Douglas Partners
Geotechnics • Environment • Groundwater

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REPORT
on

GROUNDWATER SUPPLY INVESTIGATION
GREAT KEPPEL ISLAND

prepared for
OZTON PTY LTD

Project 33976
February 2007

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ACEA
The Association of Consulting Engineers Australia

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GREAT KEPPEL ISLAND

1.0 INTRODUCTION

This report describes the results of a groundwater supply investigation carried out on Great Keppel Island. Douglas Partners Pty Ltd (DP) was commissioned by Ozton Pty Ltd to carry out the work.

It is understood that a major redevelopment of Great Keppel Island is proposed, including an upgrade of the existing resort, construction of new resorts, two golf courses, new tourist/ residential accommodation, construction of a new airstrip, and a 300 boat marina. Previously, the Mercure Resort extracted groundwater from the dune sand deposit in the southwestern end of the island for potable water supply. However, salt water intrusion reportedly caused a decline in the quality of the groundwater, and resort management installed a desalinisation plant in 2004 and ceased extraction of groundwater.

This report describes hydrogeological investigations carried out to assess the potential to obtain a potable groundwater supply elsewhere on the island. Investigations included an electromagnetic (EM) geophysical survey, installation and construction of monitoring bores, water quality sampling and analysis, and groundwater modelling.

2.0 SCOPE OF WORK AND OBJECTIVES

The objectives of the groundwater supply investigation were to:

- Identify a groundwater resource of suitable quality and an extraction regime to supply approximately 300 kL/day (~3.5 L/s) to the existing resort whilst minimising impacts from saline intrusion and water table drawdown in sensitive areas;
- Assess the maximum sustainable yield of potable groundwater for the entire island for future planning purposes whilst minimising impacts from saline intrusion and water table drawdown in sensitive areas; and

- Assess the groundwater quality to allow Sustainable Solutions International Pty Ltd (SSI) to develop an appropriate water treatment regime to obtain potable water.

To achieve these objectives, the following scope of work was carried out:

- Desktop review of existing groundwater information, including a search of the Department of Natural Resources and Water (NR&W) groundwater database;
- Site visit to assess existing groundwater bores, and map the dune sand deposits;
- EM-34 geophysical surveying;
- Drilling of test bores and construction of ten monitoring bores;
- Groundwater sampling and analysis to establish baseline groundwater quality;
- Development of conceptual hydrogeological models (CHMs) for the dune sand deposits; and
- Groundwater modelling to assess sustainable yields.

3.0 SITE DESCRIPTION

3.1 Site Location and Description

Great Keppel Island is the largest island in the Keppel group of islands, lying approximately 12 km east of Yeppoon on the Central Queensland coastline. It is located within the Mackay/Capricorn region of the Great Barrier Reef Marine Park.

The Mercure Great Keppel Island Resort is located on a dune sand deposit on the south-western end of the island (Drawing 1) between Fisherman's Beach and Long Beach. The main accommodation and resort facilities are situated mainly near Fisherman's Beach where the topography is generally flat. Residential houses and the Keppel Haven Resort are also located on this dune sand deposit between Fisherman's Beach and Putney Beach. The topography becomes slightly undulating on the eastern side towards the surf beach.

The topography of Great Keppel Island is relatively steep and is dominated by two southeast-northwest trending ridges with a maximum elevation of 174 mAHD. Leeks, Putney, and Blackall creeks drain these ridges to the west. Other minor, perennial creeks are relatively short and flow directly to the ocean. A flat to undulating topography is present in the dune sand areas in the northeast and southwest regions of the island.

3.2 Geology

Reference to the Rockhampton 1:100,000 Geological Sheet indicates that the island is primarily underlain by the Carboniferous aged Shoalwater Formation comprising metamorphic quartzose and lithic sandstones, with minor mudstone and schist. In three separate areas this Carboniferous sequence is overlain by thin veneers of Quaternary deposits, as shown on Drawing 2.

The northeastern area between Wreck Beach and Butterfish Bay, as well as the southwestern area between Long Beach and Fisherman's Beach (Drawing 2), are mapped as Quaternary dune sand. However, part of the southwestern area adjacent to Fisherman's and Putney Beaches is mapped as coastal sand beach ridges, a different geological unit. The central western part of the island comprises fine grained alluvial sediments such as clay, silt, sandy mud and minor gravel.

3.3 Hydrogeology

Potential aquifers with potable groundwater are likely to occur within the Quaternary dune sand deposits located within the northeastern and southwestern parts of Great Keppel Island. The Carboniferous sequence is not considered to be a potential viable aquifer and thus was not considered in this hydrogeological investigation. The fine grained Quaternary sediments in the central western region adjacent to Leek's Beach were also not considered as a potential viable aquifer due to the low permeability of the sediments. These sediments were not considered further.

The two dune sand deposits offer the best potential for a viable groundwater supply on the island and would be expected to comprise an unconfined or water table aquifer with fresh groundwater. Groundwater would most likely flow from a central groundwater mound, developed through the infiltration of rainfall, towards the coastline and discharge into the beaches. Max Winders and Associates (2006) states that the Livingstone Shire's Structural Map shows the southwestern dune sand deposit designated as an "Aquifer".

3.4 Climate

Max Winders and Associates (2006) indicated that the climate for Great Keppel is subtropical. The annual mean daily maximum temperature is 26.1^0C, and the minimum temperature is 20.9^0C based upon data from the Bureau of Meteorology for Heron Island. The hottest month is January. Mean annual rainfall for Heron Island was reported to be 1047 mm/year.

Rainfall data collected from Mercure Great Keppel Island Resort shows the annual rainfall for the island between 1995 and 2005 was 780 mm, well below the average for Heron Island. The total annual rainfall for the island is provided as a histogram in Figure A.1 of Appendix A. The data shows that the months with the highest average rainfall over the ten year period are December, January and February.

A more complete climatic data set was obtained from the Bureau of Meteorology for the region surrounding Great Keppel Island between 1960 and 2006. This data set comprised monthly totals for rainfall and evaporation. Total annual rainfall varied between 468 mm (2001) and 1686 mm (1990). The average annual rainfall between 1960 and 2006 was calculated to be approximately 1,040 mm. The total annual rainfall from this data set is provided as a histogram in Figure A.2 of Appendix A along with the five year moving average. The data indicated the region receives the highest rainfall during the summer months. A good match was observed between the onsite rainfall records (between 1996 and 2006) and the data from the Bureau of Meteorology.

Using rainfall data obtained from the Bureau of Meteorology between 1960 and 2006, a rainfall residual mass histogram based upon the monthly rainfall data was also developed and plotted along with the annual rainfall as shown in Figure A.2 of Appendix A. The residual mass histogram provides an estimate of groundwater level behaviour in shallow unconfined aquifers such as the dune sand aquifers on Great Keppel Island. Figure A.2 indicates groundwater levels have been declining since approximately 1993.

4.0 REVIEW OF EXISTING GROUNDWATER INFORMATION

The review of existing information included review of the geological and topographic maps for the island (as discussed in Section 3.0), a review of the NR&W groundwater database, and water quality information supplied by SSI.

The groundwater regime and potential for a groundwater supply for the site are described in the following sections.

4.1 NR&W Groundwater Database Review

A search of the NR&W groundwater database revealed nine registered bores located within the southwestern dune sand deposit. Four were located around the Mercure Great Keppel Island Resort near Fisherman's Beach and five were located near Long Beach, as shown on Drawing 4. All bores had intersected an unconfined aquifer within the Quaternary sand deposit. A summary of the bore depth, aquifer formation and depth, as well as water quality information obtained from the NR&W bore cards is provided in Table 1, and copies of NR&W's bore card reports and bore locality map are provided in Appendix B.

Table 1: Summary of NR&W Groundwater Database

Registered Bore No & Onsite Name	Total Bore Depth (mbGL)	Depth of Sand (mbGL)	Aquifer Formation	Bore Yield (L/s)	Water Level (mbGL)	Water Quality	
						pH	EC (µS/cm)
62672 (Desal Plant Bores 1 and 2)	7.0	6.0	Sand beach ridges	NR	4.24	NR	NR
62679 (Oval Bore 1)	6.0	6.0	Sand beach ridges	NR	1.60	NR	NR
84902	10.8	10.8	Dune sand	NR	4.60	NR	NR
88366 (Golf Course Bore)	6.0	6.0	Sand beach ridges	NR	NR	NR	NR
88367 (Long Beach Pump House)	13.0	15.0	Dune Sand	8.0	2.6	5.7	340
88368	14.0	15.0	Dune Sand	8.0	2.7	6.0	370
88369	18.0	19.0	Dune Sand	8.0	7.7	5.8	425
88370 (Long Beach Bore 1)	13.6	>16.0	Dune Sand	NR	NR	NR	NR
88696 (Oval Bores 2)	6.0	NR	Sand Beach Ridges	NR	NR	NR	NR

Notes: NR – No record available.
mbGL – metres below ground level.
Brackets show the bore name used by the Mercure Great Keppel Island Resort for the bores identified onsite and sampled for field water quality purposes (refer Table 4 for results).

The bore records revealed the following information on the southwestern dune sand deposit:

- An aquifer existed within dune sand deposits near Long Beach to approximately 18 m depth;
- An aquifer existed within beach ridge sand deposits near Fisherman's Beach to approximately 6 m depth;
- Depths to groundwater ranged between 1.6 m and 7.7 m below ground surface;
- Groundwater near Long Beach is acidic with a pH of approximately 5.8 and is fresh.

4.2 Water Quality Information Provided by SSI

Water quality information from the Mercure Great Keppel Island Resort comprises the following:

- Microbiological testing for the golf course bore carried out every three months between February 2005 and February 2006; and
- Laboratory report for water quality testing of several samples including the Long Beach bores, Bungalow bore and BFS bore dated 3 August 2004.

The results indicate that the groundwater collected from the golf course bore did not contain *E.Coli*. The groundwater quality within the Long Beach bores was reported to be slightly acidic with a pH of approximately 5.9 and fresh with a total salt content of 300 mg/L. The groundwater from the Bungalow bore and BFS bore was reported to be neutral but was brackish with a total salt content of approximately 3,000 mg/L; however the locations of these bores were not identified onsite by DP but are assumed to be near the staff accommodation near the desalinisation plant.

5.0 ELECTROMAGNETIC GEOPHYSICAL SURVEY

The EM geophysical survey was carried out over the northeastern and southwestern dune sand deposits to assess groundwater quality, location of the salt water interface along the coastline, and possibly the depth to bedrock. The EM survey lines were generally run perpendicular to the coastline to better identify the salt water interface, with measurements recorded at approximately 50 m intervals. The survey lines were recorded with a GPS and the locations are shown on Drawings 3 and 4.

5.1 EM Methodology and Equipment

The principle of the EM geophysical method is that a primary EM field generated by an electric coil causes the generation of a secondary EM field within the subsurface, which is detected and measured by a receiving coil. The response of the volume of earth being measured is primarily affected by its apparent electrical conductivity. The factors most affecting the electrical conductivity are the salt content of the groundwater and clay content of the subsurface. It is therefore a useful method for detecting sand/gravel layers, i.e. drilling targets in alluvium, or as a preliminary investigation into the depth of sands or salt water intrusion of coastal dune environments.

DP's Geonics EM34 equipment which can operate at frequencies of 4 kHz, 1.6 kHz and 0.4 kHz at variable inter-coil separations of 10 m, 20 m and 40 m was used for the EM survey. The different coil spacings allow an average depth of investigation of 7.5 m, 15 m, 30 m and 60 m. The EM survey over the northeastern and southwestern dune sand deposits was conducted at 7.5 m and 15 m depths with a coil separation of 10 m. These depths were chosen to assess the depth of the sands and groundwater quality within the dune sand, since the existing bore logs from the NR&W database indicated the depth of the sand was between 6 m and 18 m.

Generally, a low EM conductivity reading of the subsurface indicates the subsurface is comprised of sand containing fresh groundwater, and a high conductivity can indicate either clay subsurface or sand with saline groundwater. Typically, an EM conductivity reading of less than 20 mS/m within dune sand is considered to indicate the groundwater is fresh, whereas values greater than 20 mS/m indicate the groundwater is brackish, and above 50 mS/m the groundwater is most likely saline.

5.2 EM Survey Results

The results for each survey line are provided in Appendix C as graphs of the EM conductivity reading for both depths against the distance from the starting point of each survey line. The survey lines were labelled Run 1 to Run 5 and the locations of survey lines are shown on Drawings 3 and 4. Initially the EM readings were recorded at both the 7.5 m and 15 m depths of penetration using the 10 m cable for separation between the transmitter and receiver coils. However, after the first two runs, it was apparent the EM signal was not being recorded at the 15 m depth of penetration due to the very low apparent electrical conductivity of the sand deposit, thickness of dry sand (or depth to the water table), and possible interference from the electrical generator and transformers at the Mercure Great Keppel Island Resort. Consequently, Runs 2 to 5 were only carried out at the 7.5 m depth of penetration.

Runs 1 and 2 were undertaken within the southwestern dune sand deposit and started on Long Beach (Drawing 4). Run 1 indicated that the edge of the salt water interface, transition zone between salt water and fresh, was present approximately 100 m inland of the high tide mark on Long Beach. The salt water interface is in reality a broad transition zone comprised of brackish water instead of a sharp line/interface as the name implies. Run 1 was completed prematurely within the brackish water of the interface due to thick scrub. Run 2 indicated the salt water interface was located approximately 50 m from the Long Beach high tide mark, with fresh groundwater present from this point to the start of the airstrip.

Runs 3, 4 and 5 were carried out within the northeastern dune sand deposit as shown on Drawing 3. Run 3 started on Wreck Beach and followed a walking track all the way through to Butterfish Bay. As can be seen on the graph in Appendix C, the salt water interface was located within 40 m from the high tide mark on both beaches. Runs 4 and 5 also confirmed these results, indicating a substantial storage of fresh water within the dune sand aquifer and an aquifer depth in excess of 7.5 m.

6.0 DRILLING AND GROUNDWATER MONITORING

The field investigation was carried out under the supervision of Mr Carl Deegan, a Hydrogeologist from DP, between 23 and 29 July 2006 and comprised:

- Drilling of eleven bores, ten of which were completed as monitoring bores (or piezometers);
- Development of each monitoring bore;
- Measurement of depth to groundwater in all new monitoring bores;
- Recording each bore location with a GPS;
- Groundwater sampling;
- Field analysis for pH, electrical conductivity (EC), and temperature; and
- Collection of sand samples from the monitoring bores for particle size distribution tests (PSD).

General views of the drilling, installation and development of the monitoring bores are shown on Photographs 1 to 4 attached.

6.1 Drilling and Construction of Monitoring Bores

Eleven bores (MB1 to MB11) were drilled under the supervision of Mr Deegan between the 23 and 29 July 2006. Ten of these bores were completed as monitoring bores (MB1 to MB8, MB10 and MB11). Drillsure Pty Ltd undertook the drilling and installed the monitoring bores with a tracked drilling rig to provide access across the sand dunes (Photos 1 and 2) using rotary mud drilling techniques. The bores were drilled at the locations shown on Drawings 3 and 4 to provide information on the quality of groundwater, depth of sand and depth to groundwater.

Monitoring Bores MB3 to MB6 were installed within the northeastern dune sand deposit, whilst MB1, MB2 and MB7, MB8, MB10 and MB11 were installed within the southwestern dune sand deposit. MB1 and MB2 were installed beside existing underground fuel tanks to investigate the possible leakage of fuel and contamination of the groundwater.

Boreholes were lithologically logged based on an inspection of the drill cuttings. Details of the subsurface conditions encountered are described on the test bore report sheets in Appendix D.

The bores were completed as monitoring bores by the installation of 50 mm diameter, Class 18 uPVC casing and a 3 m or 6 m length of factory slotted screen. A filter pack consisting of 2-3 mm graded sand (washed) was installed in the annulus between the bore wall and casing/screen. A bentonite seal was placed in the annulus above the screen to prevent surface water from entering the bore and impacting upon the groundwater. Galvanised steel covers were concreted over the top of bores for protection.

Construction details for the monitoring bores are summarised in Table 2 and are illustrated on the test bore report sheets in Appendix D. The monitoring bores were surveyed for height to allow the depth to groundwater measurement to be referenced to a common datum (mAHD).

Table 2 – Monitoring Bore Construction Details

Bore	*Location and Elevation (mAHD)*[3]	Total Depth (mbGL)[1]	Screen Interval (mbGL)[1]	Bentonite Seal (mbGL)[1]	Filter Pack (mBGL)[1]	SWL on Completion	
						mbGL[1]	mAHD
MB1	E288785 N7434995; 4.28	7.6	3.1 – 7.6	2.0 – 3.0	3.0 – 7.70	3.38	0.90
MB2	E289195 N7434893; 5.40	6.0	3.0 – 6.0	0.3 – 0.8	0.8 – 6.0	4.00	1.40
MB3	E291804 N7437610; 6.59	11.5	5.5 – 11.5	0.3 – 1.0	1.0 – 14.0	5.40	1.19
MB4	E292046 N7437631; 7.75	17.4	11.4 – 17.4	0.3 – 1.0	1.0 – 18.1	6.30	1.45
MB5	E292144 N7437549; 5.31	8.5	5.5 – 8.5	0.3 – 0.8	0.8 – 14.0	3.85	1.46
MB6	E292374 N7437392; 5.34	21.5	12.5 – 21.5	0.4 – 1.0	1.0 – 21.5	3.94	1.40
MB7	E289102 N7434740; 9.39	14.0	5.0 – 11.0	0.3 – 1.0	1.0 – 14.0	8.15	1.24
MB8	E289265 N7434616; 13.92	14.0	9.5 – 12.5	0.3 – 1.0	1.0 – 14.0	11.75	2.17
MB10	E289826 N7434203; 8.64	17.2	11.2 – 17.2	0.3 – 1.0	1.0 – 17.2	7.35	1.29
MB11	289685 7434579 34.34	23.0	17.0 – 23.0	0.4 – 1.0	1.0 – 24.0	Dry	Dry

Note: 1) mbGL – metres below ground level.
2) mbTOC – metres below top of casing.
3) Locations surveyed by Schlencker surveying Pty Ltd in GDA94. Elevation provided is the ground level elevation as mAHD.

6.2 Monitoring Bore Development, Purging and Sampling Procedure

Monitoring bore installation and development was conducted in accordance with The Land and Water Biodiversity Committee's *"Minimum Construction Requirements for Water Bores in Australia",* Edition 2, dated September 2003. The bores were drilled using rotary mud drilling techniques, which introduces drilling mud into the borehole and formation for stability. Development of the bores was carried out to remove the drilling mud and fine sand/clay particles from the screens of the bores to ensure they did not become blocked, so that representative groundwater samples could be obtained. Development comprised airlifting and surging (Photo 3) followed by pumping of the bores (Photo 4) until they produced clean groundwater with a constant pH and EC.

The groundwater sampling complied with the standard operating procedures described in DP's Field Procedures Manual, as well as the *"Murray-Darling Basin Groundwater Quality Sampling Guidelines"*, published by the Murray-Darling Basin Commission in 1997. After the bore development was completed, the general sampling procedure comprised:

- Purging a minimum of three well-volumes of groundwater from the bores using a sampling pump;
- Allowing the groundwater level to recover to within 15 % of its natural level prior to sample collection;
- Collection of representative groundwater samples using a sampling pump or disposable bailers and transferring the sample directly into the appropriate laboratory prepared containers;
- Field-filtering of the groundwater sample through a 0.45 μm filter for lead analysis;
- Labelling of sample containers with individual and unique identification, including project number and sample location; and
- Samples remained refrigerated until delivered to the laboratory within the recommended holding times.

Using the above procedures, groundwater samples were collected from Bores MB1, MB2, MB3, MB5, MB6, MB8, MB9 and MB10.

6.3 Particle Size Distribution Tests and Permeability Estimates

Disturbed samples were collected from Bores MB4, MB6, MB9, MB10 and MB11, and tested for PSD at DP's NATA registered soils laboratory. The results of these tests are provided in Appendix E. The Hazen method, as described by Fetter (1994), was then employed on these results to estimate the hydraulic conductivity (or permeability) of the sand samples in order to obtain an indication of the hydraulic conductivity of the aquifers within the dune sand deposits. The results are provided in Table 3.

Table 3: Permeability Estimated From PSD Tests

Sample	Dune Sand Deposit	Lithology	Permeability	
			m/day	m/sec
MB4: 6-8 m	Northeastern	Sand	21	2.4×10^{-4}
MB6: 16-20 m	Northeastern	Sand	21	2.4×10^{-4}
MB9: 2.5-4 m	Southwestern	Sand	20	2.25×10^{-4}
MB10: 8-11 m	Southwestern	Sand	21	2.4×10^{-4}
MB11: 15-18 m	Southwestern	Sand	20	2.25×10^{-4}

7.0 WATER QUALITY TESTING

7.1 Field Water Quality Analyses

Groundwater samples were analysed in the field using calibrated hand-held equipment for pH, EC and temperature, between the 11 and 27 July 2006. New and existing bores were sampled, as well as the desalinisation plant water. Sampling locations are shown on Drawings 3 and 4, and the results are provided in Table 4.

Table 4: Groundwater Field Monitoring Results

Monitoring Point	Parameter					
	pH (pH units)	EC (μS/cm)	Temperature (°C)	Groundwater level (mbGL)	Groundwater level (mbTOC)	Groundwater level (mAHD)
New Bores:						
MB1	7.3	21,750	27.3	3.38	3.88	0.90
MB2	5.8	550	27.8	4.00	4.60	1.40
MB3	7.5	600	28.1	5.40	5.85	1.19
MB4	7.1	620	28.0	6.30	6.85	1.45
MB5	6.3	380	28.5	3.85	4.35	1.46
MB6	7.3	740	26.5	3.94	4.43	1.40
MB7	8.9	450	29.0	8.15	8.65	1.24
MB10	6.3	450	27.5	7.35	7.78	1.29
Existing Bores:						
Long Beach Bore 1	6.8	510	27.4	5.00	5.26	1.16
Long Beach Pump House	8.0	10,100	28.0	7.95	8.25	0.87
Desal. Plant Bore 1	6.9	2,100	30.0	3.70	3.95	-
Desal. Plant Bore 2	6.7	3,610	30.0	3.65	3.70	-
Golf Course Bore	7.3	3,870	27.7	-	-	-
Oval Bores 1	7.2	1,340	26.7	2.50	2.50	1.23
Oval Bores 2	7.2	3,810	24.6	-	-	
Residential Bore (spear)	6.5	21,250	27.5	-	-	
Desalinisation Plant:						
Plant outlet	8.1	1,160	-	-	-	-
Room 115	8.0	890	24.3	-	-	-
Drinking Water Guideline	6.5-8.5	<2,200	-	-	-	-

Notes: 1) mbGL metres below ground surface.
2) mBTOC – metres below top of casing.
3) Shaded cells contain levels of an analyte greater than the Australian Drinking water guideline (1996).

7.2 Laboratory Analyses

Samples from seven bores, and one water sample collected from the desalinisation plant at the request of Ozton Pty Ltd, were sent to ALS, a NATA registered laboratory, for the following analyses:

- Total dissolved salts (TDS)
- Total hardness;
- Major cations (Ca, Na, Mg, K);
- Major anions (Cl, CO_3, HCO_3, and SO_4);
- Dissolved metals (As, Ba, Be, Cd, Cr, Co, Cu, Mn, Hg, Ni, Pb, V, and Zn);
- Iron; and
- TPH/BTEX (MB1 and MB2 only).

7.3 Regulatory Criteria

Groundwater results have been compared to the NHMRC/ARMCANZ *Australian Drinking Water Guidelines* (2004) Guidelines. In addition, the TPH/BTEX results for MB1 and MB2 are compared to the EPA's unpublished guidelines.

7.4 Laboratory Results

Laboratory results are summarised in Table 5, and the laboratory report and chain of custody documentation are attached in Appendix F.

Table 5: Groundwater Laboratory Results

Analyte[1]	ANZECC/EPA Guideline	Sample and Date collected						
		MB1	MB2	MB3	MB4	MB5	MB10	115
		28/7/06	28/7/06	24/7/06	25/7/06	25/7/06	26/7/06	27/6/06
General Water Quality (mg/L) :								
TDS	<1,000	-	-	280	218	106	236	352
Total Hardness	200	-	-	208	126	72	64	15
Bicarbonate	-	-	-	183	92	71	19	4
Chloride	250[2]	-	-	47	80	14	96	241
Sulphate	-	-	-	11	16	3	8	6
Calcium	-	-	-	60	25	22	4	1
Magnesium	-	-	-	11	15	4	12	3
Sodium	-	-	-	25	42	10	46	145
Potassium	-	-	-	2	2	<1	3	5
Heavy Metals (mg/L) :								
Arsenic	0.007	-	-	0.001	<0.001	0.002	<0.001	<0.001
Beryllium	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	0.7	-	-	0.019	0.029	0.006	0.091	0.002
Cadmium	0.002	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	0.05 (CrVI)	-	-	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5 (cont): Groundwater Laboratory Results

Analyte[1]	ANZECC/EPA Guideline	Sample and Date collected						
		MB1	**MB2**	**MB3**	**MB4**	**MB5**	**MB10**	**115**
		28/7/06	28/7/06	24/7/06	25/7/06	25/7/06	26/7/06	27/6/06
Heavy Metals (mg/L) (cont):								
Cobalt	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	2	-	-	0.002	0.003	0.001	<0.001	0.027
Lead	0.01	-	-	<0.001	0.002	<0.001	<0.001	<0.001
Manganese	0.5	-	-	0.003	0.073	<0.001	0.005	<0.001
Nickel	0.02	-	-	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	3[2]	-	-	0.005	0.023	<0.005	0.007	0.028
Iron	0.3[2]	-	-	0.07	0.06	0.09	0.06	<0.05
Mercury	0.001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
TPH: (µg/L)								
C_6-C_9	-	<400	<400	-	-	-	-	-
C_{10}-C_{14}	-	<50	<50	-	-	-	-	-
C_{15}-C_{28}	-	<100	<100	-	-	-	-	-
C_{29}-C_{36}	-	<50	<50	-	-	-	-	-
Total TPH	500[3]	<LOR	<LOR	-	-	-	-	-
BTEX: (µg/L)								
Benzene	30[3]	<1	<1	-	-	-	-	-
Toluene	-	<2	<2	-	-	-	-	-
Ethyl-Benzene	-	<2	<2	-	-	-	-	-
m & p Xylene	200	<2	<2	-	-	-	-	-
Ortho-Xylene	350	<2	<2	-	-	-	-	-

Notes: 1 Units are mg/L unless otherwise stated.
2 Aesthetic guideline level. No health guideline available.
3 Unpublished EPA thresholds.
4 Shaded cells contain levels of an analyte greater than the ANZECC 95 % protection trigger levels.
5 <LOR - Less than the laboratory's level of reporting.
6 - Not tested/no recommended guideline available.

7.5 Water Quality Summary

7.5.1 Northeastern Dune Sand Deposit

Field water quality testing reported that the groundwater was fresh with a low dissolved salt content and a pH which varied from slightly acidic within the central region of the aquifer to slightly alkaline close to the beaches (MB3 and MB6).

Concentrations of major cations and anions for MB3, MB4 and MB5 were converted into milliequivalents and percentage reacting values of anions and cations were calculated. The percentage of each cation and anion was then plotted on the piper (trilinear) diagram (Drawing 5) to classify the hydrochemical facies of the groundwater. The piper diagram shows that water within the northeastern aquifer appears to be two distinct types of water; with MB4 reporting a sodium-chloride type of water, whilst MB3 and MB5 reported the groundwater to be a calcium–bicarbonate type of water.

None of the water quality parameters or heavy metals tested reported levels which exceeded the drinking water guidelines, with the exception of the total hardness level in groundwater from MB3. MB4 also reported a relatively high total hardness level. Iron levels were also considered to be low. The laboratory results indicate that the groundwater is potable for the parameters analysed.

7.5.2 Southwestern Dune Sand Deposit

Field water quality testing reported the groundwater varied in quality due to salt water intrusion from the beaches bordering the aquifer. The Long Beach side of the aquifer reported fresh groundwater and a slightly acidic pH; however the Long Beach Pump House monitoring bore reported saline groundwater (10,000 µS/cm) with an alkaline pH indicating substantial salt water intrusion has occurred from Long Beach. The Mecure Resort side of the dune sand deposit generally reported the groundwater to be brackish to saline with a neutral pH; however, groundwater from MB2 and MB7 were fresh. The field analysis results indicated substantial salt water intrusion has occurred into this side of the aquifer from Fisherman's Beach and Putney Beach (Drawing 4). The salt water intrusion is probably a result of below average rainfall or recharge entering the aquifer over the past fifteen years (Appendix A, Figure A.2), as well as historical extraction of groundwater that has exceeded the sustainable yield of the aquifer.

The major cations and anions for MB10 were converted into milliequivalents and the percentages of the total anions and cations were calculated. The percentage of each cation and anion were then plotted on the piper (trilinear) diagram (Drawing 5) to classify the hydrochemical facies of the groundwater. The piper diagram shows that water within the southwestern aquifer on the Long Beach side is a sodium–chloride type of water.

Monitoring bores MB1, MB2, MB7, MB8, MB10 and the existing bores listed in Table 5 are located within the southwestern sand dune deposit. Laboratory testing on a sample collected from MB10, located between the airstrip and Long Beach (Drawing 4), reported no levels of water quality parameters or heavy metals which exceeded the drinking water guidelines, indicating the water is potable. Iron levels are also considered to be low.

The field water quality testing indicates significant salt water intrusion into the aquifer from Fisherman's Beach, i.e. beneath the Mercure Great Keppel Island Resort, as well as from Putney Beach and from Long Beach. The salt water intrusion is a result of historical water usage in this area.

8.0 CONCEPTUAL HYDROGEOLOGICAL MODEL

The CHMs for both dune sand aquifers identified by this investigation as the best potential for a groundwater supply on the island are based on a review of the geological and topographic maps, review of the existing information sourced from NR&W and SSI, the EM geophysical survey, and the drilling and installation of monitoring bores. The CHMs for the two dune sand deposits are outlined in the following sections.

8.1 Northeastern Dune Sand Aquifer CHM

8.1.1 Geological Setting

The northeastern aquifer is composed of Quaternary dune beach sand. The sand deposit is a relatively well-sorted fine to medium grained sand that is generally between 7.5 m to greater than 21.5 m in thickness based on all available bore logs. The full extent of the northeastern dune sand deposit was inferred from field hydrogeological investigations, onsite geological mapping, and the Rockhampton 1:100,000 Geological Sheet, and is shown on Drawing 3.

The general profile of the Quaternary sands comprises light orange/brown, fine to medium grained sand underlain by light grey/yellow, fine to medium grained sand. No shell layers or indurated sand layers (or coffee rock) were evident in the drilling of the monitoring bores. The basement of the aquifer is comprised of residual sandy clay/clayey sand or weathered rock which overlies the metamorphic quartzose and lithic sandstones of the Carboniferous Shoal-water Formation. The dune sand deposit is bounded to the north and south by outcrop of the Shoalwater Formation.

8.1.2 Hydrogeology

The Great Keppel Island northeastern dune sand aquifer extends from Wreck Bay to Butterfish Bay, as shown on Drawing 3. The aquifer is bounded by outcrop of the Shoalwater Formation to the north and south. The basement of the aquifer is composed of residual clay or weathered rock of the same formation.

It is an unconfined (or water table) aquifer that receives the majority of its recharge through direct infiltration of rainfall over its entire natural ground surface. The groundwater discharges to the Pacific Ocean via both Butterfish Bay and Wreck Bay.

Permeability estimates based on PSD tests were derived for MB4 and MB6, indicating hydraulic conductivities of 21 m/day for both holes, a value which is characteristic of clean medium grained sands.

The saturated thickness of the aquifer varies from 5 m to approximately 18 m in proximity to Wreck Bay as shown in a cross section on Drawing 6. Over half the sand mass was saturated in July 2006 according to water level measurements recorded at that time.

The basement topography of the aquifer was inferred from available bore logs, and a contour map was generated as shown on Drawing 7.

Water inputs to the aquifer are:

- Rainfall infiltration; and
- Minor component of stormwater runoff from the slopes to the north and south of the aquifer.

Water outputs or losses from the aquifer are:

- Evapotranspiration from the vegetation across the surface of the aquifer; and
- Discharge to the Wreck Bay and Butterfish Bay.

8.1.3 Groundwater Flow

Standing water levels as measured in July 2006 range between 3.85 – 6.3 m below ground surface. These data were used to generate the groundwater table surface shown on Drawing 7 following surveying of the bores for location and height.

A groundwater divide is located midway between the two bays probably in the vicinity of MB5 which appears to be located on a bedrock high. Groundwater flows from this divide south eastward towards Wreck Bay, as well as north westward toward Butterfish Bay. The relative high permeability of the sands results in a low hydraulic gradient and a relatively flat water table with a maximum elevation of approximately 1.5 mAHD.

8.1.4 Aquifer Recharge

Recharge to the aquifer comprises the direct infiltration of rainfall over the entire surface area of the aquifer, as shown on Drawing No.3. There may be a lesser contribution from surface runoff from the slopes bounding the aquifer to the north and south. For this assessment of aquifer recharge, any runoff component of recharge has been ignored.

Recharge to the aquifer was estimated by multiplying the surface area of the aquifer by a percentage of average annual rainfall for the region obtained from the resort records. Rainfall recharge represents the amount (i.e. percentage) of rainfall percolating downward into the ground and not taken up by the vegetation (through transpiration) or lost through direct evaporation (collectively known as evapo-transpiration) or surface runoff. Taking into consideration several factors including studies conducted in the Tomago Sands region of NSW and North Stradbroke Island, and the presence of sandy soils over the aquifer area, a conservative estimate for rainfall recharge would be 20-30% of the rainfall.

The average annual rainfall (based on data from 1960-2006) for Great Keppel Island is 1,040 mm. The records of annual rainfall range from 468 mm in 2001, up to 1686 mm in 1990.

The surface area of the aquifer as shown in Drawing No. 3 was estimated to be 0.7 km^2. The total recharge for the entire Great Keppel Island northeastern dune aquifer can be estimated as follows:

Annual Recharge Potential = Aquifer Surface Area x Annual Rainfall x 25%

Thus recharge for:	a wet year	=	295 ML
	an average year	=	180 ML
	a dry (drought) year	=	80 ML

8.1.5 Aquifer Sustainable Yield

A commonly adopted value for the sustainable yield of an aquifer is 70 % of the long-term average recharge. Because of the potential for salt water intrusion from the ocean, a more practical estimate of the sustainable yield is considered to be approximately 50 % of the total recharge.

The total average annual recharge was calculated to be 180 ML/year. When multiplied by 50 %, this results in a sustainable yield for the aquifer of 90 ML/year (0.25 ML/day or 250 kL/day). Using the same methodology for the driest year on record, the sustainable yield of the aquifer would have been 40 ML/year (0.11 ML/day or 110 kL/day).

The method of assessing sustainable yield as an estimate based on a proportion of long-term average recharge is approximate only (Bredehoeft, 2002)[1]. This is particularly so for dynamic systems such as coastal sand deposits. The sustainable yield of a groundwater extraction system will depend on its design and the volume of discharge from the aquifer that it can capture. This volume will depend on the dynamic response of the aquifer to the extraction of groundwater, and can be better assessed using groundwater flow modelling.

[1] *Bredehoeft, J.D., 2002, "The Water Budget Myth Revisited: Why Hydrogeologists Model". Ground Water Journal, Volume 40, No.4, July-August 2002.*

8.2 Southwestern Dune Sand CHM

8.2.1 Geological Setting

The southwestern aquifer is composed of Quaternary dune beach sand. The sand deposit is a relatively well-sorted fine to medium grained sand that is generally between 6 m and 17 m in thickness (based on data from bore logs). The full extent of the southwestern dune sand deposit, based on the field hydrogeological investigations, onsite geological mapping, and the Rockhampton 1:100,000 Geological Sheet, is shown on Drawing 4.

The general profile of the Quaternary sands comprises light orange/brown, fine to medium grained sand underlain by light grey/yellow, fine to medium grained sand. A shell layer was encountered in Bore MB1 which accords with the mapped cheniers in this area. No indurated sand layers (coffee rock) were evident in the drilling of the monitoring bores. The basement of the aquifer is comprised of residual sandy clay/clayey sand or weathered rock, underlain by Carboniferous aged Shoalwater Formation comprising metamorphic quartzose and lithic sandstone. The dune sand deposit is bounded to the northeast and southwest by the Shoalwater Formation.

8.2.2 Hydrogeology

The Great Keppel Island southwestern dune sand aquifer extends from Fishermans Beach to Long Beach as shown on Drawing 4. The aquifer is bounded by outcrop of the Shoalwater Formation to the northeast and southwest. The basement of the aquifer is composed of residual clay or weathered rock of the same formation and rises beneath the southern end of the airstrip to divide the southwestern dune sand deposit into two distinct aquifers as shown in cross-section on Drawing 9. These separate aquifer areas are referred to as the Mecure Resort aquifer and the Long Beach aquifer in the following sections to distinguish between the two.

Both aquifers are unconfined (or water table) aquifers and receive the majority of recharge through direct infiltration of rainfall over the entire natural dune sand ground surface. The groundwater discharges to the Pacific Ocean via Fishermans Beach, Putney Beach and Long Beach.

The saturated thickness of the Mecure Resort aquifer is relatively thin and varies from 2 m to 5 m as shown on Cross Section B on Drawing 9. The saturated thickness of the Long Beach aquifer generally varies from 5 m to 11 m as shown on Cross Section B on Drawing 9. The topography of the base of both aquifers was inferred from available drill logs and a basement contour map generated, as shown on Drawing 10.

Permeability estimates based on PSD tests derived for sand samples from Bores MB9, MB10 and MB11, indicate hydraulic conductivity values of between 20 m/day and 21 m/day. Such values are characteristic of clean medium grained sands.

Water inputs to both aquifers are:

- Rainfall infiltration; and
- A very minor component of overland flow from the slopes to the northeast of the aquifer.

Water outputs or losses from both aquifers are:

- Evapotranspiration from the wetlands/swamps water surface and vegetation;
- Discharge to the Pacific Ocean via Fishermans Beach, Putney Beach and Long Beach; and
- Groundwater extraction through spears or bores.

8.2.3 Groundwater Flow

Standing water levels as measured on July 2006 range between 2.6 mbGL and 11.75 m bGL. These data were used to generate a piezometric surface as shown on Drawing 11. Based on the elevation of the bedrock surface in relation to the groundwater levels, it is likely that the aquifer is unsaturated (at the time of data collection) in the vicinity of MB9 and MB11. Thus, in effect, the southwest dune sand aquifer is divided into two aquifers by the rise in the basement bedrock. These two aquifers comprise one draining into Long Beach (i.e. Long Beach aquifer), and the other, beneath the Mecure Resort, drains into Putney Beach and Fisherman's Beach (Mecure Resort aquifer).

Drawing 11 shows that the groundwater flow direction within the Long Beach aquifer is generally to the southeast towards Long Beach. Groundwater flow within the Mecure Resort aquifer is generally towards the east and northeast.

8.2.4 Aquifer Recharge

Recharge to both aquifers occurs from the direct infiltration of rainfall over the entire surface area of the dune sand deposit, as shown on Drawing 4, and surface runoff from the slopes located along the western and eastern boundaries of the aquifer.

The recharge estimation method described in Section 8.1.4 was also applied for the southwest aquifer.

The surface area of the dune sand deposit as shown on Drawing 4 was estimated to be 1.54 km^2. The total recharge for the entire southwestern aquifer can be estimated as follows:

Annual Recharge Potential = Aquifer Surface Area x Annual Rainfall x 25%

Thus recharge for:	a wet year	=	650 ML/year
	an average year	=	400 ML/year
	a dry (drought) year	=	180 ML/year

8.2.5 Aquifer Sustainable Yield

A commonly adopted value for the sustainable yield of an aquifer is 70 % of the long-term average recharge. Because of the potential for salt water intrusion from the ocean, a more practical estimate of the sustainable yield is considered to be approximately 50 % of the total recharge.

The total average annual recharge was calculated to be 400ML/year. This, when multiplied by 50 %, provides an average sustainable yield for the entire dune sand deposit of 200 ML/year (0.55 ML/day or 550 KL/day). Using the same methodology for the driest year on record, the sustainable yield of the aquifer would have been 90 ML/year (0.25 ML/day or 250 kL/day).

However, as the southwest dune sand aquifer is actually divided into two separate aquifers, this assessment will over-estimate the recharge into those aquifers. The Mecure Resort aquifer should not be considered for a potential water supply due its poor water quality from salt water intrusion. It is therefore considered relevant to only consider the Long Beach aquifer as a potential water supply. As it only occupies approximately one-third of the total area, the estimate of sustainable yield should be reduced to one-third. Thus the sustainable yield for this aquifer in an average rainfall year would be approximately 66 ML/year (0.18 ML/day or 180 KL/day). However, due to the salt water intrusion from Long Beach, it is considered that the actual sustainable yield would be less than this estimate which is based upon rainfall recharge alone.

The sustainable yield of a groundwater extraction system will depend on its design and the volume of discharge from the aquifer that it can capture. This volume can be better assessed using groundwater flow modelling.

9.0 GROUNDWATER MODELLING

Two numerical groundwater models were generated for Great Keppel Island based upon the CHMs described in Sections 8.1 and 8.2. These include:

- a groundwater model of the entire northeast dune sand deposit; and
- a groundwater model of the Long Beach aquifer section of the southwest dune sand deposit.

The Mecure Resort aquifer portion of the southwest dune sand deposit was not modelled because it is not considered a viable option for obtaining a potable water supply. Field water quality testing has shown that the aquifer contains brackish to saline water as a result of salt water intrusion.

9.1 General

Development of a groundwater flow model requires at least a reasonable approximation of the aquifer geometry, its hydraulic parameters, and the stresses (such as recharge, extraction etc) acting upon it. Once the geometry of the aquifer is defined and location of various existing and future stress points are determined, the aquifer is discretised into cells or elements and hydraulic properties are assigned to each cell. Prior to any predictive simulations, the model predictions are usually required to be confirmed as reasonable, by calibrating the model to observed groundwater levels and flow patterns. This calibration usually requires a number of model runs during which modifications are made of the unknown or uncertain aquifer parameters until a match between observed and simulated groundwater levels is achieved.

Model simulations were conducted using *MODFLOW* (McDonald & Harbaugh, 1988), a numerical groundwater flow model developed by the United States Geological Survey. This is a three-dimensional groundwater head and flow model and it is accepted as the industry standard and is legally defensible. The models were based on site-specific data where possible, as well as estimates of unknown parameters based on experience with similar environments. The models were developed using the pre-processor or graphical interface program *Visual MODFLOW*.

The purpose of developing the models was to aid in the assessment of the sustainable yield of the aquifers, and to assist in designing an optimum borefield layout.

9.2 Northeast Dune Sand Aquifer Model

9.2.1 Model Geometry

The entire aquifer is represented as a one layer model. The aquifer boundaries of the model coincide with the known natural boundaries such as Butterfish Bay and Wreck Beach and the geological boundaries between the dune sand and the Shoalwater Formation.

The model grid extends 1400 m in an east-west direction and 1600 m in a north-south direction. The finite difference grid was initially discretised into 266 rows and 280 columns with variable cell dimensions. The dimensions were reduced to approximately 5 m by 5 m in the area of expected high hydraulic gradients, ie. in the vicinity of the borefield.

The top of the model was set to correspond to the natural surface contours. The base of the model was set to correspond approximately to the base of the dune sand as shown on Drawing 7.

9.2.2 Model Hydraulic Boundaries

Boundary conditions are applied to numerical models to represent the physical environment and to constrain the model calculation domain. The types of boundaries selected were consistent with the conceptual model (Section 8.1) and include no-flow and constant head boundaries as described below:

- Constant head boundaries were applied to the model where the aquifer is connected to Butterfish Bay and Wreck Beach. Tidal information supplied by SSI indicated the mean tidal level was 0.01 m AHD for Great Keppel Island. The constant heads were initially set at 0.0 m AHD; and

- No-flow boundary along the western side of the aquifer to represent the impermeable geological boundary between the aquifer sands and bedrock.

9.2.3 Initial Aquifer Parameters

Aquifer parameters required for the one-layer model included horizontal hydraulic conductivity, effective porosity and specific yield. Initial estimates were obtained from the PSD tests carried out on sand samples collected from the monitoring bores. Using Hazen's method, the average permeability for the sand was 20 m/day. Estimates for the specific yield and porosity were obtained from published ranges for a medium grained sand. Initial estimates for these parameters used in the development of the aquifer model were:

- Horizontal hydraulic conductivity = 20 m/day
- Porosity = 0.20
- Specific yield = 0.15

9.2.4 Recharge

Aquifer recharge is the infiltration of rainfall over the entire surface area of the aquifer and through runoff from the hills which border the aquifer's northern and southern boundaries. As the runoff component is difficult to estimate and assumed to be minor compared to rainfall infiltration, it was not included in the model.

For a given value of hydraulic conductivity, various values of recharge will result in different elevations of the groundwater table. Rainfall recharge was simulated in the steady state simulations by obtaining the historical rainfall set for Great Keppel Island and applying a recharge coefficient of 30 % - 60 % to the average rainfall. This recharge was applied uniformly to the top layer of cells in the model.

9.2.5 Evapotranspiration

The *MODFLOW* evapotranspiration module was used for the steady state and transient simulations. The digital surface elevations were incorporated into the model as the evapotranspiration surface. The maximum evapotranspiration rate was the average pan evaporation rate. The evaporation data and correction factor were obtained from the Bureau of Meteorology. The extinction depth used was 2 m.

9.2.6 Steady State Model Calibration

Calibration of a flow model refers to the trial and error process by which model parameters (hydraulic conductivity, recharge and boundary conditions) are adjusted to produce an acceptable match between simulated and observed groundwater levels. Typical model outcomes depend on several different parameters and combinations leading to the non-uniqueness problem where different sets of model inputs produce nearly identical model outputs. To reduce this possibility and increase the reliability of the model, it is preferred that as many model variables or inputs as possible are accurately determined, and the model is calibrated using both steady state and transient simulations. However, for this model, only one set of water level data (groundwater levels measured on the 24 and 25 July 2006) was available for the calibration. Hence, a transient calibration was not possible.

The steady state calibration of the model was aimed at reproducing the observed groundwater levels in Monitoring Bores MB3, MB4, MB5 and MB6, and the expected flow patterns given the geometry of the aquifer, as shown on Drawing 8. The model calibration was carried out using a combination of manual and automated calibration using the parameter estimation (PEST) module of *Visual MODFLOW.*

During the calibration process, the aquifer parameters were limited to the following ranges:

- Hydraulic conductivity between 10 and 20 m/day;
- Constant head boundary between 0.0 mAHD and 0.1 mAHD; and
- Recharge between 30% (or 312 mm/year) and 60% (or 625 mm/year) of average annual rainfall.

A summary of the measured and simulated groundwater levels for the final calibration run at the monitoring bore locations is shown in Table 5, and the *Visual MODFLOW* calibration curve and statistics are shown in Appendix G. The simulated steady state water table contours from this calibration run are shown on Drawing 12 and are considered to compare well with the geometry of the observed water table contours.

Table 5: Model Calibration Results

Bore	K_H (m/day)	Recharge (% of Rainfall)	Observed SWL (mAHD)	Simulated Heads (mAHD)	Difference (m)
MB3	15	55	1.19	0.77	0.42
MB4	15	55	1.45	1.68	-0.23
MB5	15	55	1.46	1.76	-0.30
MB6	15	55	1.40	1.21	0.19
RMS (m)					**0.30**

A measure of the success of model calibration can be evaluated using the root mean square error (RMS) expressed as:

$$RMS = [1/n\sum(h_m-h_s)^2]^{0.5}$$

where
n = number of measurements
h_m = measured head
h_s = simulated head

The calculated RMS error for the model was 0.30 m. This calibration result is considered acceptable for the size of the model domain, limited calibration data, and the dynamic system that was modelled.

Final adopted model parameters, following completion of the steady state calibration, were:

- Hydraulic conductivity = 15 m/day.
- Recharge = 55% average rainfall.
- Constant head along Butterfish Bay and Wreck Beach = 0.1 mAHD.

9.3 Predictive Modelling – Northeast Dune Sand Aquifer

To evaluate the optimum borefield design and sustainable yield, the calibrated model was run for various transient simulations with different extraction scenarios. To be conservative, the long-term predictive simulations to identify the maximum sustainable yield were run over a 15 year period (January 1992 to December 2006) which was one of the driest periods on record, where the residual mass balance and five year running average continually decreased (Figure A.2, Appendix A).

Hydraulic heads obtained from the calibrated steady state simulation were incorporated into the transient model as the initial heads. The simulations comprised 180 monthly stress periods to allow for changes in the monthly rainfall to be simulated.

9.3.1 Sustainable Yield Criteria

The sustainable yield was assessed at the maximum extraction rate that did not cause the following:

- Excessive drawdown causing the aquifer to dry out in the vicinity of the borefield or extraction well; and
- Reversal of the hydraulic gradient near the constant head boundaries representing Butterfish Bay or Wreck Beach, thereby inducing salt water intrusion.

To assess if a reversal of the hydraulic gradient occurred during the simulations, the simulated head was recorded at every stress period (ie. monthly) at locations of Bores MB3 and MB6. These bores are located within 100 m and 150 m of the constant head boundaries, respectively. If the extraction from the borefield caused the groundwater at these locations to be lower than the constant head of 0.10 mAHD, then it would reverse the natural gradient, and salt water would potentially flow into the aquifer. Thus, if the pumping scenario resulted in a level of less than 0.1 mAHD at MB3 or MB6 at any time throughout the simulation, the pumping scenario was considered not to be sustainable.

9.3.2 Predictive Modelling Results

The production bores in the model were located within the highest steady state water table region (or groundwater mound) of the aquifer (Drawing 8), and at a maximum distance from the constant head boundaries to minimise the potential impact of extraction on the groundwater levels near the beaches. The following predictive scenarios were run under transient conditions using the historical set of monthly rainfall from January 1992 to December 2006:

Run 1:

Predictive Run 1 was a no-pumping scenario carried out to obtain the simulated rise and fall of the groundwater levels with variation in rainfall only. The simulated heads were saved at the end of stress periods to validate that the calibration of the model was reasonable; ie. the model did not dry out under natural rainfall conditions and that fluctuations of the water table in response to rainfall were within likely bounds. This also allowed a better assessment of the impact of pumping from the borefield. The results are presented as hydrographs for each monitoring bore in Appendix H.

Run 2:

Predictive Run 2 simulated a total extraction of 400 kL/day from two production bores, located in the central region of the aquifer along the main access track where Bores MB4, MB5 and MB6 were also located. Each bore was set to extract 200 kL/day. The borefield comprised these two production bores, which were separated by approximately 150 m, with the following coordinate locations:

- PB1 – E292181, N7437599; and
- PB2 – E292071, N7437512

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 in the simulation. The simulated hydrographs for MB3 and MB6 show that the groundwater level dropped below 0.1 mAHD on several occasions including 1994, 1997, 2001, 2003 and 2004 (Appendix H). The pumping simulated from the borefield was therefore considered not to be sustainable, as it would likely cause salt water intrusion.

Run 3:

Predictive Run 3 simulated a total extraction of 300 kL/day from three production bores, located in the central region of the aquifer. Each bore was set to extract 100 kL/day. The borefield comprised these three production bores, which were separated by between 100 m and 150 m, with the following coordinate locations:

- PB1 – E292181, N7437599;
- PB2 – E292071, N7437512; and
- PB3 – E292092, N7437489.

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 in the simulation. The simulated hydrographs for MB3 and MB6 show that the groundwater level dropped below 0.1 mAHD on several occasions including 1997, 2001 and 2004 (Appendix H). The extraction simulated from the borefield was therefore considered not to be sustainable, as it would likely cause salt water intrusion.

Run 4:

Predictive Run 4 simulated a total extraction of 270 kL/day from three production bores, located in the central region of the aquifer. PB1 and PB3 were set to extract 100 kL/day, and PB2 was set to extract 70 kL/day to lessen the impact to water levels near Butterfish Bay and MB3. The borefield comprised these three production bores, which were separated by approximately 150 m, with the following coordinate locations:

- PB1 – E292181, N7437599;
- PB2 – E292071, N7437512; and
- PB3 – E292092, N7437489.

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 in the simulation. Groundwater contours at this stage of the simulation are shown on Drawing 13. The simulated hydrographs for MB3 and MB6 show that the groundwater level did not fall below 0.1 mAHD at any occasion throughout the simulation (Appendix H). The extraction simulated from the borefield is therefore considered sustainable, as it did not indicate salt water intrusion into the aquifer at any time during the simulation.

9.4 Long Beach Aquifer (Southwest Aquifer) Model

9.4.1 Model Geometry

The entire aquifer is represented as a one layer model. The aquifer boundaries of the model coincide with the known natural boundaries such as Long Beach and the geological boundaries between the dune sand and the Shoalwater Formation.

The model grid extends 1500 m in an east-west direction and 1400 m in a north-south direction. The finite difference grid was initially discretised into 142 rows and 148 columns with variable cell dimensions. The dimensions were reduced to approximately 7 m by 7 m in the area of expected high hydraulic gradients, ie. in the vicinity of the borefield.

The top of the model was set to correspond to the natural surface contours. The base of the model was set to correspond approximately to the base of the dune sand, as inferred from the bores located within the Long Beach aquifer (Drawing 10).

9.4.2 Model Hydraulic Boundaries

Boundary conditions are applied to numerical models to represent the physical environment and to constrain the model calculation domain. The types of boundaries selected were consistent with the conceptual model (Section 8.1) and include no-flow and constant head boundaries as described below:

- A constant head boundary was applied to the model where the aquifer is hydraulically connected to Long Beach. Tidal information provided by SSI indicated the mean tidal level was 0.01 mAHD for Great Keppel Island. However, following the calibration of the north-eastern aquifer model, 0.1 mAHD was set for the Long Beach constant head boundary; and

- No-flow boundary along the remaining boundaries (north, east and west) of the aquifer to represent the low permeability of the geological boundary between the aquifer sands and bedrock.

9.4.3 Initial Aquifer Parameters

Aquifer parameters required for the one-layer model included horizontal hydraulic conductivity, effective porosity and specific yield. Initial estimates were obtained from PSD tests carried out on sand samples collected from the monitoring bores. Using Hazen's method, the average permeability for the sand was calculated to be 20 m/day. Estimates for the specific yield and porosity were obtained from published ranges for a medium grained sand. Initial estimates for parameters used in the development of the aquifer model were:

- Horizontal hydraulic conductivity = 20 m/day
- Porosity = 0.20
- Specific yield = 0.15

9.4.4 Recharge

Aquifer recharge is the infiltration of rainfall over the entire surface area of the aquifer and through runoff from the hills which border the aquifer's northern and southern boundaries. As the runoff component is difficult to estimate and assumed to be minor compared to rainfall infiltration, it was not included in the model.

For a given value of hydraulic conductivity, various values of recharge will result in different elevations of the groundwater table. Rainfall recharge was simulated in the steady state simulations by obtaining the historical rainfall set for Great Keppel Island and applying a recharge coefficient of 30 % - 55 % to the average rainfall. This recharge was applied uniformly to the top layer of cells in the model.

9.4.5 Evapotranspiration

The *MODFLOW* evapotranspiration module was used for both steady state and transient simulations. The digital surface elevations were incorporated into the model as the evapo-transpiration surface. The maximum evapotranspiration rate was set to the average pan evaporation rate. The evaporation data and correction factor were obtained from the Bureau of Meteorology. The extinction depth used was 2 m.

9.4.6 Steady State Model Calibration

Calibration of a flow model refers to the trial and error process by which model parameters (hydraulic conductivity, recharge and boundary conditions) are adjusted to produce an acceptable match between simulated and observed groundwater levels. Typical model outcomes depend on several different parameters and combinations leading to the non-uniqueness problem where different sets of model inputs produce nearly identical model outputs. To reduce this possibility and increase the reliability of the model, it is preferred that as many model variables or inputs as possible are accurately determined, and the model is calibrated using both steady state and transient simulations. However, for this model, only one set of water level data (groundwater levels measured on the 27 July 2006) were available for the calibration. Hence, a transient calibration could not be undertaken.

The steady state calibration of the model was aimed at reproducing the observed groundwater levels in Monitoring Bores MB10, Long Beach Bore 1, and Long Beach Pump House piezometer and the expected flow patterns given the geometry of the aquifer. These conditions are illustrated on Drawing 11. The model calibration was carried out using a combination of manual and automated calibration using the parameter estimation (PEST) module of *Visual MODFLOW.*

During the calibration process, the aquifer parameters were limited to the following ranges:

- Hydraulic conductivity between 10 and 20 m/day; and
- Recharge between 30% (or 312 mm/year) and 55% (or 573 mm/year) of average annual rainfall.

A summary of the measured and simulated groundwater levels for the final calibration run at the monitoring bore locations is shown in Table 6, and the *Visual MODFLOW* calibration curve and statistics are shown in Appendix H. The simulated steady state water table contours from this calibration run are shown on Drawing 14 and are considered to agree well with observed water table levels.

Table 6: Model Calibration Results

Bore	K_H (m/day)	Recharge (% of Rainfall)	Observed SWL (mAHD)	Simulated Heads (mAHD)	Difference (m)
MB10	15	35	1.29	1.21	0.08
LB Bore 1	15	35	1.16	1.16	0.00
LB Pump House	15	35	0.87	0.86	0.01
RMS (m)					**0.05**

A measure of the success of model calibration can be evaluated using the root mean square error (RMS) expressed as:

$$RMS = [1/n\sum(h_m-h_s)^2]^{0.5}$$

where n = number of measurements
h_m = measured head
h_s = simulated head

The calculated RMS error for the model was 0.05 m, which is considered a good match given the limited data available.

Final adopted model parameters, following completion of the steady state calibration, were:

- Hydraulic conductivity = 15 m/day.
- Recharge = 35% average rainfall.
- Constant head along Long Beach = 0.1 mAHD.

9.5 Predictive Modelling – Long Beach Aquifer

To evaluate the optimum borefield design and sustainable yield, the calibrated model was run for various transient simulations with different extraction scenarios. A conservative approach was adopted. The long-term predictive simulations to identify the maximum sustainable yield were run over a 15 year period (January 1992 to December 2006) which was one of the driest periods on record, where the residual mass balance and five year running average continually decreased (Figure A.2, Appendix A).

Hydraulic heads obtained from the calibrated steady state simulation were used in the transient model as the initial heads. The simulations comprised 180 monthly stress periods to allow for changes in the monthly rainfall to be simulated.

9.5.1 Sustainable Yield Criteria

The sustainable yield was assessed at the maximum extraction rate that did not cause the following:

- Excessive drawdown causing the aquifer to dry out in the vicinity of the borefield or extraction well;
- Reversal of the hydraulic gradient near the constant head boundaries representing Long Beach, thereby inducing salt water intrusion; and
- Reversal of the hydraulic gradient or drawdown causing the salt water present beneath the Long Beach Pump House to travel towards the borefield and impact upon groundwater quality.

To assess if a reversal of the hydraulic gradient occurred during the simulations, the simulated head was recorded at every stress period (ie. monthly) at model locations of observation bores

OB1 and OB2, as well as the Long Beach Pump House piezometer. These bores are located within 100 m and 250 m of the constant head boundaries, respectively. If the extraction from the borefield caused the groundwater at these locations to be lower than the constant head of 0.10 mAHD, then it would reverse the natural gradient, and salt water would potentially flow into the aquifer. Thus, if the pumping scenario resulted in a level of less than 0.1 mAHD at OB1 or OB2 at any time throughout the simulation, the pumping scenario was considered not to be sustainable.

The particle tracking method was also utilised to assess the third point in the sustainable yield criteria. A line of particles was placed in the model at the position of the Pump House and then tracked through the transient simulations to identify the movement of this brackish water through the aquifer.

9.5.2 Predictive Modelling Results

The production bores in the model were located near Bore MB10 and the existing Long Beach Bore 1 (existing production bore) for practical purposes. These locations are also within the higher steady state water table region (or groundwater mound) of the aquifer (Drawing 14), and at a maximum distance from Long Beach to minimise the potential of salt water intrusion along the beach. The following predictive scenarios were run under transient conditions using the historical set of monthly rainfall from January 1992 to December 2006:

Run 1:
Predictive Run 1 was a no-pumping scenario carried out to assess the simulated rise and fall of groundwater levels with variation in rainfall only. The simulated heads were saved at the end of stress periods to validate that the calibration of the model was reasonable; i.e. the model did not dry out under natural rainfall conditions and that fluctuations of the water table in response to rainfall were within reasonable bounds. This also allowed for a better assessment of the impact of pumping from the borefield. The results are presented as hydrographs for each monitoring bore in Appendix J.

Tracking of the particles released from the Long Beach Pump House indicates that groundwater flow reached the constant head boundary (i.e. Long Beach mean tidal level) after approximately 750 days of the simulation as shown on Figure I.1 in Appendix I. This indicates that, under the rainfall conditions simulated, and with no extraction, the brackish water will probably be flushed out of the aquifer after approximately three to five years. This is considered to be the minimum period of time and will vary according to the amount of recharge to the aquifer and the hydraulic gradients within the aquifer. During dry climatic conditions it could take considerably longer to naturally flush out the brackish water.

Run 2:

Predictive Run 2 simulated a total extraction of 300 kL/day from two production bores, one located near Bore MB10 and the other at Long Beach Bore 1, where an existing set of production bores are located. Each bore was set to extract 150 kL/day. The borefield comprised these two production bores, which were separated by approximately 100 m, with the following coordinate locations:

- PB1 – E289872, N7434167; and
- PB2 – E289797, N7434202.

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 during the simulation. The simulated hydrographs for Bores OB1, OB2 and Long Beach Pump House show that the groundwater level dropped below 0.1 mAHD on several occasions including 1994, 1997, 1999, 2001, 2003, 2004 and 2005 (Appendix J).

Particle tracking indicated that particles released from the Long Beach Pump House reached the production bore after approximately 2,500 days, as shown on Figure I.2 in Appendix I. The pumping simulated from the borefield was therefore considered not to be sustainable, as it would likely cause salt water intrusion.

Run 3:

Predictive Run 3 simulated a total extraction of 150 kL/day from the same two production bores as used in Run 2.

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 during the simulation. Hydrographs for Bores OB1, OB2, and Long Beach Pump House show that the groundwater level did not drop below 0.1 mAHD during the simulation (Appendix J). However, particle tracking indicated that the particles released from the Long beach Pump House did trend towards the borefield during the dry periods of the simulation. The pumping simulated from the borefield was therefore considered not to be sustainable, as it would likely cause salt water intrusion (though to a lesser degree than Run 2).

However, if the aquifer did not contain the salt water at the outset and only comprised fresh water, then this total pumping rate (150 kL/day) would probably be sustainable since the pumping did not cause salt water from the constant heads to flow into the aquifer.

Run 4:

Predictive Run 4 simulated a total extraction of 100 kL/day from the same two production bores used in previous model runs. Each bore was set to extract 50 kL/day.

The simulated drawdown reached its maximum at the end of the stress period 153, which corresponds to September 2004 during the simulation. Hydrographs for Bores OB1, OB2 and Long Beach Pump House show that the groundwater level did not drop below 0.1 mAHD during the simulation (Appendix J).

Particle tracking indicated that particles released from the Long Beach Pump House did not trend towards the borefield and reached the constant heads representing Long Beach after approximately 950 days, as shown on Figure I.3 in Appendix I.

The pumping simulated from the borefield for Run 4 (100 kL/day) was therefore considered sustainable for the Long Beach aquifer, as it was unlikely to cause salt water intrusion impacting on the water quality.

10.0 CONCLUSIONS

A groundwater supply investigation has identified two dune sand deposits on Great Keppel Island as potential groundwater supply resources. These are the northeastern dune sand and southwestern dune sand deposits, which host two unconfined or water table aquifers. The investigation included development of a CHM for both aquifers.

The northeastern dune sand aquifer extends from Wreck Beach to Butterfish Bay and varies in depth from 7.5 m to greater than 21.5 m. The basement is residual sandy clay or weathered bedrock belonging to the Shoalwater Formation. It receives the majority of its recharge through the direct infiltration of rainfall across the ground surface and discharges groundwater into Wreck Beach and Butterfish Bay. The groundwater quality is fresh with a low dissolved salt content and a pH which varies from slightly acidic within the central region of the aquifer to slightly alkaline at the coastlines. Laboratory testing reported no levels for the water quality parameters or heavy metals tested in excess of drinking water guidelines, with the exception of the total hardness level in groundwater from Bore MB3.

The southwestern dune sand aquifer extends from Fisherman's Beach to Long Beach and varies in depth from 6.0 m to 17.0 m. The aquifer basement comprises residual sandy clay or weathered bedrock of the Shoalwater Formation. It receives the majority of its recharge through the direct infiltration of rainfall across the ground surface and discharges groundwater into the beaches on its northern and southern boundaries. However, the rise in basement beneath the southern end of the airstrip separates this aquifer into two – the Mecure Resort and the Long Beach aquifers. The Mecure Resort aquifer is relatively thin and contains poor quality groundwater, which is a result of salt water intrusion. Hence, this aquifer is not considered a viable option for further groundwater development.

The groundwater quality within the Long Beach aquifer was found to be fresh with a low dissolved salt content and a slightly acidic pH. Field water quality testing of groundwater from a piezometer at the Long Beach Pump House identified some salt water intrusion has probably occurred. Laboratory testing from Bore MB10 reported no levels for the water quality parameters or heavy metals tested reported in excess of drinking water guidelines.

Groundwater flow models were developed for the northeastern aquifer and Long Beach aquifer as one layer models using the pre-processor *Visual MODFLOW t*o assess the sustainability of extracting groundwater. Steady state calibration of the flow models was achieved by comparison of observed and simulated groundwater elevations.

Predictive modelling scenarios were run over a 15 year rainfall record from 1992 to 2006 which included one of the most driest periods on record. Predictive modelling has indicated the following sustainable yields for the two aquifers:

- Northeastern aquifer has a long-term maximum sustainable yield of ~270 kL/day (270 m^3/day) as simulated by predictive run 4 (Section 9.3.2). This simulated a borefield comprising three production bores located centrally within the aquifer; and

- Long Beach aquifer has a long-term maximum sustainable yield of ~100 kL/day (100 m^3/day) as simulated by predictive Run 4 (Section 9.5.2). This simulated a borefield comprising two production bores located near MB10 and Long Beach Bore 1.

Particle tracking used during the predictive modelling for the Long Beach aquifer indicates that it may take between three and five years (with no extraction of groundwater) for the natural groundwater flow regime to remove the brackish and salt water that has intruded the aquifer. This period is dependent upon the amount of recharge from rainfall entering the aquifer and may take considerably longer during a drought period. After the brackish water has been removed, the modelling indicated that the sustainable yield of the aquifer would increase to approximately 150 kL/day.

10.1 Preliminary Borefield Design

The borefields should be constructed at the locations simulated by the predictive scenarios to extract the maximum sustainable yields. The northeastern aquifer was simulated with three bores with the following coordinates:

- PB1 – E292181, N7437599;
- PB2 – E292071, N7437512; and
- PB3 – E292092, N7437489.

The Long Beach aquifer was simulated with two bores with the following coordinates:

- PB1 – E289872, N7434167; and
- PB2 – E289797, N7434202.

The volumes extracted from the individual production bores should not exceed those simulated. The modelling has shown that distribution of the pumping rates within the borefields affects the sustainable yield. If more water was pumped from the bores closer to the coastlines in the aquifers, then the yield would not be sustainable.

When the production bores are installed, additional monitoring bores should be constructed to monitor potential intrusion of salt water from the beaches within both aquifers. Two bore locations should be established in the northeastern aquifer: one to the northeast of MB3, and one between MB6 and Wreck Beach approximately 25 m above the high tide level. Two monitoring bores should also be established between the Long Beach Pump House and Long Beach.

11.0 RECOMMENDATIONS

It is recommended the following be carried out if the proposed borefields are constructed:

- The borefields are constructed in accordance with the design outlined in Section 10.1 to obtain the long term sustainable yields;

- Step drawdown and 48-hour constant rate pumping tests are carried out on each production bore installed in the borefield. Analysis of the pumping test data should be undertaken to assess the individual sustainable bore yields and allow comparison with the simulated bore yields;

- The production bores are constructed in accordance with the requirements outlined in Sections 10.1 and 11.1;

- Data loggers should be installed into two monitoring bores within each aquifer. One logger should be installed within a bore in the centre of the aquifer, and another close to the coastline;

- Monitoring of water levels and electrical conductivity should be undertaken for all monitoring bores every three months; and

- Monitoring of rainfall at the Mecure Resort should be continued and input into Excel spreadsheets.

11.1 Production Bore Construction Requirements

It is recommended that all bores be constructed in accordance with the Agriculture and Resource Management Council of Australia and New Zealand's *'Minimum Construction Requirements For Water Bores In Australia',* dated September 2003.

Construction requirements for the new production (extraction) bores are:

- Borehole diameter of at least 254 mm (10 inch) drilled to 3 m below the base of the dune sand deposits. Drilling to 3 m below the base of the sands will be required to allow for some collapsing of the borehole and to ensure the screen is set opposite the base of the aquifer;
- Boreholes are drilled with a biodegradeable polymer mud and not with bentonite. Bentonite could restrict water inflow to the bore;
- Stainless steel screens, 4 m in length, 150 mm (6 inch) in diameter, and with an aperture 0.5 mm should be used;
- Bore casings should comprise Class 12 uPVC casing, of 200 mm (6 inch) diameter;
- Gravel pack consisting of 2-3 mm graded sand/gravel should be placed adjacent to well screens;
- A 2 m bentonite seal should be placed within the annulus above the water table; and
- Lockable protective steel bore covers should be cemented in at the surface.

12.0 LIMITATIONS OF THIS REPORT

DP has performed investigation and consulting services for this project in accordance with current professional and industry standards for hydrogeological assessments. DP's assessment is necessarily based on the results of limited site investigations and upon the restricted programme of surface/subsurface sample screening and groundwater testing. Neither DP, nor any other reputable consultant, can provide unqualified warranties, nor does DP assume any liability for site conditions not observed or accessible during the time of the investigations.

This report and associated documentation and the information herein have been prepared solely for the use of Ozton Pty Ltd and SSI, and any reliance assumed by third parties on this report shall be at such parties' own risk. Any ensuing liability resulting from use of the report by third parties cannot be transferred to DP.

DOUGLAS PARTNERS PTY LTD

Carl Deegan
Associate/Hydrogeologist

Reviewed by:

Iain Hair
Senior Associate/Hydrogeologist

Photo 1: Drilling rig set up on Monitoring Bore 7 on the side of the airstrip.

Photo 2: Drill rig set up on Monitoring Bore 3, near Butterfish Bay, Northeast Aquifer.

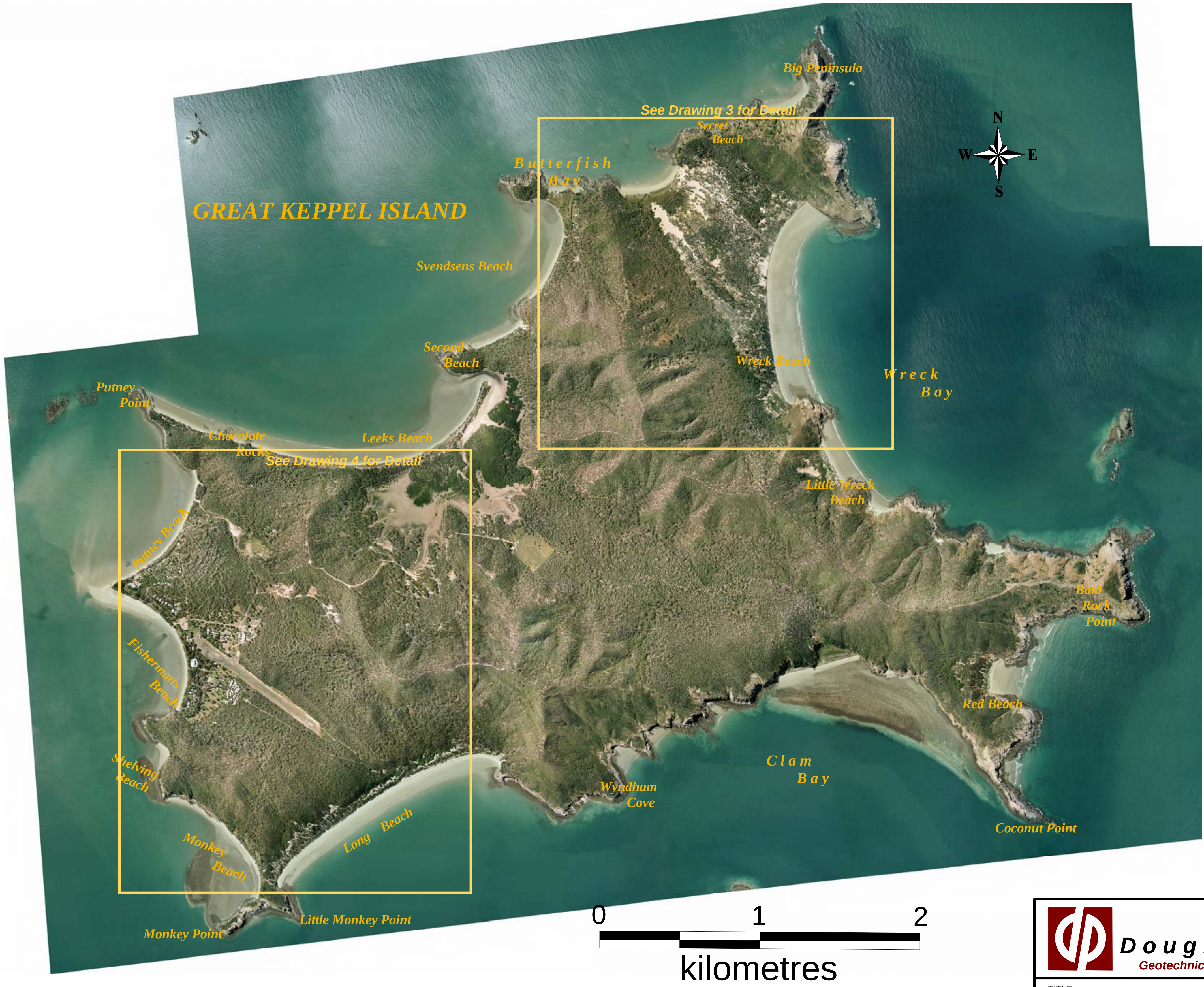
GROUNDWATER SUPPLY INVESTIGATION
GREAT KEPPEL ISLAND

Photo 3: Airlift development of Monitoring Bore 4, Northeast Aquifer.

Photo 4: Pumping Monitoring Bore 5 to complete development prior to sampling.

GROUNDWATER SUPPPLY INVESTIGATION
GREAT KEPPEL ISLAND

List of Drawings



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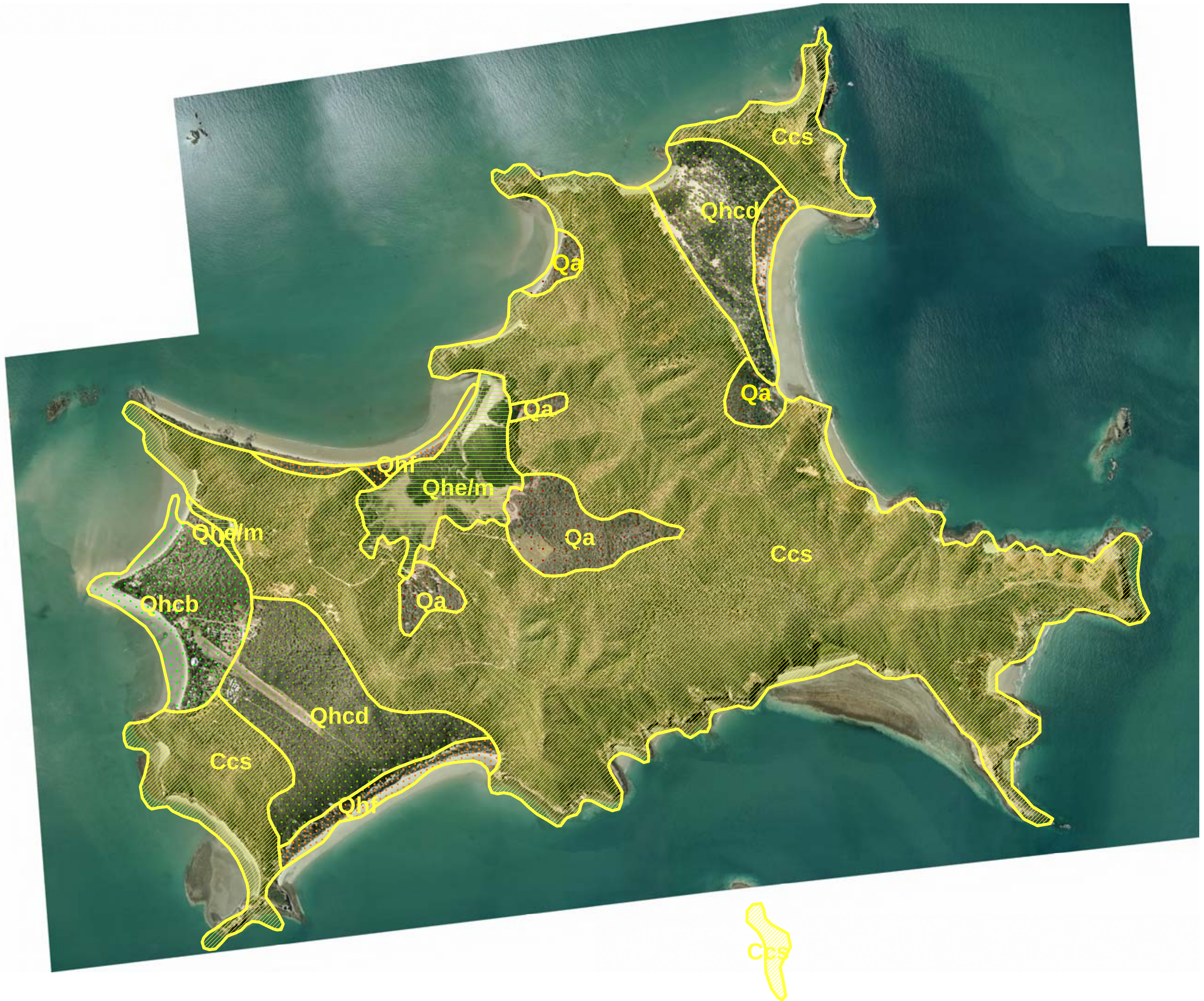
TITLE: **Great Keppel Site Plan Groundwater Supply Investigation Great Keppel Island**

CLIENT:	OZTON Pty Ltd						
DRAWN BY:	MFW	SCALE:	As Shown	PROJECT No:	33976	OFFICE:	Brisbane
APPROVED BY:				DATE:	February 2007	DRAWING No:	1



Ccs - Clay,silt,sand,gravel,active stream channel and low terraces

Qa - Clay, silt, sand, gravel, flood-plain alluvium

Qhcb - sand, coastal beach ridges, cheniers

Qhcd - Quartz sand, blow-out frontal dune

Qhe/m - Mud, sandy mud, muddy sand and minor gravel;estuarine channels,banks

Qhf - Foredune sand

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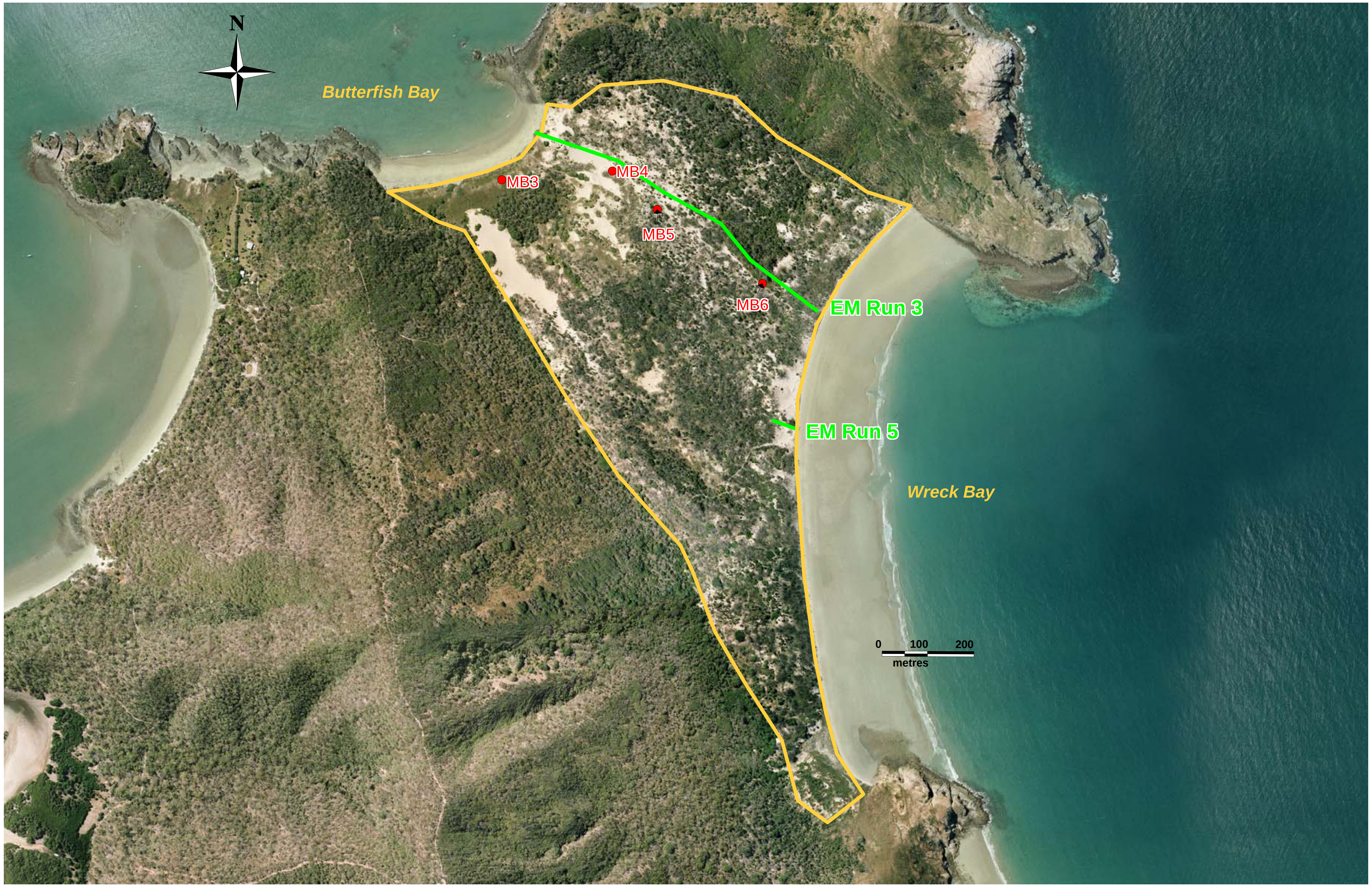
TITLE:
Great Keppel Island Geology
Groundwater Supply Investigation
Great Keppel Island

CLIENT: OZTON Pty Ltd			
DRAWN BY: MFW	SCALE: As shown	PROJECT No: 33976	OFFICE: Brisbane
APPROVED BY:		DATE: February 2007	DRAWING No: 2



Extent of dune sand aquifer

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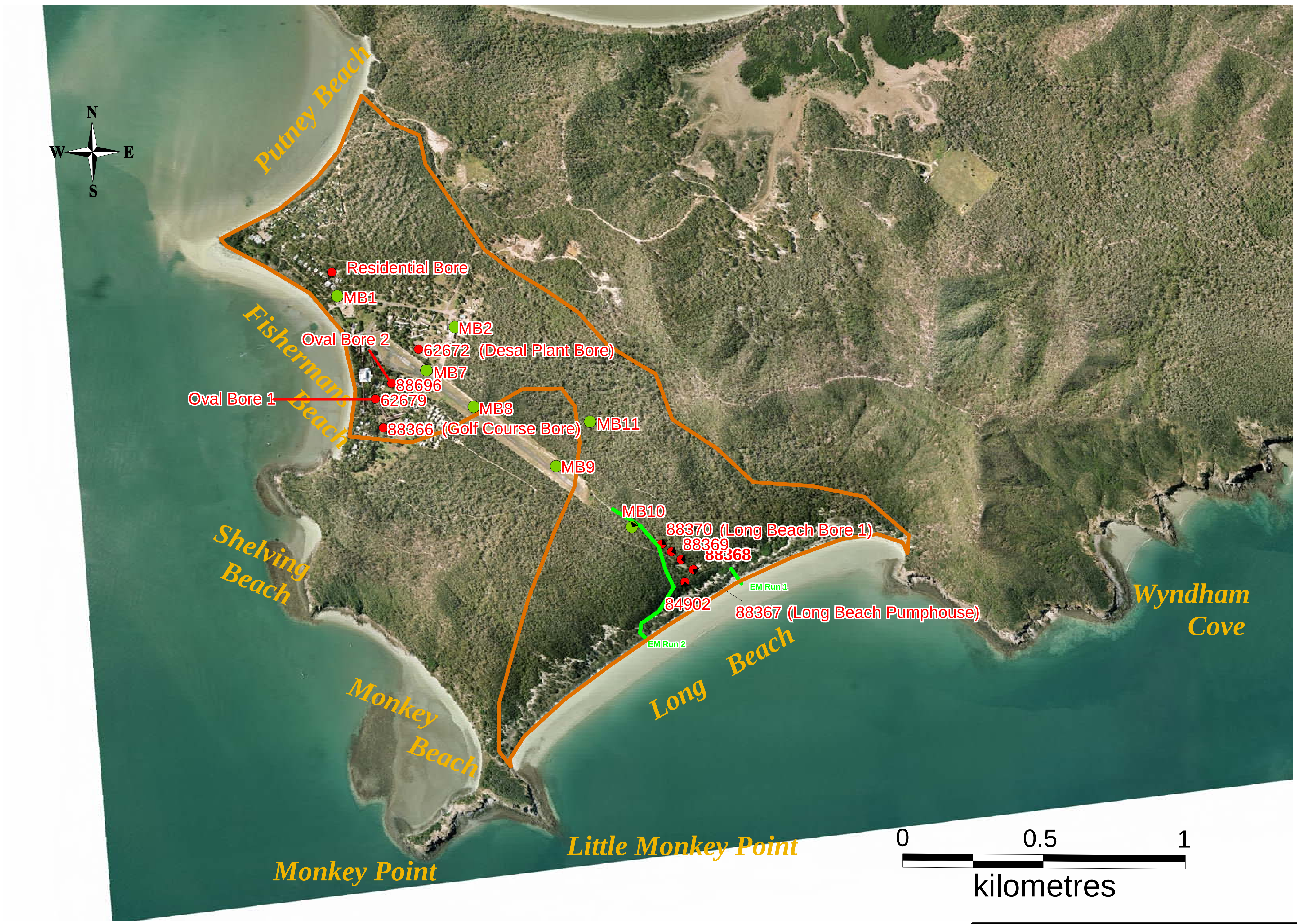
TITLE:

Test Location Plan - Northeast Aquifer
Groundwater Supply Investigation
Great Keppel Island

CLIENT:	**OZTON Pty Ltd**						
DRAWN BY:	**MFW**	SCALE:	As Shown	PROJECT No	**33976**	OFFICE:	**Brisbane**
APPROVED BY:				DATE:	**February 2007**	DRAWING No:	**3**



0 0.5 1
kilometres

Extent of Southwest Aquifer

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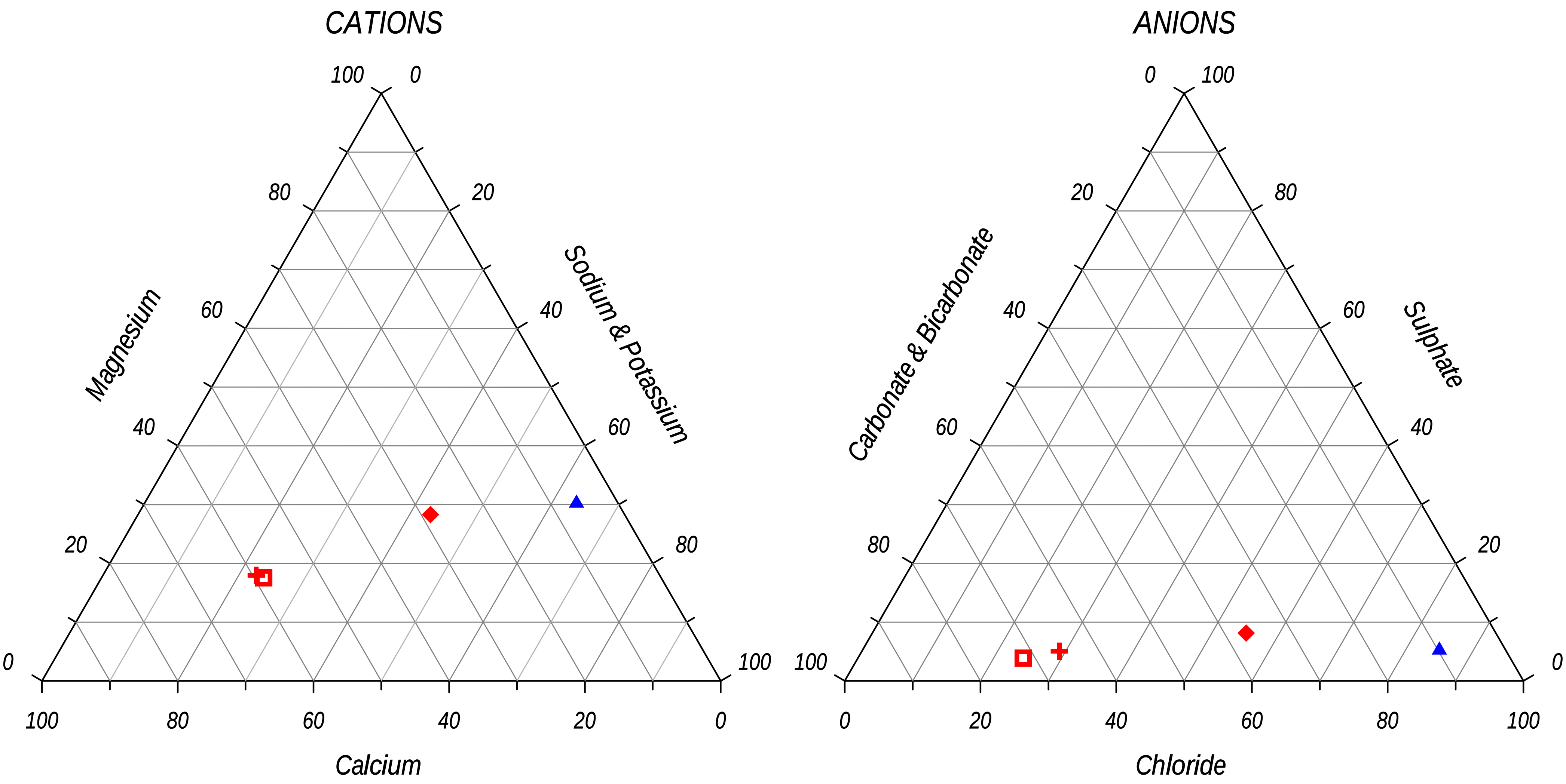
TITLE:

Test Location Plan - Southwest Aquifer
Groundwater Supply Investigation
Great Keppel Island

CLIENT: OZTON Pty Ltd			
DRAWN BY: MFW	SCALE: As Shown	PROJECT No: 33976	OFFICE: Brisbane
APPROVED BY:		DATE: February 2007	DRAWING No: 4



MONITORING WELLS

- MB3-NE AQUIFER
- MB4-NE AQUIFER
- MB5-NE AQUIFER
- MB10-SW AQUIFER

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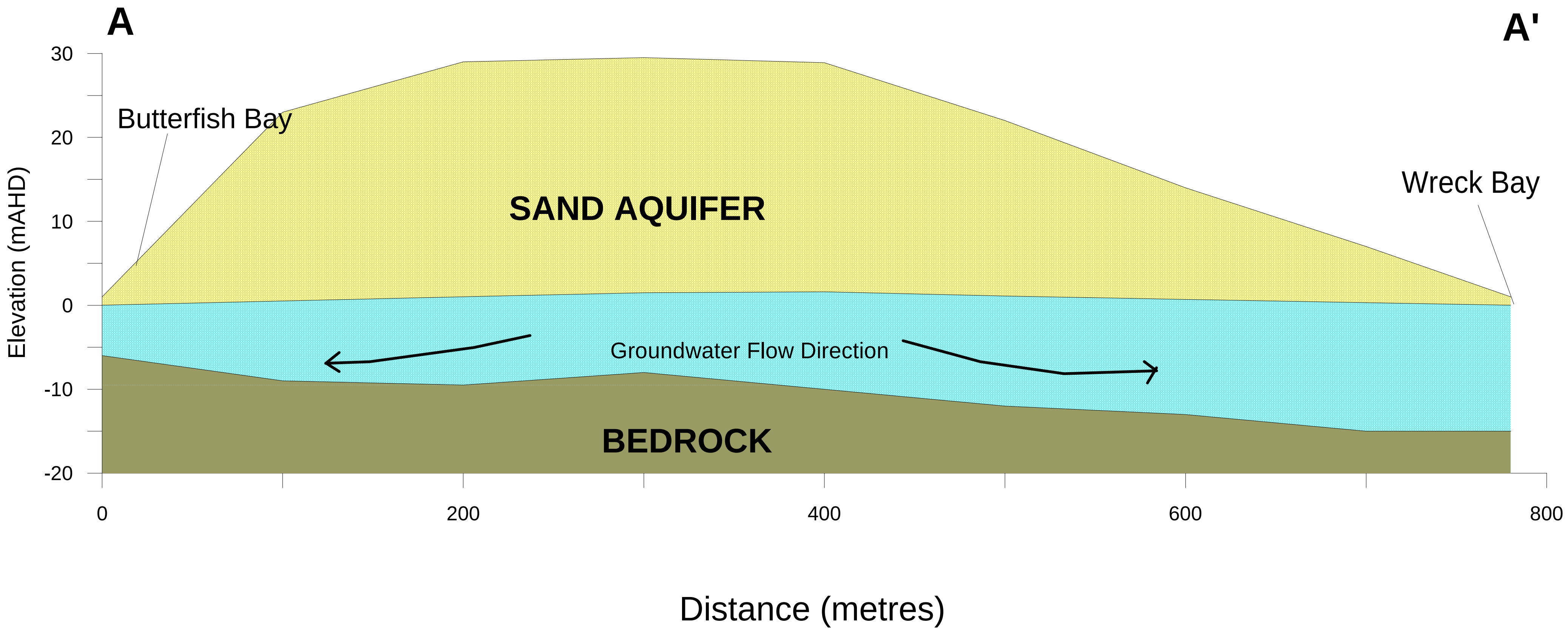
TITLE: Groundwater Chemical Composition Piper Diagram Groundwater Supply Investigation Great Keppel Island			
CLIENT:	OZTON PTY LTD		OFFICE: BRISBANE
DRAWN BY: MFW		PROJECT NO: 33976	DRAWING NO: 5
APPROVED:		DATE: February 2007	



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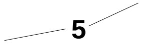
TITLE:	Northeast Aquifer - Cross Section A Groundwater Supply Investigation Great Keppel Island		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY:	MFW	PROJECT NO: 33796	DRAWING NO: 6
APPROVED:		DATE: Feb 2007	

Legend



Basement contour

Contour interval is 5 m

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TITLE	Northeast Aquifer - Inferred Base of Aquifer (mAHD) Groundwater Supply Investigation Great Keppel Island		
CLIENT:	OZTON PTY LTD		OFFICE: BRISBANE
DRAWN BY: MFW	SCALE: 1:100	PROJECT NO: 33976	DRAWING NO: 7
APPROVED BY: CMD		DATE: February 2007	

Legend

5 Standing water level (mAHD) contour
Contour interval is 0.25 m

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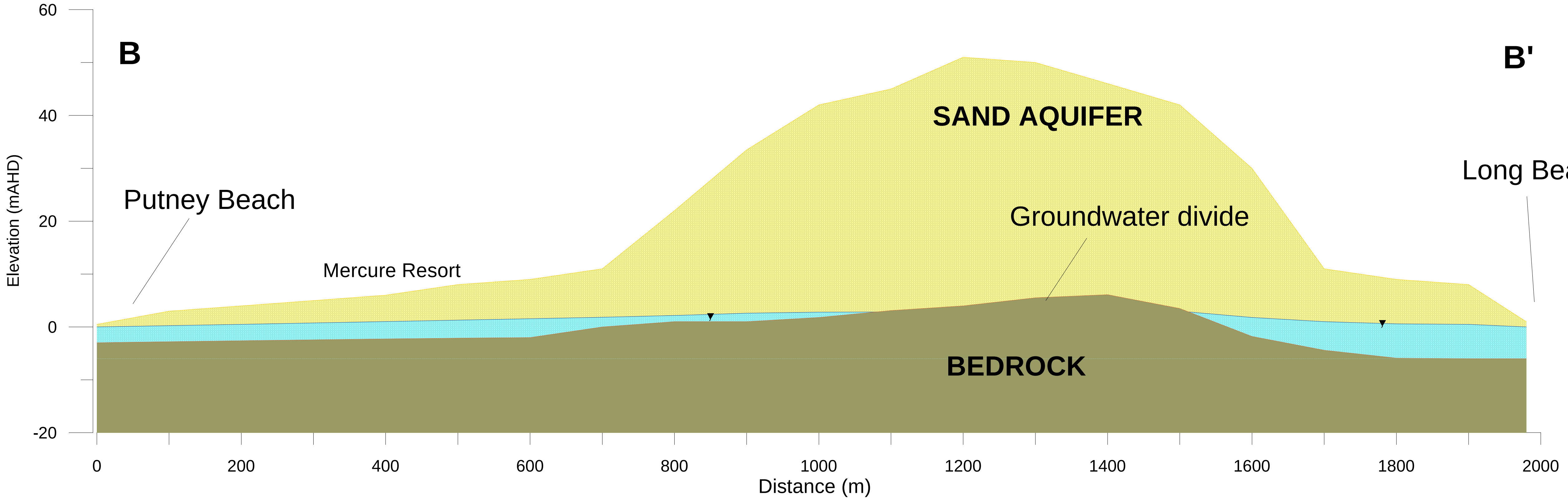
TITLE	**Observed Groundwater Levels, Northeast Aquifer Groundwater Supply Investigation Great Keppel Island**		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY: MFW	SCALE: 1:10,000	PROJECT NO: 33976	DRAWING NO: 8
APPROVED BY: CD		DATE: February 2007	



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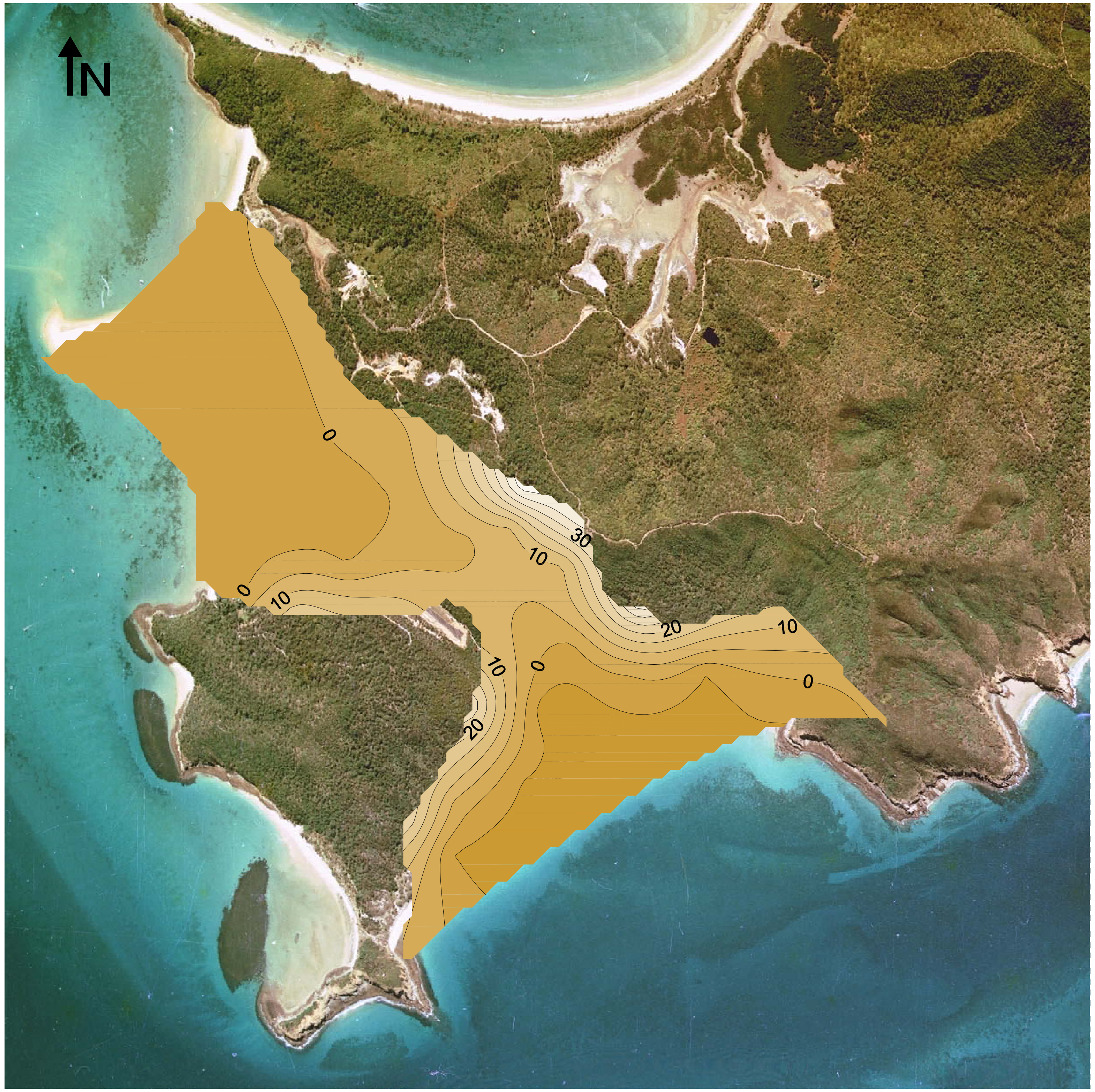
TITLE:	South-west Aquifer - Cross Section B Groundwater Supply Investigation Great Keppel Island		
CLIENT:	OZTON PTY LTD	OFFICE: BRISBANE	
DRAWN BY: MFW	PROJECT NO: 33976	DRAWING NO: 9	
APPROVED:	DATE: Feb 2007		



Legend

5 Base of Aquifer (mAHD) contour

Contour interval is 5 m

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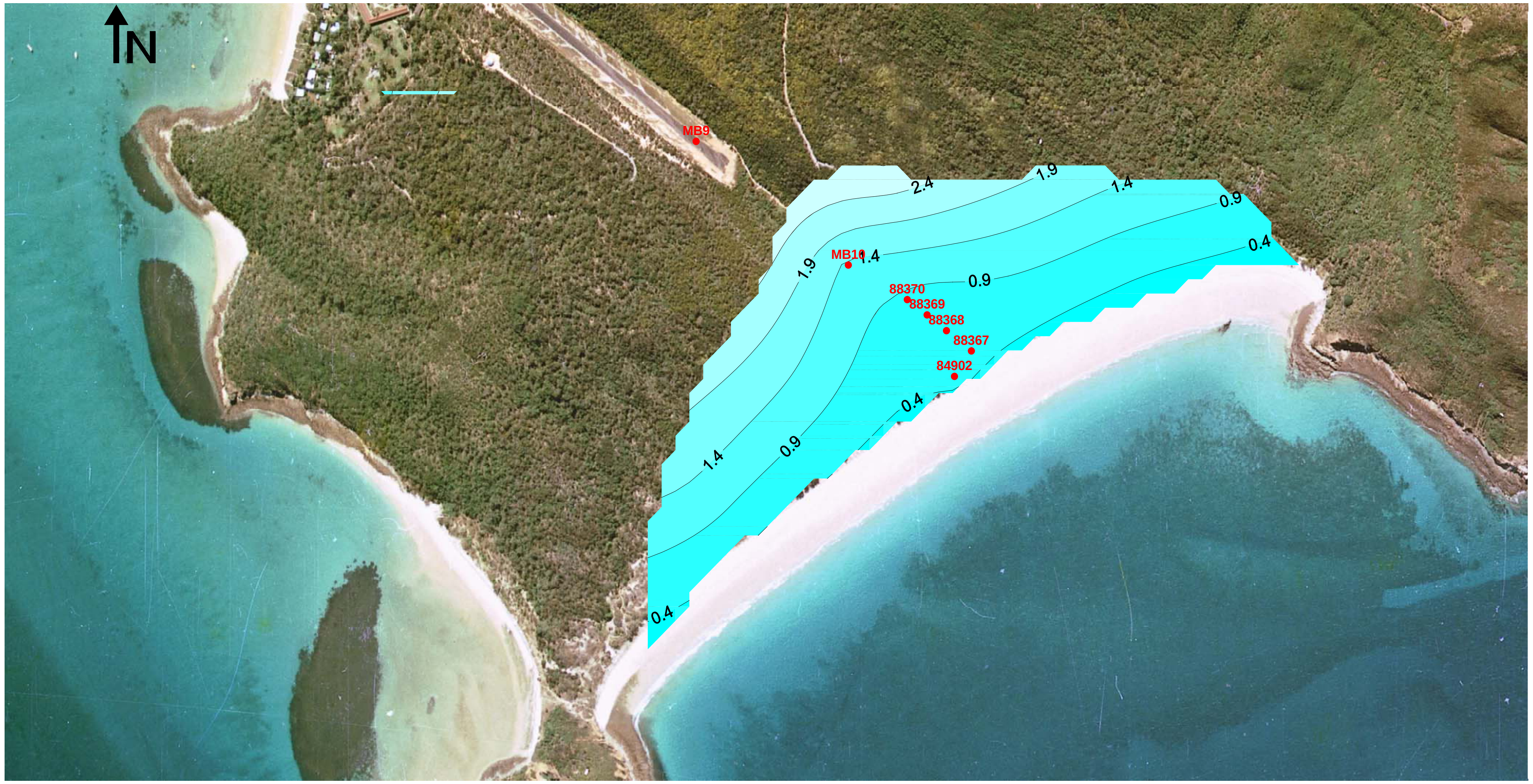
TITLE	**Southwest Aquifer - Inferred Base of Aquifer (mAHD) Groundwater Supply Investigation Great Keppel Island**		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY: MFW	SCALE: 1:15,000	PROJECT NO: 33976	DRAWING NO: 10
APPROVED BY: CMD		DATE: February 2007	



Legend

5 Standing water level (mAHD) contour
Contour interval is 0.5 m

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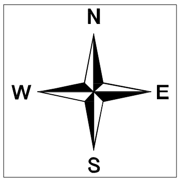
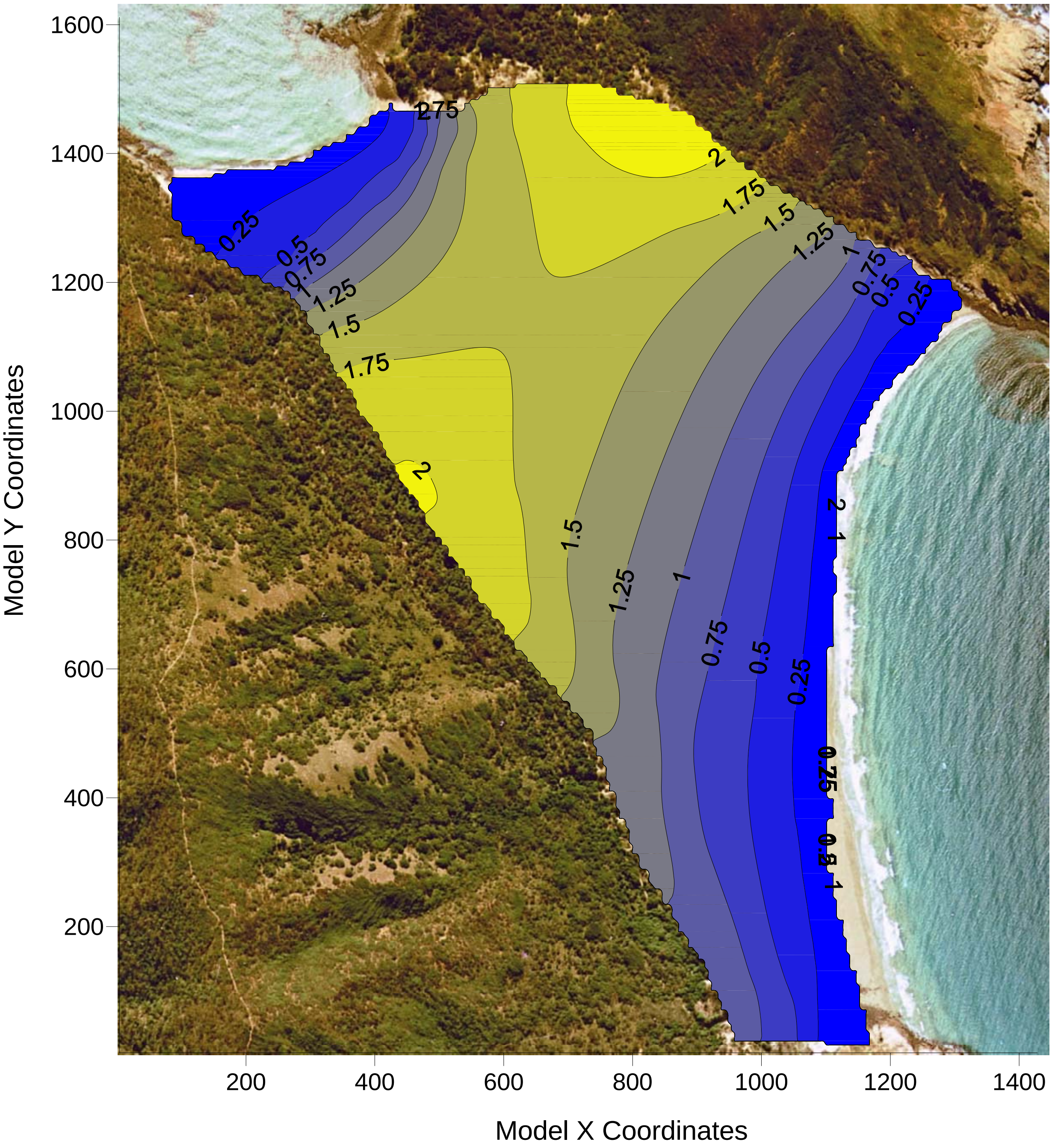
TITLE	**Observed Groundwater Levels, Long Beach Aquifer Groundwater Supply Investigation Great Keppel Island**		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY: MFW	SCALE: 1:15,000	PROJECT NO: 33796	FIGURE NO: 11
APPROVED BY: CD		DATE: February 2007	





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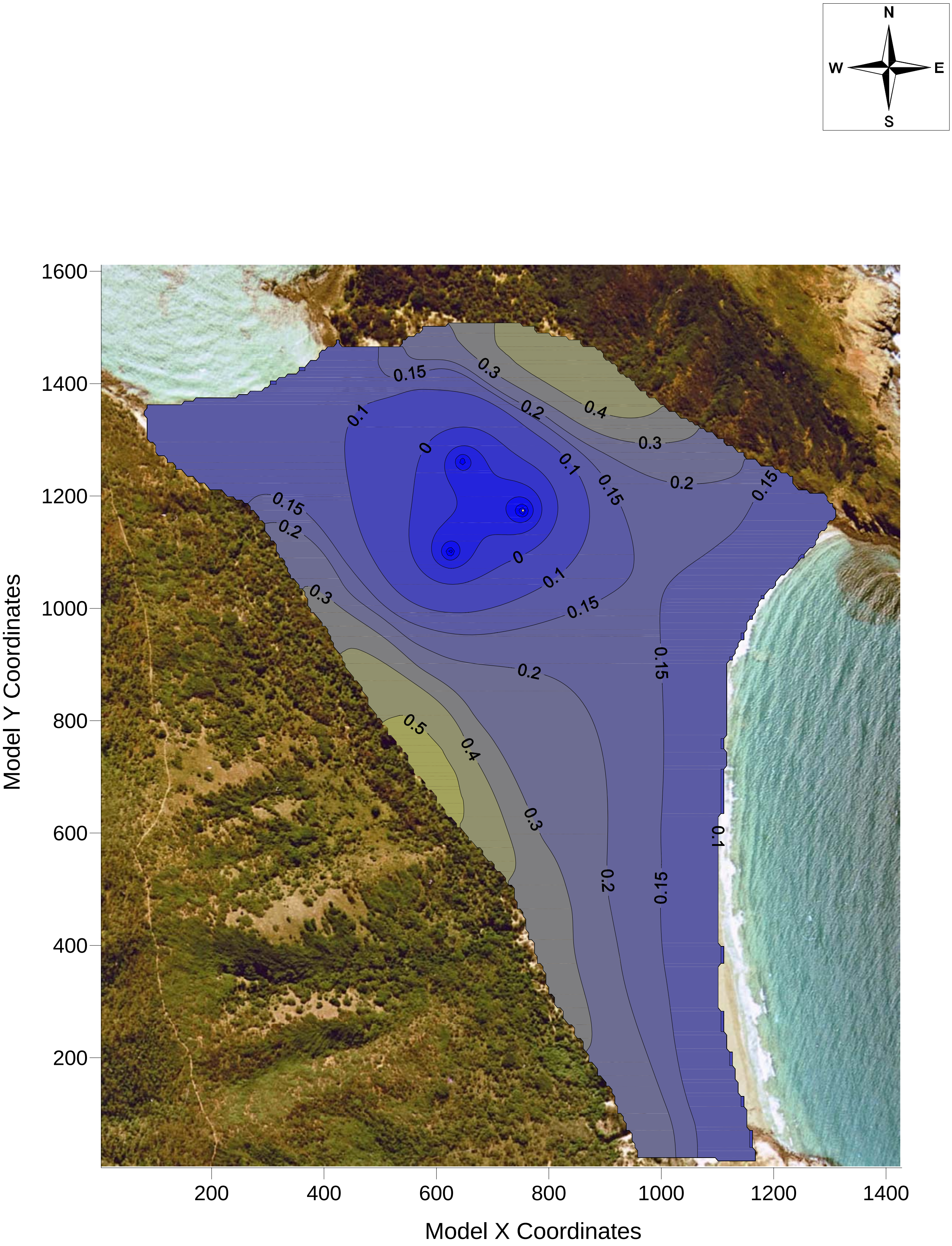
TITLE	GROUNDWATER SUPPLY GREAT KEPPEL ISLAND Steady State Calibrated Heads, Northeast Aquifer		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY: CMD	SCALE: 1:10,000	PROJECT NO: 33976	DRAWING NO: 12
APPROVED BY: CMD		DATE: Feb 2007	



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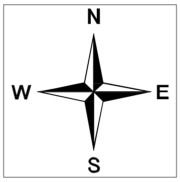
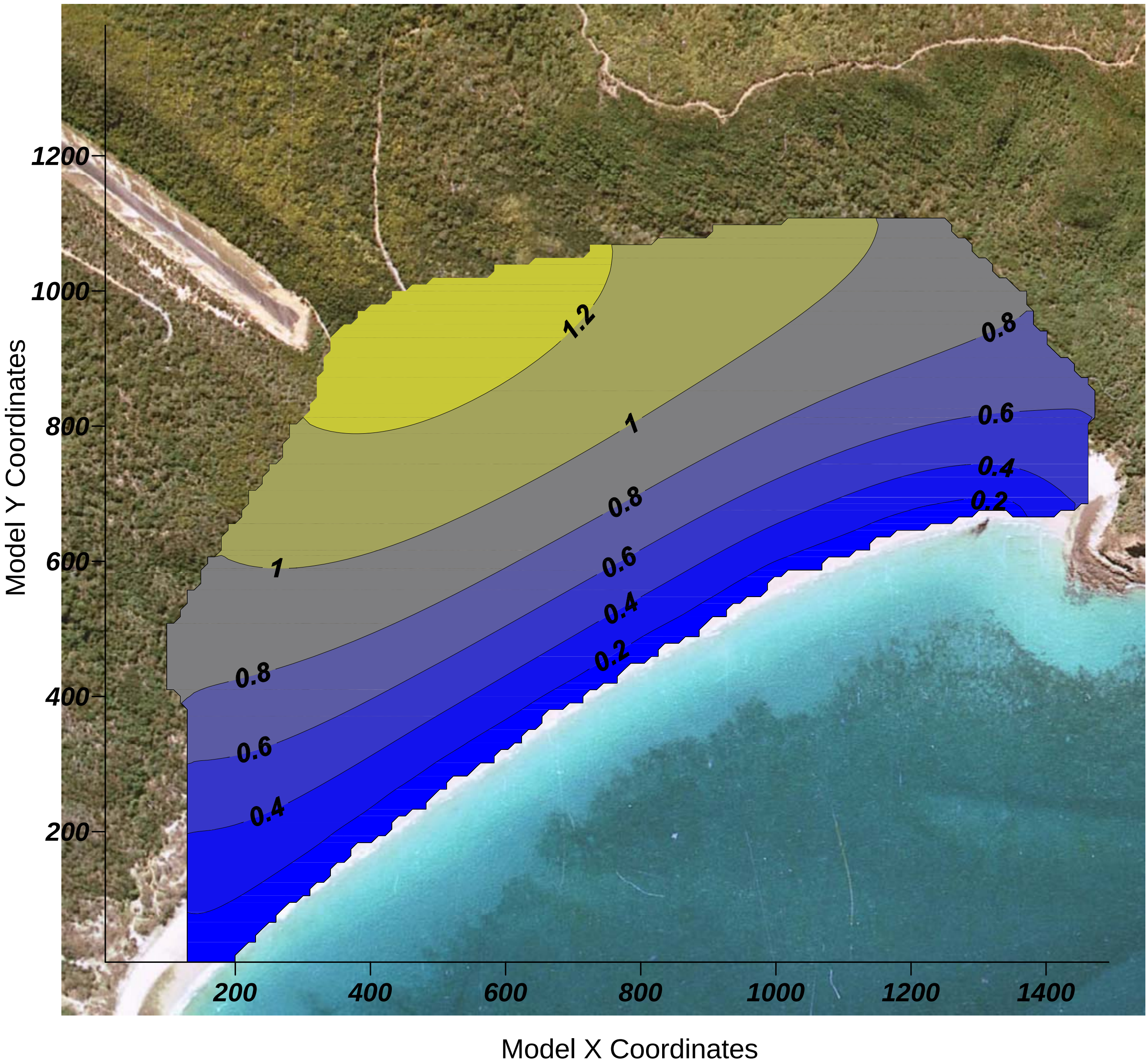
TITLE	GROUNDWATER SUPPLY GREAT KEPPEL ISLAND Run 4 Simulated Heads, Sept 2004 (SP153) Northeast Aquifer		
CLIENT: OZTON PTY LTD			OFFICE: BRISBANE
DRAWN BY: CMD	SCALE: 1:10,000	PROJECT NO: 33976	DRAWING NO: 13
APPROVED BY: CMD		DATE: Feb 2007	





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TITLE	GROUNDWATER SUPPLY GREAT KEPPEL ISLAND Steady State Calibrated Heads, Long Beach Aquifer		
CLIENT: **OZTON PTY LTD**			OFFICE: BRISBANE
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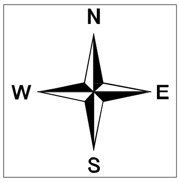

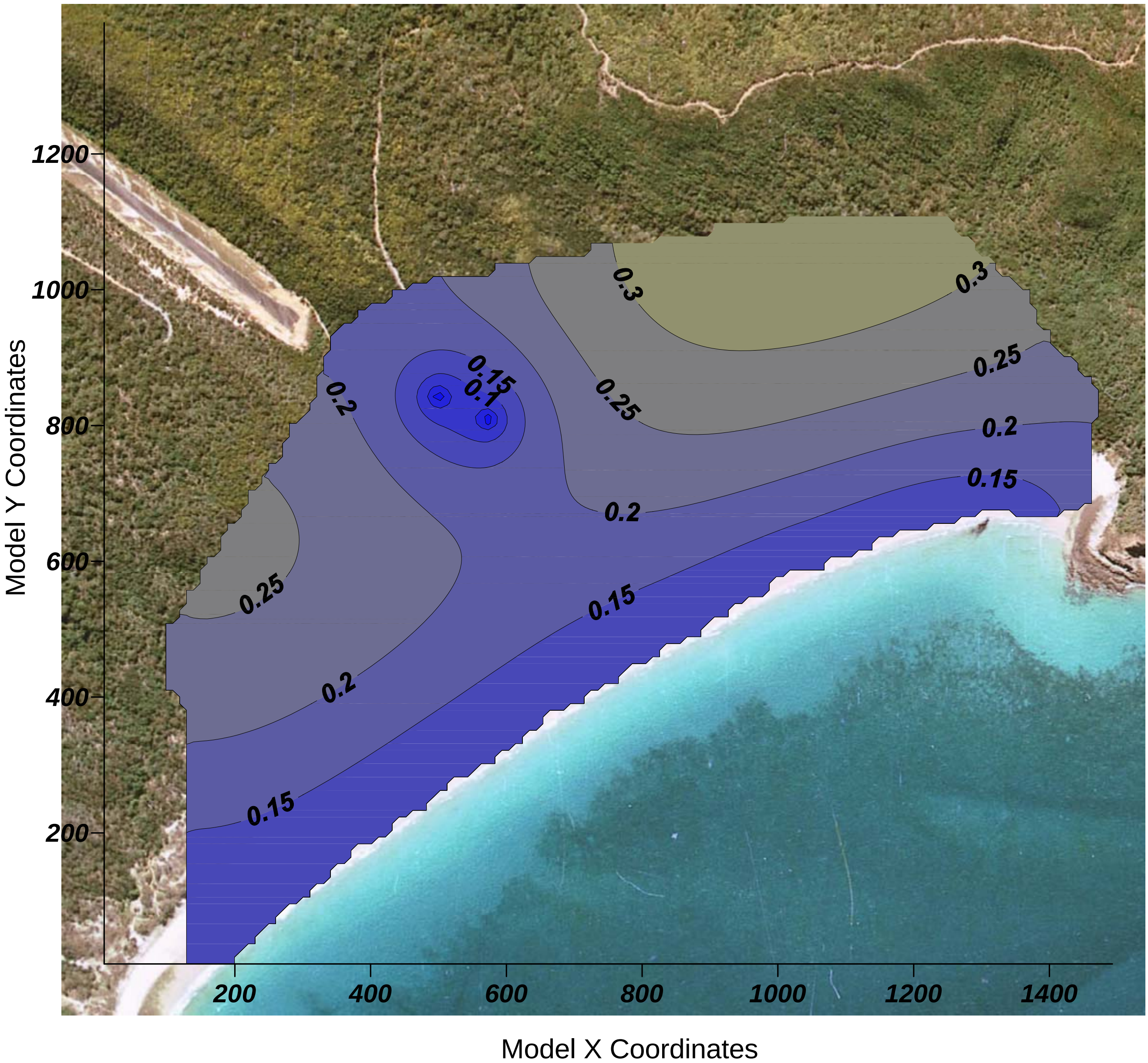

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TITLE	GROUNDWATER SUPPLY GREAT KEPPEL ISLAND Run 4 Simulated Groundwater Levels (Sept 2004), Long Beach Aquifer
CLIENT: OZTON PTY LTD	OFFICE: BRISBANE
DRAWN BY: CMD	SCALE: 1:10,000
PROJECT NO: 33976	DRAWING NO: 15
APPROVED BY: CMD	DATE: Feb 2007