Annex J

Groundwater Modelling Report

FINAL REPORT

Water Corporation

Sepia Depression Ocean Outlet Landline (SDOOL) Duplication

Groundwater Modelling and Impact Assessment Report

November 2011

Reference: 0116221

Environmental Resources Management Australia
6th Floor, 172 St Georges Terrace
Perth WA 6000
Telephone +61 8 9321 5200
Facsimile +61 8 9321 5262
www.erm.com

CONTENTS

LIST OF ACRONYMS

AEM	Analytic element method
AHD	Australian Height Datum
AMG	Australian Mapping Grid
CSM	Conceptual site model
CSMS	Contaminated sites management series
DD	Drawdown
DO	Dissolved oxygen
DoW	Department of Water
DTB	Depth to bottom
DTW	Depth to water
DQOs	Data quality objectives
EC	Electrical conductance
ERM	Environmental Resources Management Australia Pty Ltd
LF	Leederville Formation
mbgl	Metres below ground level
MBM	Mangles Bay Marina
MWH	Montgomery Watson Harza Global, Inc.
RS	Rockingham Sand formation
SBS	Safety Bay Sand formation
SDOOL	Sepia Depression Ocean Outlet Landline pipeline duplication
TD	Total depth
TL	Tamala Limestone formation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator coordinate system
WA DEC	Western Australia's Department of Environment and Conservation
WGS	World Geodetic System
WP	Worley Parsons

EXECUTIVE SUMMARY

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by the Water Corporation in February 2011 to develop a groundwater model to assess potential impacts on the local environment and groundwater users from the proposed construction and operation of the Sepia Depression Ocean Outlet Landline (SDOOL) duplication, to be developed in Peron and Rockingham, within the City of Rockingham, Western Australia (WA).

Specifically, the modelling focused on water levels and salinity in the local Safety Bay Sand aquifer and Lake Richmond. Trenching associated with SDOOL installation will require temporary dewatering to a depth of 1.86 to -1.95 meters (m) Australian Height Datum (AHD), which is up to about 2 m below mean water level. Model scenarios included both construction and long-term operation of the SDOOL duplication. Construction modelling assumed two dewatering scenarios (with and without recharge to a preceding section of the SDOOL pipeline trench) and conditions post construction.

Modelling was preceded by supplemental field work completed by Montgomery Watson Harza (MWH) and, later, by ERM, as well as literature reviews to ensure that the best available data and understandings were used to serve as the geologic and hydrogeologic bases for the model.

The two-dimensional MODAEM and three-dimensional SEAWAT models were employed for the evaluations conducted because of their applicability to complex hydrogeologic and salinity-related modelling, respectively. Results of the modelling indicated the following:

- Low seasonal water levels in Lake Richmond during the SDOOL duplication construction dewatering without recharge will be reduced by 0.11 m and return to natural conditions within a year after construction;

- Low seasonal water levels in Lake Richmond during the SDOOL duplication construction with dewatering recharge to the construction trench will be reduced by 0.009 m and return to natural conditions within 6 months after construction;

- Future Lake Richmond water levels will not be affected by the presence of the SDOOL;

- Saltwater intrusion is not discernibly affected by SDOOL construction with or without recharge to the pipeline trench;

- Salinity levels in Lake Richmond and the surrounding SBS aquifer are not expected to change discernibly during the SDOOL duplication construction and operation, with or without the recharge-to-trench option;

- Local groundwater users with bores located in the upper 'lower salinity' sections of the SBS and located in the immediate vicinity of the SDOOL duplication may be impacted with temporary drawdown effects (approximately one-week), however, the maximum drawdown is not expected to exceed the natural range of water level fluctuation of 0.5 m; and

- Impacts to Threatened Ecological Communities (TECs) surrounding Lake Richmond are not expected due to the temporary nature of dewatering, the low levels of drawdown expected (both with and without recharge to trench) and negligible impact on salinity levels in Lake Richmond and the SBS aquifer.

1 *INTRODUCTION*

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by the Water Corporation in February 2011 to develop a groundwater model to assess potential impacts on the local environment and groundwater users from the proposed construction and operation of the Sepia Depression Ocean Outlet Landline (SDOOL) duplication, to be developed in Peron and Rockingham, within the City of Rockingham, Western Australia (WA) (*Figure 1, Appendix A*).

The model study area utilised extends from the Mangles Bay coastline inland to the Serpentine River, Wellard, and Munster; north toward Fremantle; and south to Mandurah.

Impacts, measured by changes in water levels and quality (salinity) in the local aquifers and Lake Richmond, were evaluated during both construction and operation of the proposed SDOOL Duplication. Construction modelling scenarios assumed dewatering with and without recharge to the pipeline trench.

The SDOOL duplication (*Figure 1, Appendix A*) is a shallow pipeline to convey treated wastewater from the Water Corporation's Woodman Point, Kwinana, and Point Peron treatment plants to the ocean. The proposed SDOOL duplication route and depth is shown in *Figure 1, Appendix A*. Trenching associated with the SDOOL installation will require temporary dewatering to a depth of 1.86 to -1.95 meters (m) Australian Height Datum (AHD), which is up to about 2 m below mean water level. The locations and dewatering elevations were given in the engineering drawings provided to ERM by the Water Corporation. The most recent proposed SDOOL installation plan involves advancing the trenching continuously from east to west, with the pipe to be installed in 100 m sections (advancing at an approximate speed of 25 m/day) and each dewatering segment comprising of a length of approximately 200 m (100 m trench plus 50 m behind and in front of the trench).

1.1 OTHER RELATED ACTIVITIES

In addition to addressing the SDOOL duplication, the regional groundwater model developed for this report was also utilised to assess Cedar Woods proposed Mangles Bay Marina-Based Tourist Precinct (MBM) (*Figure 1, Appendix A*), which if developed would intersect the existing SDOOL and proposed SDOOL duplication, as well as potentially result in potential cumulative impacts on the local environment and groundwater users. Model simulations for the proposed development of the MBM and cumulative impacts with SDOOL have been documented in a separate report (ERM, 2011), which was recently submitted to the WA Environment Protection Authority (EPA) as part of the Cedar Woods Public Environmental Review (PER) document.

2 SITE SETTING

Regional and local geology, hydrogeology, and hydrology have been studied extensively by Montgomery Watson Harza (MWH) (MWH, 2010a) and are not repeated in detail in this modelling report. Since the date of the MWH report, supplemental field work has been completed by ERM (*Appendix B*), the results of which are included in the discussion pertaining to model development below.

In addition to supplementary field work, ERM prepared a revised Conceptual Site Model to further develop work undertaken by MWH and help support the development of the groundwater model (see *Section 3*). This report can found in *Appendix B*.

2.1 GEOLOGY

A regional geologic map is presented in *Figure 2, Appendix A* that indicates the following key geologic formations relevant to the site model. These formations, listed in order of increasing depth, are present beneath the proposed SDOOL duplication and the vicinity:

- Safety Bay Sand (SBS),
- Tamala Limestone (TL), and
- Rockingham Sand (RS).

These formations are underlain by the Leederville Formation.

Based upon lithological (including geophysical) data collected by ERM in the general project area, the SBS is 20 to 24 m thick and is expected to decrease in permeability with depth, as the upper aeolian sands transition into the silty marine Becher sand. A thin (0.5 to 1.5 m) clay layer at the base was found to begin at depths of -17.5 m AHD (well MB05 in *Figure 1, Appendix A*) to -22.5 m AHD (well LR1 in *Figure 1, Appendix A*).

The TL underlies the SBS. It is 4 to 7 m thick in the general vicinity of pipeline and is underlain by interbedded shales, clays, and the RS. These shales and clays were first encountered at -23.5 to -26.5 m AHD.

The RS rests beneath part of the TL in what is assumed to be a paleo-channel eroded into the Leederville Formation. This unit extends offshore from Rockingham to beneath the southern end of Garden Island (MWH, 2011). The unit generally consists of slightly silty, medium to coarse grained marine sand, although interbedded shales and clays are also found. The RS is as much as 110 m thick east of Lake Richmond and is expected to be thinner to the west of Lake Richmond.

The Leederville formation exists as a sub-crop in the area and consists primarily of fine to coarse grained sandstone, shale, siltstone, and claystone.

2.2 HYDROGEOLOGY

Regional and local hydrogeology has been reported extensively by MWH (MWH, 2010b and 2011) and is not repeated in detail in this modelling report. Supplemental hydrogeologic information was collected by ERM since the MWH reports and is presented in ERM's revised conceptual site model (*Appendix B*).

The SBS contains the superficial unconfined aquifer at the site, underlain by the TL's confined aquifer in the model study area. The thin clay layer at the base of the SBS appears to serve as an aquitard.

2.2.1 *Aquifer Parameters*

Table 2.1 summarises the aquifer parameters for the SBS and TL geological formations.

Table 2.1 Aquifer Parameters for SBS and TL geological formations

Aquifer Parameter	Unit	Safety Bay Sand (SBS)	Tamala Limestone (TL)
Hydraulic conductivity (horizontal)	(k_h), m/d	5 (Worley Parsons, 2005) 20 (MWH, 2011) 40 (Passmore, 1970) 50 (Davidson, 1995)	100 - 1,000 (Davidson, 1995) 5 - 3,000 (Worley Parsons, 2005)
Transmissivity	m^2/d	1,022 (Passmore, 1970) 600 (Davidson, 1995)	no field data available
Storage coefficient	-	0.11 - 0.2 (Passmore, 1970)	no field data available
Specific yield	-	0.3 (Davidson, 1995)	no field data available
Saturated thickness	m	20 (Davidson, 1995)	variable

It should be emphasised that measured aquifer hydraulic conductivity and transmissivity are known to have high variability (an order of magnitude of variation for unconsolidated formations such as the SBS (defined by Shapiro, 2004). The uncertainty of these variations is reduced by modelling techniques used, which rely more on the site water balance. The modelling is thus able to avoid the use of uncertain aquifer parameters as input data, except for the hydraulic conductivity, where the parameter is based upon the recharge rate (which has limited uncertainty). Thus, this parameter has been subjected to a sensitivity analysis, as documented in *Section 4.2.2* of this report.

2.2.2 *Overall Hydrogeologic Setting*

Figure 2, Appendix A depicts regional surficial geologic materials in plan view. A conceptual regional hydrogeologic profile is presented in *Figure 3, Appendix A*, modified using one of the cross-sections of *Figure 2, Appendix A* (Smith, 2001).

Groundwater flow in the SBS is typically from inland areas to the ocean, to the west of the groundwater divide shown in *Figure 4, Appendix A*. Saltwater intrusion is a concern in both the SBS and TL, and both are tidally influenced, with the SBS less saline and less tidally influenced than the TL, based upon the following data from *Appendix B*, see *Table 2.2*.

Table 2.2 Tidal influence on SBS and TL geological formations below the proposed SDOOL duplication

Well Number (Formation)	Water Level (m AHD)/ Time Measured*	Electrical Conductivity (µS/cm) / Elevation (m AHD)
LR1 (TL)	1.001 / 8:50 am	9,120 / -23
LR1 (TL)	0.644 / 4:30 pm	13,170 / -27
LR2 (SBS)	0.725 / 8:50 am	1,720 / -1.2
LR2 (SBS)	0.719 / 4:30 pm	3,230 / -19.5

* Data was measured on 30 June 2011

The uppermost aquifer, the SBS, has its eastern boundary approximately 8.3 km inland from Lake Richmond, where the SBS discharges to the Eastern TL Area. The Eastern TL Area elevates the SBS to the land surface and to the lakes that lie along this boundary. The western boundary of the SBS is where the SBS discharges to the ocean. Thus, the source of groundwater in the SBS is from local recharge, and the two opposing discharge zones cause the formation of a hydraulic divide in the central area of the SBS (*Figure 4, Appendix A*).

The SBS is underlain by a low-permeability basal aquitard of clay and silt. The saltwater interface elevation is situated in this aquitard and the underlying TL formation within the study area of interest for this project. Because the saltwater interface acts as an aquitard for freshwater, modelling of layers deeper than the TL is not pertinent to assessing the movement of saltwater intrusion in the study area.

East of the eastern end of the SBS, the top of the TL formation reaches the land surface, receiving local surface recharge and then discharges from the SBS on its eastern side. The TL discharges to the ocean on the west. With its high aquifer transmissivity, the TL would present a saltwater intrusion opportunity under tidal conditions; however, net movement of water in the TL is small in its saline regions.

Within the SBS, Lake Richmond lies in the top of the regional groundwater table. Like most lakes, it receives groundwater inflow from upgradient and discharges groundwater downgradient of the lake in the north-western half of the model area. Two stormwater drainage ditches connected to Lake Richmond in the 1960's also contribute surface water to the lake.

The underlying aquifer for the SBS and its associated aquitard is the TL. It receives downward leakage of water through the SBS aquitard.

The above information was used as the basis for the models described in *Section 3*. Representative data drawn from the above-cited sources, and others, as noted in the following sections, were used as inputs for the models employed.

2.3 *HYDROLOGY*

The area in the vicinity of the proposed SDOOL duplication has no natural surface water drainage systems; only man-made drainage courses. Concentration of stormwater runoff from more inland parts of the area is provided by engineering modifications to Lake Richmond that occurred in the 1960's.

Lake Richmond is a body of water approximately 1,000 m long by 600 m wide and up to 15 m deep (-13 m AHD) but much shallower near the edges. Bore logs suggest that Lake Richmond is entirely within the SBS, with the lake bottom approximately 7 to 10 m above the inferred contact between the SBS and the underlying TL. Mean lake levels vary seasonally from 0.2 to 1.2 m AHD (long-term average 0.74 m AHD).

The lake was formerly reported to be saline (it was once connected to the Indian Ocean). After the lake became an engineered outlet for Rockingham, Shoalwater, and Safety Bay stormwater, lake water quality changed from saline to fresh or marginal, although stormwater has also reportedly contributed nutrients, and other pollutants to the lake. Two inlet drains feed the lake, and one outlet (at 0.58 m AHD) discharges to Mangles Bay (*Figure 1, Appendix A)*.

Mean annual rainfall at Medina (approximately 5 km north-east of Rockingham) is 767.2 mm, less than half the mean annual potential evaporation in the Cape Peron area of 1,728 mm (MWH, 2011).

3 MODEL CONCEPTUALISATION

3.1 MODEL SOFTWARE UTILISED

ERM developed a regional groundwater flow model using the two-dimensional MODAEM to set baseline conditions and model boundaries for subsequent use in a three-dimensional saltwater intrusion model for the SBS using SEAWAT. MODAEM was developed by Dr. V. Kelson (Kelson, 2001) of Wittman Hydro Planning Associates (WHPA) in Bloomington, Indiana, U.S.A. MODAEM is an analytic element model and so does not require subdivision of the interior of the model area into cells and elements, as must be done with finite-difference and finite-element models. Instead, the model is characterised by "analytic elements" representing line sources and sinks, such as rivers and drains or specified head and flow boundaries. Wells are represented as points, and recharge and aquifer properties are defined on polygons. MODAEM then develops a set of equations from these elements to be solved for any location in the horizontal plane. After a MODAEM conceptual model has been defined, the model can be executed without establishing a model grid. Although a background grid is provided to help display the model results using contour lines, this grid is strictly for visual display and is unrelated to model accuracy. MODAEM also supports particle tracking/streamlines. MODAEM represents steady, confined and unconfined two-dimensional groundwater flow, although streamlines are calculated in three dimensions.

SEAWAT Version 4 was developed by the U.S. Geological Survey (USGS) (Langevin, 2002) specifically for saltwater intrusion modelling. It is a MODFLOW-2000/MT3DMS-based modelling program that can simulate three-dimensional, variable-density saturated groundwater flow along with multi-species solute and/or heat transport. The model's variable-density ground-water flow equation is solved via finite-difference approximation, similar to that in MODFLOW-2000. The model's solute-transport equation is solved using MT3DMS. The model's equations allow fluid density to be calculated as a function of one or more MT3DMS parameters or as a function of fluid pressure.

SEAWAT has been used to estimate brine migration in continental aquifers and saltwater intrusion in coastal aquifers. The model enables simulation of coupled flow and transport, and constant-head boundaries. Where needed, fluid viscosity variations can also be calculated using various MT3DMS species, including the effects of temperature. Unique diffusion coefficients can be entered for each MT3DMS component. This allows molecular diffusion coefficients to be used for solute species and thermal diffusivity to be used for the model's temperature component. A density value can also be associated with constant-head boundaries as desired. Because SEAWAT uses MODFLOW and MT3DMS structures, the common pre- and post-processors for those programs can respectively be used to create SEAWAT datasets and depict the model's results. SEAWAT is a public-domain computer program.

Both MODAEM and SEAWAT are well suited for the modelling objectives of this project and have been extensively used by groundwater professionals worldwide. These models are set up using the Groundwater Modelling System (GMS) developed by Aquaveo (Aquaveo, 2011). GMS is a powerful groundwater modelling platform that has been widely used for several decades.

As touched on above, MODAEM is based on the Analytic Element Method (AEM) theory (Strack, 1991), from which EPA in the United States developed the WhAEM model for regional groundwater flow modelling which relies more on natural watershed boundaries and the local water cycle to provide more reliable model simulations. Such regional models are also able to derive aquifer properties, such as aquifer transmissivity.

SEAWAT is based upon the theory of density-driven interactions between freshwater and saltwater, and incorporates the model boundaries and transmissivities from the regional MODAEM model. SEAWAT was used to predict saltwater distributions, both vertically and horizontally, in relation to freshwater and also to estimate salinity of water at a given location after a saltwater/freshwater distribution was established.

3.2 *MODEL DETAILS*

3.2.1 *Regional Groundwater Flow Model (MODAEM)*

ERM first developed this regional two-dimensional groundwater flow model for the purpose of identifying the necessary modelling region in the SBS and to develop the model's boundary conditions for the subsequent and localised SEAWAT saltwater intrusion modelling in the SDOOL area.

ERM ran several iterations of the regional groundwater MODAEM model, starting with a large area covering over 2 km^2. This modelling identified the necessary modelling region (the blue outline in *Figure 4, Appendix A*) that is relevant for developing a site area model for the SDOOL area. The following data were used in the development of the regional groundwater flow model:

- regional groundwater contour map from the WA Department of Water (DoW) (online);
- ASTER GDEM topographic elevations from U.S.A NASA (online);
- Stream flow data from DoW (online);
- Geologic map (Smith, 2001);
- Groundwater levels from DoW (online);
- Groundwater data (MWH, 2010b); and

- Surface water data (MWH, 2010a).

Much of the model's boundary consists of natural shoreline, and the course of the Serpentine River and its connecting drainage canals. A limited section in the northeast corner of the modelled area uses observed groundwater contours (online) developed by DoW. The model's interior includes lakes and local drainage ditches. The following geologic formations that are identified from the regional geologic maps (Smith and Hick, 2001) are included in the model:

- Safety Bay Sand (SBS);
- Eastern Tamala Limestone Outcrop Area; and
- Tamala Limestone Sand (east of Eastern TL Outcrop Area).

The simplified locations of these geologic areas for the model are presented in *Figures 2* and *3*, *Appendix A*.

The model receives a uniform equivalent recharge that is the net effect of infiltration from precipitation, evaporation, evapotranspiration, and exchanges in water storage. The equivalent recharges are derived from stream flow data. The regional groundwater flow model input parameters are presented in *Table 1, Appendix C*.

Modelled regional groundwater contours under mean water level conditions are presented on the right side of *Figure 4, Appendix A* underlain by a background map of observed regional groundwater contours developed by DoW.

The modelling indicates that the Eastern TL outcrop area (east of the eastern edge of the SBS), with its high aquifer transmissivity and low water table elevations, isolates the SBS and TL from regional background flow from the east. Groundwater flow dynamics in the Lake Richmond and SDOOL area is controlled by local recharge within the SBS formation along the coastal area. There is a natural groundwater divide, both modelled and observed, located approximately 4 km east of Lake Richmond (*Figure 4, Appendix A*): groundwater west of this divide discharges to the coastal area; groundwater east of this divide discharges to the TL outcrop area that connects to the coastline to the north and south.

3.2.2 *Saltwater Intrusion Model (SEAWAT)*

The saltwater intrusion SEAWAT model has been developed based on the findings derived from the regional groundwater flow model. The western boundary of the localised SEAWAT model is the coastline; the eastern boundary is the natural groundwater divide (*Figure 4, Appendix A*) in SBS that was derived from the regional groundwater flow model.

SEAWAT modelling is a transient simulation process that starts with seawater salt concentrations along the coastline and slowly grows the saltwater interface inland, taking as much as a thousand years to reach steady state. The modelling is also transient seasonally with regard to recharge and water levels in Lake Richmond. Lake Richmond is modelled as a free–floating, open water body without any head control and restriction. This allows Lake Richmond levels to change freely in the SDOOL construction and operation simulations.

ERM assigned a variable spacing to the SEAWAT model grid, with a more dense grid near the areas of interest (Lake Richmond and SDOOL) and a coarser grid away from them. This horizontal grid layout is presented on the left side of *Figure 5, Appendix A*. The model includes eight vertical grids (*Figure 5, Appendix A*) that include the SBS, TL, and the aquitard between the SBS and TL. The top four grids cover the SBS down to approximately -22 m AHD; the next two grids cover the aquitard zone down to -25 m AHD; and the bottom two grids cover the TL down to -30 m AHD (*Figure 5, Appendix A*). The inset in *Figure 5, Appendix A* depicts the 3-D SEAWAT model grids.

Model input parameters for the regional groundwater flow model (Table 1) were retained for the SEAWAT model. The SEAWAT model input parameters are presented in *Table 2, Appendix C*. While field measurements of vertical permeability in the aquitard cannot be made with certainty, because the underlying TL is tidal, aquitard vertical permeability has been back-calculated from SEAWAT (*Table 2, Appendix C*) as equalling the permeability required to generate the salinity distribution that matches observed concentrations in the SBS and TL, under the conceptual site model setting (see *Appendix B*).

Similar to the Eastern TL Area, the top of the TL has a sharp elevation change and reaches to the land surface near the northwest tip of Cape Peron. The SEAWAT model incorporates this area (*Figure 5, Appendix A*). The SEAWAT model includes two zones in the TL, reflecting the observed change in thickness of the TL: a northwest zone with a higher aquifer transmissivity and a southeast zone with a lower aquifer transmissivity.

Figures 6, 7, and *8, Appendix A* present modelled local-area groundwater contours in the SBS under mean, high and low water level conditions, respectively, in the absence of SDOOL duplication construction.

The modelled existing salinity distribution at -12 m AHD (in the mid-depth of the SBS) is presented in plan view in *Figure 9, Appendix A*. *Figure 10, Appendix A* presents existing salinity distributions at various depths at the centre of each of the eight vertical model grids.

A 3-D saltwater interface image is presented in *Figure 11, Appendix A*. This image was developed after running the SEAWAT model for 1,000 years, after which the saltwater interface reached steady-state conditions, which also demonstrates the slow-moving nature of the saltwater interface in general. Note that, while there may be some localised (molecular-level) diffusion of salt from saline to fresh water, saline water does not migrate upward across the aquitard, because of the downward gradient from the SBS and the greater density of the saline water, which causes saline water to seek lower elevations. Model sensitivity testing that assumed a much greater permeability for the aquitard (*Section 4.2.2*) showed a much stronger downward movement of water from the SBS aquifer, for this reason.

It should be emphasised that this SEAWAT saltwater intrusion model simulates the salinity that originates from the ocean along the shoreline. The model does not include other dissolved solids from land and formation related dissolved solids sources (legacy salinity), including those for sodium chloride. Because the legacy salinity is unrelated to that being provided by present-day saltwater intrusion, there was no need to incorporate this legacy salinity into the SEAWAT model developed for SDOOL duplication.

4 MODEL RESULTS

4.1 MODEL PREDICTIONS

4.1.1 *Modelled Existing Groundwater Flow Conditions*

Modelled groundwater contours and salinity distributions under existing conditions are presented in *Figures 6* through *12, Appendix A*. Modelling indicates that groundwater east and west of Lake Richmond in general flows northwest toward the shoreline; Lake Richmond typically receives groundwater from upgradient and discharges groundwater downgradient back to the SBS aquifer.

Modelling indicated a relatively small amount of existing seasonal water level fluctuation (<0.5 m). This amount of water level fluctuation is much smaller than typically observed in other areas in similar situations and is caused by the outcropping TL area and Serpentine River (*Figure 3, Appendix A*) that effectively block regional inflow, and its variability, from the much larger regional groundwater basin. Modelling indicates that groundwater recharge fluctuates around ±50% of its mean value. Given the relatively linear correlation between groundwater recharge and discharge, discharge through the area of the SDOOL duplication at high and low water-table conditions is, respectively, approximately 50% greater and lower than that of the mean value (geometric mean, i.e. square root of the product of high and low values).

Modelling indicates a small, temporary gradient reversal downgradient of Lake Richmond during the summer season when the lake level drops below approximately 0.1 m AHD. For most remaining times, the lake discharges water to the northwest.

The modelling also indicates a relatively flat saltwater interface beneath the shallow unconfined groundwater aquifer in the SBS west of Lake Richmond. East of Lake Richmond, the saltwater interface descends into the TL. There is a small amount of salt dispersion away from the saltwater interface, some of which reaches Lake Richmond because the Lake is a gaining-water impoundment. The modelled salinity content in the lake is consistent with that observed (MWH, 2010a). While water levels in the shallow SBS remain quite stable, the substantial tide-driven water level fluctuations in the underlying TL formation confirms the TL's confined aquifer conditions below the aquitard. Tidal effects travel quickly inland only in confined aquifers and in those with higher aquifer transmissivities, both of which characterise the TL.

Modelling indicates that the westernmost section of the proposed SDOOL duplication is underlain by saline water under existing conditions. These existing saline water conditions include three well bores (Wells 1, 7, and 8) identified from the DoW well bore records (*Figure 12, Appendix A*). The narrow neck of Cape Peron causes a higher degree of saltwater intrusion in that area, as compared to the other parts of the coastline.

4.1.2 Modelled SDOOL Duplication Construction without Recharge

SDOOL duplication construction in this scenario assumes temporary excavation and dewatering without recharge to that SDOOL trench for a relatively short period of time (each trench segment is not expected to be open for more than 4 days). SDOOL construction will be undertaken in 100 m sections, with dewatering to occur in 200 m trench intervals (100 m trench section plus 50 m in front and behind the trench) that move westward at approximately 25 m per day.

The modelled water level change of Lake Richmond during SDOOL construction for this scenario is presented in *Figure 13, Appendix A*. Modelling indicates that the maximum Lake Richmond low-water level drop would be approximately 0.11 m, which occurs about a half year after construction. This temporary lake level drop is well within its natural water level fluctuation of 1.2 m. *Figure 14, Appendix A* presents a snap image of modelled groundwater contours during the construction at the 1,700 - 1,900 m point. The incurred drawdown shown is temporary because of the relatively fast-moving trenching operation. The water table is able to restore itself to its natural state after trenching dewatering is completed.

The modelled mean dewater discharge rates are listed in *Table 4.1*.

Table 4.1 Modelled Mean Dewatering Discharge Rates without Recharge

Distance from Eastern End of SDOOL Duplication	Dewatering Discharge (m^3/d)
0 (Eastern End) – 500 m	3,800
500 - 1,500 m	3,400
1,500 - 2,000 m	3,000
2,000 - 3,500 m	0*
3,500 m – 3,800 m (Western end)	500

* Rate is zero due to construction of this section being above the water table, hence no requirement for trench dewatering

Note, as outlined in *Table 4.1*, that trench dewatering will only be required in certain reaches of the SDOOL duplication. The remaining SDOOL duplication route lies above the water table and so will require no dewatering. Also note that the modelled dewatering discharge rates in *Table 4.1* have an uncertainty of ±50% because of various factors, including seasonal variation.

The modelled salinity distribution at the end of this construction dewatering scenario is presented in *Figure 15, Appendix A*. Modelling does not indicate a discernible change in salinity level in Lake Richmond or the SBS aquifer throughout SDOOL construction.

4.1.3 *Modelled Post-Construction Conditions for SDOOL Duplication without Recharge*

This model simulation represents future steady-state conditions after the completion of the SDOOL duplication. Water levels along the SDOOL duplication will be allowed to recover naturally.

The modelled future water level change of Lake Richmond after the SDOOL duplication construction is presented in *Figure 16, Appendix A*. Modelling indicates that Lake Richmond levels can return to natural conditions approximately one year after the SDOOL duplication construction.

The modelled future steady-state groundwater contours with the SDOOL duplication in place under normal water table conditions are presented in *Figure 17, Appendix A*. Modelling indicates that the SDOOL duplication construction will not cause any discernible long-term change in groundwater or Lake Richmond levels.

The modelled future steady-state salinity distribution for this scenario is presented in *Figure 18, Appendix A*. Modelling does not indicate a discernible change in future salinity level in the aquifer or Lake Richmond once the SDOOL duplication is operational.

4.1.4 *Modelled SDOOL Duplication Construction with Recharge to Trench*

SDOOL duplication construction requires temporary excavation and dewatering for a relative short period of time (each 100 m trench segment is not expected to take more than 4 days). SDOOL construction and dewatering will occur in 200 m trench intervals (100 m trench section plus 50 m in front and behind the trench) that move westward at approximately 25 m per day. In this recharge scenario, dewatering discharges during trenching will be recharged back to the 100-m long trench segment excavated immediately previously. The distance between the dewatering and recharge section of the trench will be 20 m. The modelled dewater discharge rates are listed in *Table 4.2.*

Table 4.2 Modelled Mean Dewater Discharge Rates with Recharge to Trench

Distance from Eastern End of SDOOL Duplication	Dewatering Discharge (m^3/d)
0 (Eastern End) – 500 m	3,600
500 - 1,000 m	4,400
1,000 - 1,500 m	5,200
1,500 - 2,000 m	3,700
2,000 - 3,500 m	0*
3,500 – 3,800 m (Western end)	600

* Rate is zero due to construction of this section being above the water table, hence no requirement for trench dewatering

Recharge to the trench will generally require higher rates of dewatering relative to the non-recharge option because of leakage from the recharge area to the active trenching area. However, at the start of trenching, the initial dewatering recharge will actually reduce the amount of dewatering pumping required, because the recharge will disrupt the natural groundwater gradient toward the trench section being pumped. It should be emphasised that the modelled dewatering discharge rates in *Table 4.2* have an uncertainty of ±50% because of various factors, including seasonal variation.

The modelled water level change of Lake Richmond during SDOOL construction with recharge to the construction trench is presented in *Figure 19, Appendix A*. Modelling indicates that the maximum Lake Richmond low water level drop is approximately 0.009 m, which occurs approximately one-half year after construction. This temporary lake level drop is minimal and well within its natural water level fluctuation of 1.2 m.

Figure 20, Appendix A presents a snap image of modelled groundwater contours during construction at the 1,700 - 1,900 m point. This figure shows that recharge to the trench eliminates the drawdown effects east of the dewatering area. The incurred drawdown effects are temporary because of the relatively fast-moving trenching operation.

The modelled salinity distribution at the end of this construction dewatering scenario is presented in *Figure 21, Appendix A*. Modelling does not indicate a discernible change in salinity level in Lake Richmond or the SBS aquifer throughout the SDOOL duplication construction in this scenario.

The TL in this area is predominantly saline under existing conditions; therefore, modelling of its changes in salinity is not necessary.

4.1.5 Modelled Post-Construction of SDOOL Duplication with Recharge to Trench

This model simulation represents future steady-state conditions after the completion of the SDOOL duplication with construction dewatering recharge to the trench. The water level along the SDOOL duplication will be allowed to recover naturally.

The modelled future water level change of Lake Richmond after the SDOOL duplication construction is presented in *Figure 22, Appendix A*. Modelling indicates that Lake Richmond levels can return to natural conditions within approximately six months after the SDOOL duplication construction with the recharge to trench option.

The modelled future steady-state groundwater contours after the SDOOL duplication construction with recharge to the trench are presented in *Figure 23, Appendix A*. These contours depict normal water table conditions. Modelling indicates that the SDOOL duplication construction will not cause any discernible long-term change in groundwater or Lake Richmond levels from natural levels.

The modelled future steady-state salinity distribution is presented in *Figure 24, Appendix A*. Modelling does not indicate a discernible change in future salinity level in the aquifer or Lake Richmond once the SDOOL duplication with the recharge-to-trench option is operational.

4.2 *CALIBRATION AND SENSITIVITY ANALYSIS*

4.2.1 *Model Calibrations*

Groundwater level data for the SBS and TL were collected both by MWH in 2010 from bores near the proposed SDOOL duplication area and by DoW from a limited number of wells in the general region in 1984 and 1985. This model calibration is based primarily on the DoW data in 1984 and 1985, supplemented by MWH 2010 data from three SBS wells (MB02, MB09(S), and MB13). The dataset for model calibration was necessarily limited, because most of the other wells MWH monitored in 2010 penetrated through the basal aquitard of the SBS, and water levels are thus compromised by the higher tidal fluctuations in the underlying TL formation. No calibration could be conducted on the TL, because water levels measured in the TL will change with the tides and so vary instantaneously. They therefore cannot be readily correlated with modelled levels at a given instant.

Water Levels

The model calibration results for the SBS water levels are presented in *Table 3, Appendix C*. This table indicates that the mean sum of the residuals is 0.026 m, which is 1.5% of the natural water table range of 1.7 m. The root mean square (standard deviation) of the residuals is 0.10 m, which is much lower than the 1 m range recommended in the Murray Darling Basin Commision (MDBC) guideline (Middlemis, 2000) and significantly lower than the 3 m for the DoW's regional groundwater model for the Rockingham area. The model calibration results are plotted in *Figure 25, Appendix A*.

Note that data from wells LR2 and LR3 could not be included in *Table 3, Appendix C*, because there has not yet been developed a long-term record of seasonal fluctuations in water levels in these wells, as has been done for the wells monitored by MWH and DoW. However, the SEAWAT model predicts minimum and maximum water table elevations near well LR2 of 0.3 to 1.1 m AHD, respectively. The single water table measurement pair made at this well indicated values of approximately 0.7 m AHD, which is well within the modelled range.

Salt Water Interface

Table 3, Appendix C also presents observed and modelled salt water interface depths for those wells with converted salinity readings exceeding 20 g/L. The root mean square of 0.7 m of the residual of observed and modelled depths at which a salinity of 20 g/L is encountered is relatively small. It should be emphasized that these salinity readings are not directly measured, but converted from downhole electrical conductivity probe measurements, the results of which have up to five-fold variation from time to time because of the seasonal and/or tidal conditions during the time of data measurement among the monthly measurements by MWH in 2010. The electrical conductivity reading in the newly installed LR1 well (11,180 µS/cm at the midpoint of the screened interval in the TL, per Annex B of *Appendix B* to this report) likely actually ranges from 5,000 to 25,000 µS/cm. This range is based upon the observed five-fold variation in electrical conductivity observed in the MWH data coupled with the assumption that the 11,180 µS/cm value is the geometric mean of the salinity distribution in this well. The SEAWAT-modelled salinity of 13 g/L at LR1 (an equivalent of 21,000 µS/cm as electrical conductivity) lies within the range of conductivities calculated above for well LR1.

The model calibration results presented in *Table 3, Appendix C* have thus met the requirements for models accepted by the Environment Protection Authority (EPA) in WA. The developed SEAWAT model is therefore suitable for simulations of the proposed SDOOL duplication construction and operation.

4.2.2 *Model Sensitivity Analysis*

The sensitivity analysis was intended to study the impact on model outcomes of those parameters that are unknown and assumed. Because regional groundwater modelling techniques have been used for this project, the number of unknown parameters is greatly reduced, because most inputs are regional stream and shoreline boundaries, the locations and elevations of which are relatively certain.

Hydraulic Conductivity

The main unknown model input is the hydraulic conductivity of the SBS; the model value of 16 m/d was developed by the regional MODAEM model from an observed recharge rate, which may have some uncertainty associated with it. Note that a sensitivity analysis for hydraulic conductivity could not be completed for the TL because the TL is tidal. In the sensitivity analysis for this parameter for the SBS, the hydraulic conductivity of the SBS was increased and decreased over a range from 5 to 50 m/d (an order of magnitude with respect to a geometric mean of 16 m/d), and the model was recalibrated using these inputs. The modelled root mean square of the residuals of the modelled and observed water levels is presented in *Figure 26, Appendix A*, which indicates that the model is essentially not sensitive to the hydraulic conductivity input for the SBS.

The AEM model was used for the regional groundwater flow model. AEM (Strack, 1989) models are intrinsically and theoretically balanced in terms of water budget. Water balancing is thus not required with AEM modelling. The water balance difference for the SEAWAT model relative to the model input data is less than 0.07%.

5 IMPACT ASSESSMENT CONCLUSIONS

The results of the SEAWAT modelling conducted for the proposed SDOOL duplication indicated the following:

- Low seasonal water levels in Lake Richmond during the SDOOL duplication construction dewatering without recharge will be reduced by 0.11 m and return to natural conditions within a year after construction;

- Low seasonal water levels in Lake Richmond during the SDOOL duplication construction with dewatering recharge to the construction trench will be reduced by 0.009 m and return to natural conditions within 6 months after construction;

- Salinity levels in Lake Richmond and the surrounding SBS aquifer are not expected to change discernibly during the SDOOL duplication construction and operation, with or without the recharge-to-trench option;

- Local groundwater users with bores located in the upper 'lower salinity' sections of the SBS and located in the immediate vicinity of the SDOOL duplication may be impacted with temporary drawdown effects (approximately one-week), however, the maximum drawdown is not expected to exceed the natural range of water level fluctuation of 0.5 m; and

- Impacts to Threatened Ecological Communities (TECs) surrounding Lake Richmond are not expected due to the temporary nature of dewatering, the low levels of drawdown expected (both with and without recharge to trench) and negligible impact on salinity levels in Lake Richmond and the SBS aquifer.

Based upon the results of the model calibration and sensitivity analysis conducted, these SEAWAT modelling results can be used with a high degree of confidence.

6 REFERENCES

Aquaveo, 2011, GMS 8.0 User's Manual, Provo, Utah, U.S.A.

American Society for Testing and Materials, 1994, Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information. Designation: D 5490-93. ASTM. Philadelphia, Pennsylvania, U.S.A.

Bureau of Meteorology (BoM), 2010, viewed 25 January 2010, http://www.bom.gov.au/climate/dwo/201005/html/IDCJDW6008.201005.shtml.

Department of Environment and Conservation (WA DEC), 2010. Assessment Levels for Soil, Sediment and Water – Contaminated Sites Management Series.

Department of Environment and Conservation (WA DEC) (published as DoE), 2003. Development of Sampling and Analysis Programs – Contaminated Sites Management Series.

Department of Environment and Conservation (WA DEC) (published as DoE), 2004. Use of Monitored Natural Attenuation for Groundwater Remediation – Contaminated Sites Management Series.

Department of Health (WA DoH). Contaminated Sites Reporting Guideline for Chemicals in Groundwater.

Department of Water, 2010, Hydrogeochemical Assessment of the Superficial Aquifer, Perth Metropolitan Area, Hydrogeological Record Series HG37, August.

ERM, 2011, Proposed Mangles Bay Marina Based Tourist Precinct: Groundwater Modelling and Impact Assessment, prepared for Cedar Woods Properties Ltd.

Fetter, C.W., Jr., 1994, Applied Hydrology, 3rd ed. Charles E. Merrill Co., Columbus, Ohio, U.S.A>

Kelson, V., 2001, MODAEM User's Manual, Wittman Hydro Planning Associates, Bloomington, Indiana, U.S.A.

Langevin, C.D., W.B. Sheomaker, W.B., and W. Guo, 2001, Model Documentation of the SEAWAT-2000 Version with the Variable-Density Flow Process (VDF) and the integrated MT3DMS Transport Process (IMT): U.S. Geological Survey Open-File Report 03-426, 43 p., U.S.A.

McDonald, M.G., and A.W. Harbaugh, 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A1, 586 p., U.S.A.

Middlemis, H., 2000, Groundwater Flow Modelling Guideline, developed by Aquaterra Consulting Pty Ltd, South Perth, Western Australia, for Murray-Darling Basin Commission, November.

MWH, 2010a, Cape Peron Surface Water Study, Draft Report prepared for Strategen, September

MWH, 2010b, Cape Peron Groundwater Study, Draft Report prepared for Strategen, September

MWH, 2011, Conceptual Hydrogeology for Mangles Bay Area, Draft Report prepared for Strategen, September

National Health and Medical Research Council and Agriculture and Resource Management Council of Australia and New Zealand (NHMRC), 2004. Australian Drinking Water Guidelines. Commonwealth of Australia, Canberra, ACT.

Passmore, J.R., 1970, Bulletin No. 18: Shallow Coastal Aquifers in the Rockingham District Western Australia, Water Resource Foundation of Australia

Shapiro, A., 2004, Recent Advances in Characterizing Ground Water Flow and Chemical Transport in Fractured Rock: From Cores to Kilometers, Darcy's Lecture, '04 USEPA/NGWA Fractured Rock Conference, Portland, Maine, U.S.A., September.

Smith, A.J. and W.P. Hick, 2001, Hydrogeology and Aquifer Tidal Propagation in Cockburn Sound, Western Australia, CSRIO Land and Water Technical Report, 6/01, February.

Strack, O., 1989, "Groundwater Mechanics", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, U.S.A.

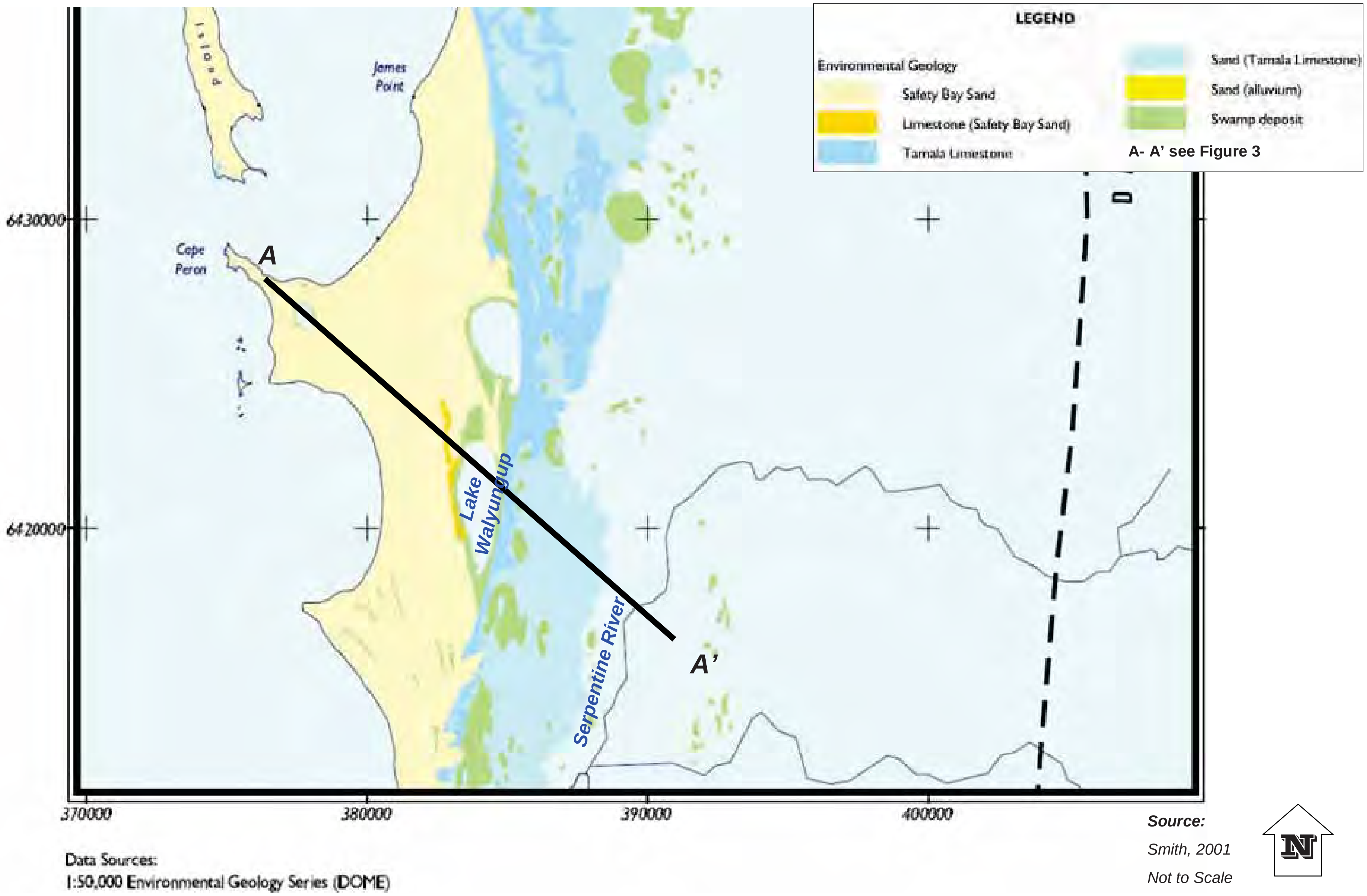
Xu, M. and Y. Eckstein, 1995, "Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale." Ground Water, 33, 6: 905–908, U.S.A.

Appendix A

Figures

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Site Map, Well Bores, and SDOOL Duplication Locations SDOOL Duplication Rockingham, Western Australia	Figure 1

0116221-11/17/2011-HYH-M:\WaterCorp\GMS Model SDOOL Model Development Figures New.ppt

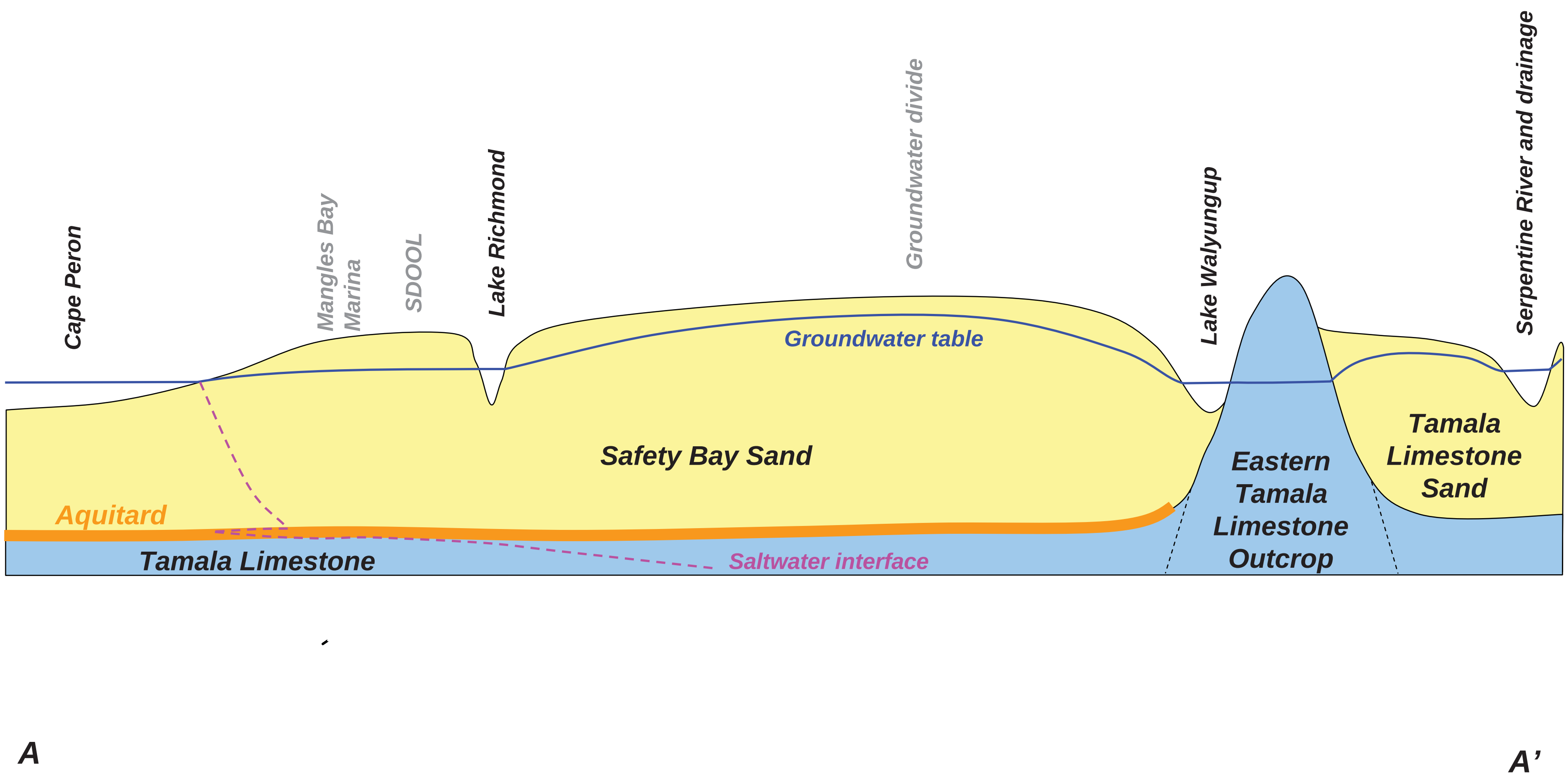


Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Regional Surficial Geological Map
SDOOL Duplication
Rockingham, Western Australia

Figure 2

0116221-11/17/2011-HYH-M:\WaterCorp\GMS Model SDOOL Model Development Figures New.ppt



Note:

A-A' transect route shown on Figure 2

Based on Smith, 2001

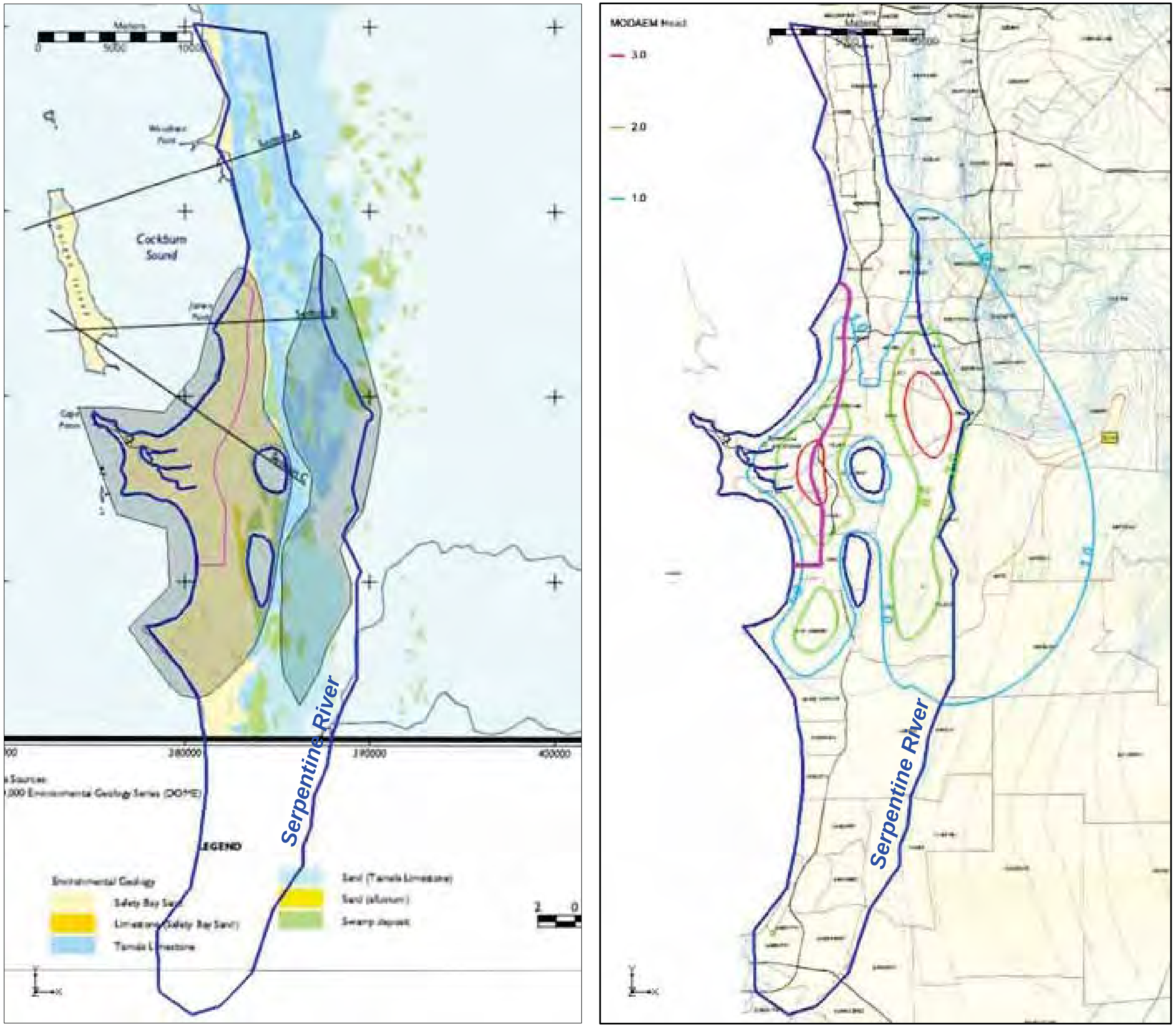
Not to Scale

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Conceptual Regional Hydrogeologic Profile
SDOOL Duplication
Rockingham, Western Australia

Figure 3

0116221-11/17/2011-HYH-M:\WaterCorp\GMS Model SDOOL Model Development Figures New.ppt



Legend

- Modelled streams, lakes, and/or shoreline
- Sand formation
- Modelled regional groundwater contours, m AHD (valid within outer model boundary)
- Modelled groundwater divide in Safety Bay Sand

Note:

Background map on left is regional geological map (Smith, 2001)

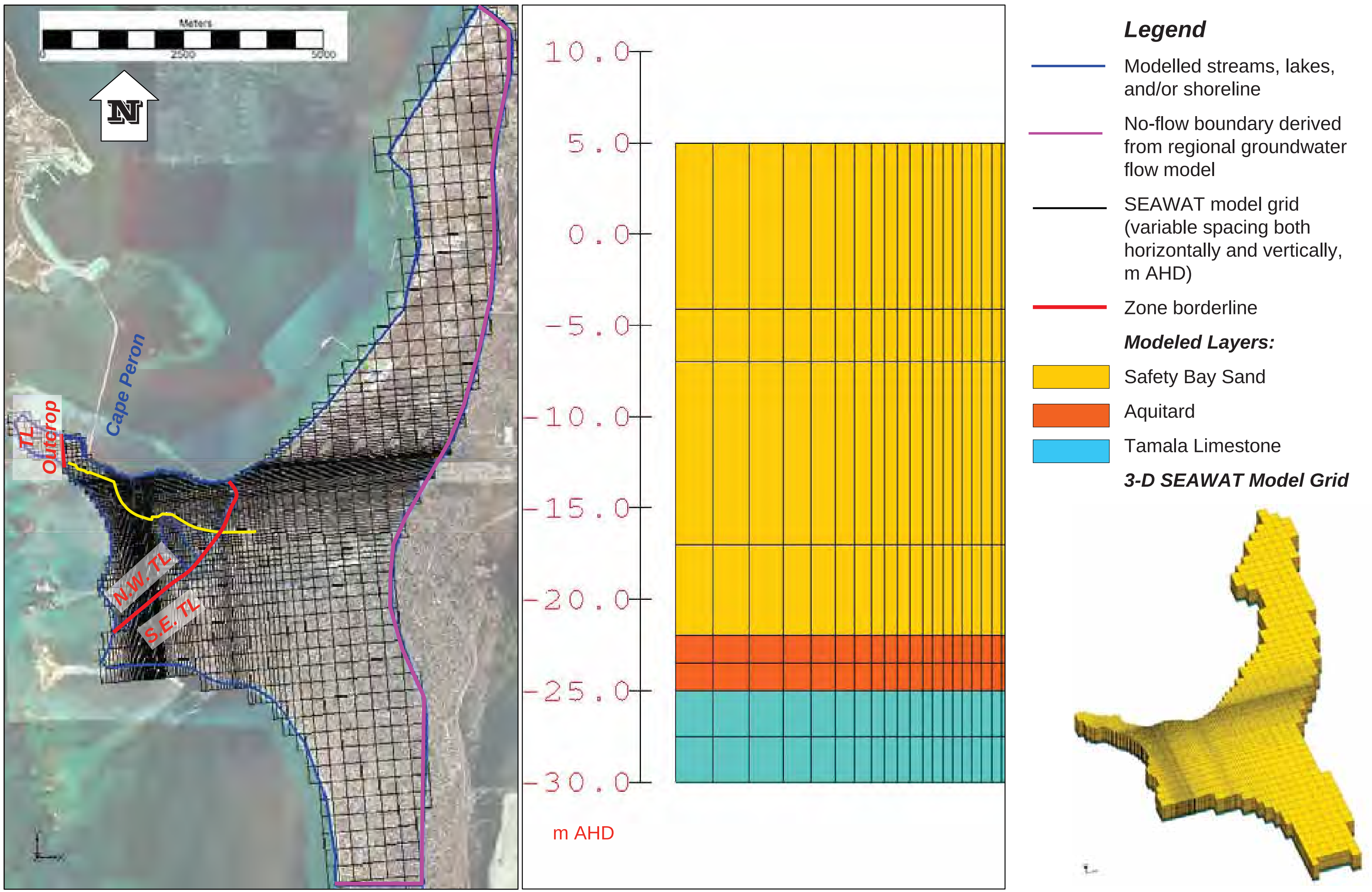
Background map on right is regional groundwater contours map developed by Department of Water

N

WGS84 UTM Coordinate System Zone -50 in m

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Regional Groundwater Flow Model Layout and Modelled Groundwater Contours SDOOL Duplication Rockingham, Western Australia	Figure 4

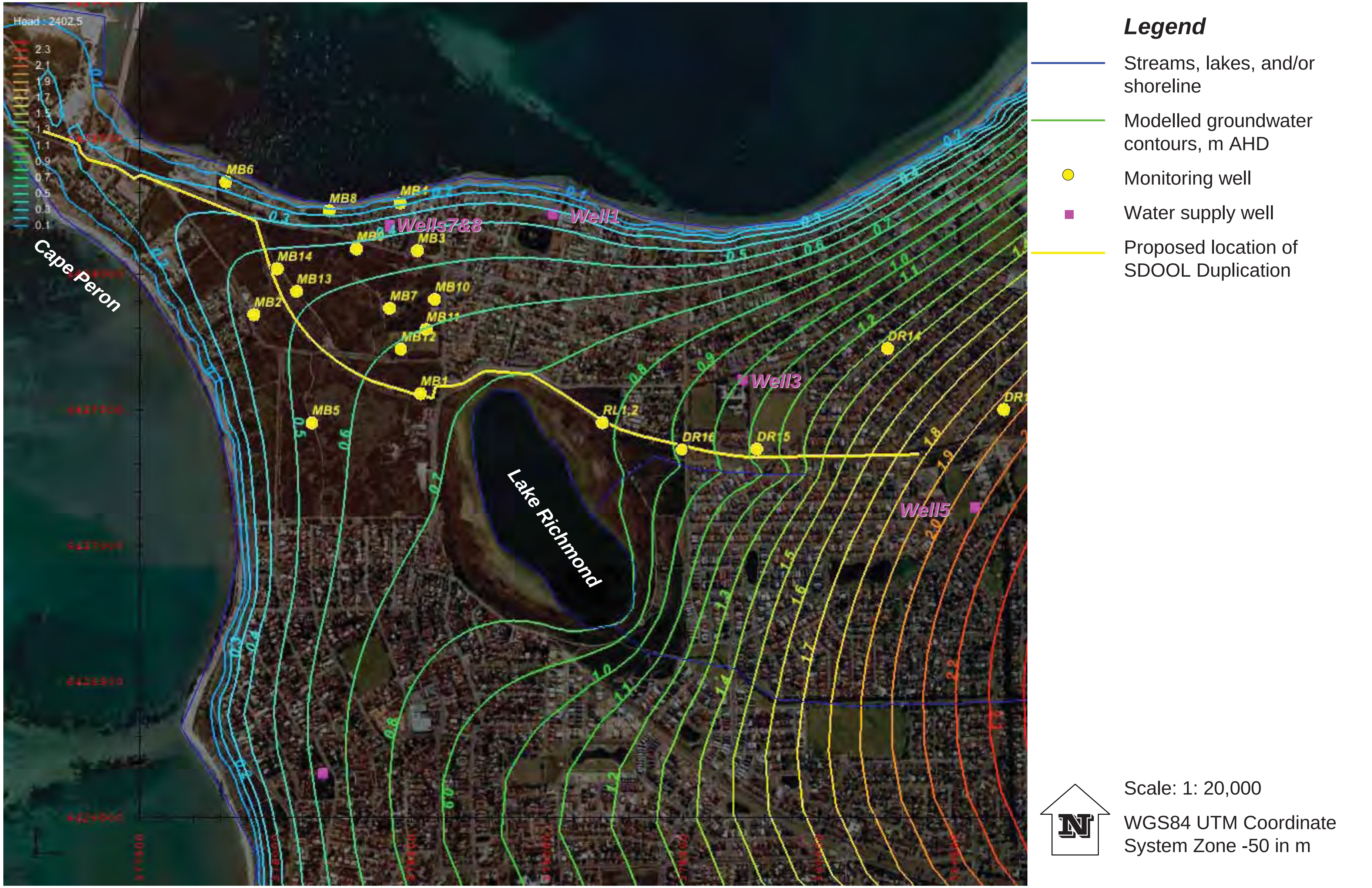
0116221-11/17/2011-HYH-M:\WaterCorp\GMS Model SDOOL Model Development Figures New.ppt



Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia
ERM

SEAWAT Saltwater Intrusion Model Layout and Grid
SDOOL Duplication
Rockingham, Western Australia

Figure 5



ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Groundwater Contours – Existing Mean Water Level Conditions
SDOOL Duplication
Rockingham, Western Australia

Figure 6

Legend

- Streams, lakes, and/or shoreline
- Modelled groundwater contours, m AHD
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM

Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Groundwater Contours – Existing High Water Level Conditions
SDOOL Duplication
Rockingham, Western Australia

Figure 7

0116221-11/17/2011-HYH-M:\WaterCorp\GMS Model SDOOL Model Development Figures New.ppt

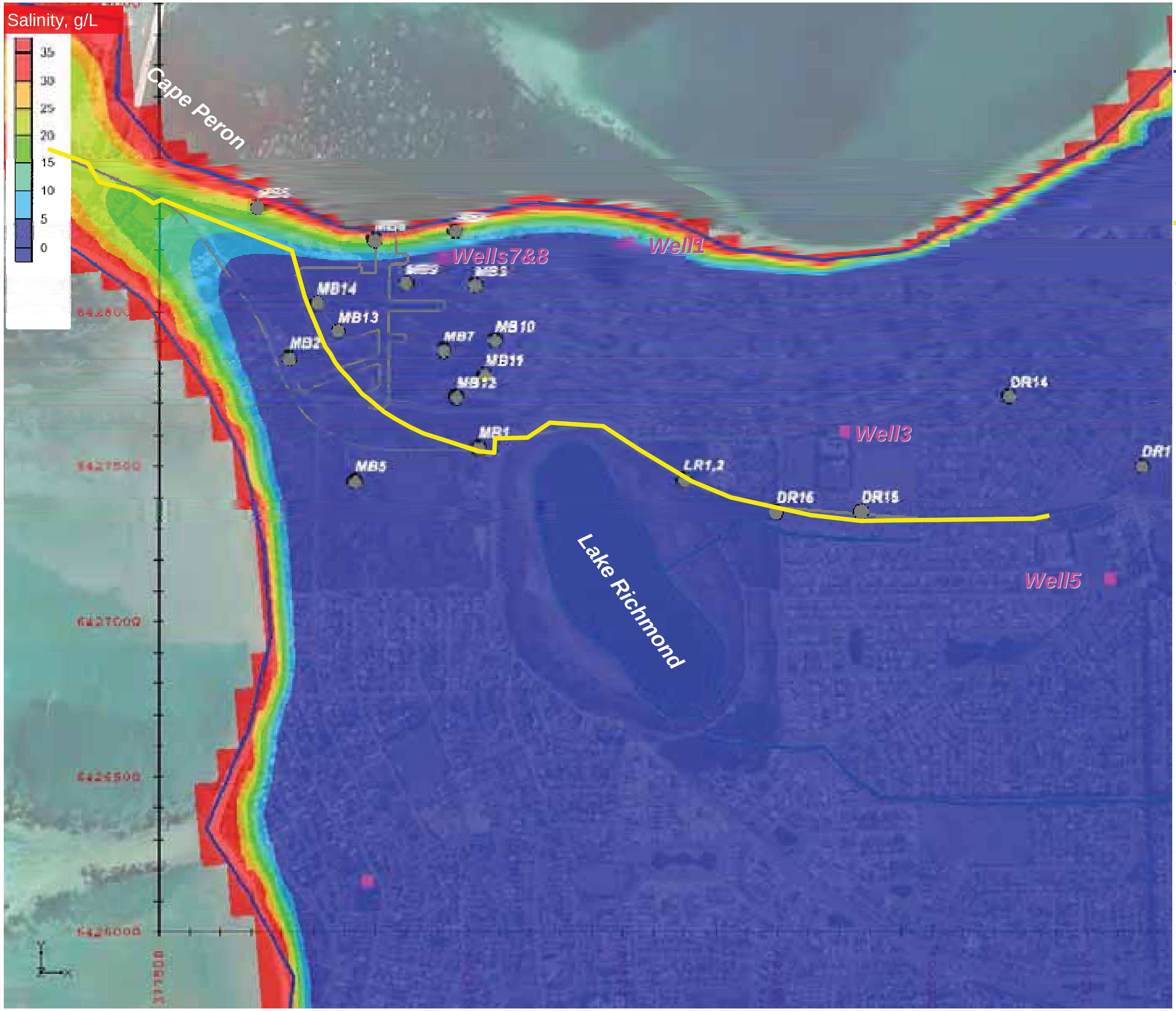
Legend

- Streams, lakes, and/or shoreline
- Modelled groundwater contours, m AHD
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Groundwater Contours – Existing Low Water Level Conditions SDOOL Duplication Rockingham, Western Australia	Figure 8



Legend

Streams, lakes, and/or shoreline

Monitoring well

Water supply well

Proposed location of SDOOL Duplication

Proposed locations of Cedar Woods SDOOL Realignment and Mangles Bay Marina

Note:

Salinity at -12 m AHD

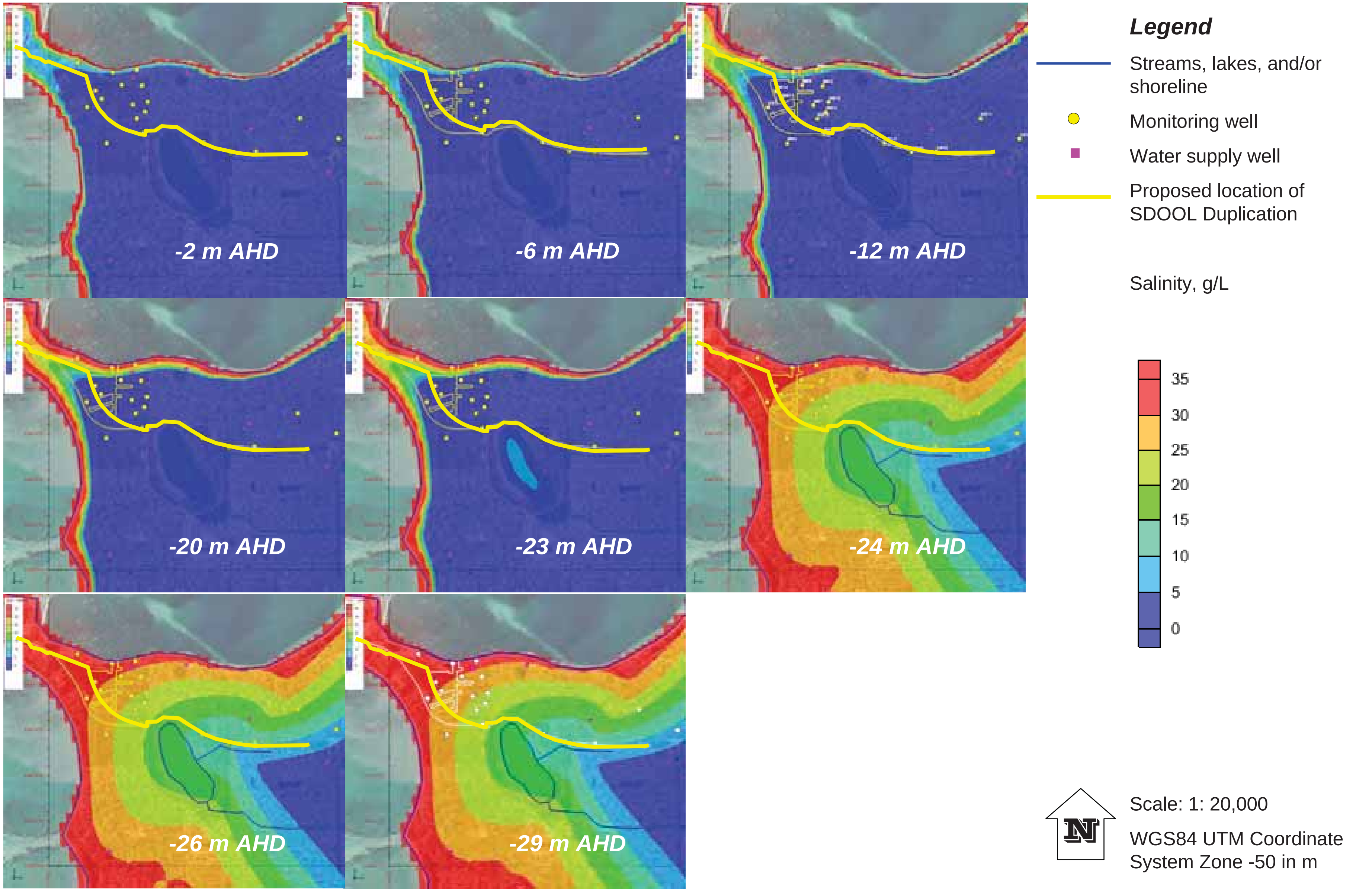
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Salinity Distribution under Existing Conditions
SDOOL Duplication
Rockingham, Western Australia

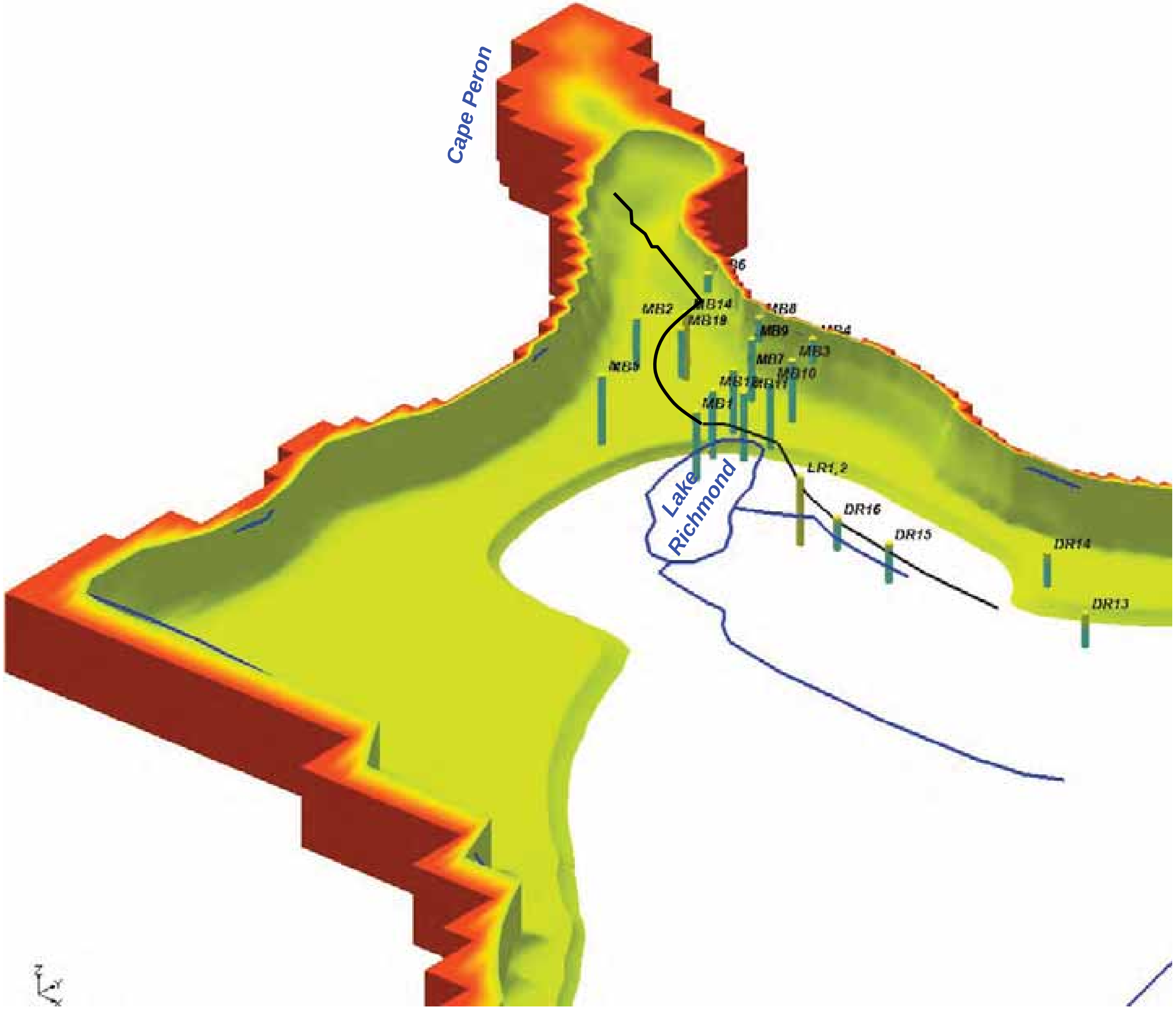
Figure 9



ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Salinity Distribution under Existing Conditions at Various Depths
SDOOL Duplication
Rockingham, Western Australia

Figure 10



Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Proposed location of SDOOL Duplication

Salinity, g/L

35
30
25
20
15
10
5
0

Note:

Salinity isosurface displayed from 25 to 35 g/L

Vertical exaggeration: 10X

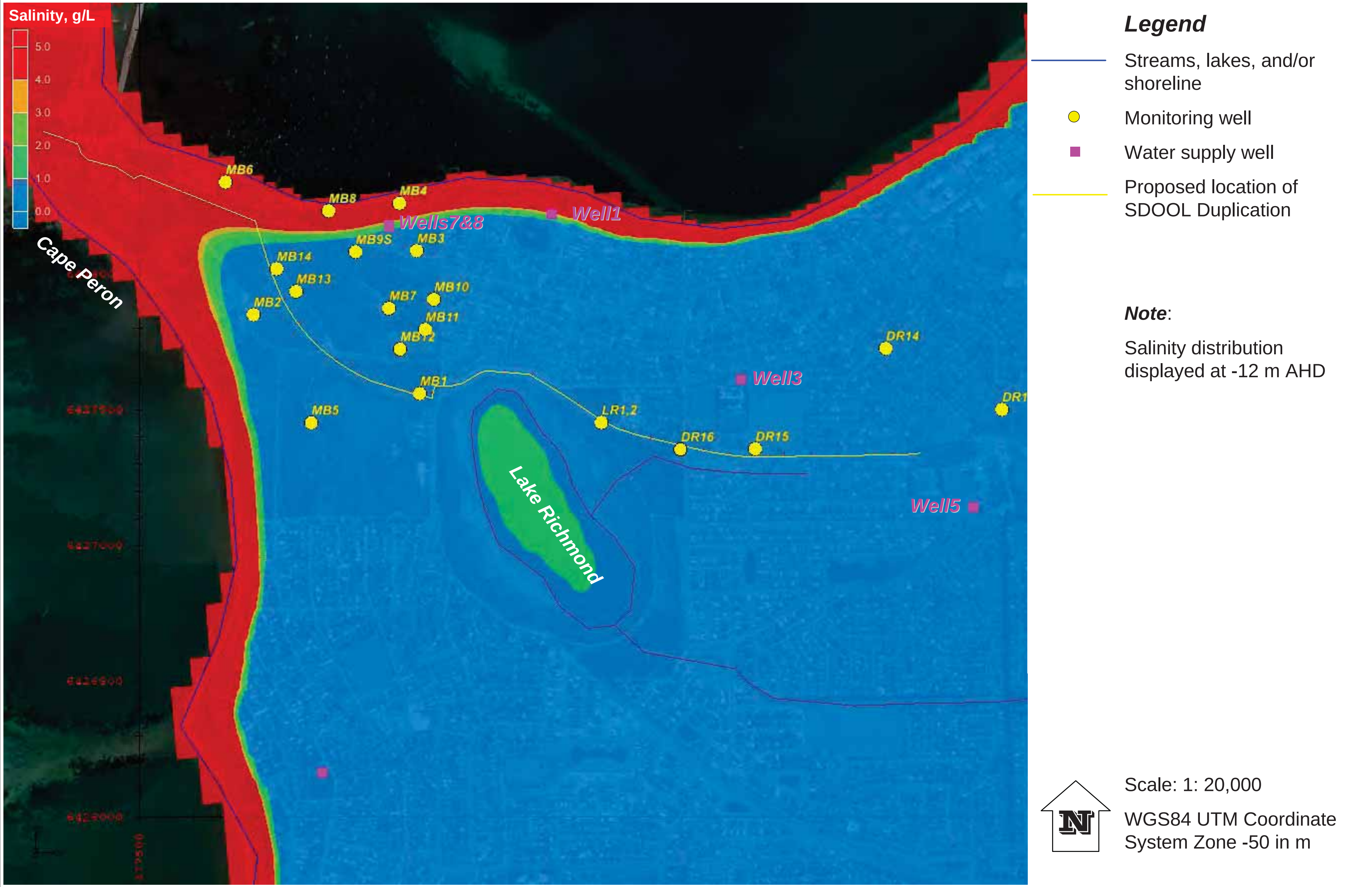
3-D View to Northwest

Not to Scale

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled 3-D Salinity Distribution Isosurface under Existing Conditions
SDOOL Duplication
Rockingham, Western Australia

Figure 11

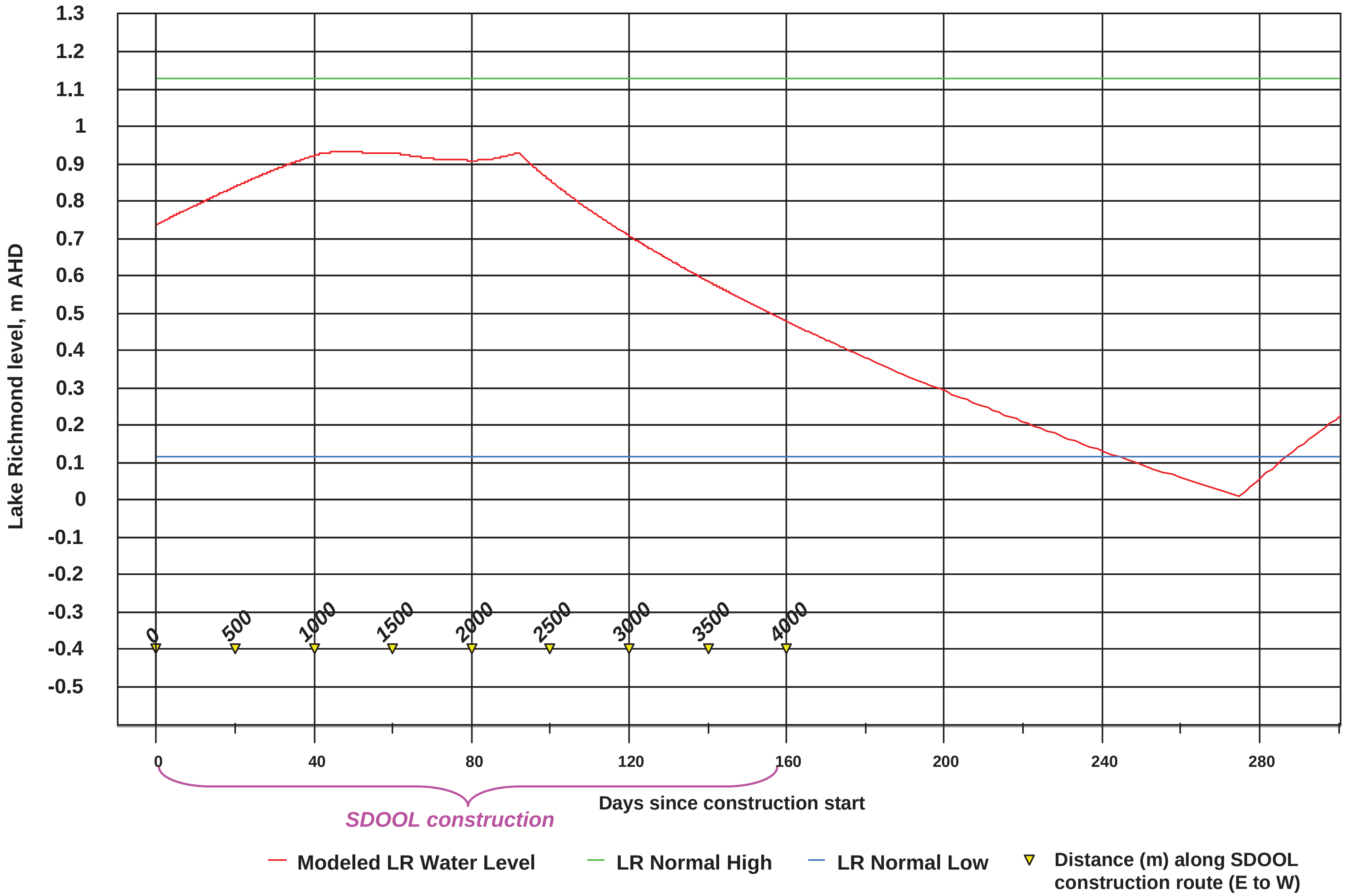


ERM

Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

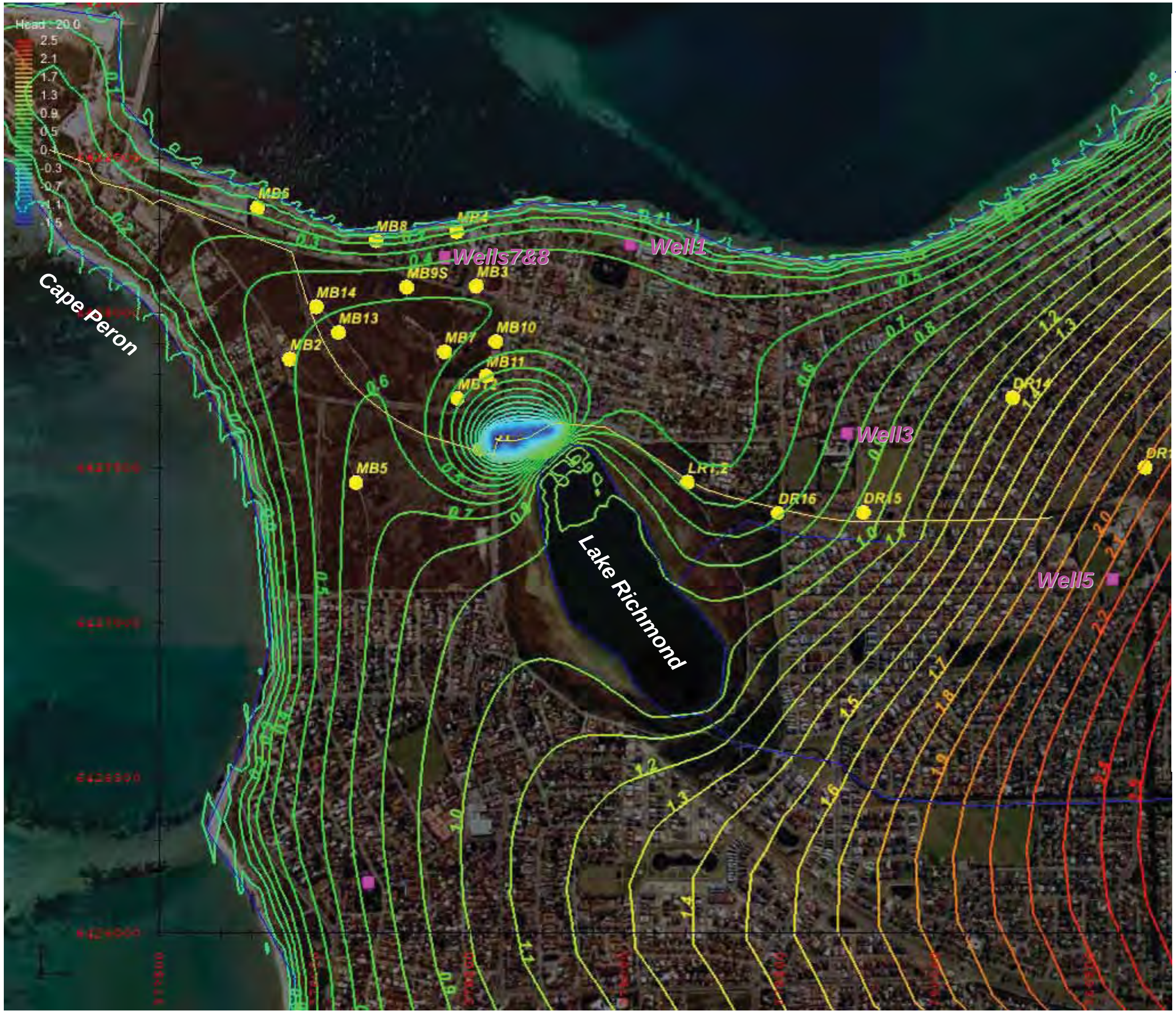
Details of Modelled Existing Salinity Distribution
SDOOL Duplication
Rockingham, Western Australia

Figure 12



Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Lake Richmond Water Level during SDOOL Construction SDOOL Duplication Rockingham, Western Australia	Figure 13

0116221-010/25/2011-HYH-M:\WaterCorp\SDOOL New Model Simulations Figures.ppt



Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication
- Modelled groundwater contours, m AHD

Note:

Modelled largest low water level decrease of Lake Richmond is 0.11 m

Modelled average SDOOL discharge rate (±50%):

Distance (m)	Discharge (m^3/d)
0-500	3,800
500-1,000	3,400
1,000-1,500	3,400
1,500-2,000	3,000
2,000-2,500	0
2,500-3,000	0
3,000-3,500	0
3,500-end	500

N

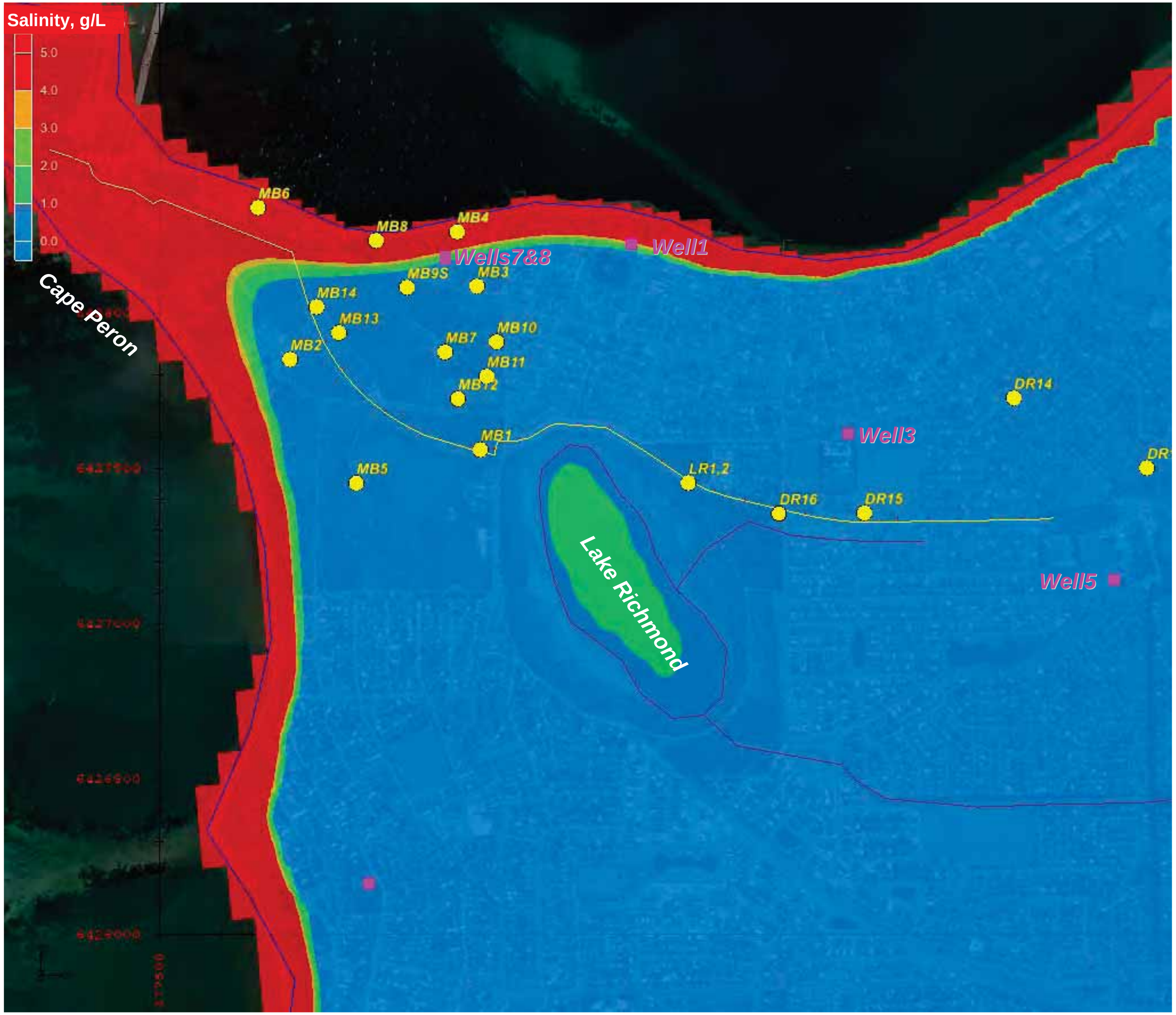
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Groundwater Contours during SDOOL Construction
SDOOL Duplication
Rockingham, Western Australia

Figure 14



Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication

Note:

Salinity distribution displayed at -12 m AHD

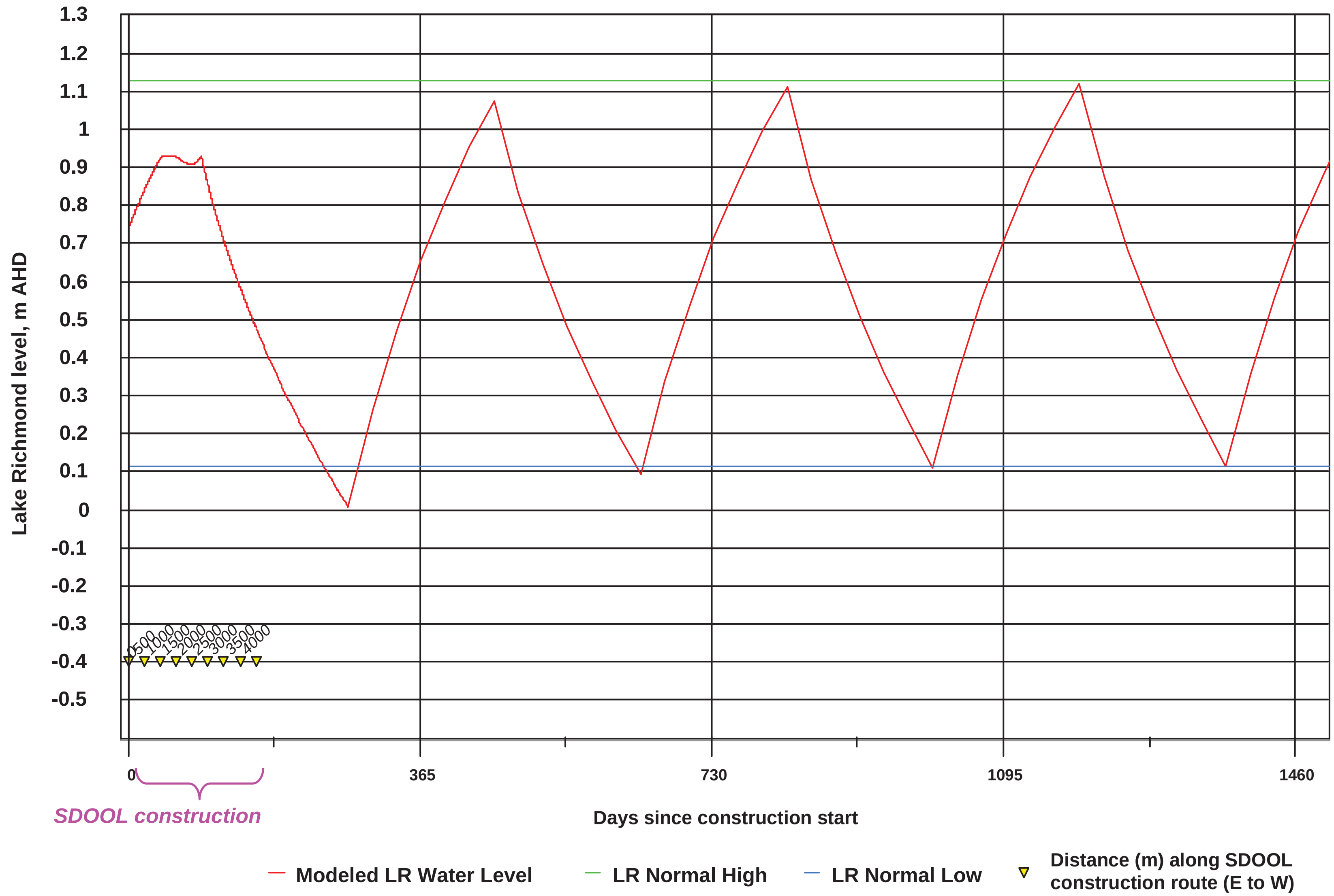
No discernible change in salinity input to Lake Richmond during SDOOL construction

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Salinity Distribution at End of SDOOL Construction SDOOL Duplication Rockingham, Western Australia	Figure 15



ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Future Lake Richmond Water Level after SDOOL Construction
SDOOL Duplication
Rockingham, Western Australia

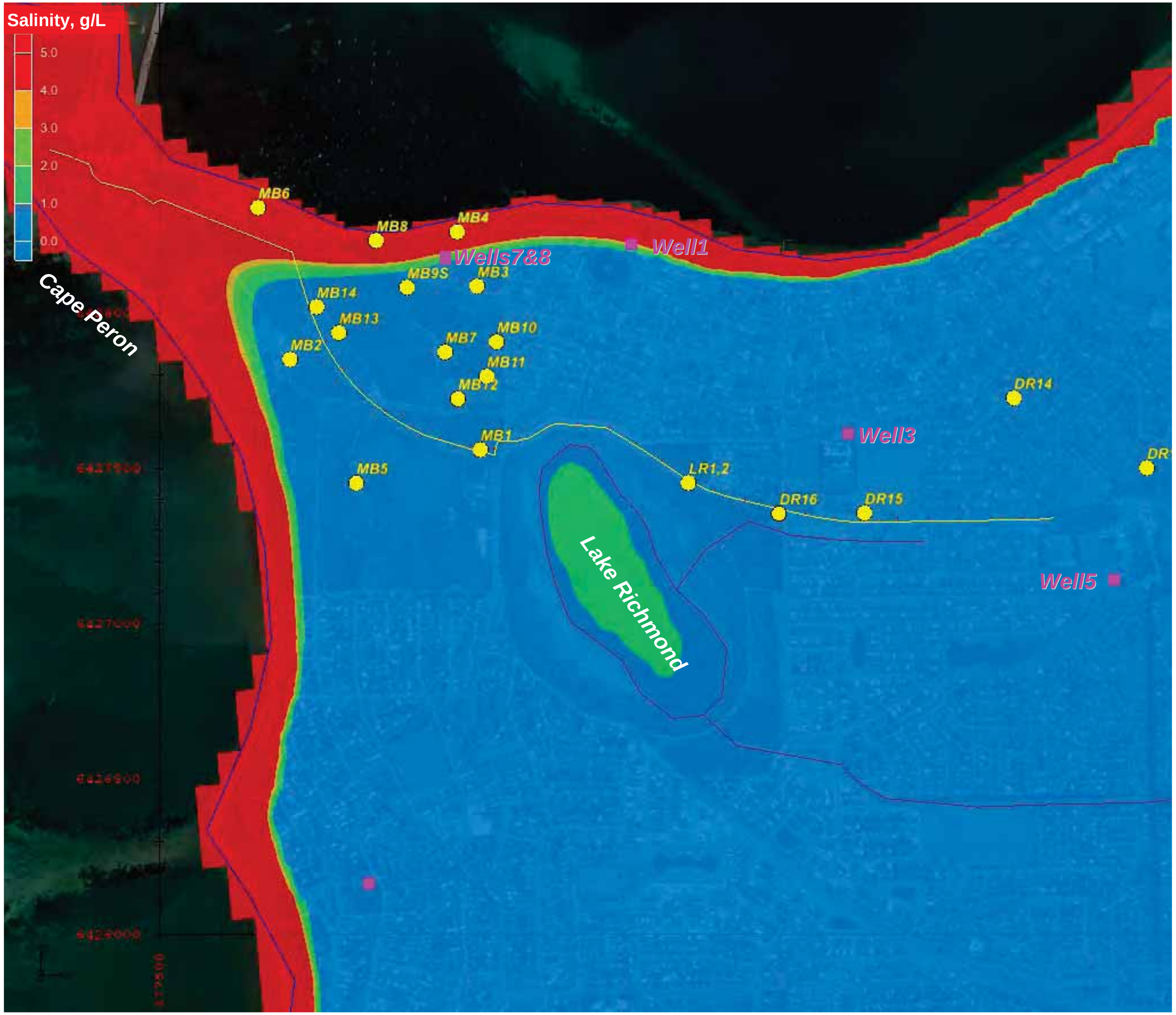
Figure 16

Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Future Groundwater Contours with SDOOL Operational Mean Water Level Conditions
SDOOL Duplication, Rockingham, Western Australia

Figure 17

0116221-010/25/2011-HYH-M:\WaterCorp\SDOOL New Model Simulations Figures.ppt



Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication

Note:

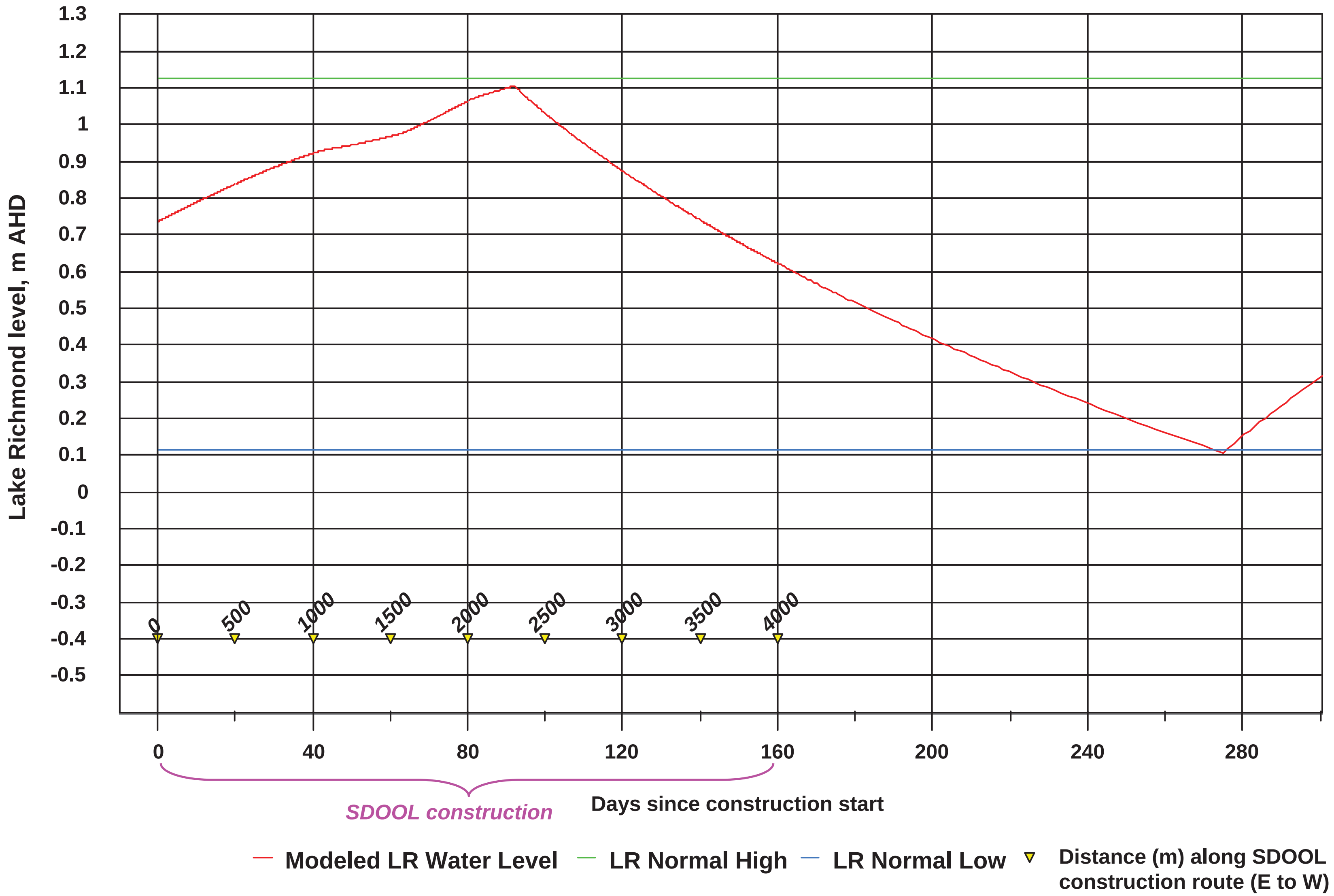
Salinity distribution displayed at -12 m AHD

No discernible change in salinity input to Lake Richmond after SDOOL construction

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Future Salinity Distribution with SDOOL Operational SDOOL Duplication Rockingham, Western Australia	Figure 18



ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Lake Richmond Water Level during SDOOL Construction with Recharge to Trench SDOOL Duplication, Rockingham, Western Australia	Figure 19

Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Water supply well
- Proposed location of SDOOL Duplication
- Modelled groundwater contours, m AHD

Note:

Modelled largest low water level decrease of Lake Richmond is 0.009 m

Modelled average SDOOL discharge rate (±50%):

Distance (m)	Discharge (m^3/d)
0-500	3,600
500-1,000	4,400
1,000-1,500	5,200
1,500-2,000	3,700
2,000-2,500	0
2,500-3,000	0
3,000-3,500	0
3,500-end	600

N

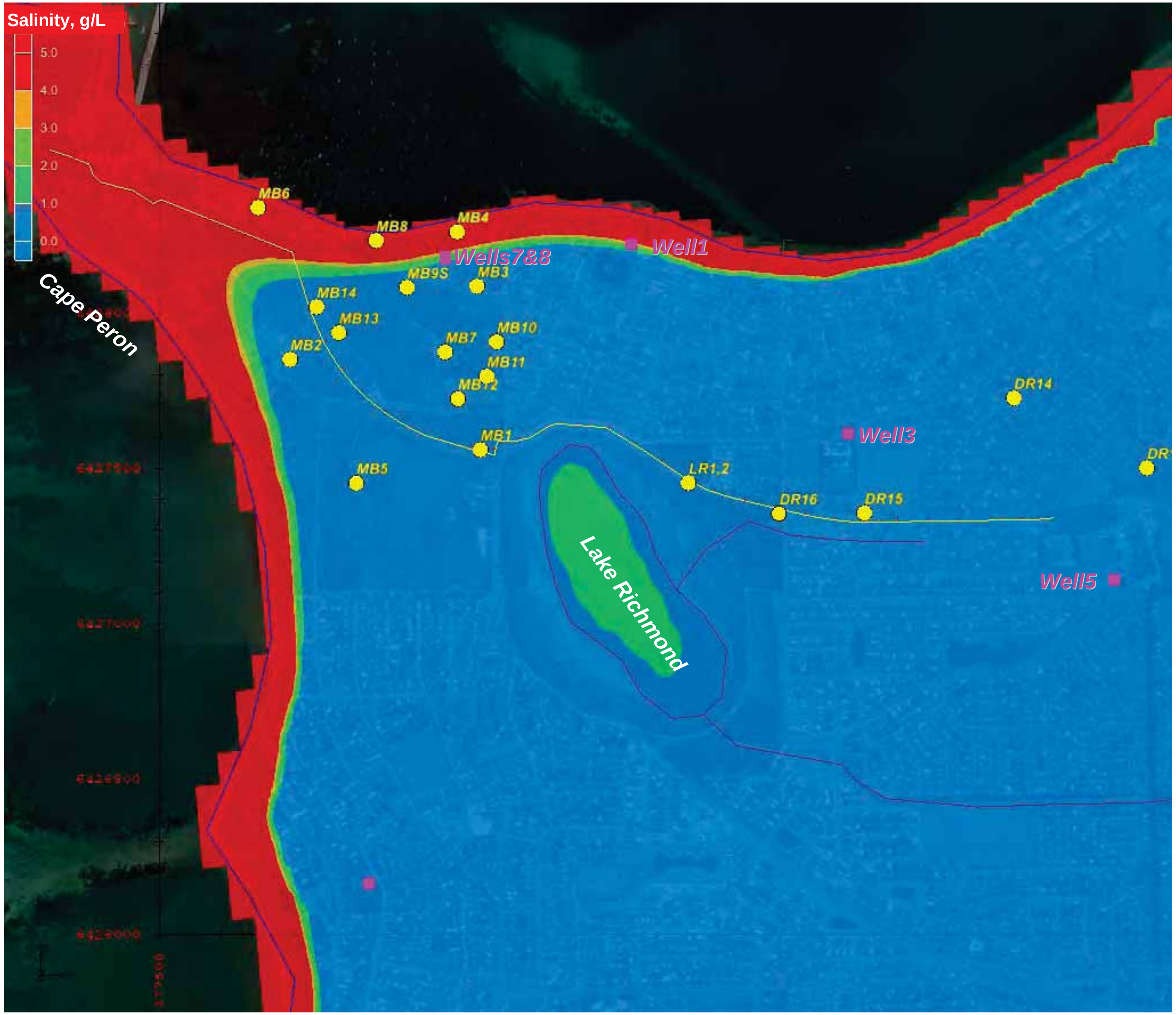
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Groundwater Contours during SDOOL Construction with Recharge to Trench
SDOOL Duplication, Rockingham, Western Australia

Figure 20



Legend

Streams, lakes, and/or shoreline

Monitoring well

Water supply well

Proposed location of SDOOL Duplication

Note:

Salinity distribution displayed at -12 m AHD

No discernible change in salinity input to Lake Richmond during SDOOL construction

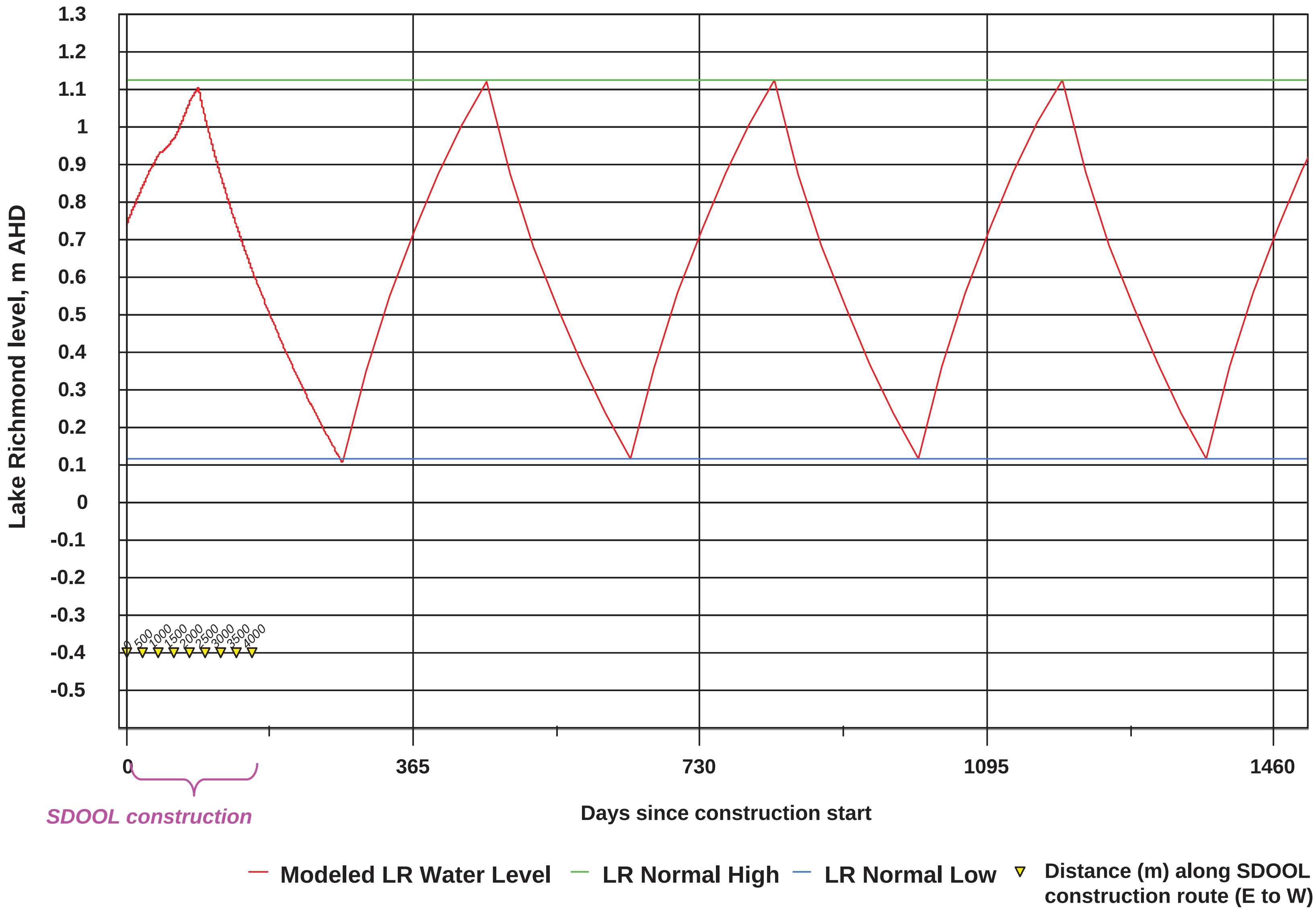
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Salinity Distribution at End of SDOOL Construction with Recharge to Trench
SDOOL Duplication, Rockingham, Western Australia

Figure 21



Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Modelled Future Lake Richmond Water Level after SDOOL Construction with Recharge to Trench
SDOOL Duplication, Rockingham, Western Australia

Figure 22

Legend

Streams, lakes, and/or shoreline

Monitoring well

Water supply well

Proposed location of SDOOL Duplication

Modelled groundwater contours, m AHD

Note:

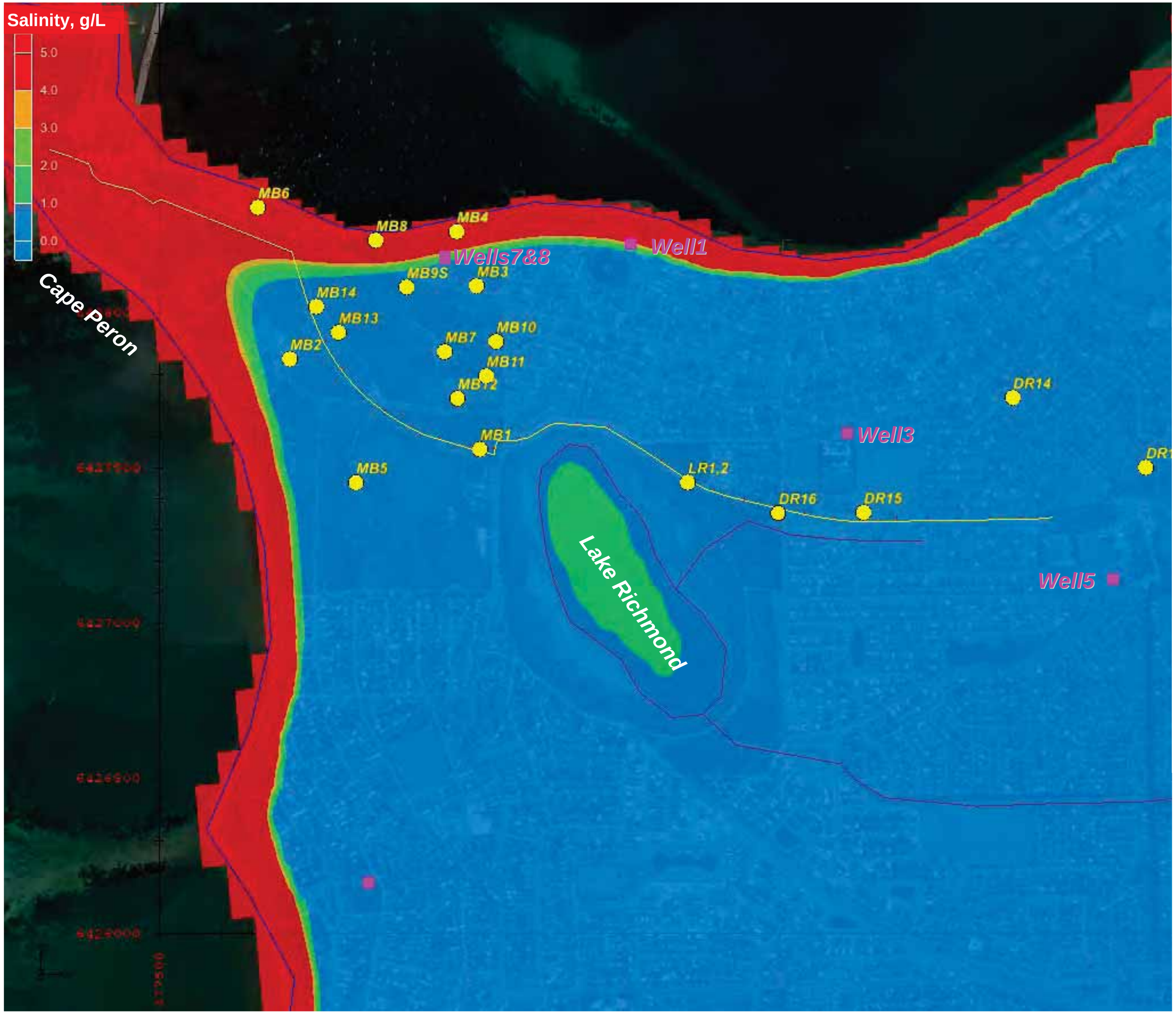
No discernible change in future water level of Lake Richmond after SDOOL construction

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Future Groundwater Contours after Construction with Recharge to Trench - Mean Water Level Conditions SDOOL Duplication, Rockingham, Western Australia	Figure 23

0116221-010/25/2011-HYH-M:\WaterCorp\SDOOL New Model Simulations Figures.ppt



Legend

Streams, lakes, and/or shoreline

Monitoring well

Water supply well

Proposed location of SDOOL Duplication

Note:

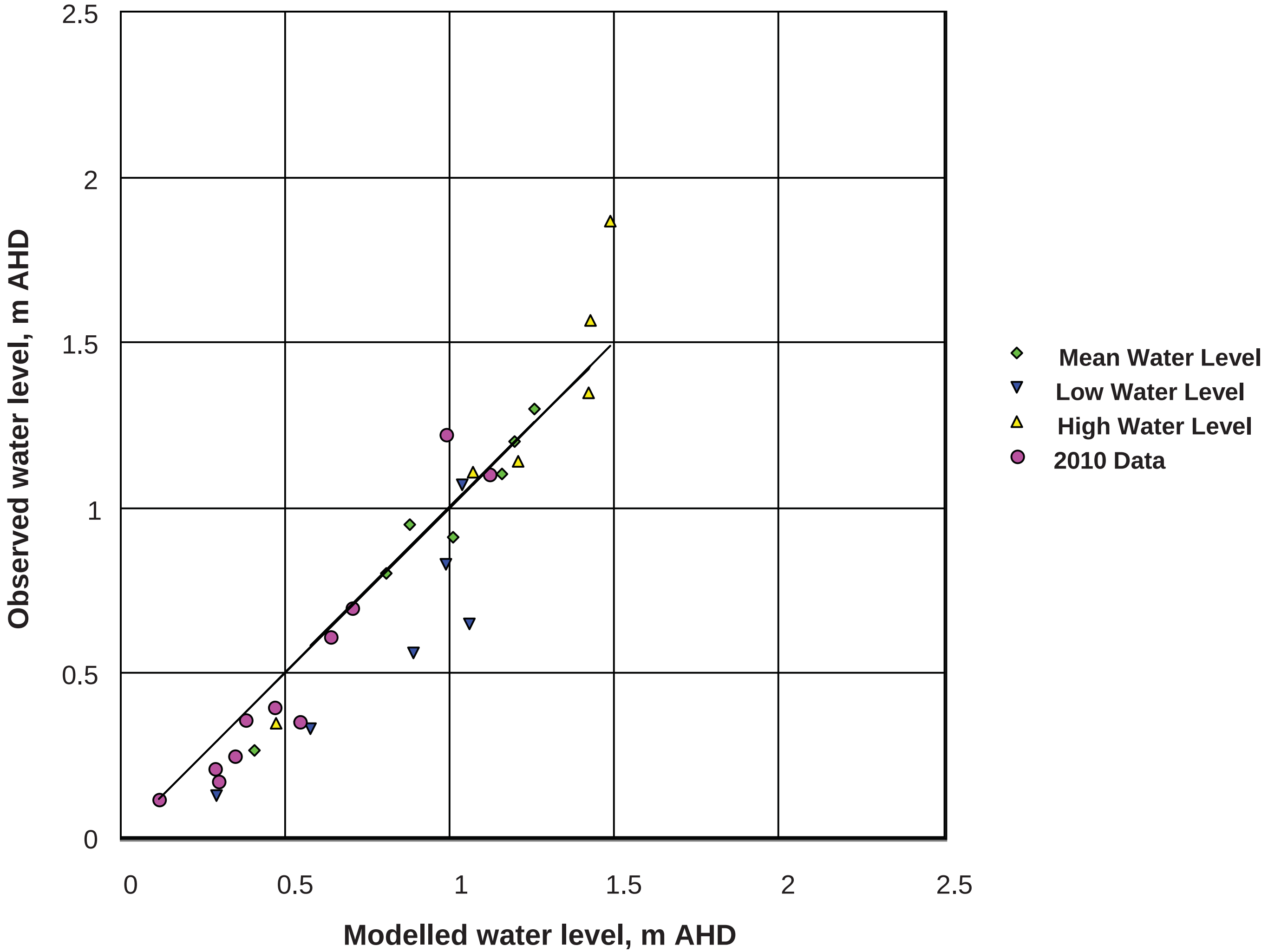
Salinity distribution displayed at -12 m AHD

No discernible change in salinity input to Lake Richmond after SDOOL construction

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

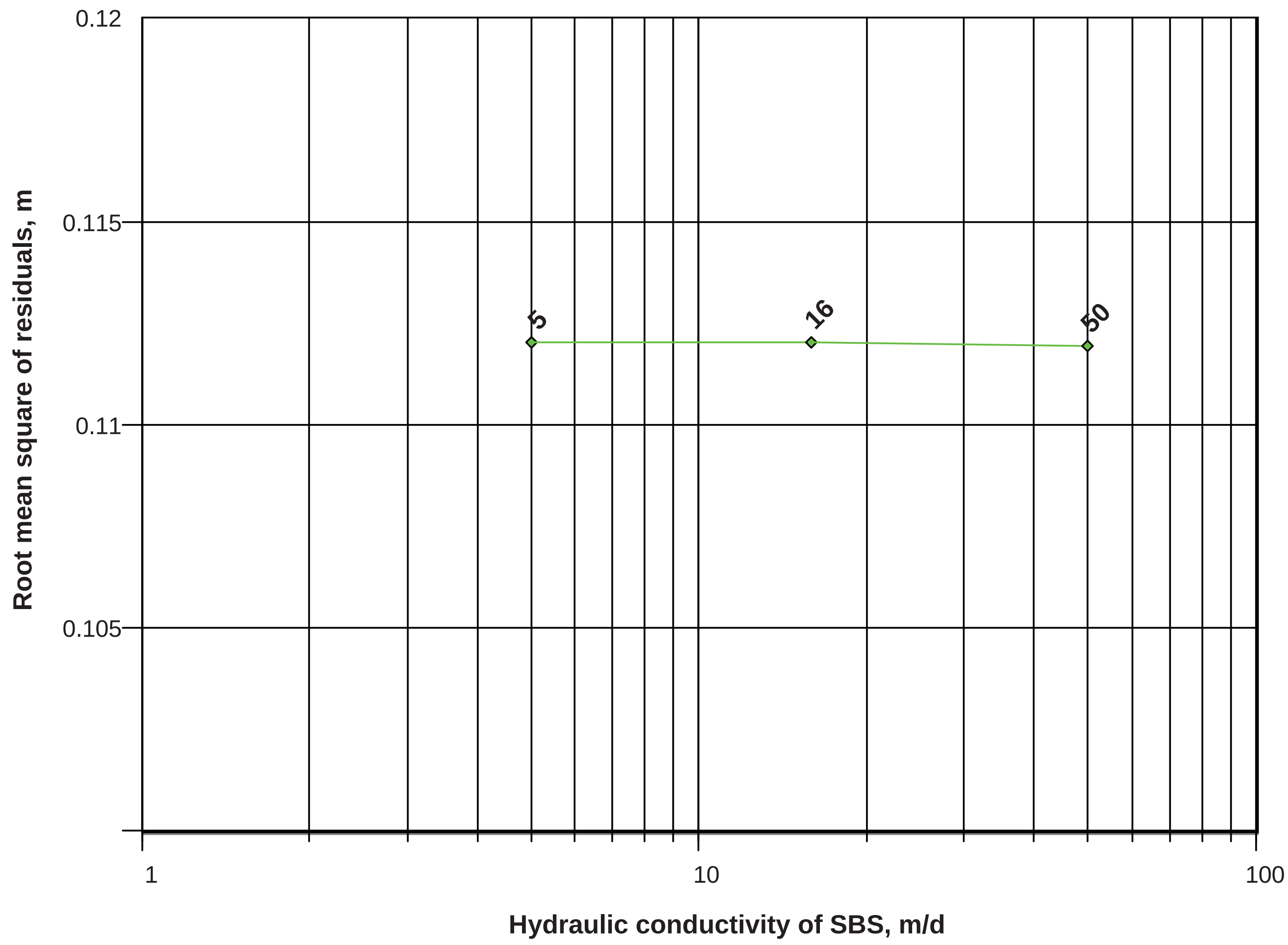
ERM Grain Pool Building, 6th Fl. 172 St. Georges Terrace Perth, WA 6000 Australia	Modelled Future Salinity Distribution after SDOOL Construction with Recharge to Trench SDOOL Duplication, Rockingham, Western Australia	Figure 24



ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Groundwater Flow Model Calibration Results
SDOOL Duplication
Rockingham, Western Australia

Figure 25



ERM
Grain Pool Building, 6th Fl.
172 St. Georges Terrace
Perth, WA 6000
Australia

Model Sensitivity Analysis Results
SDOOL Duplication
Rockingham, Western Australia

Figure 26

Appendix B

Conceptual Site Model

FINAL REPORT

Water Corporation

Sepia Depression Ocean Outlet Landline (SDOOL) Duplication Groundwater Modelling:
Revised Conceptual Site Model Report

December 2011

Reference: 0116221

Environmental Resources Management Australia
6th Floor, 172 St Georges Terrace
Perth WA 6000
Telephone +61 8 9321 5200
Facsimile +61 8 9321 5262
www.erm.com

Approved by:

Sepia Depression Ocean Outlet Landline (SDOOL) Duplication Groundwater Modelling:

Approved by:	*Brent Carter*
Position:	Project Manager
Signed:	
Date:	*6 December, 2011*
Approved by:	*Toby Whincup*
Position:	Partner
Signed:	
Date:	*6 December, 2011*

Environmental Resources Management Australia Pty Ltd Quality System

Revised Conceptual Site Model Report

December 2011

011622

www.erm.com

Quality-ISO-9001-PMS302

CONTENTS

1 PROJECT BACKGROUND

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by the Water Corporation in February 2011 to develop a groundwater model to assess potential impacts on the local environment and groundwater users from the proposed construction and operation of the Sepia Depression Ocean Outlet Landline (SDOOL) duplication, proposed to be developed in Peron and Rockingham, within the City of Rockingham, Western Australia (WA) (*Figure 1*).

In addition to addressing the SDOOL duplication, the Water Corporation was asked by the Environmental Protection Authority (EPA) to join with LandCorp to prepare a regional groundwater model to also assess LandCorp's proposed Mangles Bay Marina-Based Tourist Precinct (MBM) (*Figure 1*), which if developed would intersect the existing SDOOL and proposed SDOOL duplication, as well as potentially result in potential cumulative impacts on the local environment and groundwater users with the construction of the SDOOL duplication.

2 OVERVIEW

An initial Conceptual Site Model (CSM) was developed by MWH in 2011 (MWH, 2011)[1], using the following data sources:

- Published, available literature;
- Installation of 16 wells ranging in depth from 8 to 30m, using mud rotary techniques;
- Interpretation of lithology using logged drill cuttings samples;
- Water table monitoring;
- EC, pH, DO and redox profiling of all wells; and
- Associated study of Lake Richmond, which included water level logging and vertical profiling of EC, pH, DO and redox potential.

The MWH interpretation of the data presented a CSM that indicated:

- The presence of Safety Bay Sands (SBS - up to about 25m thick), underlain by the Tamala Limestone (TL - estimated to be over 40m thick).
- Two aquifer systems, comprising a superficial, unconfined aquifer located within the Safety Bay Sand and a confined aquifer within the Tamala Limestone. This was interpreted as a result of observed head differences between the two systems (the TL was erroneously stated as having a positive head) and the expected presence of a thin clay layer above the Tamala Limestone.
- Different (and variable) salinities in the two systems:
    - Fresh to brackish groundwater in the SBS (conductivities of 1,000µS/cm to 15,000µS/cm) with salinity increasing with depth.
    - Presence of a distinct saline wedge in the coastal areas of the SBS.
    - Saline groundwater in the TL (conductivities up to 55,000µS/cm).

Assessment of salinities, tidal influence on water levels and limited investigation of physical aquifer parameters, concluded the following:

---

[1] MWH, 2011. Conceptual Hydrogeology for the Mangles Bay Area (Draft report). Prepared for Strategen. April 2011.

2.1 *SAFETY BAY SAND AQUIFER*

- Steep, coastal salt water wedge;
- Limited inland influence of tides;
- Lower permeability than TL; and
- Increase in vertical salinities with depth, which are likely remnant of depositional conditions.

2.2 *TAMALA LIMESTONE AQUIFER*

- High permeability;
- Salinities reflective of sea water;
- Tidal influence; and
- Significant inland influence from coastal conditions.

ERM initially used the MWH CSM to undertake the modelling of the potential influence on baseline groundwater and aquifer conditions as a result of the construction, and later presence of, the SDOOL duplication. The focus of the model was on changes in water levels and salinities.

3 THIRD PARTY REVIEW

The CSM was reviewed by an independent third party (Phil Wharton) who raised the following concerns with regard to the validity of the MWH model:

- Wells cross connecting the two aquifer systems, with inference of chemical and physical parameters not being representative of the SBS (i.e. dominated by the TL due to its erroneously assumed positive head and the higher salinities);
- Lack of evidence of a clay aquitard between the SBS and TL; and
- Concerns regarding conclusions drawn about salinities in the SBS.

ERM was commissioned to undertake additional assessment to better define the CSM. Additional works included:

- Interpretation of down-hole gamma (and induction logs) completed on a number of MHW and ERM wells (attached as *Appendix A*);
- Installation of a set of nested SBS and TL wells to the east of Lake Richmond (LR1-TL, LR2-SBS and LR3-SBS);
- Water level and electrical conductivity monitoring during a 48hr pump test;
- Further assessment of available published data, including:
    - Passmore, J.R.,1970, Shallow Coastal Aquifers in the Rockingham District, Western Australia, Water Research Foundation of Australia Bulletin No. 18.
    - Data search carried out via Department of Water (DoW), Water Information Branch for all bore logs and data within a 2 km radius from Lake Richmond. Data received on 7th June 2011.
    - Worley Parsons, September 2005. Cape Peron Marina Development Groundwater Fatal Flaw Assessment. Southwest Corridor Development and Employment Foundation.
    - Semeniuk, C., 2007. The Becher Wetlands, a Ramsar Site.
    - Davidson, W.A., 1996. GSWA Bulletin 142 Perth Groundwater Atlas (1st Edition), Figure 22.
    - Davidson, W.A. 1995. Hydrogeology and groundwater resources of the Perth region, Western Australia, Western Australia Geological Survey, Bulletin 142.

- Smith, A. & Hick, W. 2001, Hydrogeology and Aquifer Tidal Propagation in Cockburn Sound, Western Australia, Technical Report 6/01, CSIRO Land and Water, Perth.

4 *WELL DATA SUMMARY*

Table 1 presents an overview of data available from the area of assessment. Discussion relating to conductivities (EC) or water levels is from a data set collected in June 2011. Interpretation of potential connection of the SBS, TL and the deeper Rockingham Sands (RS) and Leederville Formation (LF) is also presented. The graphical representation of this information is presented in *Appendix B*.

Using the down-hole geophysical data collected, it can be confirmed that wells MB01, 03, 05, 07, 10, 11 and 12 have not only cross connected the two aquifer systems, but have been screened entirely through both systems – as such, groundwater data from these wells should be discounted.

Table 4.1 Well Data Summary

Well	Total Depth	Geophysical Markers (mAHD)				Lithological Summary				Screen location	EC description µS/cm		
		Clay		Clay/ Shale							water table	bottom hole	Comment
Number	(mAHD)	top	base	top	base	SBS	TL	RS	LF				
MB06	7.5	-	-	-	-	Y				SBS: full length	22,500	42,500	Coastal well, salt water influence
MB08	8.5	-	-	-	-	Y				SBS: full length	16,700	55,600	Coastal well, salt water influence
MB04	15.5	-	-	-	-	Y				SBS: full length	2,280	53,800	Coastal well, salt water influence
LR3	9.5	-	-	-	-	Y				SBS: full length	1,610	1,750	-
MB02	15.5	-	-	-	-	Y				SBS: full length	1,300	9,850	Increase with depth
MB14(S)	7	-	-	-	-	Y				SBS: full length	1,098	15,000	Increase with depth
MB14 (D)	15	-	-	-	-	Y				SBS: 13m-15m	8,000	8,940	NOte deeper ECs lower than shallower ECs in MB14(S)
MB13	16.5	-	-	-	-	Y				SBS: full length	830	17,700	Significant increase occurs at 8-10m AHD
MB09 (S)	18.5	-	-	-	-	Y				SBS: full length	741	8,510	Increase with depth
LR2	21.5	-	-	-	-	Y				SBS: full length	1,720	3,230	Increase with depth
MB05	24	17.5	19	-	-	Y	Y			SBS & TL: full length - connect aquifers	3,500	27,500	sharp increase at about 20mAHD (coincides with start of TL)
MB07	26.5	19	20.5	23.5	-	Y	Y	?	?	SBS & TL & RS(?): full length - connect aquifers	27,700	49,500	sharp increase at about 21mAHD (coincides with start of TL)
MB12	28	19.5	20.5	25	-	Y	Y	?	?	SBS & TL & RS(?): full length - connect aquifers	25,000	48,700	sharp increase at about 20mAHD (coincides with start of TL)
MB03	24.5	19.5	20.5	-	-	Y	Y			SBS & TL: full length - connect aquifers	30,400	47,700	sharp increase at about 20mAHD (coincides with start of TL)
MB10	26	19	20.5	24.5	-	Y	Y	?	?	SBS & TL & RS(?): full length - connect aquifers	15,000	42,600	sharp increase at about 21mAHD (coincides with start of TL)
MB11	28	19	20.5	25	-	Y	Y	?	?	SBS & TL & RS(?): full length - connect aquifers	14,600	46,700	sharp increase at about 21mAHD (coincides with start of TL)
MB01	28	19	20.5	25.5	-	Y	Y	?	?	SBS & TL & RS(?): full length - connect aquifers	21,400	48,400	sharp increase at about 21mAHD (coincides with start of TL)
MB09 (D)	27	18.5	20	-	-	Y	Y			TL: isolated (19-27m)	14,700	53,300	
LR1 (bore)	36.5	22.5	23	26.5	-	Y	Y	Y	?	-			
LR1 (well)	27	22.5	23	26.5	-	Y	Y			TL: isolated (23-27m)	9,120	13,170	

5 *GEOLOGY*

Four cross sections of the area have been compiled (attached *Appendix B*):

- **A-A$_1$**: a northwest-southeast cross section, comprising well data from MB06, 14 (S&D), 13, 12, 01 and LR1 and LR2;
- **B-B$_1$**: a north-south cross section, comprising well data from MB04, 03, 10, 11 and 01;
- **C-C$_1$**: a north-south cross section, comprising well data from MB08, 9(S&D), 07, 12 and 01; and
- **D-D$_1$**: a north-south cross section, comprising well data from MB06, 02 and 05.

The gamma logs confirm a different lithological profile from that proposed in the original MWH CSM developed from logged drill cuttings. It is ERMs view that, given the drilling technique used (mud rotary) and the deeper complexity of the lithological profile, the information derived from the well logs developed through physical assessment of samples should be used as a guide only.

Accordingly, ERM has interpreted the data (primary data and those from various published documents) as follows:

5.1 *SAFETY BAY SAND*

- 20 to 24 m thick.
- Shallow aeolian sands, transitioning into silty marine Becher Sand (some shell fragments noted toward base of SBS).
- Likely decrease in permeability with depth as the formation transitions from aeolian to marine deposits.
- Thin layer (0.5-1.5 m) of clay at the base of the SBS (unique gamma log marker on downhole logs), consistently found at depths of about -18.5 to -23 m AHD.

5.2 *TAMALA LIMESTONE*

- 3.5 to 7 m thick.
- Some sand reported in this formation by MWH; however this may be related to underlying Rockingham Sand (RS).

- Formation underlain by interbedded shales, clays and sands. The clay/ shales have a unique gamma log, as identified in wells MB01, 07, 10, 11, 12 and LR1 and were consistently first encountered at about -23.5 to -26.5m AHD.

5.3 ROCKINGHAM SAND

- Various published information suggest that the interbedded shales, clays and sands are representative of the Rockingham Sands Formation, with potentially subcropping Leederville Formation (LF-the subcrop map is attached as *Appendix C*).

- A DoW well within the CSM area east of Lake Richmond intersected micaceous shale at about 35 m depth. Although this is not shown on the published subcrop map, areas of Leederville Formation subcrop are indicated to the west of Lake Richmond. The Rockingham Sand is up to 110 m thick east of Lake Richmond and will be thinner within the CSM area.

6 HYDROGEOLOGY

6.1 SAFETY BAY SANDS

The SBS comprises shallow (aeolian) and deeper (marine) Becher Sands. In this CSM no distinction is made between the SBS and the Becher Sand to maintain continuity between previous CSM reports by Worley Parsons (WP, 2005) and MWH (2011). The shallower aeolian SBS sands are underlain by marine Becher Sand (which contains some finer, siltier layers) that likely result in a reduction in permeability with depth. This reduction will be reflected in the adoption of appropriate kh values for the SBS in the ERM numerical model. The kh for the SBS has been previously estimated at 5 m/day (WP, 2005) and 20 m/day (MWH, 2011); in the ERM numerical model, the kh was set at 16 m/day from the model's internal calibration based upon an assumed recharge value. A specific yield value of 0.2 was also adopted in the model based on default model values. This is less than the 0.3 proposed by Davidson (1995), but is within the range reported by Passmore (1970).

Passmore (1970) carried out an aquifer pump test of the SBS and calculated the following aquifer coefficients:

- 1,022 m^2/day transmissivity;
- 40 m/day hydraulic conductivity; and
- Specific yield ranging from 0.11 to 0.2 throughout the aquifer.

There are insufficient data to allocate separate kh values for the upper and lower layers in the SBS.

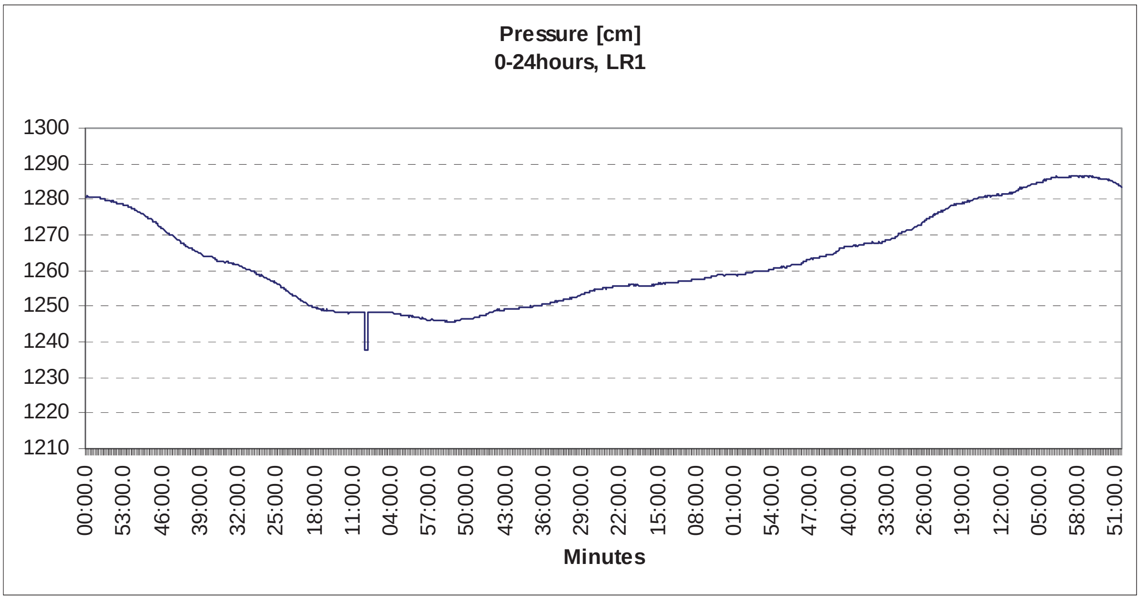
6.2 SAFETY BAY SAND – TAMALA LIMESTONE TRANSITION

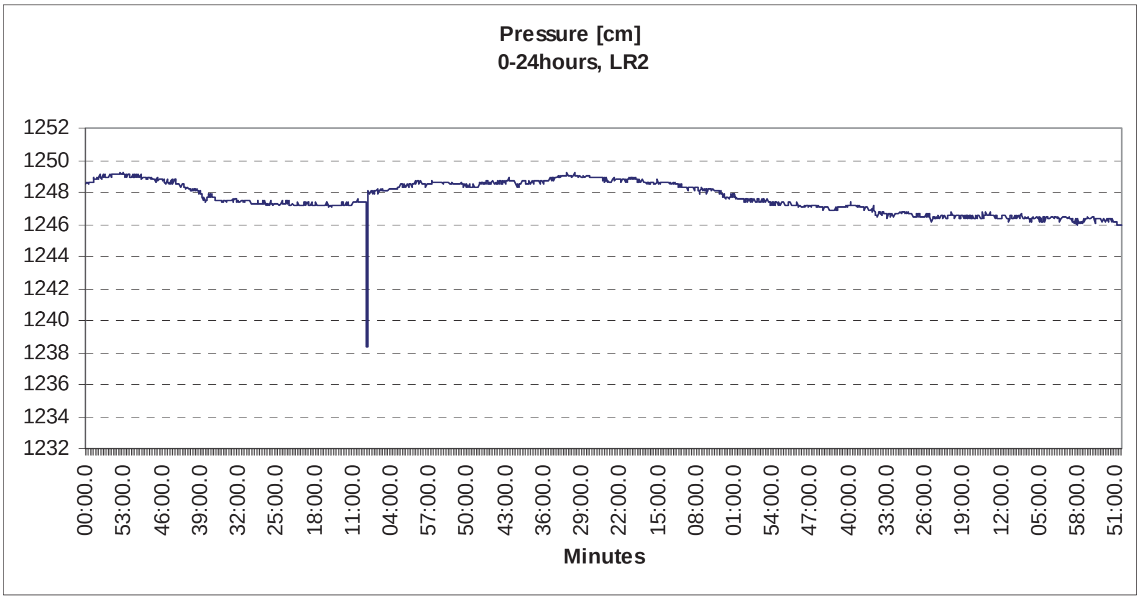
Downhole geophysics data (and some well logs), supported by water level data, confirm a confining layer between the SBS and the TL. Monitoring wells MB09 (deep and shallow) and LR1 and LR2 were constructed to ensure that the deeper wells (MB09-D and LR1) were screened within the TL only. Adjacent shallow wells (MB09-S and LR2) were screened in the SBS only. Water level measurements collected from the four wells is summarised in *Table 2*.

Water Level Measurements

Well Number	Date	Water Level (mAHD)	Formation
MB09-S	June 2011	0.38	SBS
MB09-D	June 2011	0.64	TL
LR2	June 2011	0.55	SBS
LR1	June 2011	0.86	TL

The June measurements from LR1 and LR2 suggest a 0.3 m positive head in the TL. However, further assessment of the water levels in LR1 and LR2 in July over a 24 hr period (presented overpage), indicate a distinct tidal profile in the TL (represented by LR1) compared to the SBS (represented by LR2). This finding is significant to the understanding of the TL aquitard interactions, as it indicates that there is no consistent positive head, and as such, potential for consistent upward contribution of saline waters in the TL to the SBS, through the aquitard.





To assess the characteristics of the aeolian sand, present in the shallower depths of the SBS, ERM installed a second shallow well in the SBS at location LR – LR3, which was installed adjacent to LR2, to a depth of about 11m. LR3 was screened in the aeolian sands only.

Water levels measured in June in the two wells were similar (LR2 – 0.55 m AHD and LR3 – 0.54 m AHD). Given the expected decrease in Kh with depth through the SBS as a result of different depositional conditions (aeolian and marine), it could be argued that if there was a significant interaction between the TL and SBS, this would be reflected in a positive head difference between the Becher Sands and the shallower aeolian deposits - no evidence of this was observed.

6.2.1 *Dewatering Trial Observations*

Introduction and Objective

In October 2011, Golder Associates Pty Ltd (Golders) supervised the completion of two dewatering trials within the SBS near locations LR1-LR3. The location of the dewatering trials is presented in *Figure 1, Annex D*. The objective of the works was to assess the hydrogeological response to shallow dewatering over a 48-hour period in preparation for the SDOOL construction.

Procedure

On 4th October 2011, Golders engaged and supervised Mobile Dewatering to install 18 dewatering spears of 50 mm diameter approximately six metres below the ground surface (mbgs) and spaced approximately one metre apart. The dewatering spears were all connected to an air compressor that would pump water approximately 150 m north-west to an approximately 20 m x 10 m x 1 m retention pond. The dewatering spears were installed through high water pressure direct push methodology. Minor dewatering was also conducted by Mobile Dewatering during the spear installation.

The trial was started at about 2:30 pm on 4th October and stopped before the targeted 48-hour period (at 7:56 am 5th October) due to predominantly low flow rates (less than one litre/second [L/s]) being observed. Mobile Dewatering considered the low flow rates to be the result of the spear screens having been silted up.

On 7th October, Mobile Dewatering reinstalled the spears in the same bores with filter pack surrounding the screened sections in an attempt to improve flow rates. Following completion of the reinstallations, a second dewatering trial was initiated at 12:30 pm on 7th October. Initial flows were also estimated to be predominantly 1 L/s during the second dewatering trial until Mobile Dewatering reversed the flow on 8th October at 12:30 pm for approximately 15 minutes in an attempt to clean out the screens. After the flow reversal, flow rates increased and were estimated to be approximately 6 L/s. The second dewatering trial was stopped at 1:03 pm on 9th October.

ERM was engaged by WaterCorp to continuously record groundwater levels and electrical conductivity (EC) in the LR location during the dewatering trials. On 4th October and prior to the dewatering spear installation, ERM had conducted monitoring of the three LR wells (LR1-LR3) to assess background conditions. Each well was gauged and a water quality multi-parameter probe was lowered down the well for parameter recordings every metre. Background conditions are presented in *Table 3*. Pre-dewatering groundwater EC profiles for each well are presented in *Table 1, Annex D*.

Pre-Dewatering Background Conditions

Well Number	Date	Water Level (mAHD)	EC (uS/cm) at groundwater surface (3 metres below top of casing)	EC (uS/cm) at bottom of well
LR1	4th October 2011	0.772	1770	8,635
LR2	4th October 2011	1.007	772	1,728
LR3	4th October 2011	1.004	1046	1,339
LR1	7th October 2011	1.937	NA	7,593
LR2	7th October 2011	1.831	NA	1,433
LR3	7th October 2011	2.318	NA	1,208

For the dewatering trials, transducers were installed by ERM within each well approximately seven metres below the water column. In addition, a water quality multi-parameter probe was installed at the base of each well. Both sets of instruments made continuous recordings of groundwater elevation and EC every minute. Water level and well bottom EC measurements prior to the second dewatering trial are presented in *Table 3.* Gauging and instrument inspections (including data downloads) were conducted about once a day during the trials. The instruments were retrieved from the wells approximately one day after each trial end to record groundwater recovery conditions as well.

Findings

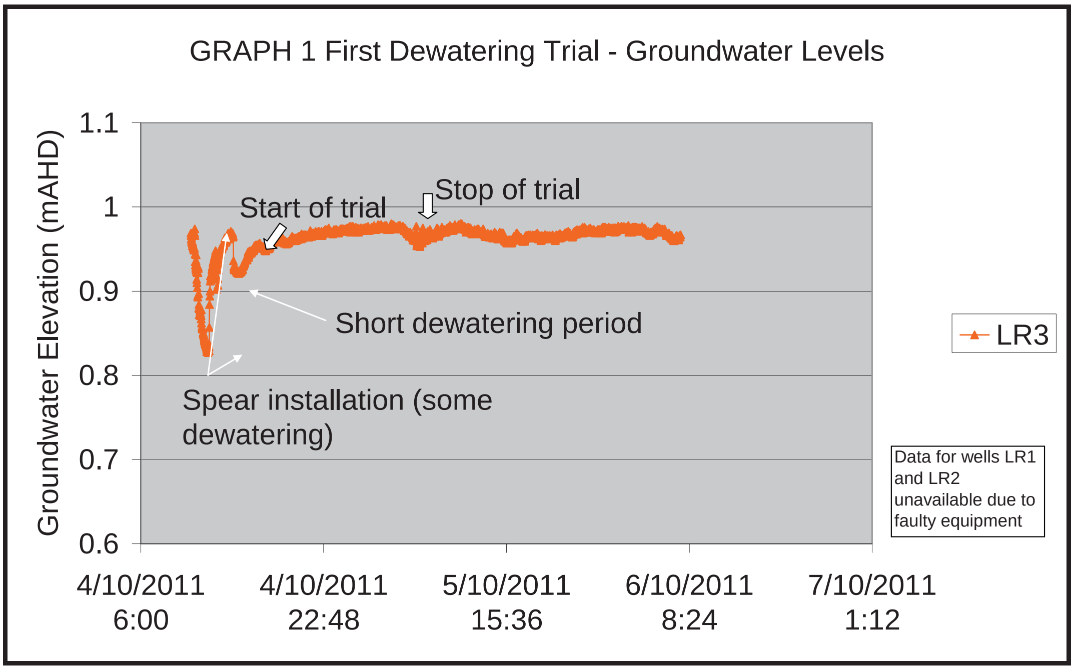
Both dewatering trials failed to lower the shallow groundwater levels by the targeted three to five metres. Groundwater level and EC values recorded during both trials are presented in *Graphs 1-4.*

Overall, the effects of the dewatering trials were evident in the groundwater levels in the SBS. Groundwater elevations within the two SBS wells LR2 and LR3 dropped by approximately 20 cm at most during both trials. The decrease in groundwater elevations was only witnessed within the first hour of the first dewatering trial. A consistent and gradual groundwater level decrease was observed during the second dewatering following the flow reverse screen clean out event.

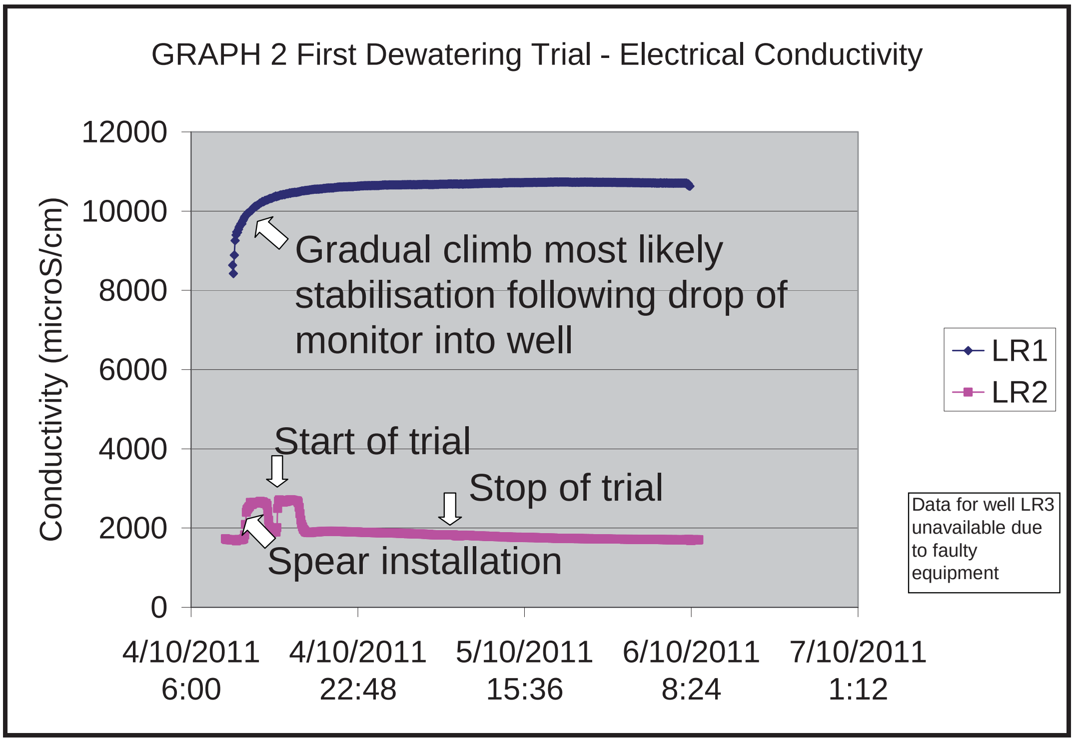
The dewatering appeared to also slightly affect EC values within the base of the SBS. EC values increased by approximately 700 uS/cm in the deeper SBS well LR2 during both trials. During the first trial, the increase was only witnessed for the initial three hours followed by a rapid recovery. During the second dewatering trial EC values increased gradually and were observed to not stabilise immediately to original levels, but rather recover across 15 hours following the trial end[2].

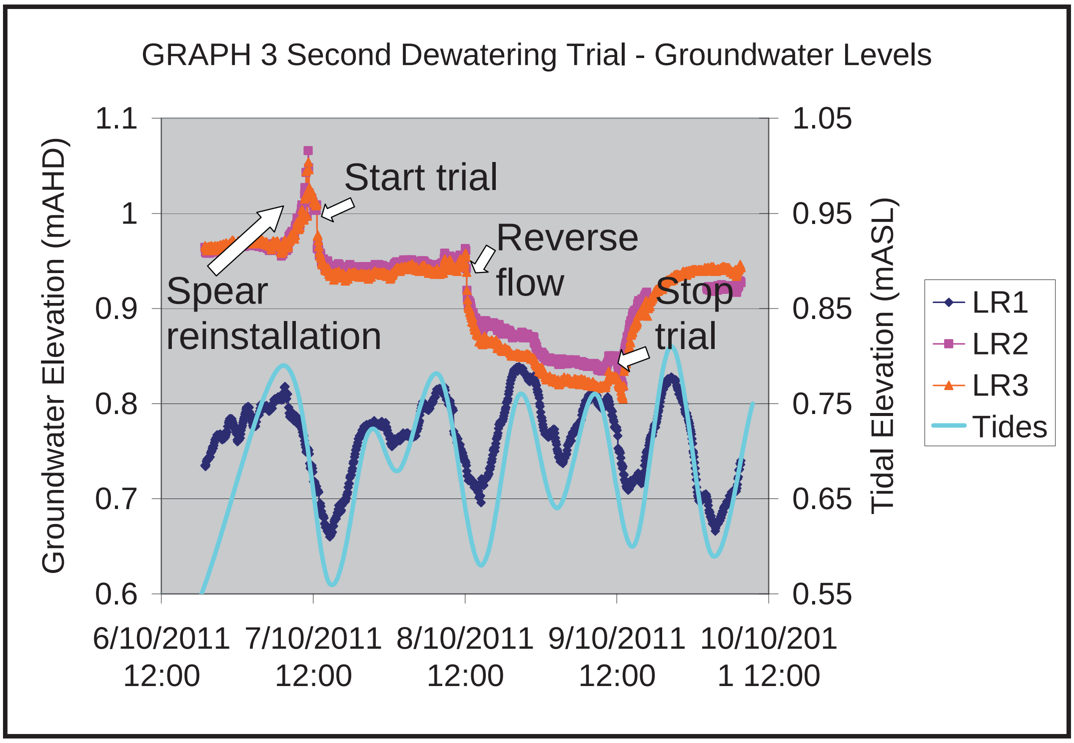
Historical water column profile data collected by ERM on 3rd June 2010 depicts EC value levels at the base of well LR2 similar to the max EC values measured at the probe depth (22.5 m) in LR2 during the two dewatering trials (approximately 3,000 uS/cm). In addition, EC and groundwater levels appeared to have stabilised in conjunction as opposed to a continuing EC increase as would occur if seawater intrusion or upward groundwater flow from TL was the cause of the increased EC. Therefore, the increase in EC observed in well LR2 (which is screened across through the predominant thickness of the SBS) during the dewatering events is considered to be entirely related to the higher EC at the base of the SBS.

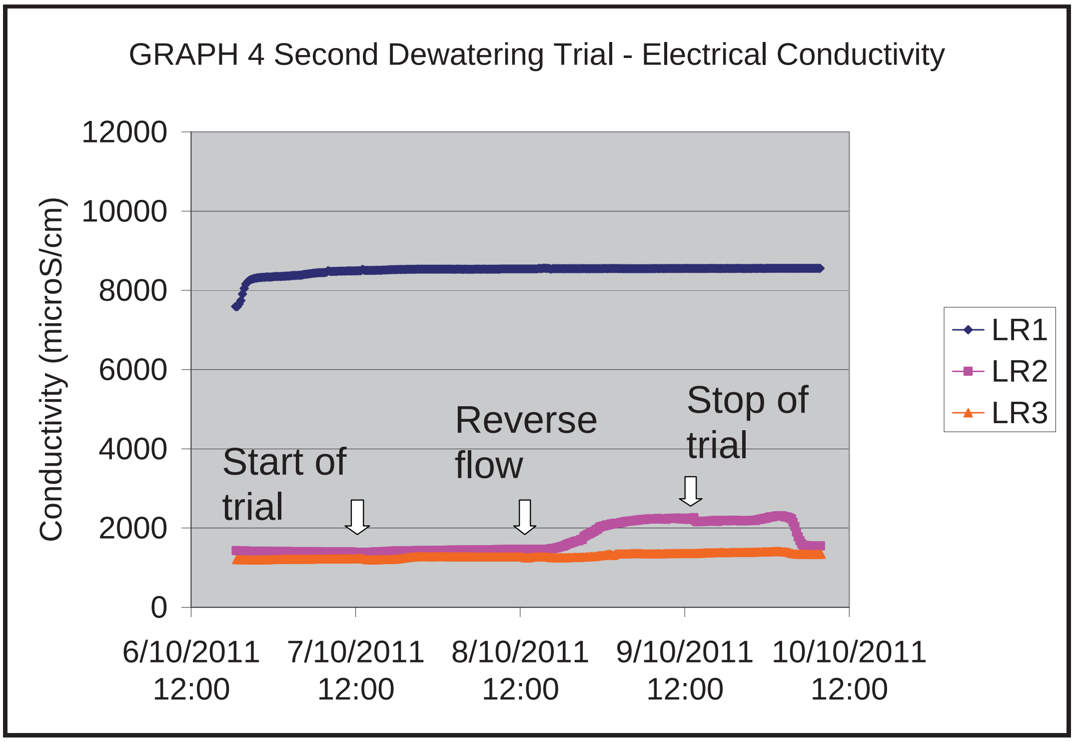
Groundwater levels and EC in the TL (well LR1) did not appear to be affected by the shallow dewatering trials. Groundwater elevations in the TL were observed to be strongly tidally influenced.



[2] It should be noted that a different set and type of water quality multi-parameter probes were used on the second trial, which with the different supplier calibration could account for the slightly different EC values between each trial.


GRAPH 2 First Dewatering Trial - Electrical Conductivity
Conductivity (microS/cm)
12000
10000
8000
6000
4000
2000
0
Gradual climb most likely stabilisation following drop of monitor into well
Start of trial
Stop of trial
Spear installation
4/10/2011 6:00
4/10/2011 22:48
5/10/2011 15:36
6/10/2011 8:24
7/10/2011 1:12
LR1
LR2
Data for well LR3 unavailable due to faulty equipment


GRAPH 3 Second Dewatering Trial - Groundwater Levels
Groundwater Elevation (mAHD)
1.1
1
0.9
0.8
0.7
0.6
Tidal Elevation (mASL)
1.05
0.95
0.85
0.75
0.65
0.55
Start trial
Reverse flow
Spear reinstallation
Stop trial
6/10/2011 12:00
7/10/2011 12:00
8/10/2011 12:00
9/10/2011 12:00
10/10/201 1 12:00
LR1
LR2
LR3
Tides



6.3 TAMALA LIMESTONE

The TL is a highly permeable formation ranging between calcarenite to calcareous sandstone with layers of coarse sand. Permeability in the TL is related to both primary and secondary porosity (solution cavities).

6.4 TAMALA LIMESTONE TRANSITION

The WP (2005) report recognises that intercalated clay and silt layers occur at the unconformable contact between TL and RS. In LR1 this sequence from about 26 to 33 m depth comprised a brown to orange plastic clay and orange clayey sand, underlain by a black sticky shale, underlain in turn by an orange coarse sand continuing to total depth of 40 m.

6.5 ROCKINGHAM SAND-LEEDERVILLE FORMATION

The Rockingham Sand is an erosional feature in the Cretaceous Leederville Formation and is recharged by infiltration from the SBS, TL and LF, particularly east of Lake Richmond. The heads and salinity distribution in the RS beneath the area covered by this CSM are uncertain but there is likely to be a lower salinity zone underlain by a salt water interface at depth (WP, 2005). It is also possible that a thinner brackish water zone may occur directly beneath the saline groundwater of the TL in this area depending on head differentials between the TL and RS. The following is taken from the WP (2005) report:

The Rockingham aquifer is defined as the Rockingham Sand and can be locally confined by discontinuous clay lenses located towards the base of the superficial formation (Tamala Limestone). Flow in this aquifer is generally in a westerly direction. As this aquifer is the deeper aquifer at the site, freshwater flows mainly discharge into the ocean well below sea level. As the Rockingham aquifer is thicker and deeper than the superficial aquifer, salt water intrusion can potentially penetrate quite deep and further inland. The aquifer contains saline groundwater beneath about -65m AHD, while the top 36 m contains groundwater of salinity less than 1,000 mg/L (Smith and Hick, 2001).

7 EC PROFILES

7.1 SAFETY BAY SANDS

EC profiles from wells screened within the SBS only suggest the groundwater is fresh to brackish, with salinity increasing with depth. EC ranges decrease in value away from the coast in the MBM area, and are generally less than 1,800 µS/cm at shallow depths, increasing to between 3,000 to 17,000 µS/cm[3]. These values contrast with those of the three coastal wells (MB04, 06 and 08), which show a distinct saline wedge (up to about 55,000 µS/cm) and LR2 (on the north-eastern shore of Lake Richmond), which ranges from about 1,700 µS/cm at the water table to just over 3,000 µS/cm at the base of the SBS.

The sources of the salinity (as EC) distribution with depth in the SBS are unknown. Immediately adjacent to Lake Richmond, groundwater appears to be influenced by the low EC of the lake waters (1,000 µS/cm, increasing to 1,400 µS/cm in the deeper sections) with some possible residual legacy groundwater salinities from the brackish waters which existed in the Lake prior to 1968. Prior to construction of influent/effluent drains in 1968 the lake water was brackish with salinity up to 3,500 mg/L TDS. There may also be a residual depositional salinity in the Becher Sand component of the SBS. These comments apply to the higher ECs recorded from the "inland" parts of the SBS within the CSM area, as distinct from the sea water interface present near the coast.

The wells that cross connect the SBS and TL have a much higher EC readings in the SBS – this is a likely function of the higher salinities in the TL and, as such, these results should be discounted for use for the SBS.

7.2 TAMALA LIMESTONE

Conductivities at the bottom of the TL are similar to those expected in coastal waters (around 50,000µS/cm), these decrease further inland (e.g. LR1), suggesting a gradual transition into fresher water. EC results from MB09D and LR1 also suggest a degree of vertical stratification within the TS.

---

[3] This also appears to be reflected in downhole induction logs.

8 *REGIONAL GROUNDWATER USE*

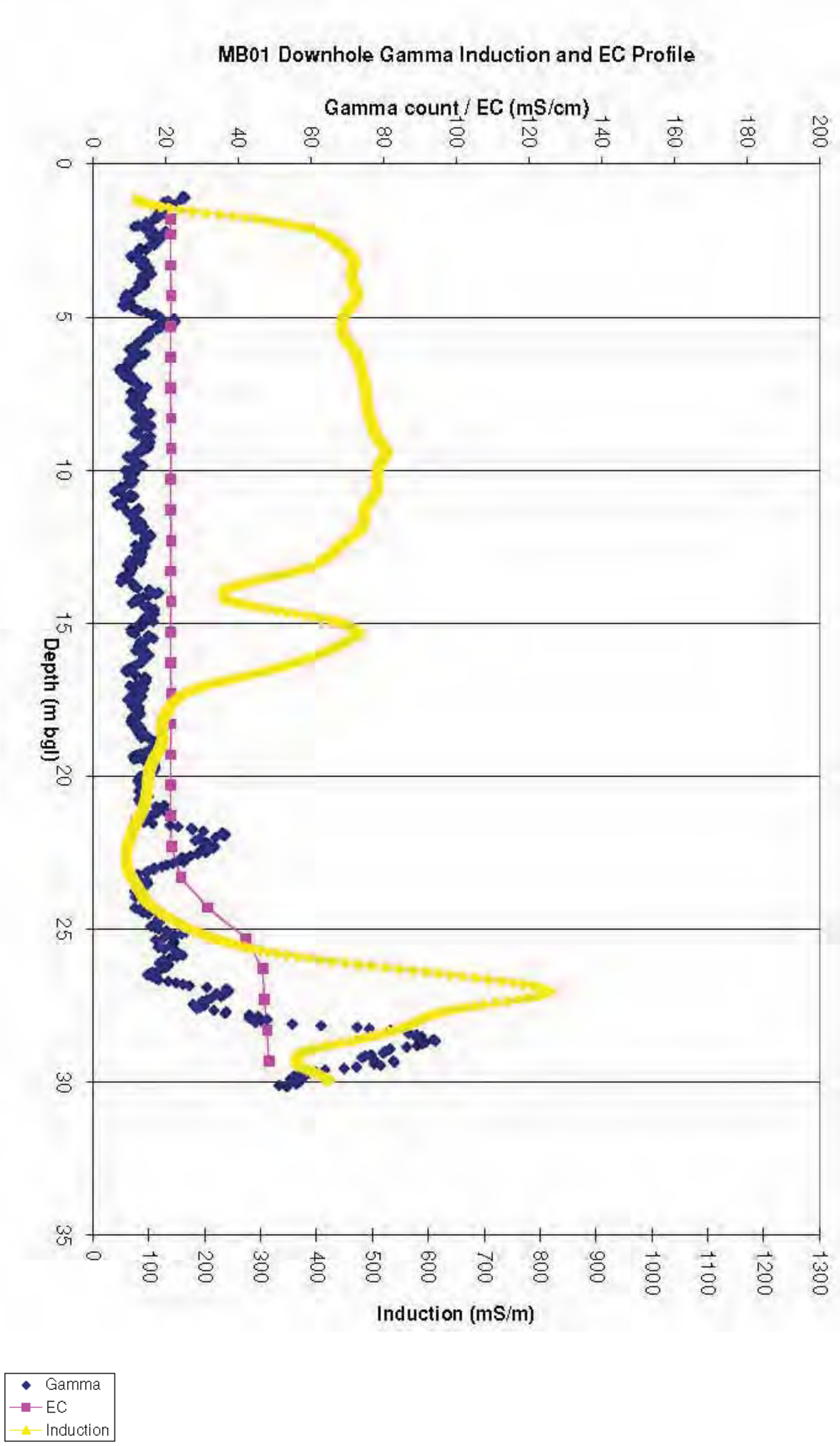
There are 42 known groundwater abstraction licenses applicable to a 2km range around the proposed SDOOL duplication and MBM developments, the majority of which are likely to be primarily for parkland/oval irrigation. Additionally, a preliminary bore census (observations only, without engagement) was carried out by ERM in the area in 2010 for the Water Corporation (*Appendix E*). The results showed evidence of significant domestic bore use in the area.

It is probable that irrigation bores in this area are constructed into the RS and/or LF, as it is unlikely that suitable yields can be obtained from the SBS. Domestic bores however may be constructed into the upper 'lower salinity' sections of the SBS.

The MWH EC profiling data indicates increases in EC readings during the month of December in SBS screened wells MB02, 9, 13 and SBS/TL cross screened well MB05. This may be associated with domestic bore use in the summer months (adjacent to observed wells); however further assessment would be required to confirm this.

Annex A

Downhole Gamma, Induction And EC Logs


MB01 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
Depth (m bgl)
Induction (mS/m)
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB01

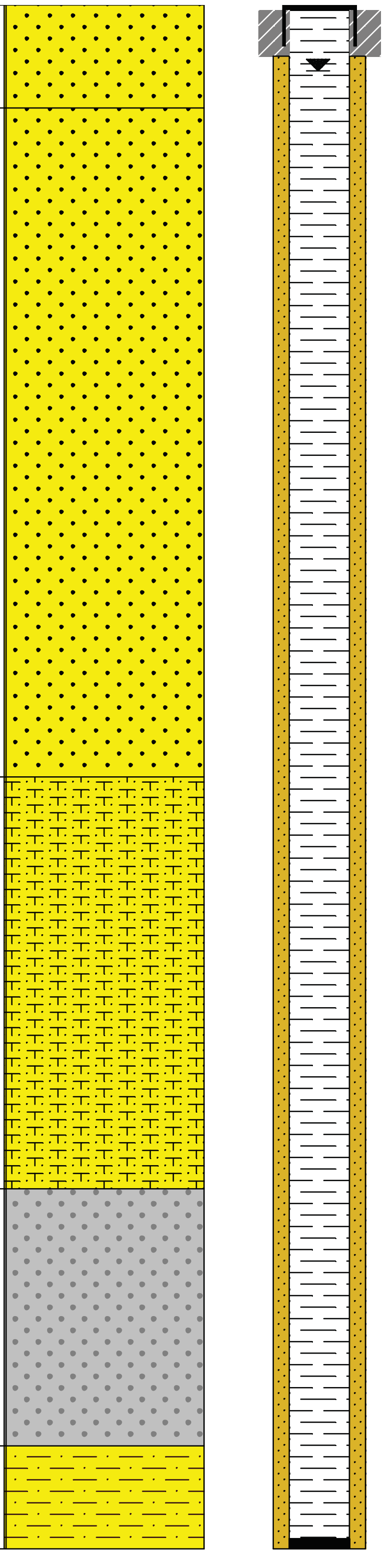
Client: Landcorp
Date Drilled: 29-30/03/10
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378534
Northing: 6427559
Surface RL: 2.11 mAHD

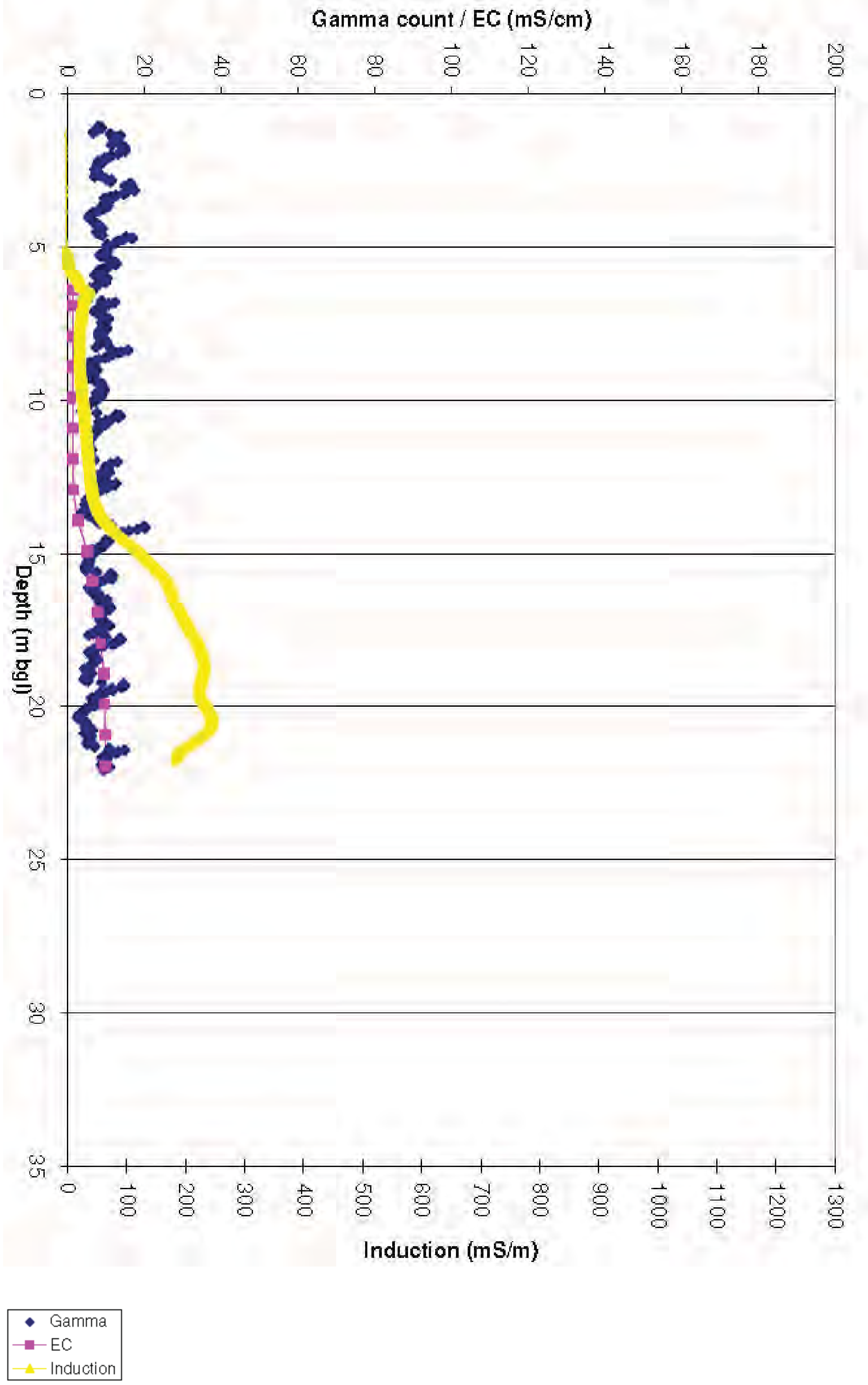
HYDRAULIC DATA: **SWL:** 1.62 mbgl
SWL Date Collected: 08/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Light brown, moderately sorted, angular to very angular shell fragments.			Steel lockable cover Cement grout (0-0.5 m)	
		SAND Light grey, moderately sorted, medium grain size, angular shell fragments.				EC; 1.61mS/cm, TDS; 0.81 ppt, Temp; 19.0 °C, pH; 8.39 at 10 m EC; 1.52 mS/cm, TDS; 0.83 ppt, Temp; 20.0 °C, pH; 8.06 at 13 m
15		SILTY SAND Brown, well sorted, silty sand. Contains some organic material.			100 mm UPVC PN9 Slotted casing (0-30 m) Gravel Pack (1.6-3.2 mm)	EC; 1.1 mS/cm, TDS; 0.56 ppt, Temp; 20.5 °C, pH; 7.69 at 16 m EC; 1.58 mS/cm, TDS; 0.80 ppt, Temp; 29.4 °C, pH; 7.88 at 23 m EC; 2.86 mS/cm, TDS; 1.27 ppt, Temp; 27.6 °C, pH; 7.88 at 24 m
	Tamala Limestone	SANDSTONE Grey, poorly sorted, cemented qaurtz rich sandstone. Clasts contain 90 % rounded to sub rounded quartz 2-5 mm in size and 10 % angular shell fragments.				EC; 4.04 mS/cm, TDS; 2.07 ppt, Temp; 27.9 °C, pH; 7.84 at 25 m EC; 5.54 mS/cm, TDS; 2.92 ppt, Temp; 26.3 °C, pH; 7.78 at 26 m EC; 13.34 mS/cm, TDS; 6.82 ppt, Temp; 24.7 °C, pH; 7.66 at 27 m
30		SILT Yellow/brown, fine grained, well sorted silt. Contains some clasts of shell fragments and rounded quartz.			End cap (30 mbgl) EOH 30 m	EC; 20+ mS/cm, TDS; 10+ ppt, Temp; 32.0 °C, pH; 7.58 at 28 m



TD: 30 m
Notes: Has data logger and barotroll installed in the bore.

MB02 Downhole Gamma Induction and EC Profile



WELL COMPLETION DETAILS: MB02

Client: Landcorp
Date Drilled: 14/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

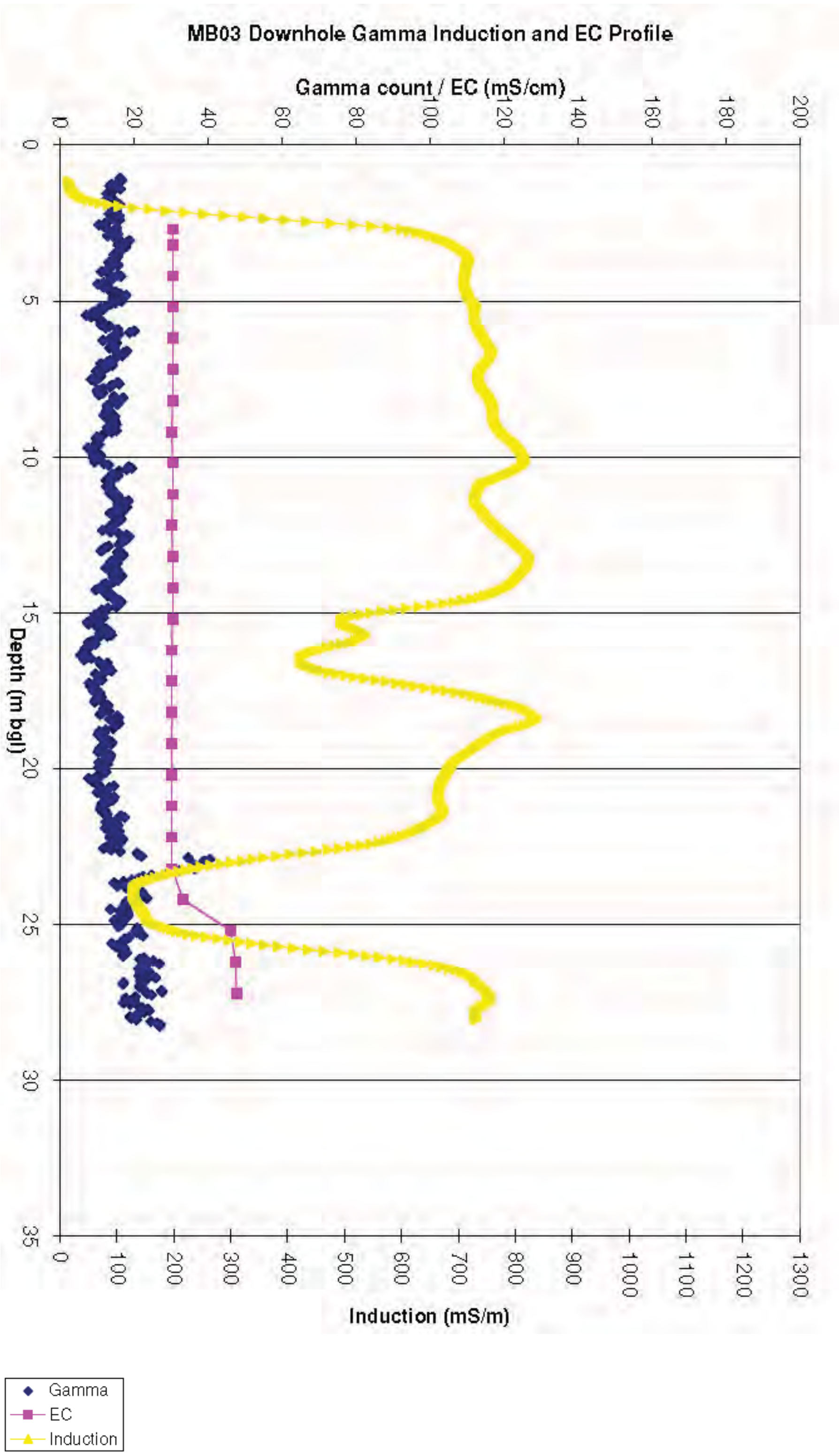
Easting: 377921
Northing: 6427850
Surface RL: 6.45 mAHD

MWH

HYDRAULIC DATA: **SWL:** 6.23 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Light brown, well sorted, angular to very angular shell fragments.			Steel lockable cover	
		SAND Cream/brown, well sorted, angular, shell rich sand.			Cement grout (0-0.5 m)	
5		SAND Cream, poorly sorted, very angular, shell rich sand.				
10		SAND Dark grey, moderately sorted, angular, shell rich sand.			100 mm UPVC PN9 Slotted casing (0-22 m)	EC; 2.05 mS/cm, TDS; 1.0 ppt, Temp; 20.6 °C, pH; 8.10 at 11 m
						EC; 1.55 mS/cm, TDS; 0.73 ppt, Temp; 18.5 °C, pH; 8.25 at 14 m
						EC; 1.55 mS/cm, TDS; 0.79 ppt, Temp; 18.7 °C, pH; 8.13 at 15 m
15					Gravel Pack (1.6-3.2 mm)	EC; 2.53 mS/cm, TDS; 1.19 ppt, Temp; 18.5 °C, pH; 8.05 at 16 m
						EC; 6.74 mS/cm, TDS; 3.51 ppt, Temp; 18.6 °C, pH; 8.08 at 17 m
						EC; 3.91 mS/cm, TDS; 1.96 ppt, Temp; 19.2 °C, pH; 8.01 at 18 m
20						EC; 5.14 mS/cm, TDS; 2.05 ppt, Temp; 19.6 °C, pH; 8.06 at 19 m
					End cap (22 mbgl)	EC; 6.42 mS/cm, TDS; 3.02 ppt, Temp; 19.5 °C, pH; 8.10 at 20 m
					EOH 22 m	

TD: 22 m
Notes:


MB03 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
Depth (m bgl)
Induction (mS/m)
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB03

Client: Landcorp
Date Drilled: 06-07/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378523
Northing: 6428086
Surface RL: 2.83 mAHD

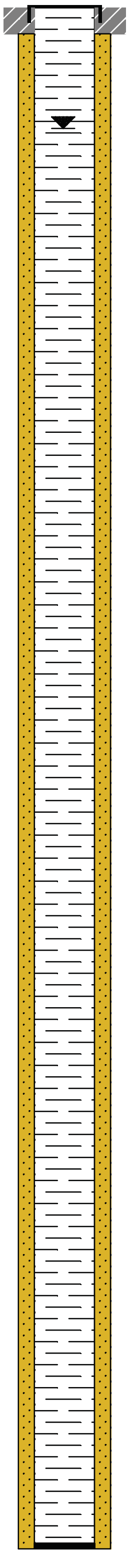
MWH

HYDRAULIC DATA:

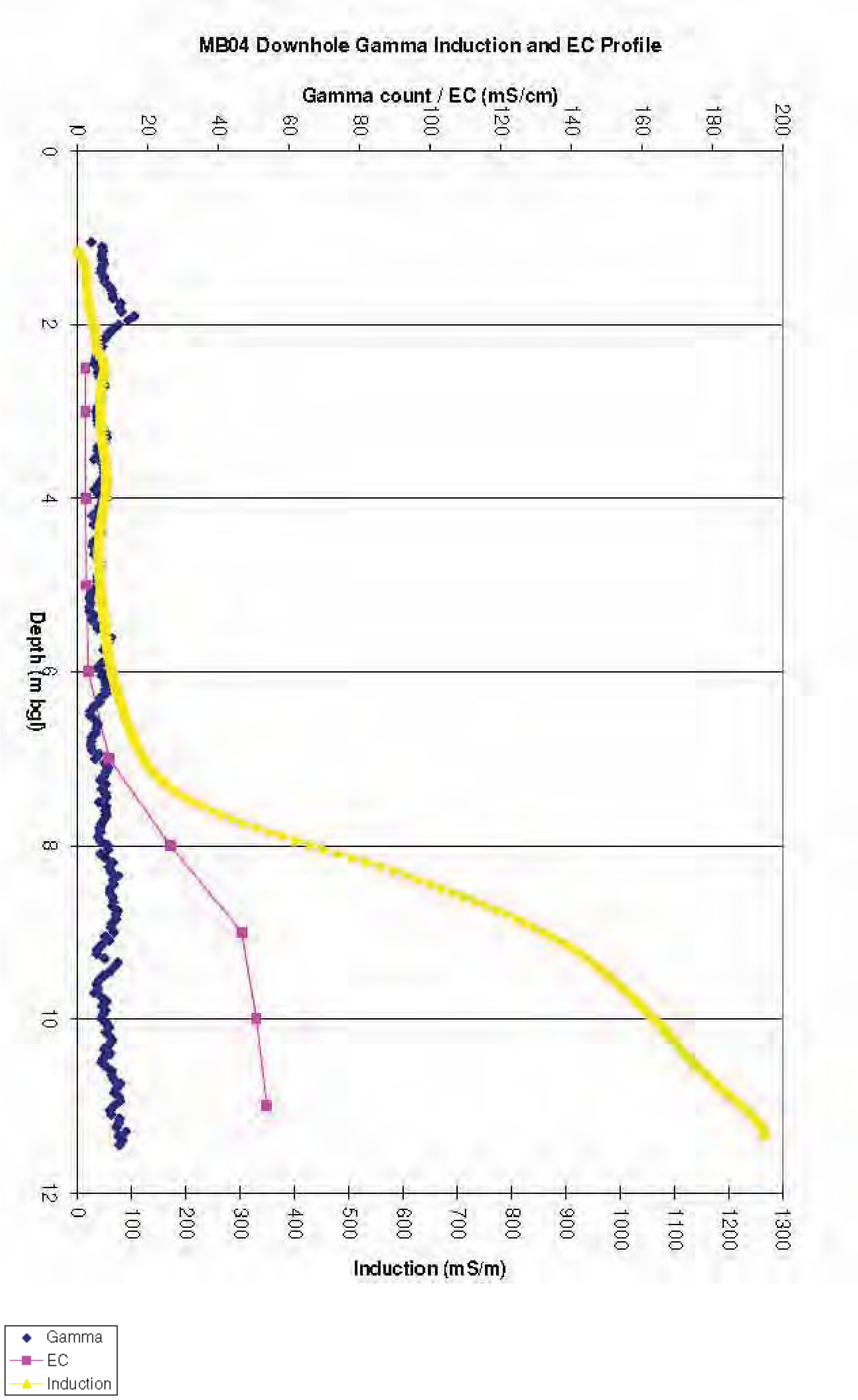
SWL: 2.16 mbgl

SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0 – 5	Safety Bay Sand	SAND Cream, moderately sorted, very angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
5 – 14	Safety Bay Sand	SAND Cream/grey, moderately-poorly sorted, very angular, shell rich sand.			100 mm UPVC PN9 Slotted casing (0-27 m)	EC; 0.88 mS/cm, TDS; 0.44 ppt, Temp; 26.2 °C, pH; 8.18 at 9 m EC; 0.80 mS/cm, TDS; 0.40 ppt, Temp; 24.3 °C, pH; 8.06 at 13 m
14 – 23	Safety Bay Sand	SANDY SILT Brown/grey, well sorted, fine silty sand. Contains some organic material.			Gravel Pack (1.6-3.2 mm)	EC; 1.34 mS/cm, TDS; 0.64 ppt, Temp; 28.7 °C, pH; 7.71 at 18 m EC; 1.83 mS/cm, TDS; 0.83 ppt, Temp; 28.3 °C, pH; 7.86 at 19 m EC; 3.16 mS/cm, TDS; 1.49 ppt, Temp; 28.6 °C, pH; 8.02 at 21 m EC; 5.05 mS/cm, TDS; 2.60 ppt, Temp; 27.1 °C, pH; 8.01 at 23 m
23 – 27	Tamala Limestone	SANDSTONE Grey, moderately sorted, sub rounded, cemented sandstone. Clasts contain approximately 70 % rounded to sub rounded quartz and minor amounts of shell fragments.			End cap (27 mbgl) EOH 27 m	EC; 5.56 mS/cm, TDS; 2.79 ppt, Temp; 26.2 °C, pH; 8.06 at 24 m EC; 5.65 mS/cm, TDS; 3.04 ppt, Temp; 25.8 °C, pH; 7.93 at 25 m EC; 6.28 mS/cm, TDS; 3.13 ppt, Temp; 27.3 °C, pH; 7.93 at 26 m EC; 13.60 mS/cm, TDS; 6.81 ppt, Temp; 27.3 °C, pH; 7.91 at 27 m



TD: 27 m
Notes:


MB04 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12
Induction (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB04

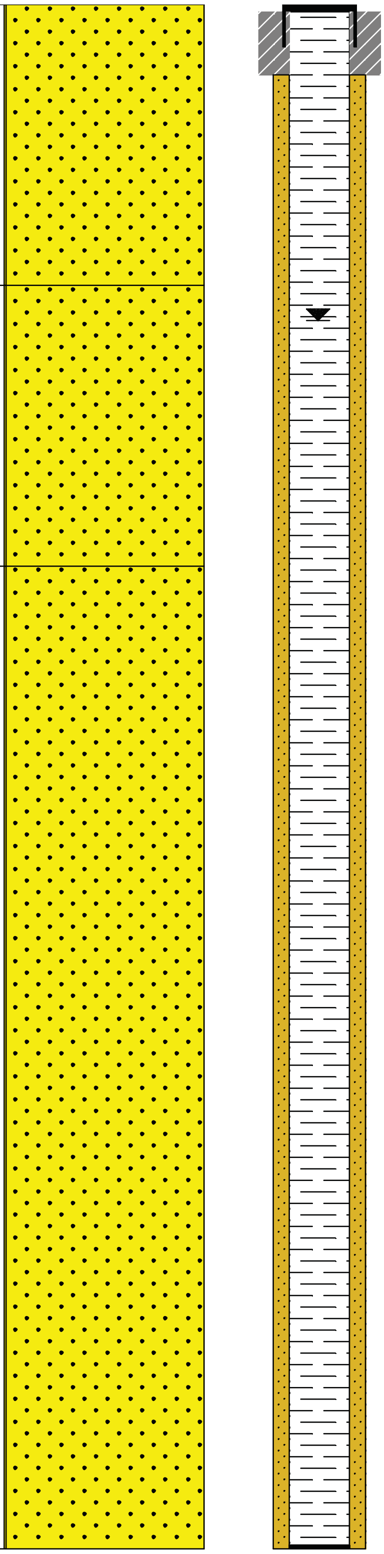
Client: Landcorp
Date Drilled: 15/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

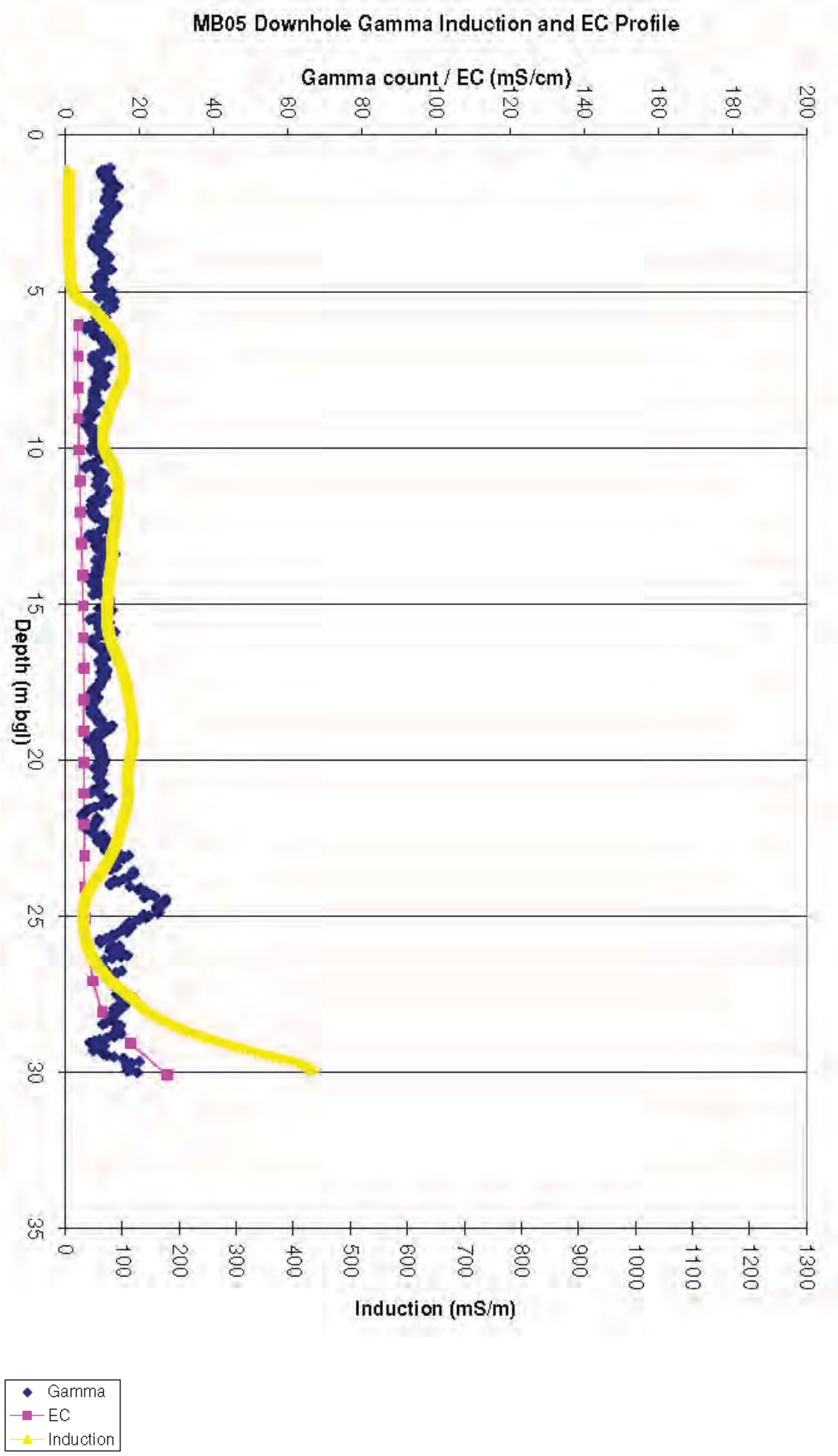
Easting: 378459
Northing: 6428261
Surface RL: 2.50 mAHD

HYDRAULIC DATA: **SWL:** 2.25 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Cream/grey, well sorted, fine grained, angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
		SAND Cream, moderately-poorly sorted, very angular, shell rich sand.				
5		SAND Grey, moderately-poorly sorted, very angular, shell rich sand.			100 mm UPVC PN9 Slotted casing (0-11 m) Gravel Pack (1.6-3.2 mm)	EC; 13.1 mS/cm, Temp; 28.7 °C at 9 m
10					End cap (11 mbgl) EOH 11 m	



TD: 11 m
Notes:


MB05 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
Depth (m bgl)
Induction (mS/m)
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB05

Client: Landcorp
Date Drilled: 09/04/2010
Logged By: Shawn Butland

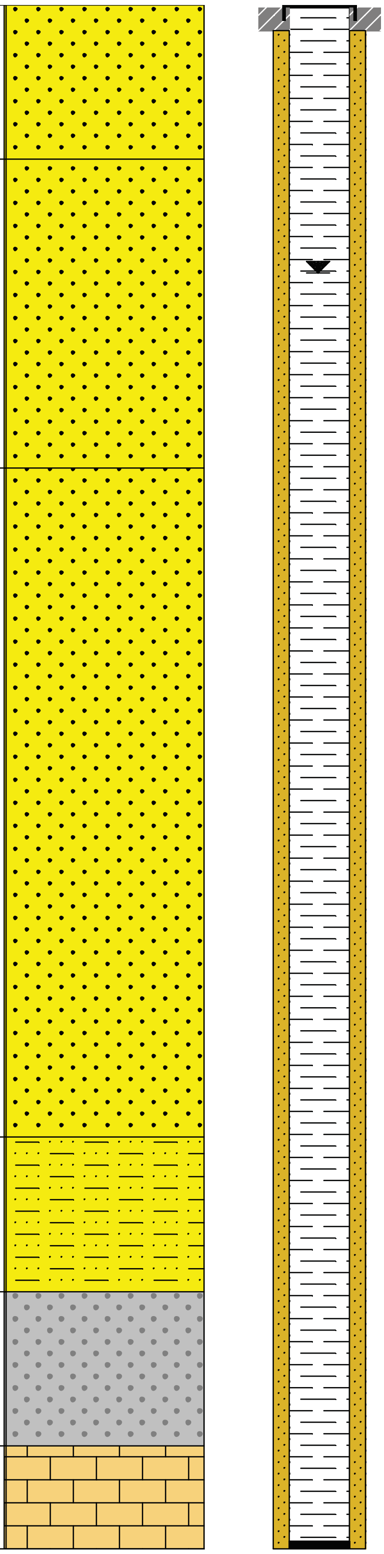
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378135
Northing: 6427452
Surface RL: 6.09 mAHD

HYDRAULIC DATA: **SWL:** 5.21 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description
0–3	Safety Bay Sand	SAND Cream, well sorted, very angular, shell rich sand.
3–9	Safety Bay Sand	SAND Cream/brown, moderately sorted, angular-sub angular, shell rich sand. Contains approximately 20 % sub rounded quartz.
9–22	Safety Bay Sand	SAND Dark grey, well-moderately sorted, angular, shell rich sand.
22–25	Safety Bay Sand	SANDY SILT Light grey, well sorted, fine grained silty sand.
25–28	Tamala Limestone	SANDSTONE Grey, poorly sorted, angular to sub angular cemented quartz rich sandstone. Clasts contain approximately 70 % quartz and 30 % shell fragments.
28–30	Tamala Limestone	LIMESTONE Light grey, poorly sorted, angular, shelly limestone. Contains some clasts of rounded quartz approximately 10 %.

Lithology / Well Construction



Well Details

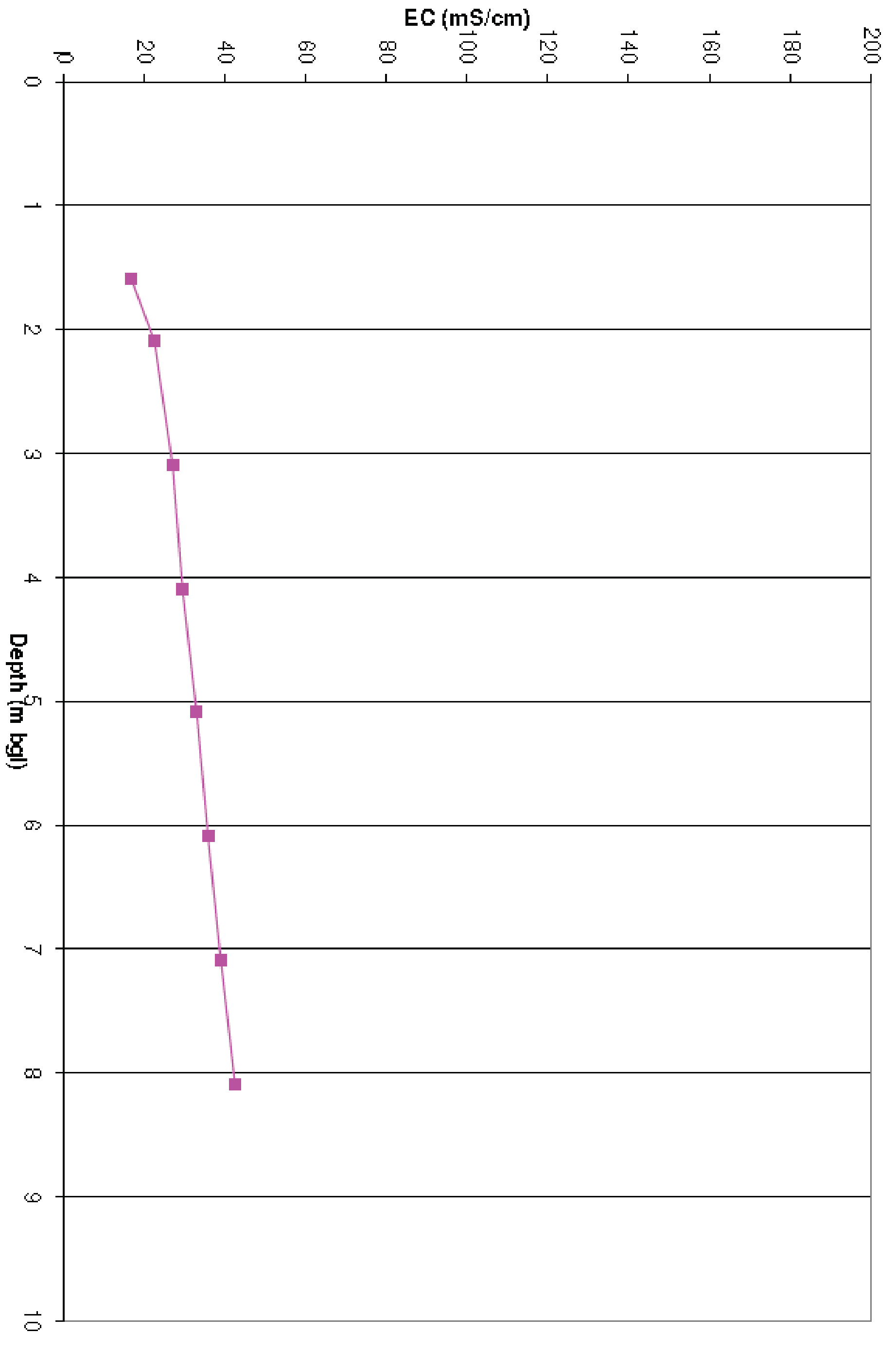
- Steel lockable cover
- Cement grout (0-0.5 m)
- 100 mm UPVC PN9 Slotted casing (0-30 m)
- Gravel Pack (1.6-3.2 mm)
- End cap (30 mbgl)
- EOH 30 m

Water Quality

- EC; 1.11 mS/cm, TDS; 0.47 ppt, Temp; 27.5 °C, pH; 8.34 at 13 m
- EC; 0.67 mS/cm, TDS; 0.38 ppt, Temp; 24.6 °C, pH; 8.48 at 15 m
- EC; 0.46 mS/cm, TDS; 0.19 ppt, Temp; 24.1 °C, pH; 8.53 at 17 m
- EC; 0.40 mS/cm, TDS; 0.20 ppt, Temp; 22.8 °C, pH; 8.45 at 19 m
- EC; 0.43 mS/cm, TDS; 0.22 ppt, Temp; 21.4 °C, pH; 8.47 at 20 m
- EC; 1.14 mS/cm, TDS; 0.58 ppt, Temp; 19.9 °C, pH; 8.15 at 26 m
- EC; 1.89 mS/cm, TDS; 0.96 ppt, Temp; 21.5 °C, pH; 8.06 at 27 m
- EC; 5.23 mS/cm, TDS; 2.68 ppt, Temp; 20.3 °C, pH; 7.93 at 28 m
- EC; 13.82 mS/cm, TDS; 7.13 ppt, Temp; 21.1 °C, pH; 7.73 at 29 m
- EC; 20+ mS/cm, TDS; 10+ ppt, Temp; 21.8 °C, pH; 7.68 at 30 m

TD: 30 m
Notes:

MB06 Downhole EC Profile



WELL COMPLETION DETAILS: MB06

Client: Landcorp
Date Drilled: 22/03/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

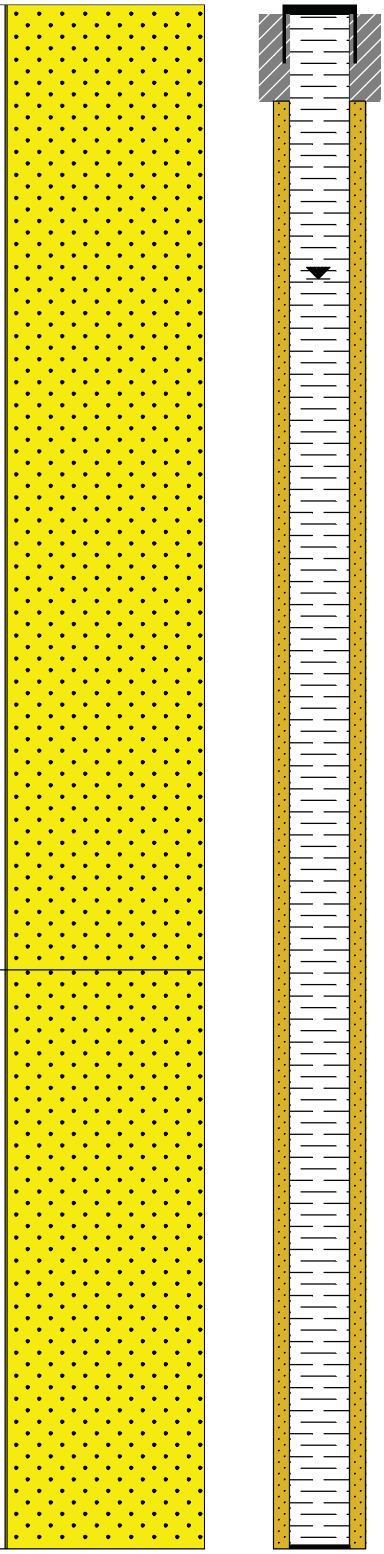
Easting: 377818
Northing: 6428338
Surface RL: 1.53 mAHD

MWH

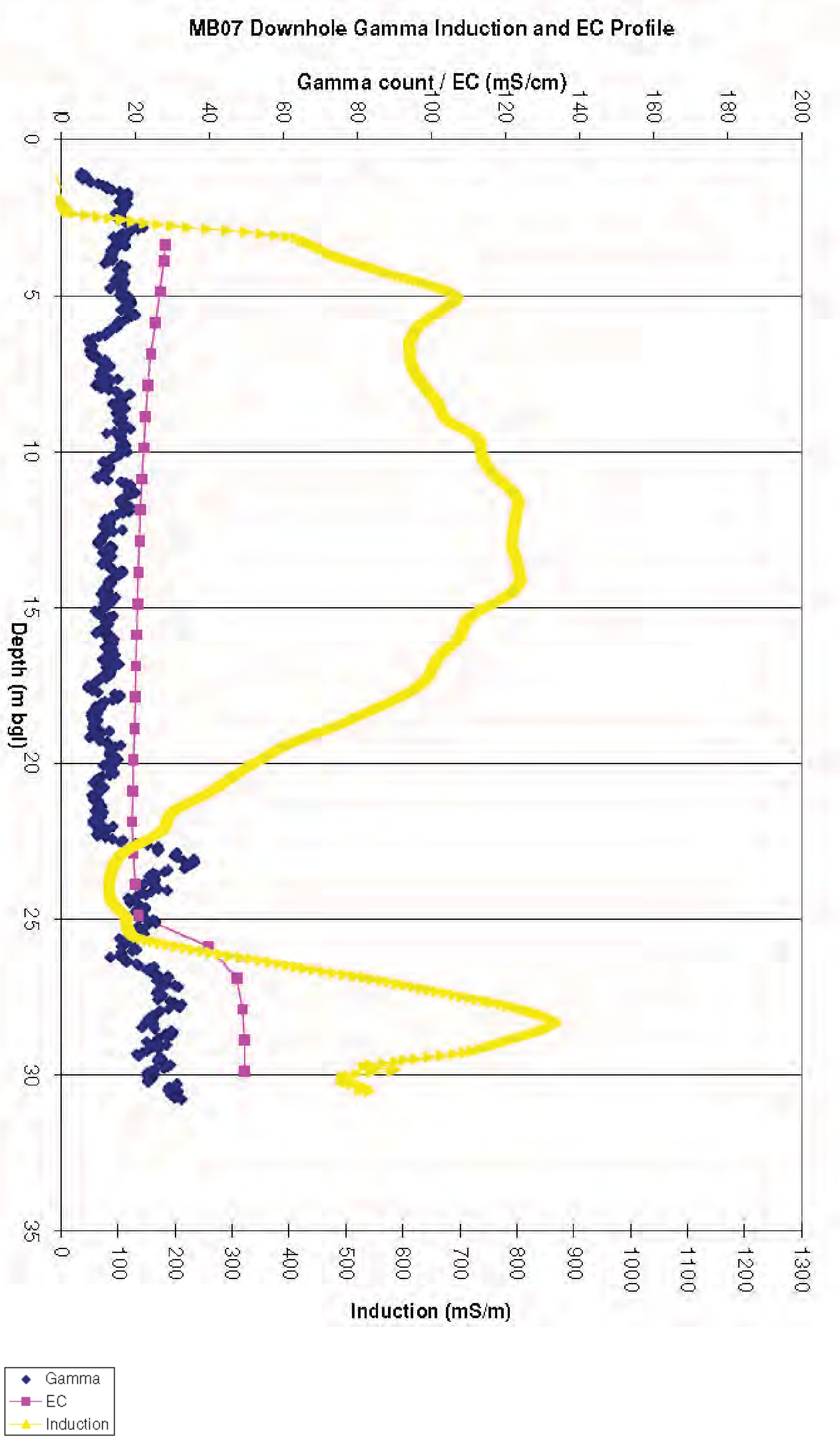
HYDRAULIC DATA:

SWL: 1.42 mbgl
SWL Date Collected: 24/03/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Grey/brown, moderately sorted, very angular, shell rich sand.			Steel lockable cover; Cement grout (0-0.5 m); 100 mm UPVC PN9 Slotted casing (0-8 m)	
5		SAND Grey, moderately sorted, very angular, shell rich sand. Contains minimal quartz grains <1 %.			Gravel Pack (1.6-3.2 mm); End cap (8 mbgl); EOH 8 m	**EC; 20 + mS/cm, TDS; 10 + ppt, Temp; 29.0 °C, pH; 8.04 at 9 m**



TD: 8 m
Notes:



MB07 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0 20 40 60 80 100 120 140 160 180 200
Depth (m bgl)
0 5 10 15 20 25 30 35
Induction (mS/m)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB07

Client: Landcorp
Date Drilled: 26/03/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378420
Northing: 6427873
Surface RL: 3.30 mAHD

MWH

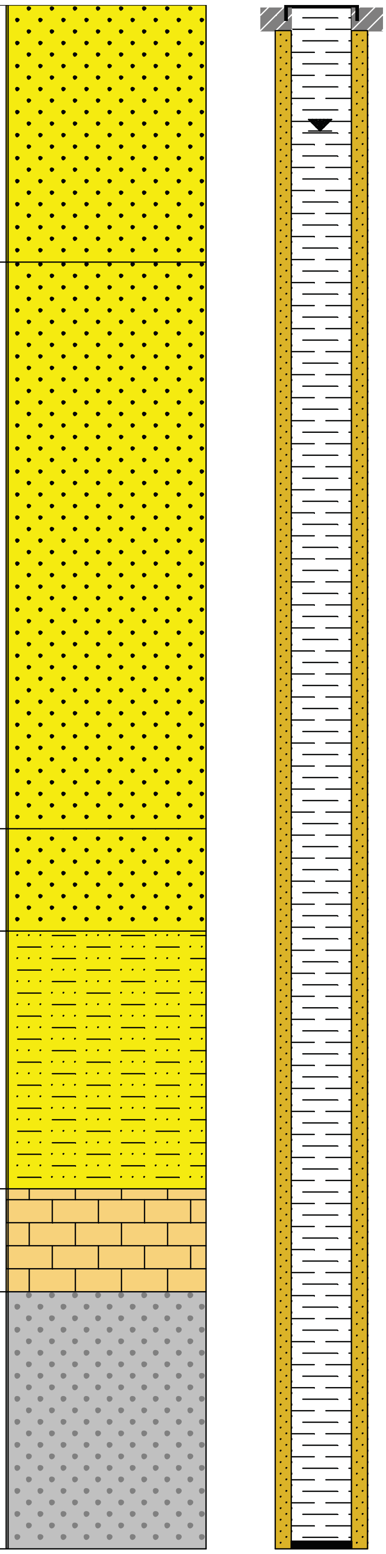
HYDRAULIC DATA:

SWL: 2.45 mbgl

SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description
0–5	Safety Bay Sand	SAND Cream, well sorted, very angular, shell rich sand.
5–16	Safety Bay Sand	SAND Light grey, moderately sorted, angular, shell rich sand.
16–18	Safety Bay Sand	SAND Dark grey, poorly sorted, angular-very angular, coarse grained, shell rich sand.
18–23	Safety Bay Sand	SANDY SILT Grey, well sorted, fine grained silty sand.
23–25	Tamala Limestone	LIMESTONE Grey, poorly sorted, very angular, shelly limestone. Contains some clasts of rounded quartz approximately 30 %.
25–30	Tamala Limestone	SANDSTONE Grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 70 % quartz and 30 % shell fragments.

Lithology / Well Construction



Well Details

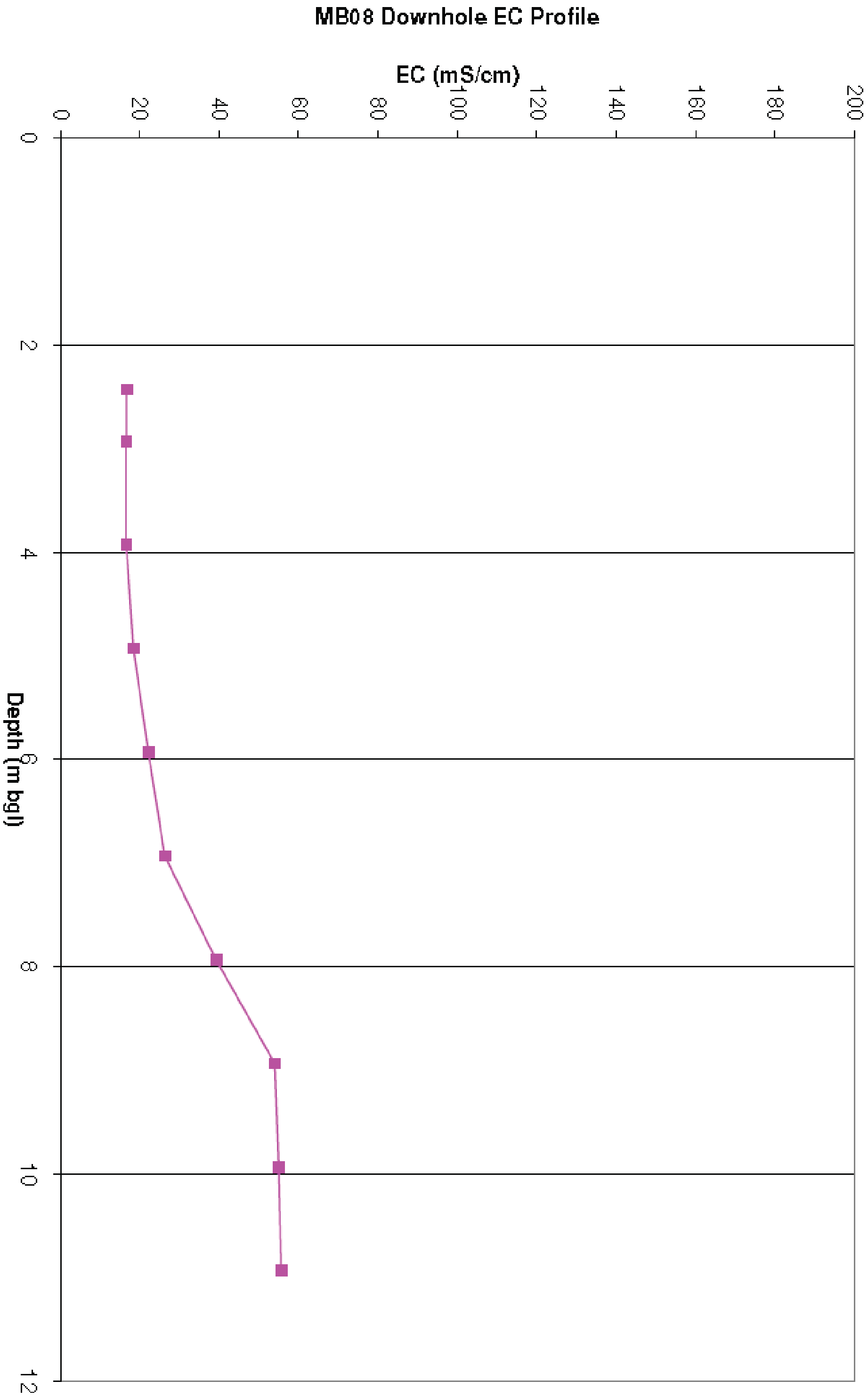
- Steel lockable cover
- Cement grout (0-0.5 m)
- 100 mm UPVC PN9 Slotted casing (0-30 m)
- Gravel Pack (1.6-3.2 mm)
- End cap (30 mbgl)
- EOH 30 m

Water Quality

- EC; 1.57 mS/cm, TDS; 0.92 ppt, Temp; 23.8 °C, pH; 8.05 at 9 m
- EC; 0.91 mS/cm, TDS; 0.47 ppt, Temp; 23.0 °C, pH; 8.04 at 14 m
- EC; 2.12 mS/cm, TDS; 0.98 ppt, Temp; 23.2 °C, pH; 8.05 at 16 m
- EC; 0.82 mS/cm, TDS; 0.44 ppt, Temp; 23.0 °C, pH; 8.12 at 18 m
- EC; 1.02 mS/cm, TDS; 0.51 ppt, Temp; 22.8 °C, pH; 8.15 at 22 m
- EC; 1.62 mS/cm, TDS; 1.05 ppt, Temp; 23.5 °C, pH; 8.06 at 24 m
- EC; 8.94 mS/cm, TDS; 4.48 ppt, Temp; 22.7 °C, pH; 7.90 at 27 m
- EC; 20+ mS/cm, TDS; 10+ ppt, Temp; 22.9 °C, pH; 7.65 at 28 m

TD: 30 m

Notes: Has data logger installed in bore



MB08 Downhole EC Profile
EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12

WELL COMPLETION DETAILS: MB08

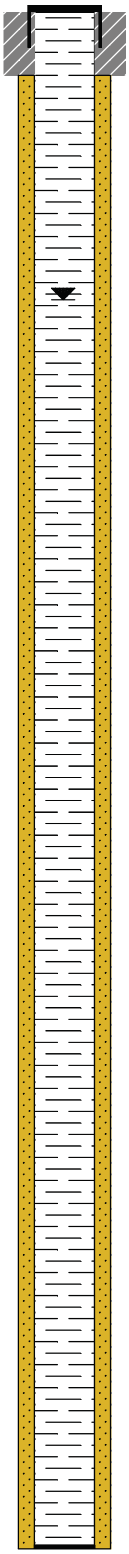
Client: Landcorp
Date Drilled: 15/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

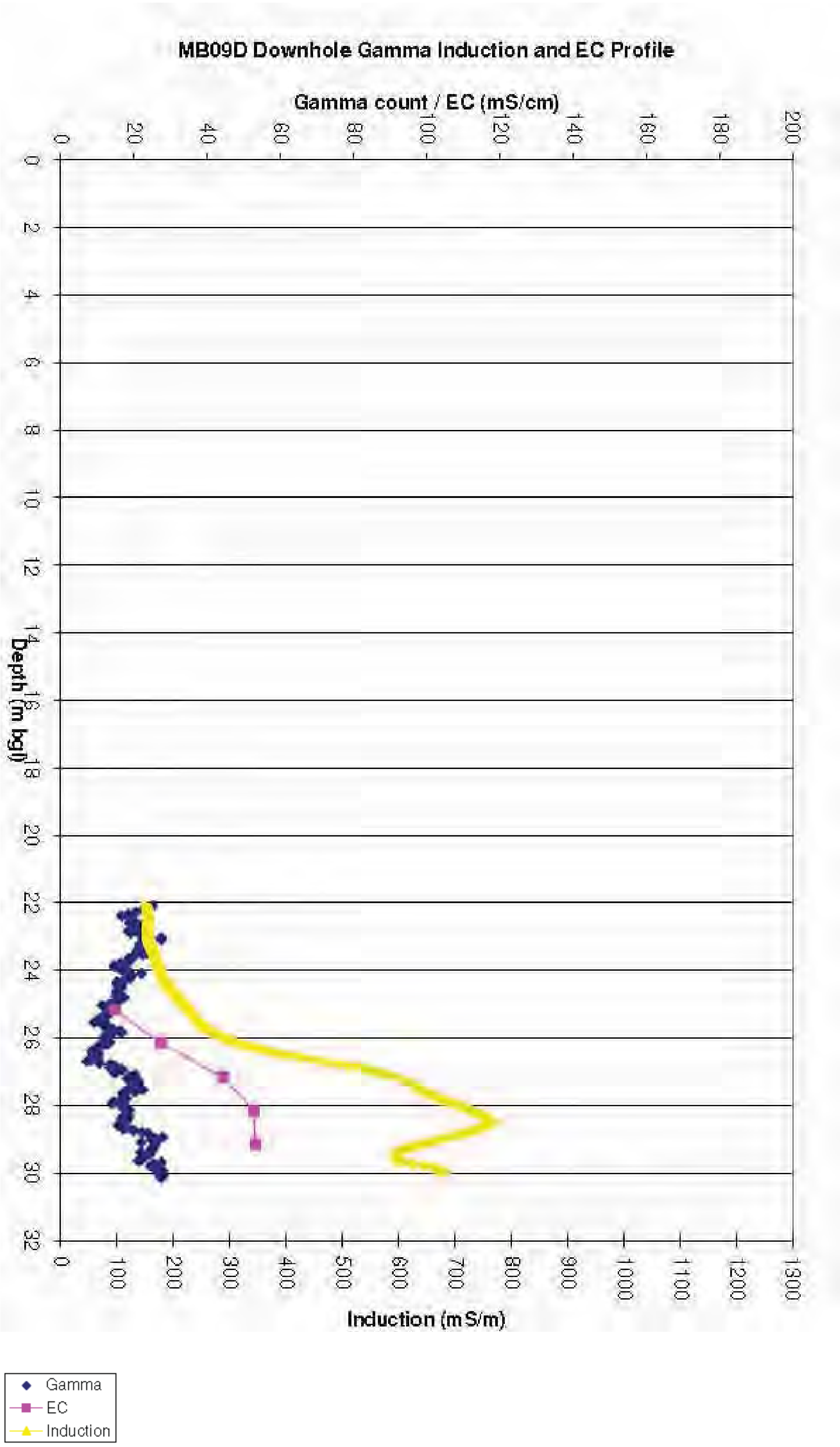
Easting: 378198
Northing: 6428232
Surface RL: 2.38 mAHD

HYDRAULIC DATA:
SWL: 2.10 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Cream, moderately sorted, very angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
		SAND Grey, moderately sorted, angular, shell rich sand.				
5					100 mm UPVC PN9 Slotted casing (0-11 m)	
					Gravel Pack (1.6-3.2 mm)	EC; 22.0 mS/cm, Temp; 22.1 °C at 9 m
10					End cap (11 mbgl) EOH 11 m	



TD: 11 m
Notes: Has data logger installed down bore.



MB09D Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
Induction (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB09D

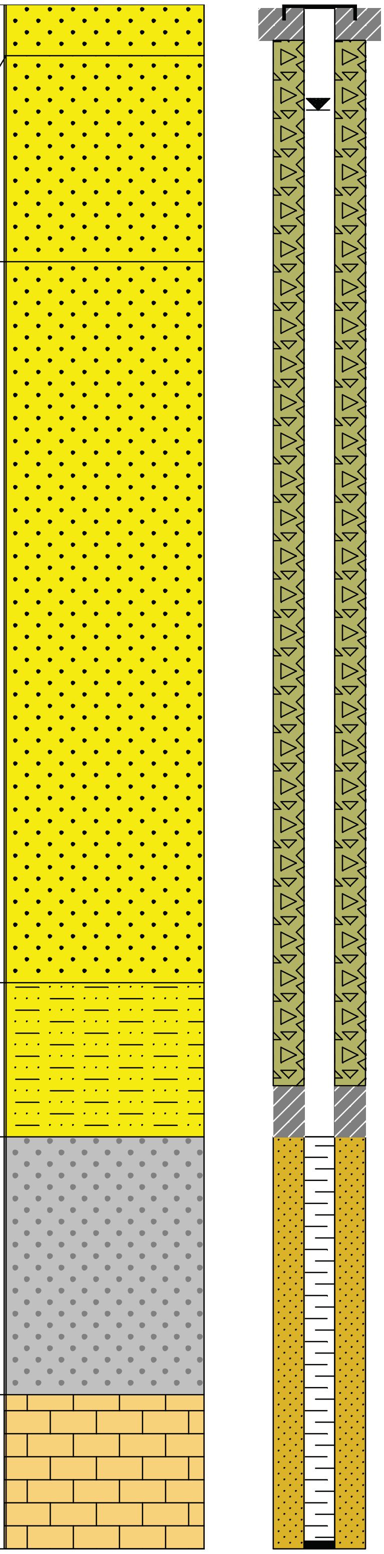
Client: Landcorp
Date Drilled: 12-14/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378299
Northing: 6428092
Surface RL: 2.80 mAHD

HYDRAULIC DATA: **SWL:** 2.05 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description
0–1	Safety Bay Sand	SAND Cream, well sorted, very angular, shell rich sand.
1–5	Safety Bay Sand	SAND Cream, poorly sorted, very angular, coarse, shell rich sand.
5–19	Safety Bay Sand	SAND Grey, moderately sorted, angular, shell rich sand.
19–22	Safety Bay Sand	SANDY SILT Grey, well sorted, fine grained silty sand.
22–27	Tamala Limestone	SANDSTONE Grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 90 % quartz and 10 % shell fragments.
27–30	Tamala Limestone	LIMESTONE Cream, poorly sorted, very angular, shelly limestone. Contains some clasts of rounded quartz approximately 15 %.



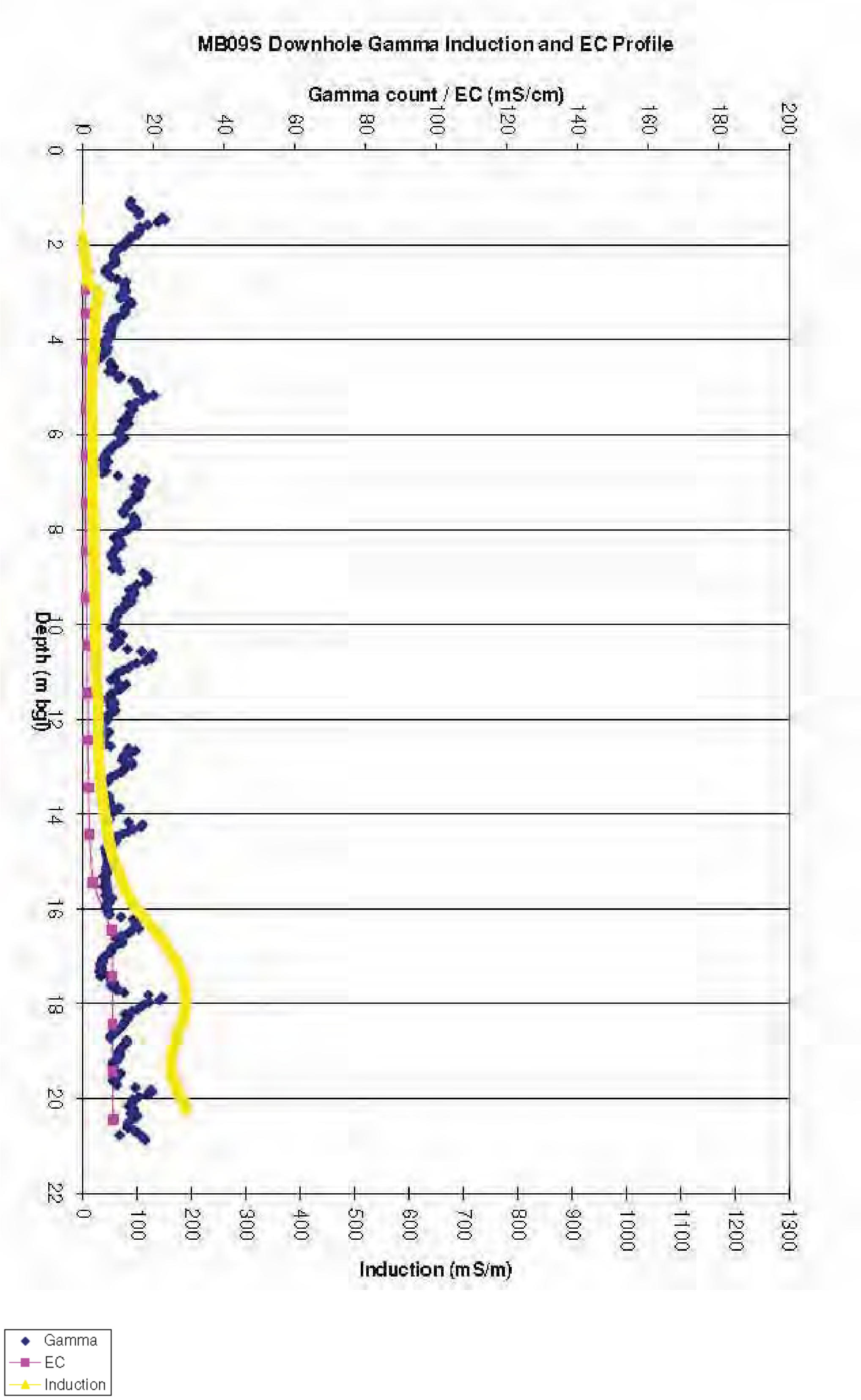
Well Details

- Steel lockable cover
- Cement grout (0-0.5 m)
- 50 mm UPVC PN9 Blank casing (0-22 m)
- Cement grout (21-22 m)
- 50 mm UPVC PN9 Slotted casing (22-30 m)
- Gravel Pack (1.6-3.2 mm)
- End cap (30 mbgl)
- EOH 30 m

Water Quality

- **EC; 0.63 mS/cm, TDS; 0.42 ppt, Temp; 17.1 °C, pH; 8.37 at 9 m**
- **EC; 0.42 mS/cm, TDS; 0.21 ppt, Temp; 17.1 °C, pH; 8.50 at 12 m**
- **EC; 0.69 mS/cm, TDS; 0.35 ppt, Temp; 17.7 °C, pH; 8.33 at 14 m**
- **EC; 1.28 mS/cm, TDS; 0.59 ppt, Temp; 17.4 °C, pH; 8.13 at 16 m**
- **EC; 2.47 mS/cm, TDS; 1.24 ppt, Temp; 17.7 °C, pH; 8.07 at 17 m**
- **EC; 3.910 mS/cm, TDS; 2.01 ppt, Temp; 18.1 °C, pH; 8.14 at 19 m**
- **EC; 7.10 mS/cm, TDS; 2.98 ppt, Temp; 16.8 °C, pH; 7.96 at 23 m**
- **EC; 10.15 mS/cm, TDS; 5.05 ppt, Temp; 17.6 °C, pH; 7.90 at 24 m**
- **EC; 12.48 mS/cm, TDS; 6.31 ppt, Temp; 17.7 °C, pH; 7.82 at 25 m**
- **EC; 17.98 mS/cm, TDS; 9.13 ppt, Temp; 17.1 °C, pH; 7.72 at 26 m**
- **EC; 20+ mS/cm, TDS; 10+ ppt, Temp; 17.3 °C, pH; 7.78 at 27 m**

TD: 30 m
Notes: Cased with 50 mm uPVC



MB09S Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0 20 40 60 80 100 120 140 160 180 200
Depth (m bgl)
0 2 4 6 8 10 12 14 16 18 20 22
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
Induction (mS/m)
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB09S

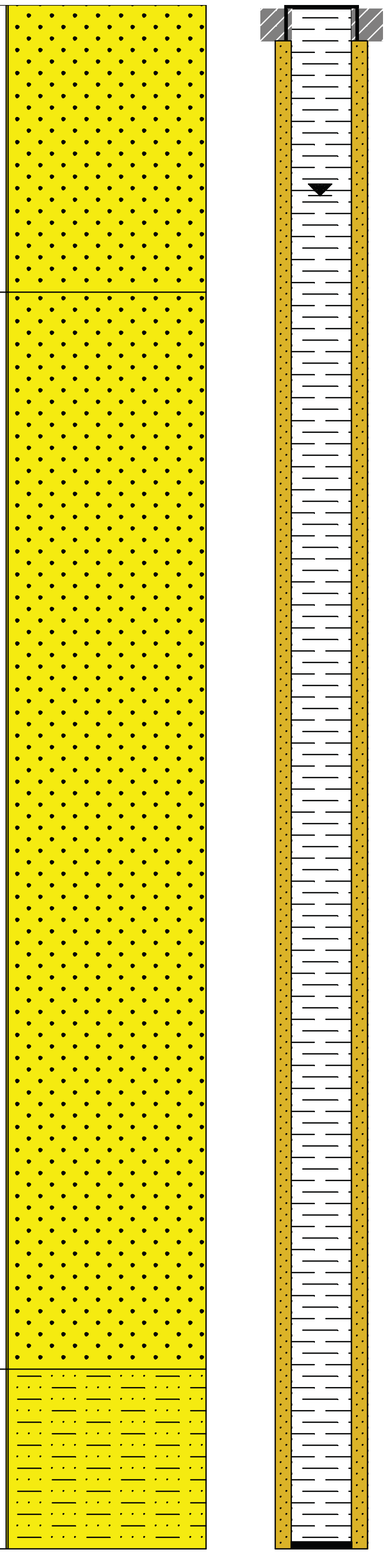
Client: Landcorp
Date Drilled: 01-06/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378298
Northing: 6428082
Surface RL: 2.83 mAHD

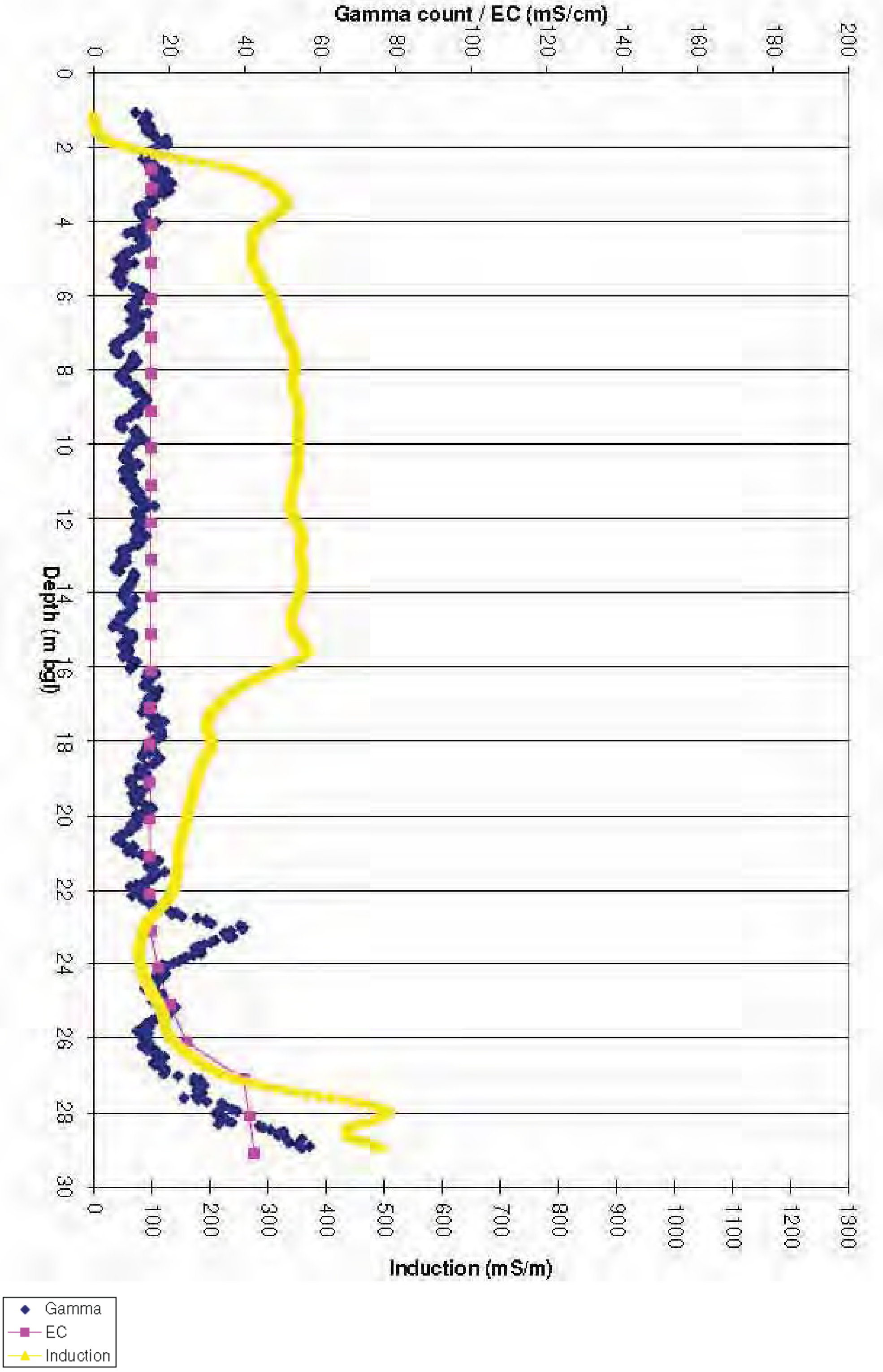
HYDRAULIC DATA: **SWL:** 2.65 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Cream/brown, moderately sorted, angular to very angular, shell rich sand.			Steel lockable cover	
					Cement grout (0-0.5 m)	
4		SAND Grey, well sorted, angular, shell rich sand.				
5						
						EC; 0.87 mS/cm, TDS; 0.37 ppt, Temp; 43.5 °C, pH; 8.26 at 10 m
10					100 mm UPVC PN9 Slotted casing (0-21.5 m)	EC; 0.34 mS/cm, TDS; 0.15 ppt, Temp; 38.7 °C, pH; 8.13 at 12 m
						EC; 0.27 mS/cm, TDS; 0.19 ppt, Temp; 37.0 °C, pH; 8.25 at 13 m
15					Gravel Pack (1.6-3.2 mm)	EC; 0.65 mS/cm, TDS; 0.32 ppt, Temp; 32.4 °C, pH; 8.12 at 15 m
						EC; 0.95 mS/cm, TDS; 0.52 ppt, Temp; 30.1 °C, pH; 8.06 at 16 m
						EC; 1.42 mS/cm, TDS; 0.72 ppt, Temp; 28.8 °C, pH; 8.10 at 18 m
19.5		SANDY SILT Grey, well sorted, silty sand.				
20						EC; 2.54 mS/cm, TDS; 1.27 ppt, Temp; 28.6 °C, pH; 8.13 at 20 m
					End cap (21.5 mbgl)	



TD: 21.5 m
Notes: Data logger installed in this bore.

MB010 Downhole Gamma Induction and EC Profile



WELL COMPLETION DETAILS: MB10

Client: Landcorp
Date Drilled: 30-31/03/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378587
Northing: 6427907
Surface RL: 2.95 mAHD

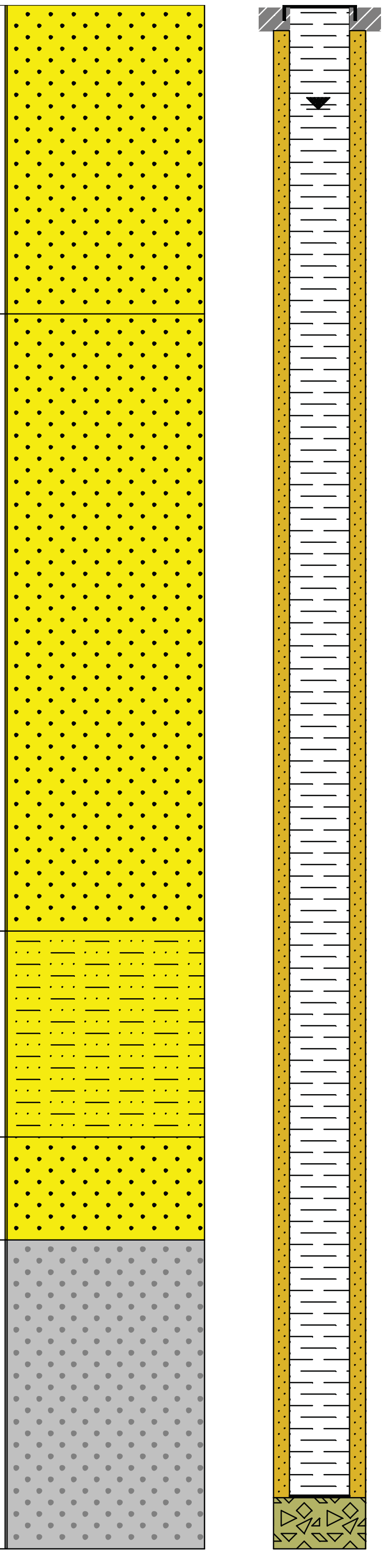
MWH

HYDRAULIC DATA:

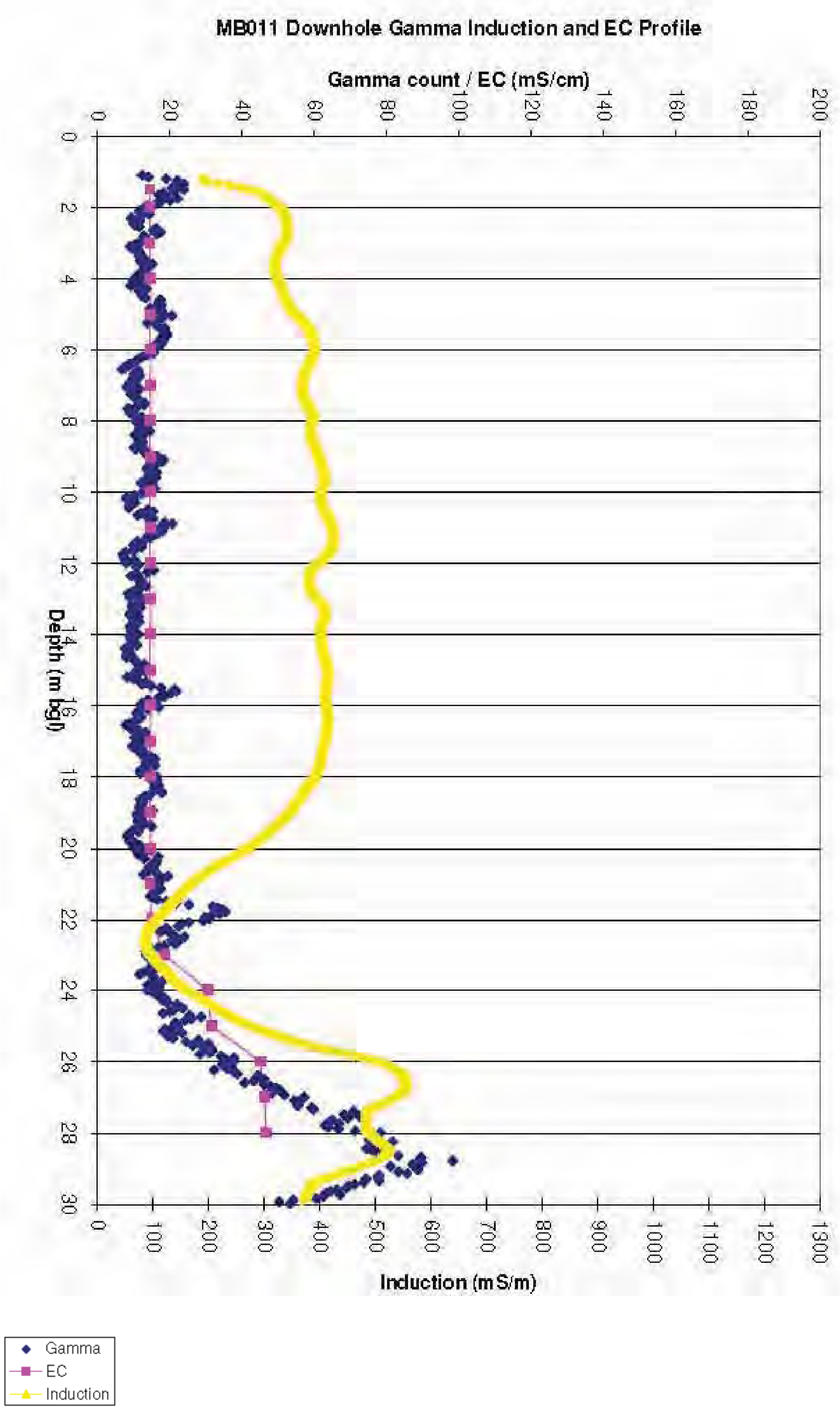
SWL: 2.02 mbgl

SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0–6	Safety Bay Sand	SAND Cream, moderately sorted, very angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
6–18	Safety Bay Sand	SAND Grey, poorly sorted, very angular, coarse, shell rich sand. Contains some organic material.			100 mm UPVC PN9 Slotted casing (0-29 m)	EC; 3.20 mS/cm, TDS; 0.93 ppt, Temp; 31.2 °C, pH; 8.03 at 10 m EC; 1.98 mS/cm, TDS; 0.98 ppt, Temp; 30.7 °C, pH; 8.09 at 11 m EC; 2.32 mS/cm, TDS; 1.17 ppt, Temp; 28.5 °C, pH; 8.22 at 13 m EC; 2.54 mS/cm, TDS; 1.23 ppt, Temp; 29.1 °C, pH; 8.20 at 15 m
18–22	Safety Bay Sand	SANDY SILT Brown/grey, moderately sorted, sandy silt. Contains some larger shell material and organics.			Gravel Pack (1.6-3.2 mm)	EC; 2.38 mS/cm, TDS; 1.05 ppt, Temp; 38.4 °C, pH; 7.96 at 21 m
22–24	Safety Bay Sand	SAND Grey, moderately sorted, very angular, shell rich sand. Contains approximately 5 % sub rounded quartz grains.				EC; 2.89 mS/cm, TDS; 1.41 ppt, Temp; 32.2 °C, pH; 8.01 at 23 m
24–30	Tamala Limestone	SANDSTONE Light grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 85 % quartz and 15 % shell fragments. Increasing in shell content towards the base of the hole.			End cap (29 mbgl) EOH 29 m	EC; 4.13 mS/cm, TDS; 1.99 ppt, Temp; 26.0 °C, pH; 8.11 at 25 m EC; 5.64 mS/cm, TDS; 2.90 ppt, Temp; 25.2 °C, pH; 7.98 at 27 m EC; 8.32 mS/cm, TDS; 4.40 ppt, Temp; 24.4 °C, pH; 7.88 at 28 m



TD: 30 m
Notes:


MB011 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Induction (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB11

Client: Landcorp
Date Drilled: 23-24/03/2010
Logged By: Shawn Butland

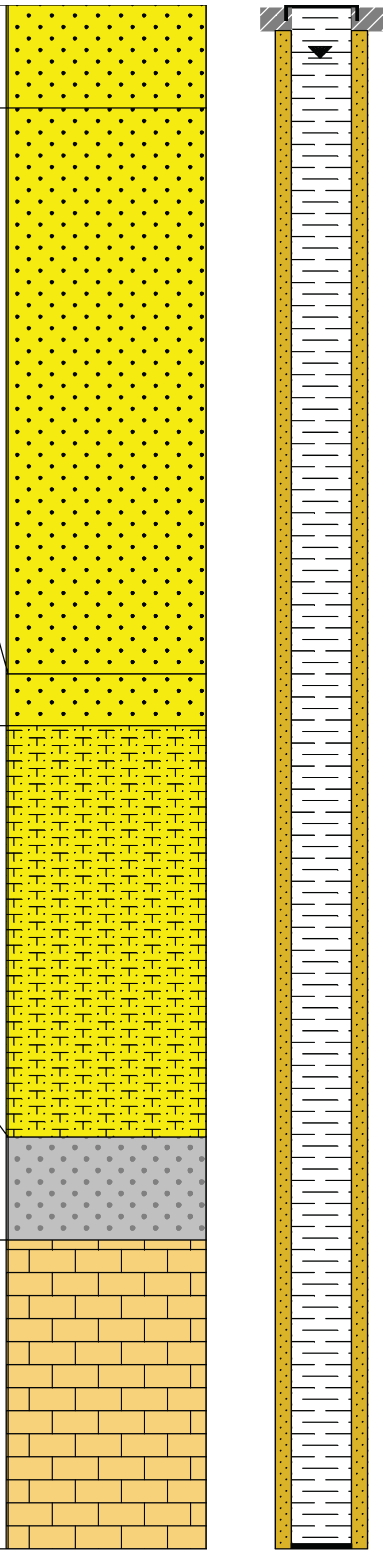
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378555
Northing: 6427796
Surface RL: 1.86 mAHD

HYDRAULIC DATA:
SWL: 1.03 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description
0	Safety Bay Sand	SAND Light brown, moderately sorted, angular, shell rich sand.
	Safety Bay Sand	SAND Dark grey, poorly sorted, very angular, coarse, shell rich sand.
	Safety Bay Sand	SAND Brown/dark grey, poorly sorted, vary angular-angular, shell rich sand. Contains some organics material.
	Safety Bay Sand	SILTY SAND Brown/grey, moderately sorted, fine grained silty sand. Contains brocken shells as well as some organic material.
	Tamala Limestone	SANDSTONE Light grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 60 % quartz and 40 % shell fragments.
30	Tamala Limestone	LIMESTONE Orange/brown, poorly sorted, angular, shell rich limestone. Contains minimal amounts of rounded quartz.

Lithology / Well Construction



Depth scale (mbgl): 0, 5, 10, 15, 20, 25, 30

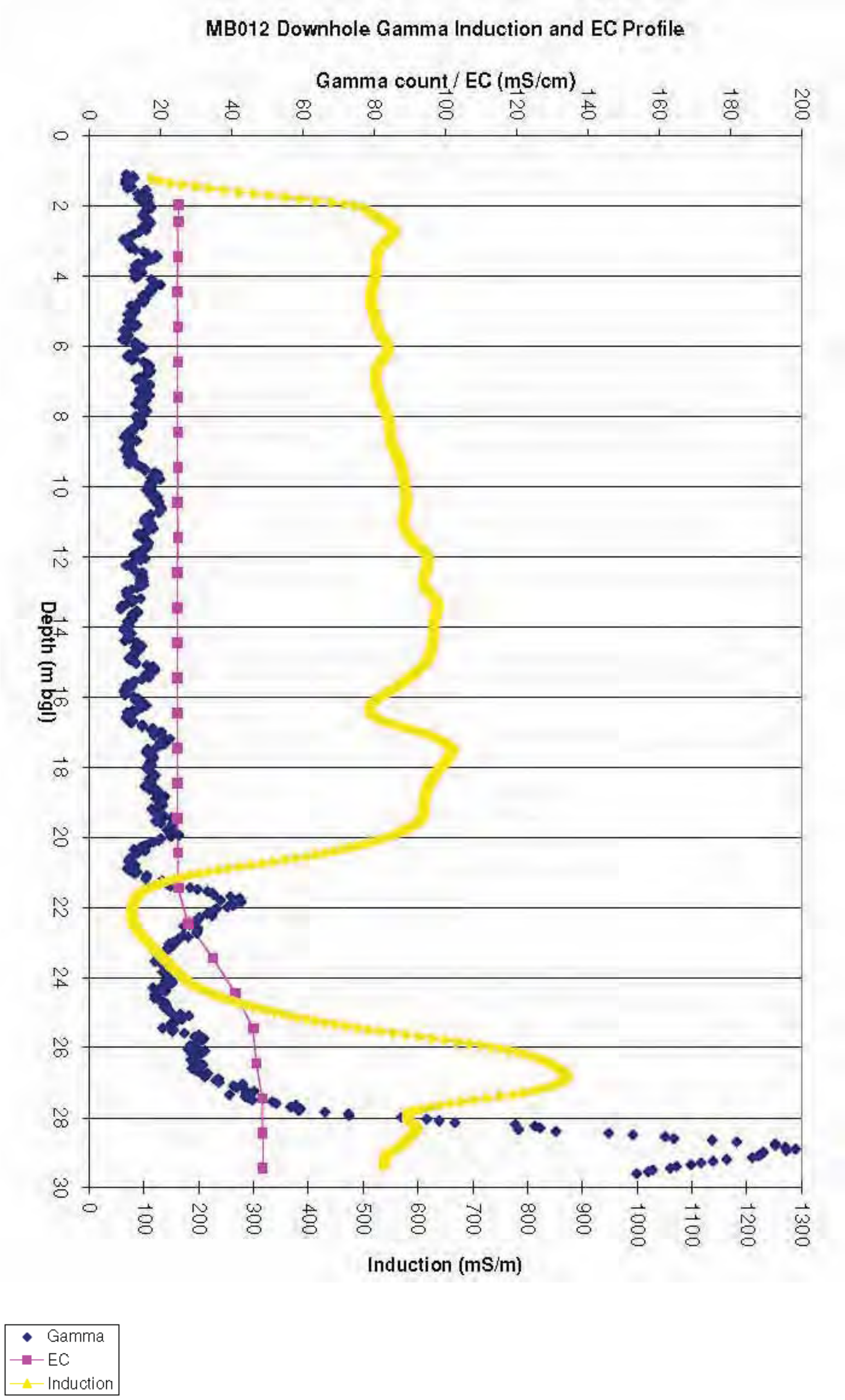
Well Details

- Steel lockable cover
- Cement grout (0-0.5 m)
- 100 mm UPVC PN9 Slotted casing (0-30 m)
- Gravel Pack (1.6-3.2 mm)
- End cap (30 mbgl)
- EOH 30 m

Water Quality

- **EC; 2.26 mS/cm, Temp; 23.4 °C, at 9 m**
- **EC; 2.32 mS/cm, TDS; 1.14 ppt, Temp; 23.3 °C, pH; 8.68 at 12 m**
- **EC; 2.45 mS/cm, TDS; 1.27 ppt, Temp; 23.0 °C, pH; 8.48 at 13 m**
- **EC; 3.30 mS/cm, TDS; 1.60 ppt, Temp; 23.1 °C, pH; 7.90 at 23 m**
- **EC; 3.54 mS/cm, TDS; 1.74 ppt, Temp; 22.9 °C, pH; 7.91 at 24 m**
- **EC; 5.50 mS/cm, TDS; 2.79 ppt, Temp; 29.9 °C, pH; 7.75 at 25 m**
- **EC; 7.76 mS/cm, TDS; 3.89 ppt, Temp; 24.7 °C, pH; 7.71 at 26 m**
- **EC; 12.62 mS/cm, TDS; 6.34 ppt, Temp; 24.8 °C, pH; 7.61 at 27 m**
- **EC; 20+ mS/cm, TDS; 10+ ppt, Temp; 24.6 °C, pH; 7.19 at 28 m**

TD: 30 m
Notes:


MB012 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Induction (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB12

Client: Landcorp
Date Drilled: 25/03/2010
Logged By: Shawn Butland

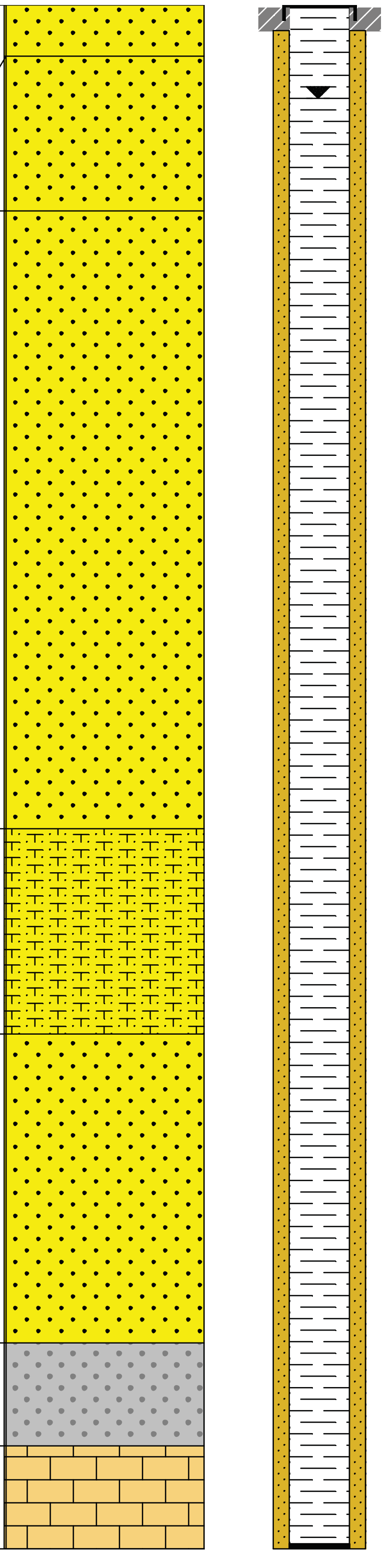
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378462
Northing: 6427723
Surface RL: 2.00 mAHD

HYDRAULIC DATA: **SWL:** 1.81 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description
0 – 1.4	Safety Bay Sand	SAND Light brown, moderately sorted, angular, shell rich sand.
1.4 – 4	Safety Bay Sand	SAND Light grey, poorly sorted, angular, coarse, shell rich sand. Contains minor amounts of sub rounded to rounded quartz grains.
4 – 16	Safety Bay Sand	SAND Grey, moderately sorted, very angular-angular, shell rich sand.
16 – 20	Safety Bay Sand	SILTY SAND Brown/grey, well sorted, fine grained silty sand.
20 – 26	Safety Bay Sand	SAND Grey, moderately sorted, sub rounded, coarse grained, quartz rich sand.
26 – 28	Tamala Limestone	SANDSTONE Light grey, poorly sorted, sub rounded, quartz rich sandstone.
28 – 30	Tamala Limestone	LIMESTONE Light brown, poorly sorted, angular to sub angular, shell rich limestone. Contains approximately 2% rounded quartz.

Lithology / **Well Construction**



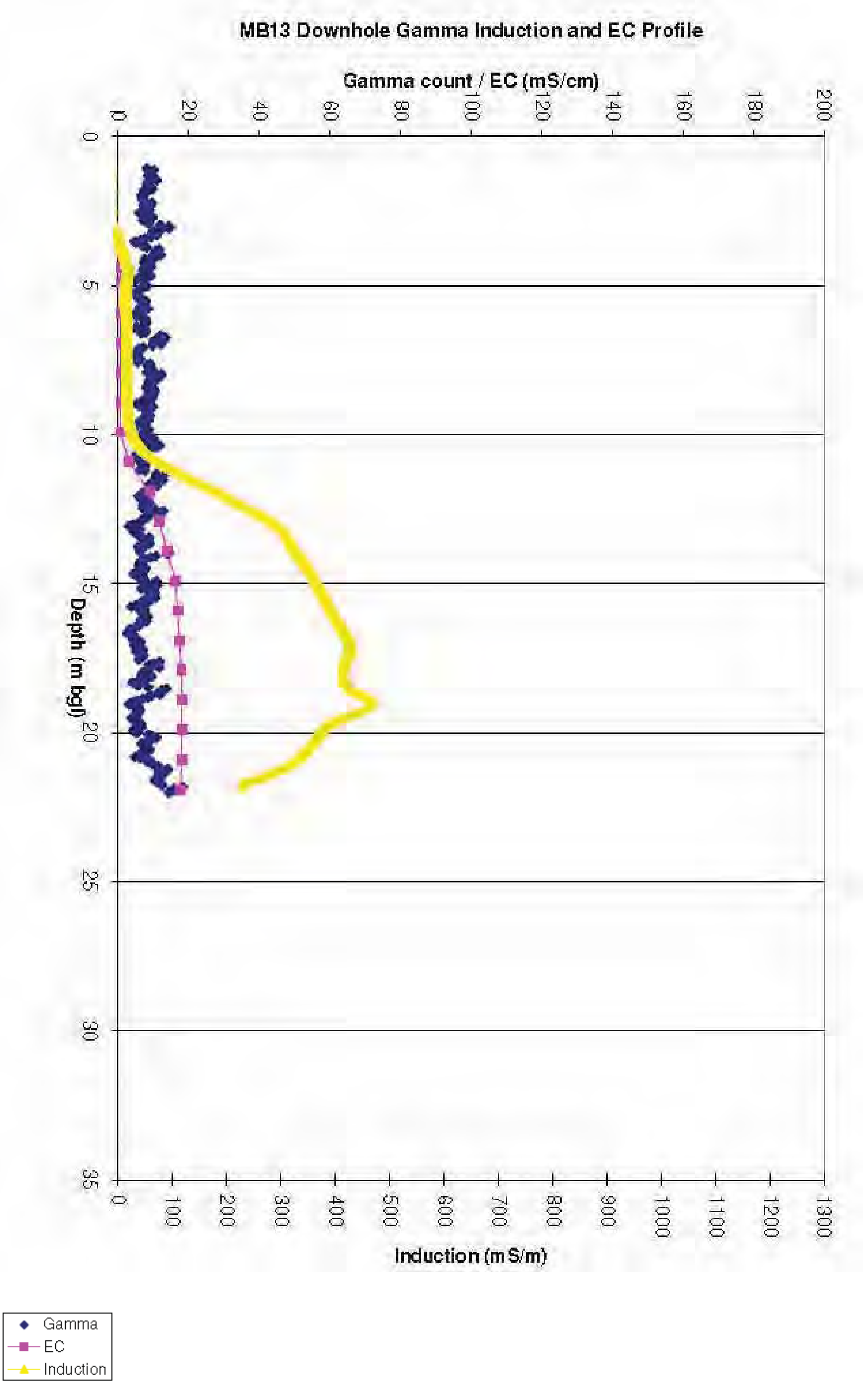
Well Details

- Steel lockable cover
- Cement grout (0-0.5 m)
- 100 mm UPVC PN9 Slotted casing (0-30 m)
- Gravel Pack (1.6-3.2 mm)
- End cap (30 mbgl)
- EOH 30 m

Water Quality

- **EC; 1.32 mS/cm, TDS; 0.65 ppt, Temp; 22.8 °C, pH; 8.04 at 6 m**
- **EC; 0.57 mS/cm, TDS; 0.37 ppt, Temp; 22.5 °C, pH; 8.29 at 10 m**
- **EC; 0.61 mS/cm, TDS; 0.31 ppt, Temp; 21.9 °C, pH; 8.21 at 14 m**
- **EC; 2.31 mS/cm, TDS; 1.20 ppt, Temp; 25.2 °C, pH; 8.08 at 21 m**
- **EC; 3.06 mS/cm, TDS; 1.54 ppt, Temp; 30.8 °C, pH; 7.93 at 24 m**
- **EC; 4.94 mS/cm, TDS; 2.34 ppt, Temp; 30.8 °C, pH; 7.93 at 25 m**
- **EC; 7.17 mS/cm, TDS; 2.34 ppt, Temp; 28.7 °C, pH; 7.79 at 26 m**
- **EC; 19.13 mS/cm, TDS; 9.40 ppt, Temp; 28.1 °C, pH; 7.64 at 27 m**
- **EC; 20 + mS/cm, TDS; 10+ ppt, Temp; 28.2 °C, pH; 7.63 at 28 m**

TD: 30 m
Notes: Data logger installed in this bore.


MB13 Downhole Gamma Induction and EC Profile
Gamma count / EC (mS/cm)
0 20 40 60 80 100 120 140 160 180 200
Depth (m bgl)
0 5 10 15 20 25 30 35
Induction (mS/m)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB13

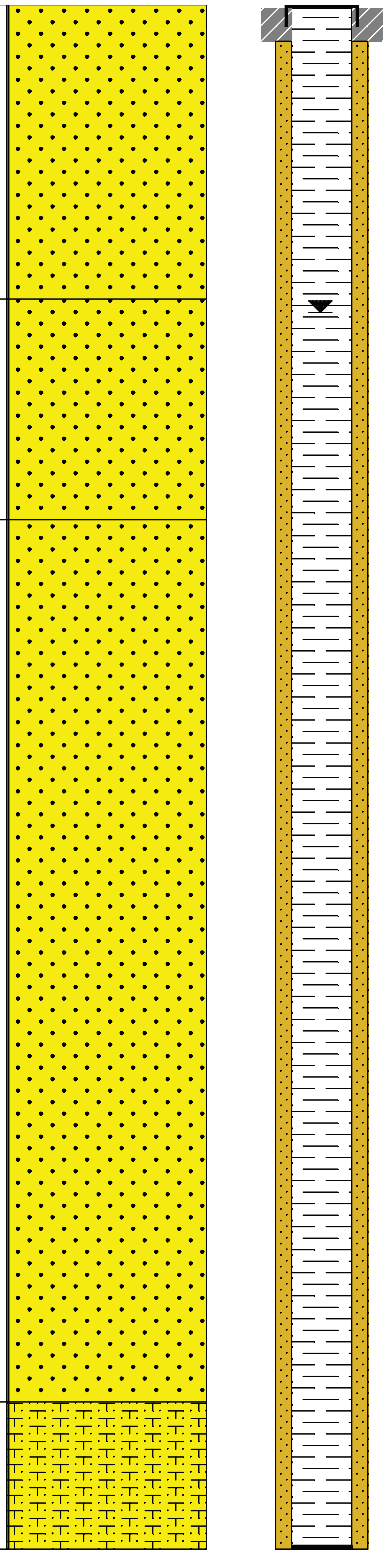
Client: Landcorp
Date Drilled: 08/04/2010
Logged By: Shawn Butland

Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378079
Northing: 6427936
Surface RL: 4.35 mAHD

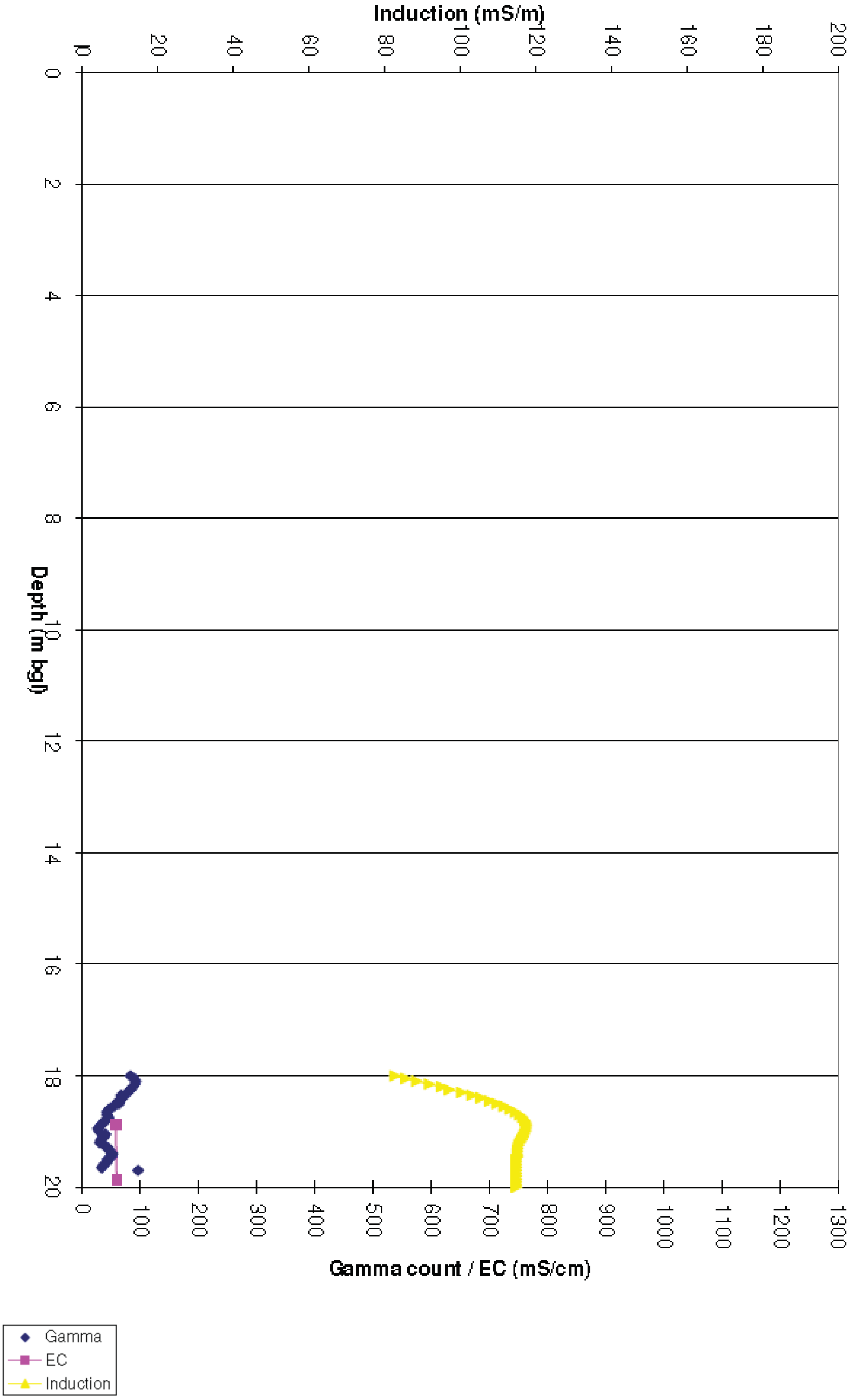
HYDRAULIC DATA: **SWL:** 4.18 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Light brown/ cream, well sorted, angular to sub angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
5		SAND Light brown/ cream, moderately sorted, angular to very angular, shell rich sand. Contains some large shell fragments up to 10 mm in size.				EC; 2.82 mS/cm, TDS; 1.19 ppt, Temp; 36.7 °C, pH; 7.89 at 13 m EC; 3.11 mS/cm, TDS; 1.73 ppt, Temp; 34.4 °C, pH; 7.79 at 14 m
10		SAND Dark grey, moderately sorted, angular, shell rich sand.			100 mm UPVC PN9 Slotted casing (0-21 m)	EC; 3.75 mS/cm, TDS; 2.06 ppt, Temp; 29.6 °C, pH; 7.86 at 15 m EC; 4.99 mS/cm, TDS; 2.53 ppt, Temp; 28.0 °C, pH; 7.86 at 16 m EC; 12.73 mS/cm, TDS; 5.75 ppt, Temp; 26.5 °C, pH; 7.86 at 17 m
15					Gravel Pack (1.6-3.2 mm)	EC; 13.23 mS/cm, TDS; 5.46 ppt, Temp; 25.8 °C, pH; 7.93 at 18 m EC; 14.86 mS/cm, TDS; 7.26 ppt, Temp; 25.1 °C, pH; 7.90 at 19 m EC; 7.39 mS/cm, TDS; 4.19 ppt, Temp; 25.5 °C, pH; 7.89 at 20 m
20		SILTY SAND Light grey, well sorted, fine grained silty sand.			End cap (21 mbgl) EOH 21 m	EC; 8.11 mS/cm, TDS; 3.94 ppt, Temp; 25.3 °C, pH; 8.00 at 21 m



TD: 21 m
Notes: Data logger installed in this bore.

MB14D Downhole Gamma Induction and EC Profile



WELL COMPLETION DETAILS: MB14D

Client: Cedar Woods
Date Drilled: 09/02/2011
Logged By: Chris Jones

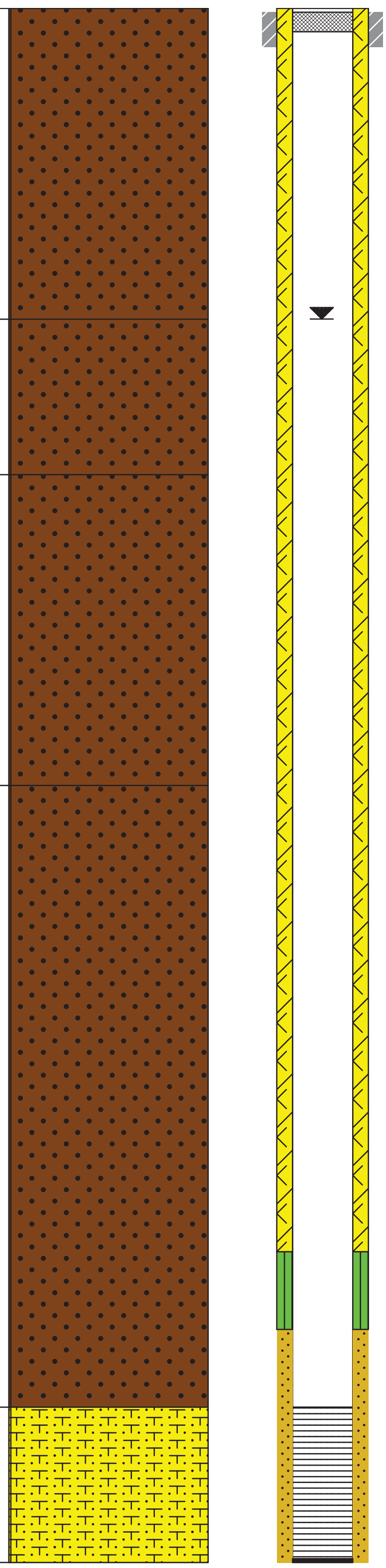
Driller: Mathews Drilling
Fluid : Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378018
Northing: 6428013
Surface RL:

HYDRAULIC DATA: **SWL:** 3.998 mbgl
SWL Date Collected: 16/02/2011

Depth mbgl	Fm.	Lithological Description
0 – 4	Safety Bay Sand	SAND Light brown / tan, shell fragments
4 – 6	Safety Bay Sand	SAND Light brown / tan, shell fragments (5 - 10 mm), limestone (subangular, 3 - 7 mm)
6 – 10	Safety Bay Sand	SAND Grey, whole shells (5 - 10 mm), minor limestone (2 mm).
10 – 18	Safety Bay Sand	SAND Grey, shell rich sand, whole shells (5 - 10 mm)
18 – 20	Safety Bay Sand	SILTY SAND Grey fine silty sand, lighter grey from 19 - 20 m.

Lithology / Well Construction



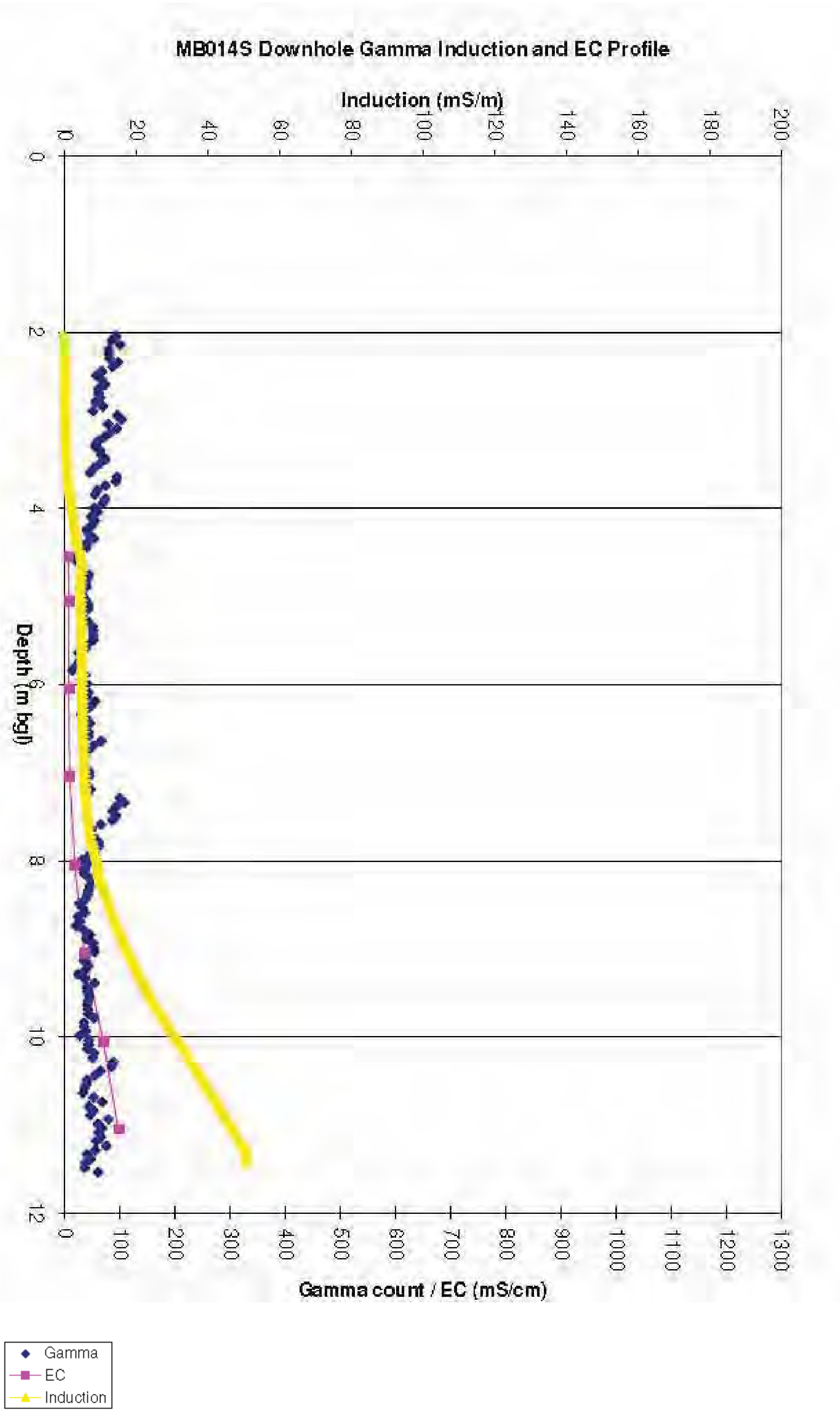
Well Details

- Steel cover (flush with ground level)
- Cement grout (0-0.5 m)
- SWL (3.998 mbgl)
- Backfill (0.5-16 m)
- 100 mm UPVC PN9 Blank casing (0-18 m)
- Bentonite seal (16-17 m)
- Gravel Pack (1.6-3.2 mm) (17 - 20 m)
- 100 mm UPVC PN9 Slotted casing (18-20 m)
- End cap (20 m)
- EOH

Water Quality

- EC; 2.47 mS/cm, pH; 10.98 at 9 m
- EC; 2.06 mS/cm, pH; 10.66 at 15 m
- EC; 2.81 mS/cm, pH; 10.37 at 18 m
- EC; 3.1 mS/cm, Temp; 28.1 °C, pH; 10.04 at 20 m

TD: 20 m
Notes:


MB014S Downhole Gamma Induction and EC Profile
Induction (mS/m)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
2
4
6
8
10
12
Gamma count / EC (mS/cm)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

WELL COMPLETION DETAILS: MB14S

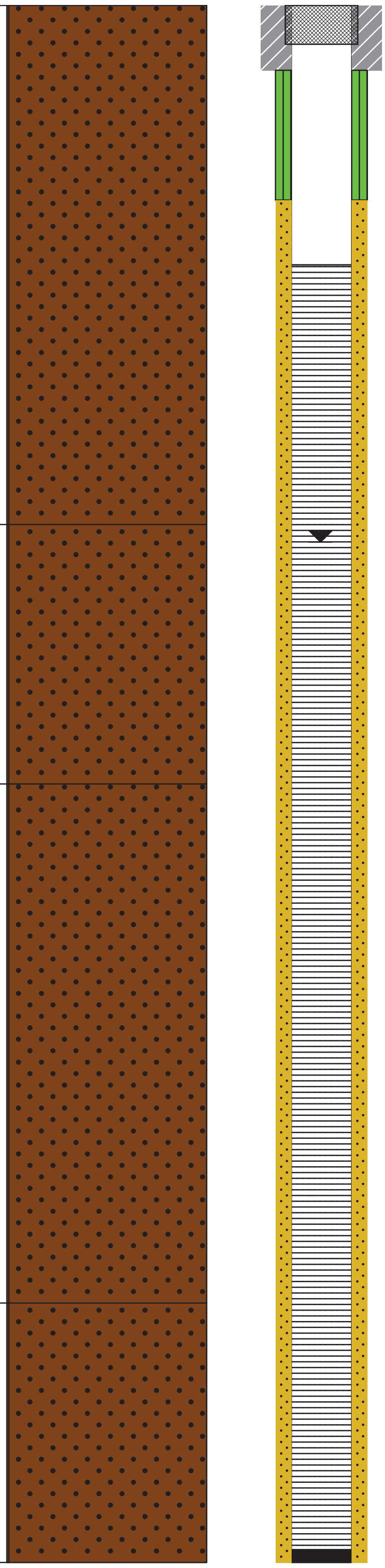
Client: Cedar Woods
Date Drilled: 10/02/2011
Logged By: Chris Jones

Driller: Mathews Drilling
Fluid : Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378021
Northing: 6428016
Surface RL:

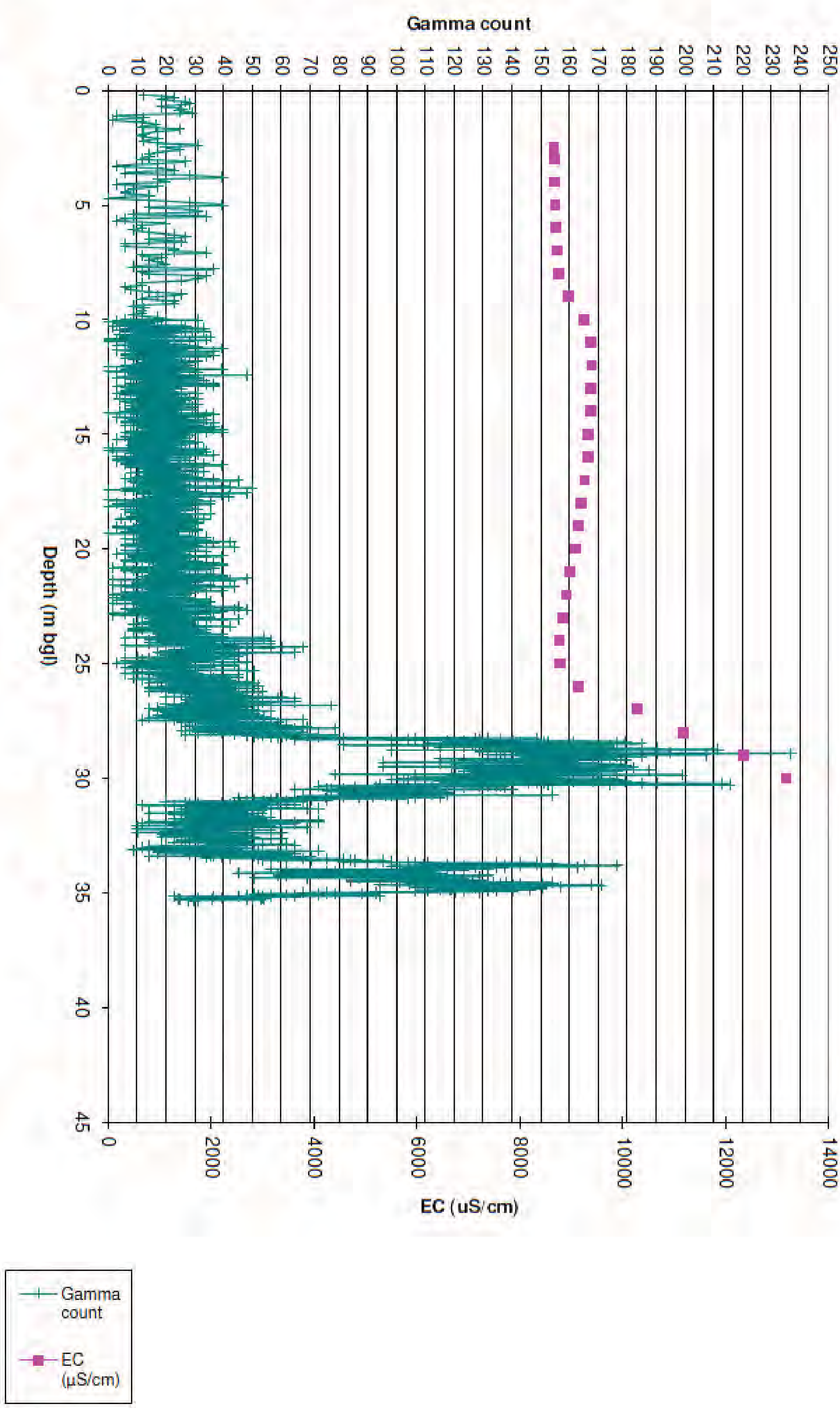
HYDRAULIC DATA: **SWL:** 4.135 mbgl
SWL Date Collected: 16/02/2011

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0	Safety Bay Sand	SAND Light brown / tan, shell fragments			Steel cover (flush with ground level) Cement grout (0-0.5 m) Bentonite seal (0.5-1.5 m) 100 mm UPVC PN9 Blank casing (0-2 m)	
		SAND Light brown / tan, shell fragments (5 - 10 mm), limestone (subangular, 3 - 7 mm)			SWL (4.135 mbgl)	
5		SAND Grey, whole shells (5 - 10 mm), minor limestone (2 mm).			Gravel Pack (1.6-3.2 mm) (1.5 - 12 m) 100 mm UPVC PN9 Slotted casing (2-12 m)	**EC; 3.63 mS/cm, Temp; 27.4 °C, pH; 11.19 at 6 m** **EC; 3.58 mS/cm, Temp; 27.7 °C, pH; 11.29 at 9 m**
10		SAND Grey, shell rich sand, whole shells (5 - 10 mm)			End cap (12 m) EOH	**EC; 3.63 mS/cm, Temp; 28.7 °C, pH; 11.01 at 12 m**



TD: 12 m
Notes:

LR1 Gamma/EC Downhole Profile



Project No: **0116221**	Drill Method: **Mud Rotary**	Water Strike:	**ID: LR1**
Project Name: **SDOOL**	Hole Type: **MW**	Water Level (Final):	
Drill Start Date: **26/05/2011**	Total Depth (m): **39**	RL Ground:	
Drill Finish Date: **27/05/2011**	Hole Diam. / Width (mm): **150**	RL Case:	
Drill Co: **Envirotech Drilling**	Casing Type/Diam. (mm): **50**	East MGA: **0379204**	
Driller: **Rock Fazari**	Surface Completion: **Gattic**	North MGA: **6427463**	

Soil type (lithology), Soil type modifier, Colour, Moisture Content, Consolidation (density, firmness), Plasticity (cohesive soil),Uniformity (grain size, sorting, angularity), Structure (slickensides, fractures). Contamination (staining, odour), Other (roots, shells,organics, nodules etc). Pocket Penetrometer Reading, Samples Taken.

ERM

ERM Australia Pty Ltd

Lithology	Symbol	Well	Depth (m)	Sample Type	PPT (kPa)	PID (ppm)	Sample ID / DUP ID	Remarks
Ground Surface			0					
Sand Light grey, damp, fine grains (<1mm), loose, well sorted, suspected fill material.			0–1					Hand augered to 1.5m
Sand Grey, coarse grains (>1mm), loose, poorly sorted, high shell (>5mm) content from 2.0m down, grain size increasing with depth, some organic content, becoming dark grey/black from 8m down.			1–23					Located between LR2 and the Watercorp concrete pad with manhole. Hard to determine the moisture content of the soil profile due to the use of mud rotary drilling technique. Hole backfilled with bentonite from 39mbgs to 30mbgs.
Silty Clay			23–24					
Limestone Grey/brown, fine (<1mm) to coarse (>1mm) limestone, loose, non plastic, some limestone/cephalopod shell fragments (>5mm) present.			24–29					
Clayey Rock Brown/grey, moderately plastic, loose, 5mm rock fragments, limestone fragments present.			29–30					
Clay Brown, plastic, soft, fine grains. Colour change to orange at 31m. Becoming increasingly sandy at 34m.			30–34					
Clayey Sand Orange, medium sized grains, some quartz.			34–35.5					
Shale Black, very fine grains, sticky. Grain size increasing at 36mbgs and some small quartz rocks present.			35.5–36					
Sand Orange, coarse grains, poorly sorted, quartz rocks (5mm).			36–39					
End of Log			39					

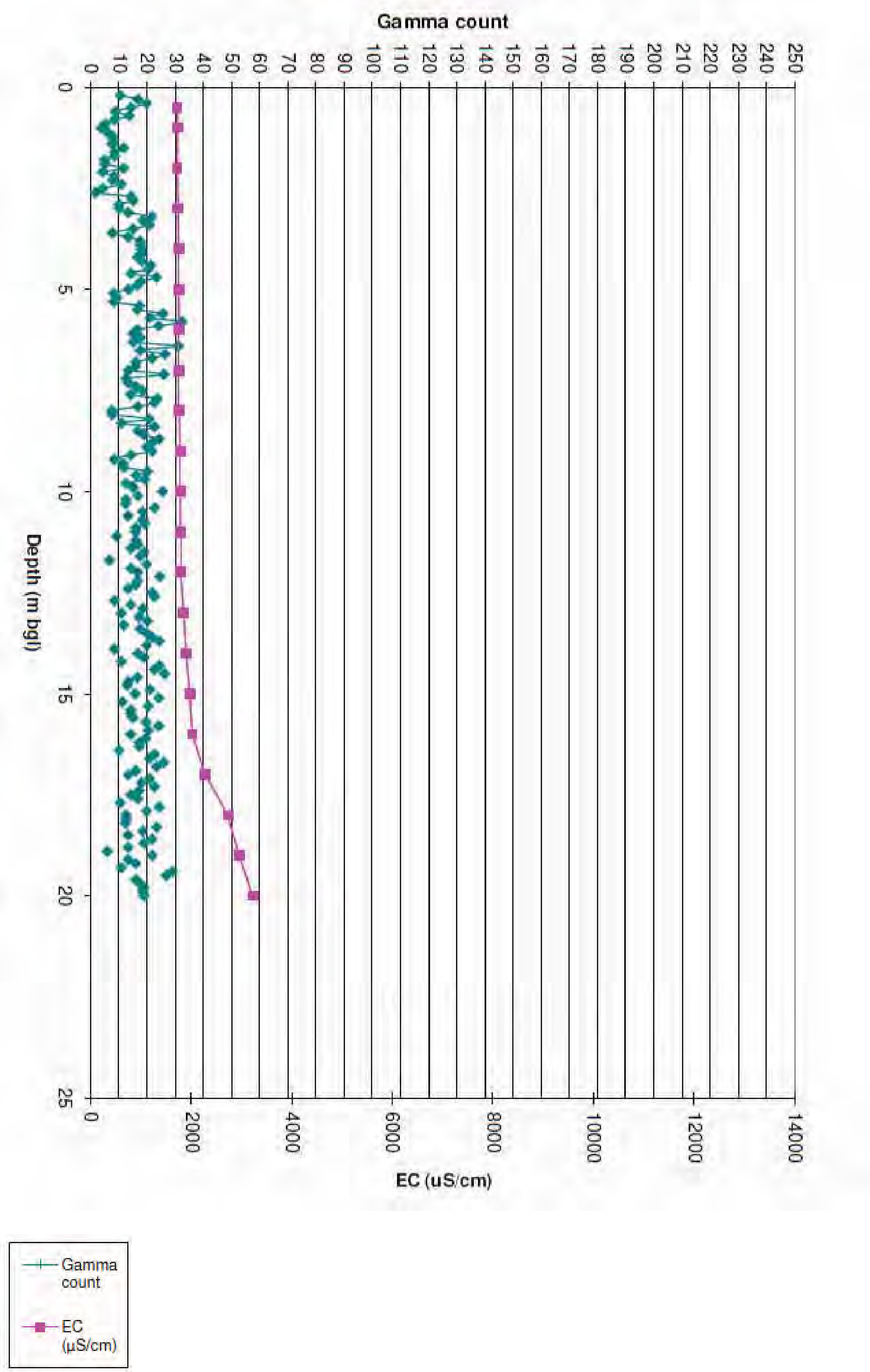
NOTE: This bore log is for environmental purposes only and is not intended to provide geotechnical information.

SITE COMMENTS:

HA = Hand Auger HSA = Hollow Stem Auger
PT = Push Tube TP = Test Pit
US = Undisturbed Soil Sample
DS = Disturbed Soil Sample

Log By: **MB**
Checked By: **EB**

LR2 Gamma/EC Downhole Profile



Project No: **0116221**	Drill Method: **Mud Rotary**	Water Strike:
Project Name: **SDOOL**	Hole Type: **MW**	Water Level (Final):
Drill Start Date: **26/05/2011**	Total Depth (m): **23**	RL Ground:
Drill Finish Date: **27/05/2011**	Hole Diam. / Width (mm): **150**	RL Case:
Drill Co: **Envirotech Drilling**	Casing Type/Diam. (mm): **50**	East MGA: **0379201**
Driller: **Rock Fazari**	Surface Completion: **Gattic**	North MGA: **6427465**

ID: LR2

ERM

ERM Australia Pty Ltd

Soil type (lithology), Soil type modifier, Colour, Moisture Content, Consolidation (density, firmness), Plasticity (cohesive soil),Uniformity (grain size, sorting, angularity), Structure (slickensides, fractures). Contamination (staining, odour), Other (roots, shells,organics, nodules etc). Pocket Penetrometer Reading, Samples Taken.

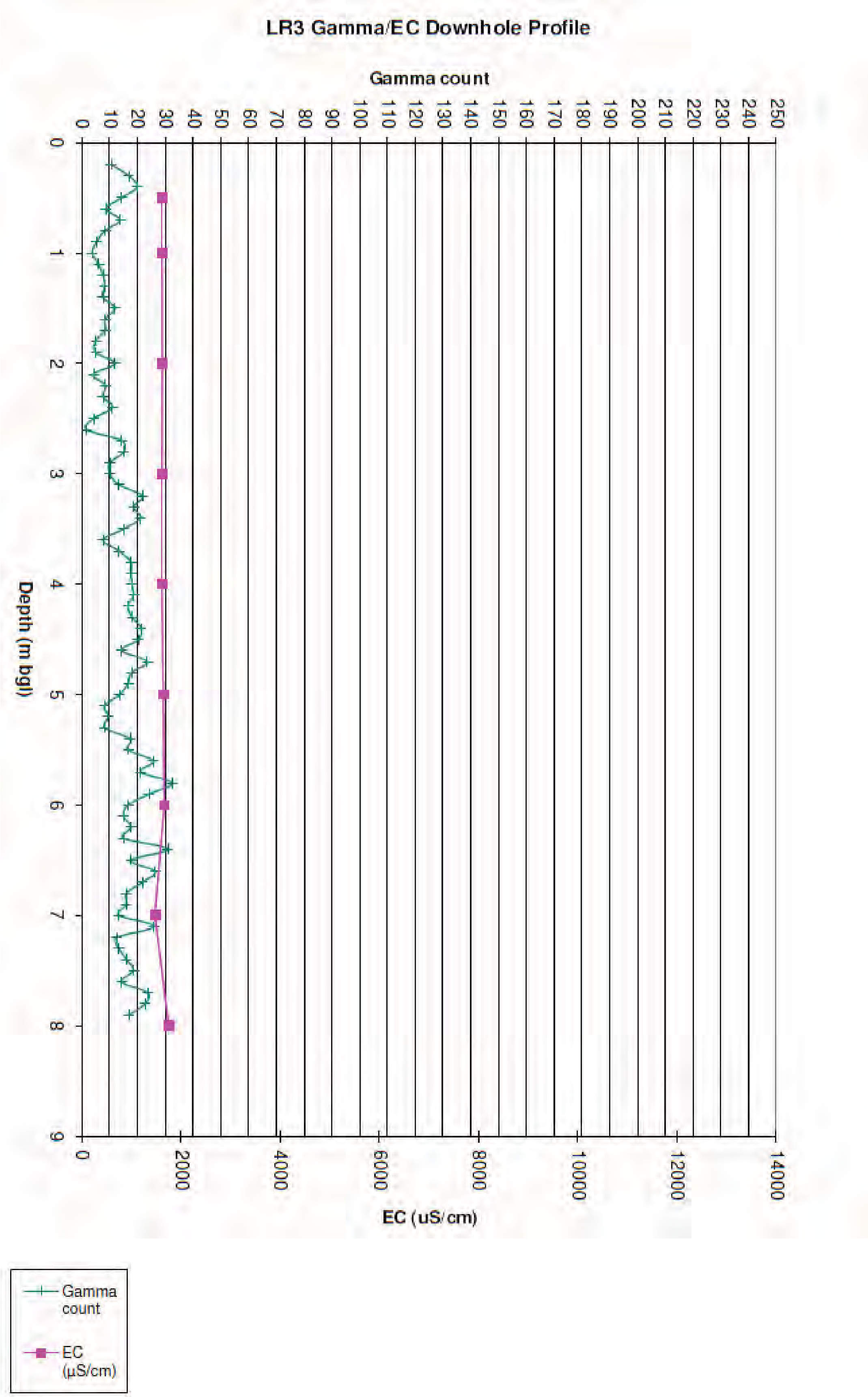
Lithology	Symbol	Well	Depth (m)	Sample Type	PPT (kPa)	PID (ppm)	Sample ID / DUP ID	Remarks
Ground Surface			0					
Sand Grey/brown, damp, medium grains, loose, some shell fragments.			1					Hand augered to 1.5m
Becoming quite coarse grained with depth. Shell content increasing with depth.			2–3					
			5					Located 1m west of LR1.
			10–11					Well construction approved by TW via phone.
			4–25					

NOTE: This bore log is for environmental purposes only and is not intended to provide geotechnical information.

SITE COMMENTS:

HA = Hand Auger   HSA = Hollow Stem Auger
PT = Push Tube   TP = Test Pit
US = Undisturbed Soil Sample
DS = Disturbed Soil Sample

Log By: **MB**
Checked By: **EB**



LR3 Gamma/EC Downhole Profile
Gamma count
Depth (m bgl)
EC (uS/cm)
Gamma count
EC (µS/cm)

Project No: **0116221**	Drill Method: **HSA**	Water Strike: **3.5**
Project Name: **SDOOL**	Hole Type: **MW**	Water Level (Final):
Drill Start Date: **23/2/11**	Total Depth (m): **10.85**	RL Ground:
Drill Finish Date: **23/2/11**	Hole Diam. / Width (mm): **150**	RL Case:
Drill Co: **Edrill**	Casing Type/Diam. (mm): **50**	East MGA: **0379204**
Driller:	Surface Completion: **Gattic**	North MGA: **6427463**

ID: LR3

ERM

ERM Australia Pty Ltd

Soil type (lithology), Soil type modifier, Colour, Moisture Content, Consolidation (density, firmness), Plasticity (cohesive soil),Uniformity (grain size, sorting, angularity), Structure (slickensides, fractures). Contamination (staining, odour), Other (roots, shells,organics, nodules etc). Pocket Penetrometer Reading, Samples Taken.

Lithology	Symbol	Well	Depth (m)	Sample Type	PPT (kPa)	PID (ppm)	Sample ID / DUP ID	Remarks
Ground Surface			0					
Sand Grey, dry, loose, medium grained, sub-rounded, shell fragments								Driller commented that due to dry sand it was
Sand Grey/yellow, dry, loose, medium grained, sub-rounde, shell fragments			1					
Sand Yellow, medium grained, sub-rounded, moist, shell fragments			2	HSA			CY5_2	
			3					
Sand Grey, medium grained (becoming finer with depth), moist			4	HSA			CY5_3.75	
			5	HSA			CY5_5	
			6					
			7					
			8					
			9					
			10					
End of Log			11					
			12					

NOTE: This bore log is for environmental purposes only and is not intended to provide geotechnical information.

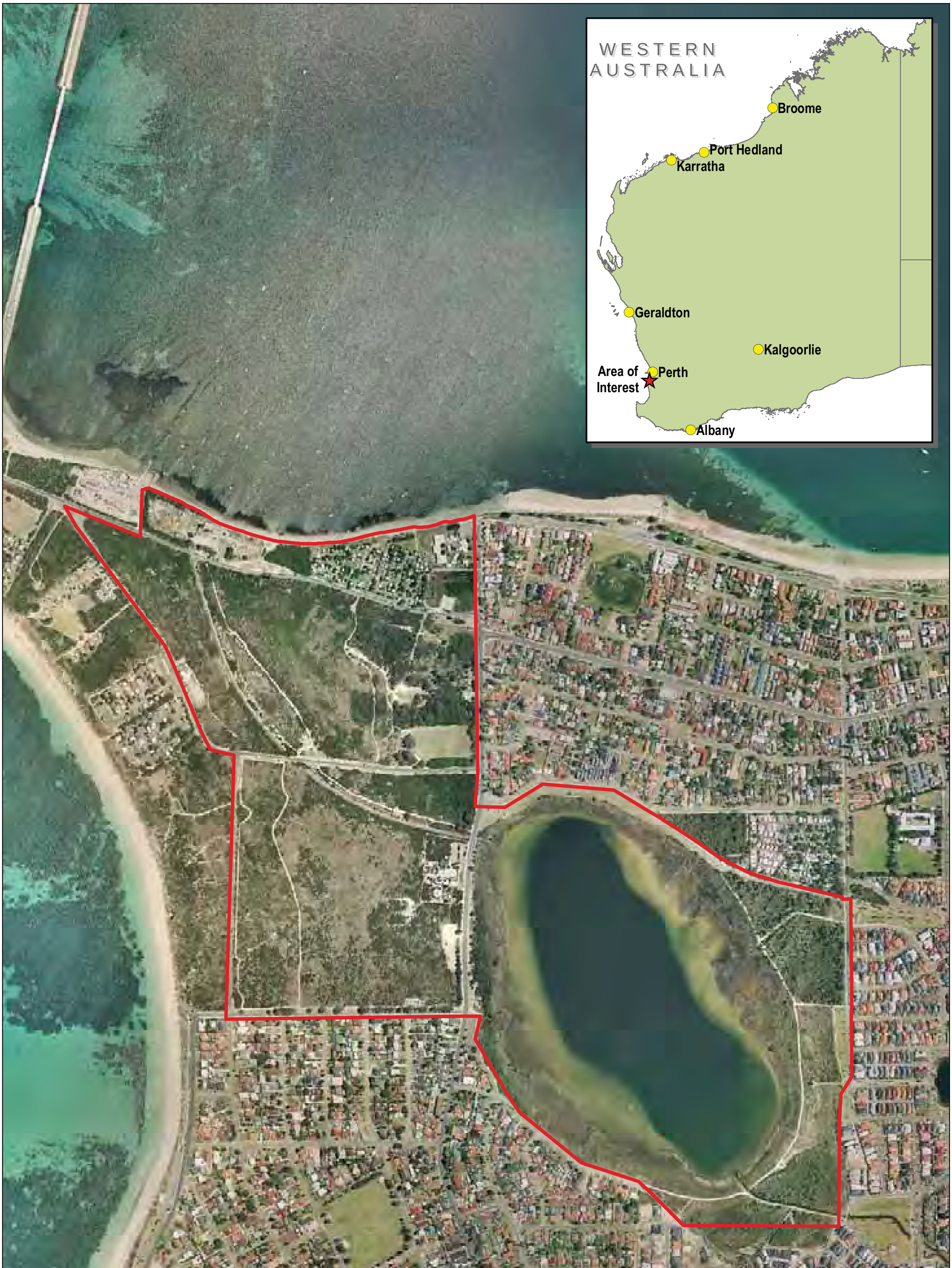
SITE COMMENTS:

HA = Hand Auger HSA = Hollow Stem Auger
PT = Push Tube TP = Test Pit
US = Undisturbed Soil Sample
DS = Disturbed Soil Sample

Log By: **PK**
Checked By: **EB**

Annex B

Geological Cross Sections



Legend

Area of Interest

N

0 150 300 450m

Client:	Cedar Woods		
Drawing No:	0128619p_CSM_G001_Site_Loc.mxd		
Date:	17/06/2011	Drawing	A4
Drawn By:	DN	Reviewed By: EB	

This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

Figure 1 - Site Location Plan

Mangles Bay Conceptual Site Model

Environmental Resources Management Australia Pty Ltd

Adelaide, Brisbane, Canberra, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM

Client:	Cedar Woods		
Drawing No:	0128619p_CSM_G002_Bore_Cross_Sect.mxd		
Date:	21/06/2011	Drawing	A4
Drawn By:	DN	Reviewed By: EB	

This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

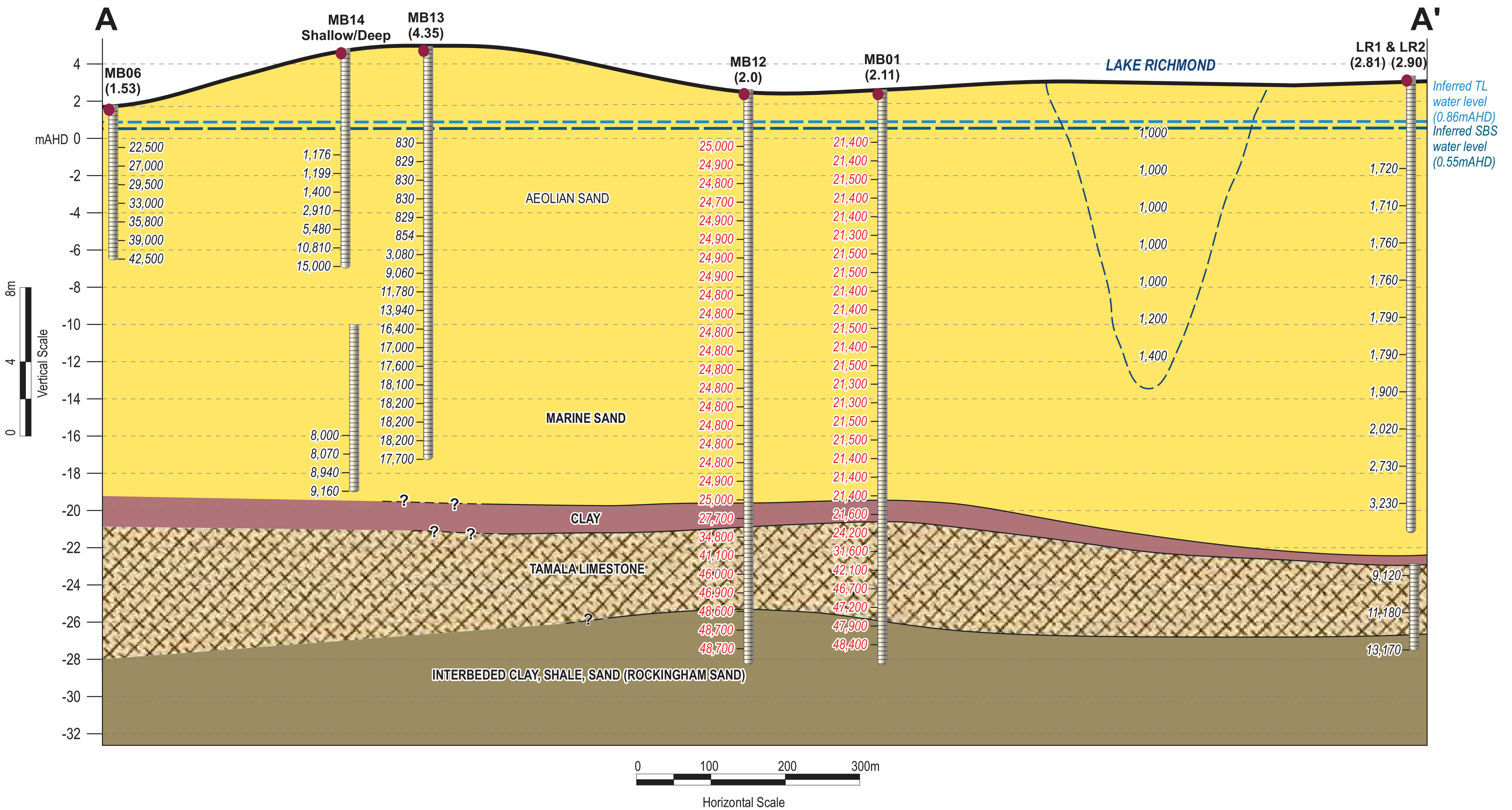
Figure 2 - Bore and Geological Cross Section Location Plan

Mangles Bay Conceptual Site Model

Environmental Resources Management Australia Pty Ltd

Adelaide, Brisbane, Canberra, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM



Legend

- SAFETY BAY SAND
- CLAY
- TAMALA LIMESTONE
- INTERBEDED CLAY, SHALE, SAND (ROCKINGHAM SAND)
- TAMALA LIMESTONE WATER LEVEL
- SAFETY BAY SANDS WATER LEVEL

1,720 DOWNHOLE FIELD EC June 2011 (µS/cm)

34,800 EC readings should be discounted as they represent cross connection between Safety Bay Sands and Tamala Limestone.

(2.50) SURFACE RL mAHD

Notes:

MB14S and MB14D survey data not available, levels interpolated based on nearby bores.

Client:	Cedar Woods
Drawing No:	0128619p_CSM_C008.cdr
Date:	21/06/2011 Drawing size: A4
Drawn by:	DN Reviewed by: EB

This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

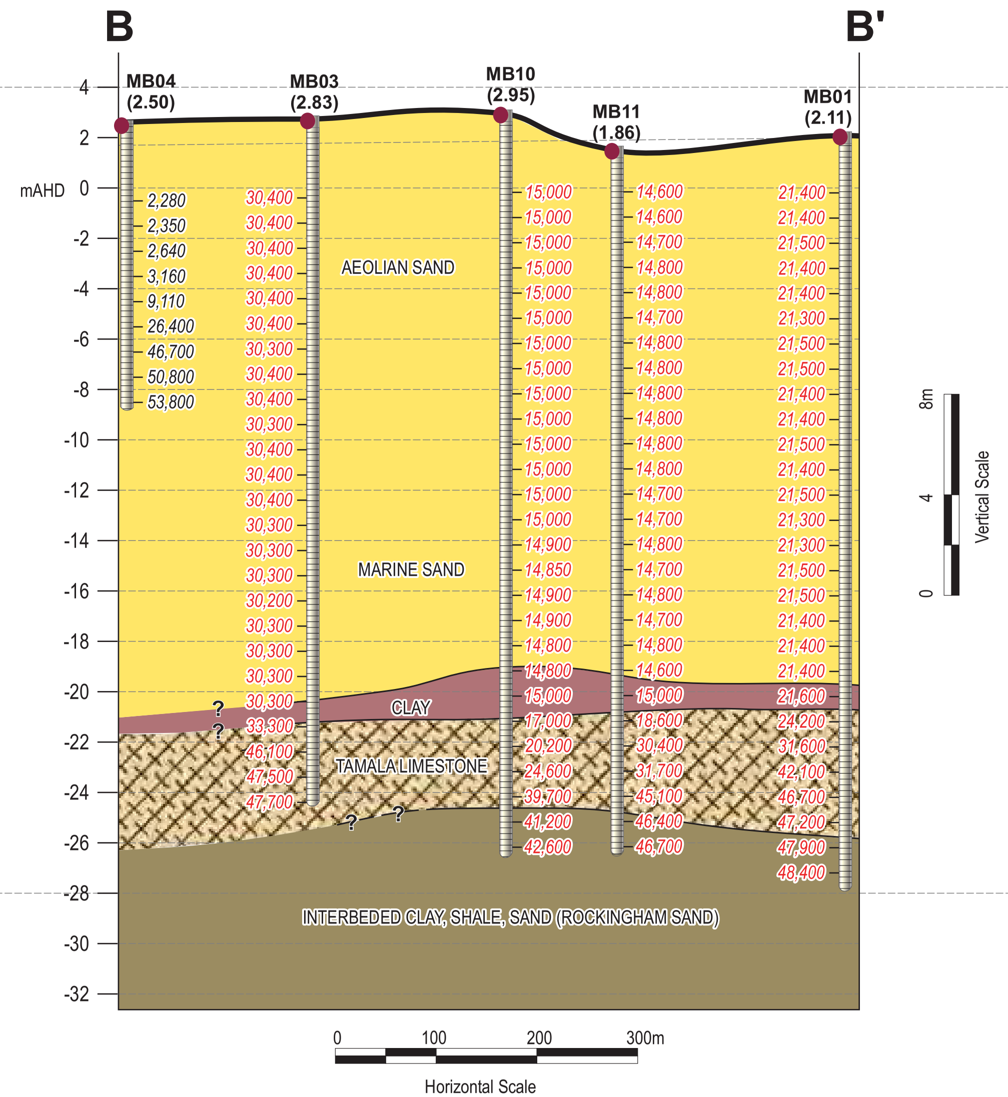
Figure 3 - Geological Cross Section A-A'

Mangles Bay Conceptual Site Model

Environmental Resources Management ANP Pty Ltd

Adelaide, Auckland, Brisbane, Canberra, Christchurch, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM



Legend

- SAFETY BAY SAND
- CLAY
- TAMALA LIMESTONE
- INTERBEDED CLAY, SHALE, SAND (ROCKINGHAM SAND)

1,720 DOWNHOLE FIELD EC June 2011 (μS/cm)

34,800 EC readings should be discounted as they represent cross connection between Safety Bay Sands and Tamala Limestone.

(2.50) SURFACE RL mAHD

Client:	Cedar Woods		
Drawing No:	0128619p_CSM_C005.cdr		
Date:	21/06/2011	Drawing size: A4	
Drawn by:	DN	Reviewed by: EB	

This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

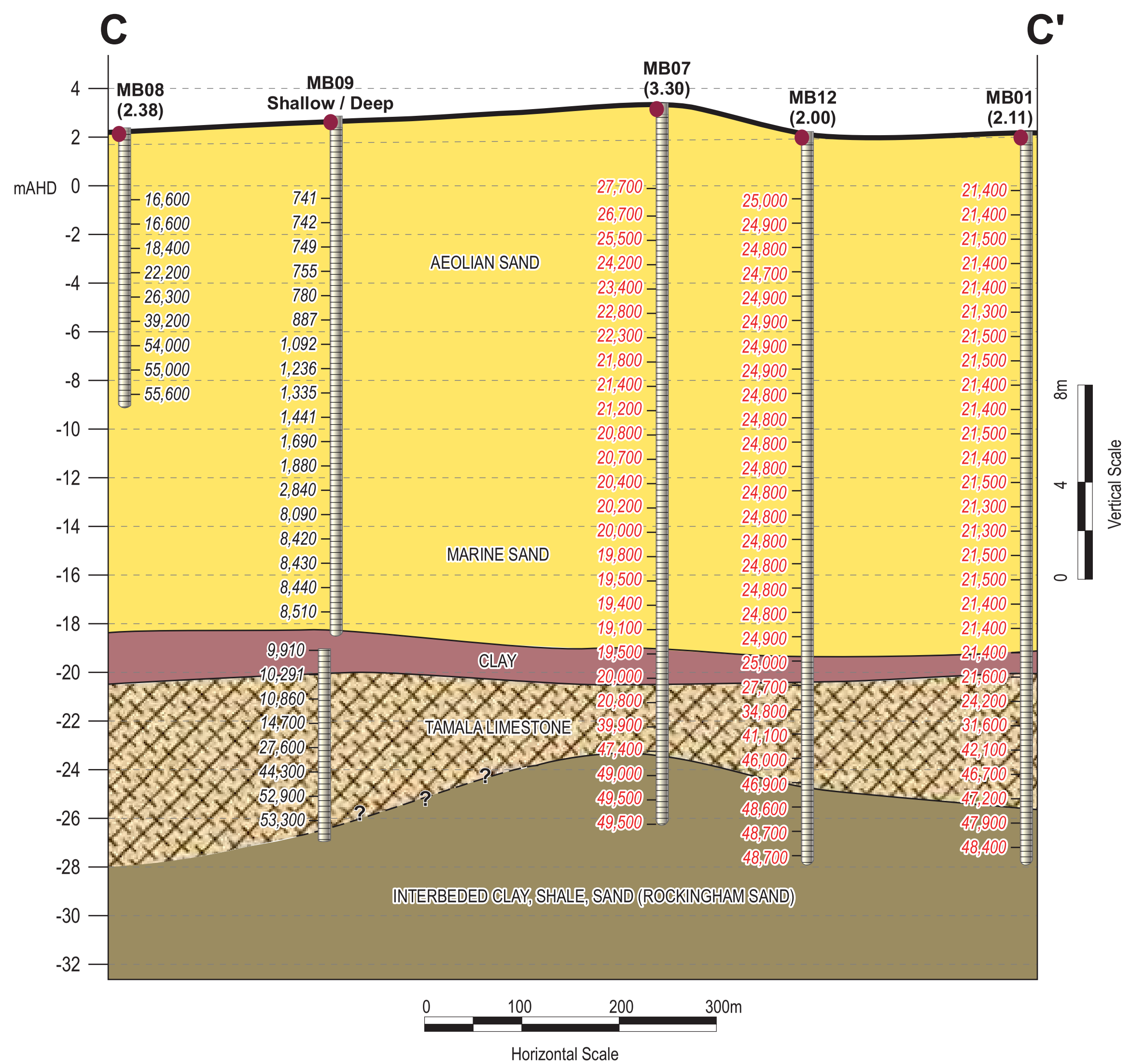
Figure 4 - Geological Cross Section B-B'

Mangles Bay Conceptual Site Model

Environmental Resources Management ANP Pty Ltd

Adelaide, Auckland, Brisbane, Canberra, Christchurch, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM



Legend

- SAFETY BAY SAND
- CLAY
- TAMALA LIMESTONE
- INTERBEDED CLAY, SHALE, SAND (ROCKINGHAM SAND)

1,720 DOWNHOLE FIELD EC June 2011 (µS/cm)

34,800 EC readings should be discounted as they represent cross connection between Safety Bay Sands and Tamala Limestone.

(2.50) SURFACE RL mAHD

Client:	Cedar Woods		
Drawing No:	0128619p_CSM_C010.cdr		
Date:	21/06/2011	Drawing size:	A4
Drawn by:	DN	Reviewed by:	EB

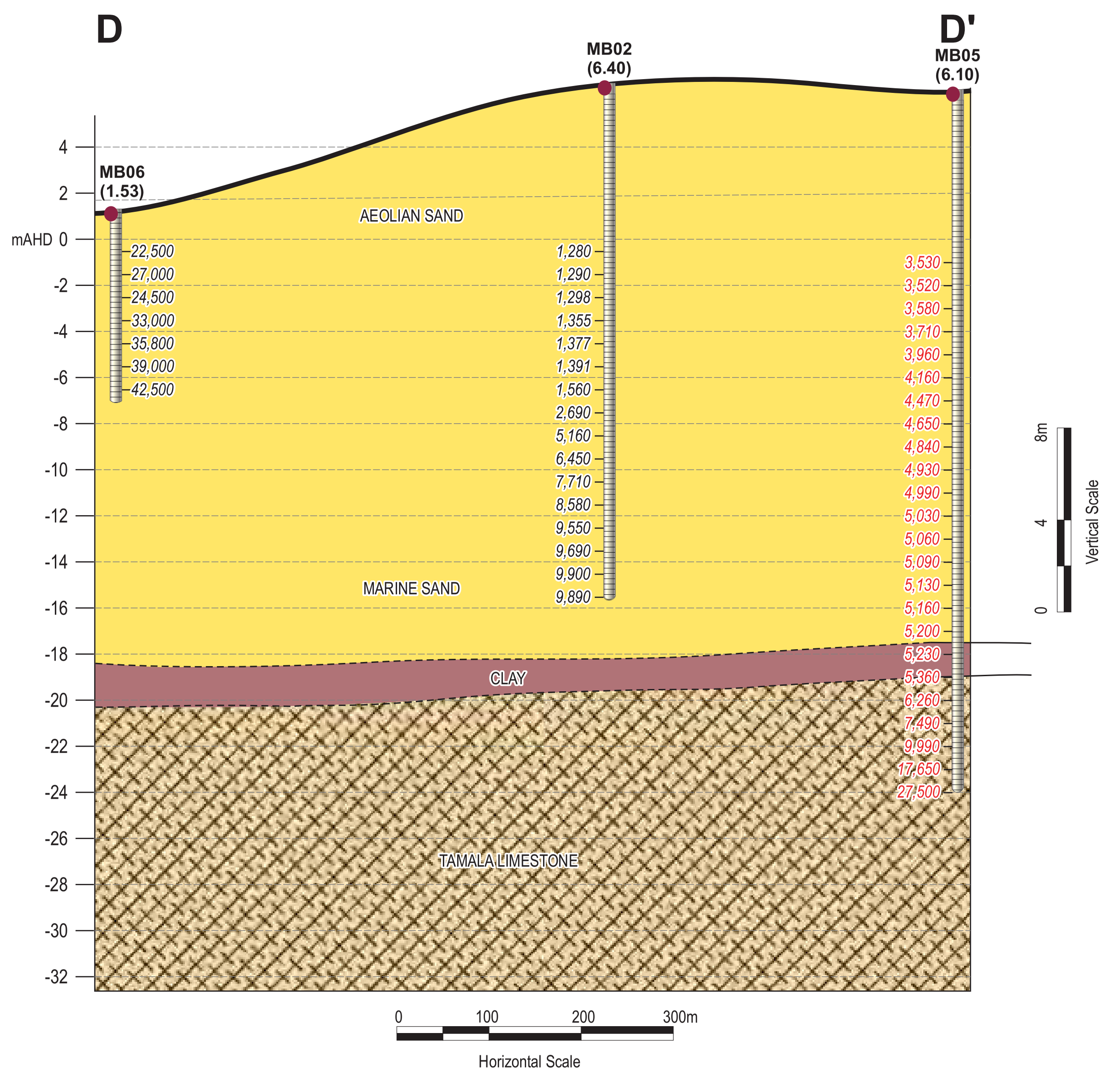
This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

Figure 5 - Geological Cross Section C-C'

Mangles Bay Conceptual Site Model

Environmental Resources Management ANP Pty Ltd

Adelaide, Auckland, Brisbane, Canberra, Christchurch, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney



Legend

- SAFETY BAY SAND
- CLAY
- TAMALA LIMESTONE

1,720 DOWNHOLE FIELD EC June 2011 (µS/cm)

34,800 EC readings should be discounted as they represent cross connection between Safety Bay Sands and Tamala Limestone.

(2.50) SURFACE RL mAHD

Client:	Cedar Woods		
Drawing No:	0128619p_CSM_C007.cdr		
Date:	21/06/2011	Drawing size:	A4
Drawn by:	DN	Reviewed by:	EB

This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

Figure 6 - Geological Cross Section D-D'

Mangles Bay Conceptual Site Model

Environmental Resources Management ANP Pty Ltd

Adelaide, Auckland, Brisbane, Canberra, Christchurch, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM

Annex C

Subcrop Map (Gswa Bulletin 142 Perth Groundwater Atlas, 1st Edition - Figure 22)

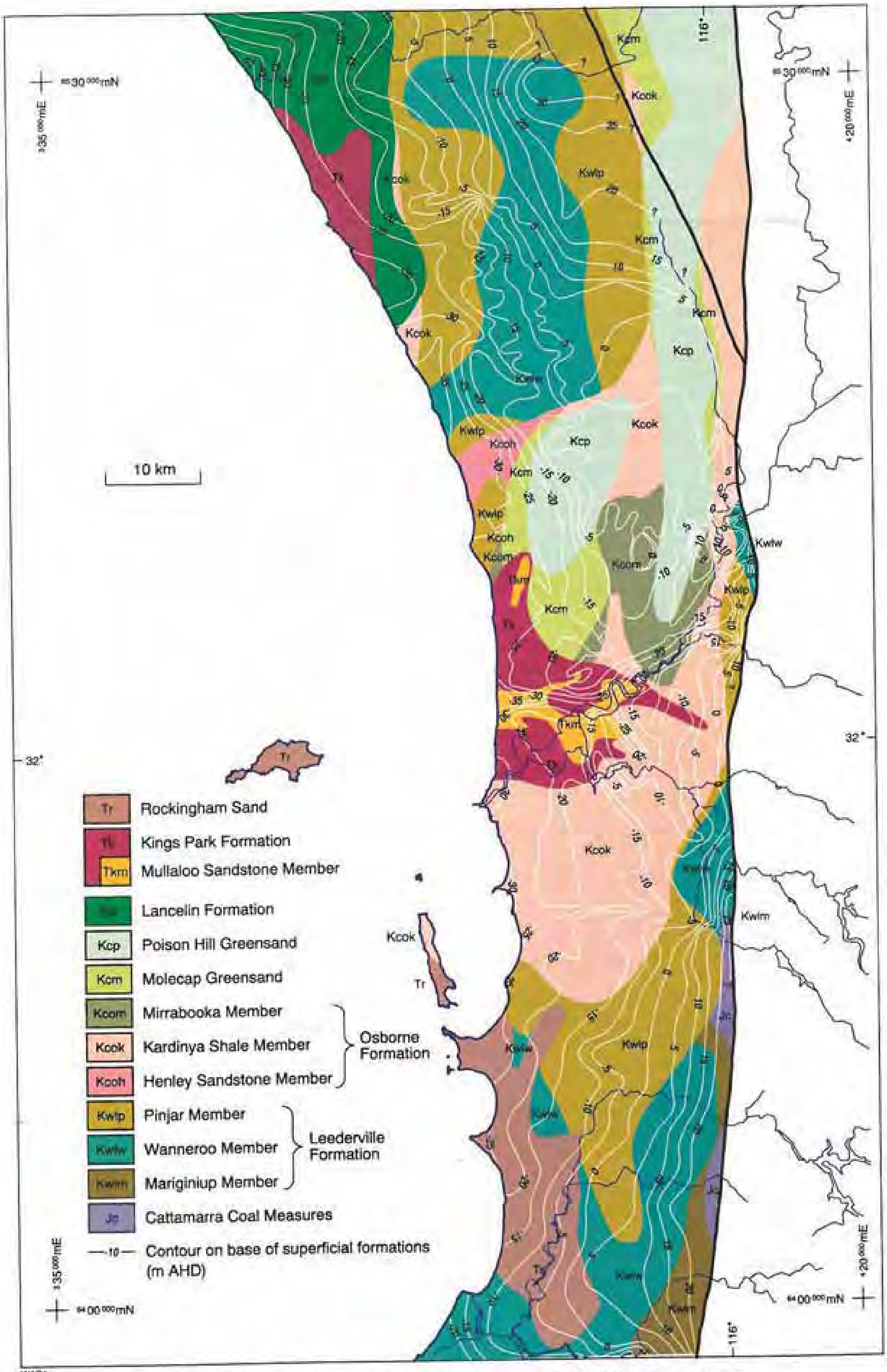


Figure 22. Superficial formations: contours on base of unit; with strata subcrop

Annex D

October 2011 Dewatering Trials Supplemental Information

Legend

Well Locations

Pipeline Route

Figure 1

Dewatering Trial Location - October 2011

Client:	Water Corporation		
Project:	Water Corporation East Rockingham WWTP		
Drawing No:	0116221p_G014_R1.mxd		
Date:	28/11/2011	Drawing Size:	A4
Drawn By:	DN	Reviewed By:	CR
Projection:	GDA 1994 MGA Zone 50		
Scale:	Refer to scale bar		

N

0 6 12 18m

Maps and figures contained within this document may be based on third party data, may not be to scale and is intended for use as a guide only. ERM does not warrant the accuracy of any such maps or figures.

Environmental Resources Management Australia Pty Ltd

Adelaide, Brisbane, Canberra, Hunter Valley, Melbourne, Perth,Port Macquarie, Sydney

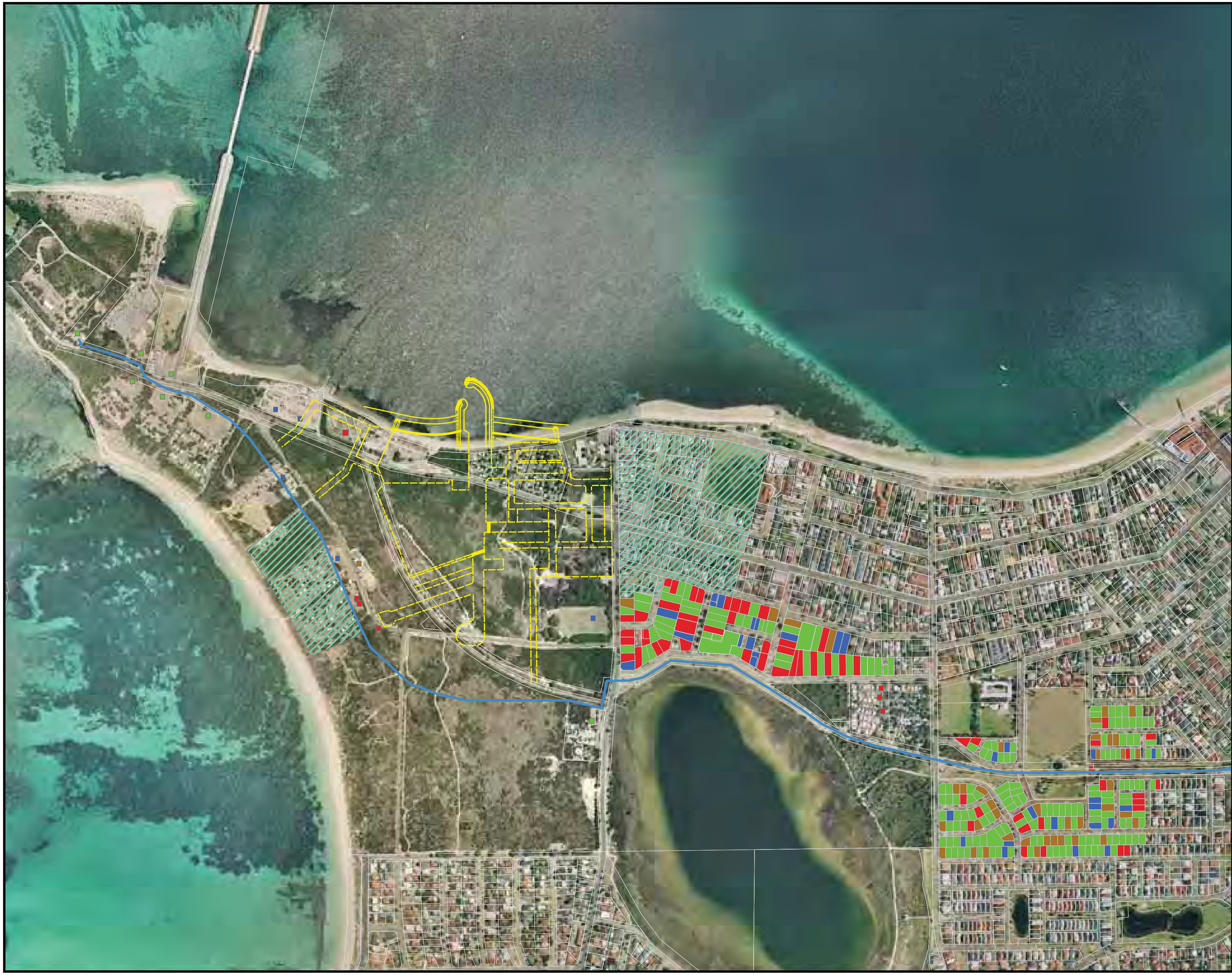
Table 1 Background Groundwater EC Profiles
SDOOL October 2011 Dewatering Trials
4th October 2011

	LR1	LR2	LR3
Depth (mbtoc)	**EC (µS/cm)**	**EC (µS/cm)**	**EC (µS/cm)**
3	1770	772	1046
4	1769	1252	1270
5	1766	1526	1301
6	1764	1594	1334
7	1763	1560	1341
8	1760	1607	1339
9	1760	1699	1339
10	1759	1693	1339
11	1758	1696	
12	1758	1699	
13	1758	1697	
14	1753	1692	
15	1751	1687	
16	1770	1690	
17	1790	1691	
18	1819	1692	
19	1854	1693	
20	1883	1693	
21	1919	1693	
22	1952	1693	
23	1995		
24	2039		
25	2084		
26	2132		
27	3372		
28	4042		
29	4049		

Notes
mbtoc = metres below top of well casing
EC = electrical conductivity

Annex E

Bore Census



Legend

- SDOOL (Cedar Woods Alignment)
- Cadastral Boundaries
- Proposed Marina

Bore Usage (cadastral lots)

- Bore Infrastructure (bore observed)
- No Bore Observed (evidence of bore use - iron staining)
- Irrigated land (no bore observed)
- No Irrigation Evident

Bore Usage (individual locations / part lots)

- Bore Infrastructure (bore observed)
- No Bore Observed (evidence of bore use - iron staining)
- Irrigated land (no bore observed)
- No Irrigation Evident
- Area not assessed for Bore Usage

Notes:
1. Non-interactive bore survey conducted on 18/10/2010.
2. Results based on visual observations from verge.

Figure 1
Bore Census

Client:	Cedar Woods
Project:	Cedar Woods Mangles Bay Marina
Drawing No: 01286191p_GWM_G002_R0.mxd	
Date: 30/08/2011	Drawing size: A3
Drawn by: DN	Reviewed by: BC
Projection:	GDA 94 MGA Zone 50
Scale:	Refer to Scale Bar

N

0 100 200 300m

Environmental Resources Management Australia Pty Ltd

Auckland, Adelaide, Brisbane, Canberra, Hunter Valley, Melbourne, Perth, Port Macquarie, Sydney

ERM

Appendix C

Model Input Parameter Tables

Table 1
Regional Groundwater Flow Model Input and Calibration Parameters
SDOOL Duplication
Rockingham, Western Australia

Input Parameter	Mean Water Level	High Water Level	Low Water Level	Units	Note
Aquifer base elevation, effective	-22	-22	-22	m, AHD	observed saltwater interface
Hydraulic conductivity, Safety Bay Sand	16	16	16	m/d	model-derived via assumed recharge
Hydraulic conductifity, Eastern Tamala Limestone Outcrop Area	1,000	1,000	1,000	m/d	model calibration; not TL beneath SBS
Hydraulic conductivity, Tamala Limestone Sand	16	16	16	m/d	model calibration-derived; eastern unit
Recharge rate, equivalent	0.00045	0.0007	0.00029	m/d	model calibration-derived
Water level along boundaries	varies	varies	varies	m, AHD	State Water publications
Water level, Lake Richmond	0.7	1.1	0.01	m, AHD	observed
Water level, shoreline	0	0	0	m, AHD	observed

Table 2
Saltwater Intrusion Model Input and Calibration Parameters
SDOOL Duplication
Rockingham, Western Australia

Input Parameter	Safety Bay Sand	P. Peron Limestone	Aquitard	Tamala Limestone NW	Tamala Limestone SE	Units	Note
Anisotropy ratio, vertical	10	10	15	10	10	dimensionless	Fetter, 1994
Specific yield	0.2	0.1	0.2	0.1	0.1	dimensionless	Fetter, 1994
Density of saltwater	1.025	1.025	1.025	1.025	1.025	kg/L	SEAWAT default
Dispersivity, lateral	1	1	1	1	1	m	modified Xu and Eckstein, 1995
Dispersivity, longitudinal	0.1	0.1	0.1	0.1	0.1	m	SEAWAT default
Dispersivity, vertical	1	1	1	1	1	m	Model calibration
Formation base elevation	-22	-25	-25	-30	-30	m, AHD	observed
Hydraulic conductivity	16	1,000	0.002	3,000*	200	m/d	Model developed
Porosity	0.3	0.1	0.3	0.1	0.1	dimensionless	Fetter, 1994
Recharge rate, equivalent	0.00045	0.00045				m/d	Regional groundwater flow model
Saltwater concentration, sea	35	35	35	35	35	g/L	SEAWAT default
Water level along boundaries	varies	varies	varies	varies	varies	m, AHD	Regional groundwater flow model
Water level, Lake Richmond	varies					m, AHD	Regional groundwater flow model
Water level, shoreline	0	0	0	0	0	m, AHD	SEAWAT default

*this model-developed conductivity, which is much higher than typical for the TL, reflects influence from the underlying Rockingham Sand. While this conductivity is at the upper bound of reported conductivities for the TL (WP, 2005), this conductivity is the minimum required to enable the existing salinity distribution in the TL to be reflected in the model and so has been accepted for use.

Table 3
SEAWAT Model Calibration Results
SDOOL Duplication
Rockingham, Western Australia

Observed and Modeled Water Level

Well		**Date**	**Observed**	**Modeled**	**Residual**	**Scaled Residual**
			mAHD	mAHD	m	
DR11B	Mean	06/19/1985	0.95	0.88	-0.070	
DR11C	Mean	06/19/1985	1.2	1.20	0.000	
DR14	Mean	06/19/1985	1.1	1.16	0.060	
DR15	Mean	06/19/1985	0.91	1.01	0.100	
DR16	Mean	06/19/1985	0.8	0.81	0.010	
DR3B	Mean	06/19/1985	1.3	1.26	-0.040	
MB13	Mean	9/06/2010	0.264	0.41	0.146	
MB02	Mean	2010	0.359	0.38	0.021	
MB09S	Mean	9/06/2010	0.25	0.35	0.100	
Lake Richmond	Mean	long-term	0.7	0.704	0.004	
DR11B	Low	04/27/84	0.610	0.640	0.030	
DR11C	Low	04/27/84	0.830	0.990	0.160	
DR14	Low	04/27/84	0.650	1.060	0.410	
DR15	Low	04/27/84	0.560	0.890	0.330	
DR16	Low	04/27/84	0.330	0.580	0.250	
DR3B	Low	04/27/84	1.070	1.040	-0.030	
MB09S	Low	21/12/2010	0.130	0.292	0.162	
MB13	Low	19/04/2010	0.174	0.299	0.125	
MB2	Low	2010	0.209	0.287	0.078	
Lake Richmond	Low	long-term	0.12	0.12	0.000	
DR11B	High	08/22/85	1.220	0.990	-0.230	
DR11C	High	08/22/85	1.570	1.430	-0.140	
DR14	High	08/22/85	1.350	1.420	0.070	
DR15	High	08/22/85	1.140	1.210	0.070	
DR16	High	08/22/85	1.110	1.070	-0.040	
DR3B	High	08/22/85	1.870	1.490	-0.380	
MB09S	High	23/08/2010	0.350	0.475	0.125	
MB13	High	23/07/2010	0.354	0.543	0.189	
MB2	High	2010	0.399	0.470	0.071	
Lake Richmond	High	long-term	1.1	1.12	0.020	
Range (Difference)			1.750			
Mean Sum (Average)					0.053	3%
Root Mean Square (Standard Deviation)					0.149	9%

Observed and Modeled Depth to Salinity of 20 g/L

Well	**Obs. Depth**	**Modeled Depth**	**Residual**	**Note**
	mAHD	mAHD	m	
MB01	-23.6	-23.5	0.1	
MB03	-22.5	-23.5	-1.0	
MB04	-6.3	-6.4	-0.1	Shoreline
MB05	-24.1	-24.6	-0.5	
MB06	-4.3	-5.8	-1.5	Shoreline
MB07	-22.3	-22.7	-0.4	
MB08	-5.3	-6.2	-0.9	Shoreline
MB09	-23.3	-24.5	-1.2	
MB10	-23.6	-22.5	1.1	
MB11	-23.8	-23.5	0.3	
MB12	-22.9	-23.4	-0.5	
Mean Sum (Average)			-0.4	
Root Mean Square (Standard Deviation)			0.7	
Note: Observed salinity converted from observed mean EC reading				

ERM has over 100 offices across the following countries worldwide

Argentina	Malaysia
Australia	Mexico
Belgium	The Netherlands
Brazil	New Zealand
Canada	Peru
Chile	Poland
China	Portugal
Colombia	Puerto Rico
Ecuador	Russia
France	Singapore
Germany	South Africa
Hong Kong	Spain
Hungary	Sweden
India	Taiwan
Indonesia	Thailand
Ireland	UK
Italy	United Arab Emirates
Japan	US
Kazakhstan	Vietnam
Korea	Venezuela

ERM's Perth Office

Level 6,
172 St Georges Tce
Perth WA 6000
T: 9321 5200
F: 9321 5262

www.erm.com

ERM