quaternary sand aquifer, indicating a flow gradient towards the floodplain. However, the available water level information is insufficient to define groundwater flow directions accurately. A conceptual model of groundwater flow in the Quaternary sand and Tertiary basalt aquifer is shown in **Figure 7**.

Discharge from the Tertiary basalt occurs to the surrounding Quaternary sands. Some discharge from the Tertiary basalt aquifer may also occur through extraction from bores, although the extent of groundwater use on the Cudgen Plateau is uncertain.

10.4.4 Water Quality

No information is available on the water quality in the Tertiary basalt. However, in areas of high rainfall, basalt aquifers typically contain good quality water. Also as discussed in the next section, groundwater from the basalt is used for irrigation of crops and for domestic purposes, suggesting it is of high quality.

10.4.5 Registered Bores – Bore Census and Groundwater Use

Twenty-five DIPNR registered bores are located in the basalt aquifer within a 4km radius of the Project Site, as shown on **Figure 5**. Seventeen bores have no information on yields, however, those that did show that yields from the bores in the Tertiary basalt are low to moderate and vary between <1L/s to about 5.5L/s.

A summary of bores listed in the database is given on **Table 7**, however, past experience suggests that there may be more bores in the area that are not registered with DWE.

Table 7
Water Bores – Tertiary Basalts

Bore Number	Date	Lot and DP	Land Owner	Purposes	Construct. Method	Final Depth (m)	SWL (mbns)	Salinity (mg/L)	Yield (L/Sec)
GW011912	-	-	N/A	Irrigation	Unknown	22.9	12.2	-	-
GW019686	-	-	N/A	Domestic Irrigation Stock	(Unknown)	6.1	-	-	-
GW019742	1958	-	N/A	Domestic Irrigation Stock	-	6.70	-	-	-
GW029865	-	-	N/A	Irrigation	-	2.40	-	-	-
GW044188	1945	-	Prichard	Domestic	-	12.1	6	-	-
GW047692	1980	-	-	-	Rotary	0	-	-	-
GW048858	1973	-	N/A	Domestic	-	4.1	-	-	-
GW056332	1981	-	N/A	Domestic Stock	Cable Tool	8.3	1	-	-
GW058755	1983	L3 - DP624162	N/A	Domestic	Rotary Air	9	5	-	-
GW058762	1982	L2 - DP217136	N/A	Domestic Stock	Unknown	6	-	-	-
GW060156	1985	L8 - DP705729	N/A	Domestic Irrigation Stock	Rotary Air	35	-	-	-
GW060536	1984	-	N/A	Domestic	Rotary Air	95	-	-	-
GW062045	-	L1 - DP547984	N/A	Irrigation	Rotary Air	54	-	-	-
GW064807	1988	L21 - DP534808	Paddon	Irrigation	Rotary	36	-	-	0.9
GW065030	1989	L101 - DP866795	Diocese Grafton "	Domestic	Rotary Air	30	12	-	3.4
GW067163	1991	L19 - DP870041	N/A	Domestic	Rotary Air	24	-	-	1.2
GW067164	1991	L6 - DP579245	N/A	Domestic	Rotary Air	36	-	-	0.88
GW067176	1991	L1 - DP596253	N/A	Domestic Stock	Rotary Air	90	-	-	-
GW068356	1989	L21 - DP534808	N/A	Domestic	Rotary	48	7.5	-	5.68
GW069108	1991	L2 - DP612182	N/A	Farming	Rotary Air	54	-	-	0.5
GW300046	1994	L6 - DP579245	Johansen	Industrial	Rotary	49	13	-	0.35
GW300707	-	L37A - DP13727	Narui	Irrigation	Dozer	-	-	-	-
GW300709		L37A - DP13727	Narui	Irrigation	Dozer	-	-	-	-
GW301284	1994	LTB - DP418423	N/A	Domestic Stock	Rotary Air	22	6	-	1.26
GW301878	1985	L6 - DP700465	N/A	Domestic	-	3	2	-	-

Note: - mbns = metres below natural surface

11 DEVELOPMENT OF NUMERICAL MODEL

11.1 Modelling Objective

The objective of modelling was to assess the impact of the proposed sand extraction operation on the regional and local groundwater regime. To achieve this objective, a numerical groundwater flow model was constructed and predictive modelling undertaken to assess the effect of the proposed sand extraction operation on the groundwater levels.

11.2 Application of Numerical Models

The application of computer-based numerical models to problem solving in groundwater engineering provides a powerful tool for the prediction of flow, and contaminant transport, in a complex, spatially and temporarily varying environment. The modelling process is a technique for simulating flow in the aquifer using a system of mathematical equations based on Darcy's Law for flow of water through porous media. The process requires definition of the aquifer in respect of some or all of the following, namely:

- aquifer geometry, including lateral and vertical extent;
- aquifer hydraulic properties; hydraulic conductivity (or transmissivity), porosity, specific yield, leakage etc; and
- groundwater level distribution, groundwater fluxes, recharge and discharge processes.

The use of a numerical model can overcome the difficulties inherent in the assessment of hydrogeological systems using classical analytical methods. These mostly assume aquifer homogeneity and are more applicable to the interpretation of localised aquifer response.

Modelling enables the simulation of complex conditions by introducing variations in aquifer hydraulic parameters and/or hydraulic loads. This is accomplished by discretizing the modelled area into a number of blocks each representing a volume of aquifer with constant hydraulic parameters. The accuracy of model predictions depends on the knowledge of all parameters having an impact on the groundwater regime, both in the area of interest as well as in more distant areas.

The development of a model also facilitates sensitivity analysis which provides a means of understanding the dominant parameters and mechanisms operating within a hydrogeological system.

11.3 Model Code

The Cudgen Lake Sand Extraction Model ("the model") was developed using the MODFLOW code (Harbaugh and McDonald, 1988). MODFLOW is a modular, three-dimensional, finite difference groundwater flow model developed by the United States Geological Survey. The MODFLOW numerical code is currently the most widely used code for groundwater flow modelling, is presently considered as industry standard and is legally defensible. The model was created with the use of the PMWIN v7.0.31 interface. PMWIN is a pre- and post-processing interface which allows the graphical input of data and output of results.

11.4 Model Design

11.4.1 Model Geometry

The area simulated at Cudgen, that is, the model domain was discretized into a single layer of cells arranged in 306 rows and 323 columns encompassing the Cudgen alluvial plain and the Cudgen Plateau. The model area was discretized so that the Project Site was covered with a grid cell size of 10m X 10m.

The grid cell size was expanded outside this area to 25m x 25m over the western area of the Cudgen alluvial plain and 25m x 50m over the eastern alluvial plain and Cudgen Plateau.

The location of the model grid origin, that is the upper left corner, is at an easting of 549529m and northing of 6870328m. The model grid was rotated by 81^{o} in the anticlockwise direction to align the cells parallel to the typical direction of the agricultural drains on the alluvial plain. The layout of the model grid is shown on **Figure 11**.

The single layer model was used to simulate the Quaternary alluvium and the Tertiary basalt aquifers. The base of the model was also set at -19m AHD and was based on a review of boreholes drilled within and around the model domain. The presence of marine clays intersected at around -19m AHD in several boreholes in the alluvial plain would be expected to have a hydraulic conductivity at least 2 orders of magnitude lower than the overlying sands and therefore in the context of numerical modelling can be considered effectively impermeable and a suitable base for the model.

Available information on the thickness of the Tertiary basalt was limited to drillers' logs for boreholes drilled in the Cudgen Plateau. Many of the drillers' logs provide only a very limited description of the strata being drilled and the quality and density of drilling data was not sufficient to confidently map the base of the Tertiary basalt aquifer. The closest bore to the Project Site (GW062045) recorded basalt and clay to a depth of 54m below ground surface, which is approximately -24m AHD. Bores further south on the Cudgen Plateau recorded the base of the Tertiary basalt aquifer as being between about -16m AHD (GW67164) and +5m AHD (GW60156). Given the limited data, the base of Tertiary basalt aquifer was therefore set at -19m AHD.

11.4.2 Boundary Conditions

In order to undertake numerical modelling, it is necessary to determine and then specify appropriate boundary conditions. The northern section of the model domain encompasses the majority of the Tweed River alluvial sand mass with the southern area covering the Cudgen Plateau Tertiary basalt. The alluvial sand mass is bounded by the Tweed River to the north and west and the Pacific Ocean to the east (**Figure 1**), each of which were specified as "constant head" boundaries in the model with a water level of 0m AHD. A "constant head" boundary is a fixed boundary condition in which the hydraulic head is unvarying. The use of "constant head" boundaries is justifiable by the fact that the these water bodies can be regarded as essentially infinite water bodies capable of absorbing, or supplying, any volume of water as necessary.

The southern boundary of the model was set at the southern boundary of the Cudgen Plateau at the contact with the alluvial sediments where ground levels are typically around 1m AHD. The southern boundary of the model was also set as constant head cells with a water level of 0m AHD.

The base of the model is defined as a "no-flow" boundary which does not permit exchange of water across the model boundaries. The location of the model boundaries is presented on **Figures 11** and **12**.

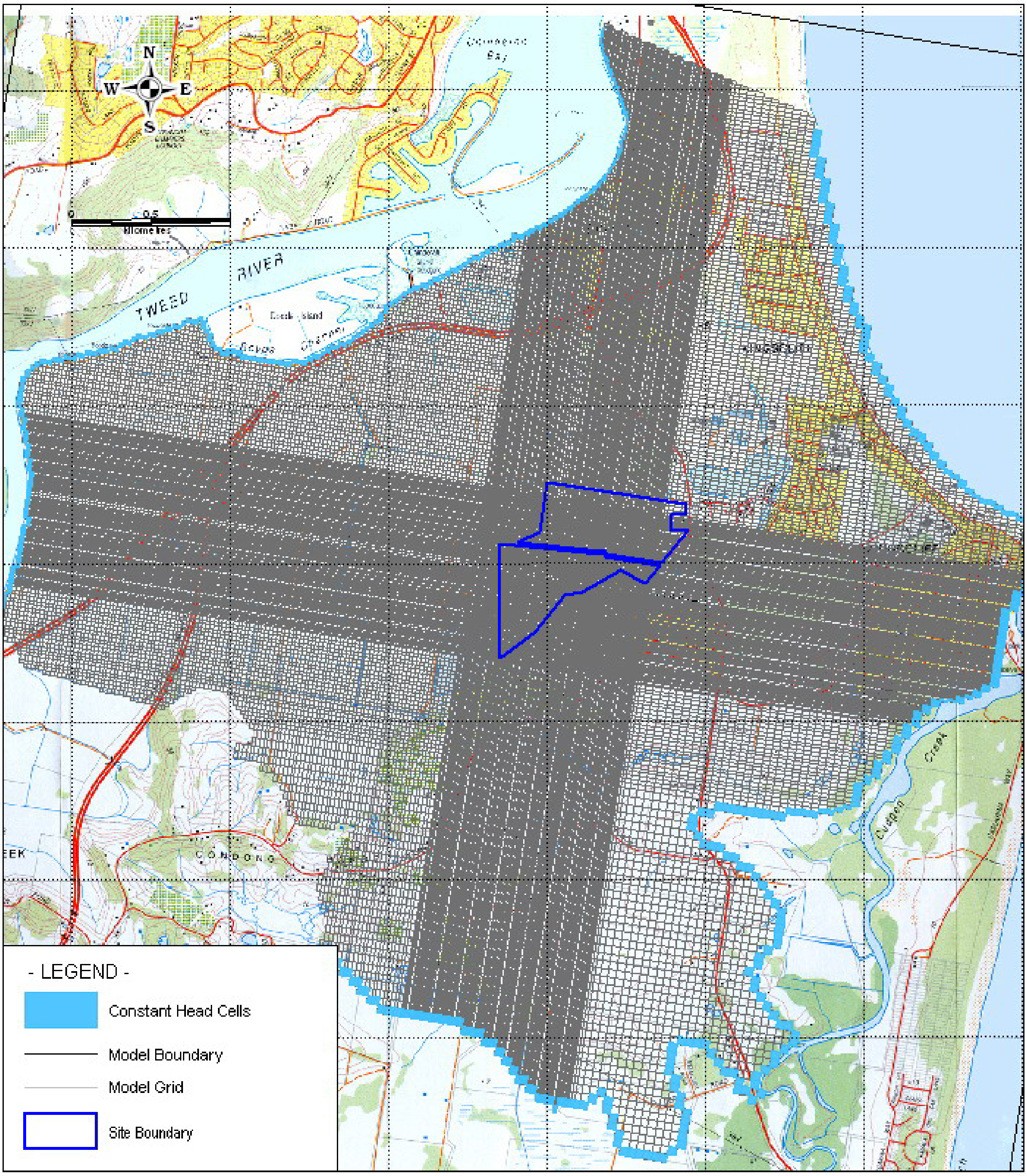


Figure 11 Model Grid

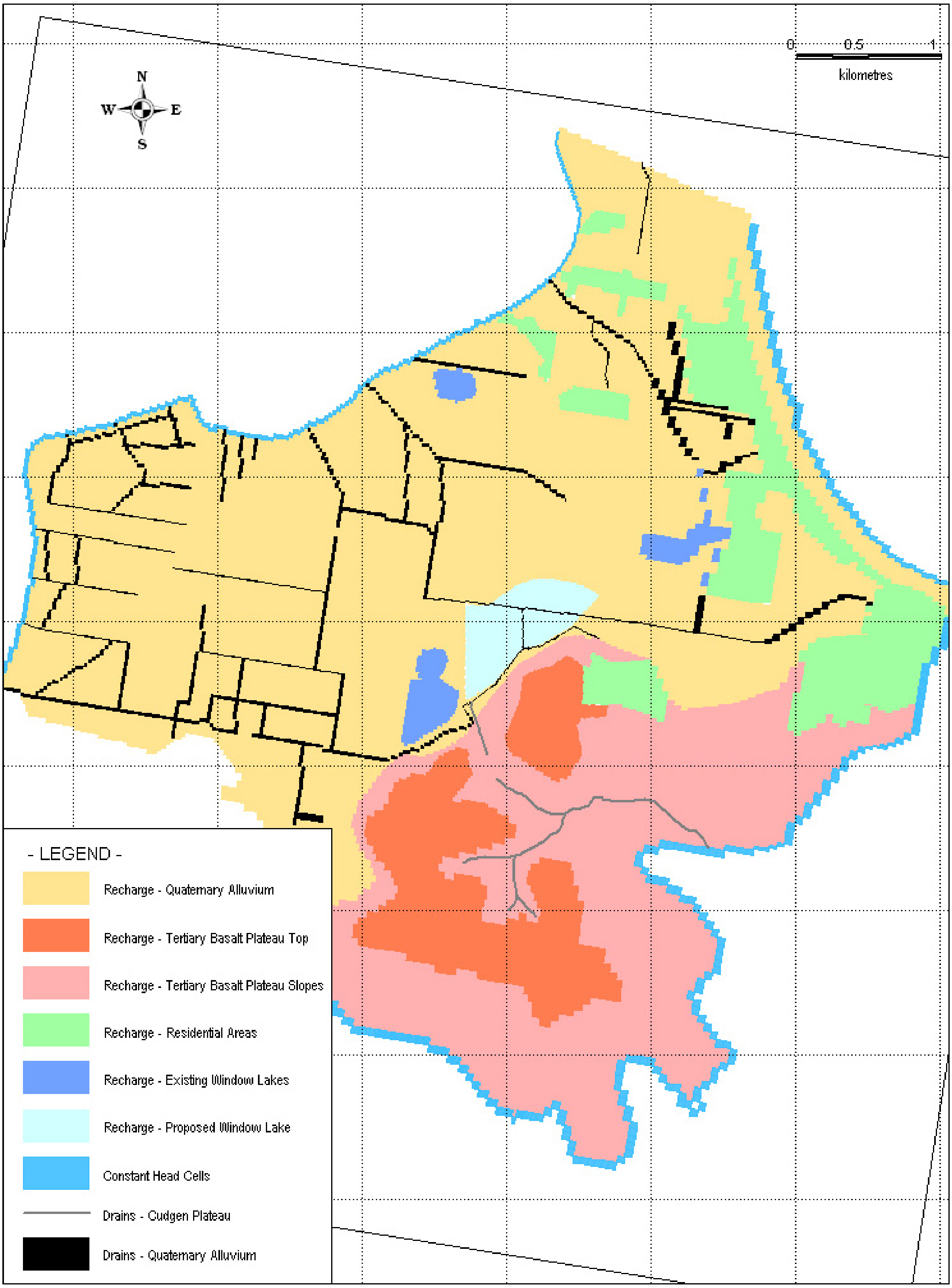


Figure 12 Recharge Zones and Drains

11.4.3 Initial Conditions

In order to promote numerical stability, the steady-state simulation commenced with a starting piezometric level of 50m AHD. As discussed above, the constant head boundaries were each assigned a value of 0m AHD, which did not change throughout the modelling. The simulated head distribution developed from the steady state model was then used as the initial condition for transient modelling.

11.4.4 Hydraulic Parameters

The sand aquifer was assumed to have a uniform hydraulic conductivity throughout the whole of the extent of the sand mass. The hydraulic conductivity of the sand aquifer was adjusted during the calibration process. Initially, prior to calibration, it was set at 5m/day, and was changed during model calibration to 10m/day. The specific yield for the sand aquifer was set at 0.1 (10%).

The hydraulic conductivity of the Tertiary basalt was adjusted between 0.01 and 1m/day and set at 0.075m/day. The specific yield for the basalt aquifer was set at 0.03 (3%).

Three window lakes are present in the sand mass viz:

- Hanson Tweed Sand extraction operation adjacent to the western boundary of the Project Site;
- Nobel Lake about 1km to the northeast; and
- Action Sands lake approximately 1.4km to the north.

The window lakes were represented by adopting a very high hydraulic conductivity (1500m/day) and an effective porosity and specific yield of 1 (100%).

It is recognised that there are a number of other small window lakes in the area in the form of small dams (eg. immediately south of the Project Site). Due to their small size, they have not been included within the model. Extraction from these areas was simulated using wells (refer Section 11.4.7).

11.4.5 Recharge

Recharge to the aquifer was based on average rainfall records recorded at the Condong Sugar Mill and Murwillumbah Stations. As average rainfall recorded at the Condong Sugar Mill between 1887 and 1972 was 16% higher than that recorded at the Murwillumbah Station between 1972 and 2004 the weighted average was calculated for use in modelling. The weighted monthly averages are shown in **Table 8**. The open water body evaporation was calculated from pan evaporation data using a pan factor, and was used to represent water loss from the surface of the window lakes. The estimated average open water body evaporation for each month is shown in **Table 8**.

Table 8
Rainfall and Evaporation Averages[1] (mm)

	Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTALS
Rainfall Condong Stn 058013	1887-1972	220	250	264	148	139	123	94	73	66	88	106	151	1720
Rainfall Murwullimbah Stn 058158	1972-2004	190	235	224	170	150	88	71	50	39	85	124	159	1585
Weighted average rainfall	1887-2004	212	246	253	154	142	113	87	67	59	87	111	153	1683
Evaporation Alstonville 058131	1963-2004	180	141	133	105	84	75	84	109	138	158	165	189	1560
Pan Factor	-	0.97	0.92	0.96	0.81	0.73	0.66	0.66	0.86	0.73	0.82	0.94	0.96	-
Open Water Body Evaporation	-	174	130	128	85	61	50	55	93	101	130	155	182	1344
Rainfall minus Evap	-	37	116	125	69	81	64	32	-26	-42	-43	-44	-29	339

[1]Source: Bureau of Meteorology http://www.bom.gov.au/climate/averages/tables/ca_nsw_names.shtml

Five different recharge zones were used in the model. Different zones were defined where recharge rates were considered to be relatively uniform. Relatively low recharge rates were specified for the residential areas due to the predominance of sealed surfaces, and on the slopes of the Cudgen Plateau where much of the rainfall is expected to be shed as runoff. The highest recharge rate was specified for the alluvial plain which is very flat and has little surface drainage.

The recharge zones and rates are summarised in **Table 9** and shown in **Figure12**.

Table 9
Summary of Recharge Zones

Recharge Area	Description	Recharge as a % of Average Rainfall	Recharge Rate (mm/year)
1	Alluvial plain – agricultural/cleared land	25%	+420
2	Cudgen Plateau – slopes	5%	+84
3	Cudgen Plateau – top	10%	+168
4	Residential areas	8.5%	+143
5	Window Lakes	Rainfall minus lake evaporation	+339

11.4.6 Drains

Drainage cells were incorporated into the model to simulate groundwater discharge to the network of agricultural drains in the alluvial areas. The elevation of the base of the drain cells in the alluvium was set at 0m AHD. The conductance of the base of the drain cells was modified during calibration.

Drainage cells were also used in the Cudgen Plateau to simulate groundwater discharge to the steeply incised gullies that run through the Plateau in a general east-west direction. The elevation of the drainage cells were interpolated from the topographic maps of the area. The location of simulated drain cells is also presented on **Figure 12**.

11.4.7 Extraction by Spearpoints, Wells, Bores

Extraction from spears located on the R. Julius property immediately south of the Project Site was simulated using the well package. A continuous extraction of 1.3L/s was simulated from each of the unregistered spears. This is an average assumed extraction rate as the actual pumped volumes at the time of modelling were unknown and could not be supplied by the landowner. All extraction was assumed to occur from the wells and no extraction from the dams was simulated.

11.5 Calibration

Calibration of a numerical flow model refers to a demonstration that the model is capable of producing field (actual) measured heads and flows. Calibration is accomplished by finding a set of parameters, boundary conditions and stresses that produce simulated heads and flows similar to those measured in the field, within an acceptable error range.

11.5.1 Steady State Calibration

Steady state modelling requires that flow conditions do not change over time. Therefore steady state calibration requires that a representative ‘average’ or steady state water level for each monitoring point be determined from water level records. Groundwater monitoring in the alluvial sand mass commenced only relatively recently in 2002 and therefore only a relatively short period of water level records is available for assessment of steady state groundwater levels.

Average water levels were assessed from the available data and used in the steady state calibration. For some bores, the number of water level observations was relatively limited and therefore simulated water levels in these areas are subject to some inaccuracy. In addition, no groundwater level monitoring data was available for the Cudgen Plateau and therefore a rigorous calibration of the model in this area was not possible.

The objective of the steady state modelling was to reproduce ‘average’ annual water levels in the area of the proposed sand extraction. During the steady state modelling rainfall recharge and hydraulic conductivity were adjusted until a close match between observed and simulated groundwater levels was achieved. The calibrated parameters for hydraulic conductivity, porosity and recharge are presented in **Table 10**.

Table 10
Summary of Steady State Calibration Parameters

Aquifer	Area	Hydraulic Conductivity (m/day)	Porosity	Recharge Rate	
				% of rainfall	mm/year
Quaternary sand mass	Agricultural lands	10	0.25	25	+421
	Urban areas	10	0.25	8.5	+141
	Window Lakes	1500	1	100[1]	+363
Tertiary Basalts	Cudgen Plateau – slopes	0.075	0.03	5	+84
	Cudgen Plateau – top	0.075	0.03	10	+168
	Urban areas	0.075	0.03	8.5	+141

1 –average rainfall less open water body evaporation (refer Section 5.4)

The observed and simulated steady state water levels are presented in **Table 11** and shown graphically in **Figure 13**.

Table 11
Predicted vs Observed Water Levels

Monitoring Bore ID	Observed Water Level (m AHD)	Simulated Water Level (m AHD)	Difference (m)
GW2	0.20	0.17	0.03
MB1	0.21	0.19	0.02
MB2	0.28	0.32	-0.04
MB4	0.28	0.08	0.2
GHD4	0.29	0.41	-0.12
MB5	0.32	0.06	0.26
GHD3	0.36	0.77	-0.41
SP3N	0.39	0.51	-0.12
GHD6	0.41	0.15	0.26
SP2N	0.43	0.54	-0.11
SP1N	0.50	0.60	-0.10
SP1S	0.57	0.30	0.27
GHD2	0.59	0.39	0.20
GHD5	0.73	0.33	0.40
GHD1	0.79	0.84	-0.05
		Variance	0.046

The calibration criteria commonly adopted for groundwater water modelling (Spitz and Moreno 1996) specifies the variance between predicted and observed data should be less than about 10% of the range of observations. The variance between the observed and predicted steady state values was 0.046m (4.6cm) which is 7.8% of the observed range of observations of 0.59m. Therefore, the steady state calibration in the alluvial area is considered to be acceptable.

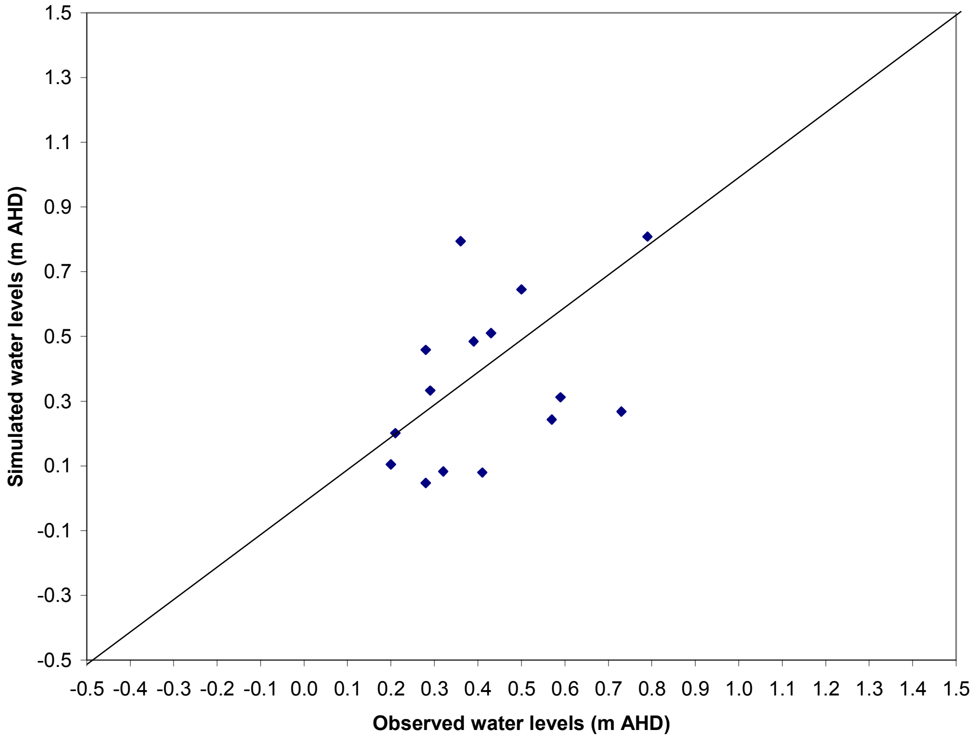


Figure 13 Observed vs Simulated Water Levels

The water balance is presented in **Table 12** which indicates that the volumetric budget error (inputs-outputs) in the model was 0%.

Table 12
Water Balance – Steady State Simulation

Budget Items	Model Inputs		Model Outputs	
	m^3/year	*m^3/day*	*m^3/year*	*m^3/day*
Constant Head	0	0	1,376,359	3,768
Wells (bores)	0	0	84,096	230
Drains	0	0	5,549,625	15,194
Recharge	7,010,080	19,193	0	0
Totals	7,010,080	19,193	7,010,080	19,193

The water balance indicates that about 79% of the rainfall recharge to the model is removed via the network of agricultural drains in the area, with discharge to surface water bodies (via constant head cells) accounting for 20% of the recharge inputs. Extraction via bores accounts for about 1% of the total recharge inputs.

The simulated groundwater table under steady state conditions is shown in **Figure 14**. Groundwater levels in the Quaternary sand aquifer vary between about 0m AHD and 1m AHD. Groundwater mounds form between agricultural drains with larger mounds present in the eastern area of the sand mass where there is less agricultural drainage. The lower hydraulic conductivity of the basalt results in a groundwater mound in the Cudgen Plateau that is a subdued reflection of the surface topography. Simulated groundwater levels vary between 1m AHD at the edge of the Plateau up to about 30m AHD at the highest point.

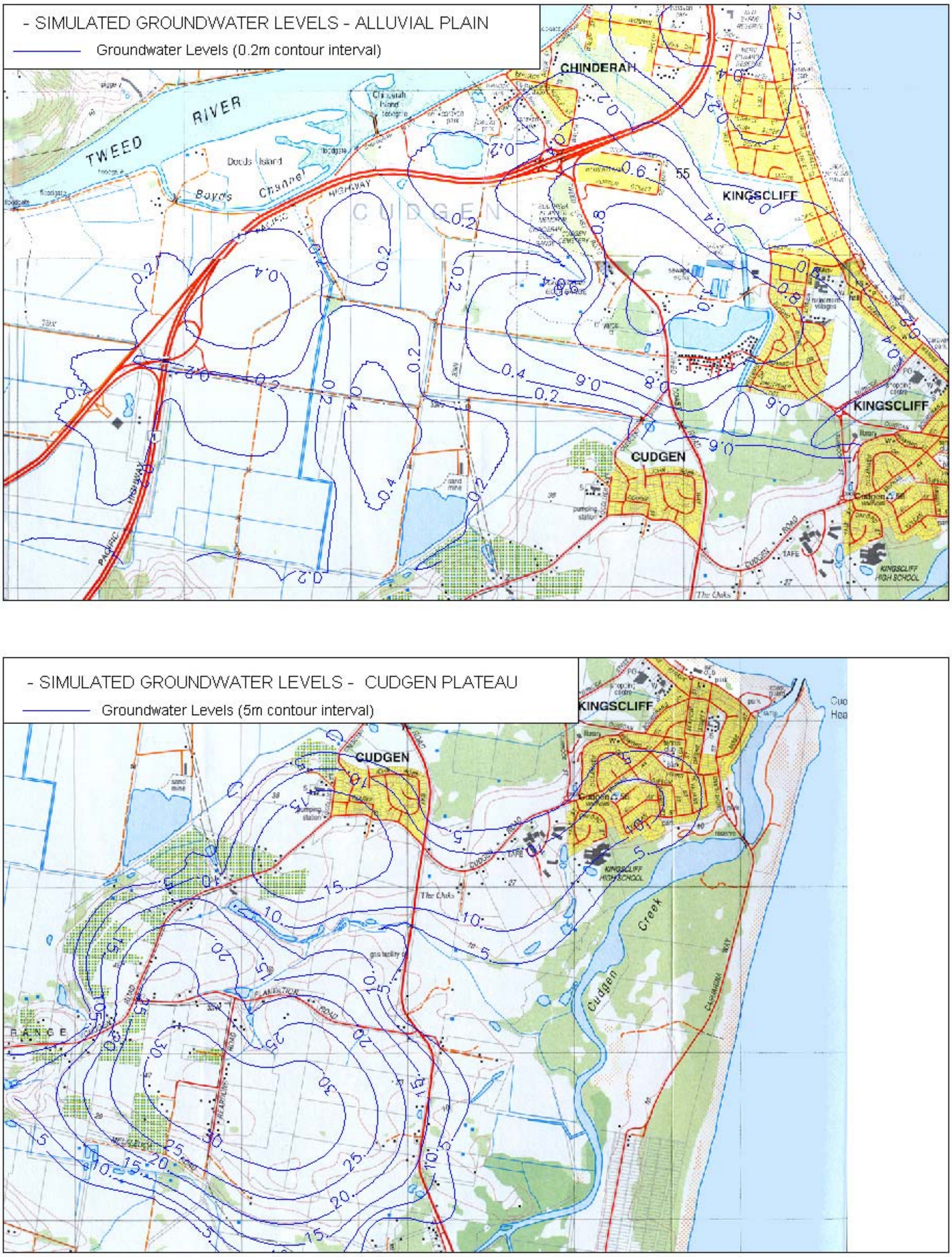


Figure 14 Simulated Steady State Water Levels

11.5.2 Transient Calibration

Once a sufficient match to the existing water levels was achieved with the steady state modelling, the model was calibrated to transient conditions. The primary purpose of the steady state modelling was to provide a set of initial heads for the transient model.

Only a small period of continuous water level measurements was available for transient calibration (refer Section 9.3.3). The objective of transient calibration was to reproduce the observed groundwater levels over the available period of data, 7 January to 3 February 2006. The calibration points were water level hydrographs from monitoring bores MB3 and MB8A.

Transient calibration results shown as observed and model simulated water level hydrographs for selected monitoring bores are shown on **Figure 15**.

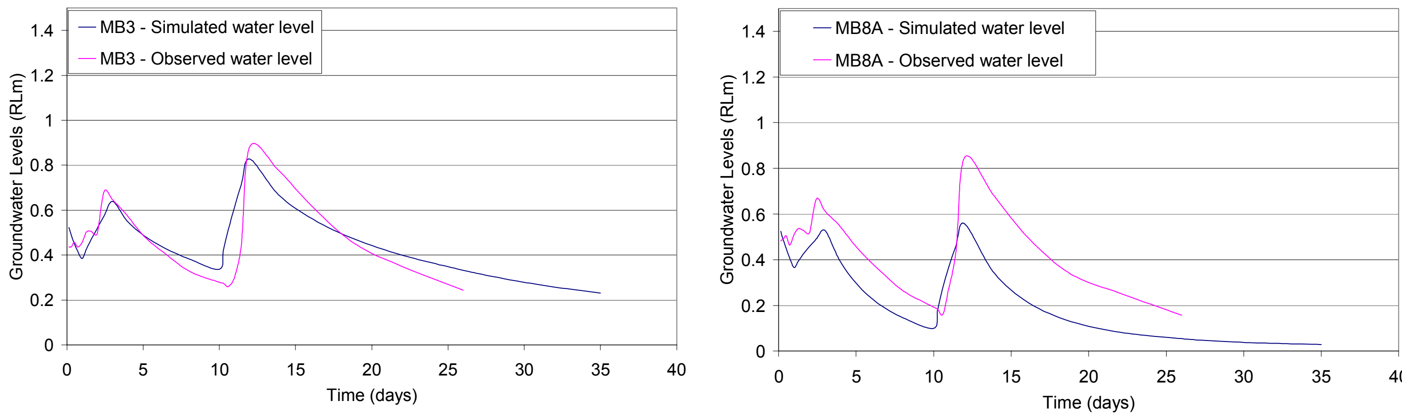


Figure 15 Simulated and Observed Transient Water Levels MB3 and MB8A

During transient calibration, the specific yield was adjusted until a satisfactory match between the observed and predicted groundwater levels was obtained. Groundwater recharge and hydraulic conductivity were held constant and were as specified in the steady state model. The water balance indicated that the volumetric budget error (inputs-outputs) in the model was 0%.

The above figures indicate that the model replicates actual water level fluctuations relatively accurately and that the model is satisfactorily calibrated to transient state conditions. The geometry of the model, boundary conditions, hydraulic stresses acting on the model and hydraulic parameters are considered sufficiently well defined to allowing predictive simulations to be undertaken.

12 PREDICTIVE MODELLING

12.1 Introduction

The initial design for the proposed sand extraction operation involved all sand extraction being undertaken south of Altona Drive (realigned), namely the southern extraction site. However, as a result of imposed development consent conditions on the realignment of Altona Drive, the southern extraction site was reduced in size and a northern extraction site north of Altona Drive (realigned) introduced.

The proposal to extract sand from north of Altona Drive (realigned) was made subsequent to the completion of the numerical modelling for the southern extraction site. Therefore, considering the comparatively small scale of the northern extraction site and the planned use of only mechanical extraction methods, it was deemed appropriate that the potential impact on groundwater levels from the introduction of the northern extraction site be assessed using analytical methods, and no additional numerical modelling be undertaken.

The following subsections outline the predictive modelling undertaken for the northern and southern extraction sites and their cumulative effect.

12.2 Numerical Modelling (Southern Extraction Site)

The objective of the predictive simulation was to assess the impact on the groundwater regime of the proposed sand extraction operations within the southern extraction site. In order to assess the difference, or impact, between sand extraction and no sand extraction, two predictive scenarios were run using the calibrated transient model, viz:

- Scenario 1 had no sand extraction operations at the Project Site; and
- Scenario 2 included a window lake created by the southern extraction pond increasing in area on an annual basis.

The simulations were run for a period of 11 years.

12.2.1 Water Balance Input to Model

12.2.1.1 Cudgen Lakes Sand Extraction Project

The water balance of the extraction pond/lake created by the southern extraction site was calculated based on the following formula.

Volume of groundwater equivalent pumped from extraction pit (m/m^2/day) =

[Vol. of sand extracted – (Vol. of sand x specific yield)] + (Open water evaporation x lake area) + (Vol. water loss from hydraulic pumping) - (rainfall x lake area)

The following assumptions were made when calculating the extraction pond/lake extraction rates.

<u>Outputs</u>

- The sand extraction rate was assumed to be 450,000m^3 per year for the first 2 years of operations and then 650,000m^3 per year for the remaining 6 years until the resource is depleted. It is noted that these rates are ‘worst case’ and in reality the average extraction rate would be lower, particularly during the initial year of operations whilst extraction rates ‘ramp up’ to maximum levels.
- The volume of groundwater required to replace the extracted sand was assumed to be the rate of sand extraction, corrected for specific yield (0.1), which is the volume of water in each cubic metre of sand that drains from the sand as it is removed.

- Evaporation from the open water body which is pan evaporation corrected by a pan factor (refer **Table 8**, Section 11.4.5)
- The net water loss from hydraulic transport was based on the assumption that the dredge would pump a 1:3 ratio of sand to water to the fill sites, with 90% of the water being returned to the extraction pond via a pipeline.

Inputs

- Rainfall inputs were based on weighted monthly averages (refer **Table 8**, Section 11.4.5)

The volume of groundwater equivalent removed from the southern extraction site was estimated on a monthly basis using the above water balance equation as shown on **Figure 16**.

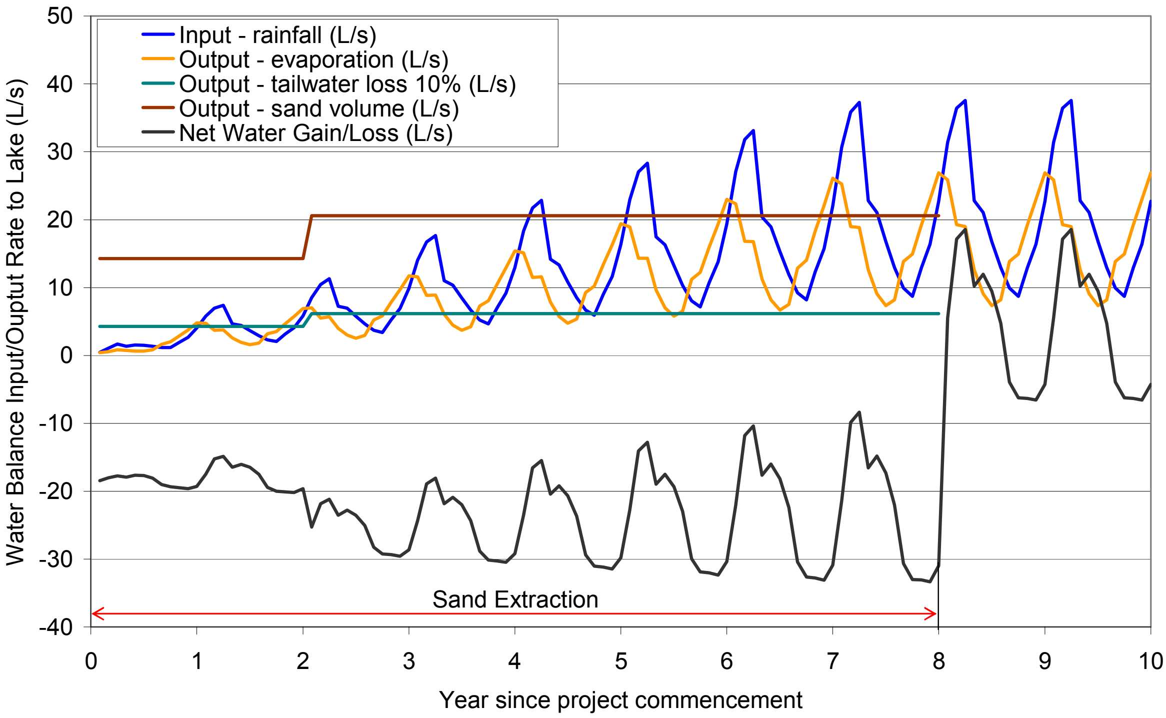


Figure 16 Water Balance for Southern Extraction Pond/Lake

The larger variations in rainfall and evaporation with time reflect the increasing area of the southern extraction pond/lake and hence increasing volumes of rainfall input and evaporation loss. The water balance was also calculated as the equivalent groundwater extraction rate per unit area of extraction pond/lake surface for each annual stage for use in the numerical model, as shown in **Figure 17**.

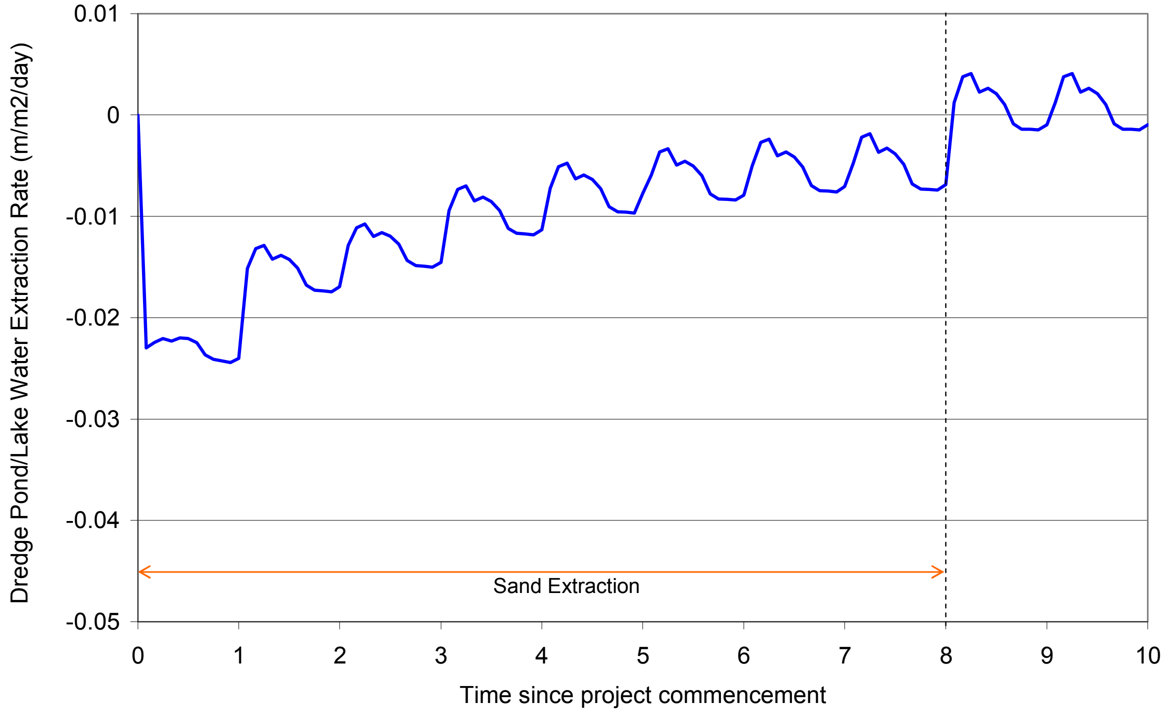


Figure 17 Water Extraction Rate per Unit Area of Southern Extraction Pond/Lake

Figure 17 indicates that the equivalent groundwater extraction rate per square metre of extraction pond surface would be greatest in the early stages of the Project when the southern extraction pond area is relatively small. As the area of the southern extraction pond increases over the life of the Project, water loss per unit surface area decreases. Input from direct rainfall increases and reduces the net water loss from the extraction pond. Also the area of aquifer exposed in the sides of the pond through which groundwater inflow can occur is much greater and the drawdown associated with this inflow is therefore less. At the end of extraction, there would be a lake to which the water inputs and losses are dependent on the average monthly rainfall and evaporation rates.

The simulation covered a total of 132 monthly stress periods (ie. 11 years) with 4 time steps per stress period. The water levels generated by the steady state model were used as the initial conditions for predictive modelling. It is noted that the sand extraction period shown is based upon continuous maximum extraction throughout the life of the Project. As previously discussed the extraction rate modelled represents a 'worst case' scenario and in reality this would not occur with sand being extracted over a period greater than 8 years. This would result in a reduction in the magnitude of the extraction rate, however, for the purposes of this assessment, the 'worst case' scenario has been modelled.

Recharge rates were based on average monthly rainfall data and applied at the fractions used in the steady state model (refer **Table 10**).

12.2.1.2 Hanson Tweed Sand Extraction Operation

A water balance was prepared for the operating Hanson Tweed Sand extraction operation on the western boundary of the Project Site using the same parameters as described in Section 12.1.1. The water balance was based on a sand extraction rate of 150,000m^3 per year and a proposed expansion area as described by JGA (2005) in the EIS for the proposed expansion

of the facility. As the sand is processed onsite the tailwater loss was assumed to be insignificant with all pumped water returned to the pond. The water balance for this facility and the proposed expansion was incorporated in the model to provide a cumulative impact assessment of both operations on the groundwater regime. It is important to note that the 2005 hydrological assessment conducted by Gilbert and Sutherland (2005) for the expansion of the quarry did not account for the volume of water required to replace the volume of sand removed which has been accounted for within this assessment.

Figure 18 shows the water balance graphically with **Figure 19** presenting the water loss from the pond per unit area that was used in the numerical modelling.

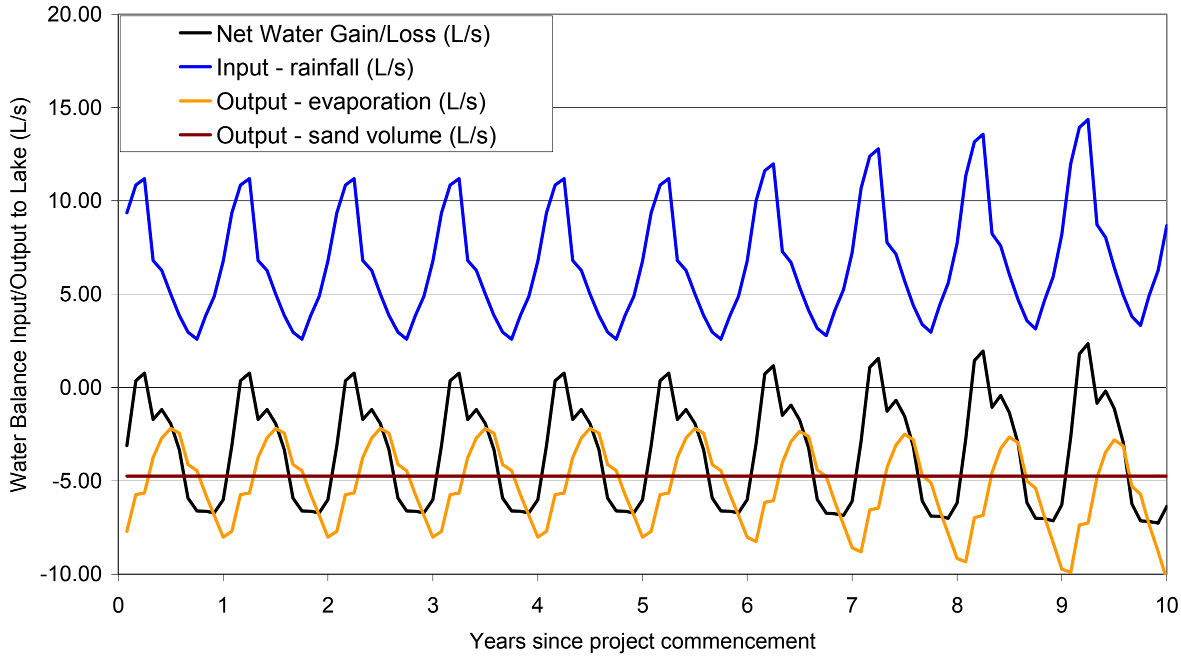


Figure 18 Water Balance for Hanson Tweed Sand Dredge Pond/Lake

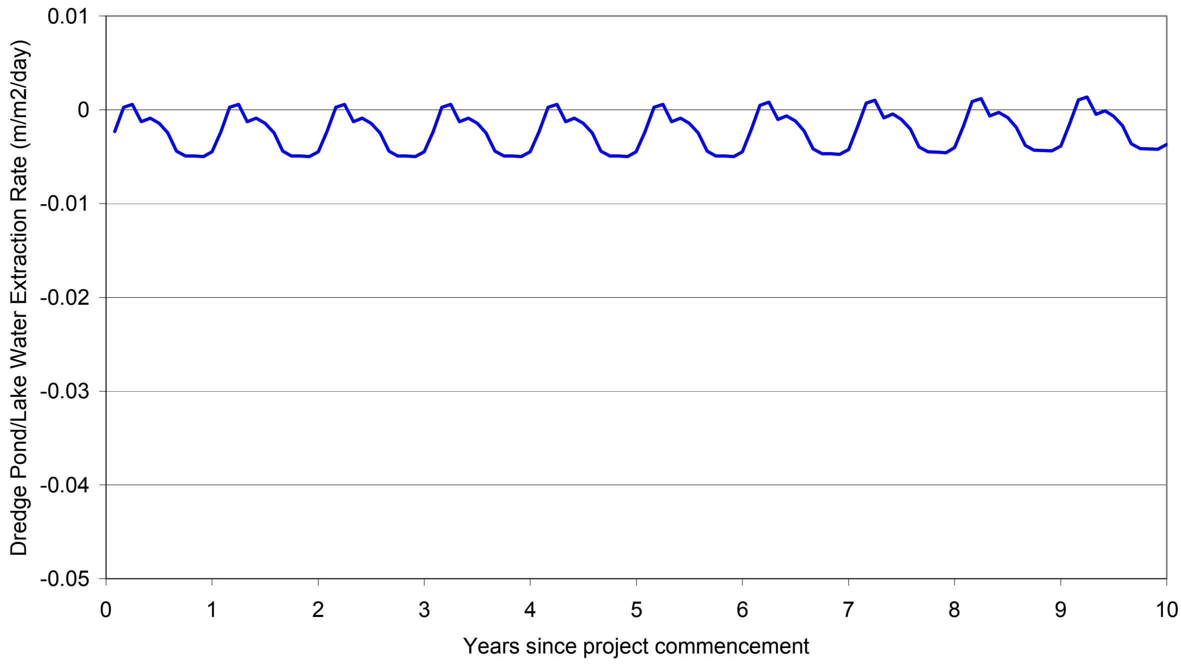


Figure 19 Water Balance for Hanson Tweed Sand Dredge Pond/Lake (per unit area)

12.2.2 Simulation Results

The simulated water level of the southern extraction pond/lake is shown in **Figure 20**. **Figure 20** indicates that, under the continuous maximum extraction rate, the water level in the southern extraction pond would fall to about -1.5m AHD during the early stages of the Project and that it would gradually recover as the Project progresses and as the size of the southern extraction pond increases. An annual fluctuation in pond levels is also evident over this period due to the wet summer and dry winter seasons. At cessation of sand extraction, the water level in the final lake recovers rapidly and within a 1 year period cycles between 0m AHD and 0.25m AHD, ie. within background levels.

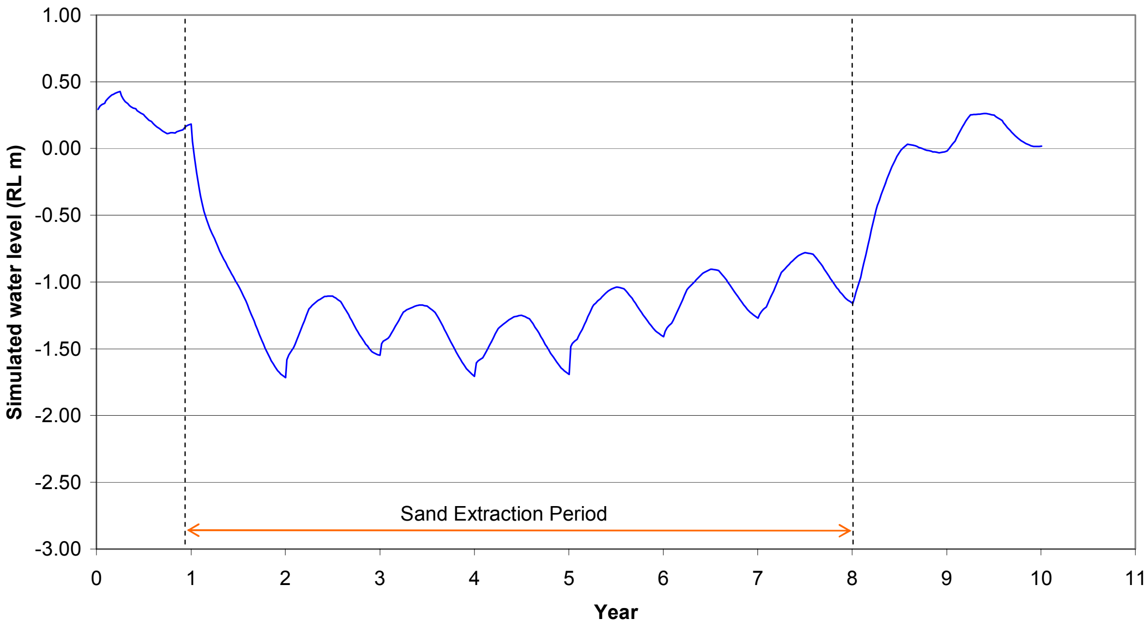


Figure 20 Simulated Southern Extraction Pond/Lake Water Level

The modelled drawdown at Years 1 3, 5 and 7 during extraction is presented in **Figure 21**. The limit of drawdown is presented as 0.5m which is the typical annual fluctuation observed in groundwater levels in the alluvium. As indicated in the hydrographs, the water levels recover to pre-extraction levels within 12 months of the cessation of extraction. It is evident from **Figure 20** that the drawdown in groundwater levels is greatest during the early years of extraction and gradually decreases due to the increasing input from rainfall as the dredge pond expands. The model predicts that drawdown extends to a maximum distance of about 500m to the north in the alluvial floodplain. At Year 7, a drawdown of between 0.5m and 1.0m extends about 500m to the south in the Cudgen Plateau.

In the likely event that extraction occurs at a rate less than the maximum modelled, the magnitude of groundwater drawdown and the geographic extent affected would be reduced, however, these reduced drawdown levels would occur over a period of greater than 8 years.

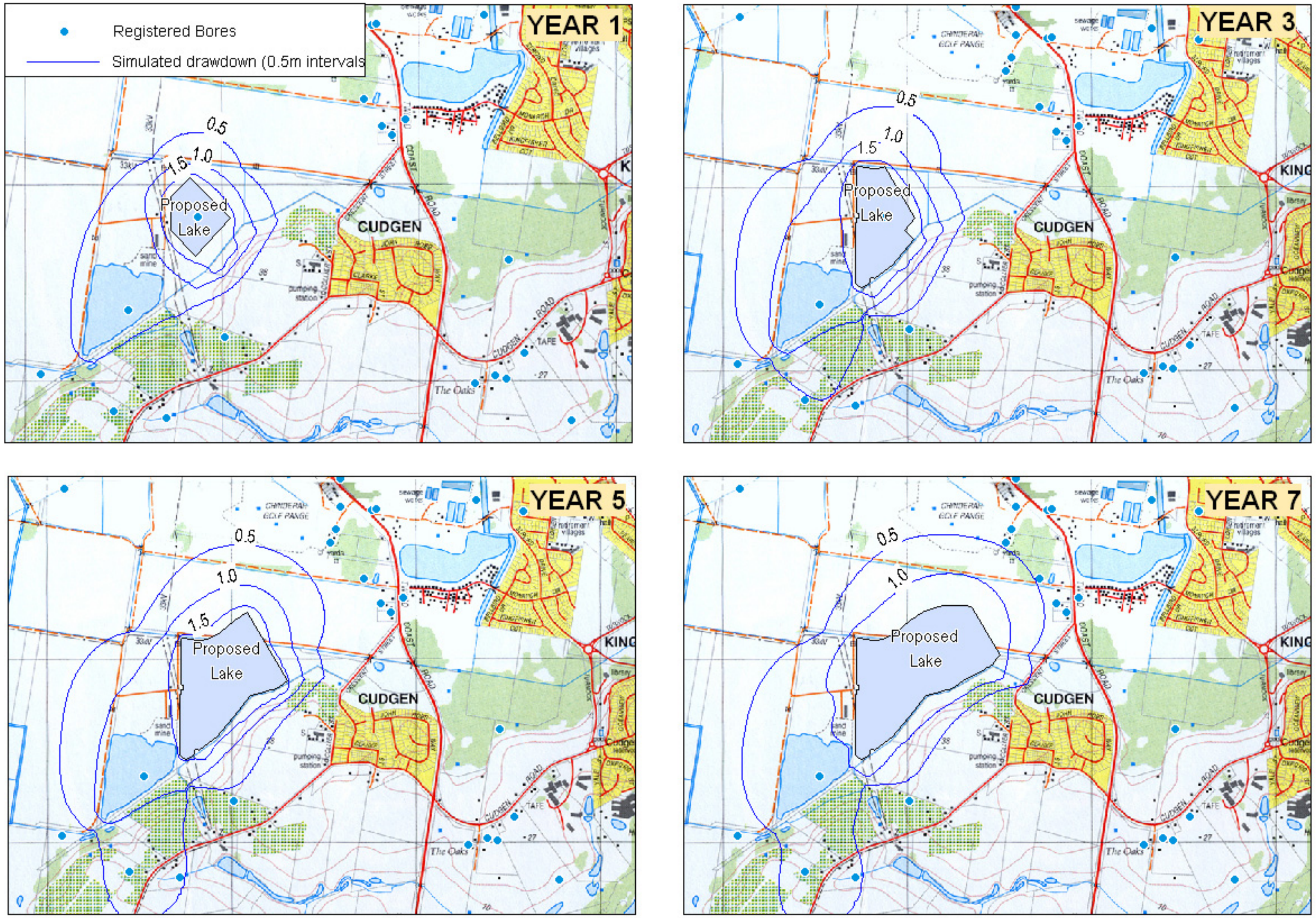


Figure 21 Simulated Water Table Drawdown

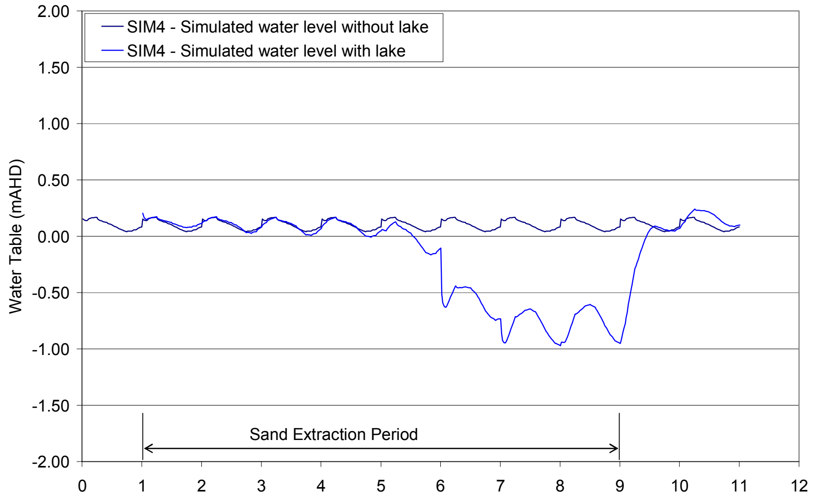


Figure 22 Simulated Water Levels SIM4

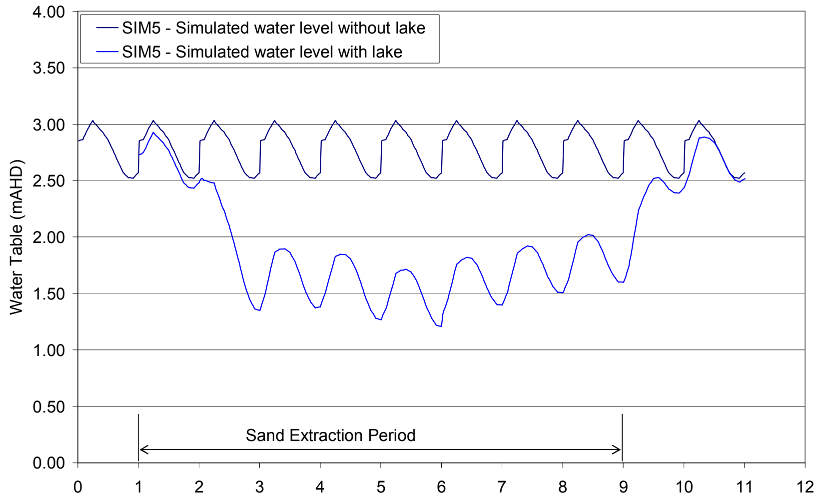


Figure 23 Simulated Water Levels SIM5

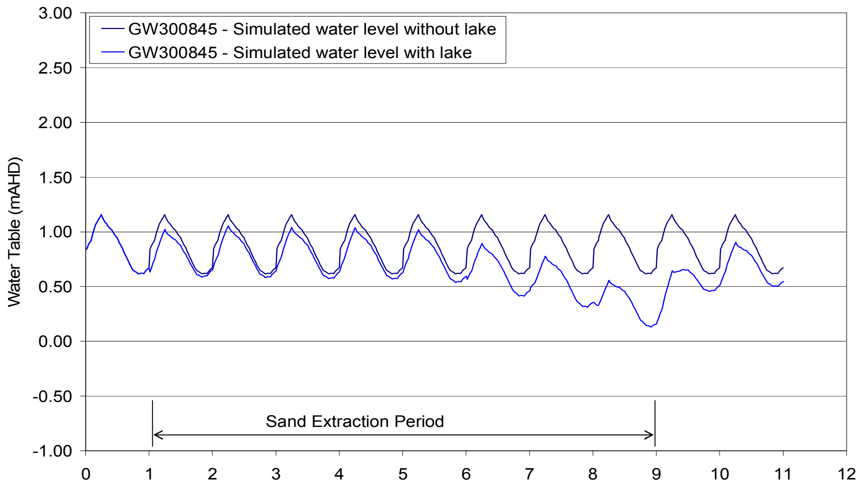


Figure 24 Simulated Water Levels GW300845

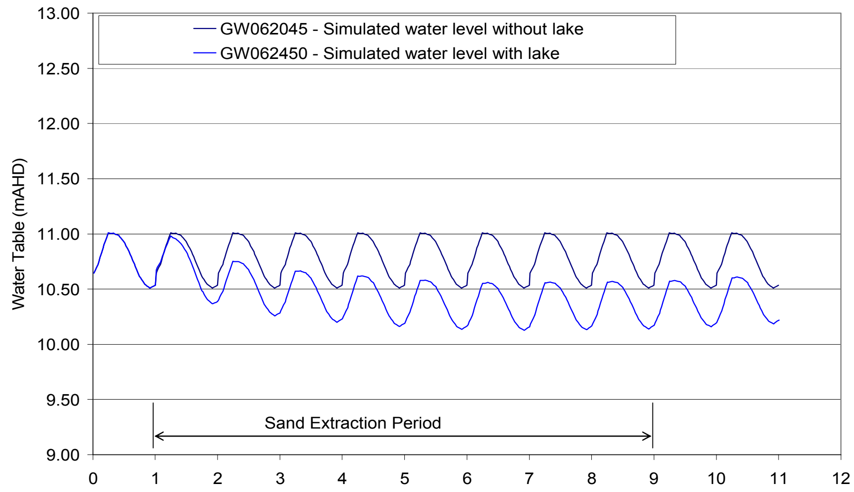


Figure 25 Simulated Water Levels GW062045

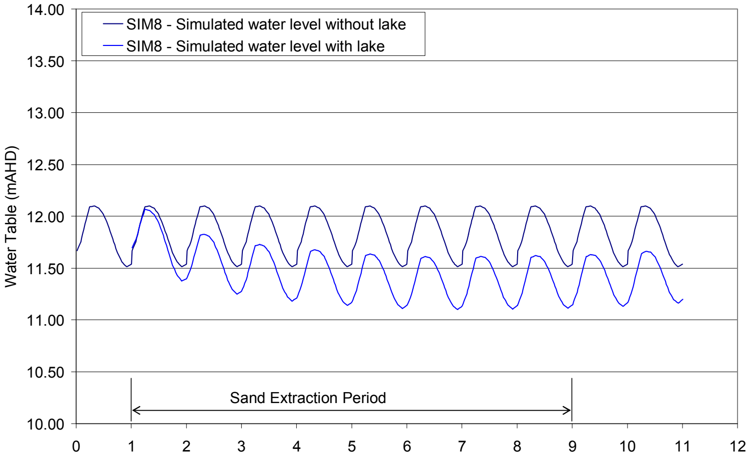


Figure 26 Simulated and Observed Transient Water Levels SIM8

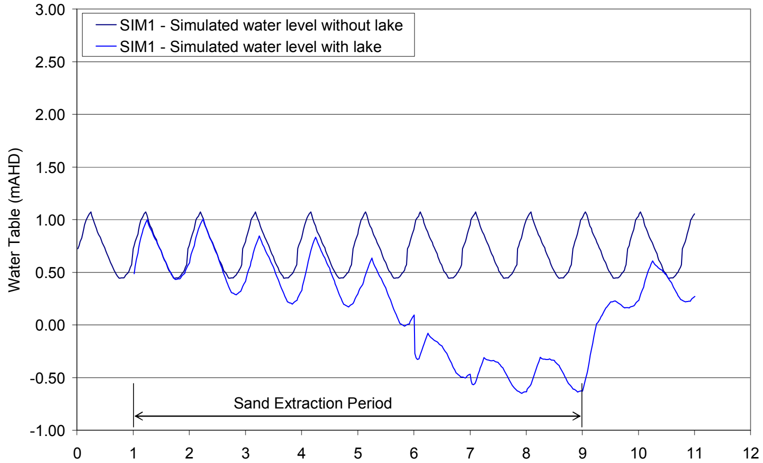


Figure 27 Simulated Water Levels SIM1

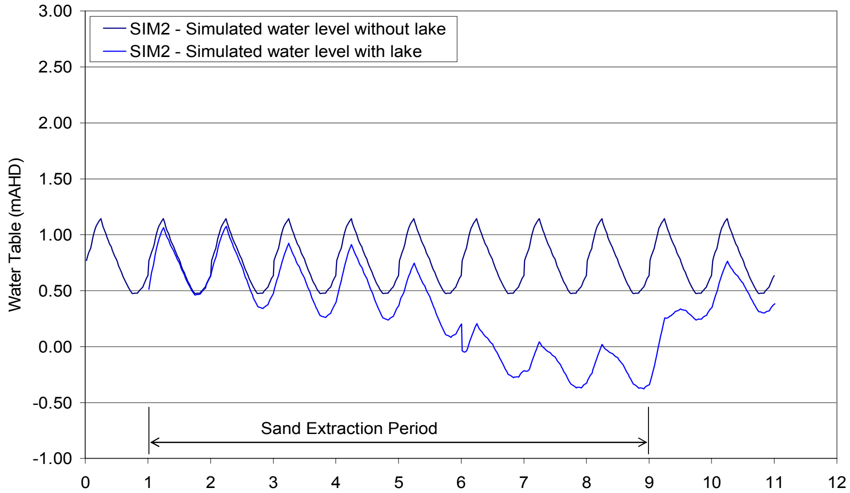


Figure 28 Simulated Water Levels SIM2

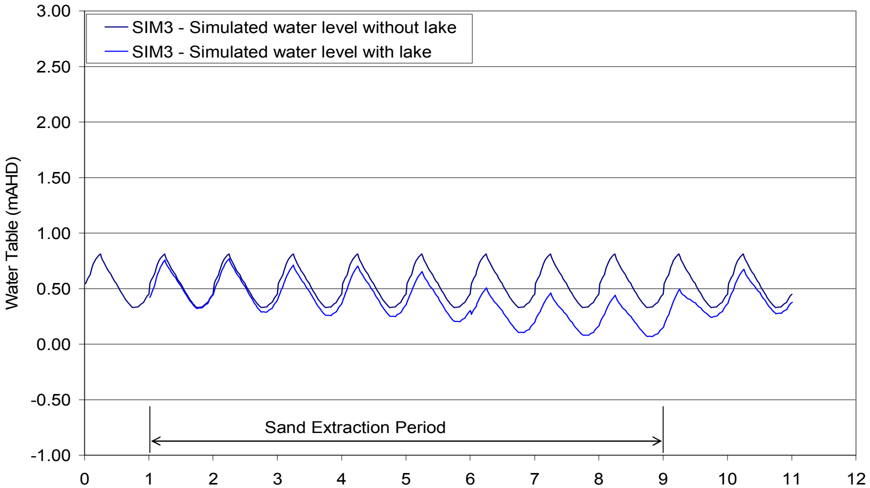


Figure 29 Simulated Water Levels SIM3

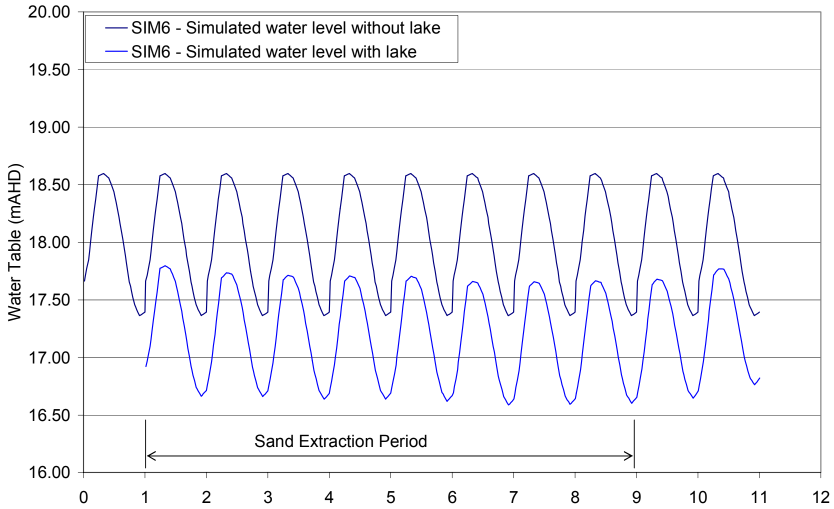


Figure 30 Simulated Water Levels SIM6

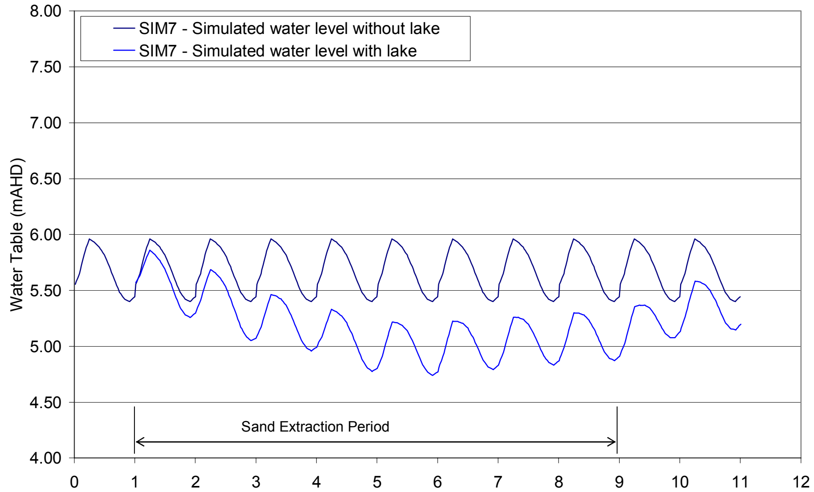


Figure 31 Simulated and Observed Transient Water Levels SIM7

12.2.3 Discussion of Numerical Modelling Results

The objective of the numerical modelling was to assess the impact of sand extraction within the southern extraction site on groundwater levels and the subsequent impact on groundwater users. The impacts of the predicted drawdown on PASS are discussed in a separate report prepared by HMC (2008).

During modelling, water levels for a selection of bores were generated for both Scenario 1 (no sand extraction) and Scenario 2 (with sand extraction). Hydrographs for the closest registered bores to the Project Site are presented along with hydrographs for simulated bores at eight locations surrounding the Project Site (see **Figures 22** to **31**). The locations of the simulated bores are shown in **Figure 4**.

It is important to note that when assessing the model predictions that the modelling was undertaken assuming a sand extraction rate of 450,000m^3 per year for a period of 2 years and then the maximum rate of 650,000m^3 per year for the following 6 years of the Project until the resource is depleted. It is understood that the extraction rate is dependent on the requirement for sand at the fill sites and, when demand is low, it is unlikely that an annual extraction rate of 650,000m^3 per year would be achieved. Furthermore, extraction rates during the first year would gradually ramp up towards the annual rate of 450 000m^3 per year. In the likely event that actual sand extraction rates are lower than the maximum rate used in the model and extraction is undertaken over a longer period, the level and extent of drawdown is expected to be less than that predicted. Therefore **the results of the modelling are considered to be a worst case scenario**.

The closest groundwater bores in the Quaternary sand aquifer to the Project Site are the spears located on the R. Julius property adjacent to the southern boundary of the Project Site. The spears are unregistered and are used for topping up dams which are used to irrigate agricultural crops on the Cudgen Plateau. As the spears are not registered, the construction details are not known. The spear locations are shown on **Figure 4** (Julius East and West). The impact of sand extraction on two bores SIM 4 and SIM5 was simulated in the model to assess the potential impact on the Julius spears. The hydrographs are shown on **Figures 22** and **23**. In the early stages of sand extraction, drawdown in the area of Julius West (SIM 5, **Figure 23**), is predicted to be between 0.75m and 1.75m, that is 0.75-1.75m below the water level that would naturally occur at the spear location without sand extraction. At Julius East (SIM 4, **Figure 22**), the drawdown is predicted to be between 0.5m and 1.0m, that is 0.5-0.1.0m below the naturally occurring water level.

The dams located adjacent to Julius East and Julius West are small window lakes were surveyed to determine the approximate base level and potential impact. The base of each dam was measured at approximately -1.7m AHD. The modelling did not indicate dewatering below this level in the simulation runs.

The closest registered bores in the Quaternary sand aquifer are the properties located on Tweed Coast Road about 500m to the northeast of the southern extraction site. Most of these properties have shallow spears that are used for irrigation of gardens. The model predicts a drawdown of less than 0.5m at the closest bore GW300845 (**Figure 24**), in the latter stages of extraction as the southern extraction pond progresses in an easterly direction. Bore GW300845 is screened between to 3.2m and 4.2m below ground level, which is from -1.7m AHD to -2.7m AHD assuming a ground level of 1.5m AHD. The predictive modelling indicates the groundwater level at this bore would be lowered to about 0.2m AHD in the latter stages of sand extraction, that is, about 0.5m below the water level that would naturally occur at the site.

At this time, a total of about 2.9m of water would remain in the bore when the pump is not operating. It is also important to note that at the cessation of sand extraction, the groundwater levels would return to pre-extraction levels relatively rapidly and the yield from existing groundwater bores and spears would return to pre-extraction conditions.

The closest registered bore on the Cudgen Plateau is bore GW062045 (**Figure 25**), located about 550m to the south of the southern extraction site. Records show this bore as being screened between 6.5m and 17m below ground level. The model predicts a drawdown at GW062045 of about 0.5m, (**Figure 25** and **26**), that is about 0.5m below the water level that would naturally occur at the site. When assessing the potential impacts on the Cudgen Plateau, it is important to note that very limited data was available on groundwater levels and aquifer thicknesses for the Cudgen Plateau and for this reason the model could not be accurately calibrated for this area. However, the predicted additional drawdown of about between 0.5m and 0.75m is very low and is less than the groundwater table fluctuation range.

The impact of the sand extraction at other locations around the Project Site is shown on hydrographs for simulation bores SIM 1 to SIM 7, (**Figures 27** to **31**). The location of these bores is shown on **Figure 4**. The data indicates a drawdown of between 0.5m and 2m due to sand extraction, the magnitude of the drawdown depending on the distance of the simulation bore from the southern extraction site.

It is should be noted that some of the SIM hydrographs show a drawdown at the first reported record between the 'lake' and 'no-lake' simulations. In some cases, a component of this pseudo drawdown is due to the lake level, but some of this is also due to the numerical nature of the model. Both models were started with the same set of initial heads, however, the presence of the lake and the subsequent modification of the aquifer parameters (hydraulic conductivity of 1500m/d and specific yield of 1.0) in the 'lake' run create a slight initial mismatch between the water levels and the groundwater flow equations which describe them. This results in a sudden redistribution of water to match the groundwater flow equations on the first time step, and hence a sudden change in heads in the model output. The most significant example of this is SIM 6 where there is an initial drop in water level before the first model output time. From this period onwards the relative drawdown in this simulated bore is minimal (as expected). The initial change is also seen in SIM 1, 2, 3, & 5 although to a lesser extent that that in SIM 6. This is because the specific yield at these bores is 10%, whereas the storage at SIM 6 is only 3% which will in-effect amplify the drawdown.

12.3 Analytical Modelling (Northern Extraction Site)

In order to assess the potential groundwater impacts of sand extraction operations within the northern extraction site, analytical equations were used based on the previously developed conceptual model.

Extraction within the northern extraction site was assumed to occur at a maximum annual rate of 200 000m^3 for the first two years of the operation. It was also assumed that the extraction pond would be progressively backfilled with VENM starting at the end of the first year. As for the southern extraction pond, it is unlikely that the maximum annual extraction rate would occur during the first year of operations with a ramp up period associated with the start-up of the processing plant and the establishment of the operation within the construction materials market.

12.3.1 Water Balance

A water balance for the northern extraction site was undertaken using the same methodology as for the southern extraction site detailed in Section 12.2.1. As the sand for the northern extraction site would be removed by excavator, no allowance was made for water loss due to hydraulic pumping. The volume of groundwater equivalent removed (ie. the volume of sand removed which would need to be replaced by groundwater) from the northern extraction site was estimated on a monthly basis as shown on **Figure 32**.

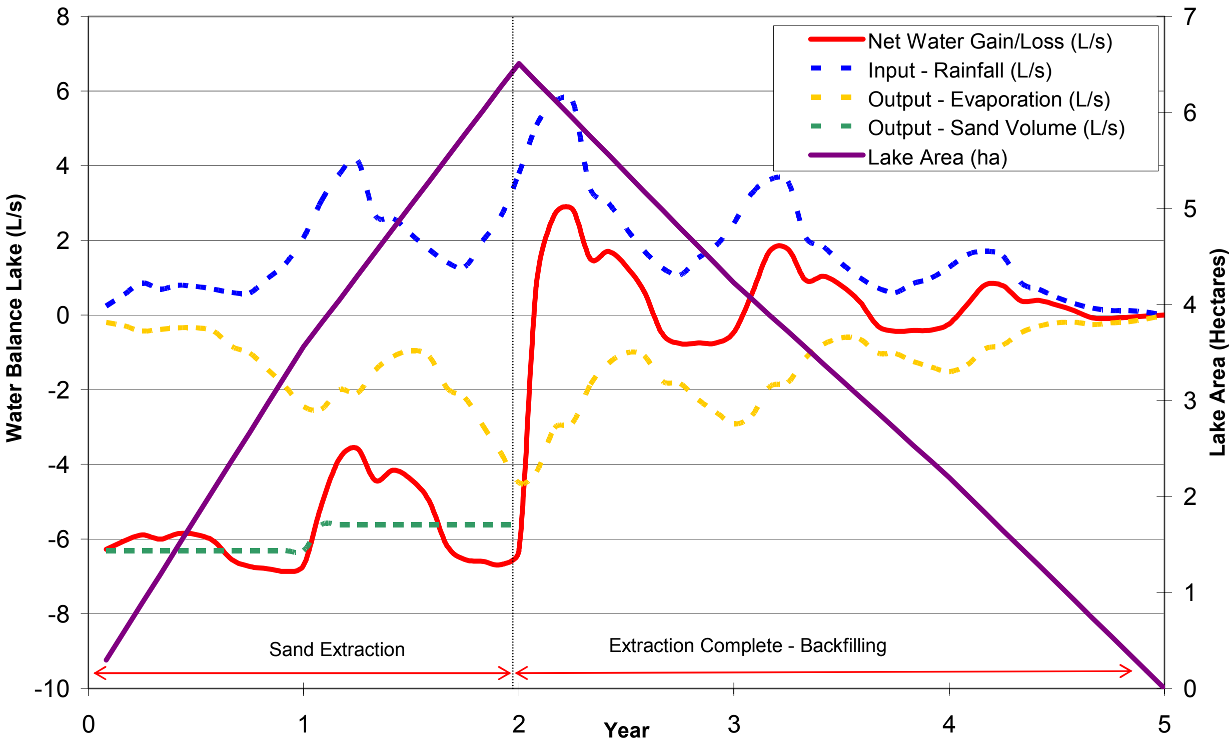


Figure 32 Water Balance – Proposed Northern Extraction Site

Figure 32 indicates that net groundwater extraction from the northern extraction site is greatest during the first two years when groundwater inflows must make up for the sand extracted. During the first two years, the net loss of groundwater from the operations reaches a maximum of 6.8L/s. Subsequently when sand extraction is complete the northern extraction pond gradually reduces as it is backfilled, resulting in a steadily reducing water loss.

12.3.2 Impact on Groundwater Levels

Analytical equations developed by Marinelli and Niccoli (2000) were used to assess the impact of the northern extraction site on groundwater levels and the radius of influence of this impact. Marinelli and Niccoli present equations for estimation of the radius of influence of an open pit or excavation and groundwater inflow rates. The analytical methods require a simplification of the hydrogeological environment and can be used to provide 'broad' ranges of potential drawdown and pit inflow.

The equations presented by Marinelli and Niccoli calculate groundwater inflow from the excavation walls, and from the base of the excavation separately, based on the conceptual model presented in **Figure 33**.

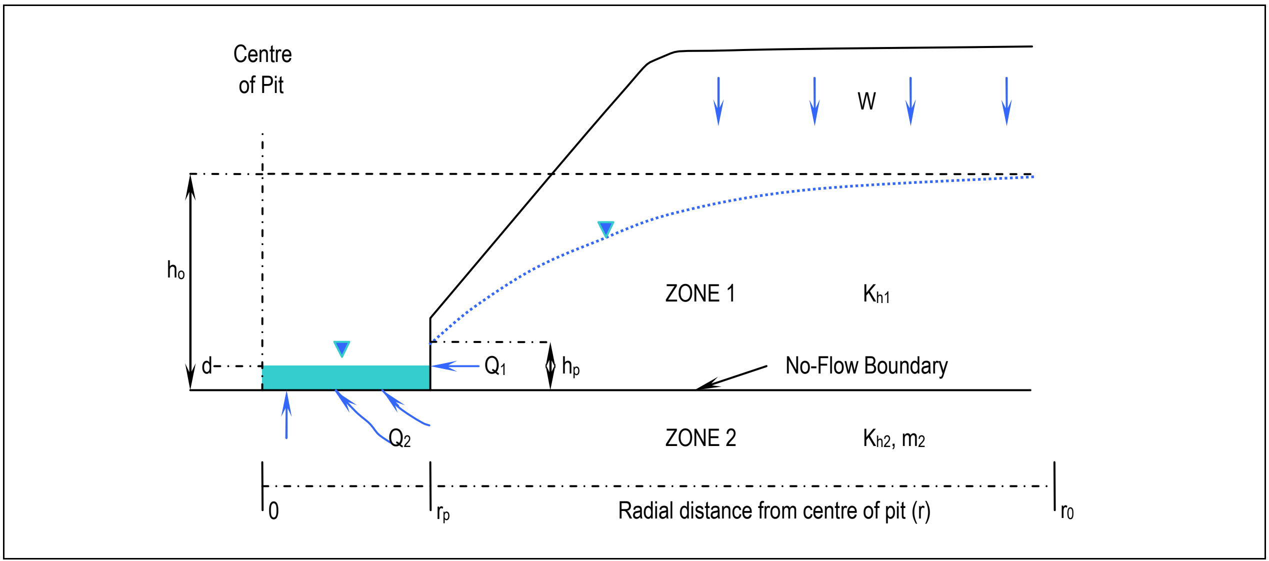


Figure 33 Pit Inflow Analytical Model (after Marinelli and Niccoli [2000])[1]

The water balance described in Section 12.3.2 indicates that groundwater extraction from the northern extraction site would be about 6.8L/s at the end of Year 2 when the extraction pond has the largest surface area. The equations presented by Marinelli and Niccoli were used to 'back calculate' the extraction pond water level at an extraction rate of 6.8L/s as follows:

Zone 1

$$Q_1 = W \pi (r_o^2 - r_p^2) \qquad m^3/day$$

Zone 2

$$Q_2 = 4 r_p \left\langle \frac{K_{h2}}{m_2} \right\rangle (h_o - d)$$

$$m_2 = \sqrt{\frac{K_{h2}}{K_{v2}}}$$

where

- Hydraulic conductivity of the alluvial aquifer k_{h1} = 10m/day
- Saturated thickness of aquifer h_o = 3.4m
- rainfall recharge 25% of annual rainfall W = 420mm/yr
- the height of the alluvial aquifer seepage face in the open excavation h_p = 3.2m
- equivalent radius of lake as a cylinder r_p = 143m
- vertical hydraulic conductivity of the alluvial aquifer k_{v2} = 1m/day
- lake water level above Zone 1 d_o = m

The back calculations indicate that the inflow for Zone 1 is 1.57L/s and for Zone 2, 5.23L/s, that is, a total of 6.8L/s which agrees with the loss assessed from the water balance. For a total loss of 6.8L/s, the extraction pond water level is assessed at 0.25m below the static water level.

Having obtained the drawdown at the extraction pond due to a net groundwater loss of 6.8L/s, the radius of influence of the loss on the water table is determined by iteration from the following equation:

$$h_0 = \sqrt{h_p^2 + \frac{W}{K_{h1}}\left[r_o^2 \ln\left(\frac{r_o}{r_p}\right) - \frac{(r_o^2 - r_p^2)}{2} \right]}$$

For Zone 1 the analytical solution considers steady-state, unconfined, horizontal, radial flow and assumes that:

- the excavation walls are approximated as a circular cylinder;
- groundwater flow is horizontal; the Dupuit-Forchheimer approximation is used to account for changes in saturated thickness due to depression of the water table;
- the static (pre-sand extraction) water table is approximately horizontal;
- uniform distributed recharge occurs across the site as a result of surface infiltration from rainfall;
- all recharge within the radius of influence (cone of depression) of the excavation is captured by the excavation; and
- groundwater flow toward the excavation is axially symmetric.

To estimate the radius of influence of the northern extraction site on the alluvial aquifer at the end of Year 2 the following parameters were used in the above equation.

Using the above equation and a hydraulic conductivity of 10m/day, the radius of influence, or cone of depression created by the northern extraction site is estimated to be 98m from the edge of the extraction pond. That is at a distance of 98m, any change in groundwater level is due to natural fluctuations. The analytical equations also indicate that at a distance of 60m from the extraction pond, the drawdown is about 0.1m, which is well within the natural range of groundwater fluctuation.

12.3.3 Conclusions

It is concluded that, based on the water balance of the proposed northern extraction site and using classical groundwater flow/drawdown equations:

- the 0.1m drawdown contour associated with sand extraction from the proposed northern extraction site would occur at a radius of about 60m from the excavation;
- the total radius of influence of the northern extraction site would be about 100m, that is groundwater levels would not be impacted at all at greater than 100m of the extraction site; and
- subsequent to completion of sand extraction in the northern area at the end of Year 2, there would be minimal net loss or gain of water to the remaining extraction pond and the water level would reflect natural groundwater levels.

12.4 Discussion of Cumulative Results

The cumulative impact on groundwater levels from the northern and southern extraction sites during Years 1 and 2 must be assessed to obtain a total potential impact. As can be seen from **Figure 21** in Year 1, the 0.5m drawdown contour from the southern extraction site only extends marginally into the northern extraction site and there would be no overlap with the 0.1m drawdown associated with the northern extraction site. At Year 3, the 0.5m drawdown from the southern extraction site extends into the northern extraction site (**Figure 21**), but by this time sand extraction has been completed and the northern extraction site is being progressively backfilled. **Figure 33** shows that, after Year 2, there is minimal net loss or gain of water from/to the northern extraction site and therefore the water level in the northern extraction pond should be at the natural water table level.

The data indicates that there would not be a cumulative impact on groundwater levels as a result of hydraulic extraction (ie dredging) in the southern extraction site and mechanical extraction (ie. excavator) in the northern extraction site during Years 1 and 2. In the likely event that extraction occurs at a reduced rate, the results of the cumulative assessment would remain valid, however, the timeframes discussed would vary.

13 POST MODELLING MONITORING DATA

13.1 Monitoring Program

In January 2006, electronic water level loggers were installed in several monitoring bores within the Project Site to gather transient data for the numerical modelling. The groundwater modelling component of the Project was completed in March 2006, however, the loggers were retained in the bores at the site to gather further data. As the modelling identified the potential for lowering of groundwater levels on the adjacent R. Julius property, electronic monitoring of water levels and extraction rates from the dams (window lakes) on this property was also implemented with the agreement of the landowner. The monitoring program was implemented by HMC Environmental Consulting with the data provided to AGE on a regular basis.

13.2 Rainfall

Rainfall recorded at the Murwillumbah Station over the monitoring period is presented in **Table 13** below.

The rainfall records indicate that above average rainfall was received in January 2006, however, since this time rainfall has been below average in nine of the last fourteen months. Over the monitoring period total rainfall was 345mm below the average for the Murwillumbah Station. The cumulative rainfall departure (CRD) also shows a declining trend due to the below average rainfall.

Table 13
Rainfall Murwillumbah Station 58158

Month	Recorded Rainfall (mm)	Monthly Average (mm)	Recorded Rainfall Minus Average Rainfall	Cumulative Rainfall Departure (mm)[1]
Jan-06	345.8	189.7	156.1	83
Feb-06	187	234.7	-47.7	35.3
Mar-06	258.2	223.9	34.3	69.6
Apr-06	79	170	-91	-21.4
May-06	18.4	150.4	-132	-153.4
Jun-06	82	88	-6	-159.4
Jul-06	86.6	70.7	15.9	-143.5
Aug-06	72	50	22	-121.5
Sep-06	82.8	39.3	43.5	-78
Oct-06	11.8	84.9	-73.1	-151.1
Nov-06	119.2	124.4	-5.2	-156.3
Dec-06	87.2	158.6	-71.4	-227.7
Jan-07	132.3	189.7	-57.4	-285.1
Feb-07	100.8	234.7	-133.9	-419

[1] Cumulative Rainfall Departure calculated since 1972.

13.3 Groundwater Levels

Groundwater levels recorded by the electronic loggers installed in selected bores within the Project Site between January 2006 and February 2007 are presented in **Figure 34**.

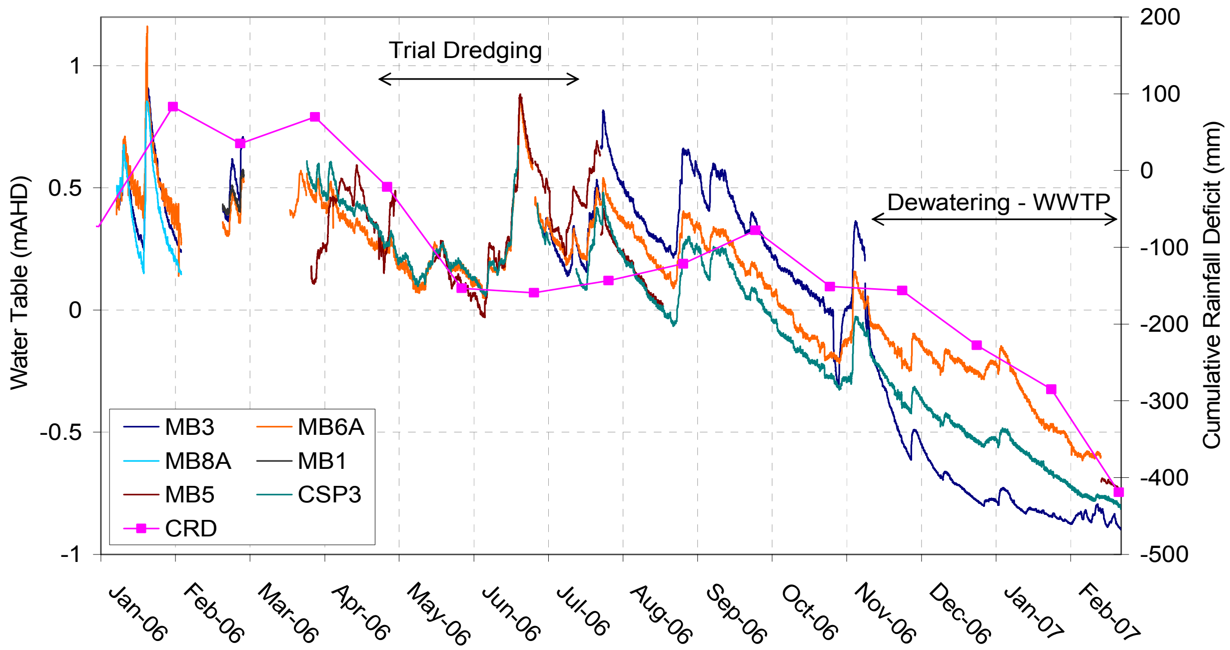


Figure 34: Monitoring Bore Hydrographs

When assessing the trends in groundwater levels, it is important to understand the inputs and outputs to the aquifer system over the monitoring period within the Project Site, inputs to the sand aquifer are primarily from rainfall recharge. Over the monitoring period there were a number of continuous and intermittent extractions from the sand aquifer that effected groundwater levels as follows.

- Discharge to drains constructed through the area.
- Evapotranspiration by Melaleucas to the north of the Project Site.
- Extraction from window lakes on neighbouring property for irrigation.
- Extraction from the neighbouring Hanson Tweed Sand Quarry (via sand removal and evaporation).
- Extraction during trial dredging period at site (via sand removal and evaporation).
- Extraction during dewatering for construction of the waste water treatment plant.

The hydrographs presented in **Figure 34** indicate that groundwater levels have generally fallen about 1.5m over the monitoring period because discharge and extraction from the aquifer has exceeded rainfall recharge. The extractions from the aquifer are discussed separately below.

13.3.1 Trial Dredging Impacts

A dredging operation was undertaken between 19 April 2006 and 12 July 2006 to establish the initial dredge pond for the approved extraction of 400 000m^3 of sand under Development Consent DA 96/518. Operational dredging has not yet commenced, however, these preparatory works have been used as a trial dredging operation to gather feasibility data that would assist to validate the assessment of the Project. The dredge was operated Monday to Friday between 7am and 4pm with a total of about 22,000m^3 of sand extracted. The tailwater was returned directly to the dredge pond. The extraction rate adopted during the trial dredging was equivalent to an annual sand extraction rate of about 104,000m^3 per year (a similar rate to which dredging would initially occur during the ramp up period for the southern extraction site).

The groundwater levels recorded over the trial dredging period are presented in **Figure 35**.

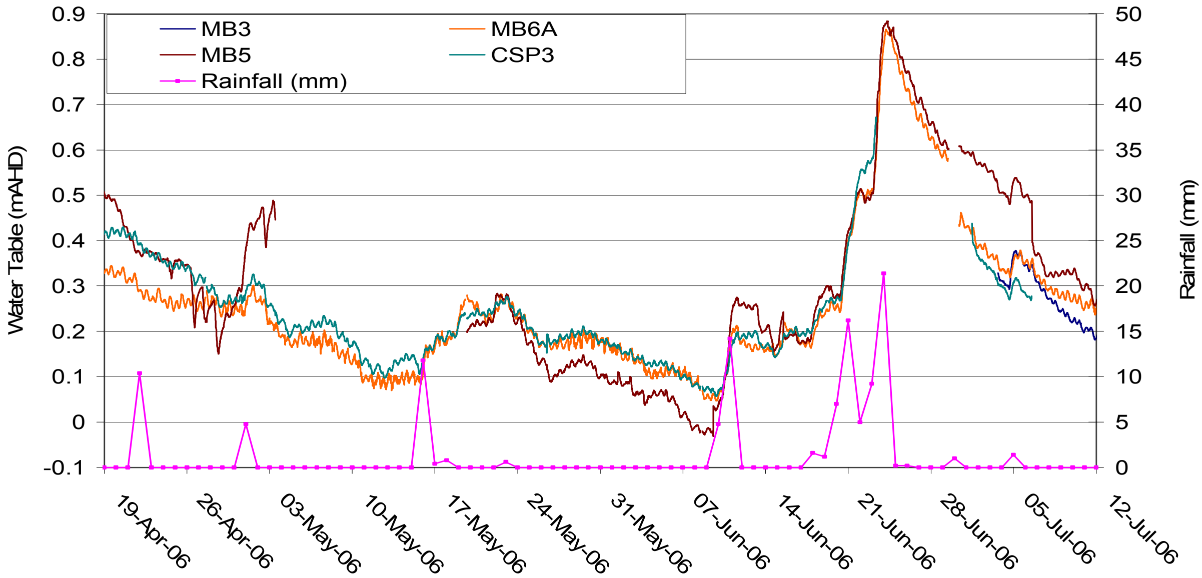


Figure 35: Monitoring Bore Hydrographs – Trial Dredging Period

The results of groundwater monitoring undertaken during the trial dredging is summarised in **Table 14**.

Table 14
Trial Dredging Monitoring Bores

Monitoring Bore	Approximate Location Relative to Dredge Pond	Monitoring Period
MB5	75m east	Entire period except 3 to 19 May 06
CSP3	150m west	Entire period except 23 June to 1 July 06
MB6A	290m south	Entire period
MB3	380m northeast	3 July to 12 July 06 only

The closest monitoring bores to the initial dredge pond were MB5 (75m east) and CSP3 (150m west). Monitoring was also undertaken in MB6A (290m) and MB3 (380m).

During the early stages of trial dredging, MB5 showed a slight drawdown of about 0.05m to 0.1m during the day with water levels recovering when the dredge was not operating overnight. None of the other monitoring bores responded significantly to the operation of the dredge.

Overall, the hydrographs show a general decline in groundwater levels from the commencement of the trial dredging on 19 April to 11 June 2006. The rate of decline in monitoring bores in close proximity to the dredging (MB5, CSP3) was similar to that observed in more distant monitoring bores (MB6A) suggesting that the general decline in water levels was due to the below average rainfall recorded over the period and was not significantly impacted by the trial dredging.

There were several rainfall events over the trial dredging period with low to moderate falls between 1mm and 22mm. A significant rise in groundwater levels occurred in June 2006 with three closely spaced rainfall events resulting in a rise of about 0.7m in groundwater levels.

As discussed in Section 12, the groundwater modelling for the Project was undertaken based on an initial sand extraction rate of 450,000m^3 per year. As the trial dredging was undertaken at an equivalent rate of about 104,000m^3 per annum, a rate similar to that which would initially occur during the ramp up period and about one-quarter of the proposed maximum extraction rate during the first two years of operation, the monitoring results record drawdown levels commensurate with the reduced rate of extraction and are supportive of the assumptions used in the modelling.

13.3.2 Waste Water Treatment Plant Construction Impacts

Dewatering associated with construction of the Tweed Shire Council Waste Water Treatment Plant (WWTP) located to the northwest of the Project Site commenced in mid Nov 2006. It is understood that spear points were installed at a depth of about 12m for dewatering with groundwater discharged into a pond which subsequently overflowed to the surrounding agricultural drains. The spear points were pumped at a rate of about 25L/s up to mid January 2007 when the rate was reduced to 20L/s until the end of February 2007. The pumping rate was further reduced from February 2007 to about 7L/s and is expected to continue until May 2007. The dewatering period is shown in **Figure 34**.

The hydrographs show again a general decline in groundwater levels in all monitoring bores from June 2006, however, the closest monitoring bore to the WWTP construction site, MB3, shows a more rapid decline in groundwater levels at the commencement of dewatering in November 2006. As the dewatering rates declined, the rate of decline observed in groundwater levels in MB3 also reduced (refer **Figure 34**). In February 2007, the groundwater levels in MB3 were similar to those in monitoring bores on the Project Site indicating that the reduced extraction rates were not resulting in any significant drawdown beyond the WWTP site.

During the initial years of sand extraction the maximum groundwater removal rate from the southern extraction pond is estimated to be between 20L/s and 30L/s (refer **Figure 16**). Groundwater extraction occurred at a similar rate (25L/s) during dewatering associated with the new WWTP site with a relatively limited impact on regional groundwater levels in the sand aquifer. Although the dewatering on the WWTP site was for a relatively limited period, the observations provide a level of confidence in the assumptions, and hence the outputs, of the numerical modelling that predicted a relatively limited cone of depression from the proposed sand extraction at similar groundwater extraction rates.

13.3.3 Dam Extraction Impacts

As detailed in Section 10, groundwater extraction occurs via two window lakes excavated in the sand mass on the adjacent R.Julius property. As the numerical modelling indicated groundwater levels will be drawn down in this area, particularly during the early years of the dredging operation, a monitoring program was implemented with the agreement of the landowner to determine baseline water levels and usage. Electronic water level loggers were installed in each window lake, referred to as Dam East and Dam West. In addition, flow meters were installed on the pumps that extract water from these dams for irrigation of crops on the Cudgen Plateau. Monitoring data collected since installation of the electronic loggers in early December 2006 are presented in **Figure 36** and **Figure 37**.

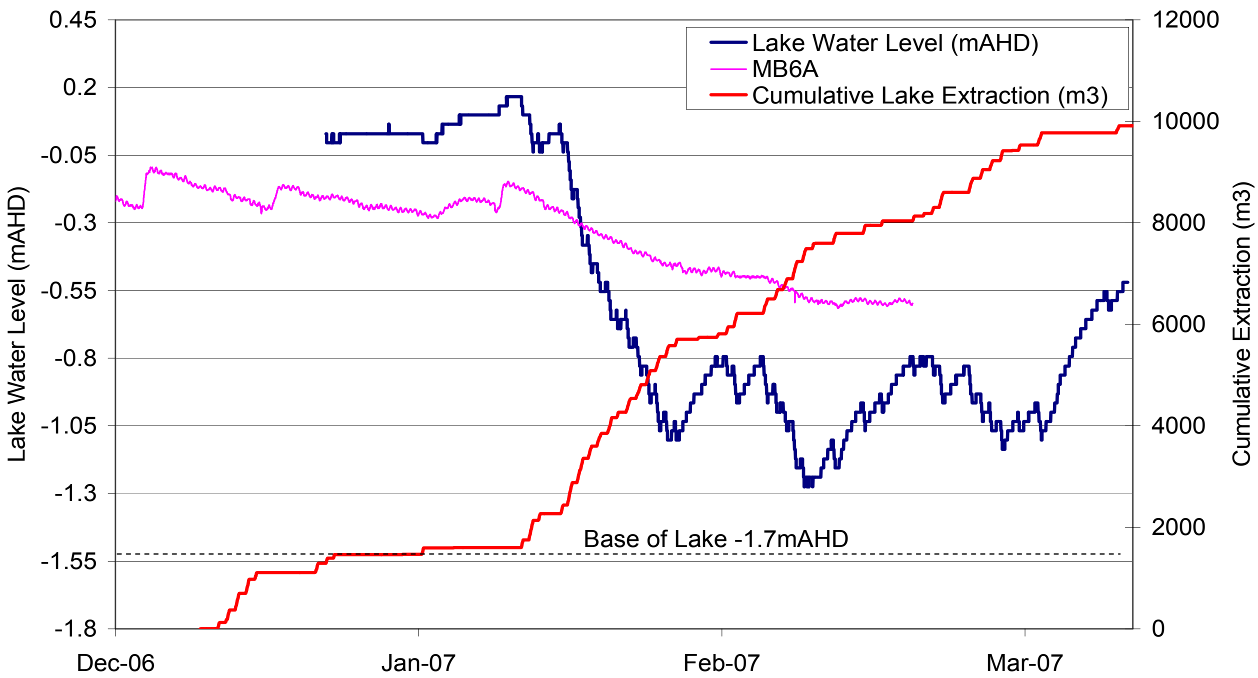


Figure 36: Western Dam Levels and Usage – R Julius Property

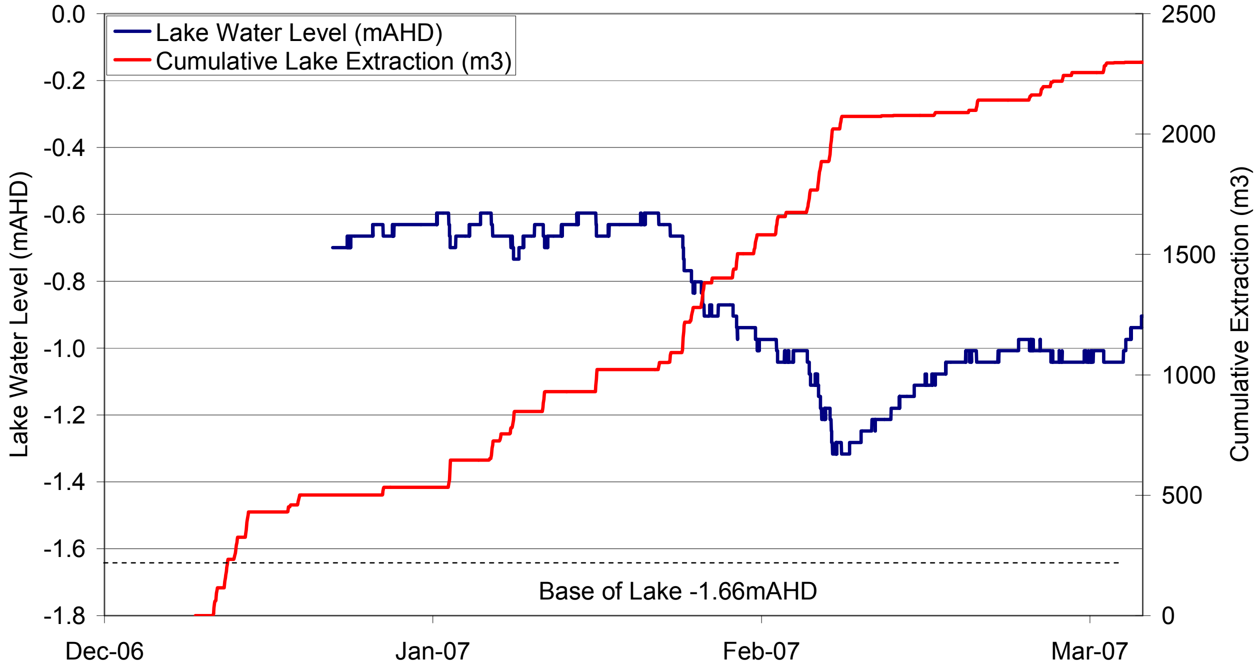


Figure 37: Eastern Dam Levels and Usage – R Julius Property

The monitoring indicates that the water levels in the window lakes are relatively low due to the extended drought being experienced in the area and that, after an extended period of extraction for irrigation, water levels are close to the base of the lakes. A slight decline in groundwater levels is evident in MB6A, located in close proximity to Dam West, during irrigation periods, however, there is no noticeable impact on the other monitoring bores on the Project Site.

The volume of water extracted since installation of the monitoring equipment in December 2006 is summarised in **Table 15**.

Table 15
Adjacent Dam Extraction Volumes

MONTH	Dam West		Dam East	
	m^3	ML	m^3	ML
Dec-06 (21 days)	1467	1.5	1048	1.0
Jan-07 (31 days)	4346	4.3	639	0.6
Feb-07 (28 days)	3412	3.4	79	0.1
Mar-07 (9 days)	683	0.7	533	0.5
TOTALS	9908	9.9	2299	2.3
Equivalent continuous extraction rate (L/s)	1.4		0.3	

About 9.9ML was extracted from the western dam and 2.3ML from the eastern dam over the summer season. This is equivalent to a continuous extraction rate of 1.4L/s and 0.3L/s for the western and eastern dams respectively. Of interest is that this measured rate is similar to the extraction rate of 1.3L/s assumed for each of the spears on the site in numerical modelling prior to availability of the monitoring data.

14 POTENTIAL IMPACTS OF THE PROJECT ON THE GROUNDWATER REGIME AND MITIGATION OPTIONS

14.1 Impact on Groundwater Table

Numerical and analytical modelling has shown that the impact of sand extraction on the groundwater table is very much dependent on the rate at which sand is extracted and on the size of the extraction ponds. During the initial years of sand extraction, when the southern extraction pond is of a relatively small size, drawdown of the water table would be greatest. Predictive modelling indicates that the drawdown would be to about -1.5m AHD in the southern extraction pond at an extraction rate of 450,000m^3 per year for the first 2 years of operations. As previously discussed, the rates modelled represent a ‘worst case’ scenario. In reality the average extraction rate would be lower than those modelled, particularly during the initial year of operations whilst extraction rates ‘ramp up’ to maximum levels. Hence the level and extent of groundwater drawdown associated with the southern extraction site is expected to be less than that predicted.

Furthermore, analytical modelling indicates that the concurrent extraction of 200,000m^3 of sand per year within the northern extraction site would not influence water levels within the southern extraction pond. The drawdown from the northern extraction site would be approximately 0.1m within a 60m radius during extraction.

As the southern extraction pond size increases with progressive extraction, an increased extraction rate within the southern extraction site could be accommodated and has been modelled at 650,000m^3 per year from Year 3 onwards. Due to the increased influence of rainfall inputs, the water table in the southern extraction pond would recover to about 1m of existing levels after Year 5. The radius of influence or the “cone of depression” created in the surrounding water table, as indicated by the 0.5m drawdown contour generally remains within the Project Site, with the exception of a 1.0m to 1.5m drawdown in the area adjacent the southern boundary at the toe of the Cudgen Plateau, as shown on **Figure 21**. Drawdown also occurs to the west of the Project Site, however, this is partially related to extraction from the adjacent Hanson Tweed Sand Quarry operation which currently extracts sand at a rate of 150,000m^3 per year. Approval has been given to extend the area and duration of extraction at this rate.

This impact on the water table has potential to:

- cause oxidation of soils within the “cone of depression”; and
- impact other groundwater users within the “cone of depression”.

These impacts are discussed in the following sections.

14.2 Acid Sulfate Soils and Sediments

The acid sulfate soil and sediment investigation for the Project has been reported separately by HMC (2008) – see Part 3 of the *Specialist Consultant Studies Compendium*. Based on conclusions reached in the report, no impacts would be expected where groundwater drawdown remains within the range of previously observed groundwater fluctuations. The observed groundwater level fluctuation range is from about -0.75m AHD to 0.75m AHD with a mean of about 0.25m AHD. Therefore the maximum simulated drawdown that can occur whilst remaining within this range is 1.0m.

As indicated in **Figure 21,** areas where simulated drawdown is greater than 1.0m are generally contained within the Project Site. Therefore, as the southern extraction pond size increases any PASS exposed would be removed with sand extraction. As discussed by HMC (2008), a precise elevation at which groundwater drawdown would result in the generation of acid cannot be defined. Testing by HMC (2008) recorded the presence of PASS above observed groundwater fluctuations, however monitoring of groundwater quality indicated that no adverse effects have occurred as a result of this exposure. The water quality analyses suggest that oxidation of acid sulfate soils has occurred in the area, as evidenced by the low Chloride/Sulfate ratios in the groundwater, however this oxidation has not resulted in any significant acidification of the water. It is considered likely then that exposure of PASS below the observed groundwater fluctuations would similarly not result in adverse impacts on groundwater quality (HMC, 2008).

Regardless, in the event that acid is generated as a result of groundwater drawdown, the southern extraction pond would always be a sink to groundwater flow during extraction operations. Therefore any acidic groundwater would discharge into the southern extraction pond rather than discharging off site or to the drainage network. Due to the buffering capacity within the sand and sediments below 6.0m in depth (-5.0m AHD), any acidic groundwater entering the southern extraction pond is likely to be effectively neutralised (HMC, 2008).

Should the Project receive Project Approval, an acid sulfate soil and water management plan would be developed outlining monitoring of extraction ponds water quality and acidity. The plan would also outline management options in the event that the pH of the extraction ponds departs from accepted criteria, such as treatment using hydrated lime or similar products, to return the pH to within the accepted range. Monitoring of the extraction ponds would continue post extraction until it can be demonstrated that there is no further risk of acid generation.

14.3 Impact on Other Groundwater Users

There is potential during the initial years of sand extraction for the landowners on the northern slopes of the Cudgen Plateau, and in particular at the base of the Plateau, to be adversely impacted. As discussed groundwater levels are predicted to be lowered by between 1.0m and 1.5m in this area which could result in lower yields from bores or spears, and dams excavated below the water table level may go dry in an extended drought.

The most potentially affected landowner (R. Julius) was visited as part of the bore census and on a number of subsequent occasions. An agreement has been reached to monitor water levels within the dams on the property that would potentially be affected and water usage rates. Monitoring of water levels and water usage has been occurring since December 2006. In the event that groundwater supplies are adversely affected as result of the proposed operation, it is recommended that an agreement be negotiated for compensation or the provision of an alternative water supply.

It is suggested that the most practical long-term measure would be the installation of a replacement bore within the tertiary basalt aquifer located to the south of the existing spears (Julius East and West). The quality or quantity of water within the tertiary basalt aquifer would not be affected by the Project and the replacement bore should provide a high quality water source suitable for irrigation. Alternatively, the existing spears may be deepened or an alternative supply from surrounding groundwater bores located on the Proponent's landholdings could be provided.

It is noted that the adjoining Hanson Tweed Sand Quarry would also experience groundwater drawdown levels greater than currently experienced under the quarry's existing operations. The effect of the Project on the Hanson Tweed Sand Quarry would be greatest during the initial years of development with drawdown levels of between approximately 1.0m and 1.5, within the easternmost part and between 0.5m to 1.0m over the remainder of the Hanson Tweed Quarry site.

It is important to note that a proportion of the drawdown would be as a result of operation of the Hanson Tweed Sand Quarry itself. The hydrological assessment undertaken by Gilbert and Sutherland (2005) for the extension to the quarry mistakenly assumed that the groundwater drawdown would not occur as precipitation exceeds rainfall within the Tweed area. However this assessment did not take into account the groundwater inflow required to replace the volume of sand extracted. As discussed within Section 12.2.1.2, the groundwater model prepared for the Project includes a water balance for the Hanson Tweed Sand Quarry which allows for the extraction of 150 000m^3 per year.

It is accepted that the bulk of the predicted drawdown during the early years of operation would be as a result of the Project, however, the contribution of the Project during the later years of the Project life would be greatly reduced. It also reiterated that modelling has predicted the worst case scenario, based on the maximum extraction rate and that it is unlikely that the predicted magnitude of drawdown would eventuate. Continued monitoring, particularly within bore MB2, would be undertaken and regular discussions held with site management at the Quarry to ensure that drawdown related to the Project is not significantly affecting the operation.

14.4 Groundwater Dependent Ecosystems

It is considered unlikely that groundwater dependent ecosystems would be adversely impacted for the following reasons.

1. As the shallow water table of the floodplain has previously been lowered by the extensive drainage network.
2. The area has been used for agricultural pursuits for a long period of time, leaving the Project Site, and much of the surrounding areas devoid of woody vegetation.
3. The radius of influence of dewatering is relatively small and is essentially contained within the Project Site. Any drawdown outside of the Project Site which would influence potential groundwater dependent ecosystems would be within previously recorded levels of groundwater fluctuation.

14.5 Impact on Groundwater Quality

Water quality monitoring in the operating sand extraction facility of Hanson Tweed Sand on the western boundary of the Project Site and in surrounding groundwater monitoring bores has been undertaken as part of the licence conditions for the operation, and is reported by JGA (2005) in Appendix K of the EIS for the proposed expansion of the facility. It is stated in Appendix K, that *"the approved monitoring program results and unofficial monitoring records of deep dredging EC have demonstrated that no increase in salinity has occurred despite dredging operations being undertaken at approximately 20m depth"* (pp29-30). It is also reported that depth profile monitoring was undertaken at two locations in the pond at 1m intervals, between October 2002 and December 2003. The results indicate a pH range of 7.34 to 8.44 with EC monitoring providing average results of 2346 and 2425µS/cm at stations SW1 and SW2 respectively. It was concluded that *"the mean results are consistent with the EC levels recorded during the previous 12 months of monitoring".* The overall conclusion reached in the EIS was that with respect to water quality, the monitoring records demonstrate *"satisfactory environmental performance of the site operations".*

Groundwater quality has been monitored on a regular basis in seven bores constructed around the existing sand extraction operation. It is concluded in Appendix K of the EIS (JGA 2005) that *"no significant or sustained increase or decrease in EC was recorded at any of the monitoring bore locations".*

Given this example from the adjacent operating sand extraction facility, it can be concluded that the EC of the dredge pond water of the Cudgen Lakes Sand Extraction Project would be similar, that is an EC of around 2500µS/cm. However, as previously discussed, there would be a lowering of the water table which would potentially expose PASS material, leading to the generation of acidic water. It is expected that the buffering capacity of the sand and sediments below -5.0m AHD would be sufficient to maintain the extraction pond water at a neutral pH. However, an Acid Sulfate Soils and Sediments management plan would be developed and measures implemented to ensure that any acidity is managed to prevent environmental harm.

15 GROUNDWATER MONITORING PROGRAM

15.1 Monitoring Objective

To prevent the degradation of groundwater quality and minimise potential impacts on the existing groundwater movement regime.

15.2 Monitoring Network

A groundwater monitoring program has been established on the Project Site with a total of 21 monitoring bores established within and surrounding the proposed sand extraction sites as shown on **Figure 4** and summarised in **Table 3**. The bores are currently monitored at quarterly intervals, however, during the first year of operations, monthly monitoring would be undertaken (see Section 15.3). In addition three bores, MB3, MB6A and MB8A shown on **Figure 4**, would have data loggers installed to measure groundwater levels at hourly intervals. Water levels would also continue to be monitored within the two dams (window lakes) on the R. Julius property. Extraction from the Julius dams would be monitored using flow meters connected to the pumps extracting from the dams.

In addition, an agreement should be sought with the relevant landowners for the monthly monitoring of water levels within the closest potentially affected non-project related groundwater bores.

15.3 Monitoring Frequency

The following groundwater monitoring regime would be undertaken throughout the life of the Project.

- Monthly monitoring for pH, EC, temperature, REDOX potential and groundwater level (m AHD) in the groundwater network and the two dams located on the R. Julius property would be undertaken during the first year of operations and subject to review, monitoring would be extended to quarterly monitoring.
- Groundwater level monitoring (m AHD) within the northern and southern ponds and the two Julius dams would be undertaken concurrently with the monthly / quarterly groundwater monitoring program. Extraction from the Julius dams (as indicated by flow meter readings) would also be recorded on a monthly basis.
- Quarterly monitoring for pH, EC, temperature, REDOX potential, groundwater level (m AHD), dissolved oxygen, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, filterable iron, aluminium and arsenic would be undertaken by a suitably qualified person at the approved monitoring locations. All analyses would be undertaken at a NATA accredited laboratory.
- Quarterly groundwater monitoring in accordance with the above schedule would continue following the cessation of extraction and placement of VENM. This would continue for 12 months with a reduction to annual monitoring if compliance with background water quality objectives can be demonstrated. Annual monitoring would cease after five years if there are no substantial variations in water quality (due to previous site activities) can be demonstrated.

15.4 Auditing

Monitoring results would be reviewed quarterly by a suitably qualified person as part of the auditing process for the site during the first year to ensure the data being collected is meaningful to the ongoing monitoring of potential impacts of the Project. Following the first year, monitoring results would be reviewed on a six monthly basis. All results, and the commentaries by the suitably qualified person would be incorporated in the relevant Annual Environmental Management Report.

15.5 Reporting

Results of the monthly / quarterly in situ monitoring program would be compiled and forwarded to DWE (if requested or required). The monthly and quarterly results (including interpretation) would be compiled and forwarded to DWE as part of the annual return for the site.

15.6 Identification of Incident or Failure of Management Practices

The following events are indicators of the occurrence of an incident or failure of management practices.

- Deterioration in groundwater quality outside of the effects of drought or flood due to on-site activities.
- Significant variations in groundwater level outside drought or flood conditions due to on-site activities.
- Formation of a cone of depression or a groundwater mound greater than observed variations and that extends beyond the Project Site boundary.

15.7 Corrective Action

Should a decline in groundwater levels occur beyond the predicted levels or if a decline in groundwater quality beyond the effects of drought or flood is identified a detailed sampling and analysis program would be undertaken to identify the reason for the drawdown or the source of the contamination. Once appropriate actions, such as implementation of an agreement or a reduction in the extraction rate, have been undertaken to remedy the problem the detailed monitoring program may cease.

16 SUMMARY AND RECOMMENDATIONS

The review of existing hydrogeological information for the Project Site indicates that there are two aquifers in the area, namely the Quaternary sands of the Tweed River flood plain and the Tertiary basalts of the Lamington Volcanics.

The Quaternary sand aquifer is about 20m thick and is saturated from about 0.5m below ground level. The groundwater in the aquifer is fresh close to the Cudgen Plateau but becomes brackish at the base of the aquifer with increasing distance to the north. Groundwater use in the area appears to be relatively limited because the poor quality groundwater at the base of the aquifer restricts the depth and hence yield of bores. Groundwater extraction from the sand aquifer via spears and window lakes occurs on the properties immediately adjacent to the southern boundary of the Project Site. The landholders on the adjacent property use groundwater from the sand aquifer for irrigation of a variety of crops on the Cudgen Plateau during dry periods. Monitoring of water levels in surrounding dams and water usage rates has commenced and would continue throughout the life of the Project.

An analytical model was developed to assess the potential impacts of the northern extraction site. The model assumed an extraction rate of 200 000m^3 per year for the first 2 years of operation. Groundwater drawdown as a result of the northern extraction site was predicted to be 0.1m at 60m with no influence beyond 100m from the northern extraction pond. It was also determined that there would be no cumulative impact with the concurrent operation of the northern and southern extraction ponds.

A numerical model was also constructed to simulate the groundwater regime in the area and to assess the potential impacts of the southern extraction site. Numerical models require simplification of the groundwater regime and use of assumptions where actual data is limited. The model assumed the proposed operation extracted 450,000m^3 per year for the initial 2 years of extraction then 650,000m^3 per year for the remaining life of the Project (about 6 years at the maximum extraction rate). It is understood that the extraction rate is dependent on the requirement for sand at the fill sites and, when demand is low, it is unlikely that an annual extraction rate of 650,000m^3 per year would occur. Therefore the results of the modelling are considered to be a worst case scenario. In the likely event that extraction rates are less than those modelled, the extraction would occur over a longer period and the level and extent of groundwater drawdown would be reduced.

Within the southern extraction pond, the equivalent groundwater extraction rate from the extraction pond surface was determined to be greatest in the early stages of the Project when the extraction pond area is relatively small. A drawdown of up to 1.5m would occur within the pond. As the area of the extraction pond increases over the life of the Project, the volume of groundwater removed per unit surface area of the pond would be reduced.

A larger area of aquifer would be exposed at the sides of the pond as the extraction pond increases in size, thus resulting in greater groundwater inflow and less drawdown. The relative input from rainfall would also increase and hence reduce the net water loss from the southern extraction pond. The drawdown in the pond would therefore decrease to about 1m in the latter stages of sand extraction and greater extraction rates could be accommodated with negligible additional impacts on groundwater levels. At the end of sand extraction, under average rainfall conditions, there would be a net input to the lake (completed southern extraction pond), and therefore the impact on the groundwater regime would be negligible.

Drawdown of the water table of below observed fluctuation levels may expose PASS material that has not previously been exposed, potentially resulting in acid generation. The area where water levels would potentially be drawn below previous fluctuation levels is generally contained within the Project Site. It is noted that PASS material has been recorded above the observed groundwater fluctuation levels without adverse impacts on water quality (HMC, 2008). Regardless, as the extraction ponds would always be a sink to groundwater flow during extraction operations any acidic groundwater that may be generated would discharge into the extraction ponds rather than discharging off site or to the drainage network. Due to the buffering capacity within the sand and sediments below 6.0m in depth (-5.0m AHD), any acidic groundwater entering the southern extraction pond is likely to be effectively neutralised (HMC, 2008). Furthermore, any oxidised PASS would be removed by subsequent sand extraction.

In the early stages of sand extraction within the southern extraction site, groundwater levels at the location of the spear point referred to as Julius West and adjacent dam on the R. Julius property to the south, are predicted to be lowered between 0.75m and 1.75m below the water level that would naturally occur at the location without sand extraction. At the spear point referred to as Julius East and the adjacent dam, the additional drawdown is predicted to be between 0.5m and 1.0m. Therefore in the early stages of the Project there is potential for the water supply for the adjacent agricultural operation to be impacted if below average rainfall occurs during this period. The extent of impact would depend on the spear point depths which are not known. In the event that unacceptable impacts attributable to the Project are identified, an agreement for compensation or an alternative water supply is in place with the landholder.

It is recommended that the most practical and long-term solution would be the installation of a replacement bore within the Tertiary basalt aquifer as the quantity and quality of water within this aquifer would not be affected by the Project.

A number of bores are also located within properties adjoining Tweed Coast Road about 500m to the northeast of the Project Site. Most of these properties have shallow spears that are used for irrigation of gardens. No drawdown is predicted during the early stages of extraction, however, the model predicts an additional drawdown of typically less than 0.5m at the closest bore, GW300845 during the latter stages of extraction in the southern extraction site. This level of drawdown is within the range of natural fluctuations and above the total depth of the registered bores in this area, hence it is predicted that any impacts would be negligible.

It is also predicted that groundwater drawdown levels at the adjoining Hanson Tweed Sand Quarry operation would also be affected by the Project. The combined groundwater drawdown levels are expected to be between approximately 1.0m and 1.5m within the easternmost part and 0.5m and 1.0m over the remainder of the site during the early stages of the Project. As the Project progresses, the contribution of the Project to groundwater drawdown levels within the Hanson Tweed Sand Quarry would reduce. It is considered unlikely that these levels of drawdown would significantly impact upon the operation and regular discussions would be held with the operator.

Water levels within and surrounding the Project Site are predicted to return to pre-extraction levels rapidly following the cessation of extraction.

Based on the available information collected during the groundwater investigations, it is recommended that, pre-existing condition reports should be prepared for all private bores in a 1.5km proximity to the Project Site prior to extraction, should the Project proceed. This would include collection of samples, water quality analysis, measurement of groundwater levels and surveying of bore elevations.

In summary, it is concluded that the Project would have minimal impacts to groundwater and groundwater-related aspects. Management plans would need to be developed to monitor any changes to the groundwater environment and mitigation measures would need to be implemented where adverse impacts are likely to occur.

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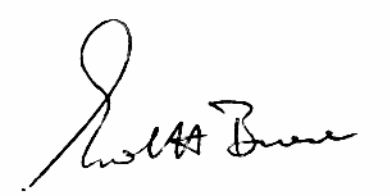
AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD

JAMES TOMLIN
Senior Hydrogeologist



ERROL H. BRIESE
Managing Director/Principal Hydrogeologist

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Appendices

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Appendix 1

Coverage of Environmental Assessment Requirements and Issues Relating to Groundwater

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Table A1-1
Coverage of *Environmental Assessment* Requirements and Environmental Issues in the Groundwater Assessment

Page 1 of 3

ENVIRONMENTAL REQUIREMENTS RAISED BY THE DIRECTOR-GENERAL RELATING TO GROUNDWATER (06.01.06)	
	Relevant Section(s)
Key Assessment Requirements, namely: • *Groundwater* - Assess the potential impacts of the Project (including any potential cumulative impacts that may arise from the combined operation of the Project with the existing or approved operations at the Bolster Quarry), and describe what measures would be implemented to avoid, minimise, mitigate, offset, manage and/or monitor these impacts.	12.1.2
References Refer to the: • *Guidelines for Fresh and Marine Water Quality* (ANZECC); • *Managing Urban Stormwater: Soils & Construction* (Landcom); and • the various *State Groundwater Policy* documents and *Floodplain Development Manual* (Department of Natural Resources).	10.3.4

ENVIRONMENTAL REQUIREMENTS RAISED BY GOVERNMENT AGENCIES RELATING TO GROUNDWATER		
Government Agency	**Paraphrased Requirement**	**Relevant Section(s)**
Department of Environment and Conservation (15 October 2004)	Provide maps showing the locality of the proposed development in a regional and local context. Base local context maps on 1:25 000 topographic plans.	Figure 1
	Provide a description of: – the existing environment on the subject and surrounding land; – the proposed development and ancillary works; and – the manner in which the environment will be modified by the proposal.	10 2 13
	Clearly identify on an appropriately scaled plan the area subject to development.	Figure 1
	Consult the general requirements from the EIS Guidelines Extractive Industries – Dredging and other extraction in riparian and coastal areas during the preparation of the EIS.	3
	Document surveys and assessments that have been undertaken by suitably qualified persons and provide the qualifications and experience of the person(s) undertaking the work.	7, 9
	Describe dates, site locations, design, methodology, analysis techniques, and weather conditions at the time of the assessments and surveys. The limitations of surveys should be identified and the results interpreted accordingly.	7, 9

Table A1-1 (Cont'd)
Coverage of *Environmental Assessment* Requirements and Environmental Issues in the Groundwater Assessment

Page 2 of 3

ENVIRONMENTAL REQUIREMENTS RAISED BY GOVERNMENT AGENCIES RELATING TO GROUNDWATER		
Government Agency	**Paraphrased Requirement**	**Relevant Section(s)**
Department of Environment and Conservation (Cont'd) (15 October 2004)	Substantiate conclusions drawn in surveys and assessments with evidence resulting from those surveys and assessments.	Appendices 1 and 3
	Address the cumulative impact on groundwater for this proposal, the local existing dredging activities and the adjoining proposed sand extraction dredge ponds in the local areas.	12
	Identify any potential impacts on quality or quantity of groundwater describing their source.	13
	Describe hydrological impact mitigation measures including: – site selection; – minimising runoff; – minimising reductions or modifications to flow regimes; – avoiding modifications to groundwater.	NA
	Describe groundwater impact mitigation measures including: – site selection; – retention of native vegetation and revegetation; – artificial recharge; – providing surface storages with impervious linings; and – monitoring program.	13
Department of Natural Resources (North Coast Region) (6 December 2004)	Licence all bores with the Department prior to any drilling on site.	TBP
	Undertake the following aquifer investigations using a qualified groundwater consultant.	
	1. Provide a detailed map showing the location of all drill holes and monitoring bores.	Figure 4
	2. Install monitoring bores at key locations to measure both shallow and deep groundwater quality across the site.	8, 9, App 2
	3. Install monitoring bores based on geology/depth of proposed excavation, with relatively short screens intervals, installed at multiple depths.	8, 9, App 2
	4. Undertake an assessment of the discrete groundwater hydrogeochemistry by a qualified consultant to determine the impact of mining and mixing of groundwater through the aquifers water column.	13.4

Table A1-1 (Cont'd)
Coverage of *Environmental Assessment* Requirements and Environmental Issues in the Groundwater Assessment

Page 3 of 3

ENVIRONMENTAL REQUIREMENTS RAISED BY GOVERNMENT AGENCIES RELATING TO GROUNDWATER		
Government Agency	**Paraphrased Requirement**	**Relevant Section(s)**
Department of Natural Resources (North Coast Region) (Cont'd) (6 December 2004)	5. Measure groundwater quality parameters for pH/EC/DO/EH from each of the bores.	10.3.4
	6. Analyse shallow and deep groundwater for the following: cations/anions, (Ca, Mg, Na, K / HC_{O3}, S_{O4}, Cl), (Fe), (As) (Mn), (Al).	10.3.4
	7. Measure groundwater levels to define flow contours (relative to AHD) to show groundwater flow directions.	10.3.3
	8. Provide test results detailing the percentage of pyritic material and its size present in the acid sulfate (pyritic) fines, microscopic examination to describe the morphology of iron sulphide fragments and their range of sizes, and visual estimation of the abundance of iron sulphide.	NA
	9. Provide a visual estimation by microscopic examination of the percentage of shell material and other calcareous components within unconsolidated sediments.	NA
	10. Determine aquifer hydraulic parameters and surrounding impacts based on the proposed extraction volume.	11.4.4 and 12
	11. Outline a management plan for the disposal/storage of acid sulfate fines.	NA
	12. Provide an interpreted hydrogeological report detailing the impacts that the development may have with respect to water quality, quantity and groundwater dependant ecosystems	This report
	13. Detail a proposed groundwater management plan for the site and progressive rehabilitation plan in the EIS.	
	Obtain licences under Part V of the Water Act 1912 for the following. 1. A monitoring bore licence. 2. An industrial groundwater licence (aquifer interference licence) to carry out sand extraction.	 Noted Noted
	Obtain a licence to pump water from the pit or bores to carry out washing of the extracted material and dust suppression (Low volume – no lowering of the water table will be permitted).	3
Department of Primary Industries (Agriculture) (7 October 2004)	Provide a measure of potential cumulative impacts resulting from additional sand extraction on the Chinderah floodplain.	12

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Appendix 2

Borehole Logs and Maps

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GEOTECHNICAL ENGINEERING SERVICES
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BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 1 Page 1
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
TOPSOIL/ ALLUVIUM			0.2		Silty **SAND:** Fine grained sand, With organic material (fine roots), Very moist, Black **(SM)**	
ALLUVIUM		▼	0.8		**SAND:** Fine grained sand, Very moist, Pale yellow/ brown **(SP)**	
			3.8		Silty **SAND:** Fine grained sand, Wet, Grey (SM)	
	7.0m SPT 9,12,14 N = 26 7.45m		7.35		Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	

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BOREHOLE PROFILE

CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:** BH 1 Page 2
PROJECT: CHINDERAH SAND QUARRY	**JOB No:** BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
			7.35		*Continued from Page 1*	
	8.0m SPT 11,14,14 N = 28 8.45m					
	9.0m SPT 8,11,10 N = 21 9.45m				Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	
	10.0m		10.1			
	SPT 8,5,4 N = 9 10.45m		10.7		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	
ALLUVIUM	11.0m SPT 9,12,15 N = 27 11.45m					
	12.0m SPT 13,15,18 N = 33 12.45m				Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	
	13.0m SPT 13,14,14 N = 28 13.45m					
	14.0m SPT 9,14,17 N = 31 14.45m					
			15.0		*Continued on Page 3*	

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CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 1 Page 3
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
	15.0m		*15.0*		*Continued from Page 2*	
	SPT 9,20,38 N = 58					
	15.45m					
	16.0m					
	SPT 15,25,30/100 N = >50					
	16.4m					
	17.0m					
	SPT 18,31,20/60 N = >50					
ALLUVIUM	17.36m				Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	
	18.0m					
	SPT 15,26,40 N = 66					
	18.45m					
	19.0m					
	SPT 20,29 N = >50					
	19.3m					
	20.0m		20.0			
	SPT 24,31 N = >50				**BH 1 TERMINATED AT 20.0m** **LIMIT OF INVESTIGATION**	
	20.3m					

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BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 2 Page 1
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM / TOPSOIL			0.4		Silty **SAND:** Fine grained sand, Very moist, Black **(SM)**	
ALLUVIUM		▼	1.1		Silty **SAND:** Fine grained sand, Very moist, Brown **(SM)**	
			3.3		Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	
	7.0m SPT 9,9,11 N = 20 7.45m		7.35		Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	

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CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:** BH 2 Page 2
PROJECT: CHINDERAH SAND QUARRY	**JOB No:** BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
			7.35		*Continued from Page 1*	
			7.6		Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	
	8.0m SPT 10,12,12 N = 24 8.45m					
	9.0m SPT 11,14,14 N = 28 9.45m					
	10.0m SPT 13,14,20 N = 34 10.45m					
ALLUVIUM	11.0m SPT 17,23,20 N = 43 11.45m				Silty **SAND:** Fine grained sand, With a trace of shell fragments, Wet, Grey **(SM)**	
	12.0m SPT 7,12,20 N = 32 12.45m					
	13.0m SPT 12,18,19 N = 37 13.45m					
	14.0m SPT 11,16,22 N = 38 14.45m					
			15.0		*Continued on Page 3*	

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BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 2 Page 3
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM	15.0m SPT 11,18,23 N = 41 15.45m		*15.0* 15.4		*Continued from Page 2* Silty **SAND:** Fine grained sand, With a trace of shell fragments, Wet, Grey **(SM)**	
	16.0m SPT 6,10,12 N = 22 16.45m		16.8		Silty **SAND:** Fine grained sand, With a trace of shell fragments, Fine chips of burnt wood, Wet, Grey **(SM)**	
	17.0m SPT 5,8,10 N = 18 17.45m		17.9		Silty **SAND:** Fine grained sand, Trace of clay, With chips of burnt wood Wet, Dark grey **(SM)**	
	18.0m SPT 1/450 N = 0		18.5		Marine **CLAY**	
	18.45m				**BH 2 TERMINATED AT 18.5m** **LIMIT OF INVESTIGATION**	

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BOREHOLE PROFILE

CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:** BH 3 Page 1
PROJECT: CHINDERAH SAND QUARRY	**JOB No:** BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM / TOPSOIL			0.2		Silty **SAND:** Fine grained sand, With a trace of clay and organic material (fine roots), Very moist, Black **(SM)**	
ALLUVIUM		▼	1.0		Silty **SAND:** Fine grained sand, Very moist, Pale brown with some pale orange mottling **(SM)**	
			3.7		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	
	7.0m SPT 13,16,17 N = 33 7.45m		7.35		Silty **SAND:** Fine grained sand, With some shell fragments, Wet, Dark grey **(SM)**	

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BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 3 Page 2
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
			7.35		*Continued from Page 1*	
	8.0m SPT 11,11,14 N = 25 8.45m					
	9.0m SPT 13,16,15 N = 31 9.45m					
	10.0m SPT 11,13,14 N = 27 10.45m					
ALLUVIUM					Silty **SAND**: Fine grained sand, With some shell fragments, Wet, Dark grey **(SM)**	
	13.0m SPT 13,11,17 N = 28 13.45m					
			15.0		*Continued on Page 3*	

Logged By	GDM	Date	18/5/05	Checked By	[signature]	Date	21/6/05

Form R32 Issue 3

BORDER - TECH

GEOTECHNICAL ENGINEERING SERVICES
6/12 Greenway Drive, Tweed Heads South Ph (07) 5524 6199
1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 3 Page 3
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM			*15.0*		*Continued from Page 2*	
					Silty **SAND:** Fine grained sand, With some shell fragments, Wet, Dark grey **(SM)**	
	18.0m		17.6		Silty **SAND:** Fine to medium grained sand, With some shell fragments, Trace of organic material (burnt wood), Wet, Dark grey **(SM)**	
	SPT Sunk N = 0 18.45m		18.0		Clayey **SAND:** Fine to medium grained sand, With some shell fragments, Very moist, Dark grey **(SC)**	
			18.5		**BH 3 TERMINATED AT 18.5m** **LIMIT OF INVESTIGATION**	

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GEOTECHNICAL ENGINEERING SERVICES
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1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD		**BOREHOLE No:**	BH 4 Page 1
PROJECT: CHINDERAH SAND QUARRY		**JOB No:**	BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm		

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM / TOPSOIL			0.3		Silty **SAND:** Fine grained sand, With organic material (fine roots), Very moist, Black **(SM)**	
ALLUVIUM		▼	0.7		Silty **SAND:** Fine grained sand, Very moist, Brown with some orange mottling **(SM)**	
			4.3		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	
	7.0m SPT 8,9,12 N = 21 7.45m		7.35		Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	

Continued on Page 2

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BORDER - TECH

GEOTECHNICAL ENGINEERING SERVICES
6/12 Greenway Drive, Tweed Heads South Ph (07) 5524 6199
1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:** BH 4 Page 2
PROJECT: CHINDERAH SAND QUARRY	**JOB No:** BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
			7.35		*Continued from Page 1*	
	8.0m SPT 13,14,16 N = 30 8.45m					
	9.0m SPT 12,16,18 N = 34 9.45m					
	10.0m SPT 12,20,24 N = 44 10.45m					
ALLUVIUM	11.0m SPT 10,21,24 N = 45 11.45m				Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	
	12.0m SPT 15,25,34 N = 59 12.45m					
	13.0m SPT 14,29 N = >50 13.3m					
	14.0m SPT 18,34 N = >50 14.3m		14.8			
			15.0		*Continued on Page 3*	

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Form R32 Issue 3

BORDER - TECH

GEOTECHNICAL ENGINEERING SERVICES
6/12 Greenway Drive, Tweed Heads South Ph (07) 5524 6199
1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 4 Page 3
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
	15.0m SPT 13,23,21 N = 44 15.45m		*15.0*		*Continued from Page 2*	
	16.0m SPT 14,34 N = >50 16.3m					
	17.0m SPT 17,34,30/100 N = >50 17.4m					
ALLUVIUM					Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	
	18.0m SPT 22,34 N = >50 18.3m					
	19.0m SPT 24,26 N = 50 19.3m		19.8			
	20.0m SPT Sunk N = 0		20.1		Silty **SAND:** Fine to medium grained sand, Trace of clay, With shell fragments, Wet, Dark grey **(SM)**	
	20.45m		20.5		Marine **CLAY:**	
					BH 4 TERMINATED AT 20.5m **LIMIT OF INVESTIGATION**	

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1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:** BH 5
PROJECT: CHINDERAH SAND QUARRY	**JOB No:** BT 14650
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM / TOPSOIL			0.2		**Silty SAND:** Fine grained sand, With organic material (fine roots), Very moist, Black **(SM)**	
ALLUVIUM			0.8		**Silty SAND:** Fine grained sand, Moist, Pale brown and orange mottled **(SM)**	
		▼	3.8		**Silty SAND:** Fine grained sand, Very moist, Dark grey **(SM)**	
			4.8		**Silty SAND:** Fine grained sand, With some fine shell fragments, Wet, Grey **(SM)**	
			6.0		**Silty SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	
					BH 5 TERMINATED AT 6.0m **LIMIT OF INVESTIGATION**	

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GEOTECHNICAL ENGINEERING SERVICES
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1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 6 Page 1
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM / TOPSOIL			0.2		Silty **SAND:** Fine grained sand, With organic material (fine roots), Very moist, Black **(SM)**	
ALLUVIUM		▼	0.8		**SAND:** Fine grained sand, Very moist, Pale brown and orange mottled **(SP)**	
			1.3		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	
			2.1		Silty **SAND:** Fine grained sand, With a trace of clay, Wet, Dark grey **(SM)**	
			2.7		Silty **SAND:** Fine grained sand, With shell fragments, Trace of clay, Wet, Grey **(SM)**	
			4.7		Silty **SAND:** Fine grained sand, With shell fragments, Wet, Grey **(SM)**	
	7.0m SPT 9,12,14 N = 26 7.45m		7.35		Silty **SAND:** Fine grained sand, With shell fragments. Wet, Pale grey **(SM)**	

Continued on Page 2

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BORDER - TECH

GEOTECHNICAL ENGINEERING SERVICES
6/12 Greenway Drive, Tweed Heads South Ph (07) 5524 6199
1/35 Old Pacific Highway, Yatala Ph (07) 3804 6844

BOREHOLE PROFILE

CLIENT:	HMC ENVIROMENTAL CONSULTING PTY LTD	**BOREHOLE No:**	BH 6 Page 2
PROJECT:	CHINDERAH SAND QUARRY	**JOB No:**	BT 14650
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	100mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM	9.0m SPT 17,25,36 N = 61 9.45m		7.35 9.8		*Continued from Page 1* Silty **SAND:** Fine grained sand, With shell fragments. Wet, Pale grey **(SM)**	
RESIDUAL			11.0		Clayey Sandy **GRAVEL:** Fine to coarse grained sand and gravel, Moist, Orange with some grey mottling **(GP)**	
NERANLEIGH FERNVALE BEDS			11.2		**ROCK**	
					BH 6 TERMINATED AT 11.2m **TUNGSTEN CARBIDE REFUSAL**	

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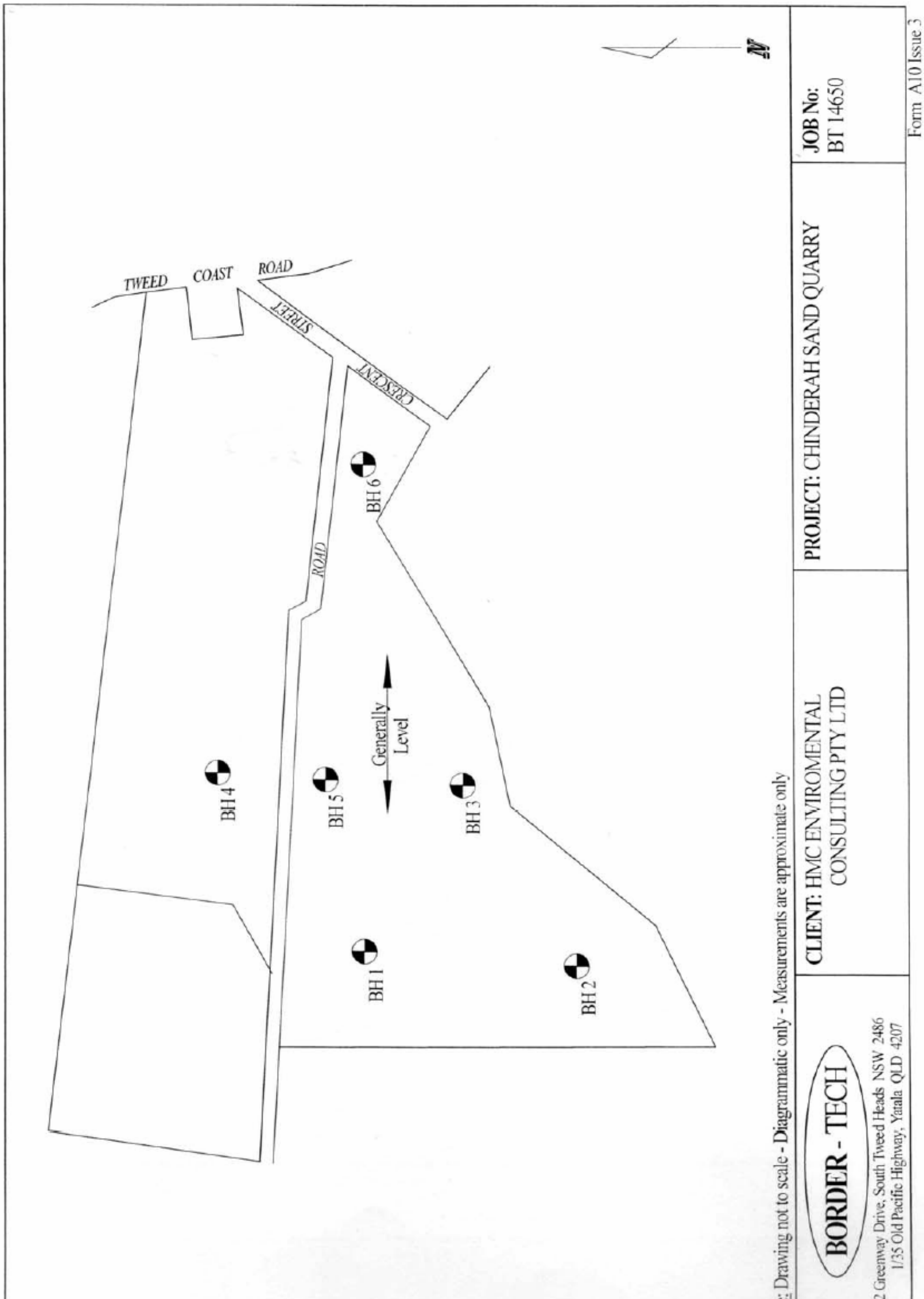
Form R32 Issue 3


N
TWEED COAST ROAD
STREET
CRESCENT
ROAD
BH 6
Generally Level
BH 4
BH 5
BH 3
BH 1
BH 2
Note: Drawing not to scale - Diagrammatic only - Measurements are approximate only
JOB No: BT 14650
PROJECT: CHINDERAH SAND QUARRY
CLIENT: HMC ENVIROMENTAL CONSULTING PTY LTD
BORDER - TECH
12 Greenway Drive, South Tweed Heads NSW 2486
1/35 Old Pacific Highway, Yatala QLD 4207
Form A10 Issue 3

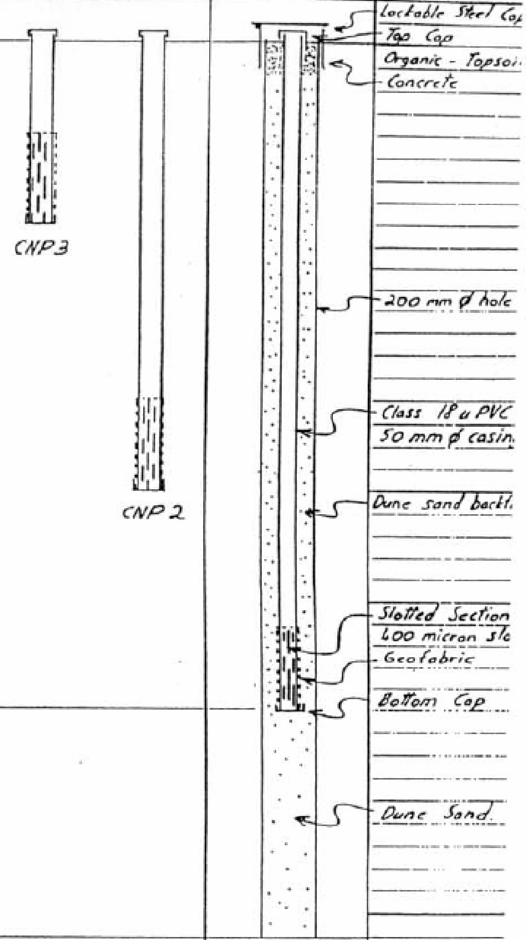
HOLE No.: CNP1 JOB No. 4236/4
CO-ORDINATES: E N RL
LOCATION: REFER LOCALITY PLAN - FIGURE 1

Drilling method: ROTARY – HOLLOW AUGER

Water: SWL at 15.43hrs 21/7/91

scale (m)	GEOLOGICAL LOG
0 – 0.5	CLAYEY SAND: Fine to medium, dark grey/black
0.5 – 5	SAND: Fine to medium grained, dark grey, slightly clayey/silty, wet. – with shell fragments
5 – 10	SAND: Fine to medium grained, grey, trace silt, trace shell fragments/shells, wet
10 – 15	SAND: Fine to medium grained, grey to light grey, trace shells, wet
15	CNP1 Completed at depth 15.0m
19.5 – 20	SILTY CLAY: High plasticity, grey with yellow brown mottling, moist. Auger Hole Penetrated to 20m

ADDITIONAL LOGS – Adjacent boreholes construction details (diagrammatic) | bore hole construction details | airlift yield structure and additional observations



DRILL TYPE: HYDRAPOWER
FEED: HYDRAULIC
DRILLER: GEOPROBE
COMMENCED: 19/7/91
COMPLETED: 19/7/91
LOGGED BY: JNW/ASW
CHECKED BY: JNW
VERTICAL SCALE: SHOWN

KEY

penetration: no resistance ranging to refusal

water: 10.1.80 water level and date; water inflow; water outflow

AGC Woodward-Clyde

CLIENT: KEOWN & DRUMMOND PTY LTD

PROJECT: SAND WINNING PROJECT, CUDGEN RESULTS OF SITE INVESTIGATION

LOG OF BORE CNP1
(CNP2 and CNP3 similar)

Date:	Drg No:	Fig No:
JUL 1992	4236/4/A1	A1

HOLE No.: CSP 1 JOB No. 4236/4
CO-ORDINATES: E N RL
LOCATION: REFER LOCALITY PLAN - FIGURE 1

Drilling method: ROTARY - HOLLOW AUGER

Water: SWL at 1645 hrs 21/7/91

scale (m)	GEOLOGICAL LOG
0 – 0.5	CLAYEY SAND: fine to medium, dark grey/black.
0.5 – 2	SAND: fine to medium grained, light grey, some coarse sand, slightly organic, moist - becomes wet
2 – 5	SAND: fine to medium grained, dark grey wet.
5 – 11	SAND: fine to medium grained, grey to dark grey, trace shell fragments wet
11 – 15	SAND: fine to medium grained, dark grey, wet.
15	CSP1 Completed at depth 15.2m
23 – 23.5	SILTY CLAY: High plasticity, grey to light grey, moist.
23.5	CSP1 Auger Hole Penetrated to 23.5m

ADDITIONAL LOGS Adjacent boreholes construction details (diagrammatic): CSP3, CSP2

Bore hole construction details / airlift yield structure and additional observations:

- Lockable Steel Ca[p]
- Top Cap
- Organic - Topso[il]
- Concrete
- 200 mm ø hole
- Class 18 uPVC 50 mm ø casin[g]
- Dune Sand back fill
- Slotted Section 400 micron sl[ot]
- Geofabric
- Bottom Cap
- Dune Sand

DRILL TYPE HYDRAPOWER
FEED HYDRAULIC
DRILLER GEOPROBE
COMMENCED 19/7/91
COMPLETED 19/7/91
LOGGED BY JNW/ASW
CHECKED BY JNW
VERTICAL SCALE SHOWN

KEY
penetration: no resistance ranging to refusal
water: 10.1.80 water level and date; water inflow; water outflow

AGC Woodward-Clyde

CLIENT: KEOWN & DRUMMOND PTY LTD
PROJECT: SAND WINNING PROJECT, CUDGEN RESULTS OF SITE INVESTIGATION

LOG OF BORE CSP1
(CSP 2 and CSP3 similar)

Date: JUL 1992 Dwg No: 4236/4/A2 Fig No: A2

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 1

sheet 1 of 1

office and job no: BRISBANE H162/

client: J.W. KEOWN PTY LTD

hole commenced: 25.11.85
hole completed: 27.11.85
supervised by: JAG
checked by: JAG

project: PROPOSED DEVELOPMENT, CUDGEN, N.S.W.
borehole location: Refer FIGURE 1

drill model and mounting: CABLE TOOL-Truck
hole diameter: 150 mm
slope: 90 deg.
bearing: deg.
R.L. surface: m
datum:

method	penetration 123	support	water	notes samples, tests, etc.	R.L.	depth metres	graphic log	classification symbol	material: soil type: plasticity or particle characteristics colour, secondary and minor components	moisture condition	consistency/density index	hand penetrometer kPa	structure and additional observations
CT		C				0		SP	SAND-Quartzose, fine-medium grained, brown-grey, with some shells & organic fragments.	M-W	MD		0.2m of black silty SAND Topso Alluvial/deltaic deposit
						5			SAND-Quartzose, medium grained, with some fine grained, grey.				
						10 11							
									Terminated at 11.0m.				

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V "V" bit
T TC bit
e.g. ADT

support C casing, M mud

penetration 1 2 3 — no resistance ranging to refusal

water
10 Jan 78 water level on date shown
water outflow
water inflow

notes samples and tests
U50 undisturbed sample 50 mm diameter
D disturbed sample
N standard penetration test: figure = result
N* SPT + sample
Nc cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 2
sheet 1 of 1

office and job no: BRISBANE H162/1

client:	J.W. KEOWN PTY LTD	hole commenced:	5.12.85
		hole completed:	5.12.85
project:	PROPOSED DEVELOPMENT, CUDGEN, N.S.W.	supervised by:	JAG
borehole location:	Refer FIGURE 1	checked by:	JAG

drill model and mounting:	REVERSE CIRCULATION- 4wd	slope:	90 deg.	R.L. surface:	m
hole diameter:	50 mm	bearing:	deg.	datum:	

method	penetration 123	support	water	notes samples, tests, etc.	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics colour, secondary and minor components	moisture condition	consistency/density index	hand penetrometer kPa	structure and additional observations
RC				D	0		SP	SAND-Fine-medium grained, dark grey.	M	MD		Alluvial/deltaic deposit
				D				SAND-Medium-fi.e grained, dark grey togrey, some shells.	W			
				D	5			As above, grey.				
				D				As above, light grey, minor shell & organic fragments.				
				D	10							
				D								
				D								
				D	15							
				D				SAND-Medium-fine grained, light grey.				
				D	20							
							OL	SILTY CLAY-Medium plasticity black to dark grey, organic.		St		Swamp deposit - shells below 22.0m
					25 26		CH	GRAVELLY CLAY-High plasticity, mottled grey & brown, fine-medium grained gravel.		VSt		COLLUVIUM to RESIDUAL SOIL
								Terminated at 26.0m.				

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V 'V' bit
T TC bit
e.g. ADT

support C casing, M mud

penetration 1 2 3 — no resistence ranging to refusal

water
10 Jan 78 water level on date shown
water outflow
water inflow

notes samples and tests
U50 undisturbed sample 50 mm diameter
D disturbed sample
N standard penetration test: figure = result
N* SPT + sample
Nc cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 3
sheet 1 of 1

office and job no BRISBANE H162/1

client:	J.W. KEOWN PTY LTD	hole commenced:	5.12.85
		hole completed:	5.12.85
project:	PROPOSED DEVELOPMENT, CUDGEN, N.S.W.	supervised by:	JAG
borehole location:	Refer FIGURE 1	checked by:	JAG

drill model and mounting:	REVERSE CIRCULATION- 4wd	slope:	90 deg.	R.L. surface:	m
hole diameter:	50 mm	bearing:	deg.	datum:	

method	penetration 1 2 3	support	water	notes samples, tests, etc.	depth metres	graphic log	classification symbol	material: soil type: plasticity or particle characteristics, colour, secondary and minor components	moisture condition	consistency/density index	hand penetrometer kPa	structure and additional observations
RC				D	0		SP	SAND-Medium-fine grained, light grey, minor CLAY, brown	M	MD		Alluvial/deltaic deposit
				D				As above, minor shell fragments.	W			
				D	5							
				D				As above, shells & fragments up to 30mm.				
				D								
				D	10			SAND-Medium-fine grained, light grey.				
				D								
				D	15							
				D								
				D	20			As above, with minor shell fragments.				
					23		CL	SILTY CLAY-Medium plasticity, dark grey to black.		St		Swamp deposit
								Terminated at 23.0m.				

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V "V" bit
T TC bit
e.g. ADT

support C casing, M mud

penetration 1 2 3 — no resistance ranging to refusal

water
10 Jan 78 water level on date shown
water outflow
water inflow

notes samples and tests
U50 undisturbed sample 50 mm diameter
D disturbed sample
N standard penetration test: figure = result
N* SPT + sample
Nc cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 4
sheet 1 of 1

office and job no: BRISBANE H162/1

client: J.W. KEOWN PTY LTD
project: PROPOSED DEVELOPMENT, CUDGEN, N.S.W.
borehole location: Refer FIGURE 1

hole commenced: 5.12.85
hole completed: 5.12.85
supervised by: JAG
checked by: JAG

drill model and mounting: REVERSE CIRCULATION-4wd
hole diameter: 50 mm
slope: 90 deg.
bearing: deg.
R.L. surface: m
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material: soil type: plasticity or particle characteristics, colour, secondary and minor components	moisture condition	consistency/density index	hand penetrometer kPa	structure and additional observations
RC				D	0		SP	SAND-Fine-medium grained, dark grey.	M	MD		Alluvial/deltaic deposit
				D				SAND-Medium-fine grained, grey, with shell fragments.	W			
				D	5			As above, light grey, with minor shell fragments.				
				D				SAND-Fine-medium grained, light grey, with shell & organic fragments.				
				D				SAND-Medium-fine grained, grey.				
				D	10			As above, light grey.				
				D				As above, light brown-grey, with a trace of coarse gr. sand				
				D	15			SAND-Fine-medium grained, light brown-grey.				
				D				SAND-Medium-fine grained, light grey-brown.				
				D	20			As above, dark grey, with shell fragments.				
					23		CL	SILTY CLAY-Medium plasticity, grey to dark grey.		St		Estuarine(?) deposit
								Terminated at 23.0m.				

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V "V" bit
T TC bit
e.g. ADT

support C casing, M mud
penetration 1 2 3 — no resistance ranging to refusal

water
10 Jan 78 water level on date shown
water outflow
water inflow

notes samples and tests
U50 undisturbed sample 50 mm diameter
D disturbed sample
N standard penetration test: figure = result
N* SPT + sample
Nc cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 5
sheet 1 of 1

office and job no: BRISBANE H162/

client: J.W. KEOWN PTY LTD
project: PROPOSED DEVELOPMENT, CUDGEN, N.S.W.
borehole location: Refer FIGURE 1

hole commenced: 5.12.85
hole completed: 5.12.85
supervised by: JAG
checked by: JAG

drill model and mounting: REVERSE CIRCULATION- 4wd
hole diameter: 50 mm
slope: 90 deg.
bearing: deg.
R.L. surface: m
datum:

method	notes samples, tests, etc.	depth metres	classification symbol	material: soil type: plasticity or particle characteristics, colour, secondary and minor components	moisture condition	consistency/ density index	structure and additional observations
RC	D	0	SP	SAND-Medium-fine grained, dark grey, with shell fragments	M	MD	Alluvial/deltaic deposit
	D			As above, grey.	W		
	D	5		SAND-Medium-fine grained, light grey.			
	D						
	D			As above, with shell fragments.			
	D	10					
	D			SAND-Medium-coarse grained, light grey-brown, with minor shell fragments.			
	D	15					
	D						
	D			SAND-Medium-fine grained, brown.			
		20	OL	PEAT-Brown-black.		F	Swamp deposit
		23	CL	SILTY CLAY-Medium plasticity, grey to dark grey.		St	Estuarine(?) deposit
				Terminated at 23.0m.			

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V "V" bit
T TC bit
e.g. ADT

support C casing, M mud
penetration 1 2 3 — no resistance ranging to refusal

water
10 Jan 78 water level on date shown
water outflow
water inflow

notes samples and tests
U50 undisturbed sample 50 mm diameter
D disturbed sample
N standard penetration test: figure = result
N* SPT + sample
Nc cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Coffey & Partners Pty. Ltd.

engineering log borehole

COFFEY

borehole no.: 6
sheet 1 of 1

office and job no: BRISBANE H162/1

client: J.W. KEOWN PTY LTD
hole commenced: 5.12.85
hole completed: 5.12.85
project: PROPOSED DEVELOPMENT, CUDGEN, N.S.W.
supervised by: JAG
borehole location: Refer FIGURE 1
checked by: JAG

drill model and mounting: REVERSE CIRCULATION- 4wd
slope: 90 deg.
R.L. surface: m
hole diameter: 50 mm
bearing: deg.
datum:

method	notes samples, tests, etc.	depth metres	classification symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components)	moisture condition	consistency/density index	structure and additional observations
RC	D	0	SP	SAND-Fine-medium grained, dark grey.	M	MD	Alluvial/deltaic deposit
	D			As above, grey, with shells & fragments.	W		
	D	5		As above, light grey, with shells & fragments.			
	D			SAND-Medium-fine grained, light grey, w/shells & fragments.			
	D			As above, light grey.			
	D	10		As above, light brown-grey, with minor shell fragments.			
	D			As above, light brown-grey.			
	D	15					
	D			As above, with minor organic fragments.			
	D	20		As above, light brown-grey, with a trace of coarse grained sand.			
		23	CL	SILTY CLAY-Medium plasticity grey to dark grey.		St	Estuarine deposit
				Terminated at 23.0m.			

method
AS auger screwing*
AD auger drilling*
R roller/tricone
W washbore
CT cable tool
*bit shown by suffix:
B blank bit
V 'V' bit
T TC bit
e.g. ADT

support
C casing
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U50 undisturbed sample 50 mm diameter
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N standard penetration test: figure = result
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classification symbols and soil description
based on unified classification system

moisture
D dry
M moist
W wet

consistency/density index
VS very soft
S soft
F firm
St stiff
VSt very stiff
H hard
Fb friable
VL very loose
L loose
MD medium dense
D dense
VD very dense

Appendix 3

Bore Census

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Bore Census Summary

Land Owner	**L & P Hermann**	**K Martin**	**H & R Taylor**	**P Phillips**	**P Phillips**
DIPNR Registered Number	GW300845	GW300856	GW062450	Not registered	Not registered
Bore Name					
Bore Location	Map Ref No.6 No. 216 Chindrah Road	Map Ref No. 5 No. 214 Chinderah Road	Map Ref No. 12. Recently relocated to near Cudgen Road. Earlier map location also not correct	Map Ref No. 3	Map Ref No. 3
Easting					
Northing					
RL	~1.0m AHD	~ 1.0mAHD			
CONSTRUCTION					
Year Drilled	> 33 years ago	>22 years ago	Relocated September 2005	2005 (Previous bores on site from 1964)	~2001
Total Drilled Depth (m)	4.2m	4m	17.1m	5.5m (Tweed Coast Irrigation)	5.1m
Casing Type	uPVC 110mmOD	No casing	140mmm OD UPC	UPVC	50mmUPVC
Screen Type		600mm length stainless steel	?	?	?
Top of Screen	3.2m	3.4m	6.5m	4m (Tweed Coast Irrigation)	3.6m
Bottom of Screen	4.2m	4.0m	17m	5.5m (Tweed Coast Irrigation)	5.1m
Bore Diametre	38mm Gal	25mm UPVC	140mm	32mm (Tweed Coast Irrigation)	50mmUPVC
Water Struck Depth	1.49m		6.46m	~1-1.5m (Tweed Coast Irrigation)	1.08m
STRATIGRAPHY					
DIPNR Log Available					
Owners Log Available					
Water Bed Details					
WATER LEVEL					
Water Depth Below Ref.			6.46m (0.32m stickup)		
Date of Measurement			17/01/2006		23/01/2006
Description of Ref.					
Height of Ref. aGL					
PUMPING DETAILS					
Bore in Use	Y	Y	No	Yes	No
Pumping Equipment	1 HP 115kw Davey Pump	0.5 hp	Not installed yet	XJ70 Davey 1HP	Nil
Power Supply	240V Electricity	240V electricity	NA	Electricity	Nil
Pump Suction Setting			NA		NA
Pumping Rate		>20L/min	Advised 1000gal/hr	50L/min	>10L/min
Daily Pumping Period	1-2 periods/wk (Summer 3/wk), 2 garden sprinklers 2-3 hrs	Rarely now - previously on zucchinis every day 2-3 hrs		2-3 hoses @ 2-3 times a week (summer) less in winter	Nil
WATER USAGE					
Primary Use of Bore	Garden Irrigation	Garden irrigation	Irrigation of commercial crops	Domestic garden irrigation	Monitoring bore
No. Stock on Bore	NA	Nil	Nil	Nil	Nil
Land Irrigated	Domestic garden	Domestic garden		Domestic garden	NA
DISTRIBUTION					
Storage Type	Nil	Nil	Nil	Nil	NA
No. Of Troughs	NA	NA	NA	Nil	NA
Trough Description	NA	NA	NA	NA	NA
WATER QUALITY					
pH	5.54 Temp 20.4 DO 4.23mg/L	5.29 Temp 20.3 DO 1.59	4.77, Temp 24.3, DO 5.74mg/L	5.50, DO 1.73mg/L, Temp 21.4	5.16, DO 0.70mg/L, Temp 13
Electrical Conductivity	77 uS/cm2	145 uS/cm2	137 uS/cm2	139 uS/cm2	424uS/cm2
COMMENTS					
Comments	Used for drinking water prior to excavation of Nobles Lake to east. GW level dropped to almost full depth of bore during dewatering	Brown colour, sulphide odour now. Before Noble Lake dewatering clear & no odour	Bore relocated due to installation of new electrical sub-station off Cudgen Road. Map location wrong actual site previously immediately NW of small block (white) on Fig A. New bore also in this area.	Water quality reduced in area following Noble Lake. Iron staining & sulphide odour noted.	Monitoring bore installed by NSW Agriculture to assess GW adjacent demolished cattle dip site. Background monitoring bore adjacent Chinderah Road
CENSUS DETAILS					
Completed by	M Turks HMC	M Turks HMC	M Turks HMC	M Turks HMC	M Turks HMC
Date	11:00am 27/10/05	12:00pm 27/10/06	2:00pm 27/10/05, 16/1/06, 2:45pm 17/1/06	3.00pm 23/1/06	12.00pm 1/12/06

Bore Census Summary

Land Owner	B Rudman	S & G Melville	Baclon Pty Ltd	Gales Holdings 1	Gales Holdings 2	Gales Holdings 3
DIPNR Registered Number	Not Registered?	GW301284	GW300848	GW300834	GW300835	GW300764
Bore Name						
Bore Location	Map Ref No. 19		Noble Mobile Home Park - Chinderah Road	Between Map Ref 20 & 21 - Chinderah Rd	Between Map Ref 20 & 21 Chinderah Rd. same property as GW300834	Map Ref No. 1 Cnr Chinderah Rd & access to TSC STW
Easting						
Northing						
RL						
CONSTRUCTION						
Year Drilled	~48 years ago	?		~20 years ago	30 years ago	Mid 1990s?
Total Drilled Depth (m)	4.1m					
Casing Type	?			50mm UPVC		
Screen Type	?					
Top of Screen	?					
Bottom of Screen	?					
Bore Diametre	32mm UPVC	?				50mm UPVC
Water Struck Depth	?			1.8m		
STRATIGRAPHY						
DIPNR Log Available						
Owners Log Available						
Water Bed Details						
WATER LEVEL						
Water Depth Below Ref.				1.8m		
Date of Measurement				27/10/2005		
Description of Ref.						
Height of Ref. aGL						
PUMPING DETAILS						
Bore in Use	Y			No		
Pumping Equipment	1 HP			Nil		
Power Supply	240V Electricity			NA		
Pump Suction Setting						
Pumping Rate	>20L/min			<2L/min		
Daily Pumping Period	3/week for ~3hrs					
WATER USAGE						
Primary Use of Bore	Garden irrigation					
No. Stock on Bore	Nil					
Land Irrigated	Domestic garden					
DISTRIBUTION						
Storage Type	Nil					
No. Of Troughs	NA					
Trough Description	NA					
WATER QUALITY						
pH	6.05, Temp 24.5C, DO 4.13mg/L			5.83, Temp 21.3, DO 1.24		
Electrical Conductivity	413 uS/cm2			259 uS/cm2		
COMMENTS						
Comments	Drinking water (after aeration to remove iron) prior to adjacent dewatering by Noble Lake. Water previously clear. Now brown with strong sulphide odour. Sample 19/4/78 results pH 6.0, EC 145 uS/cm2, Ca 2.6, Mg 2.6, Na 18.4, K 2.0, N 0.6, Fe 5.4, HCO3 6.1, CO3 ND, SO4 9.6, Cl 33.7, Tot Alk (Na2CO3) 5.3, Res Alk (Na2CO3) 17.0, Hardness (CaCO3) 17.0, Tot Salts 75.7,	No details available. Owners requested they not be included in bore census.	Owner advises monitoring bores removed	Very shallow bore. No longer in use & not protected from siltation. Good quality water until Noble Lake dewatering. At this time 2 dams on site (40years old & 20 years old) turned blood red (iron oxide?) She oaks etc in front of proerty died- some immediately others over 2-3 years. Buldozers & scrapers used in Noble Lake dry excavation. Very deep! 25 acres & 1,000,000m3?	Damaged & no longer in use - (see comments for GW300834)	Monitoring bore for proposed TSC turf farm. This is probably monitoring bore EW2
CENSUS DETAILS						
Completed by	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC
Date	18/01/2006	27/10/2005	27/10/2005	27/10/2005	27/10/2005	27/10/2005

Bore Census Summary

Land Owner	**Gales Holdings 4**	**Gales Holding 5**	**Gales Holding 6**	**Gales Holdings 7**	**Gales Holding 8**	**Gales Holdings 9**
DIPNR Registered Number		GW048858	GW300760	GW300759	GW300847	GW304283
Bore Name	GW300752					
Bore Location	Map Ref No. 1 Cnr Chinderah Rd & TSC STW access Rd	Map Ref No. 1 TSC STW site adj Chinderah Rd	Map Ref No. 1 TSC STW site	Map Ref No. 1 TSC STW site	Shown as Map Ref No. 17. Probably demolished windmill immediately south on Map Ref no. 1	Adjacent Gales dredge pond. Appears to be CSP1, 2, & 3
Easting						
Northing						
RL						~1.0m AHD
CONSTRUCTION						
Year Drilled	Mid 1990s?	Mid 1990s?	Mid 1990s?	Mid 1990s?	?	
Total Drilled Depth (m)						
Casing Type						
Screen Type						
Top of Screen						
Bottom of Screen						
Bore Diametre						
Water Struck Depth						
STRATIGRAPHY						
DIPNR Log Available						
Owners Log Available						
Water Bed Details						
WATER LEVEL						
Water Depth Below Ref.						
Date of Measurement						
Description of Ref.						
Height of Ref. aGL						
PUMPING DETAILS						
Bore in Use						
Pumping Equipment						
Power Supply						
Pump Suction Setting						
Pumping Rate						
Daily Pumping Period						
WATER USAGE						
Primary Use of Bore						
No. Stock on Bore						
Land Irrigated						
DISTRIBUTION						
Storage Type						
No. Of Troughs						
Trough Description						
WATER QUALITY						
pH						
Electrical Conductivity						
COMMENTS						
Comments	Proposed TSC turf farm monitoring bore. Removed	Monitoring bore for proposed turf farm - removed	Proposed TSC turf farm monitoring bore - removed	Proposed TSC Turf farm monitoring bore - Removed	Owner Map Ref No. 17 overseas. No evidence of bore on this site. Seems to be for windmill (demolished) on Gales site immediately to the south.	Details on CSP1, 2, & 3 available
CENSUS DETAILS						
Completed by	M Tunks	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC
Date	27/10/2005	27/10/2005	27/10/2005	27/10/2005	18/01/2006	18/01/2006

Bore Census Summary

Land Owner	**I Kettle & M Stephens**	**I Kettle & M Stephens**	**R Julius East**	**R julius West**
DIPNR Registered Number	GW005988	GW060536		
Bore Name				
Bore Location	Map Ref 15 SE of Bolsters sand quarry below Cudgen Plateau	Map Ref 15 Cudgen Plateau - south of Bolsters sand quarry	Map Ref 7	Map Ref 7
Easting				
Northing				
RL	~2mAHD	~34m AHD	~2m AHD	~4m AHD
CONSTRUCTION				
Year Drilled	?	?		
Total Drilled Depth (m)	5.5m	20.6	3.1m	?
Casing Type	UPVC	160mm UPVC	UPVC	UPVC
Screen Type	?			
Top of Screen				
Bottom of Screen				
Bore Diametre	80mm	40mm	32mm	32mm
Water Struck Depth	0.35m	11.5m	~200mm	?
STRATIGRAPHY				
DIPNR Log Available				
Owners Log Available				
Water Bed Details				
WATER LEVEL				
Water Depth Below Ref.				
Date of Measurement				
Description of Ref.				
Height of Ref. aGL				
PUMPING DETAILS				
Bore in Use	No	yes	Yes	Yes
Pumping Equipment	Tractor driven PTO pump	Grundfos PT18	Petrol pump	
Power Supply		240V	Petrol	240v
Pump Suction Setting		550 kPa		1.2 hp
Pumping Rate	?	1 l/sec		?
Daily Pumping Period	Nil	3/wk for 2 hrs		
WATER USAGE				
Primary Use of Bore		washing vegetables	Irrigation	Irrigation
No. Stock on Bore		Nil	Nil	Nil
Land Irrigated		Nil		
DISTRIBUTION				
Storage Type		NA	Dam	Dam
No. Of Troughs		NA	NA	NA
Trough Description		NA	NA	NA
WATER QUALITY				
pH	7.83, DO 0.99, Temp 23.0	5.70, DO 6.71mg/L, Temp 23.0		
Electrical Conductivity	528 uS/cm2	133 uS/cm2		
COMMENTS				
Comments	Series of bores connected to manifold. 80mm bores to 90mm manifold increasing to 150mm suction line to pump. Pump outlet 90mm poly. Overgrown but 4-6 bores were connected but now damaged and no longer in use		Spearpoint used to augment dam supply for irrigation during dry times. Spearpoint pumps into dam. No access for submersible pump to sample	Spearpoint used to augment dam supply for irrigation during dry times. Spearpoint pumps into dam. No access for submersible pump to sample
CENSUS DETAILS				
Completed by	M Tunks HMC	M Tunks HMC	M Tunks HMC	M Tunks HMC
Date	6/02/2006	6/02/2006	6/02/2006	6/02/2006