Proposed Mangles Bay Marina Based Tourist Precinct

Groundwater Modelling and Impact Assessment

Cedar Woods Properties Ltd.

29 August 2011

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DRAFT REPORT

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Environmental Resources Management Australia Pty Ltd Quality System

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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 Cedar Woods Properties Ltd (Cedar Woods) in February 2011 to develop a groundwater model of the land area adjacent to Mangles Bay, within the City of Rockingham, Western Australia. The groundwater model would be used in the assessment of impact of Cedar Woods Mangles Bay Marina-Based Tourist Precinct (MBM) on the local environment and groundwater users. Specifically, the modelling focused on water levels and salinity in the local Safety Bay Sand aquifer and nearby Lake Richmond.

In addition to modelling impacts from the proposed MBM, Cedar Woods was required to take into account the Water Corporation's proposed installation of the Sepia Depression Ocean Outlet Landline (SDOOL) duplication, as the existing SDOOL and the proposed SDOOL duplication run through Cedar Woods proposed MBM development. In conjunction with the Water Corporation, Cedar Woods developed an option for the realignment of a portion of the existing SDOOL and proposed SDOOL duplication around the proposed MBM. The cumulative dewatering effects of both the SDOOL and MBM, should the two projects be constructed at the same time, were also modelled.

For the modelling scenario's, several construction methods for MBM were proposed to determine the scenario likely to have the least impact on the surrounding environment and groundwater users. Three scenarios were modelled:

1) *Option 1: Dewatering to enable dry construction of both the proposed marina and all canals in the MBM development plan;*

2) *Option 2: Dewatering to enable dry construction of only the proposed marina and the main canal; and*

3) *Option 3: Wet excavation (comprising installation of impermeable barrier wall, combined with dredging) of marina and canal configuration.*

The groundwater model was preceded and accompanied by supplemental field work (completed by both MWH, initially, then ERM) and literature reviews to ensure that the best available data and understandings were available 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. The sensitivity analysis conducted on the model results indicated that the results of the modelling can be used with a high degree of confidence.

Modelling outputs indicated that wet excavation techniques resulted in least water level and salinity impacts to the area surrounding the proposed MBM, and are summarised as follows:

- *Lake Richmond water levels during MBM construction will be reduced by 0.032 m;*

- *Lake Richmond water levels during SDOOL construction will be reduced by 0.24 m;*

- *Lake Richmond water levels during combined MBM and SDOOL construction will be reduced by 0.25 m;*

- *Lake Richmond water levels during the long term (after all construction is complete) will be reduced by 0.038 m;*

- *Saltwater intrusion is expected to be confined to the vicinity of the MBM during MBM construction and post construction;*

- *Saltwater intrusion is not discernibly affected by SDOOL construction; and*

- *Salinity levels in Lake Richmond are not expected to change discernibly during both combined and separate MBM and SDOOL construction and operation.*

1 *INTRODUCTION*

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by Cedar Woods Properties Ltd (Cedar Woods) in February 2011 to develop a groundwater model of the land area adjacent to Mangles Bay, within the City of Rockingham, Western Australia (WA) (*Annex A*, *Figure 1*). This work was requested to determine impacts from the proposed Cedar Woods Mangles Bay Marina-Based Tourist Precinct (MBM) on the local environment and groundwater users.

In addition to modelling impacts from the proposed MBM, Cedar Woods was required to take into account the Water Corporation's proposed installation of the Sepia Depression Ocean Outlet Landline (SDOOL) duplication, as the existing SDOOL and the proposed SDOOL duplication run through Cedar Woods proposed MBM development. In conjunction with the Water Corporation, Cedar Woods developed an option for the realignment of a portion of the existing SDOOL and proposed SDOOL duplication around the proposed MBM.

Specifically, the model was developed to assess the impact of the proposed MBM and SDOOL duplication/relocation (*Annex A*, *Figure 1*) on the local environment and groundwater users as measured by changes in water levels and quality (salinity) in the local aquifers and Lake Richmond. Impacts were evaluated during both construction and operation of the proposed MBM and SDOOL duplication/relocation, with cumulative effects of both the SDOOL and MBM projects being constructed at the same time taken into account.

For the modelling scenario's, several construction methods for MBM were proposed to determine the scenario likely to have the least impact on the surrounding environment and groundwater users. Three scenarios were modelled:

1) Option 1: Dewatering to enable dry construction of both the proposed marina and all canals in the MBM development plan;

2) Option 2: Dewatering to enable dry construction of only the proposed marina and the main canal; and

3) Option 3: Wet excavation (comprising installation of impermeable barrier wall, combined with dredging) of marina and canal configuration.

Modelling outputs indicated that wet excavation techniques resulted in least water level and salinity impacts to the area surrounding the proposed MBM, and as such were chosen by Cedar Woods as the optimum methods for the development. As such, this report focuses on the results of this construction scenario, however modelled results for the other two construction techniques are presented in *Annex B* for reference.

1.1 MBM DEVELOPMENT OVERVIEW

The proposed MBM (*Annex A*, *Figure 1*) consists of canals and a marina, surrounded by a variety of compatible development features (a landmark building, hotel or high-density mixed uses, moderate-density mixed uses, a club and chandlery, public beach, residential areas, and recreation areas). *Annex A*, *Figure 1* shows the outline of the water features within the MBM. MBM construction will involve installation of sheet piling to -5.5 meters (m) Australian Height Datum (AHD) to sections of the marina boundary, installation of temporary walls between construction stages and/or shoreline, and wet excavation.

Table 1.1 demonstrates the construction timeframes that is proposed for MBM (note that no underwater construction is required in Stage 3 of the development).

Table 1.1 MBM Construction Stages

Stage	Construction	Cumulative Duration (mo.)
S1	Wet excavation, sheet piling, temporary wall installation (shoreline, between S1 and S1.5, and between S1 and S2), and shoreline wall removal at end of S1	1-18
S1.5	Wet excavation, sheet piling, temporary wall installation (between S1.5 and S4), and temporary wall (between S1 and S1.5) removal at end of S1.5	18-30
Break	No wet construction	31-37
S2	Wet excavation, sheet piling, and temporary wall removal (between S1 and S2) at end of S2	38-59
Break	No wet construction	60-66
S3	No wet construction	67-79
Break	No wet construction	80-86
S4	Wet excavation, sheet piling, and temporary wall removal (between S1.5 and S4) at end of S4	68-101

1.2 SDOOL DUPLICATION/RELOCATION DEVELOPMENT OVERVIEW

The SDOOL pipeline duplication/relocation (*Annex A*, *Figure 1*) is a relatively shallow-excavation relief sewer installation to convey treated wastewater from the Water Corporation's Woodman Point, Kwinana, and Point Peron treatment plants to the ocean. The existing SDOOL and original proposed duplication from the Water Corporation runs through the proposed MBM.

Accordingly, in liaison with the Water Corporation, Cedar Woods developed an alternative alignment for the SDOOL duplication, which will also include the relocation of a section of the existing SDOOL. This pipeline is proposed to be placed adjacent to the MBM for part of its route (*Annex A*, *Figure 1*).

Trenching associated with SDOOL duplication and relocation installation will require temporary dewatering to a depth of 1.84 to -1.56 m AHD. The locations and dewatering elevation were provided in the engineering drawings provided to ERM by TABEC. The proposed installation plan uses two separate working crews, each advancing the trenching continuously from east to west in 100 m segments, with each dewatering segment comprising a length of approximately 200 m (50 m in front and behind the 100 m trench), advancing at an approximate speed of 12.5 m/day.

2 *SITE SETTING*

Regional and local geology, hydrogeology and hydrology have been reported by MWH (MWH, 2010a) and are not repeated in detail in this modelling report. Since the MWH report, supplemental field work has been completed by ERM (*Annex C*), the results of which are included in the discussion pertaining to the model development below.

2.1 *GEOLOGY*

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

- 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 MWH and ERM in the general vicinity of the proposed MBM, 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 (well MB05 on *Annex A*, *Figure 1*) to -22.5 m AHD (well LR1 on *Annex A*, *Figure 1*).

The TL underlies the SBS. It is 4 to 7 m thick in the general vicinity of the MBM and is underlain by interbedded shales, clays, and the Rockingham Sand. 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 in the MBM area.

The Leederville Formation exists as a subcrop 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 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 (*Annex C*).

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 serves as an aquitard.

2.2.1 *Aquifer Parameters*

Table 2.1 summarises aquifer parameters for the SBS and TL units.

Table 2.1 Aquifer parameters for the SBS and TL units

Aquifer Parameter	Safety Bay Sand	Tamala Limestone
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 and six orders of magnitude of variation for fractured rock formations (defined by Shapiro to include limestone)) according to a leading United States authority (Shapiro, 2004). The uncertainty of these variations is greatly reduced in ERM's modelling through the advanced modelling used, which rely more on the site water balance, which can be well defined. The modelling is thus able to avoid the use of these uncertain aquifer parameters as input data, except for the hydraulic conductivity, which 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*

Groundwater flow in the SBS is typically from inland areas to the ocean, to the west of the groundwater divide shown in *Annex A*, *Figure 4*. 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 *Annex C*:

Table 2.2 Water Level and Electrical Conductivity/Elevation Data within SBS and TL

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

Salt water below the saltwater interface in the TL is essentially stationary according to general saltwater intrusion theory.

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

The uppermost aquifer, the SBS, has its eastern boundary approximately 8.3 km inland from the MBM site, 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 (*Annex A*, *Figure 4*).

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 the 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. Saline conditions across the thickness of the TL extend inland from the MBM area under current conditions to approximately the groundwater divide (Smith, 2001).

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

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 the following section. 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 MBM has no defined surface water drainage systems except for swales among sand dunes. Concentration of stormwater runoff for 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), however reports from MWH in 2010 suggested that water levels have previously dropped beneath 0m AHD (noting however potential confusion in the datum reference height).

The Lake was formerly reported to be saline (it was once connected to the Indian Ocean). Thus, salt levels observed in this lake are likely primarily legacy-salt related. 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.

Mean annual rainfall at Medina, approximately 5 km northeast 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, USA. 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 groundwater 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. MODAEM and SEAWAT and are set up using the Groundwater Modeling System (GMS) developed by Aquaveo (Aquaveo, 2011).

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. Instead of relying on artificial boundaries of traditional box-style modelling with higher uncertainties, regional-scale modelling 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, field data for which have orders of magnitude of uncertainty (Shapiro, 2004).

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 been 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 MBM and SDOOL area.

ERM ran several iterations of the regional groundwater MODAEM model, starting with a large area covering over 2,000 square kilometres. This modelling identified the necessary modelling region (the blue outline in *Annex A*, *Figure 4*) that is relevant for developing a site area model for the MBM and 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 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 geological 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 *Annex A*, *Figures 2* and *3*.

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. Recharge rates remains relatively uniform throughout the study region. The regional groundwater flow model input parameters are presented in *Annex D*, *Table 1*.

Modelled regional groundwater contours under mean water level conditions are presented on the right side of *Annex A*, *Figure 4* 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, MBM 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 4,000 m east of Lake Richmond (*Annex A*, *Figure 4*) with: groundwater west of this divide discharging to the costal area; and groundwater to the east of this divide discharging 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 model developed for the site using SEAWAT is a large, complex, 3-D, multi-layer, transient groundwater flow and salinity transport model. The SEAWAT model has been developed based on the findings derived from the regional groundwater flow model. The western boundary of the localized SEAWAT model is the coastline; the eastern boundary is the natural groundwater divide (*Annex A*, *Figure 4*) in SBS that was derived from the regional groundwater flow model.

ERM assigned a variable spacing to the SEAWAT model grid, with a more dense grid near the areas of interest (Lake Richmond, SDOOL, and MBM) and a coarser grid away from them. This horizontal grid layout is presented on the left side of *Annex A*, *Figure 5*. The model includes eight vertical grids (*Annex A*, *Figure 5*) 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 (*Annex A*, *Figure 5*). The inset in *Annex A*, *Figure 5* depicts the 3-D SEAWAT model grids.

The model input parameters for the regional groundwater flow model (*Annex D, Table 1*) were retained for the SEAWAT model. The SEAWAT model input parameters are presented in *Annex D, Table 2*. 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 (*Annex D, Table 2*), 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. 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 MBM and SDOOL construction and operation simulations.

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 (*Annex A*, *Figure 5*). 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.

Annex A, *Figure* 6, *7*, and *8* present modelled local-area groundwater contours in the SBS under mean, high, and low water level conditions, respectively, in the absence of SDOOL or MBM development.

The modelled existing salinity distribution at -12 m AHD (in the mid-depth of the SBS) is presented in plan view in *Annex A*, *Figure 9*. *Annex A*, *Figure 10* 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 *Annex A*, *Figure 11*. 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 localized (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.

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 this project

4. *MODEL RESULTS*

4.1 *MODELLING PREDICTIONS*

4.1.1 *Modelled Existing Groundwater Flow Conditions*

The modelled groundwater contours and salinity distributions under existing conditions are presented in *Annex A*, *Figures 6* through *12*. Modelling indicates that groundwater in general flows northwest in the MBM area 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 (*Annex A*, *Figure 3*) 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 MBM and SDOOL 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 seasons when the lake level drops below approximately 0.1 m AHD. For most remaining times, the lake discharges water to the northwest.

The modelling indicates a relatively flat saltwater interface beneath the shallow unconfined groundwater aquifer in the SBS in the MBM area. This saltwater interface separates the fresh water above and saline water below, and does not allow significant vertical water leakage through it even though the saltwater interface can shift slightly because of various pumping and dewatering conditions. 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 that part 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 (or saline interface equivalent of it). Tidal effects travel quickly inland only in confined aquifers and in those with higher aquifer transmissivities, both of which characterize the TL.

Modelling indicates that the northwestern portion of the MBM and the western section of the SDOOL are 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 (*Annex A*, *Figure*

12). 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 *Mangles Bay Marina Construction Method Selection*

For the modelling scenario's, several construction methods for MBM were proposed to determine the scenario likely to have the least impact on the surrounding environment and groundwater users. Three scenarios were modelled:

1) Option 1: Dewatering to enable dry construction of both the proposed marina and all canals in the MBM development plan;

2) Option 2: Dewatering to enable dry construction of only the proposed marina and the main canal; and

3) Option 3: Wet excavation (comprising installation of impermeable barrier wall, combined with dredging) of marina and canal configuration.

Ultimately, based on the results of each modelling scenario (see *Table 4.1* below), wet excavation construction was chosen as the proposed construction methodology.

Table 4.1 ***Summary of Modelling Scenario Results for MBM and SDOOL***

Option	**Timeframe**	**Modeled Maximum Change in Lake Richmond Water Level (m)**	**Modeled Change in Salinity (SBS in vicinity of MBM)**	**Modeled Change in Salinity (Lake Richmond)**
1: Dry excavation (marina and all canals)	Construction	-0.42	greater inland extent than Scenario 2	None discernible
	Operation	-0.038	greater inland extent than Scenario 2	None discernible
2: Dry excavation (marina and main canal only)	Construction	- 0.19	reduced inland extent relative to Scenario 1	None discernible
	Operation	- 0.016	reduced inland extent relative to Scenario 1	None discernible
3: Wet excavation	Construction	- 0.032	None discernible	None discernible
	Post-Construction	- 0.038	None discernible	None discernible
SDOOL	Construction	- 0.24	None discernible	None discernible
Option 3 + SDOOL (cumulative)	Construction	- 0.25	None discernible	None discernible

Detailed discussion of the MBM (wet excavation) and SDOOL modelling results are provided in the Sections below. Further detailed modelling results of the other scenario options discussed above are provided in *Annex B*.

4.1.3 *Modelled Mangles Bay Marina Construction Scenario*

The MBM construction requires wet excavation (wet dredging) for canal and marina construction, temporary wall installation and removal, and sheet piling installation along several sections of the marina boundary. The construction details and timing are described in Section 1 of this report.

The modelled water level changes of Lake Richmond during MBM construction are presented in *Annex A*, *Figure 16*. Modelling indicates that the maximum Lake Richmond level drop is approximately 0.032 m in Stage 4 of the construction. This temporary lake level drop is well within its natural water level fluctuation of 1.2 m. *Annex A*, *Figure 17* presents a snap image of modelled groundwater contours during construction.

The modelled salinity distribution at the end of the wet dredging scenario is presented in *Annex A*, *Figure 18*. The modelled saltwater intrusion area under the proposed construction scenario is greater than that under natural conditions (*Annex A*, *Figure 12*) but less than that under the modelled future steady-state condition with the SDOOL and MBM in place (*Annex A*, *Figure 23*). Once the MBM is constructed, the canals and marina will be connected to the sea and thus enable saltwater to be present within these features, which extend inland from the natural coast. Consequently, salinity will be locally higher in the SBS under future steady-state conditions than during construction, because as the saltwater fills the MBM water features, it will gradually sink below fresh water and form a new saltwater interface near the MBM boundary. The modelled saltwater intrusion area does not impact other well bores in the area, except wells 1, 7, and 8, all of which had been impacted by the saltwater under existing, natural conditions.

Modelling does not indicate a discernible change in salinity level in Lake Richmond throughout the MBM construction scenario.

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

4.1.4 *Modelled SDOOL Construction Scenario*

The SDOOL construction requires temporary excavation and dewatering for a relatively short period of time. The construction details and timing are described in Section 1 of this report. SDOOL construction and dewatering occur in 200-m trench intervals that move westward at approximately 12.5 m per day. It is assumed that excavation and dewatering for both the SDOOL duplication and the proposed rerouting of the existing SDOOL in the MBM area will occur concurrently, for economies of construction and to minimise disruption along the route.

The modelled water level change of Lake Richmond during SDOOL construction is presented in *Annex A*, *Figure 13*. Modelling indicates that the maximum Lake Richmond level drop is approximately 0.24 m, which occurs shortly after construction. This temporary lake level drop is well within its natural water level fluctuation of 1.2 m. *Annex A*, *Figure 14* presents a snap image of modelled groundwater contours during the construction. *Annex A*, *Figure 14* also lists modelled dewatering rates during various periods of the trenching: 2,500 to 2,900 m^3/day for the eastern front, and 500 m^3/day for the western one. It should be emphasized that these modelled dewatering discharge rates 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 *Annex A*, *Figure 15*. Modelling does not indicate a discernible change in salinity level in Lake Richmond or the SBS aquifer throughout SDOOL construction.

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 Combined SDOOL and MBM Construction Scenario

This scenario evaluates the impacts of SDOOL and MBM construction combined. The construction details and timing for each of these projects are described in Section 1 of this report. The SDOOL construction is assumed to start at Stage 1 of MBM construction.

The modelled water level change of Lake Richmond during the SDOOL/MBM construction is presented in *Annex A*, *Figure 19*. Modelling indicates that the maximum Lake Richmond level drop is approximately 0.25 m in Stage 1 of MBM construction. This temporary lake level drop is well within its natural water level fluctuation of 1.2 m. *Annex A*, *Figure 20* presents a snap image of modelled groundwater contours during the construction. *Annex A*, *Figure 20* also lists modelled dewatering rates during various periods of the SDOOL trenching: 2,500 to 2,900 m^3/day for the eastern front and 500 m^3/day for the western one. It should be emphasized that these modelled dewatering rates have an uncertainty of approximate ±50% because of various factors, including seasonal variation.

The modelled salinity distribution at the end of this construction dewatering scenario is presented in *Annex A*, *Figure 21*. The modelled saltwater intrusion area under the proposed SDOOL and MBM construction scenario is greater than that under natural conditions (*Annex A*, *Figure 12*) but less than that under the modelled future steady-state condition with SDOOL and MBM in place (*Annex A*, *Figure 23*). Once the MBM is constructed, the canals and marina will be connected to the sea and thus enable saltwater to be present within these features, which extend inland from the natural coast. Consequently, salinity will be locally higher in the SBS under future steady-state conditions than during construction, because as the saltwater fills the MBM water features, it will gradually sink below fresh water and form a new saltwater interface near the MBM boundary. The modelled saltwater intrusion area does not impact other well bores in the area, except wells 1, 7, and 8, all of which had been impacted by the saltwater under existing, natural conditions.

Modelling does not indicate a discernible change in salinity level in Lake Richmond throughout the combined SDOOL and MBM construction scenario.

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

4.1.6 Modelled Post-Construction Conditions

This model simulation represents future steady-state conditions after the completion of SDOOL and MBM construction. The water level along the SDOOL will be allowed to recover naturally, and the MBM will maintain sea-level water levels, which are slightly lower than those under existing conditions. The locations of the SDOOL and MBM are presented in *Annex A*, *Figure* 22.

The modelled future steady-state groundwater contours with the SDOOL duplication/realignment and MBM in place are presented in *Annex A*, *Figure 22*. The modelled total groundwater discharge rate to the MBM on average is 380 m^3/d, which is modelled to increase to 570 m^3/d (a 50% increase) in winter and decrease to 250 m^3/d (a 50% decrease) in summer.

Modelling indicates that the Lake Richmond level drops approximately 0.038 m, which is insignificant compared to its natural water level fluctuation of 1.2 m.

The modelled future steady-state salinity distribution is presented in *Annex A*, *Figure 23*. The modelled saltwater intrusion area is confined to the MBM vicinity and is greater than those modelled during the SDOOL and MBM construction stages. This is because saltwater has been introduced further inland through the construction of the canals and marina. The modelled saltwater intrusion area does not impact other well bores in the area, except the bores for Wells 1, 7, and 8, all of which had been impacted by saltwater under existing conditions.

Modelling does not indicate a discernible change in future salinity level in Lake Richmond once the SDOOL and MBM are 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 MBM 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 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 *Annex D, Table 3*. This table indicates that the mean sum of the residuals is 0.053 m, which is 3 percent of the natural water table range of 1.75 m. The root mean square of the residuals is 0.149 m which is much lower than the 1 m range recommended in the 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 *Annex A*, *Figure 24*.

Note that data from wells LR2 and LR3 could not be included in *Annex D, Table 3*, 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

Annex D, Table 3 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 5-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 *Annex C* to this report) likely actually ranges from 5,000 to 25,000 µS/cm. This range is based upon the observed 5-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 *Annex D, Table 3* have exceeded those models that have been accepted by EPA in Western Australia. The developed SEAWAT model is therefore suitable for simulations of the proposed SDOOL and MBM 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 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 error 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 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 *Annex A*, *Figure 25*, which indicates that the model is essentially not sensitive to the hydraulic conductivity input for SBS.

The regional groundwater model conducted for this project employs a unique intrinsic relationship between the hydraulic conductivity of the SBS and other parameters, including the recharge rate. This relationship is governed by Darcy's Law. The model's derived recharge rate, especially during winter while recharge is high and withdrawal is low, is consistent with the observed one. This further indicates that the model-assumed hydraulic conductivity value for the SBS is reasonable.

Similar to the hydraulic conductivity of SBS, the vertical hydraulic conductivity of the basal aquitard has been determined by the model calibration process. An increase or decrease of this value would result in modelled SBS water levels lower or higher than the observed conditions, respectively. The model-determined value of 0.00013 m/d resulted in a reasonable 15% of SBS recharge leakage to the underlying TL. The model was also used to test a scenario of an assumed vertical hydraulic conductivity of 0.02 m/d for the aquitard. The modelling indicated 90% of SBS recharge to the TL and water levels in the SBS more than 1 to 3 meters below those observed. Note that the vertical hydraulic conductivity of the aquitard is not an assumed value and so is not subject to model sensitivity analyses.

The AEM model was used for the regional groundwater flow model. AEM (Strack, 1988) models are intrinsically and theoretically balanced in terms of water budget and water balancing not therefore required. The water balance difference for the SEAWAT model is less than 0.07%.

5 MODEL ASSESSMENT CONCLUSIONS

The results of the SEAWAT modelling conducted for the proposed SDOOL and MBM projects indicated the following:

- Lake Richmond water levels during MBM construction will be reduced by 0.032 m;
- Lake Richmond water levels during SDOOL construction will be reduced by 0.24 m;
- Lake Richmond water levels during combined SDOOL and MBM construction will be reduced by 0.25 m;
- Lake Richmond water levels during the long term (after all construction is complete) will be reduced by 0.038 m;
- Saltwater intrusion is expected to be confined to the vicinity of the MBM during MBM construction and operation;
- Saltwater intrusion is not discernibly affected by SDOOL construction;
- Salinity levels in Lake Richmond are not expected to change discernibly during both combined and separate MBM and SDOOL construction and operation.

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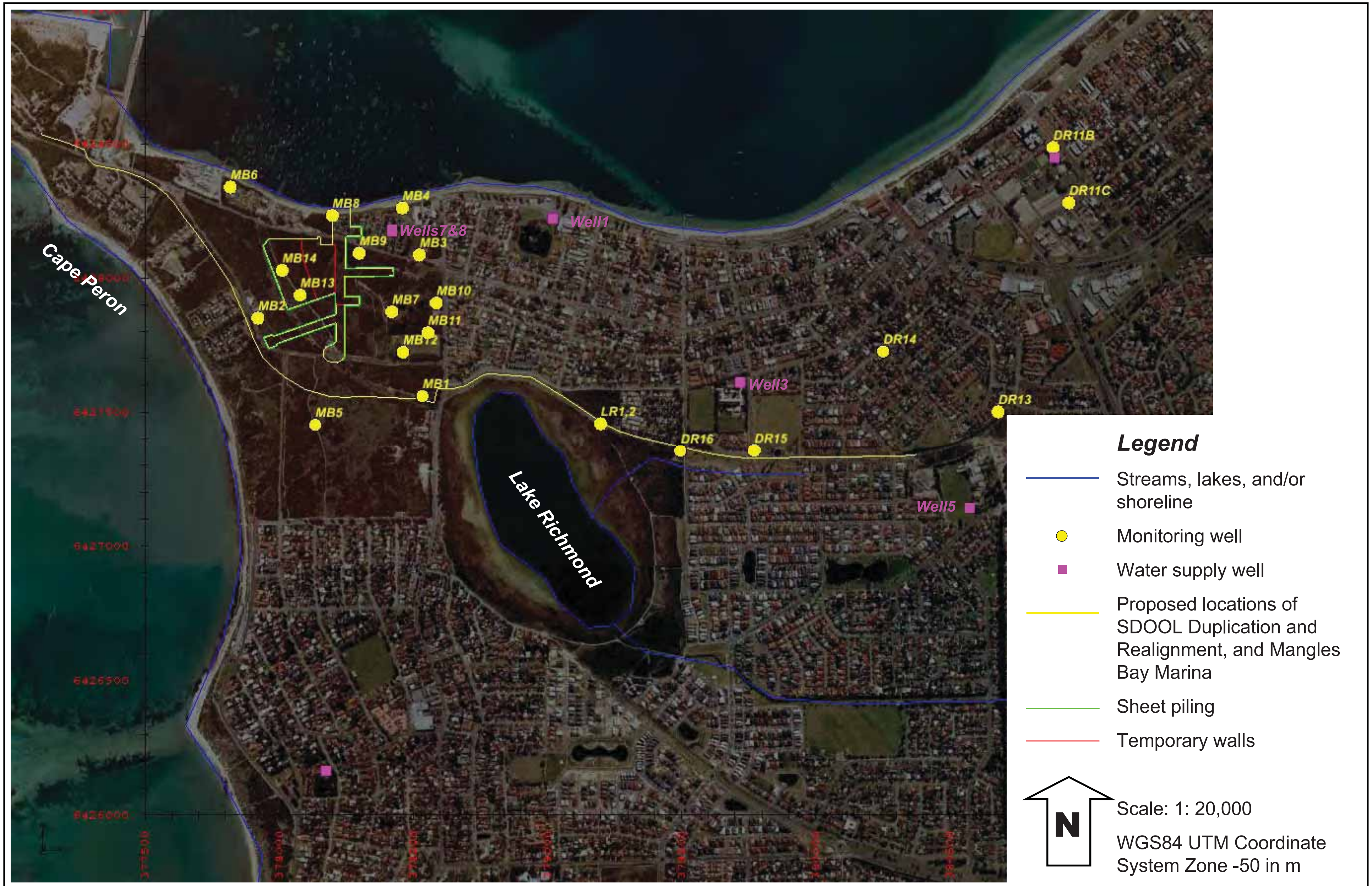
Annex A

Figures



ERM
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172 St. Georges Terrace
Perth, WA 6000
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Site Map, Well Bores, SDOOL and Mangles Bay Marina Locations
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 1

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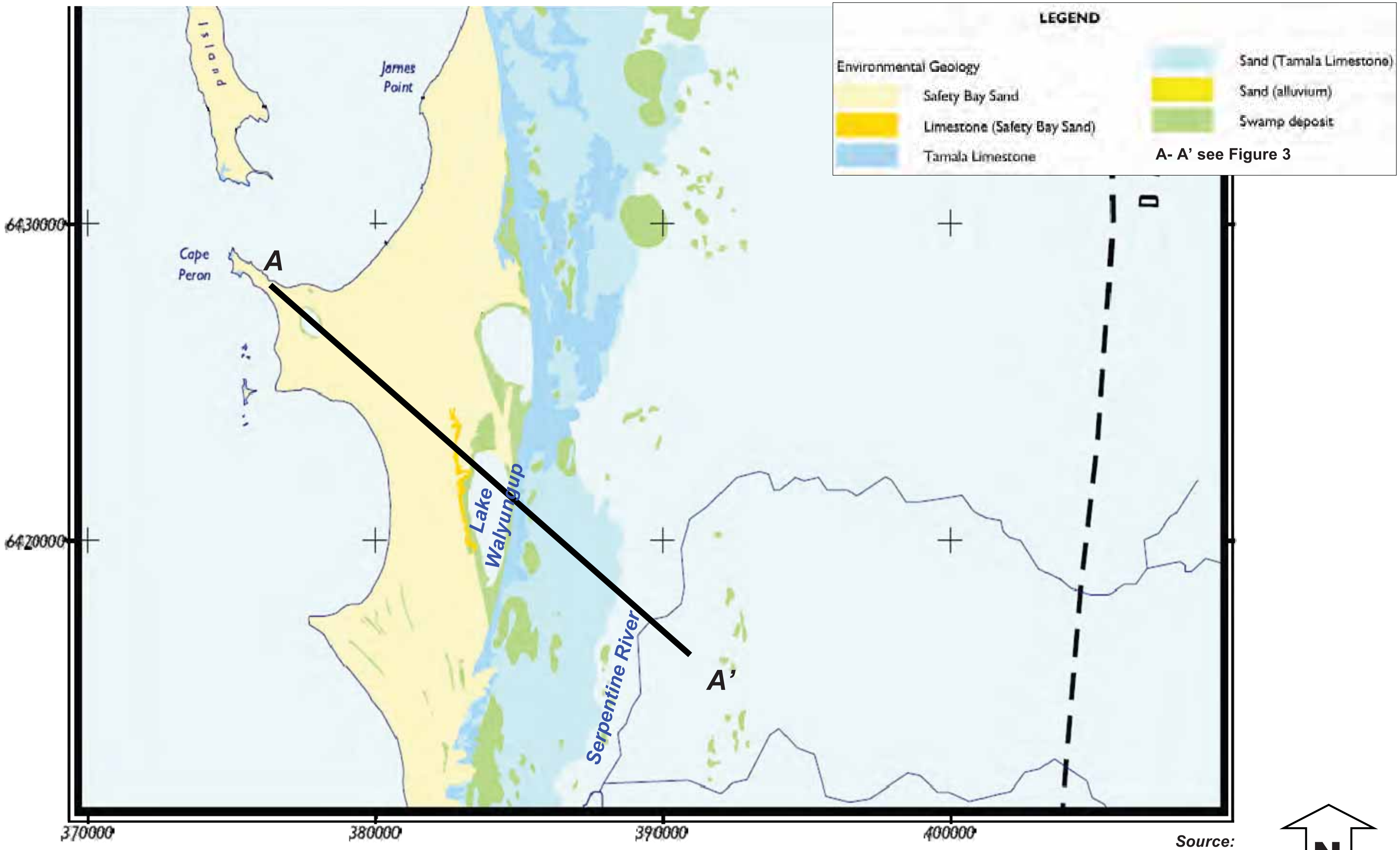

Data Sources:
1:50,000 Environmental Geology Series (DOME)

Source:
Smith, 2001
Not to Scale

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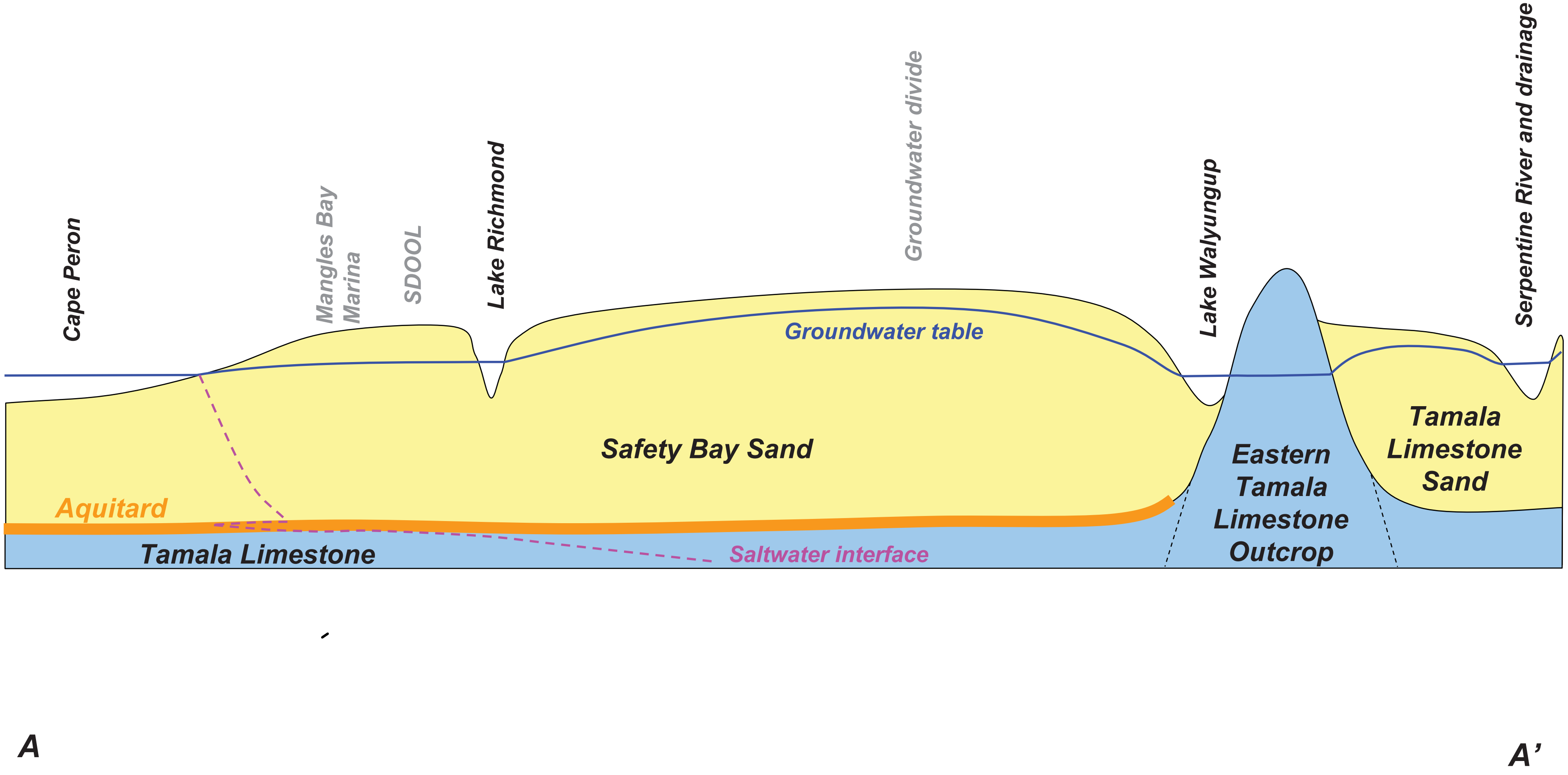
Perth, WA 6000
Australia

Regional Surficial Geological Map
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 2



Note:

A-A’ transect route shown on Figure 2

Based on Smith, 2001

Not to Scale

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Australia

Conceptual Regional Hydrogeologic Profile
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 3

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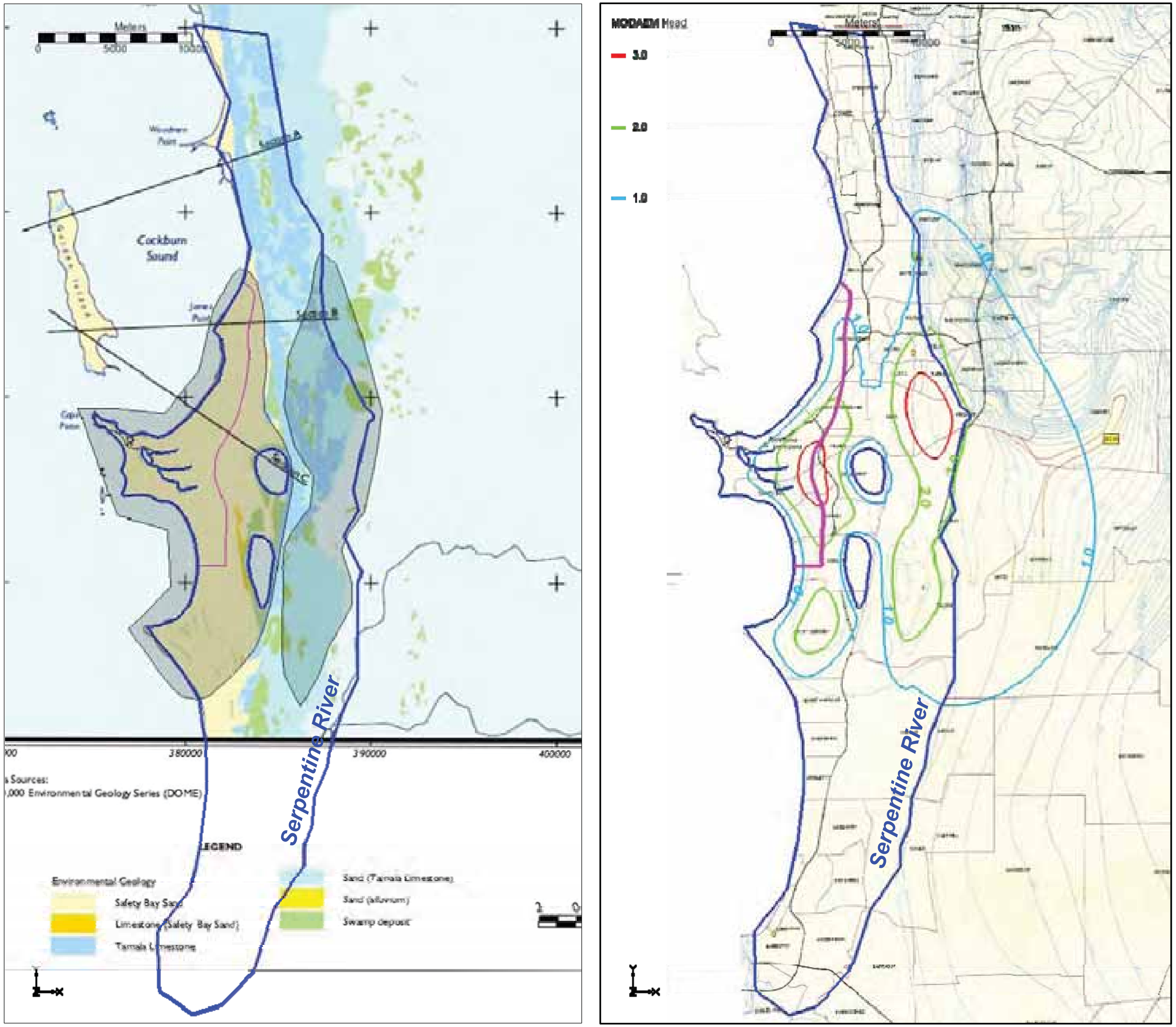

Legend

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

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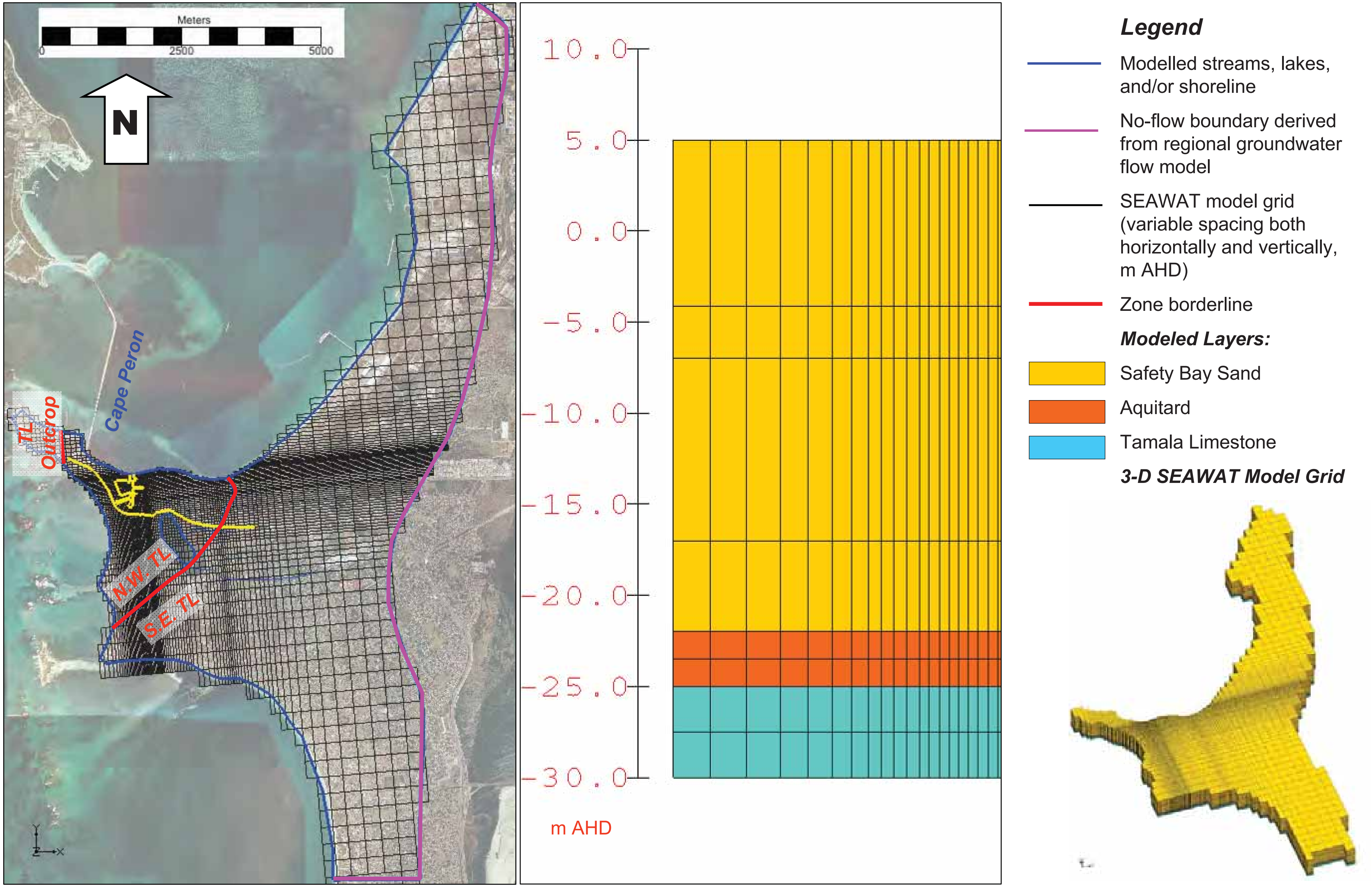
Regional Groundwater Flow Model Layout and Modelled Groundwater Contours
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 4



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

Figure 5

Legend

━	Streams, lakes, and/or shoreline
━	Modelled groundwater contours, m AHD
●	Monitoring well
■	Water supply well
━	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM

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Modelled Groundwater Contours – Existing Mean Water Level Conditions
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 6

Legend

―	Streams, lakes, and/or shoreline
―	Modelled groundwater contours, m AHD
○	Monitoring well
■	Water supply well
―	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM

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Modelled Groundwater Contours – Existing High Water Level Conditions
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 7

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Legend

- Streams, lakes, and/or shoreline
- Modelled groundwater contours, m AHD
- ● Monitoring well
- ■ Water supply well
- Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

N

Scale: 1: 20,000

WGS84 UTM Coordinate
System Zone -50 in m

ERM

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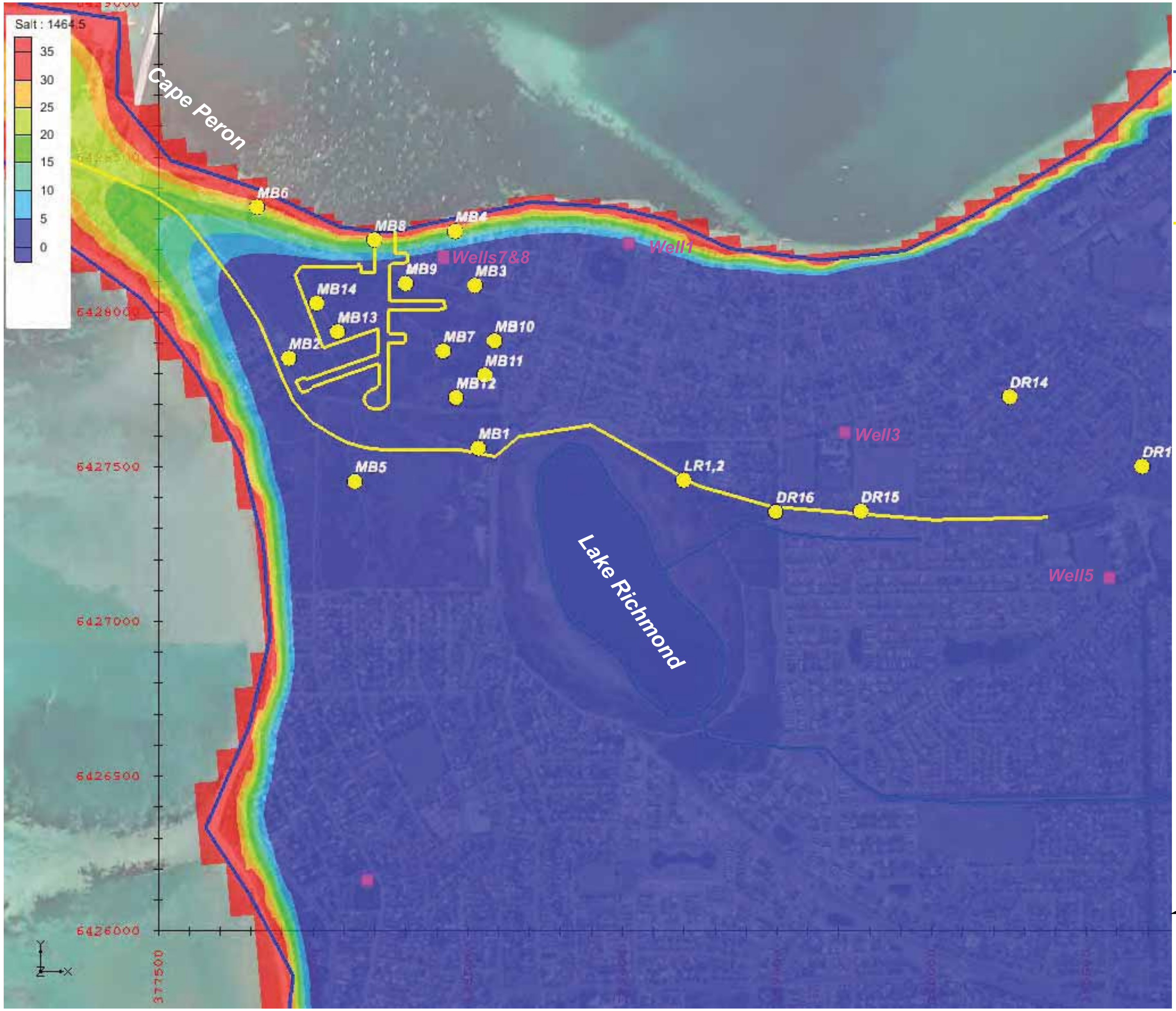
Modelled Groundwater Contours – Existing Low Water Level Conditions
(to be modified) SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 8



Legend

— Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

— Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity at -12 m AHD

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

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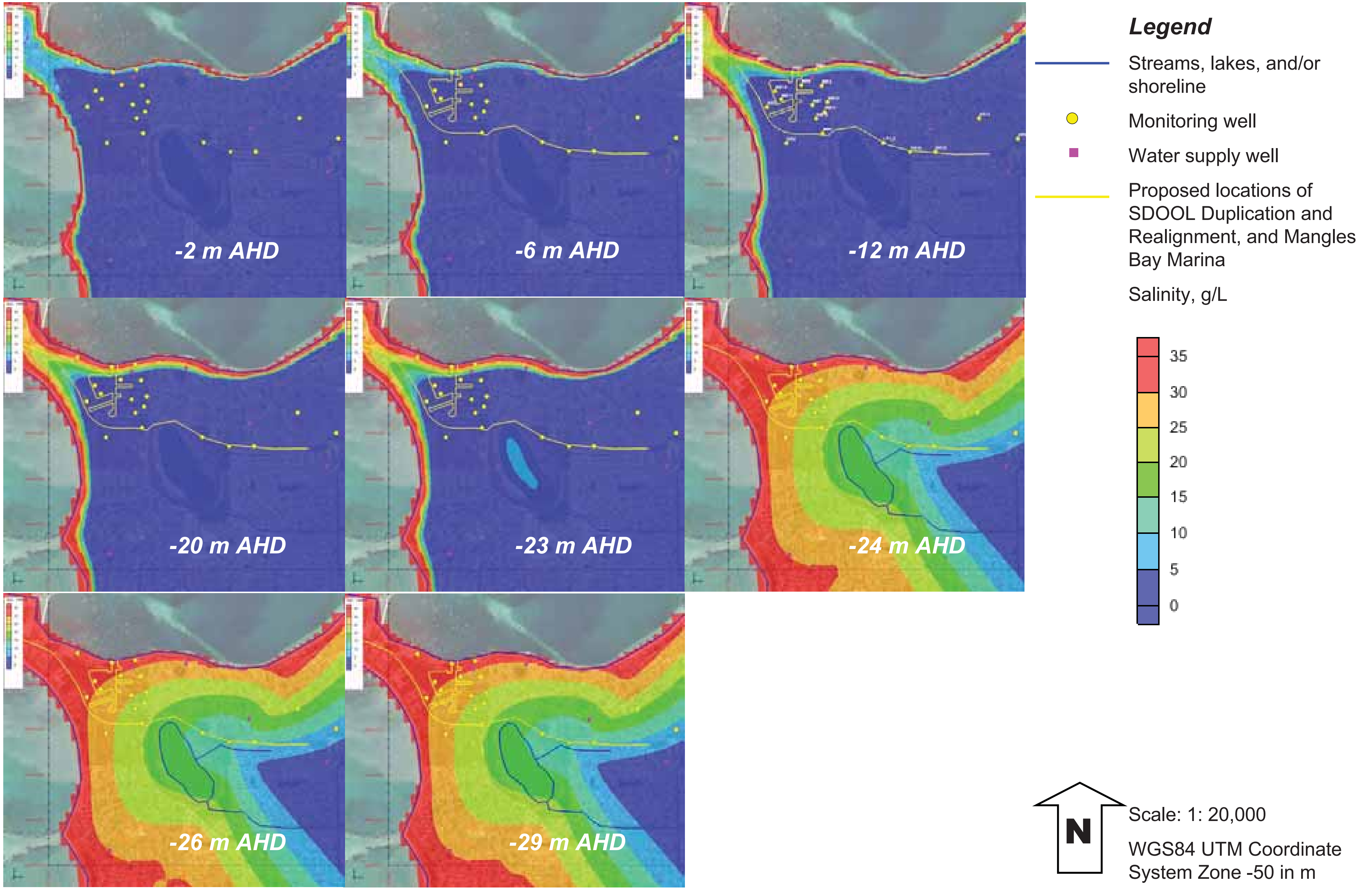
Modelled Salinity Distribution under Existing Conditions
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 9



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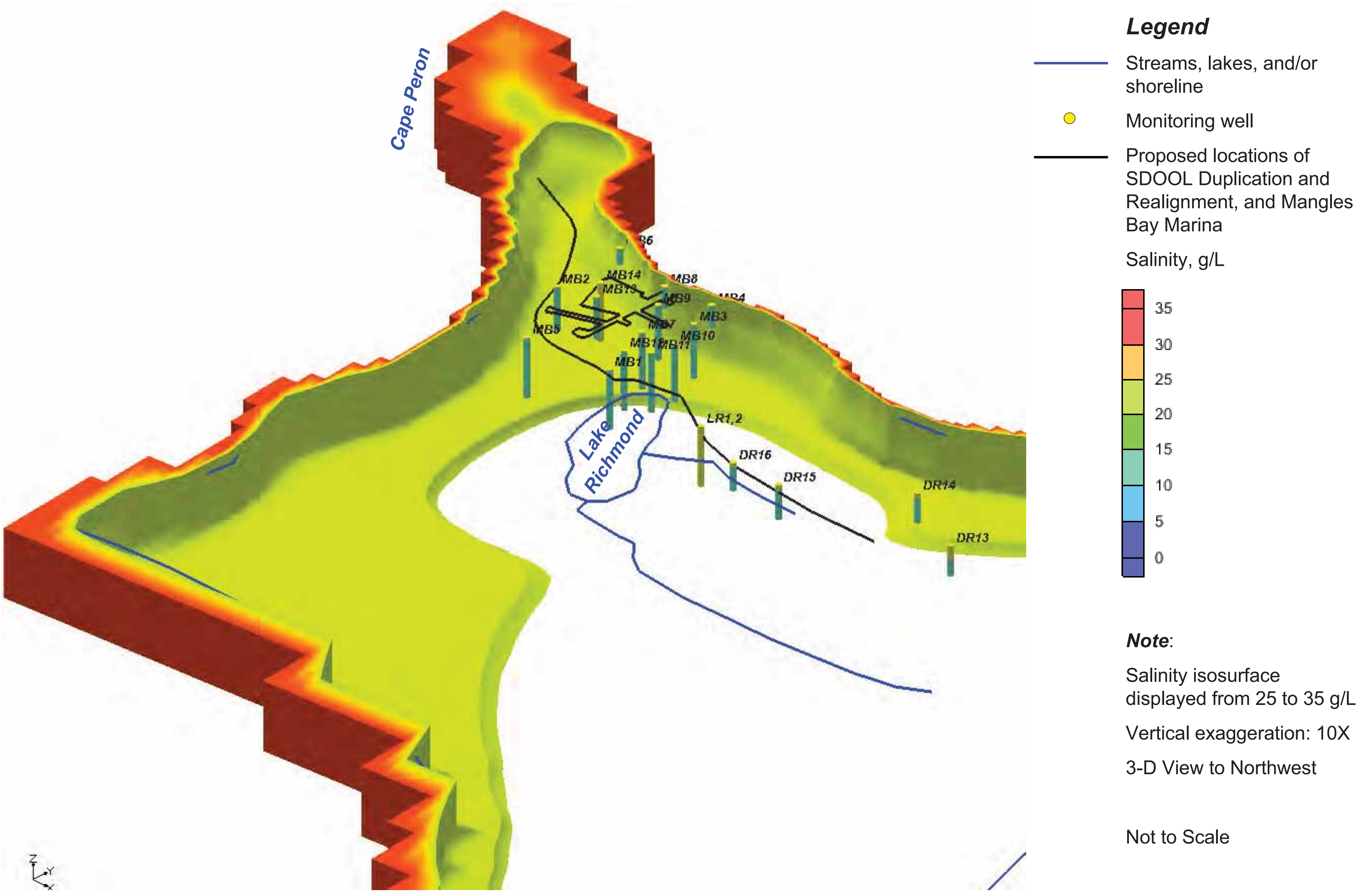
Modelled Salinity Distribution under Existing Conditions at Various Depths
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 10



Legend

Streams, lakes, and/or shoreline

Monitoring well

Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Salinity, g/L

Note:

Salinity isosurface displayed from 25 to 35 g/L

Vertical exaggeration: 10X

3-D View to Northwest

Not to Scale

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

Figure 11

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Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

Model version for -5.5 mAHD sheep piling simulations

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM
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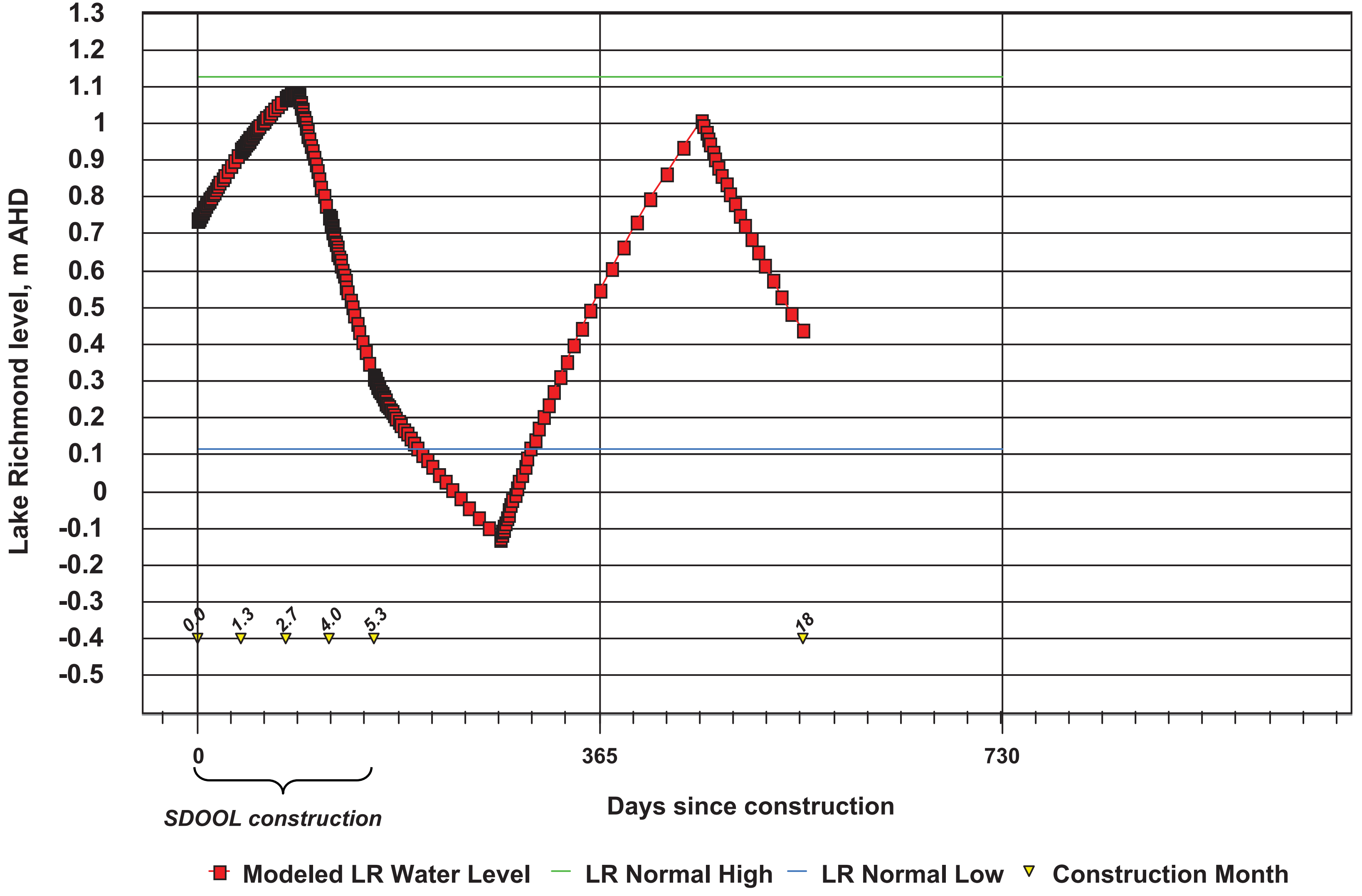
Modelled Existing Salinity Distribution
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 12



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Modelled Lake Richmond Water Level during SDOOL Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 13

Legend

Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

Proposed locations of SDOOL Duplication and Realignment and MBM

Modelled groundwater contours, mAHD

Note:

Modelled largest water level decrease of Lake Richmond is 0.24 m

Modelled average SDOOL discharge rate (±50%), m^3/d:

Days	East Front	West Front
1-40	2900	0
40-80	2500	0
80-120	2700	0
120-160	2500	500

N

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

ERM

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Modelled Groundwater Contours during SDOOL Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 14

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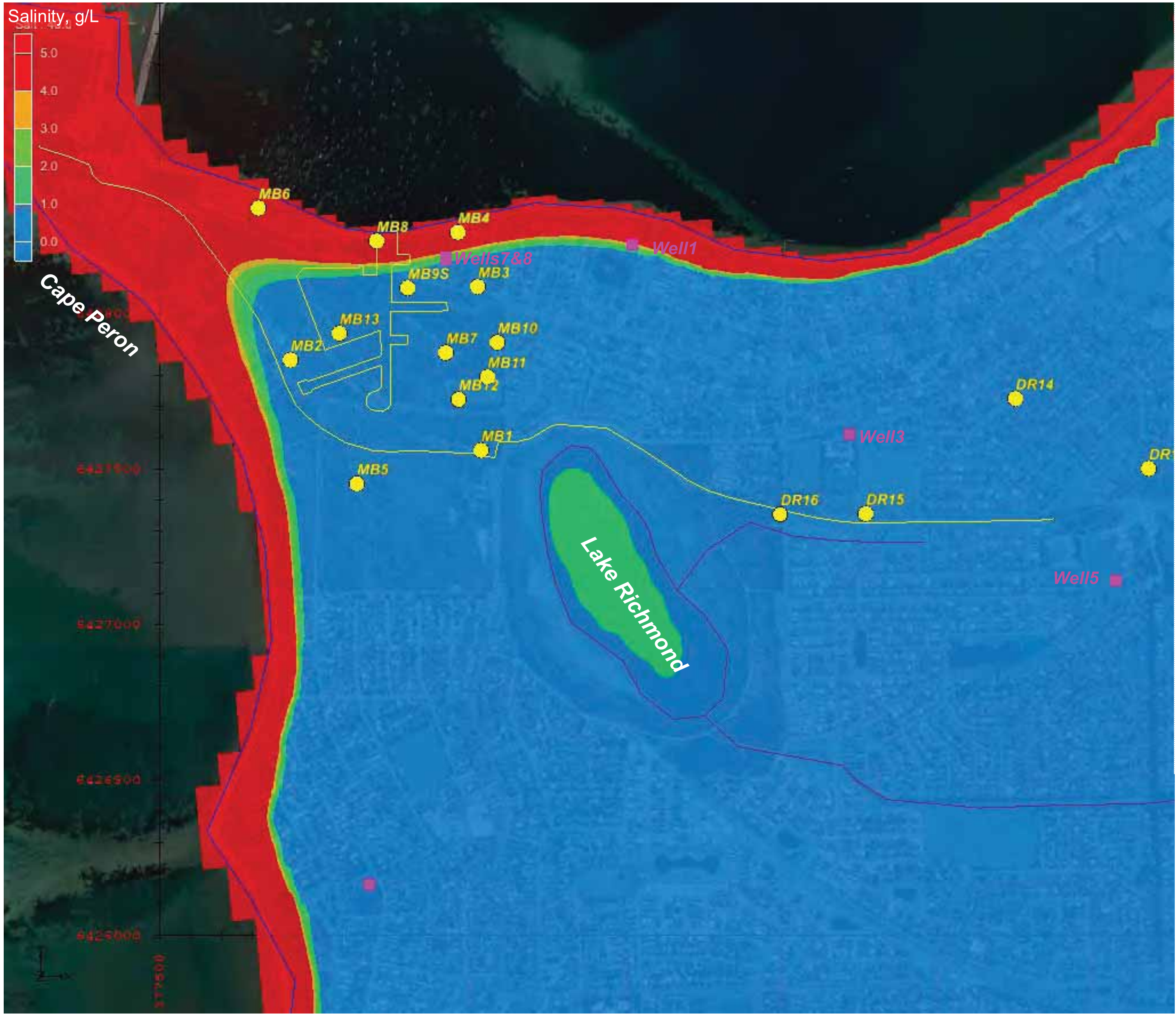

Legend

- Streams, lakes, and/or shoreline
- 🟡 Monitoring well
- ■ Water supply well
- Proposed locations of SDOOL Duplication and Realignment and MBM

Note:

Salinity distribution displayed at -12 mAHD

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

Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

N

ERM
Grain Pool Building, 6th Fl.
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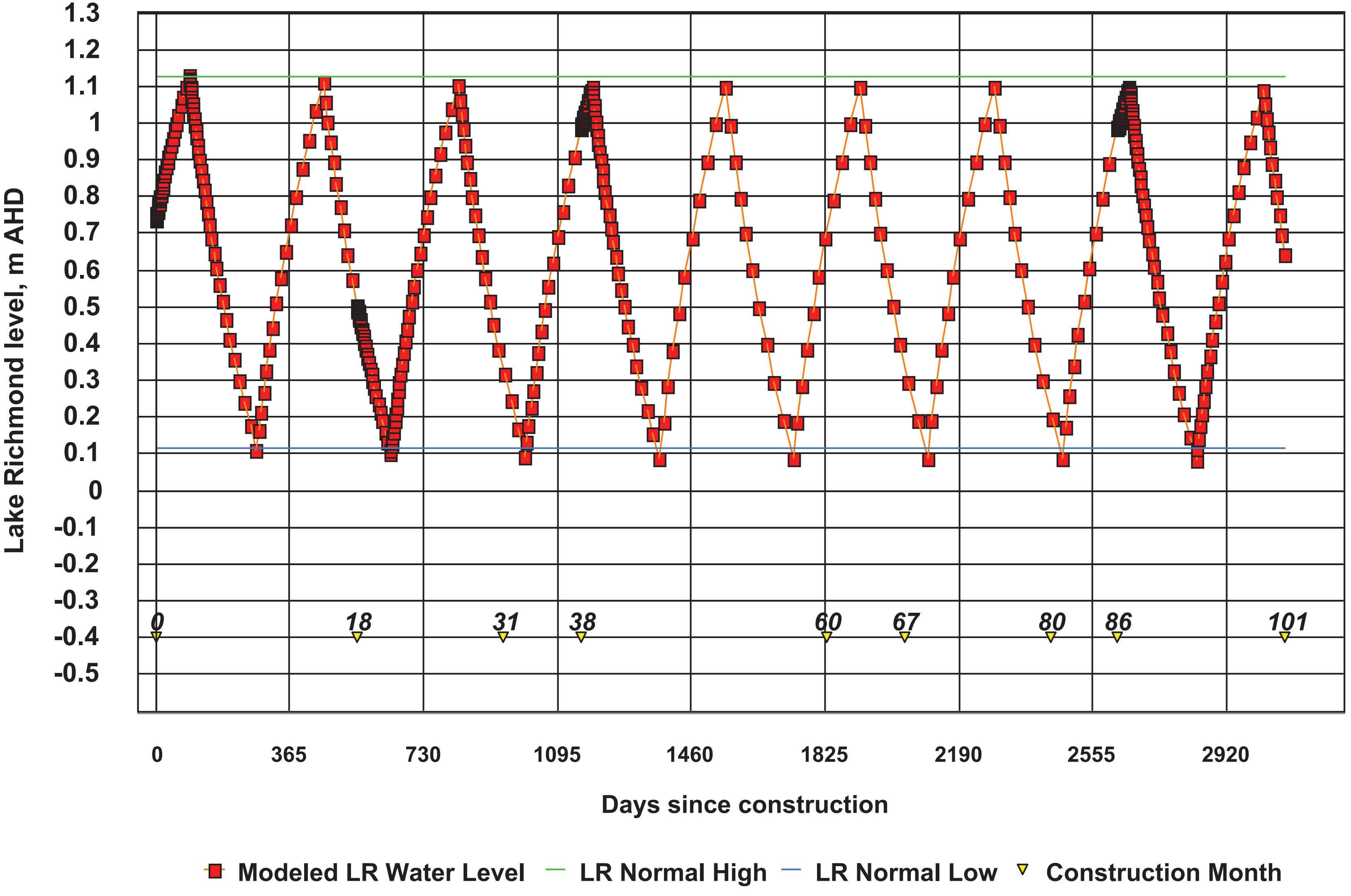
Modelled Salinity Distribution at End of SDOOL Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 15

028619-08/25/2011-HYH-M:\WaterCorp\SDOOL MBM Mew Model Simulations Figures.ppt



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

Modelled Lake Richmond Water Level during MBM Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 16

Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
—	Modelled groundwater contours, mAHD
—	Temporary wall locations
—	Sheet piling

Note:

MBM construction includes sheet piling to -5.5 mAHD, wet excavation, and temporary walls

Water level contours displayed for low water level conditions in Stage 4

Modelled largest water level decrease of Lake Richmond is 0.032 m during Stage 4 of MBM construction

N

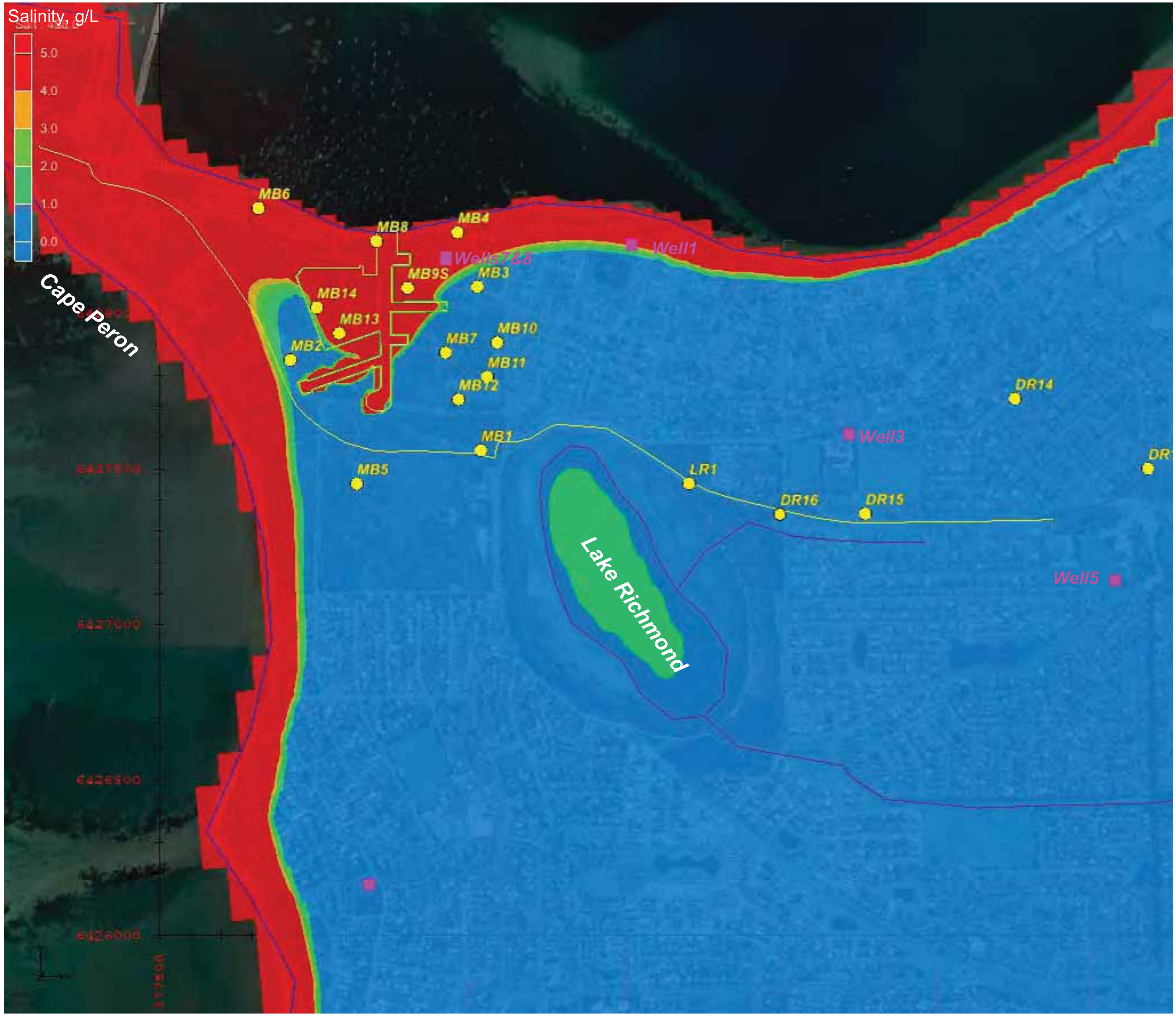
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

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

Modelled Groundwater Contours during MBM Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 17



Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
—	Temporary wall locations
—	Sheet piling

Note:

MBM construction includes sheet piling to -5.5 mAHD, wet excavation, and temporary walls

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond during MBM construction period

N

Scale: 1: 20,000

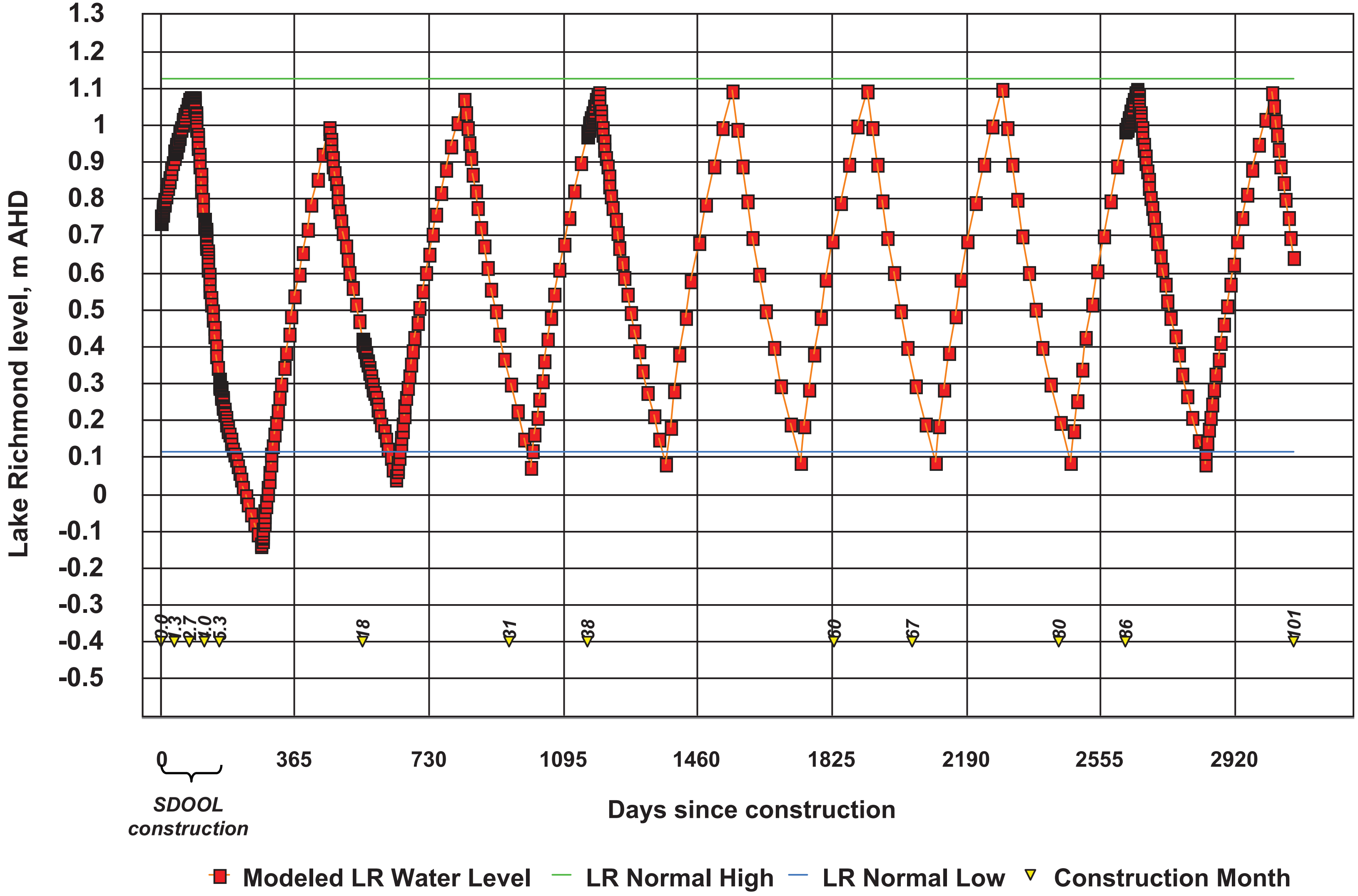
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Salinity Distribution during MBM Construction
SDOOL Duplication and Mangles Bay Marina
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 and MBM Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 19

028619-08/25/2011-HYH-M:\WaterCorp\SDOOL MBM Mew Model Simulations Figures.ppt

Legend

- Streams, lakes, and/or shoreline
- ● Monitoring well
- ■ Water supply well
- Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
- Modelled groundwater contours, mAHD
- Temporary wall locations
- Sheet piling

Note:

Modelled largest water level decrease of Lake Richmond is 0.25 m during Stage 1 of MBM construction

Modelled average SDOOL discharge rate (±50%), m^3/d:

Days	East Front	West Front
1-40	2900	0
40-80	2500	0
80-120	2700	0
120-160	2500	500

N

Scale: 1: 20,000

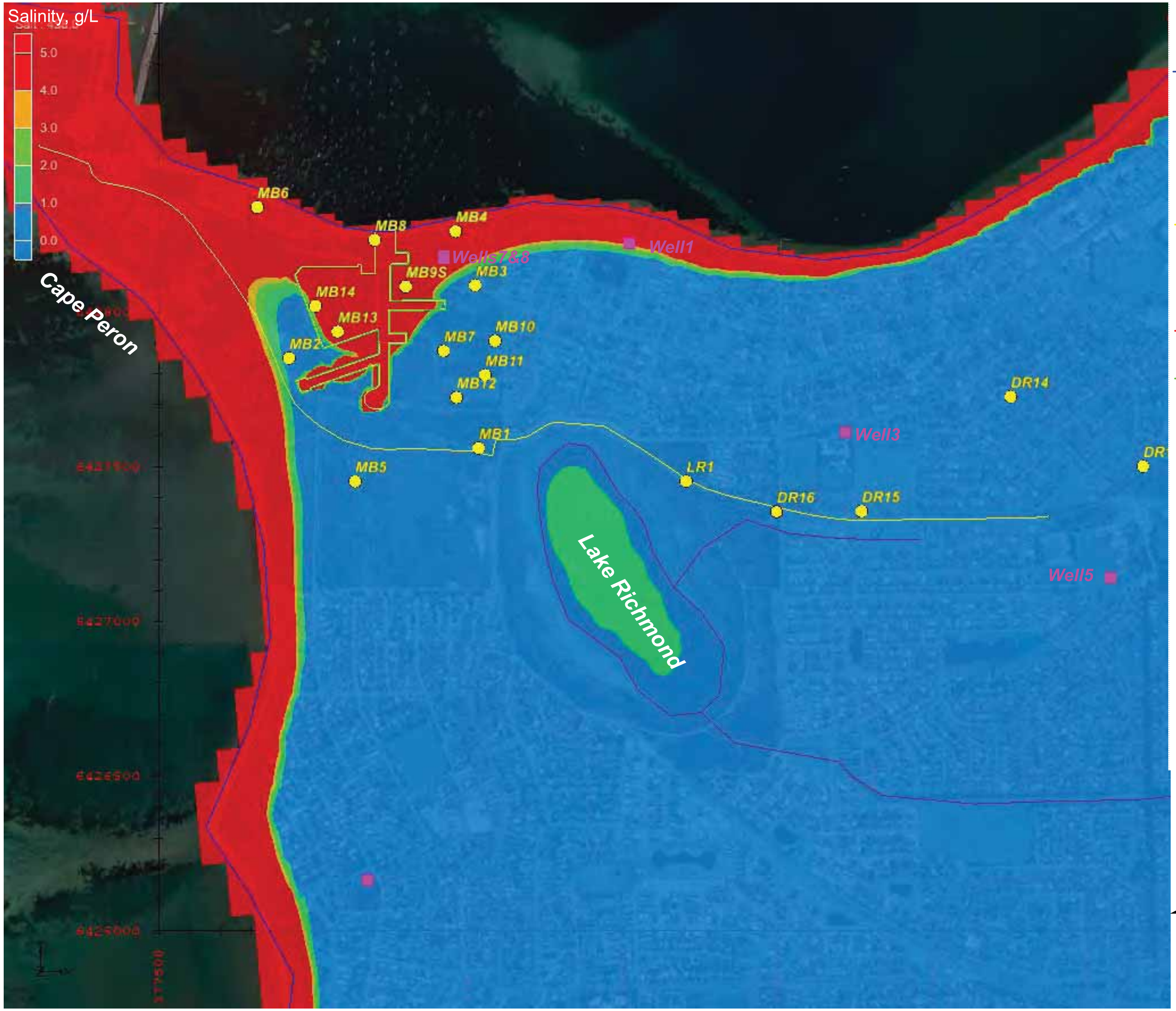
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Groundwater Contours during SDOOL and MBM Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 20



Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
—	Temporary wall locations
—	Sheet piling

Note:

Salinity distribution displayed at -12 mAHD

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

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 and MBM Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 21

Legend

- Streams, lakes, and/or shoreline
- Monitoring well
- Water supply well
- Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
- Modelled groundwater contours, m AHD

Note:

MBM construction includes sheet piling to -5.5 mAHD

Water level contours displayed for low water level conditions

Modelled largest water level decrease of Lake Richmond is 0.038 m

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 with SDOOL and MBM Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 22

Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond

N

Scale: 1: 20,000

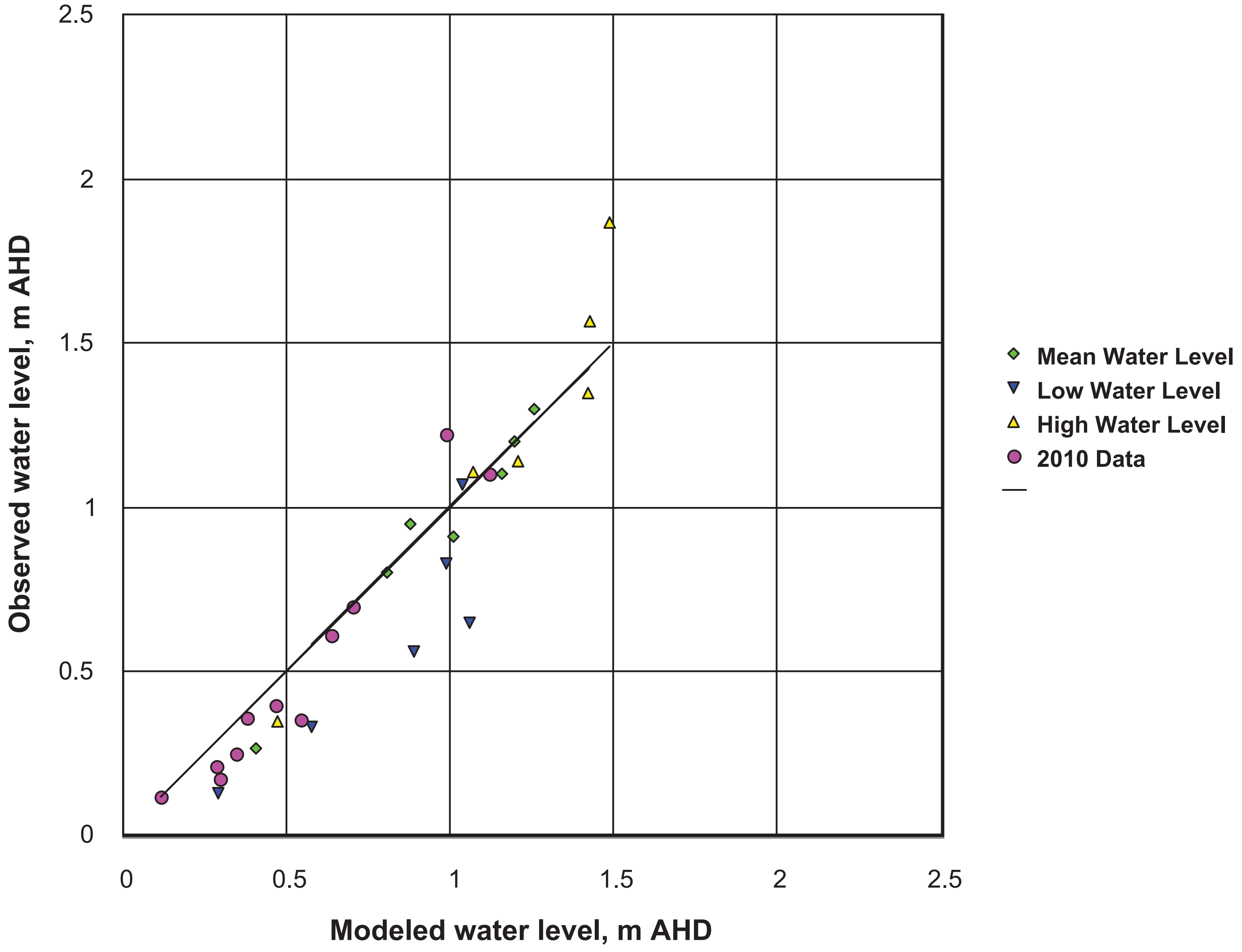
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Future Salinity Distribution with SDOOL and MBM Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

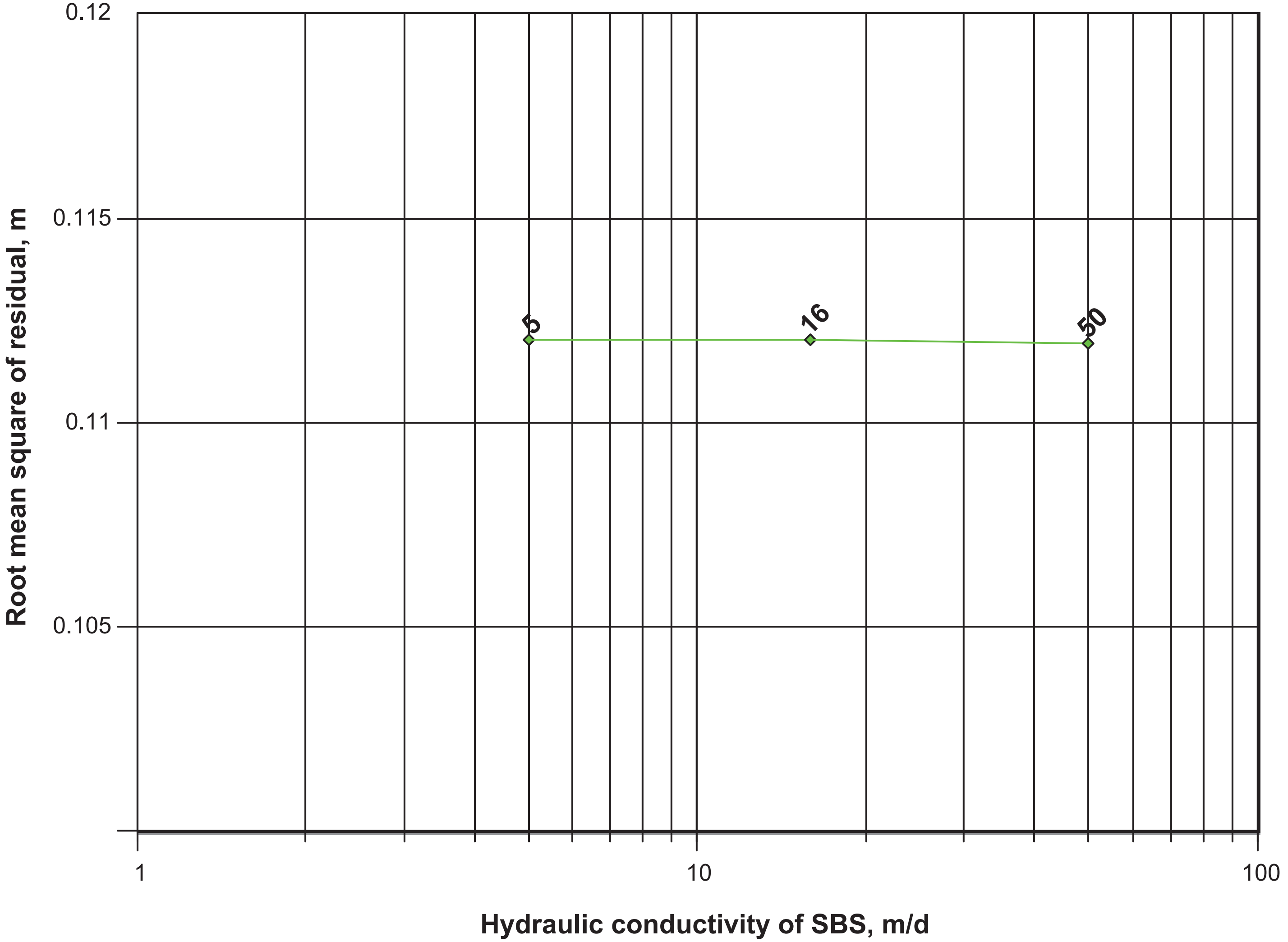
Figure 23



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

Groundwater Flow Model Calibration Results
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 24



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

Model Sensitivity Analysis Results
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure 25

Annex B

Additional MBM Construction Scenarios

ANNEX B CONTENTS

LIST OF ANNEX B FIGURES

B-1 INTRODUCTION

In addition to the final selected modelling scenarios presented in the report to which this Annex is appended, ERM conducted additional modelling using SEAWAT for construction scenarios that were ultimately rejected, because these scenarios (although less expensive to construct) caused greater impacts on Lake Richmond and local aquifer water levels.

The two construction scenarios that were rejected were (1) dewatering to enable dry construction of both the proposed marina and all canals in the MBM development plan and (2) dewatering to enable dry construction of only the proposed marina and the main canal.

For Scenario 1, construction would involve dewatering over the following periods of time (note that no dewatering is required in Stage 3 (12 months) of development):

- Stage 1 (construction of the main canal and three eastern side canals): 20 months, to a depth of -3 m Australian Height Datum (AHD);
- Stage 1.5 (construction of the easternmost marina portion): 12 months during the last 6 months of Stage 1 and the first 6 months of Stage 2, to a depth of -4 m AHD;
- Stage 2 (construction of southwestern canals): 12 months of dewatering, to a depth of -3 m AHD; and
- Stage 4 (construction of the western marina portion): 12 months of dewatering, to a depth of -4 m AHD.

For Scenario 2, construction would involve the dewatering of the marina and main canal area in a stepwise process according to the timetable for Scenario 1, as follows:

- Stage 1 (construction of the main canal): 20 months, to a depth of -3 m AHD;
- Stage 1.5 (construction of the easternmost marina portion): 12 months during the last 6 months of Stage 1 and the first 6 months of Stage 2, to a depth of -4 m AHD; and
- Stage 4 (construction of the western marina portion): 12 months of dewatering, to a depth of -4 m.

The finger canals were assumed to not be constructed in this scenario, and Stage 2 would not entail any dewatering in Scenario 2, but rather would be an additional break from construction requiring dewatering.

B-2 MODELLING RESULTS

B-2.1 MBM DRY MARINA AND CANAL CONSTRUCTION (SCENARIO 1) MODELLING RESULTS

After the temporary dewatering for canal and marina excavation and bay wall installation, water levels will return to sea level once the construction is completed. The model simulation depicted represents a stage of the MBM construction that lasts approximately 56 months, as described in Section B-1. In this scenario, the Sepia Depression Ocean Outlet Landline (SDOOL) pipeline duplication (plus realignment of a portion of the existing SDOOL) is not included.

Modelled water levels in Lake Richmond during MBM dry marina and canal construction are presented in *Figure B-1*. Modelling indicates that the maximum Lake Richmond level drop is approximately 0.42 m during the 56-month construction period. This temporary lake level drop is within its natural water level fluctuation of 1.2 m. Modelled groundwater contours at the end of the 56-month construction period are presented in *Figure B-2*.

The modelled salinity distribution in the Safety Bay Sand (SBS) aquifer at the end of the 56-month construction period is presented in *Figure B-3*. The modelled saltwater intrusion area under the proposed construction scenario is greater than under natural conditions but less than that under the modelled future steady-state condition with the MBM marina and canals in place (*Figure B-5*). This is because the dewatering pulls more water toward the ocean, than it pulls from the ocean inland. When construction is complete, because active dewatering is no longer occurring, less fresh water is being drawn from inland areas toward the ocean to dilute salinity coming inland from the ocean. The modelled saltwater intrusion area does not impact other well bores in the area, except wells 1, 7, and 8, all of which had been impacted by the saltwater under existing, natural conditions.

Modelling does not indicate a discernible change of salinity level in Lake Richmond during MBM marina and canal construction.

B-2.2 SCENARIO 1 MODELLED POST-CONSTRUCTION CONDITIONS WITH MBM MARINA AND CANALS OPERATIONAL

This model simulation represents future steady-state conditions after the completion of MBM marina and canal construction. The MBM marina and canals will maintain sea-level water levels, which are slightly lower than those under existing conditions.

The modelled future steady-state groundwater contours with the MBM marina and canals in place are presented in *Figure B-4*. The modelled maximum lake-level drop of Lake Richmond from existing conditions is approximately 0.038 m. This lake level drop is well within its natural water level fluctuation of 1.2 m.

The modelled future steady-state salinity distribution is presented in *Figure B-5*. The modelled saltwater intrusion area is confined to the MBM vicinity and, as explained in the previous section, is greater than that modelled during the MBM construction stages. The modelled saltwater intrusion area does not impact other well bores in the area, except the bores for Wells 1, 7, and 8, all of which had been impacted by saltwater under existing conditions.

Modelling does not indicate a discernible change in future salinity level in Lake Richmond once the MBM marina and canals are operational.

B-2.3 MBM DRY MARINA AND MAIN CANAL CONSTRUCTION (SCENARIO 2) MODELLING RESULTS

Dewatering for the MBM dry marina and main canal construction and bay wall installation is temporary, and water levels will return to sea level once construction is complete. The model simulation depicted represents a duration of MBM construction of approximately 56 months. In this scenario, SDOOL-related construction is excluded.

Modelled water level in Lake Richmond during MBM dry marina and the main canal construction is presented in *Figure B-6*. Modelling indicates that the maximum Lake Richmond level drop is approximately 0.19 m during the 56-month construction period. This temporary lake level drop is within its natural water level fluctuation of 1.2 m and less than that for Scenario 1. Modelled groundwater contours at the end of the 56-month construction period are presented in *Figure B-7*. The temporary drawdown caused by Scenario 2 causes less impact than that for Scenario 1 (*Figure B-2*), both in areal extent and water table depression.

The modelled salinity distribution at the end of the 56-month construction period is presented in *Figure B-8*. The modelled saltwater intrusion area under the proposed construction scenario is greater than under natural conditions but less than that under the modelled future steady-state condition with the MBM marina and the main canal in place (*Figure B-10*), for the reason given in Section B-2.1 above. The modelled saltwater intrusion area does not impact other well bores in the area, except wells 1, 7, and 8, all of which had been impacted by the saltwater under existing, natural conditions.

Modelling does not indicate a discernible change of salinity level in Lake Richmond during MBM marina and the main canal construction.

B-2.4 *MODELLED POST-CONSTRUCTION CONDITIONS WITH MBM MARINA AND MAIN CANAL OPERATIONAL (SCENARIO 2)*

This model simulation represents future steady-state conditions after completion of MBM marina and main canal construction. The MBM marina and main canal will maintain sea-level water levels, which are slightly lower than those under existing conditions.

The modelled future steady-state groundwater contours with the MBM marina and main canal in place are presented in *Figure B-9*. The modelled maximum lake-level drop of Lake Richmond from existing conditions is approximately 0.016 m. This lake level drop is well within its natural water level fluctuation of 1.2 m.

The modelled future steady-state salinity distribution is presented in *Figure B-10*. The modelled saltwater intrusion area is confined to the MBM vicinity and is greater than that modelled during the MBM construction stages. This is because saltwater has been introduced further inland through construction of the canals and marina. The modelled extent of saltwater intrusion for Scenario 2 is less than that for Scenario 1, because the finger canals are not included in Scenario 2, thereby preventing saltwater from moving farther inland via these finger canals. The modelled saltwater intrusion area does not impact other well bores in the area, except the bores for Wells 1, 7, and 8, all of which had been impacted by saltwater under existing conditions.

Modelling does not indicate a discernible change in future salinity level in Lake Richmond once the MBM marina and main canal are operational.

B-3 *SUMMARY*

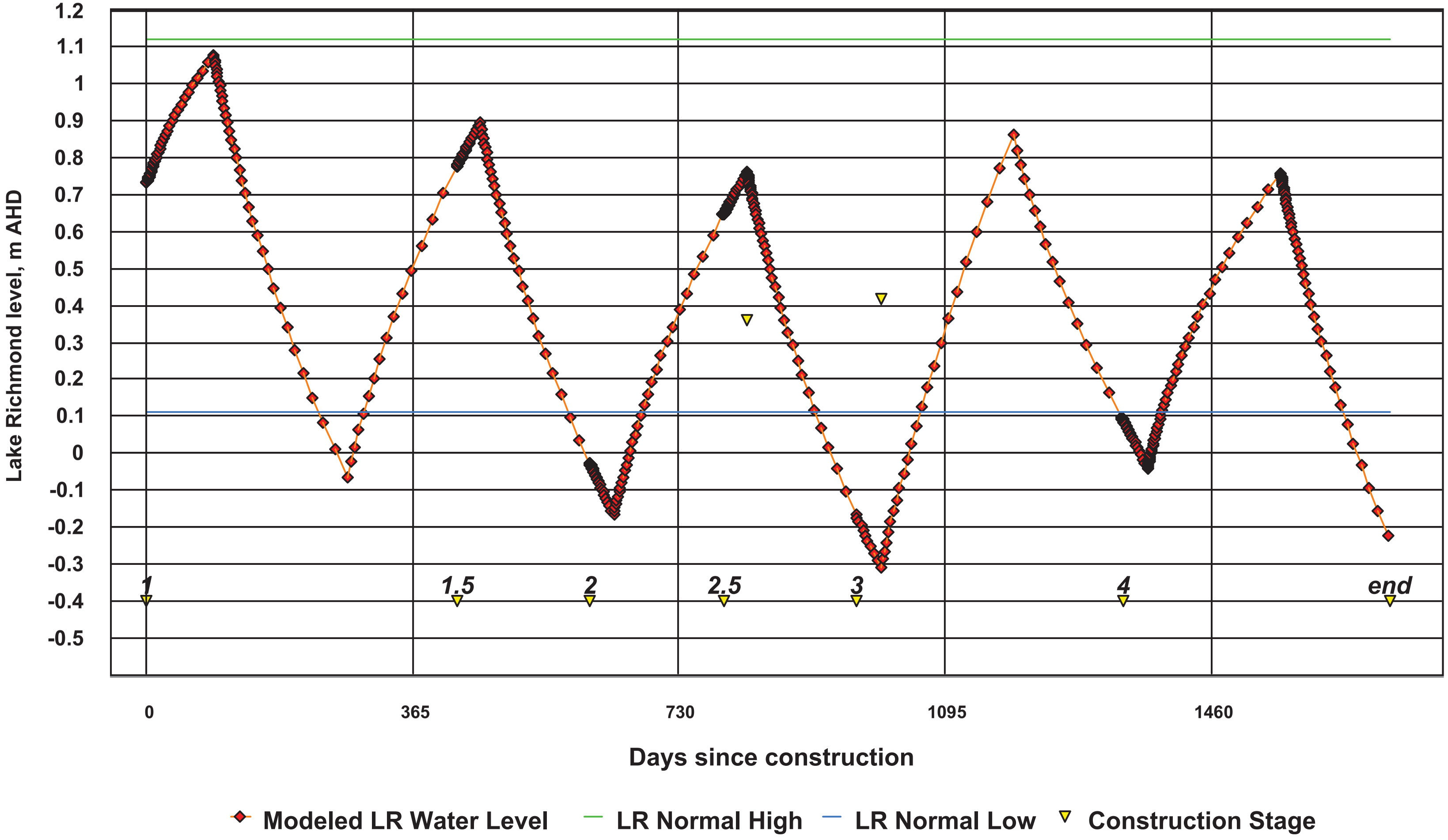
The results of these less favoured construction scenarios are tabulated below for ease of comparison. As may be seen from the modelled results, Scenario 2 causes less impact on both aquifer and Lake Richmond water levels than Scenario 1, although both scenarios cause greater impacts than the wet dewatering scenario evaluated in the report to which this Annex is appended.

Option	**Timeframe**	**Modelled Maximum Change in Lake Richmond Water Level (m)**	**Modelled Change in Salinity (SBS in vicinity of MBM)**	**Modelled Change in Salinity (Lake Richmond)**
1: Dry excavation (marina and all canals)	Construction	-0.42	greater inland extent than Scenario 2	None discernible
1: Dry excavation (marina and all canals)	Operation	-0.038	greater inland extent than Scenario 2	None discernible
2: Dry excavation (marina and main canal only)	Construction	- 0.19	reduced inland extent relative to Scenario 1	None discernible
2: Dry excavation (marina and main canal only)	Operation	- 0.016	reduced inland extent relative to Scenario 1	None discernible

Saltwater Intrusion Model Simulations – MBM Dry Construction Scenarios

SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

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



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

Modelled Lake Richmond Water Level during MBM Dry Marina and Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-1

Legend

— Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

— Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

— Modelled groundwater contours, mAHD

Note:

Modelled largest water level decrease of Lake Richmond is 0.42 m

N

Scale: 1: 20,000

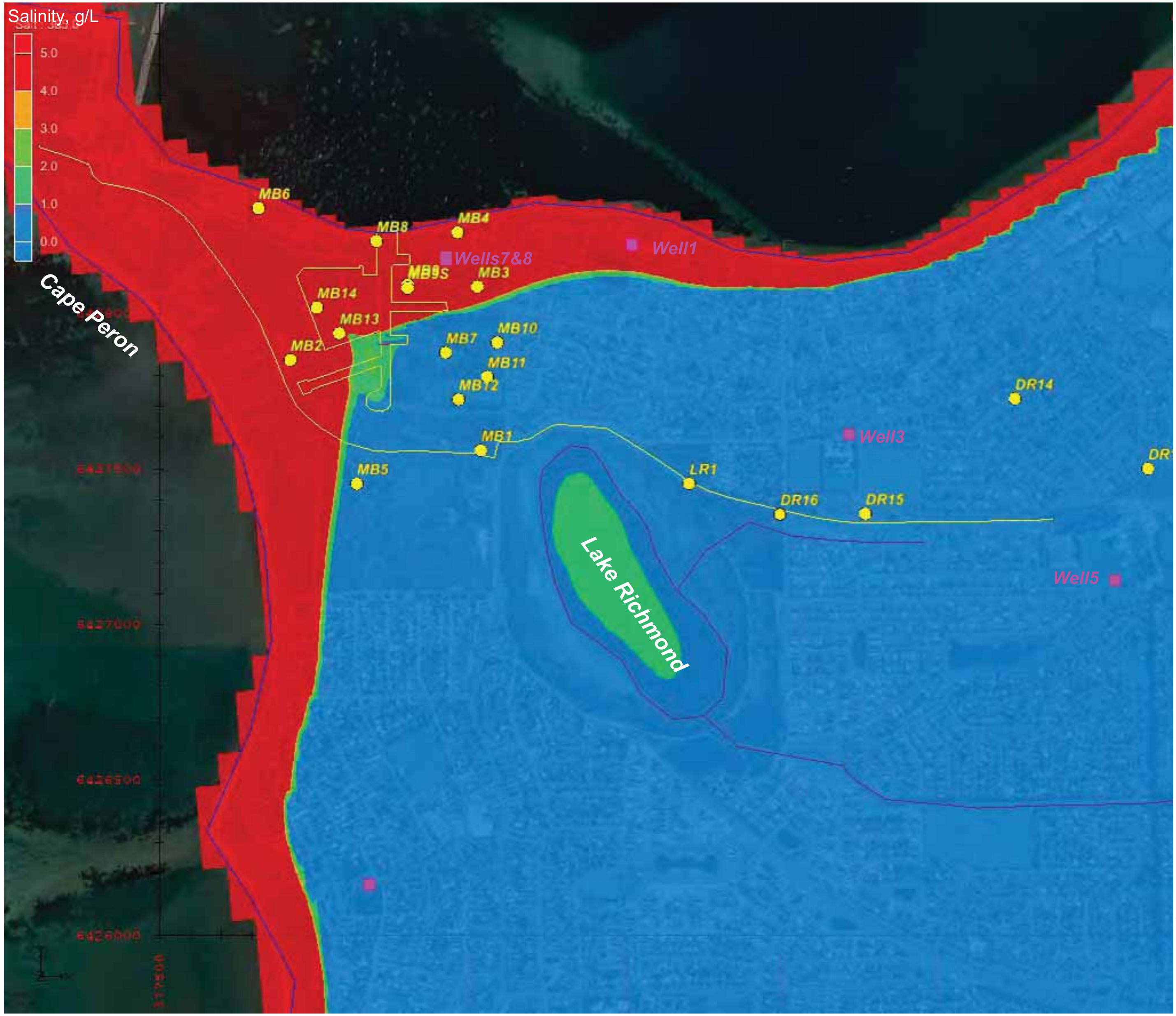
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Groundwater Contours at End of MBM Dry Marina and Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-2



Legend

	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond during MBM construction period

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 MBM Dry Marina and Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-3

028619-08/29/2011-HYH-M:\WaterCorp\SDOOL MBM Report Annex B.ppt

Legend

— Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

— Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

— Modelled groundwater contours, mAHD

Note:

Modelled largest water level decrease of Lake Richmond is 0.038 m

N

Scale: 1: 20,000

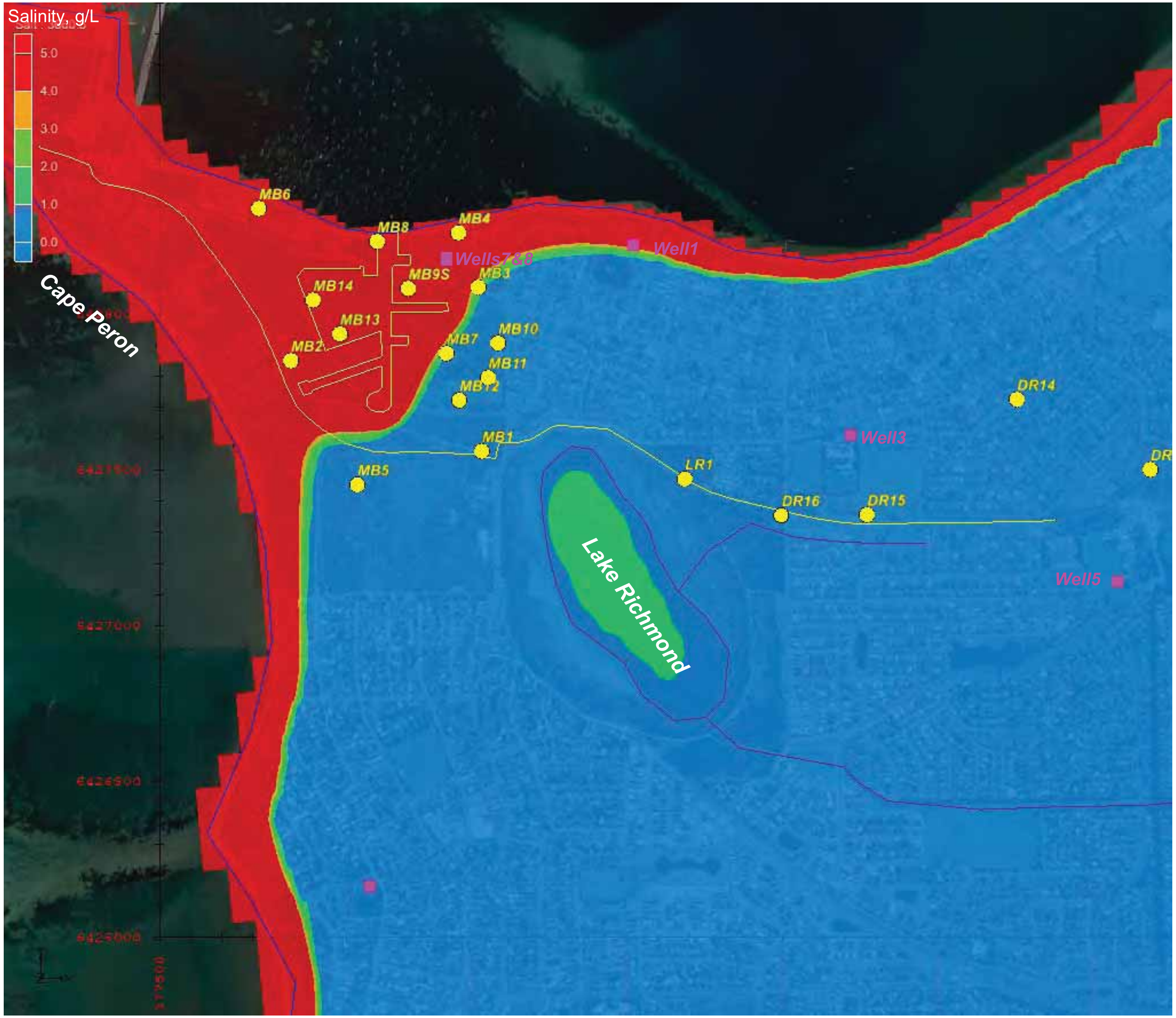
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Future Groundwater Contours with MBM Marina and Canals Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-4



Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond during MBM construction period

N

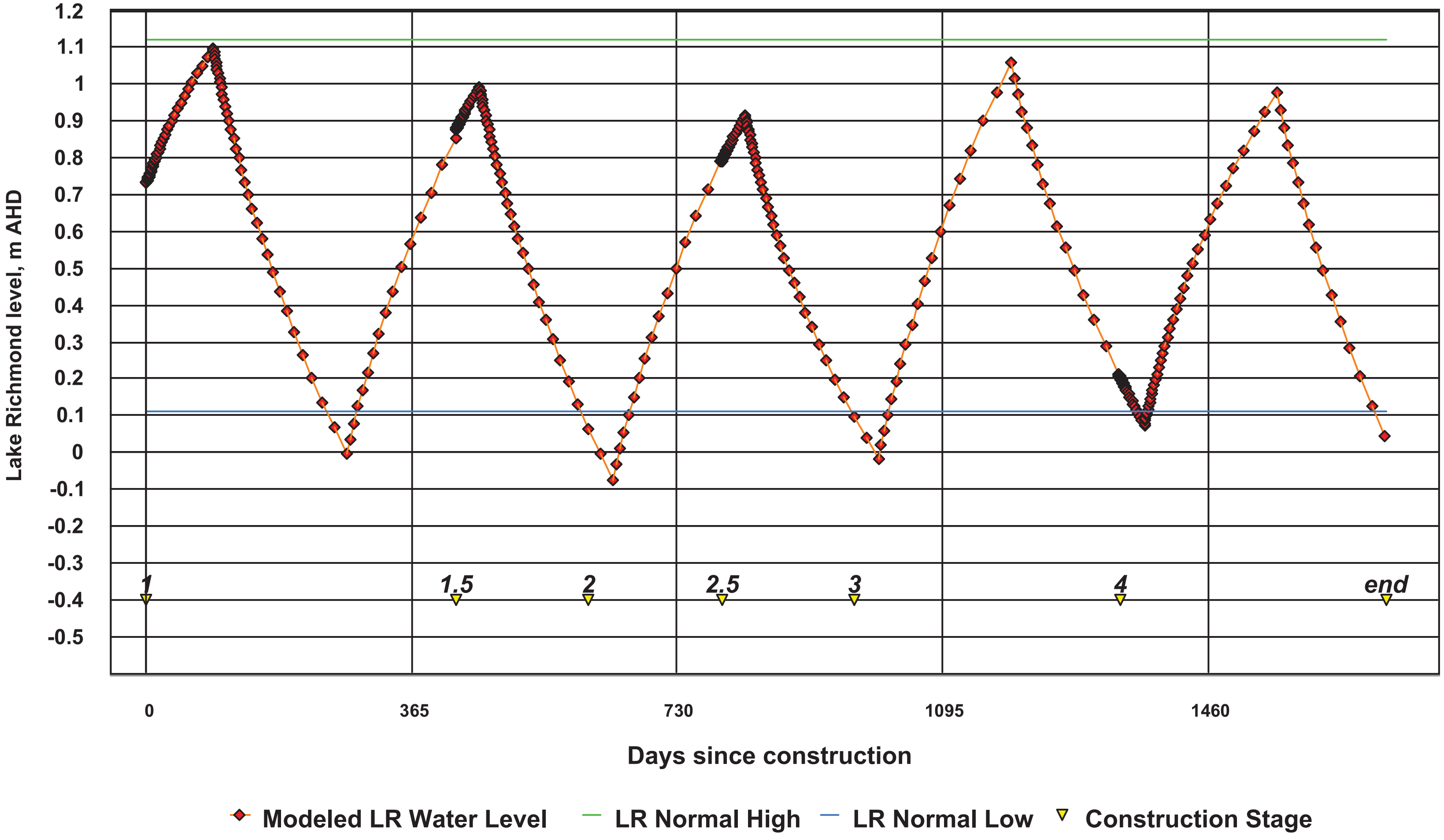
Scale: 1: 20,000

WGS84 UTM Coordinate System Zone -50 in m

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

Modelled Future Salinity Distribution with MBM Marina and Canals Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-5



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

Modelled Salinity Distribution during MBM Dry Marina/Main Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-6

Legend

―	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
―	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
―	Modelled groundwater contours, mAHD

Note:

Modelled largest water level decrease of Lake Richmond is 0.19 m

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 at End of MBM Dry Marina/Main Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-7

Legend

— Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

— Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond during MBM construction period

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 MBM Dry Marina/Main Canal Construction
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-8

Legend

—	Streams, lakes, and/or shoreline
●	Monitoring well
■	Water supply well
—	Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina
—	Modelled groundwater contours, mAHD

Note:

Modelled largest water level decrease of Lake Richmond is 0.016 m

N

Scale: 1: 20,000

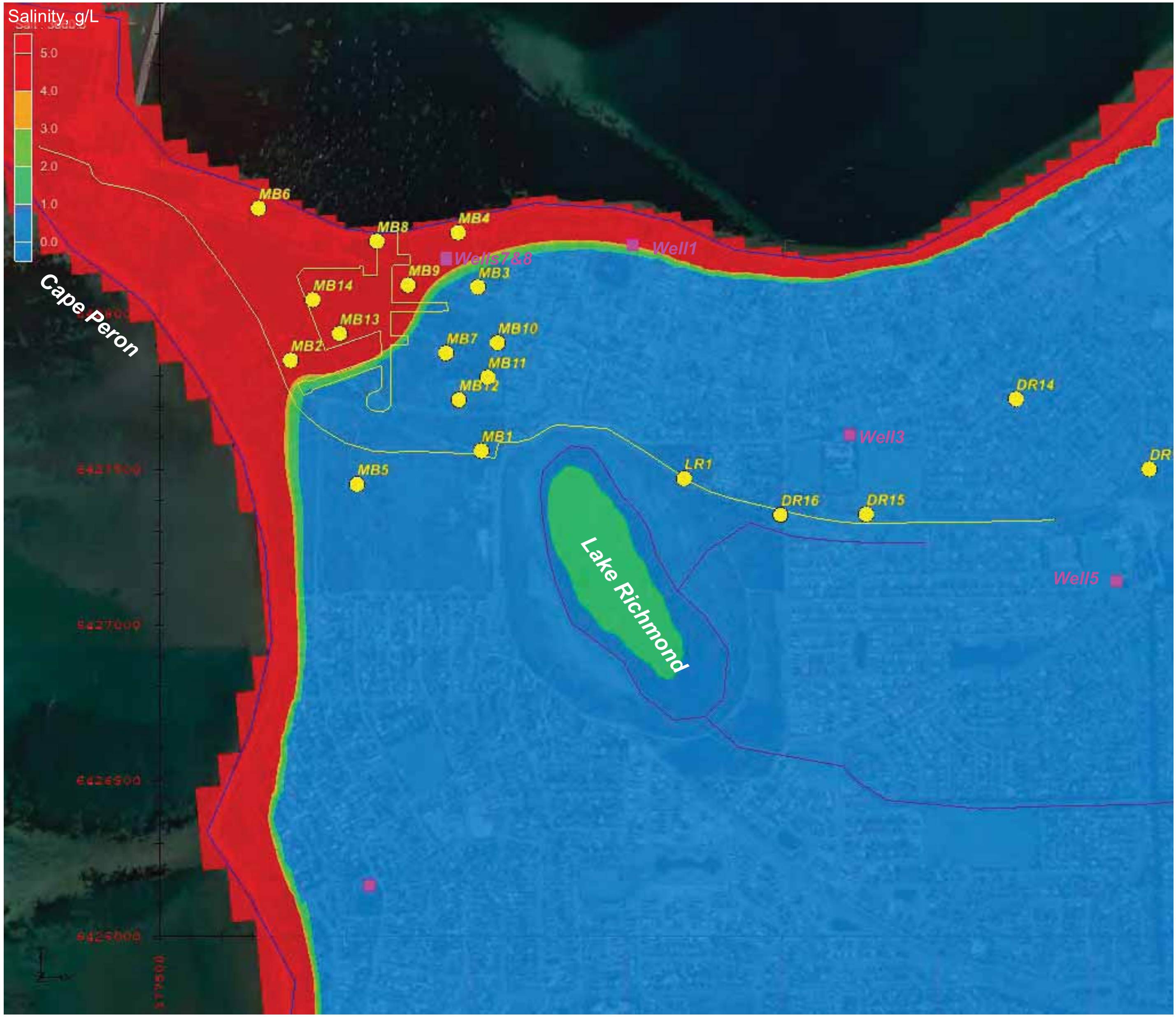
WGS84 UTM Coordinate System Zone -50 in m

ERM

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

Modelled Future Groundwater Contours with MBM Marina Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-9



Legend

Streams, lakes, and/or shoreline

● Monitoring well

■ Water supply well

Proposed locations of SDOOL Duplication and Realignment, and Mangles Bay Marina

Note:

Salinity distribution displayed at -12 mAHD

No discernible change in salinity input to Lake Richmond during MBM construction period

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 Future Salinity Distribution with MBM Marina Operational
SDOOL Duplication and Mangles Bay Marina
Rockingham, Western Australia

Figure B-10

Annex C

ERM Conceptual Site Model Report

**Environmental
Resources Management
Australia**

6th Floor,
172 St. Georges Terrace
Perth WA 6000

PO Box 7338
Cloisters Square WA 6850

Telephone +61 8 9321 5200
Facsimile +61 8 9321 5262

www.erm.com

30 August, 2011

Marcus Deshon
Cedar Woods
Level 4, 66 Kings Park Road
WEST PERTH WA 6872
AUSTRALIA

Our Reference: *0128619*

Attention: **Marcus Deshon**

Dear Marcus,

RE: MANGLES BAY MARINA GROUNDWATER MODELLING: REVISED CONCEPTUAL SITE MODEL REPORT

1. 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).

---

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

- 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:

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.

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 Mangles Bay Canal Development. The focus of the model was on changes in water levels and salinities.

2. 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 *Annex A*);
- Installation of a set of nested SBS and TL wells to the east of Lake Richmond (LR1-TL, LR2-SBS and LR3-SBS);
- 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.

3. 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 *Annex 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 1 Well Data Summary

		Geophysical Markers (mAHD)				Lithological Summary				Screen location	EC description µS/cm		
Well	Total Depth	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	

4. GEOLOGY

Four cross sections of the area have been compiled (attached *Annex 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:

4.1 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.

4.2 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.

4.3 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 *Annex 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.

5. HYDROGEOLOGY

5.1 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.

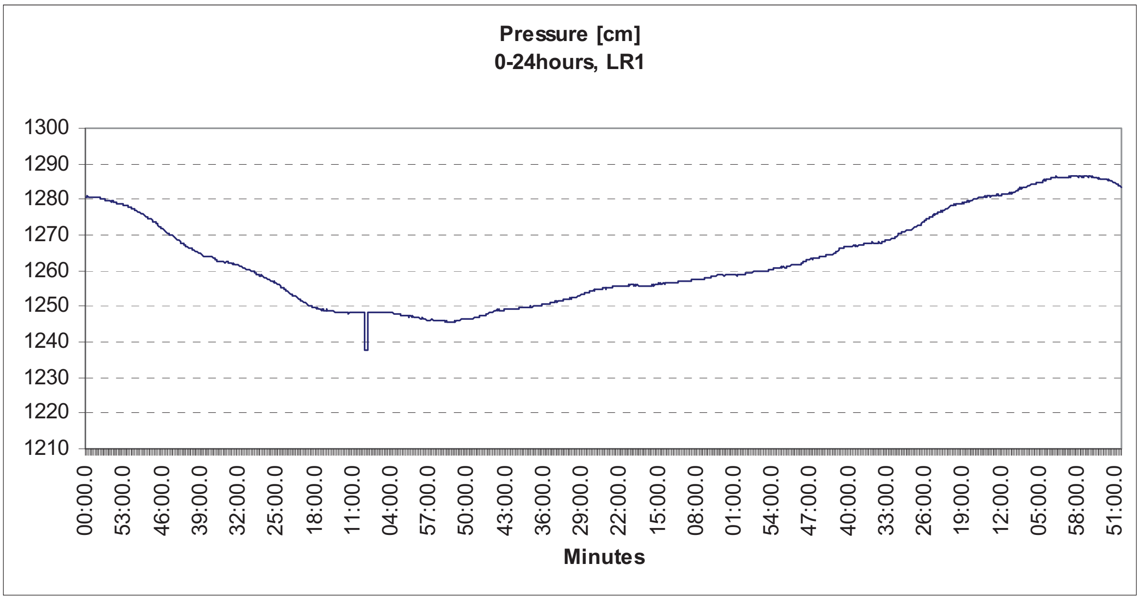
5.2 SAFETY BAY SAND – TAMALA LIMESTONE TRANSITION

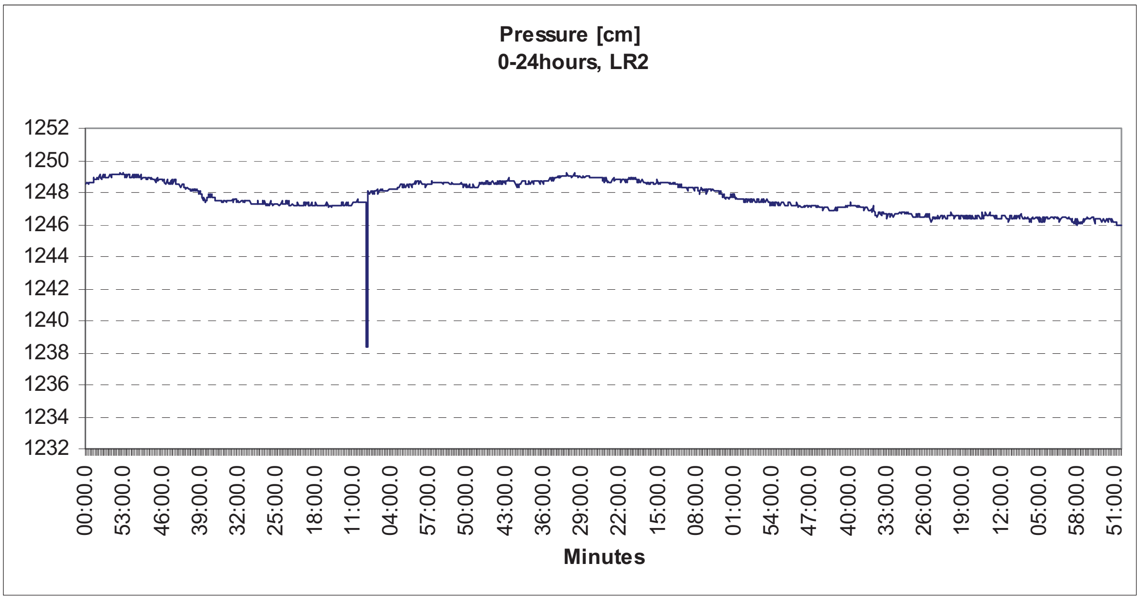
Downhole geophysics data (and some well logs), supported by water level data, confirm a confining layer between the SBS and the TL. Monitoring wells MB09 (deep and shallow) and LR1 and LR2 were constructed to ensure that the deeper wells (MB09-D and LR1) were screened within the TL only. Adjacent shallow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

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.

5.3 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).

5.4 TAMALA LIMESTONE TRANSITION

The WP 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.

5.5 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 Worley Parsons (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).

6. EC PROFILES

6.1 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[2]. 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.

6.2 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.

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

7. REGIONAL GROUNDWATER USE

There are 42 known groundwater abstraction licenses applicable to a 2km range around the proposed canal development, 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 (*Annex D*). 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.

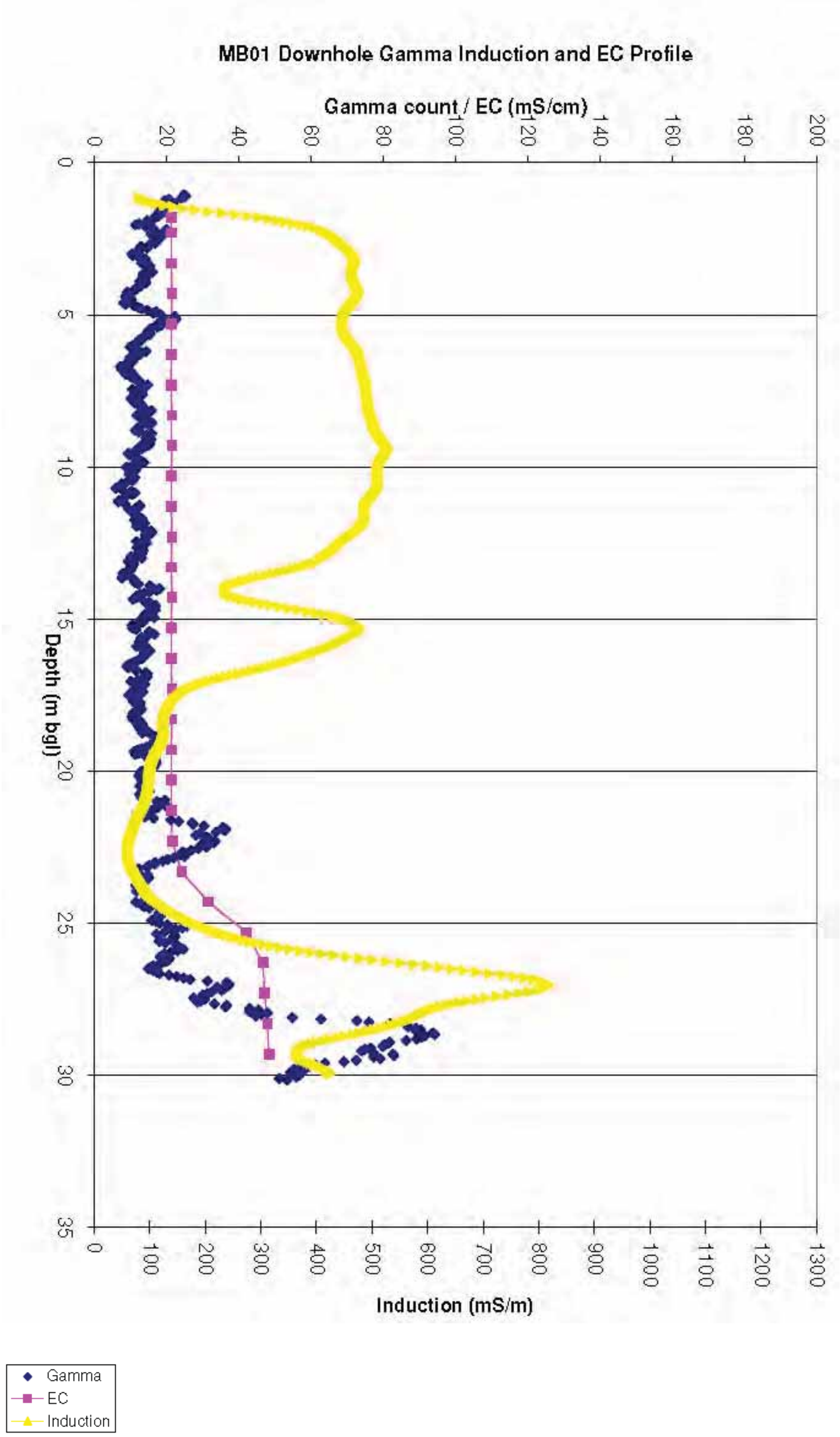
The MWH EC profiling data indicates increases in EC readings during the month of December in SBS screened wells MB02, 9, 13 and SBS/TL cross screened well MB05. This may be associated with domestic bore use in the summer months (adjacent to observed wells); however further assessment would be required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

Yours sincerely,
for Environmental Resources Management Australia Pty Ltd

Toby Whincup
Perth Office Managing Partner

ANNEX A:

DOWNHOLE GAMMA, INDUCTION AND EC LOGS


MB01 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

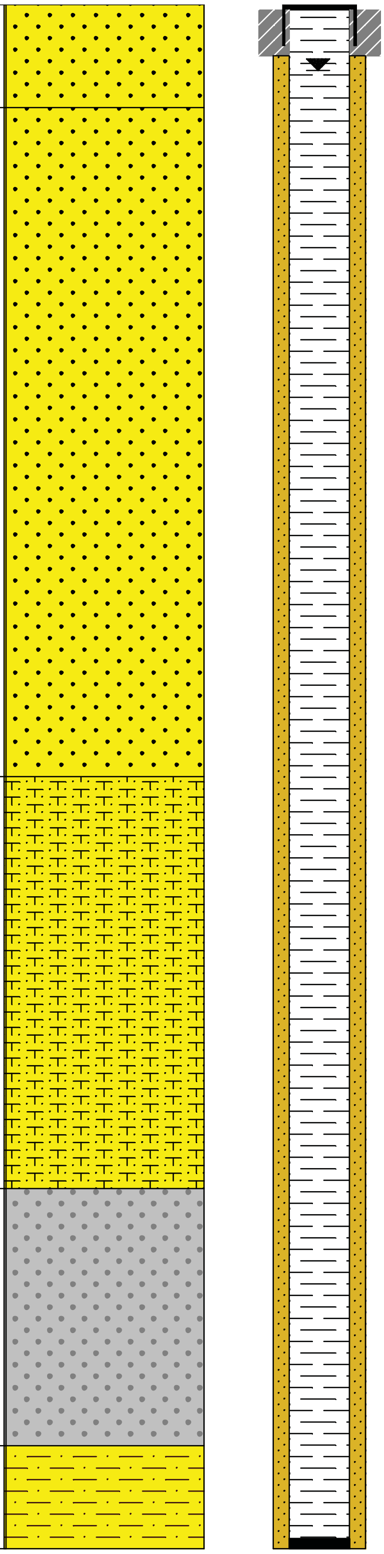
WELL COMPLETION DETAILS: MB01

Client: Landcorp	**Driller:** Mathews Drilling	**Easting:** 378534
Date Drilled: 29-30/03/10	**Fluid :** Air/Water	**Northing:** 6427559
Logged By: Shawn Butland	**Drilling Method:** Reverse Circulation	**Surface RL:** 2.11 mAHD
	Drilled Diameter: 152.4 mm	

HYDRAULIC DATA: **SWL:** 1.62 mbgl

SWL Date Collected: 08/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
	Safety Bay Sand	SAND Light brown, moderately sorted, angular to very angular shell fragments.				
		SAND Light grey, moderately sorted, medium grain size, angular shell fragments.				
		SILTY SAND Brown, well sorted, silty sand. Contains some organic material.				
	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.				
		SILT Yellow/brown, fine grained, well sorted silt. Contains some clasts of shell fragments and rounded quartz.				



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; 1.61mS/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

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

EC; 4.04 mS/cm, TDS; 2.07 ppt, Temp; 27.9 °C, pH; 7.84 at 25 m

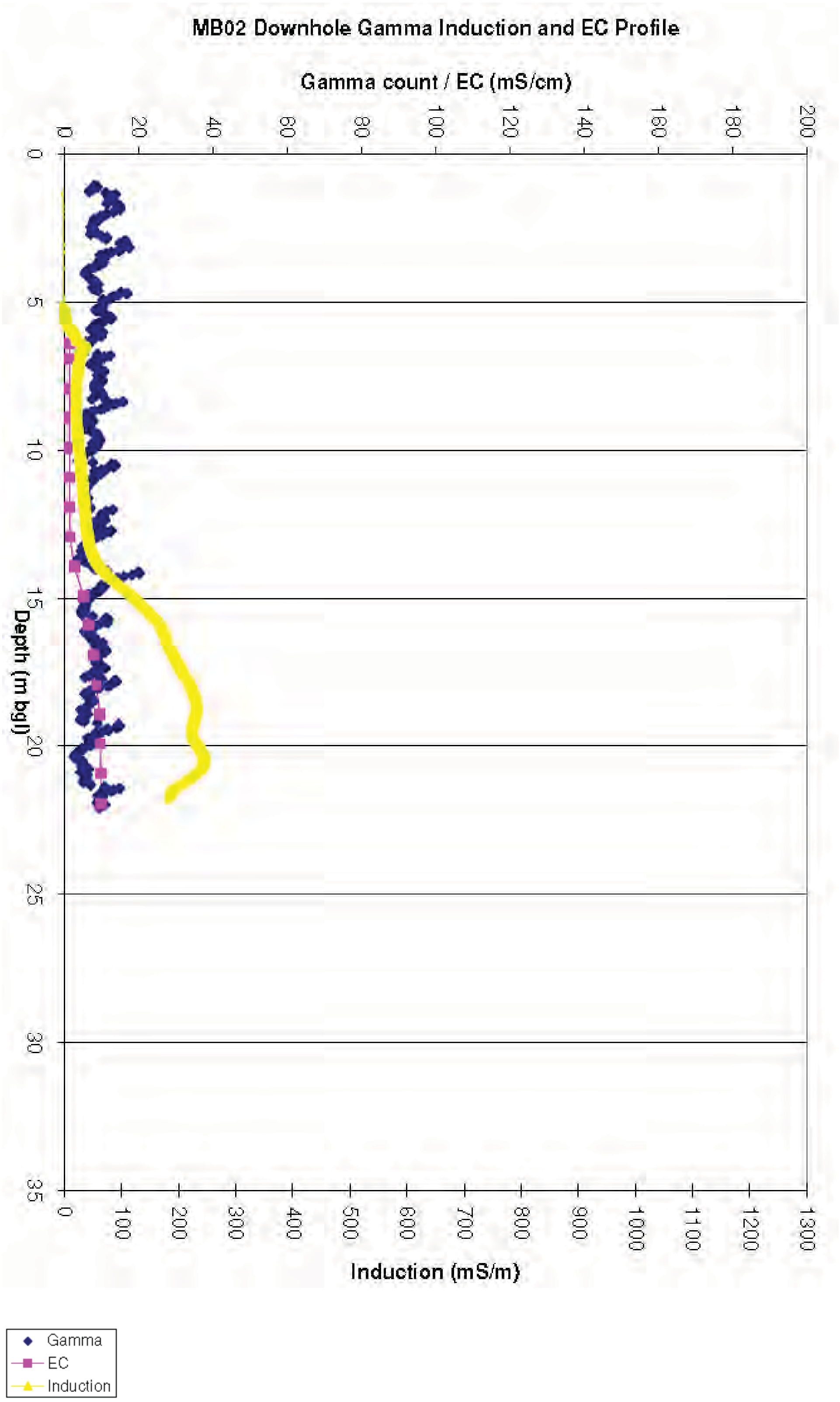
EC; 5.54 mS/cm, TDS; 2.92 ppt, Temp; 26.3 °C, pH; 7.78 at 26 m

EC; 13.34 mS/cm, TDS; 6.82 ppt, Temp; 24.7 °C, pH; 7.66 at 27 m

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

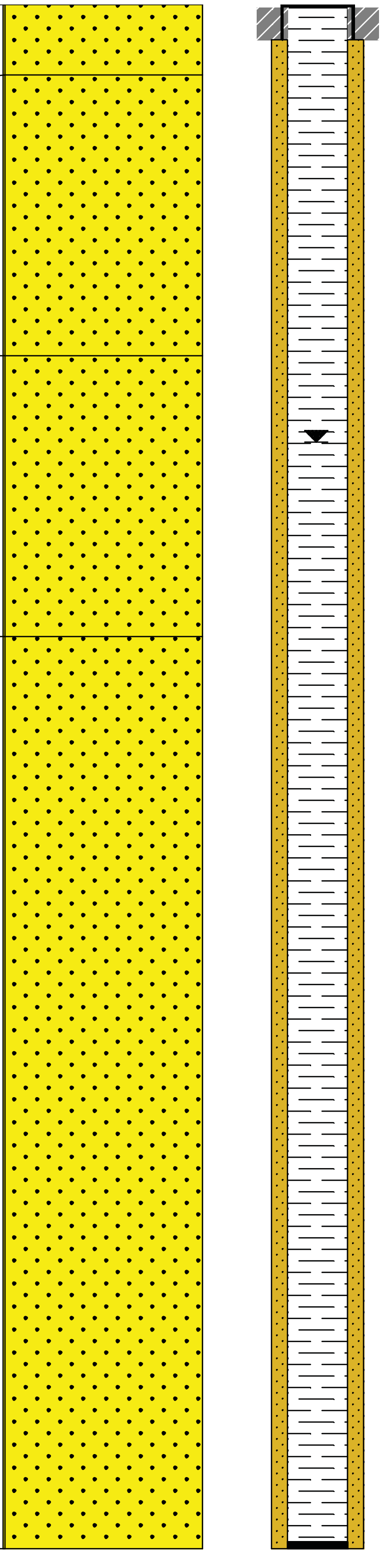
WELL COMPLETION DETAILS: MB02

Client: Landcorp	**Driller:** Mathews Drilling	**Easting:** 377921
Date Drilled:14/04/2010	**Fluid :** Air/Water	**Northing:** 6427850
Logged By: Shawn Butland	**Drilling Method:** Reverse Circulation	**Surface RL:** 6.45 mAHD
	Drilled Diameter: 152.4 mm	

HYDRAULIC DATA: **SWL:** 6.23 mbgl

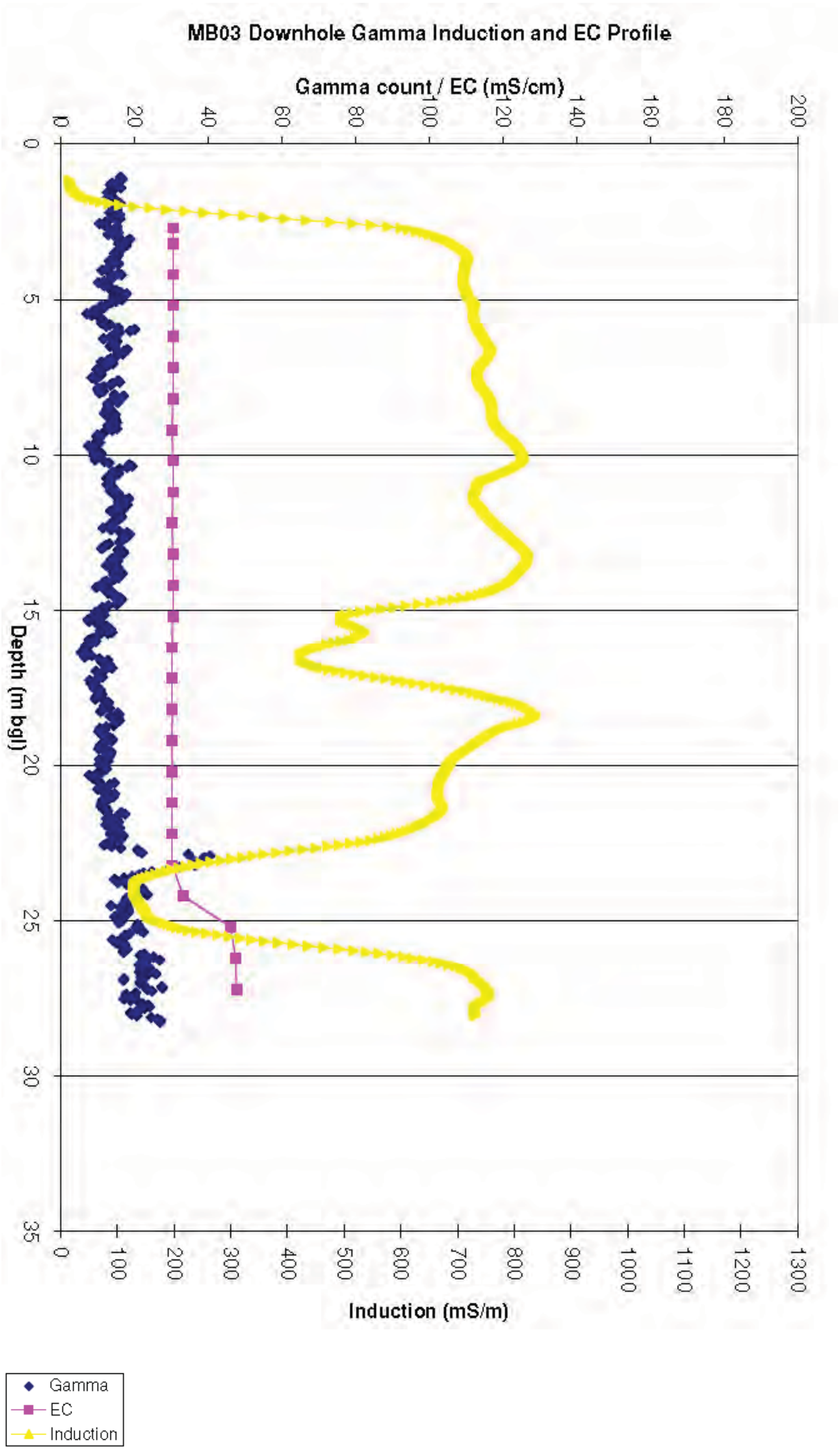
SWL Date Collected: 19/04/2010

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) EOH 22 m	**EC; 6.42 mS/cm, TDS; 3.02 ppt, Temp; 19.5 °C, pH; 8.10 at 20 m**



TD: 22 m

Notes:


MB03 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: MB03

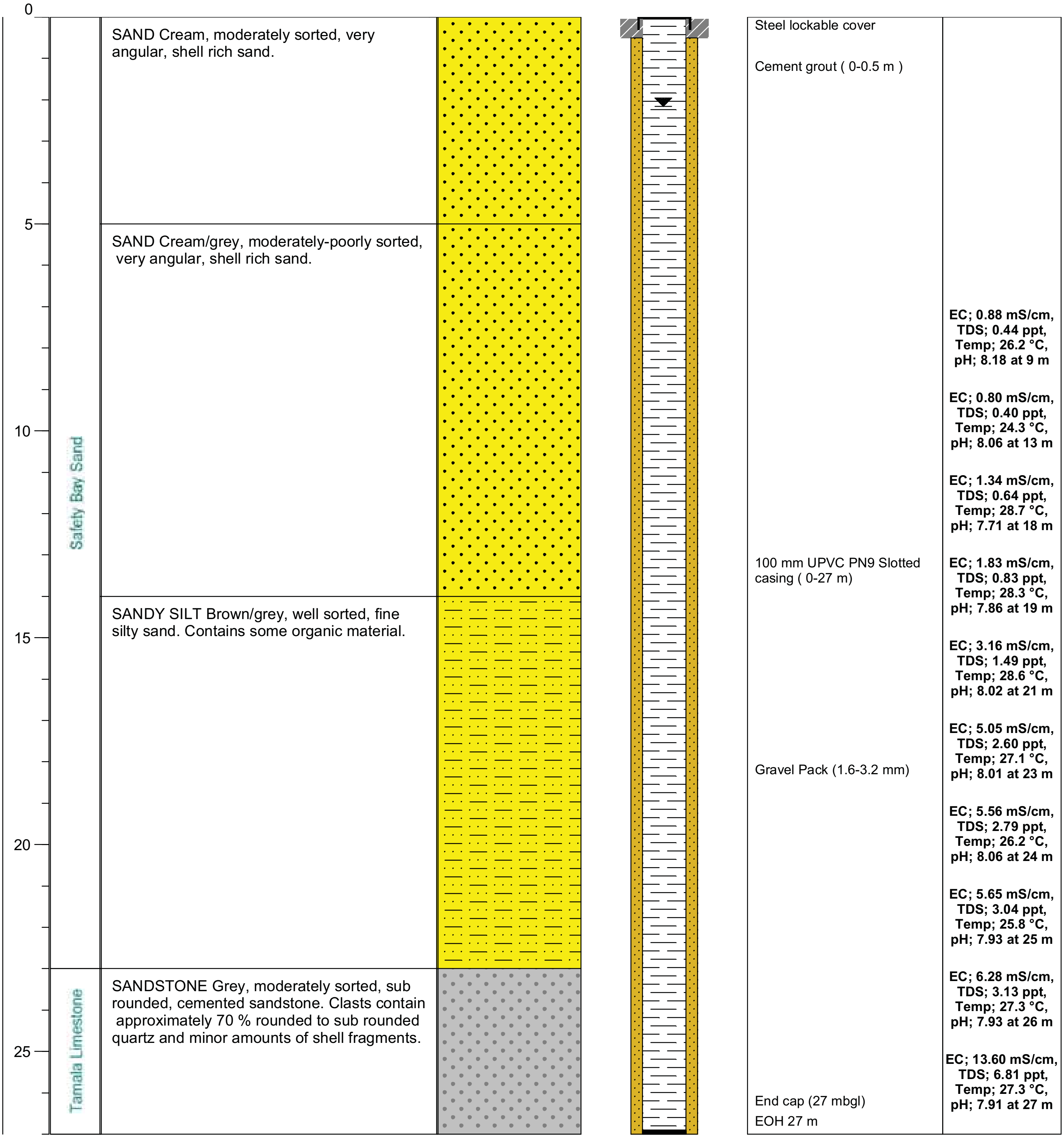
Client: Landcorp
Date Drilled: 06-07/04/2010
Logged By: Shawn Butland

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

Easting: 378523
Northing: 6428086
Surface RL: 2.83 mAHD

HYDRAULIC DATA:
SWL: 2.16 mbgl
SWL Date Collected: 19/04/2010

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality



SAND Cream, moderately sorted, very angular, shell rich sand.

SAND Cream/grey, moderately-poorly sorted, very angular, shell rich sand.

SANDY SILT Brown/grey, well sorted, fine silty sand. Contains some organic material.

SANDSTONE Grey, moderately sorted, sub rounded, cemented sandstone. Clasts contain approximately 70 % rounded to sub rounded quartz and minor amounts of shell fragments.

Steel lockable cover

Cement grout (0-0.5 m)

100 mm UPVC PN9 Slotted casing (0-27 m)

Gravel Pack (1.6-3.2 mm)

End cap (27 mbgl)

EOH 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

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

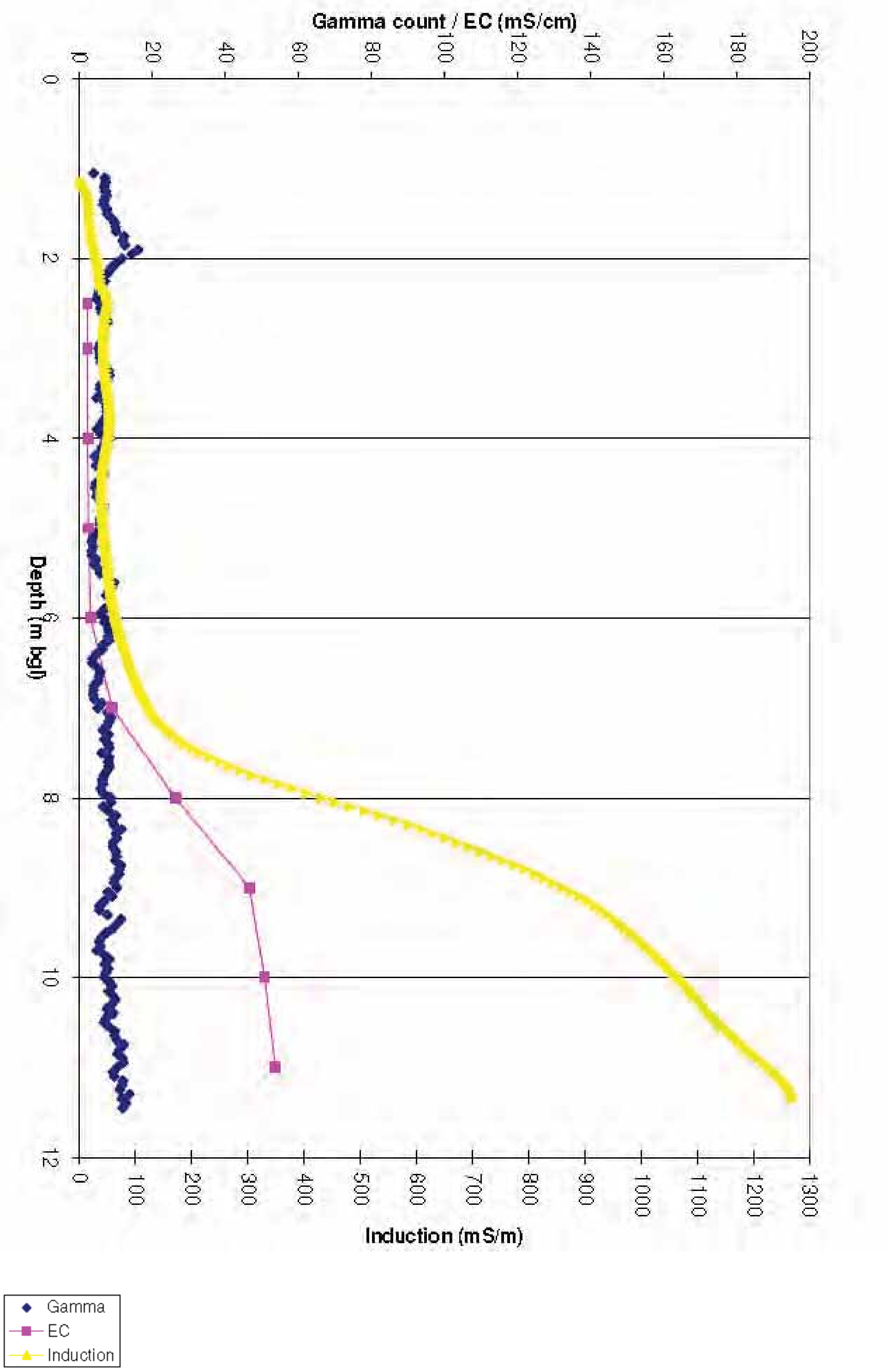
EC; 5.56 mS/cm, TDS; 2.79 ppt, Temp; 26.2 °C, pH; 8.06 at 24 m

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

WELL COMPLETION DETAILS: MB04

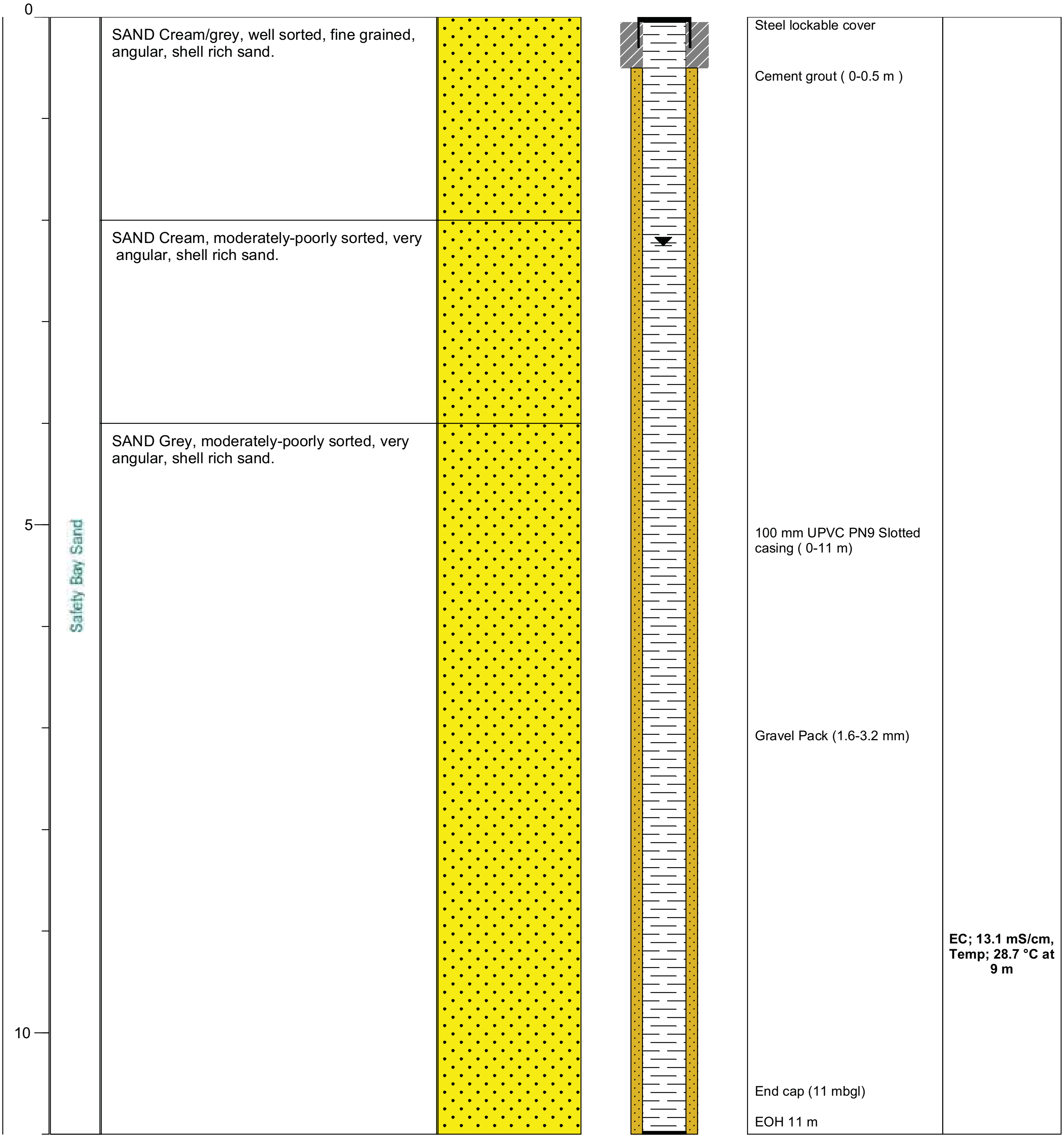
Client: Landcorp
Date Drilled:15/04/2010
Logged By: Shawn Butland

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



SAND Cream/grey, well sorted, fine grained, angular, shell rich sand.

SAND Cream, moderately-poorly sorted, very angular, shell rich sand.

SAND Grey, moderately-poorly sorted, very angular, shell rich sand.

Steel lockable cover

Cement grout (0-0.5 m)

100 mm UPVC PN9 Slotted casing (0-11 m)

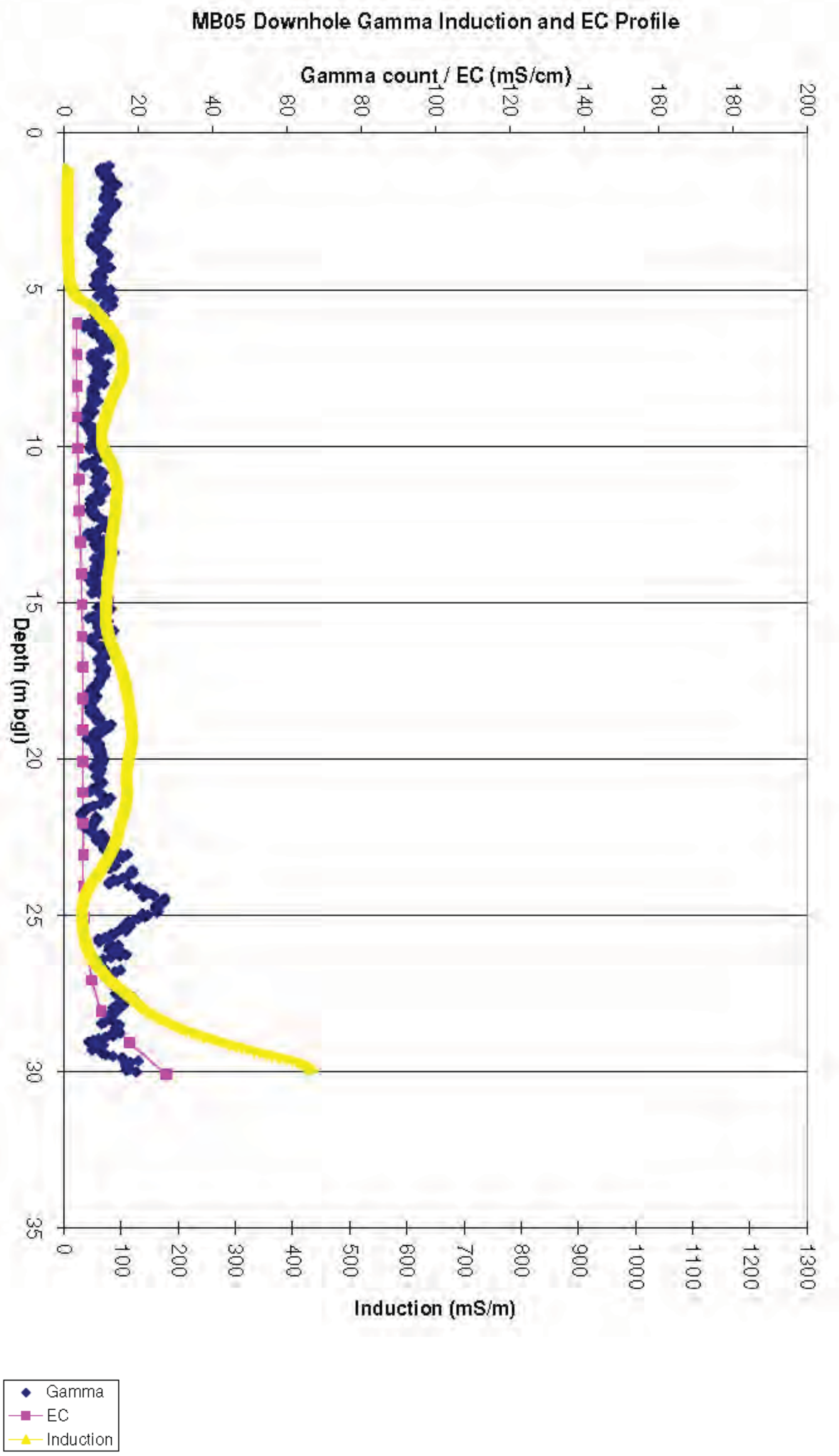
Gravel Pack (1.6-3.2 mm)

End cap (11 mbgl)

EOH 11 m

EC; 13.1 mS/cm, Temp; 28.7 °C at 9 m

TD: 11 m
Notes:


MB05 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: MB05

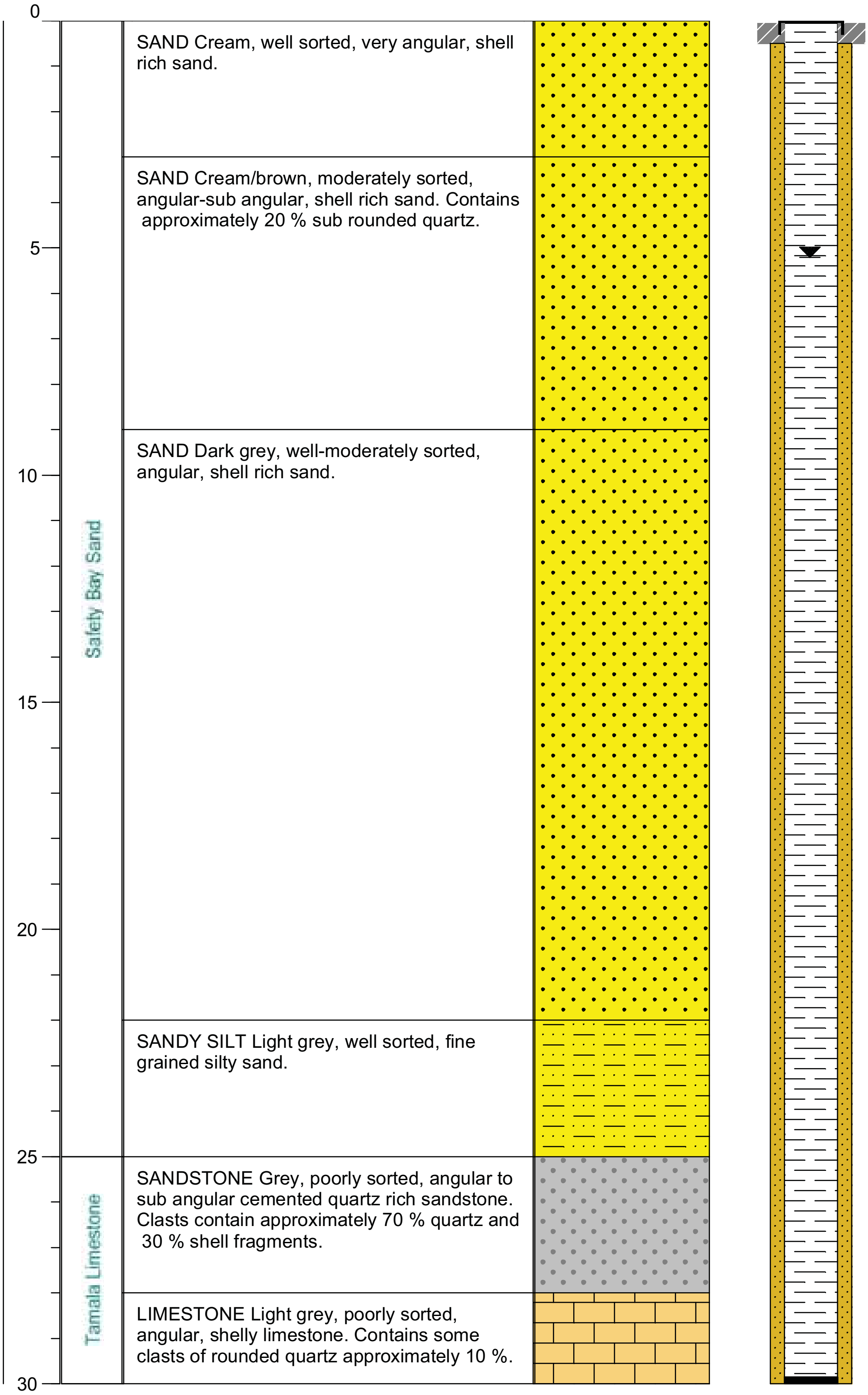
Client: Landcorp
Date Drilled: 09/04/2010
Logged By: Shawn Butland

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

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



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

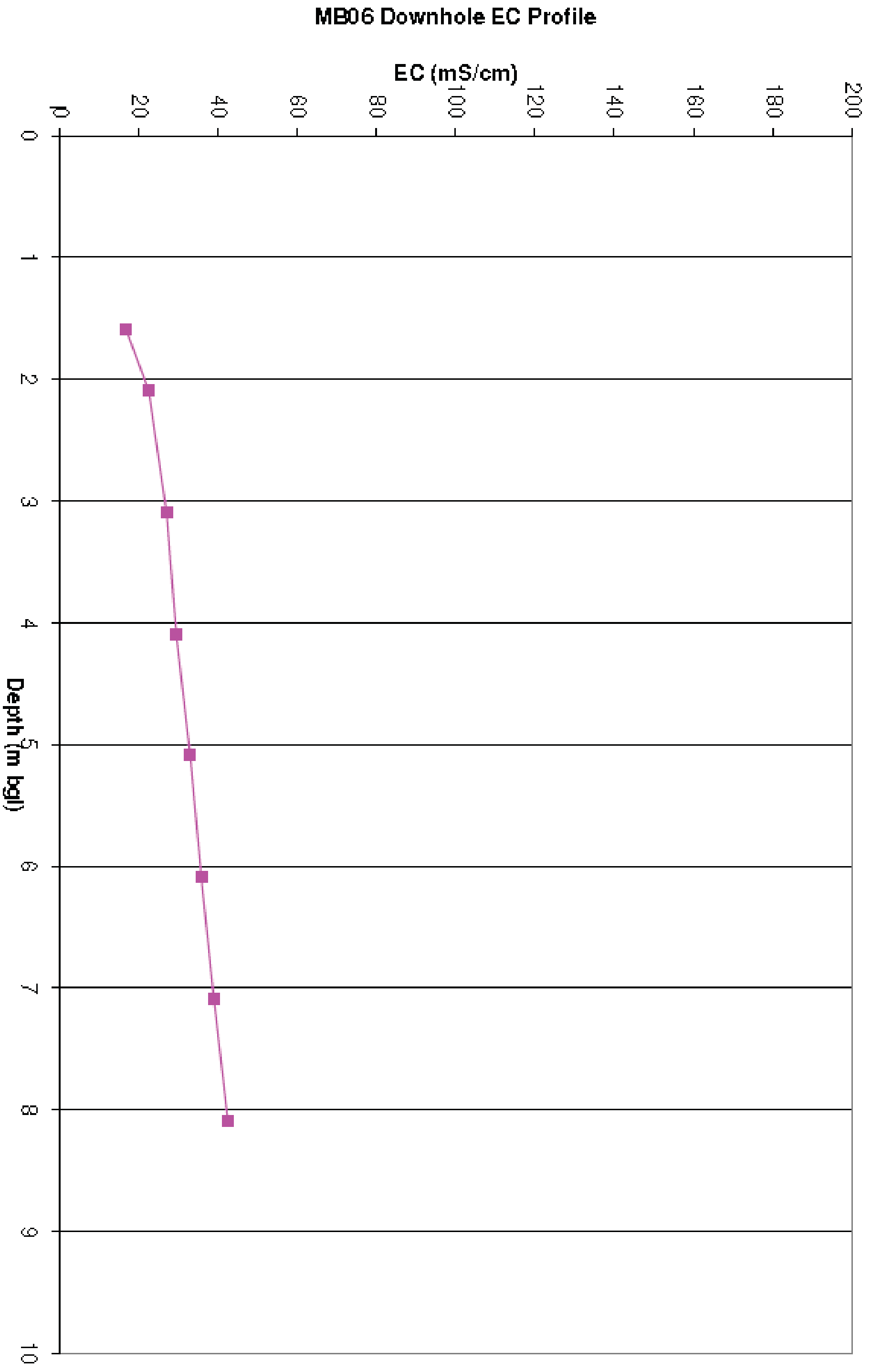
EC; 1.89 mS/cm, TDS; 0.96 ppt, Temp; 21.5 °C, pH; 8.06 at 27 m

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
EC (mS/cm)
0
20
40
60
80
100
120
140
160
180
200
Depth (m bgl)
0
1
2
3
4
5
6
7
8
9
10

WELL COMPLETION DETAILS: MB06

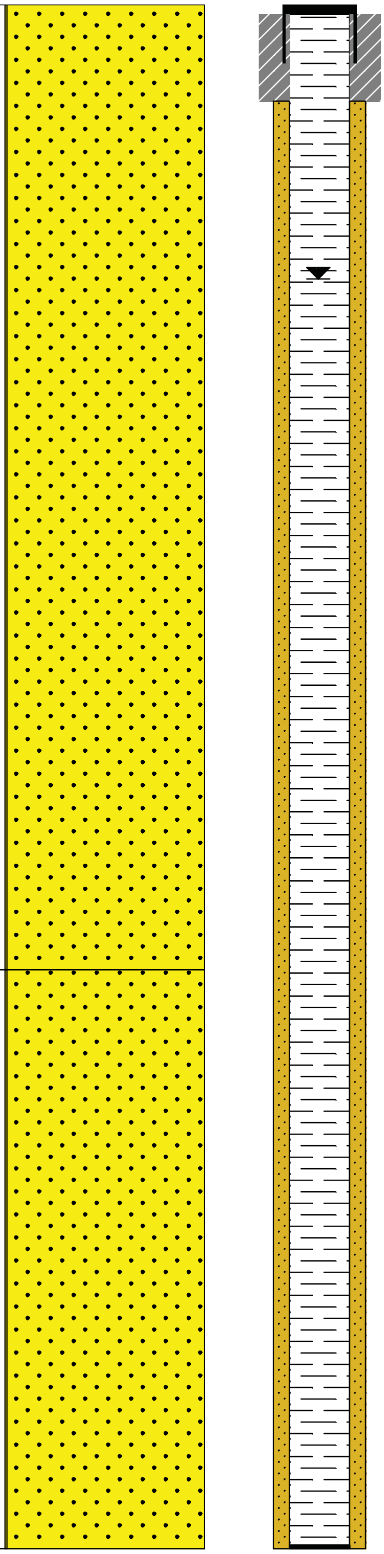
MWH

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

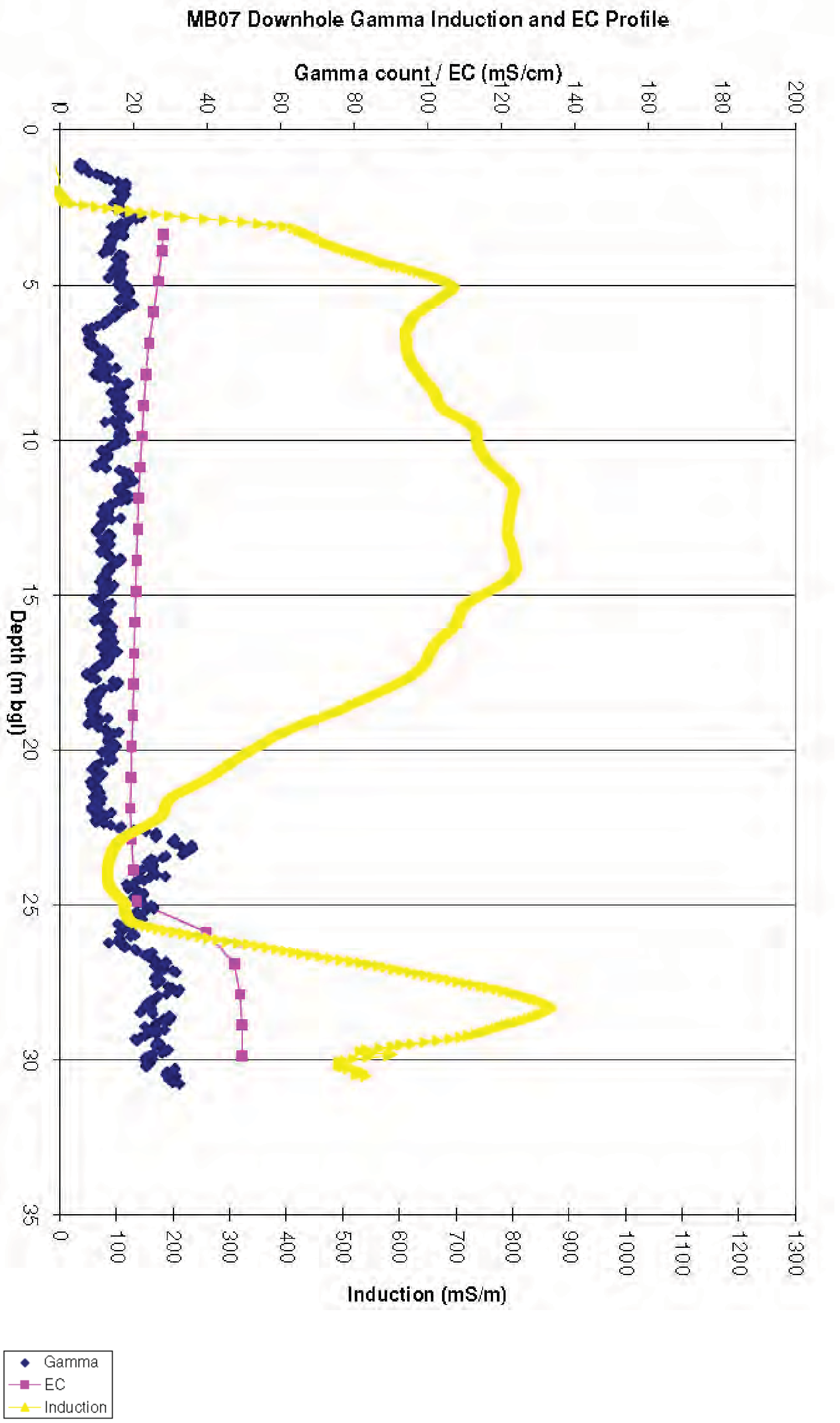
Easting: 377818
Northing: 6428338
Surface RL: 1.53 mAHD

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

WELL COMPLETION DETAILS: MB07

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

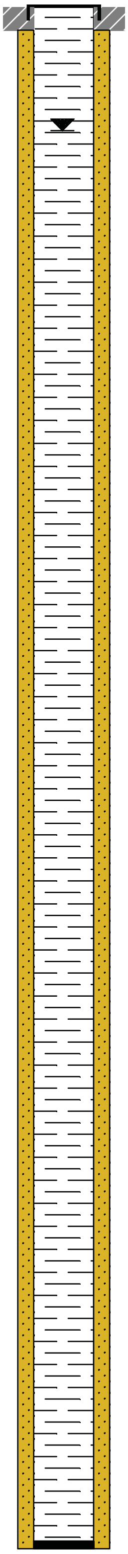
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378420
Northing: 6427873
Surface RL: 3.30 mAHD

HYDRAULIC DATA:
SWL: 2.45 mbgl
SWL Date Collected: 19/04/2010

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

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

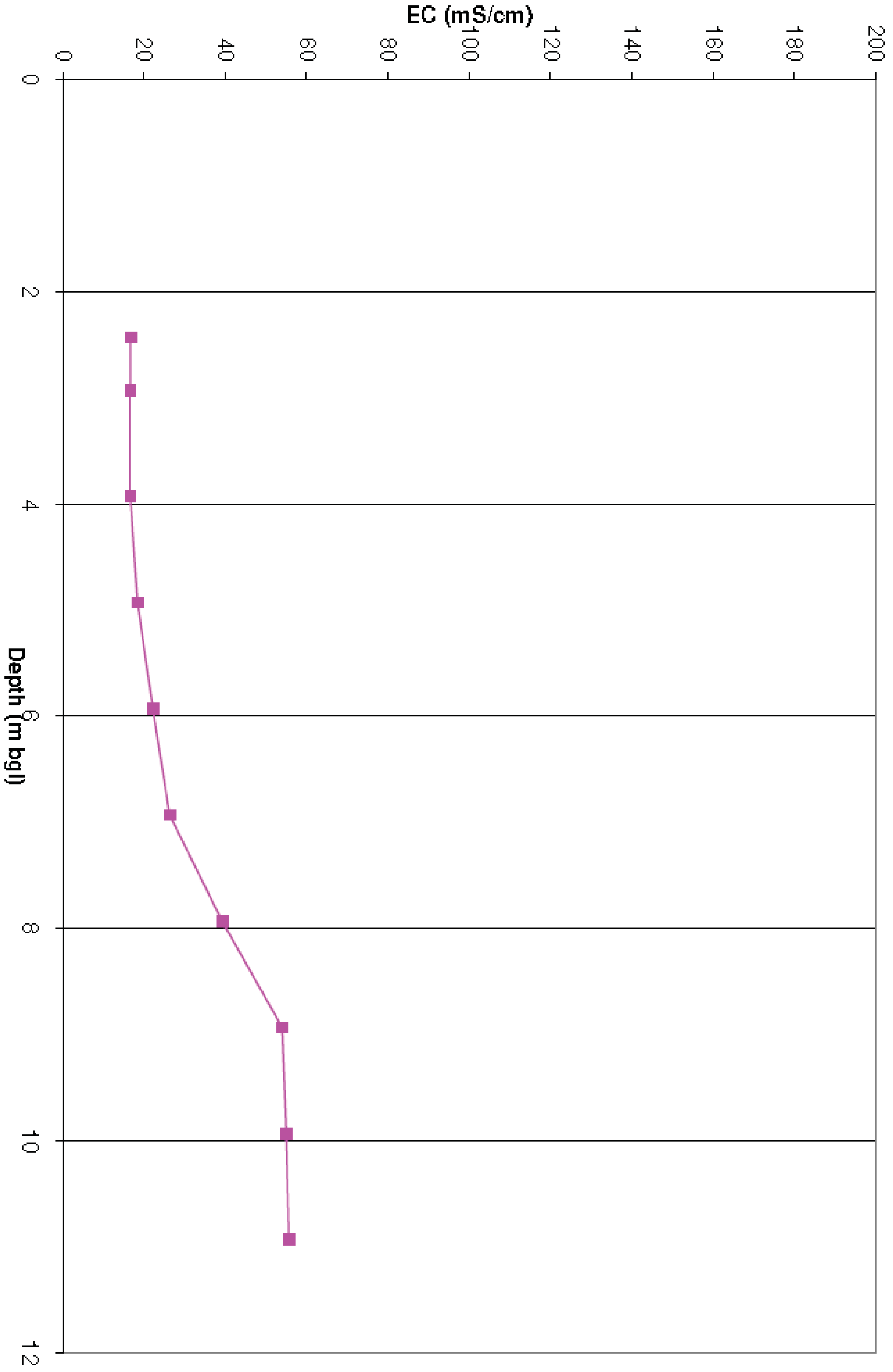
EC; 1.62 mS/cm, TDS; 1.05 ppt, Temp; 23.5 °C, pH; 8.06 at 24 m

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



WELL COMPLETION DETAILS: MB08

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

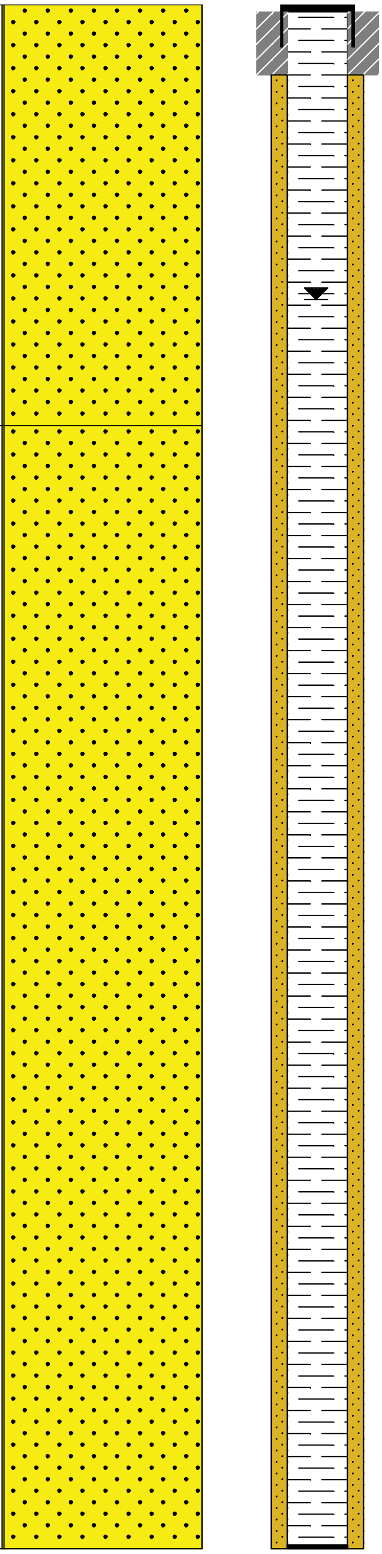
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

Easting: 378198
Northing: 6428232
Surface RL: 2.38 mAHD

HYDRAULIC DATA:

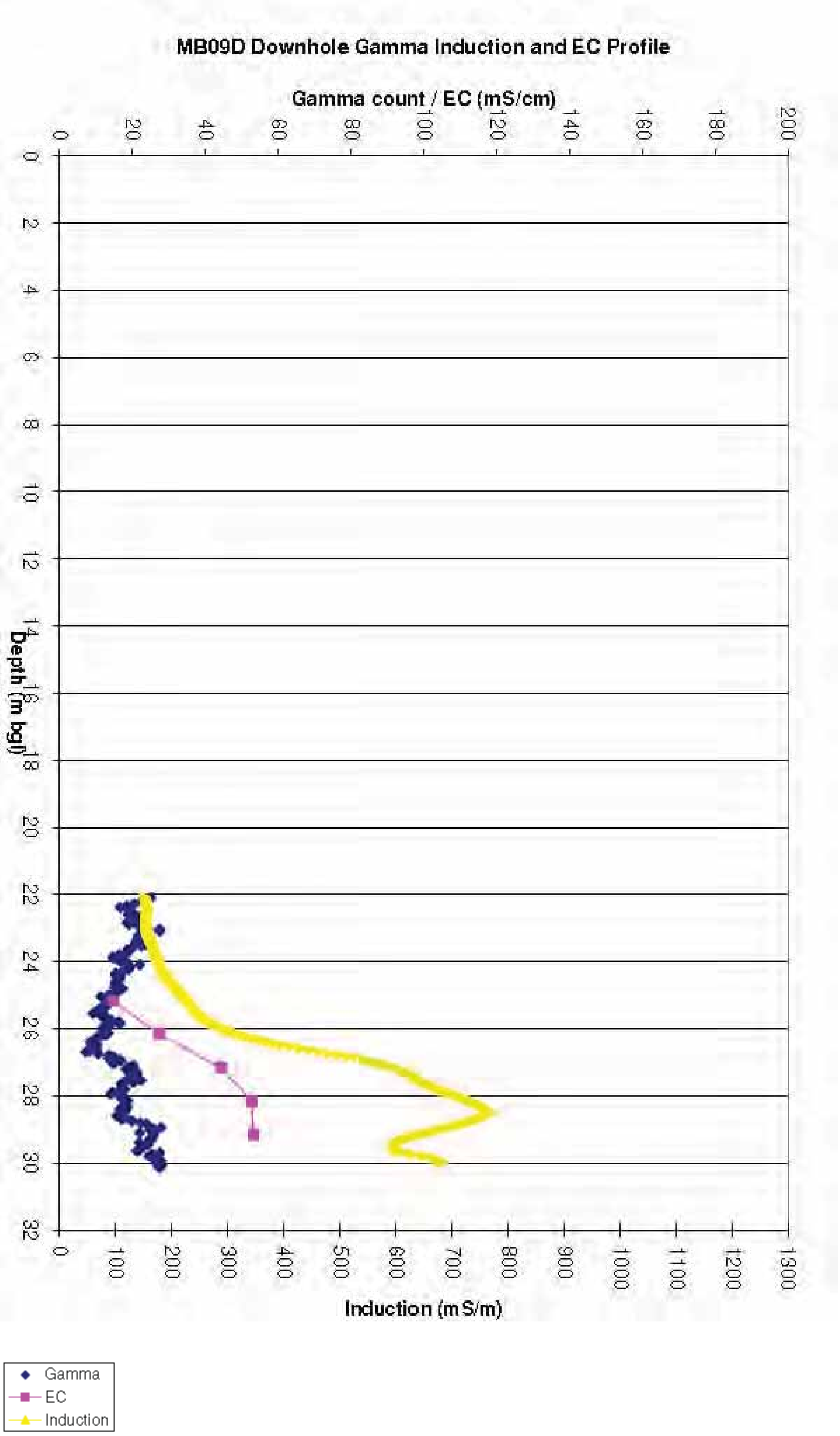
SWL: 2.10 mbgl

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

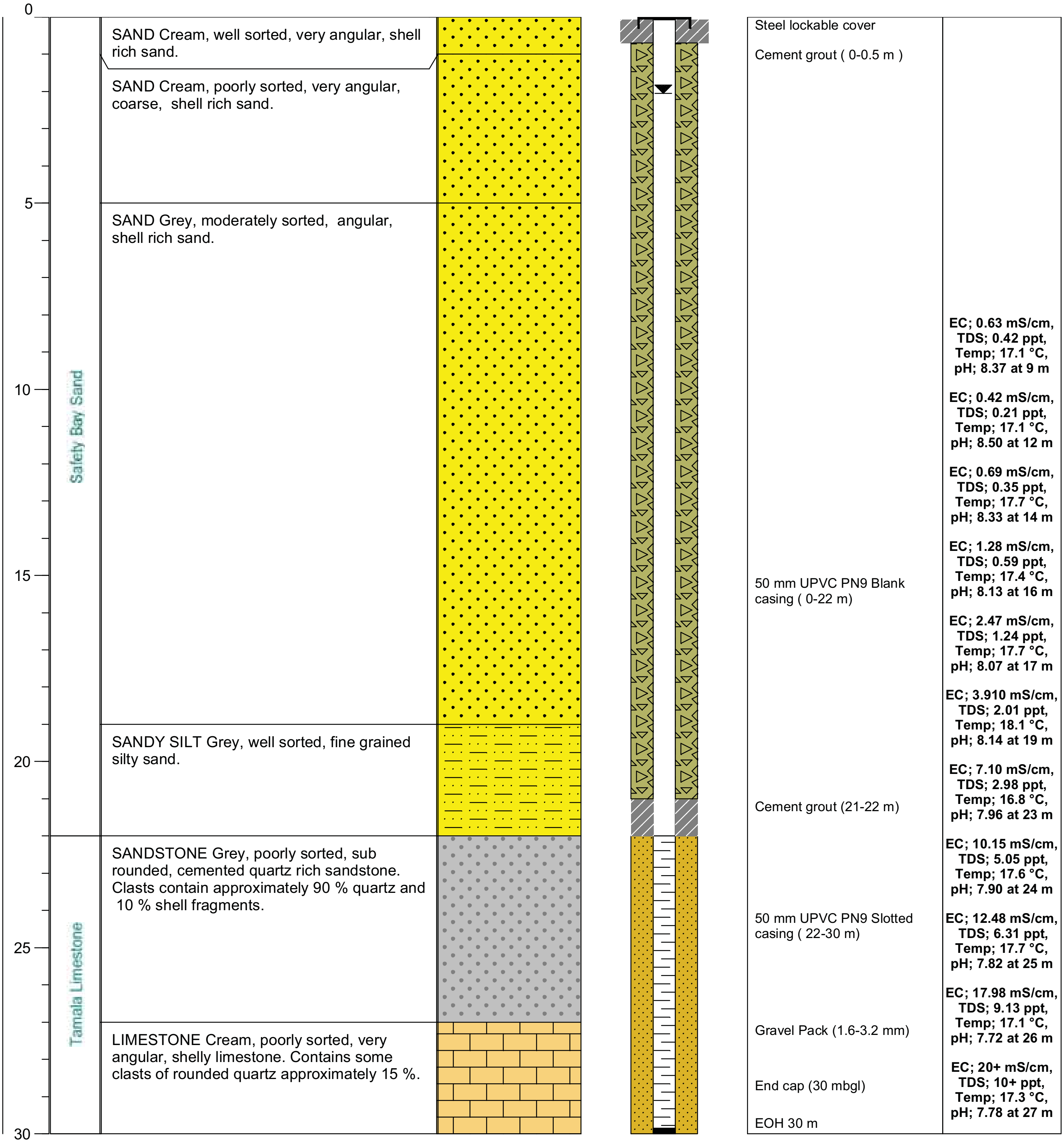
Client: Landcorp
Date Drilled: 12-14/04/2010
Logged By: Shawn Butland

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	Lithology	Well Construction	Well Details	Water Quality



Fm.	Lithological Description
Safety Bay Sand	SAND Cream, well sorted, very angular, shell rich sand.
	SAND Cream, poorly sorted, very angular, coarse, shell rich sand.
	SAND Grey, moderately sorted, angular, shell rich sand.
	SANDY SILT Grey, well sorted, fine grained silty sand.
Tamala Limestone	SANDSTONE Grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 90 % quartz and 10 % shell fragments.
	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

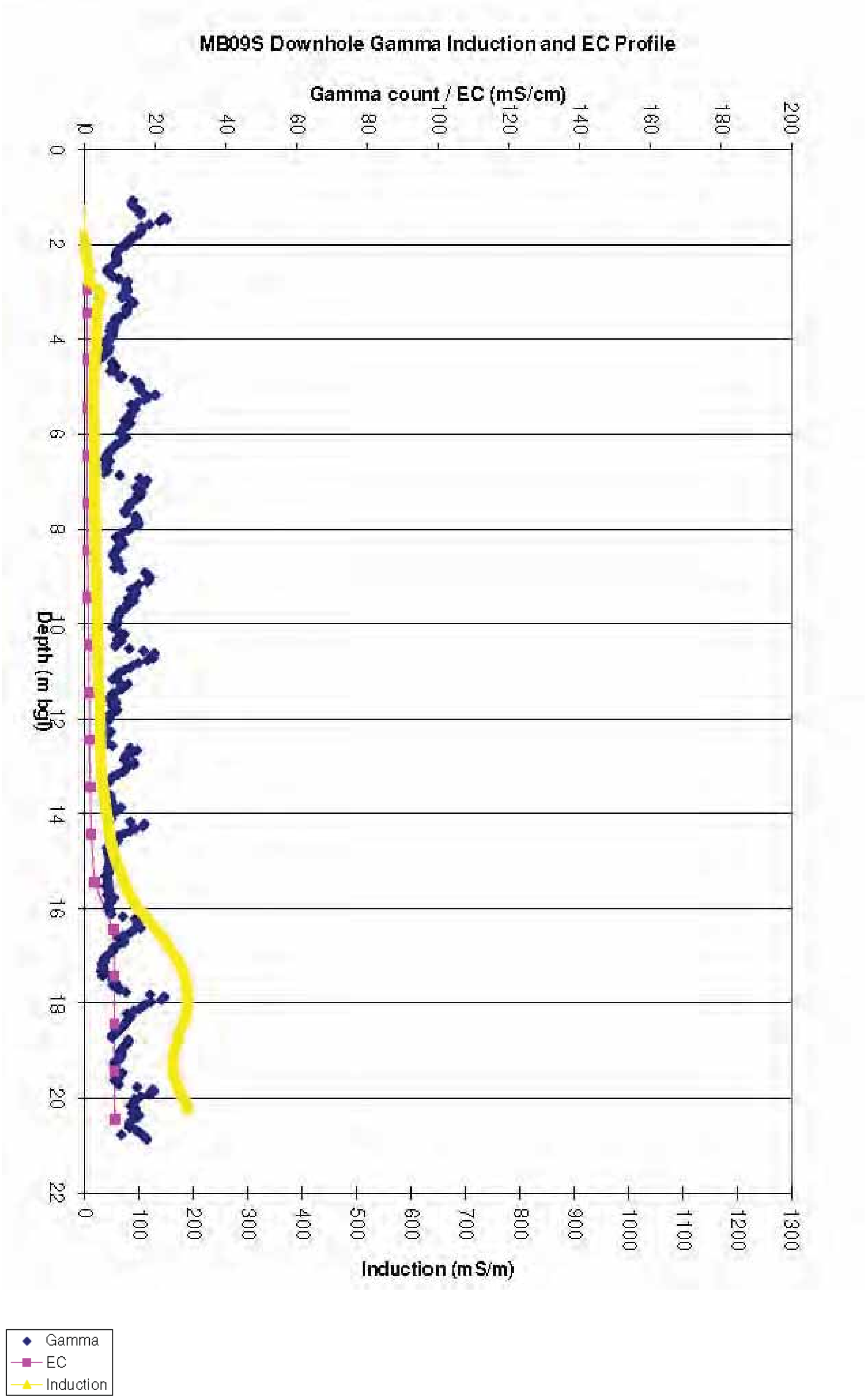
EC; 10.15 mS/cm, TDS; 5.05 ppt, Temp; 17.6 °C, pH; 7.90 at 24 m

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
Induction (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma
EC
Induction

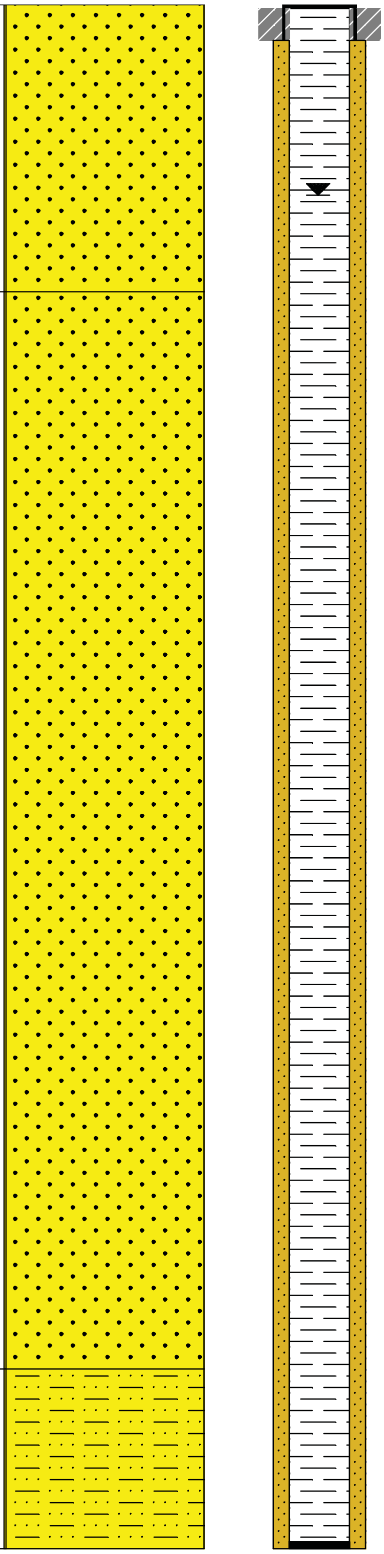
WELL COMPLETION DETAILS: MB09S

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

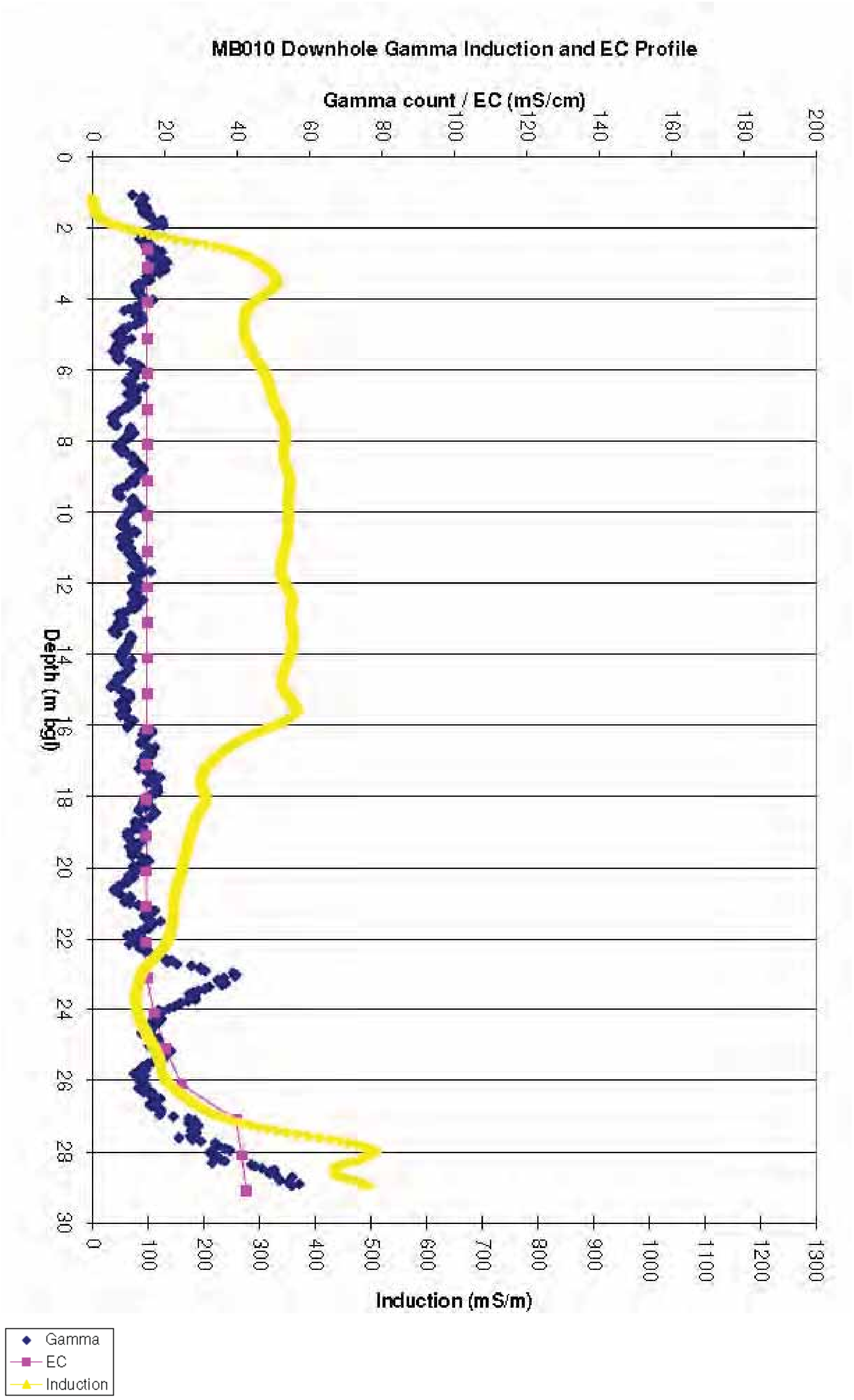
Easting: 378298
Northing: 6428082
Surface RL: 2.83 mAHD

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)	
5 10 15		SAND Grey, well sorted, angular, shell rich sand.			100 mm UPVC PN9 Slotted casing (0-21.5 m) Gravel Pack (1.6-3.2 mm)	EC; 0.87 mS/cm, TDS; 0.37 ppt, Temp; 43.5 °C, pH; 8.26 at 10 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 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
20		SANDY SILT Grey, well sorted, silty sand.			End cap (21.5 mbgl)	EC; 2.54 mS/cm, TDS; 1.27 ppt, Temp; 28.6 °C, pH; 8.13 at 20 m

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


MB010 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: MB10

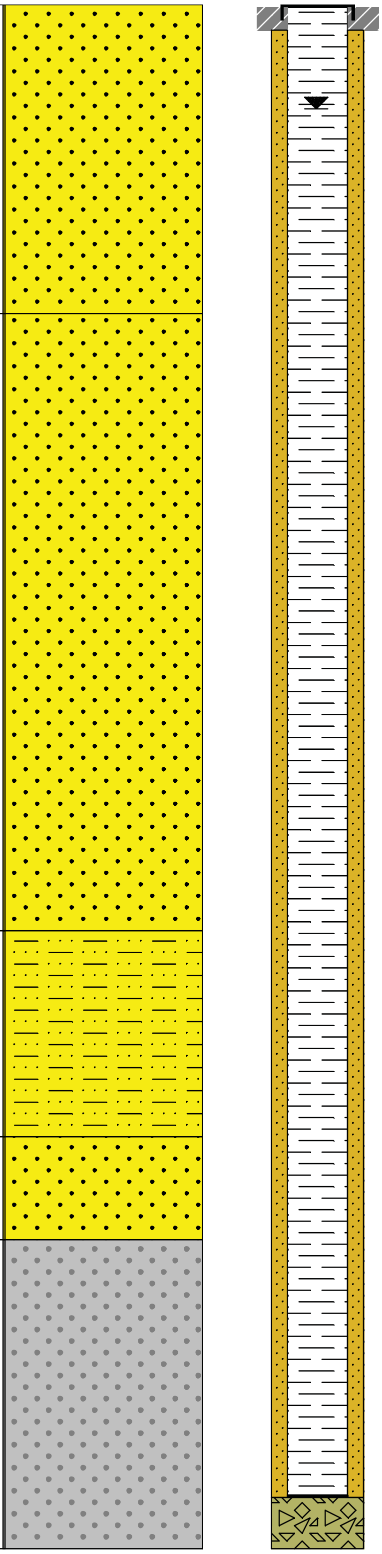
Client: Landcorp
Date Drilled:30-31/03/2010
Logged By: Shawn Butland

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

Easting: 378587
Northing: 6427907
Surface RL: 2.95 mAHD

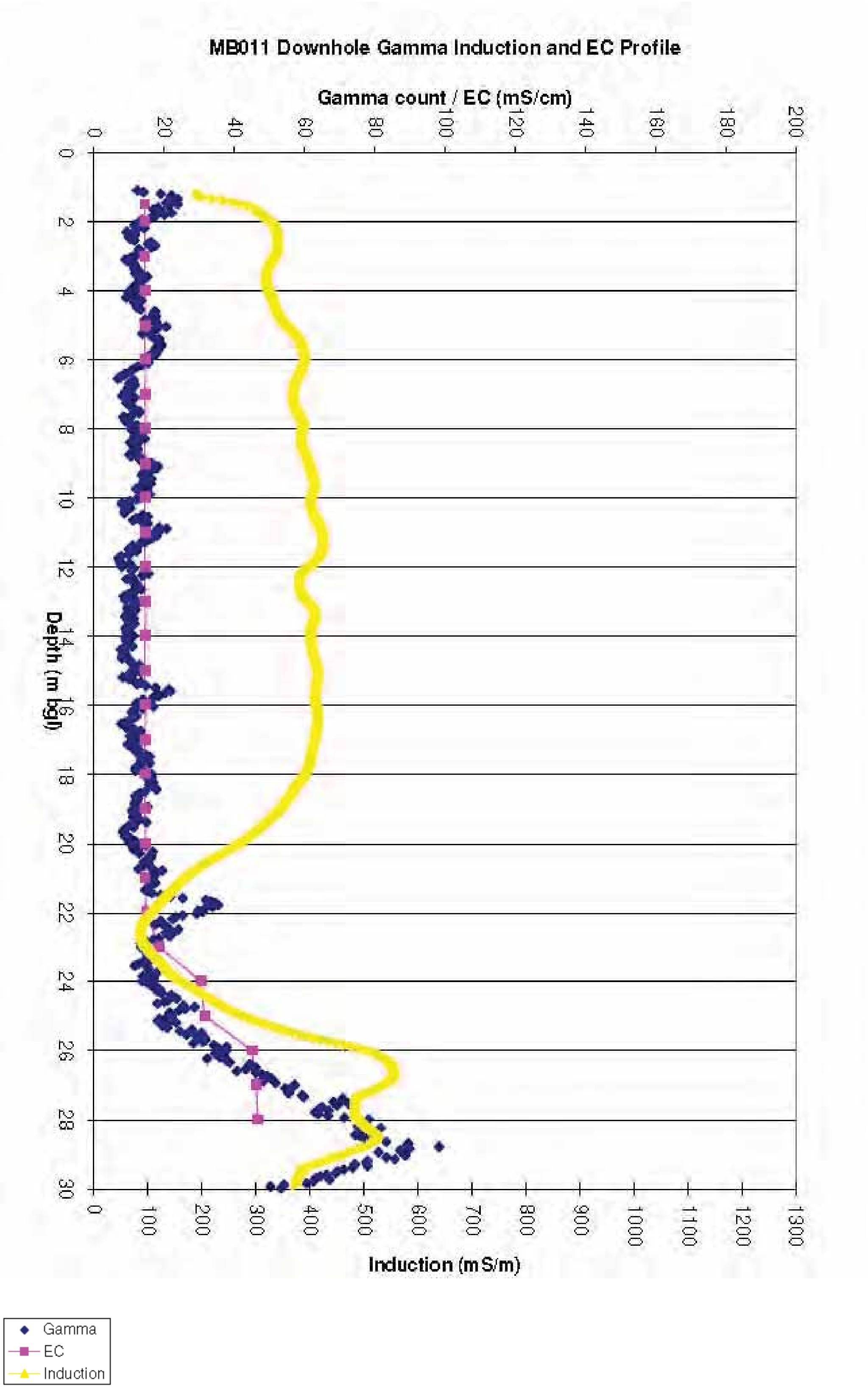
HYDRAULIC DATA: **SWL:** 2.02 mbgl

SWL Date Collected: 19/04/2010



Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality
0 5	Safety Bay Sand	SAND Cream, moderately sorted, very angular, shell rich sand.			Steel lockable cover Cement grout (0-0.5 m)	
10 15		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**
20		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**
		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**
25 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

WELL COMPLETION DETAILS: MB11

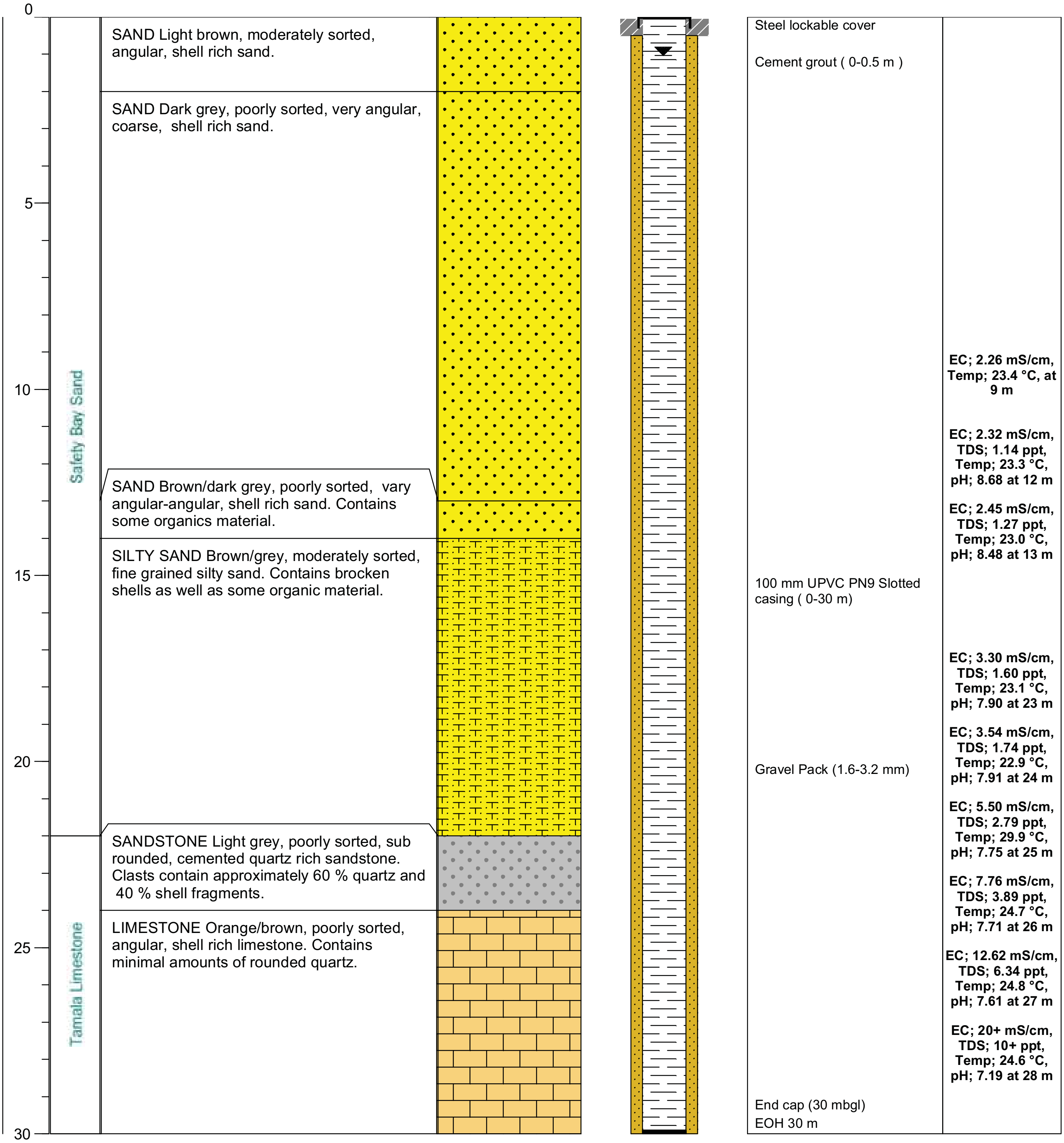
Client: Landcorp
Date Drilled:23-24/03/2010
Logged By: Shawn Butland

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**	**Lithology**	**Well Construction**	**Well Details**	**Water Quality**



SAND Light brown, moderately sorted, angular, shell rich sand.

SAND Dark grey, poorly sorted, very angular, coarse, shell rich sand.

SAND Brown/dark grey, poorly sorted, vary angular-angular, shell rich sand. Contains some organics material.

SILTY SAND Brown/grey, moderately sorted, fine grained silty sand. Contains brocken shells as well as some organic material.

SANDSTONE Light grey, poorly sorted, sub rounded, cemented quartz rich sandstone. Clasts contain approximately 60 % quartz and 40 % shell fragments.

LIMESTONE Orange/brown, poorly sorted, angular, shell rich limestone. Contains minimal amounts of rounded quartz.

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

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

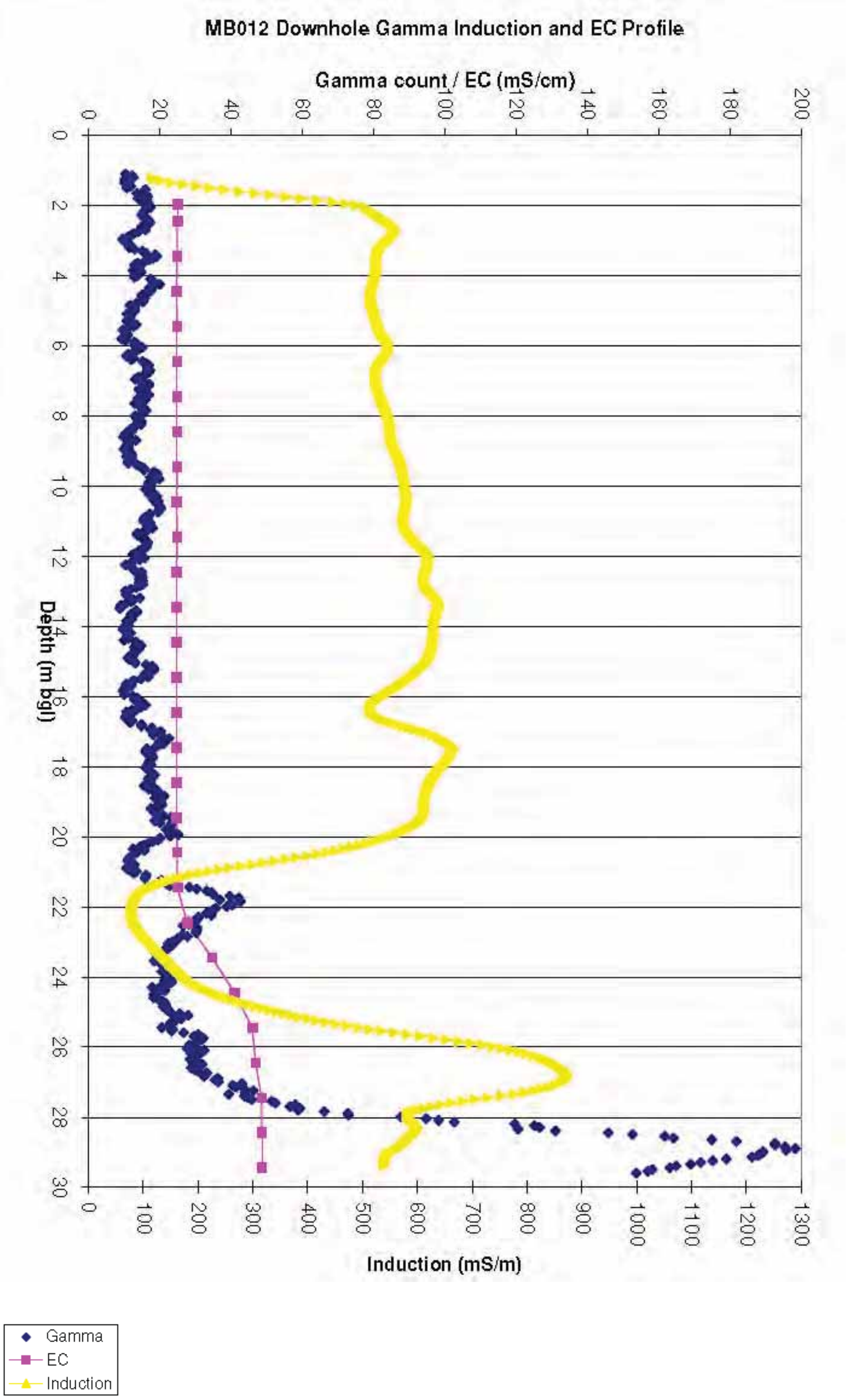
EC; 5.50 mS/cm, TDS; 2.79 ppt, Temp; 29.9 °C, pH; 7.75 at 25 m

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

WELL COMPLETION DETAILS: MB12

MWH

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

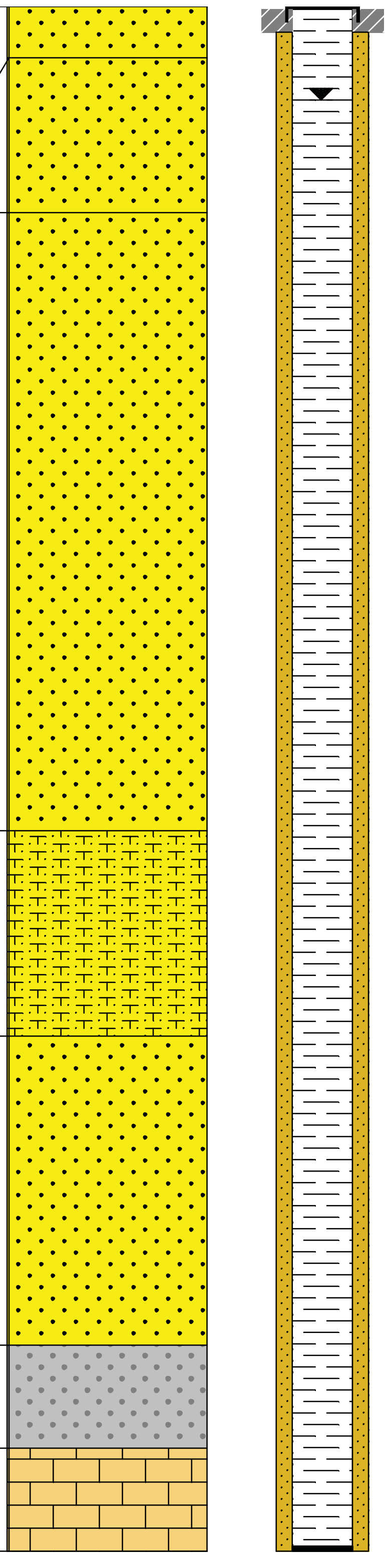
Driller: Mathews Drilling
Fluid : Air/Water
Drilling Method: Reverse Circulation
Drilled Diameter: 152.4 mm

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	Safety Bay Sand	SAND Light brown, moderately sorted, angular, shell rich sand.
		SAND Light grey, poorly sorted, angular, coarse, shell rich sand. Contains minor amounts of sub rounded to rounded quartz grains.
5		SAND Grey, moderately sorted, very angular-angular, shell rich sand.
		SILTY SAND Brown/grey, well sorted, fine grained silty sand.
20		SAND Grey, moderately sorted, sub rounded, coarse grained, quartz rich sand.
	Tamala Limestone	SANDSTONE Light grey, poorly sorted, sub rounded, quartz rich sandstone.
30		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

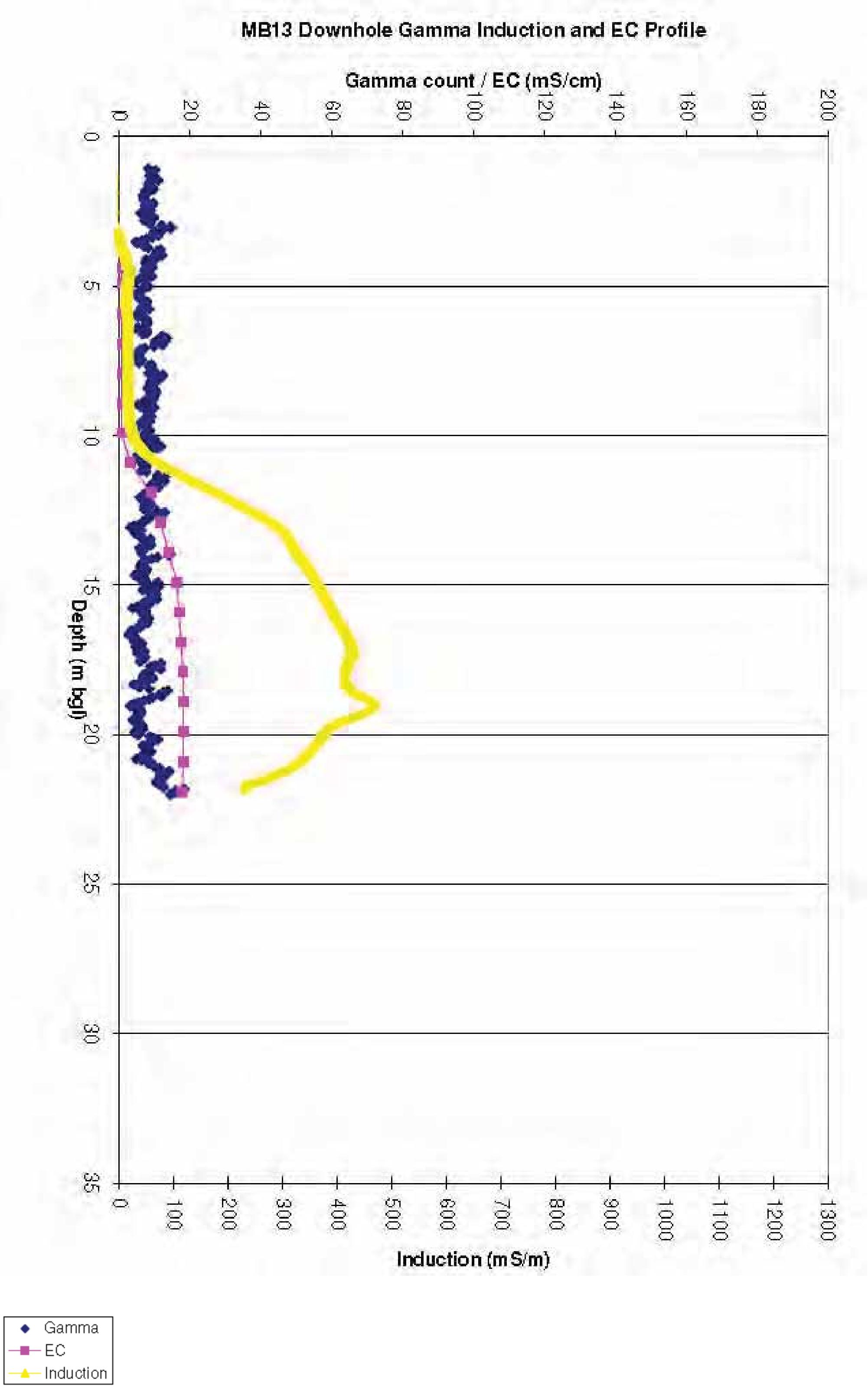
EC; 4.94 mS/cm, TDS; 2.34 ppt, Temp; 30.8 °C, pH; 7.93 at 25 m

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

WELL COMPLETION DETAILS: MB13

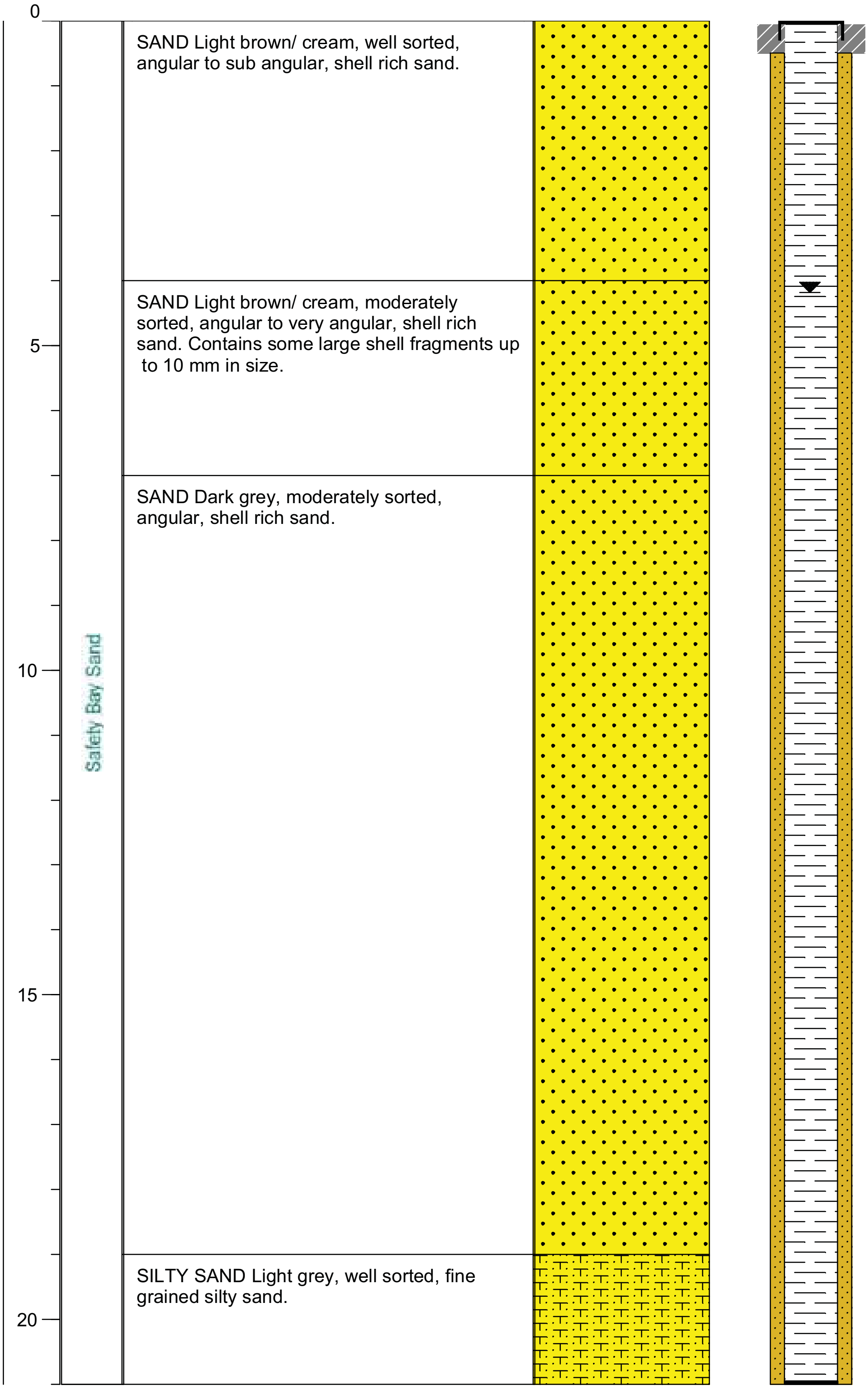
Client: Landcorp
Date Drilled: 08/04/2010
Logged By: Shawn Butland

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



SAND Light brown/ cream, well sorted, angular to sub angular, shell rich sand.

SAND Light brown/ cream, moderately sorted, angular to very angular, shell rich sand. Contains some large shell fragments up to 10 mm in size.

SAND Dark grey, moderately sorted, angular, shell rich sand.

SILTY SAND Light grey, well sorted, fine grained silty sand.

Well Details:

Steel lockable cover

Cement grout (0-0.5 m)

100 mm UPVC PN9 Slotted casing (0-21 m)

Gravel Pack (1.6-3.2 mm)

End cap (21 mbgl)

EOH 21 m

Water Quality:

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

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

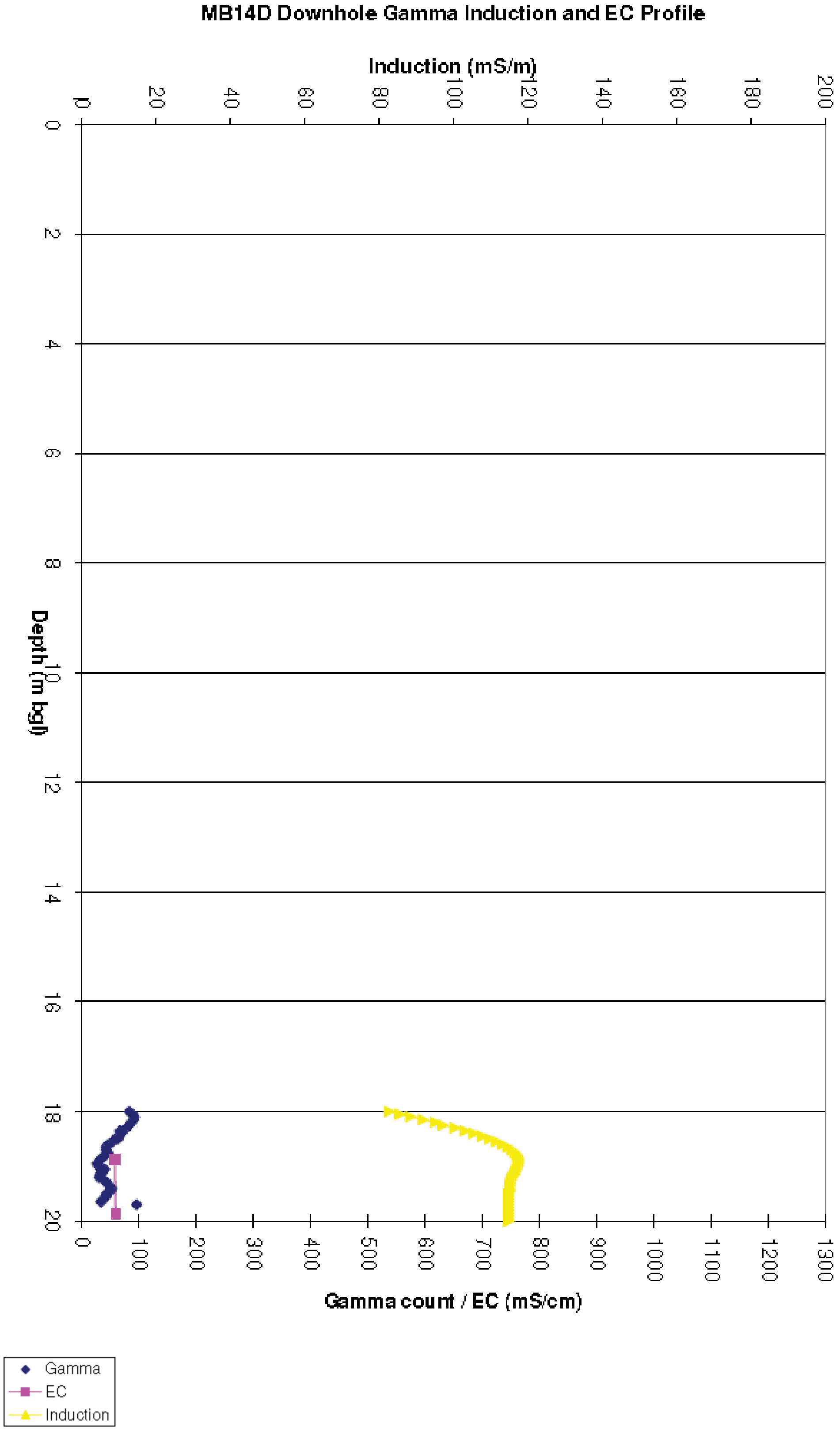
EC; 13.23 mS/cm, TDS; 5.46 ppt, Temp; 25.8 °C, pH; 7.93 at 18 m

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

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
Induction (mS/m)
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
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Gamma count / EC (mS/cm)
Gamma
EC
Induction

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

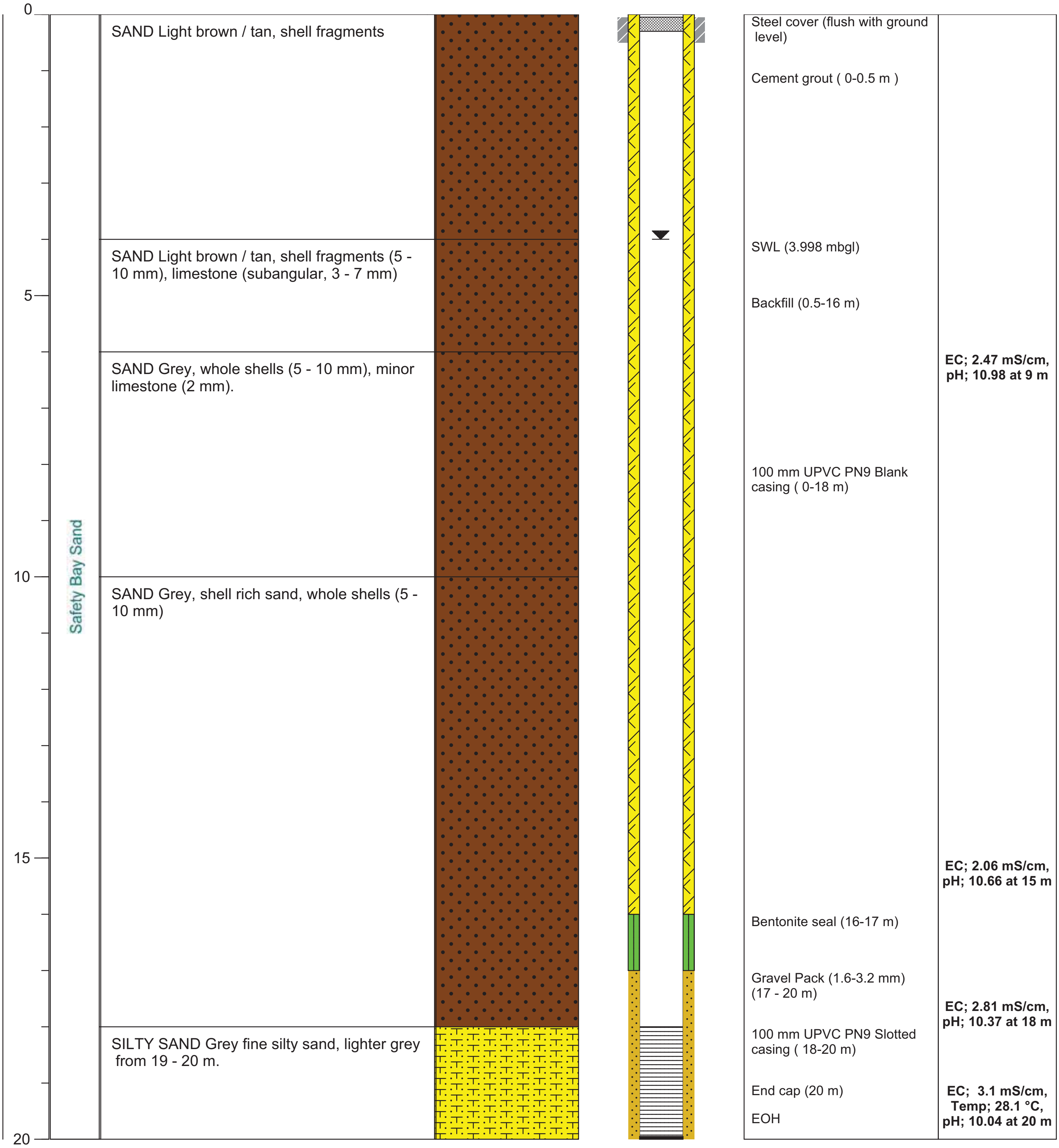
Easting: 378018
Northing: 6428013
Surface RL:

HYDRAULIC DATA:

SWL: 3.998 mbgl

SWL Date Collected: 16/02/2011

Depth mbgl	Fm.	Lithological Description	Lithology	Well Construction	Well Details	Water Quality



SAND Light brown / tan, shell fragments

SAND Light brown / tan, shell fragments (5 - 10 mm), limestone (subangular, 3 - 7 mm)

SAND Grey, whole shells (5 - 10 mm), minor limestone (2 mm).

SAND Grey, shell rich sand, whole shells (5 - 10 mm)

SILTY SAND Grey fine silty sand, lighter grey from 19 - 20 m.

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

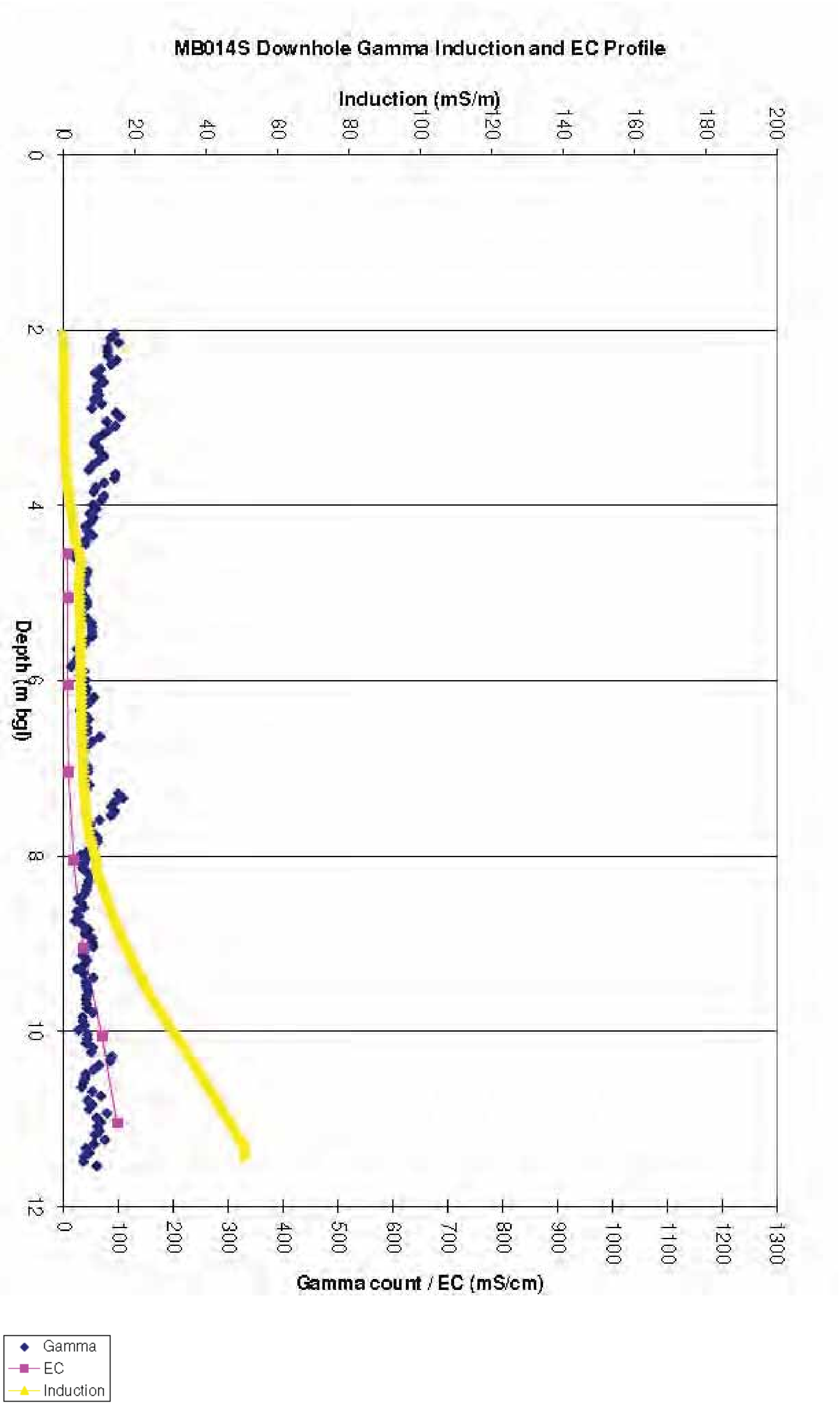
EC; 2.47 mS/cm, pH; 10.98 at 9 m

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

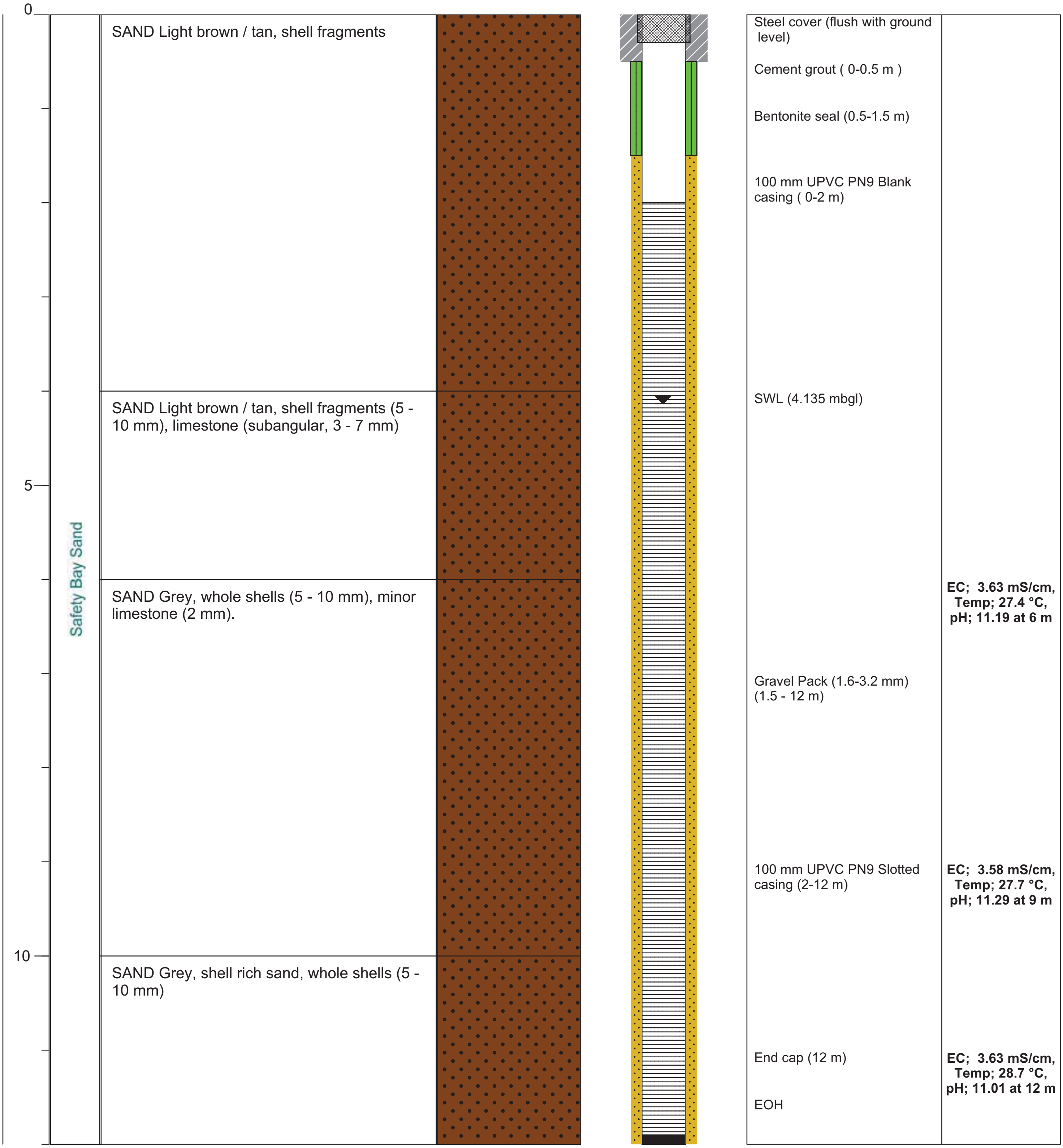
Client: Cedar Woods
Date Drilled: 10/02/2011
Logged By: Chris Jones

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



SAND Light brown / tan, shell fragments

SAND Light brown / tan, shell fragments (5 - 10 mm), limestone (subangular, 3 - 7 mm)

SAND Grey, whole shells (5 - 10 mm), minor limestone (2 mm).

SAND Grey, shell rich sand, whole shells (5 - 10 mm)

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)

SWL (4.135 mbgl)

Gravel Pack (1.6-3.2 mm) (1.5 - 12 m)

100 mm UPVC PN9 Slotted casing (2-12 m)

End cap (12 m)

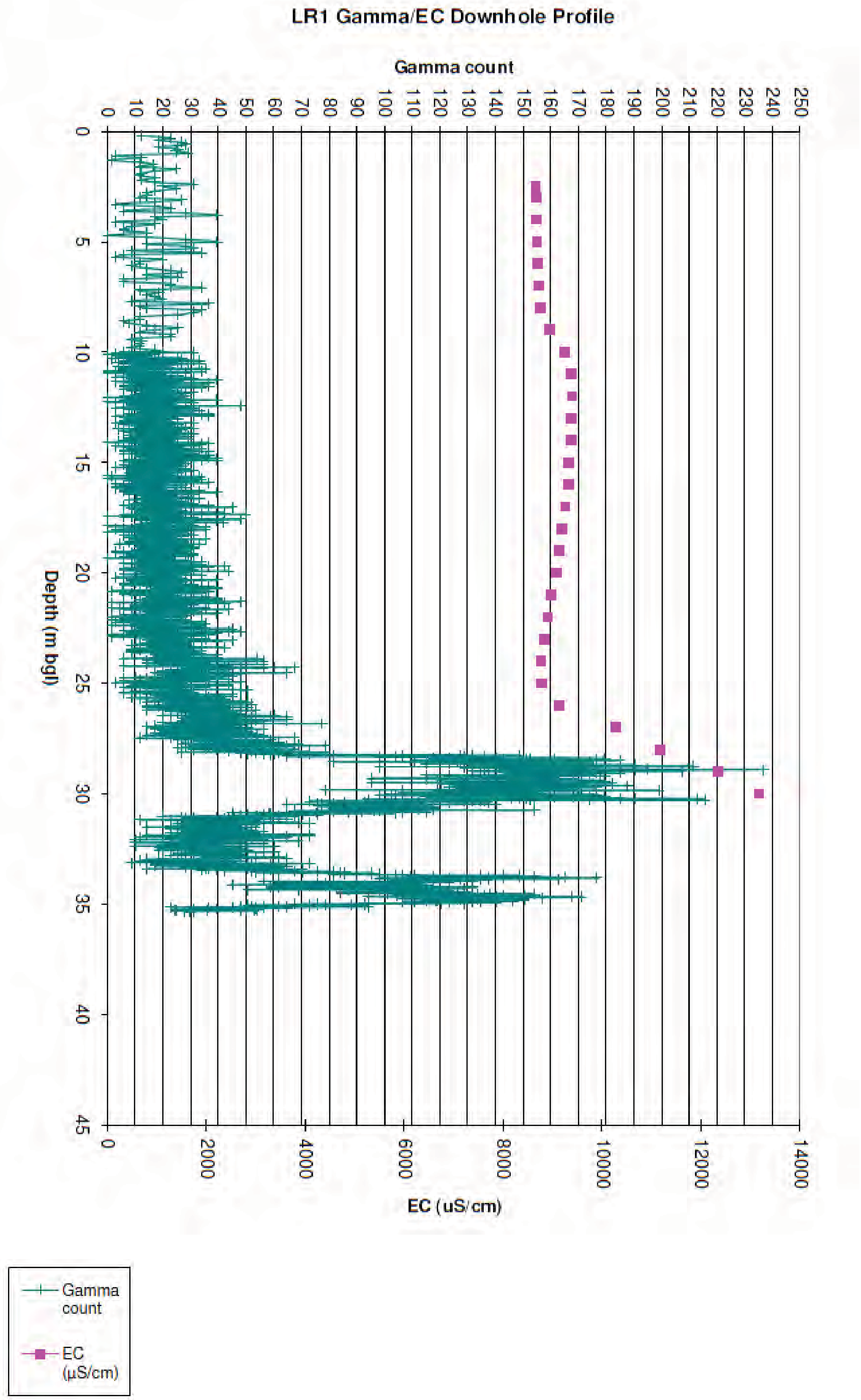
EOH

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

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**
Project Name: **SDOOL**
Drill Start Date: **26/05/2011**
Drill Finish Date: **27/05/2011**
Drill Co: **Envirotech Drilling**
Driller: **Rock Fazari**

Drill Method: **Mud Rotary**
Hole Type: **MW**
Total Depth (m): **39**
Hole Diam. / Width (mm): **150**
Casing Type/Diam. (mm): **50**
Surface Completion: **Gattic**

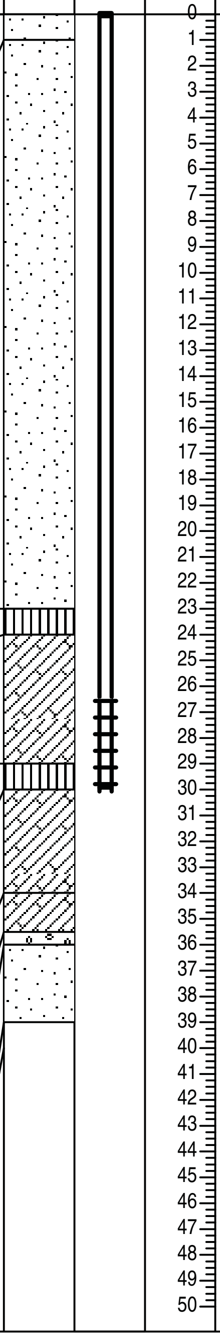
Water Strike:
Water Level (Final):
RL Ground:
RL Case:
East MGA: **0379204**
North MGA: **6427463**

ID: LR1

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								
Sand Light grey, damp, fine grains (<1mm), loose, well sorted, suspected fill material.								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.								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								
Limestone Grey/brown, fine (<1mm) to coarse (>1mm) limestone, loose, non plastic, some limestone/cephalopod shell fragments (>5mm) present.								
Clayey Rock Brown/grey, moderately plastic, loose, 5mm rock fragments, limestone fragments present.								
Clay Brown, plastic, soft, fine grains. Colour change to orange at 31m. Becoming increasingly sandy at 34m.								
Clayey Sand Orange, medium sized grains, some quartz.								
Shale Black, very fine grains, sticky. Grain size increasing at 36mbgs and some small quartz rocks present.								
Sand Orange, coarse grains, poorly sorted, quartz rocks (5mm).								
End of Log								

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

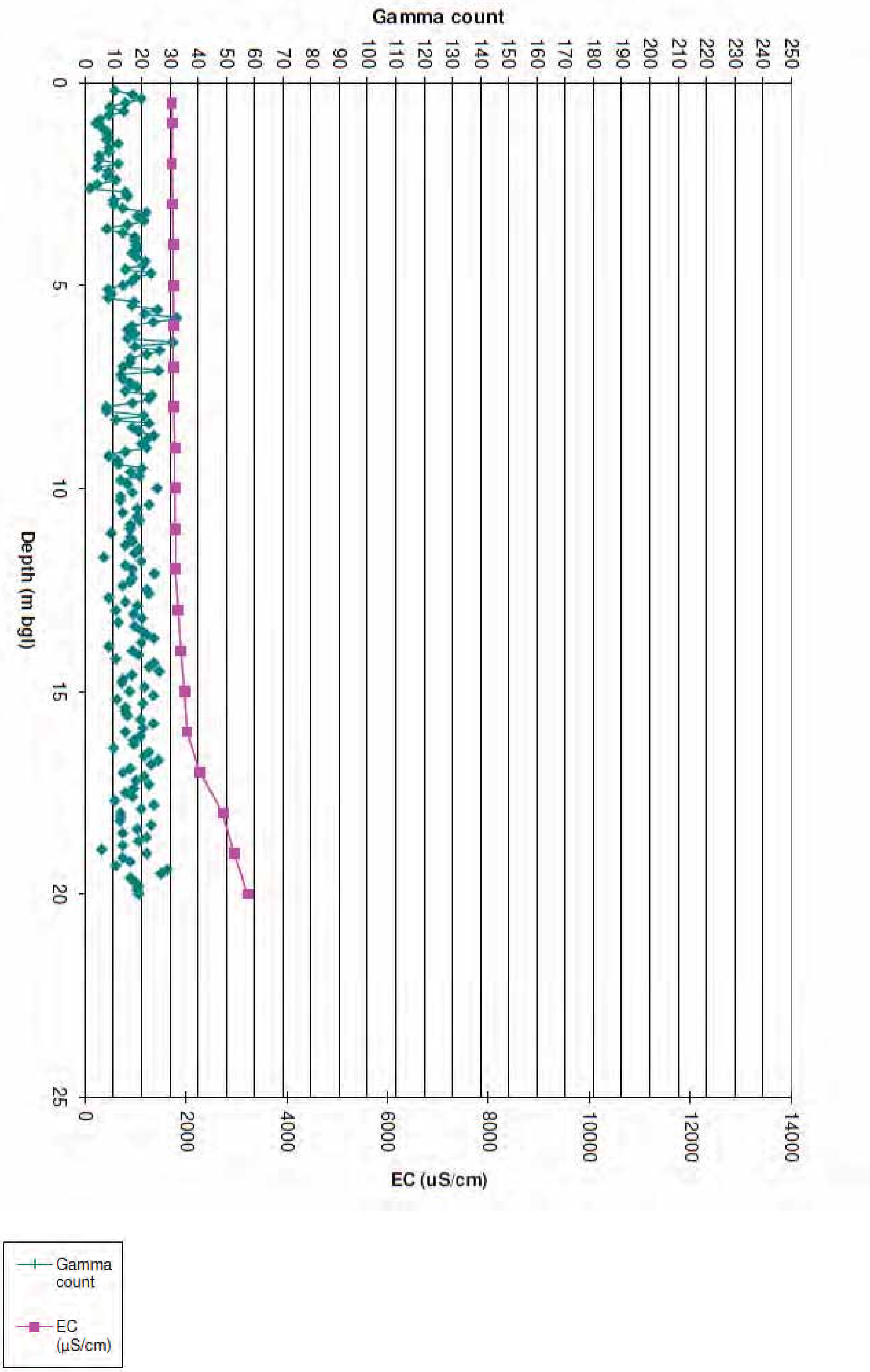
SITE COMMENTS:

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**
Project Name: **SDOOL**
Drill Start Date: **26/05/2011**
Drill Finish Date: **27/05/2011**
Drill Co: **Envirotech Drilling**
Driller: **Rock Fazari**

Drill Method: **Mud Rotary**
Hole Type: **MW**
Total Depth (m): **23**
Hole Diam. / Width (mm): **150**
Casing Type/Diam. (mm): **50**
Surface Completion: **Gattic**

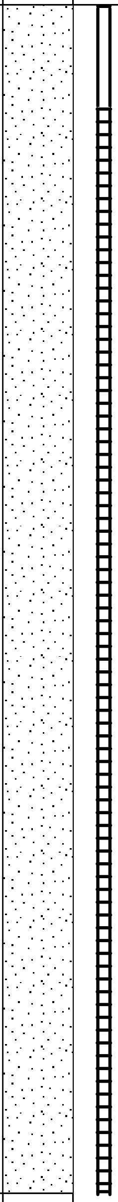
Water Strike:
Water Level (Final):
RL Ground:
RL Case:
East MGA: **0379201**
North MGA: **6427465**

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								
Sand Grey/brown, damp, medium grains, loose, some shell fragments.			0					Hand augered to 1.5m
			1					
Becoming quite coarse grained with depth. Shell content increasing with depth.			2					
			3					
			4					
			5					Located 1m west of LR1.
			6					
			7					
			8					
			9					
			10					Well construction approved by TW via phone.
			11					
			12					
			13					
			14					
			15					
			16					
			17					
			18					
			19					
			20					
			21					
			22					
			23					
			24					
			25					

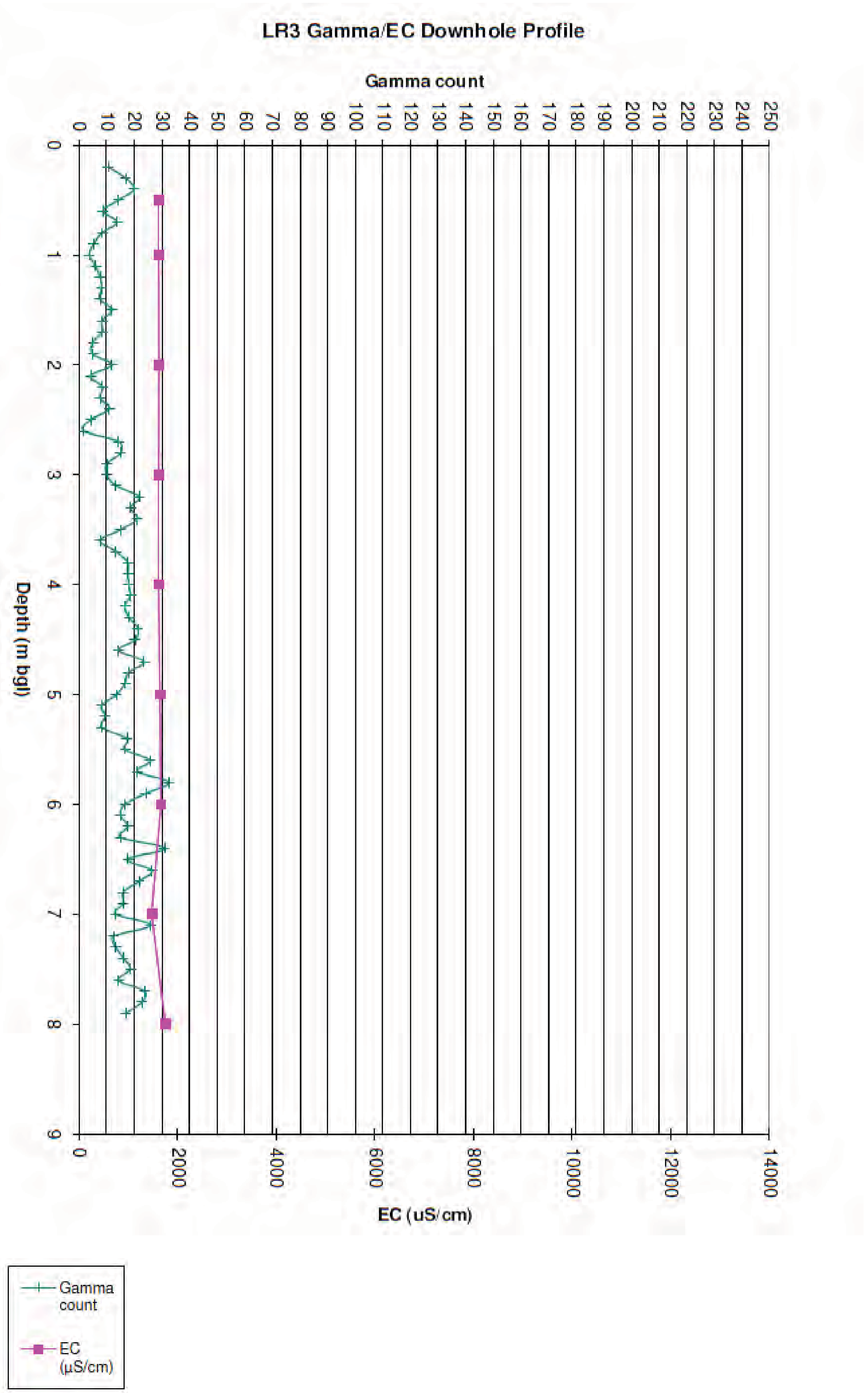
NOTE: This bore log is for environmental purposes only and is not intended to provide geotechnical information.

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**

Page **1 of 1**


LR3 Gamma/EC Downhole Profile
Gamma count
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
Depth (m bgl)
0
1
2
3
4
5
6
7
8
9
EC (uS/cm)
0
2000
4000
6000
8000
10000
12000
14000
Gamma count
EC (µS/cm)

Project No: **0116221**
Project Name: **SDOOL**
Drill Start Date: **23/2/11**
Drill Finish Date: **23/2/11**
Drill Co: **Edrill**
Driller:

Drill Method: **HSA**
Hole Type: **MW**
Total Depth (m): **10.85**
Hole Diam. / Width (mm): **150**
Casing Type/Diam. (mm): **50**
Surface Completion: **Gattic**

Water Strike: **3.5**
Water Level (Final):
RL Ground:
RL Case:
East MGA: **0379204**
North MGA: **6427463**

ID: LR3

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

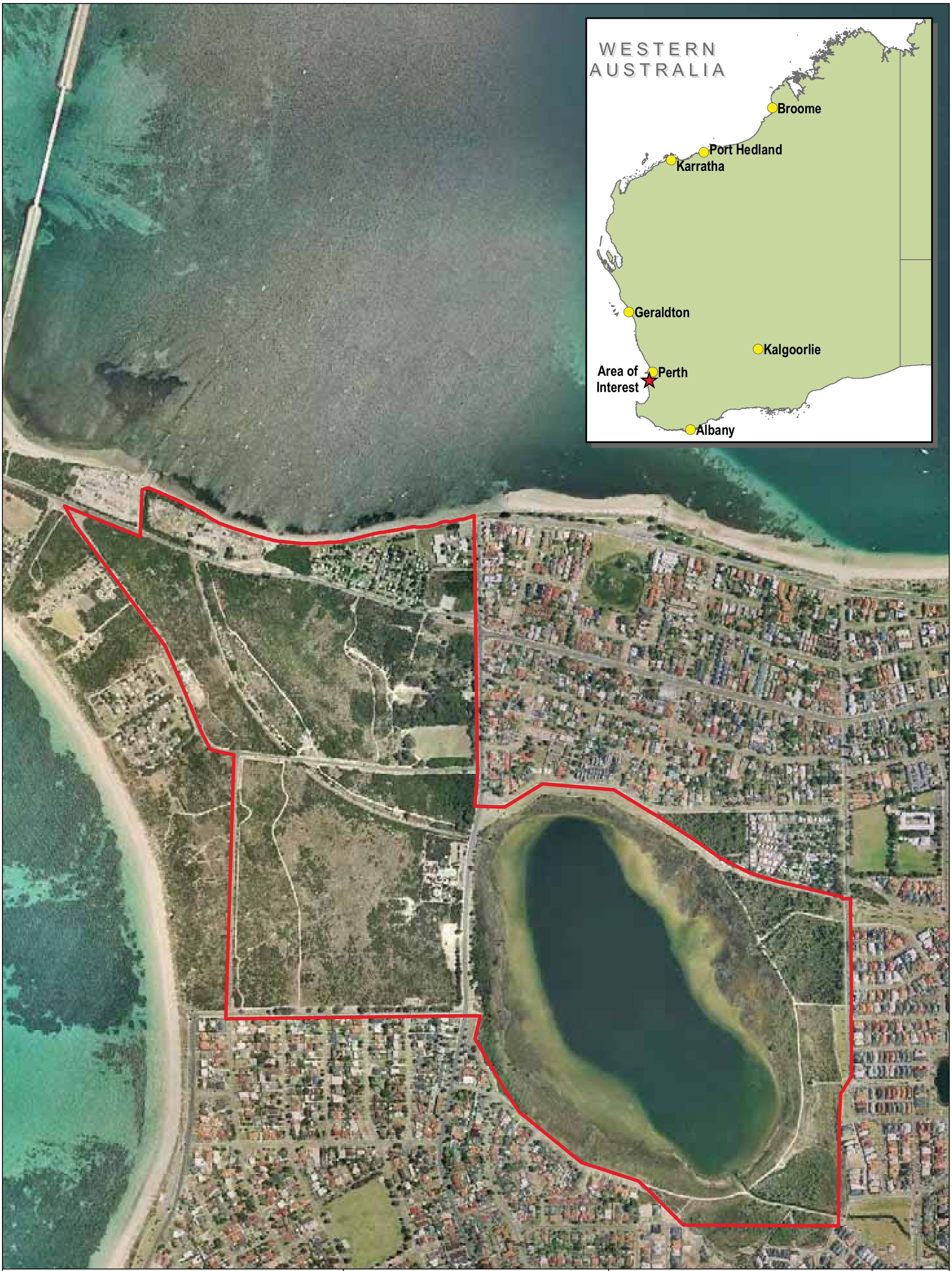
US = Undisturbed Soil Sample
DS = Disturbed Soil Sample

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

Page **1 of 1**

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

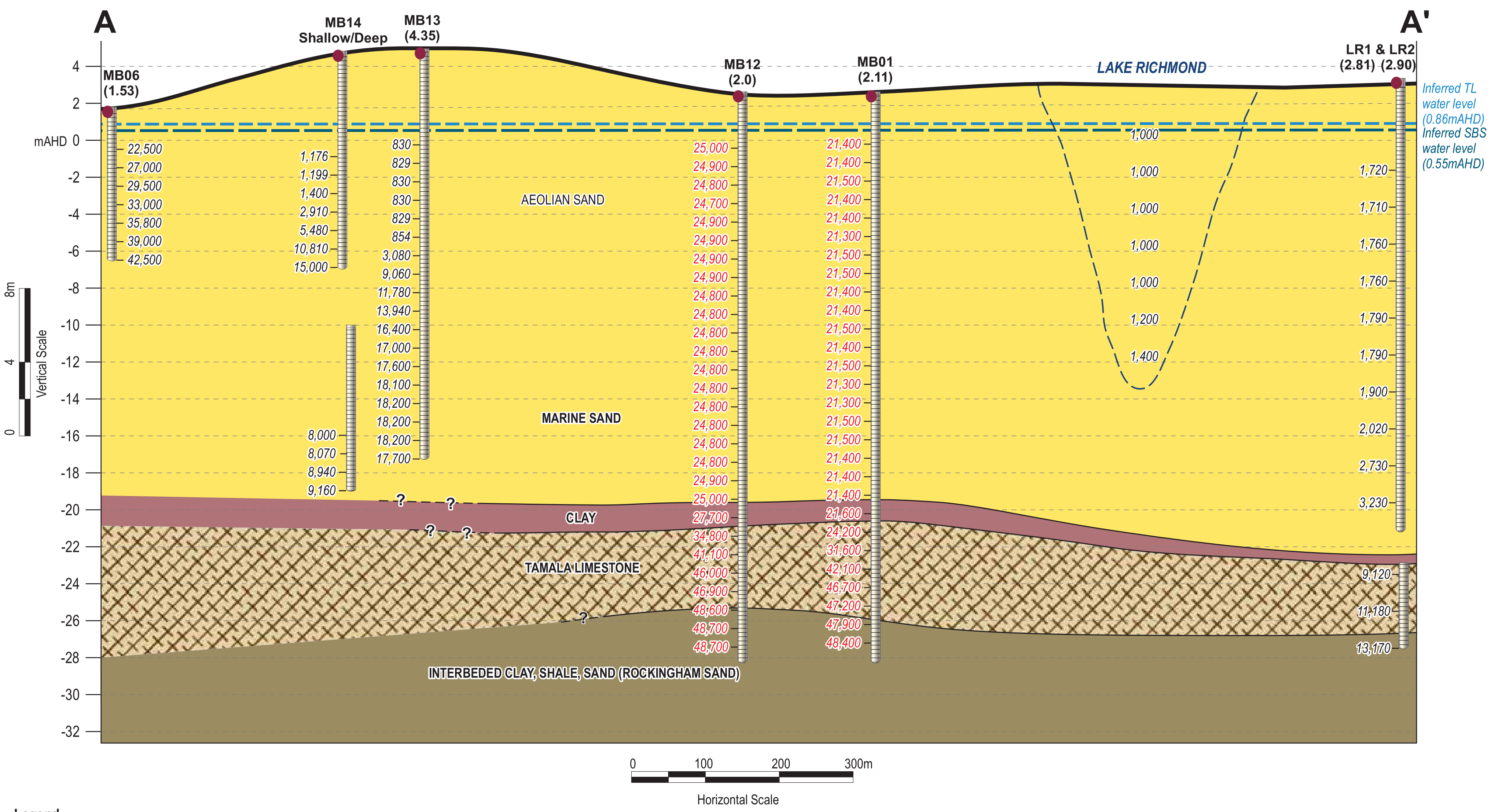
This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

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



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

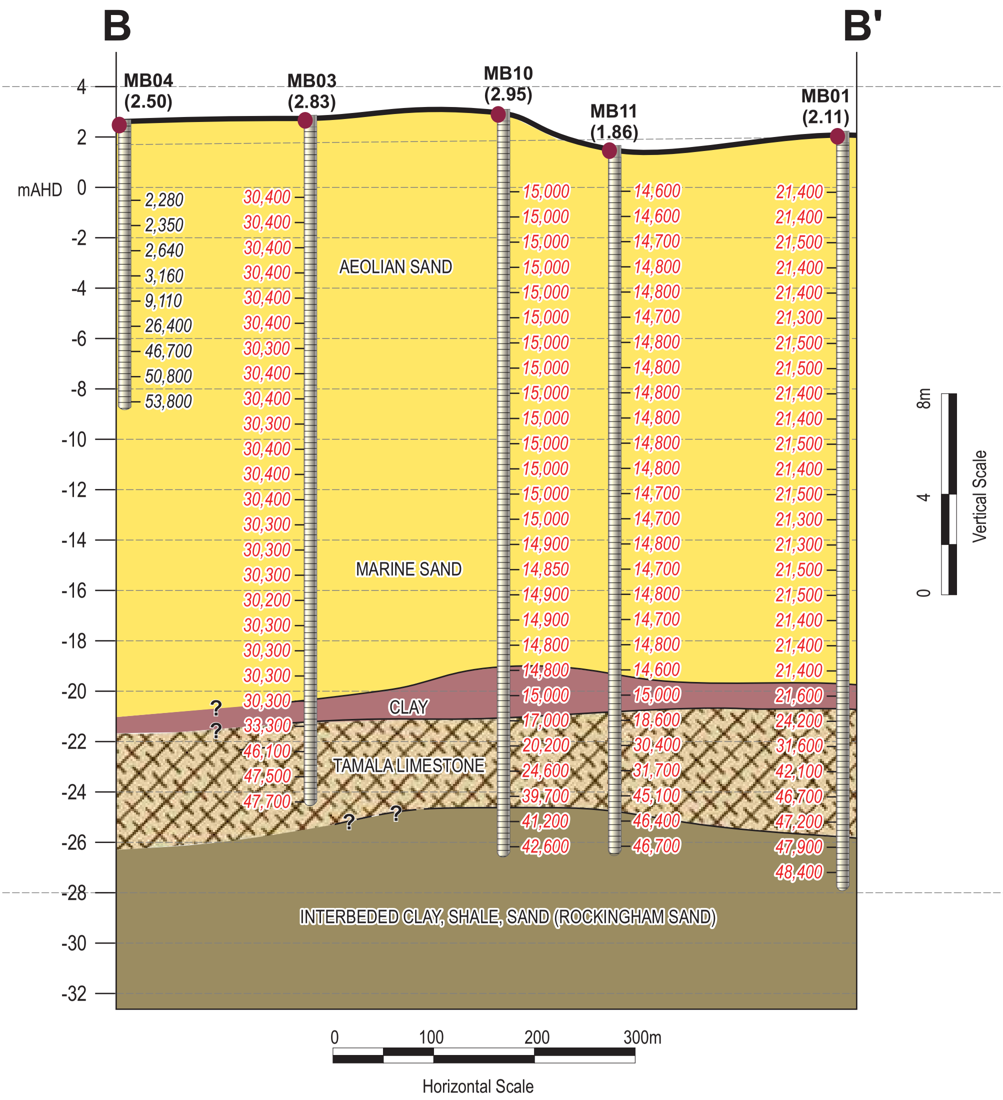
This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

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



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.

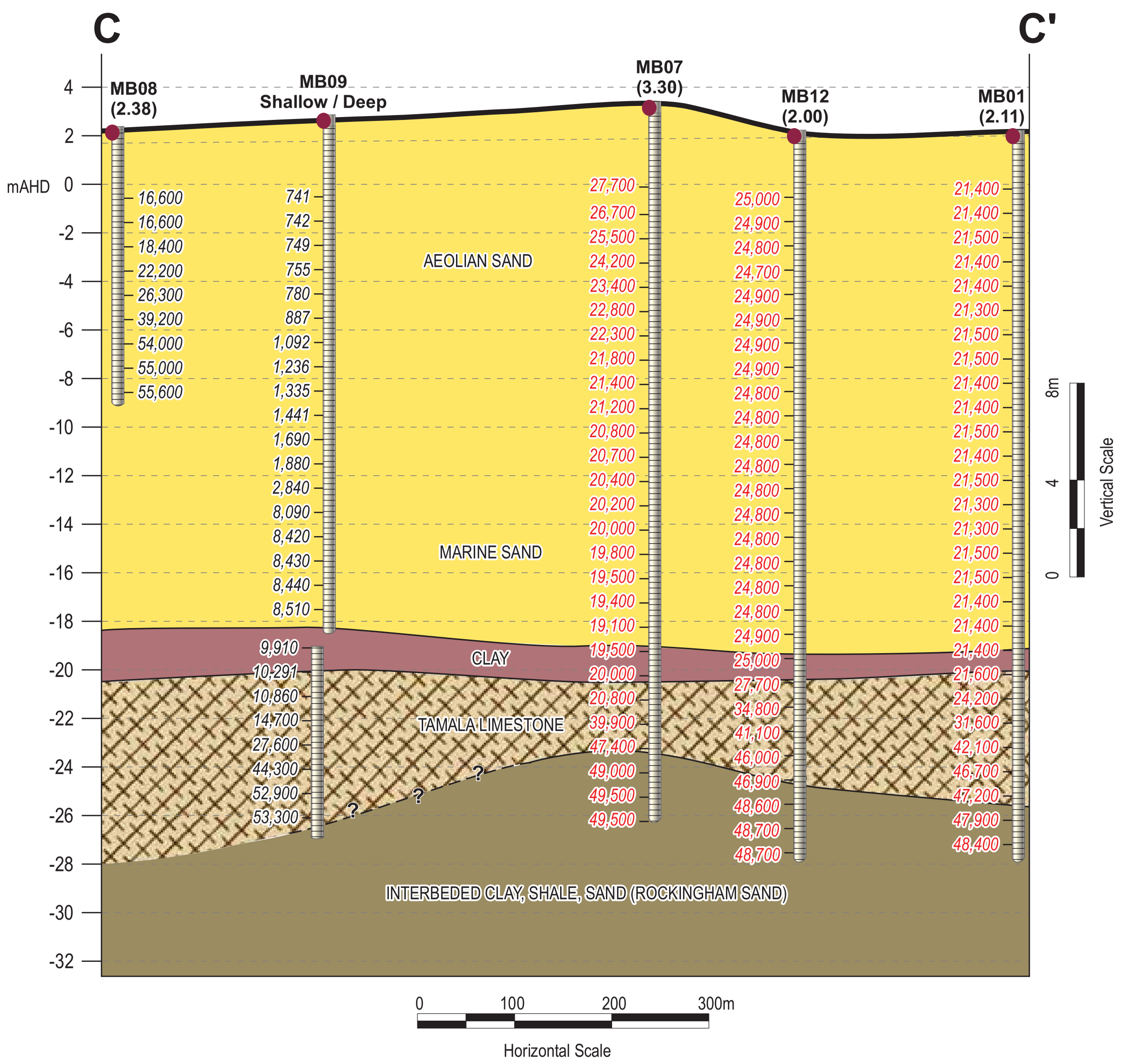
Figure 4 - Geological Cross Section B-B'

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.

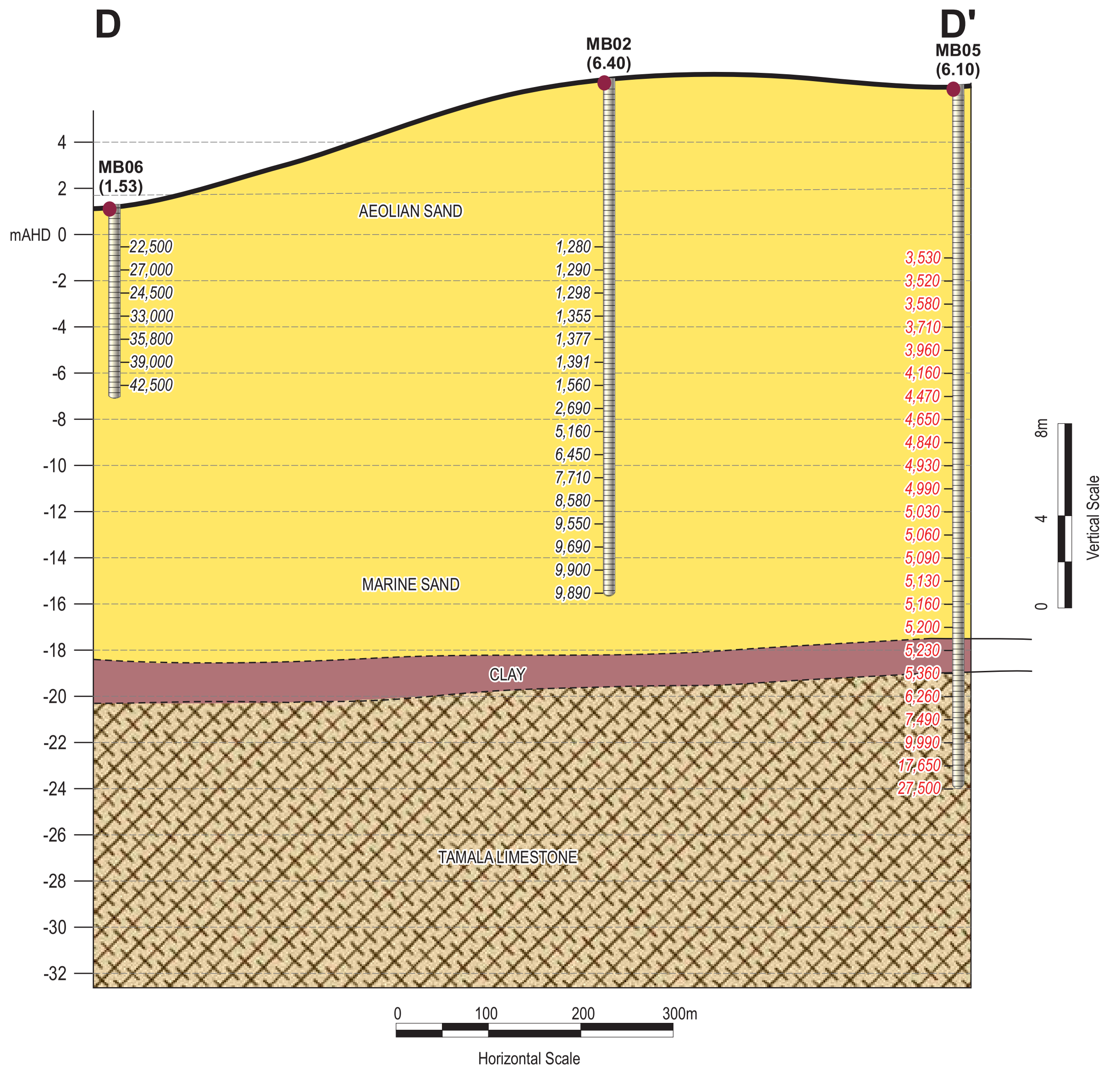
Figure 5 - Geological Cross Section C-C'

Mangles Bay Conceptual Site Model

Environmental Resources Management ANP Pty Ltd

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

ERM



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

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)

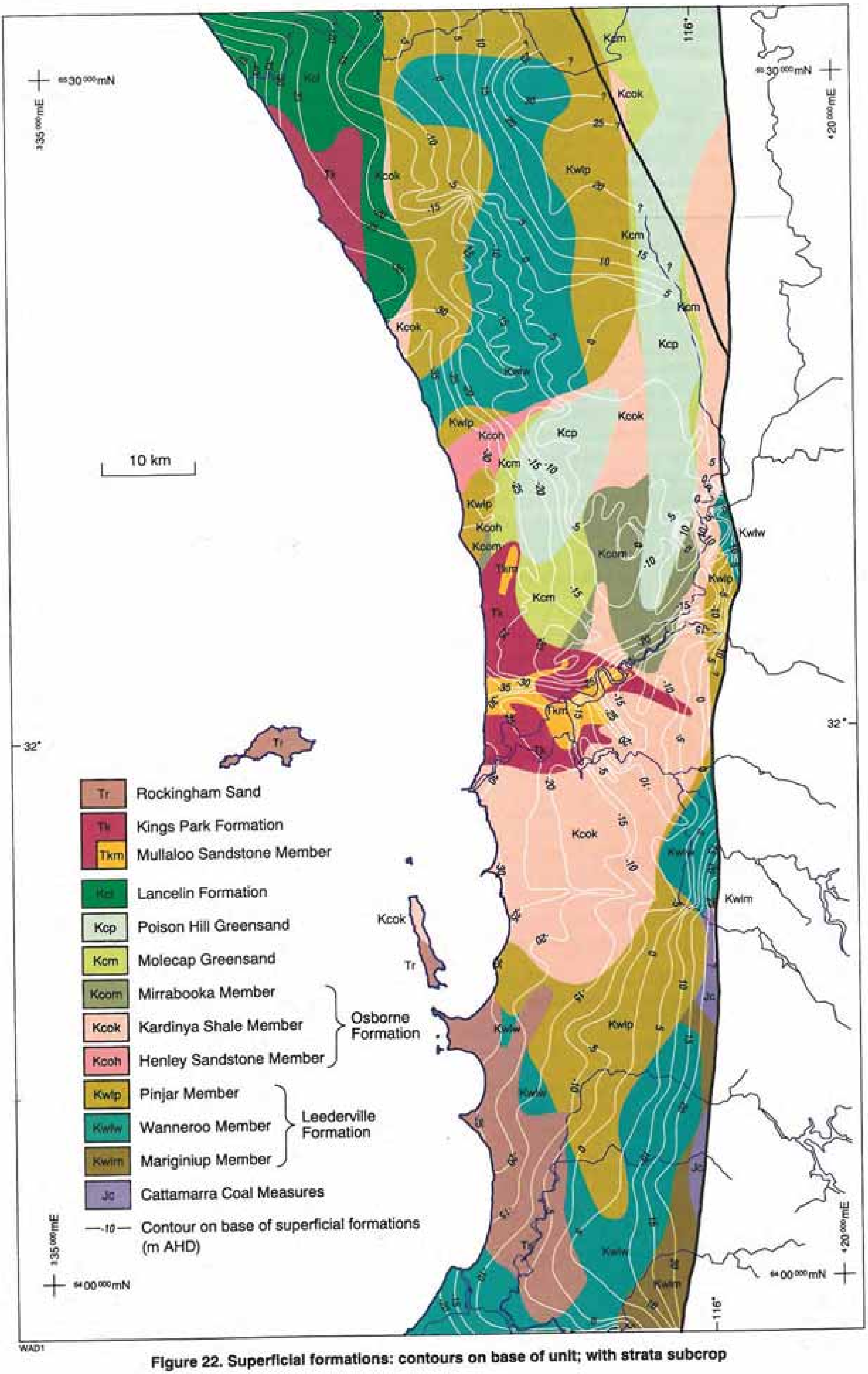
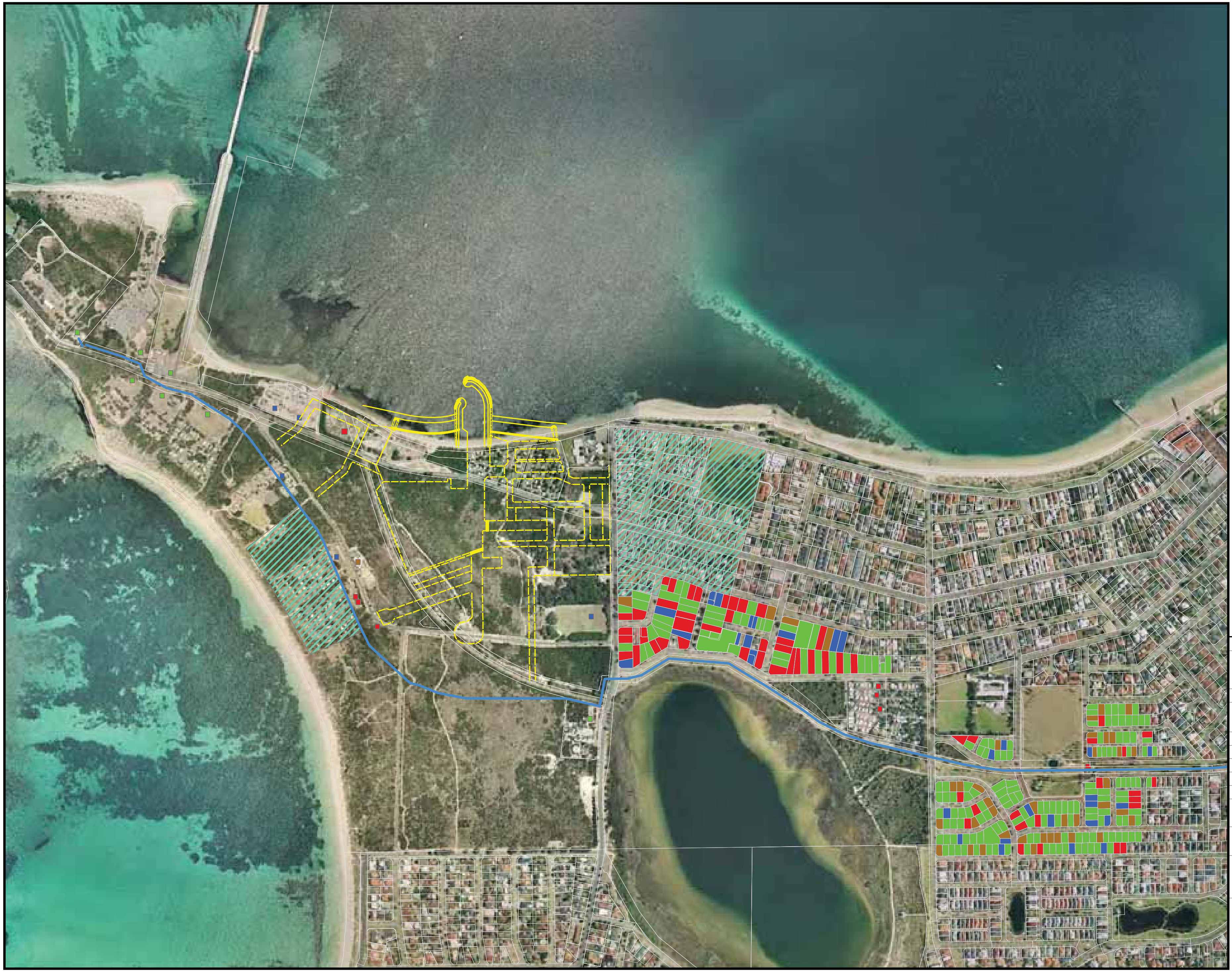


Figure 22. Superficial formations: contours on base of unit; with strata subcrop

ANNEX D:

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

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Environmental Resources Management Australia Pty Ltd

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Annex D

Tables

Table 1

Regional Groundwater Flow Model Input and Calibration Parameters

SDOOL Duplication/Realignment and Mangles Bay Marina
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/Realignment and Mangles Bay Marina
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/Realignment and MBM

Rockingham, Western Australia

Observed and Modeled Water Level

Well		**Date**	**Observed** mAHD	**Modeled** mAHD	**Residual** m	**Scaled Residual**
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** mAHD	**Modeled Depth** mAHD	**Residual** m	**Note**
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				