5.2.6 Discussion of Surface Geological Mapping and Local Geological Framework

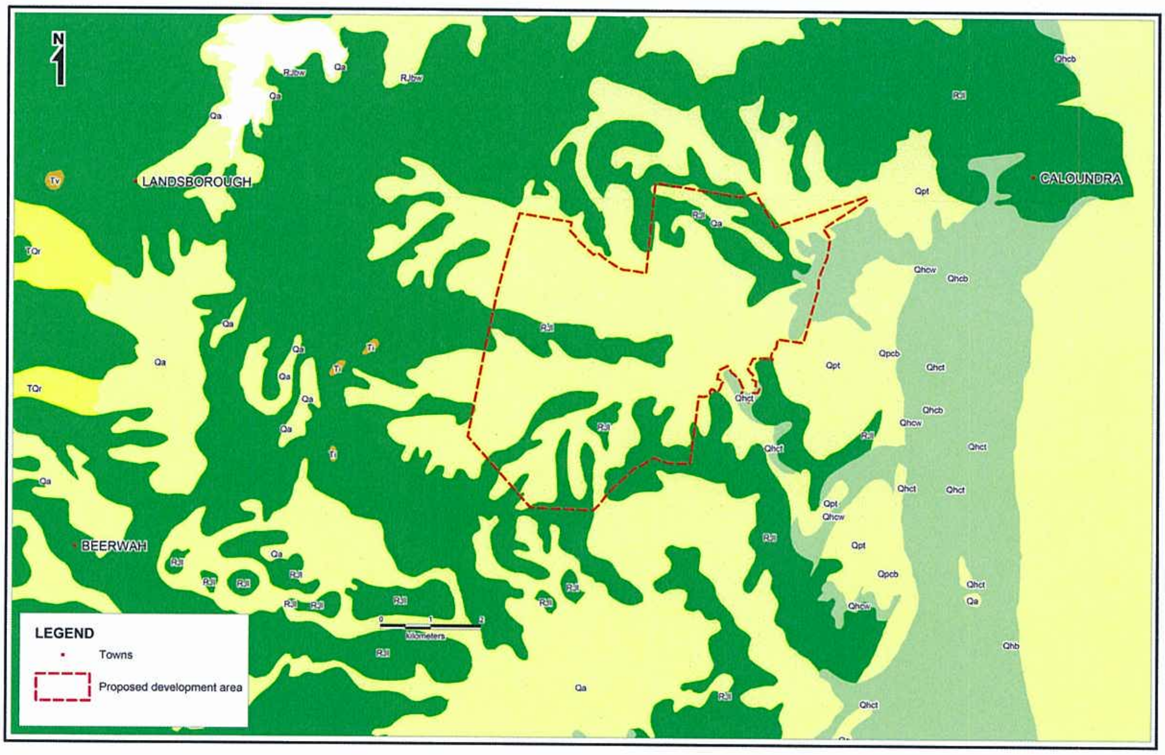


Figure 5-8 Published Surface Geological Mapping for the Caloundra South Area

Figure 5-8 Published Surface Geological Mapping for the Caloundra South Area

indicates published surface geological mapping (QDNRM, 2008) in the broader area around the Caloundra South site. In this figure:

- Holocene age tidal flats are indicated by geological mapping symbol Qhct;
- Holocene age coastal swamp is indicated by geological mapping symbol Qhcw;
- Holocene age beach ridge deposits are indicated by geological mapping symbol Qhcb;
- Holocene age beach deposits are indicated by geological mapping symbol Qhb;
- Pleistocene age estuarine deposits are indicated by geological mapping symbol Qpt;
- Pleistocene age beach ridges are indicated by geological mapping symbol Qpcb;
- Pleistocene age estuarine deposits are indicated by geological mapping symbol Qpt;
- Tertiary to Quaternary age colluvium is indicated by geological mapping symbol TQr;
- Tertiary age rhyolite is indicated by geological mapping symbol Ti;
- Tertiary age basalt is indicated by geological mapping symbol Tv;
- The Landsborough Sandstone is indicated by geological mapping symbol RJl (with RJlw indicating weathered formation);
- The Woogaroo Sub-Group is indicated by geological mapping symbol RJbw; and
- The Myrtle Creek Sandstone is indicated by geological mapping symbol RJdm.

The Figure 5-8 mapping indicates that the site is underlain by a basement of Landsborough Sandstone which is in part overlain by Quaternary age alluvium and to the east by Quaternary age (Holocene to Pleistocene) coastal sediments.

5.3 Hydrogeology

5.3.1 Available Sources of Groundwater Level and Quality Data

QUT researchers observed groundwater levels at the Caloundra South site on an irregular basis from a series of 19 observation bores located on and adjacent to the Caloundra South site. The QUT monitoring occurred from March 2002 through to March 2003 with an observation frequency varying from a reading every 5 days to a reading every 100 days and an overall mean frequency of an observation every 20 days.

In addition to the frequent observation of groundwater levels at the site, the QUT team undertook a series of four rounds of detailed groundwater quality sampling and analysis for the observation bore network on 3 April 2002, 2 June 2002, 17 August 2002 and 24 August 2002. For these sampling rounds, field observations were made for pH, electrical conductivity, temperature, dissolved oxygen, and oxidisation reduction potential. Laboratory determinations were made for major cations and anions and for iron, zinc, bromide, fluoride and nitrate.

An additional observation round was made on 2 November 2002 however this round only covered field observation of pH, electrical conductivity, temperature dissolved oxygen, and oxidisation reduction potential.

5.3.2 Current Groundwater Monitoring

After the cessation of groundwater monitoring by QUT, groundwater monitoring was re-established at the site in March 2006. Since that time, groundwater levels and quality have been routinely observed on behalf of Stockland by Cardno Bowler in a series of nine of the QUT bore locations (including one paired deep and shallow pipe site). These bores are monitored on an approximate monthly interval for standing groundwater level. Groundwater samples are also drawn on an approximately monthly interval for field observation of pH, electrical conductivity, temperature, salinity, dissolved oxygen, oxidisation reduction potential and turbidity. Samples drawn from these bores are also analysed for acidity to pH 7 and from pH 7 to 8.3.

A series of shallow groundwater monitoring bores was established across the Caloundra South area between September and October 2010. Since establishment of these bores, they have been monitored for standing groundwater level on a monthly basis. Groundwater samples are also drawn on a monthly interval for field observations of pH, electrical conductivity, temperature, salinity, dissolved oxygen, oxidisation reduction potential and turbidity. A series of additional samples was collected in October 2010 from a selected series of 16 of these shallow groundwater monitoring bores to support characterisation of the quality of the shallow groundwater at the Caloundra South site. As well as the suite of physical and physico-chemical parameter adopted for the routine groundwater sampling, water samples were also submitted for laboratory analysis of the following parameters:

- Total dissolved solids;
- Turbidity;

- Calcium, magnesium, sodium and potassium;
- Chloride and sulphate as SO_4^{2-};
- Hydroxide alkalinity, carbonate alkalinity, bicarbonate alkalinity and total alkalinity as $CaCO_3$;
- Bromide;
- Fluoride;
- Aluminium, arsenic, cadmium, chromium, copper, nickel, lead, iron, mercury, manganese and zinc;
- Boron;
- Sulphide as S^{2-};
- Dissolved organic carbon;
- Total organic carbon;
- Organochloride pesticides including alpha-BHC, hexachlorobenzene (HCB), beta-BHC, gamma-BHC, delta – BHC, heptachlor, Aldrin, heptachlor epoxide, trans-Chlordane, alpha-Endosulfan, cis-Chlordane, Dieldrin, 4.4`-DDE, endrin, beta-Endosulfan, 4.4`-DDD, endrin aldehyde, endosulfan sulphate, 4.4`-DDT, endrin ketone, dibromo-DDE, and methoxychlor;
- Organophosphorus pesticides including dichlorvos, demeton-S-methyl, monocrotophos, dimethoate, diazinon, chlorpyrifos-methyl, parathion-methyl, malathion, fenthion, chlorpyrifos, parathion, pirimphos-ethyl, chlorfenvinphos, bromophos-ethyl, fenamiphos, prothiofos, ethion, carbophenothion, azinphos methyl and DEF; and
- Triazine pesticides including atrazine and simazine.

In addition to the manual observation of groundwater levels at and around the Caloundra South site, seven automatic groundwater level data loggers were installed in selected bores. These loggers were installed on 17 September 2010 and were first interrogated on 22 October 2010.

5.3.3 Representative Hydrogeological Sections

Five schematic hydrogeological sections have been prepared to illustrate key hydrological features at the Caloundra South site. Figure 5-9 indicates the locations of these schematic sections.

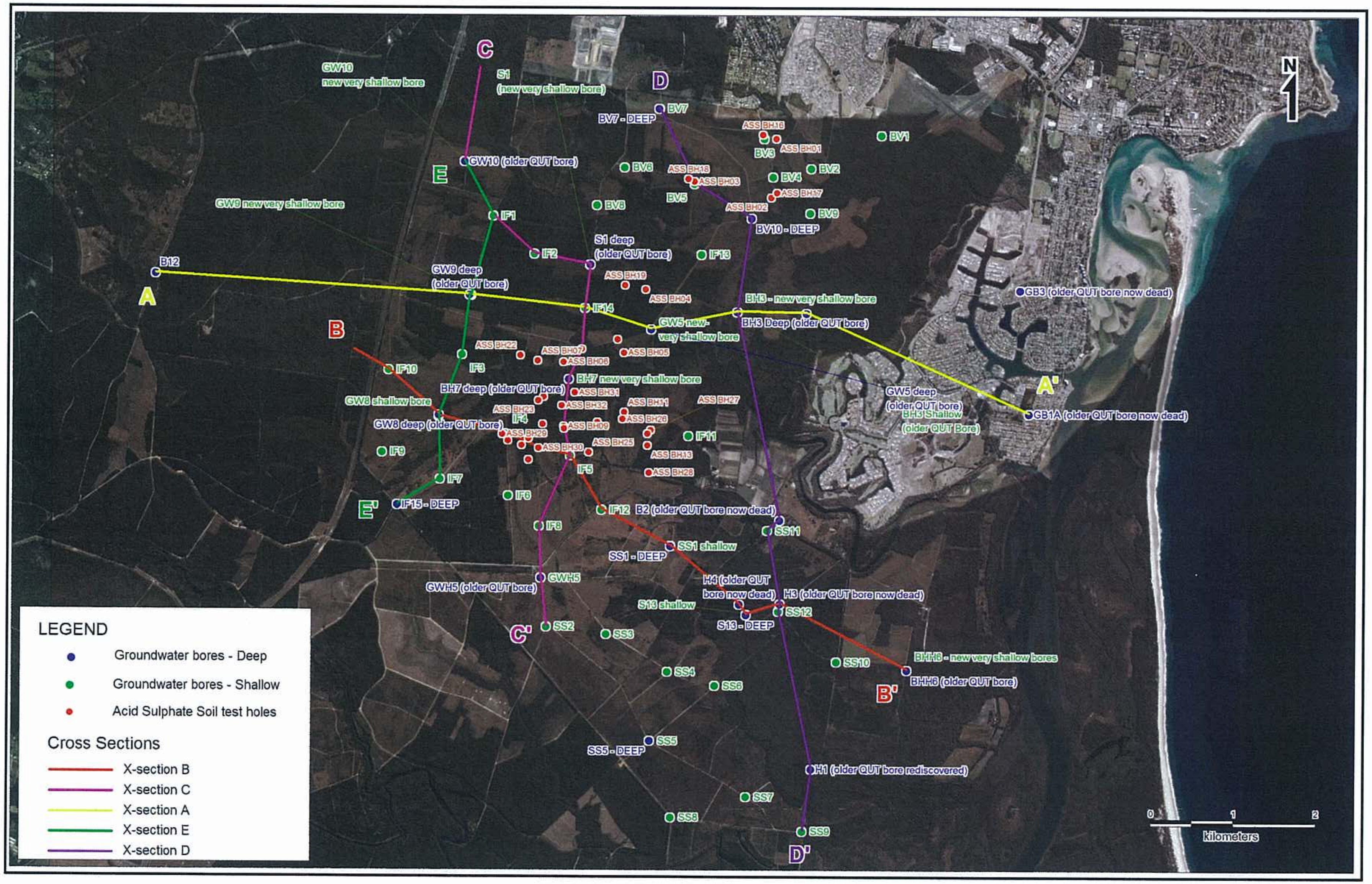
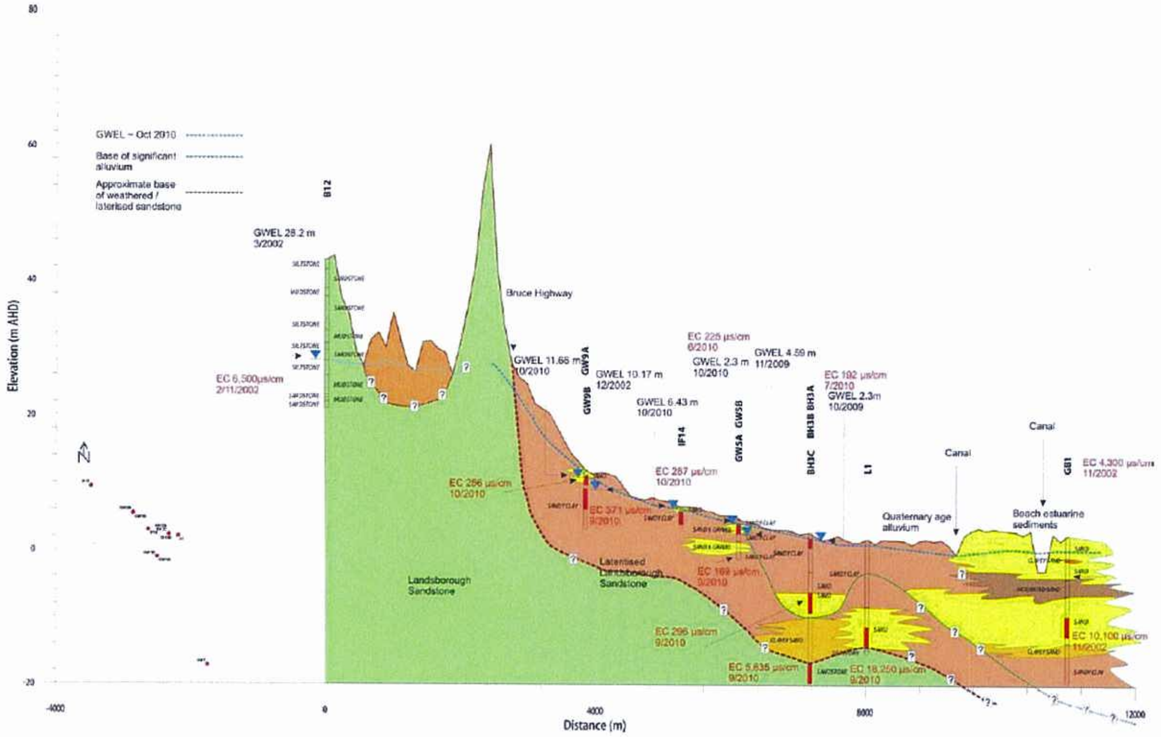


Figure 5-9 Location of Schematic Hydrogeological Cross-sections

5.3.3.1 *Discussion of Schematic Section A – A'*



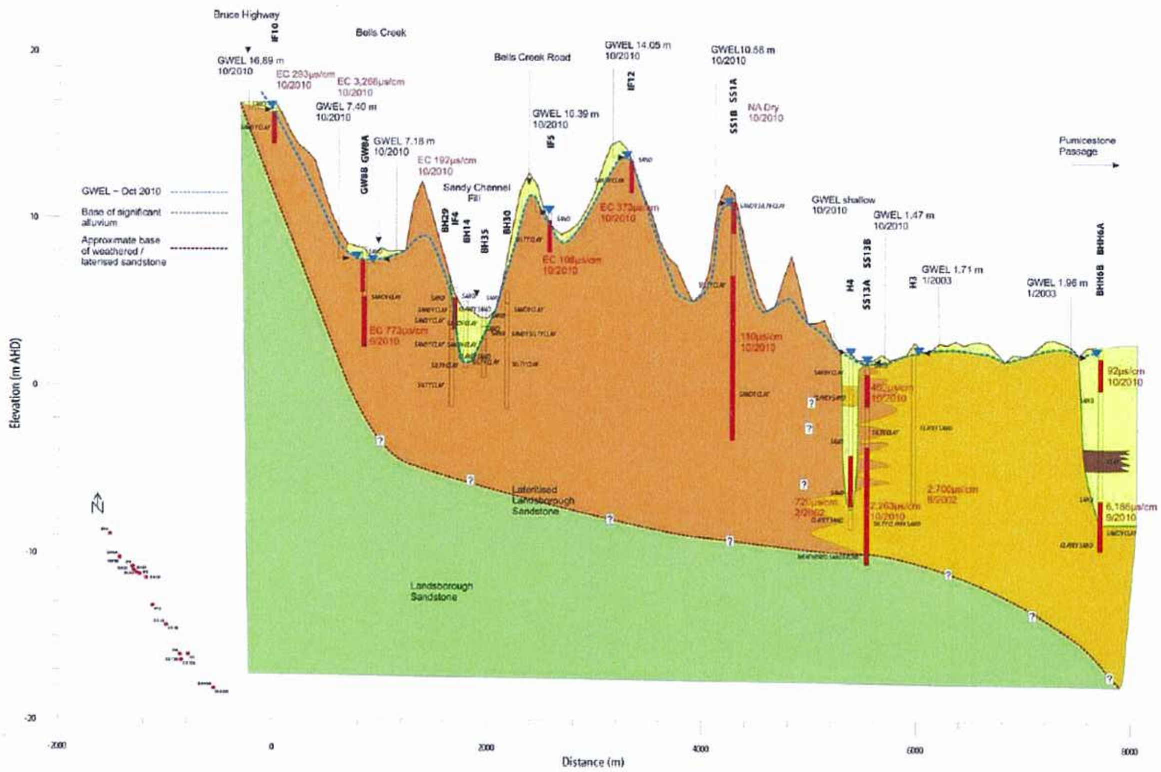
Schematic Section A – A' extends from just west of the Bruce Highway, eastwards across the Caloundra South site and terminates in the Pelican Waters canal estate.

This section clearly illustrates the presence of Landsborough Sandstone deeply weathered to what has generally been described as sandy clay and to a lesser extent clayey sand and sand. The alluvium and coastal sediments on this section appear to become sandier to the east and in bore GB1 the coastal sediments host an indurated sand ("coffee rock") layer, overlain and underlain by sands. It is noted that in the west of the section, the QUT researchers described the strata penetrated in bore B12 as sandstone, siltstone and mudstone rather than as sandy / silty clays or clayey sands.

Groundwater levels indicated on Section A – A' are notable for their generally shallow depth across the site. Greater depths to groundwater are indicated only to the west and well to the east of the site.

The most recent available spot values of groundwater electrical conductivity illustrates the presence of relatively low salinity groundwater in both the Landsborough Sandstone and the alluvium out to near the site of bore BH3. Such data also indicates the presence of relatively saline groundwater at the site of bore GB1 with the salinity increasing with depth at this site. The presence of significantly saline groundwater at depth can also be seen in the Landsborough Sandstone in bores BH3 (deep) and L1 (deep). These more saline values would reflect the influence of the seawater wedge in the aquifer formed by the unconsolidated sediments at this location. It is unlikely that the position of the seawater wedge is entirely natural, as changes to the local groundwater hydrology would have been influenced by the construction of canals.

5.3.3.2 Discussion of Schematic Section B – B'



Schematic Section B – B' extends from just west of the Bruce Highway, in an east south easterly direction across the southern section of the Caloundra South site and terminates in farm land to the south of Bells Creek and the Pelican Waters canal estate.

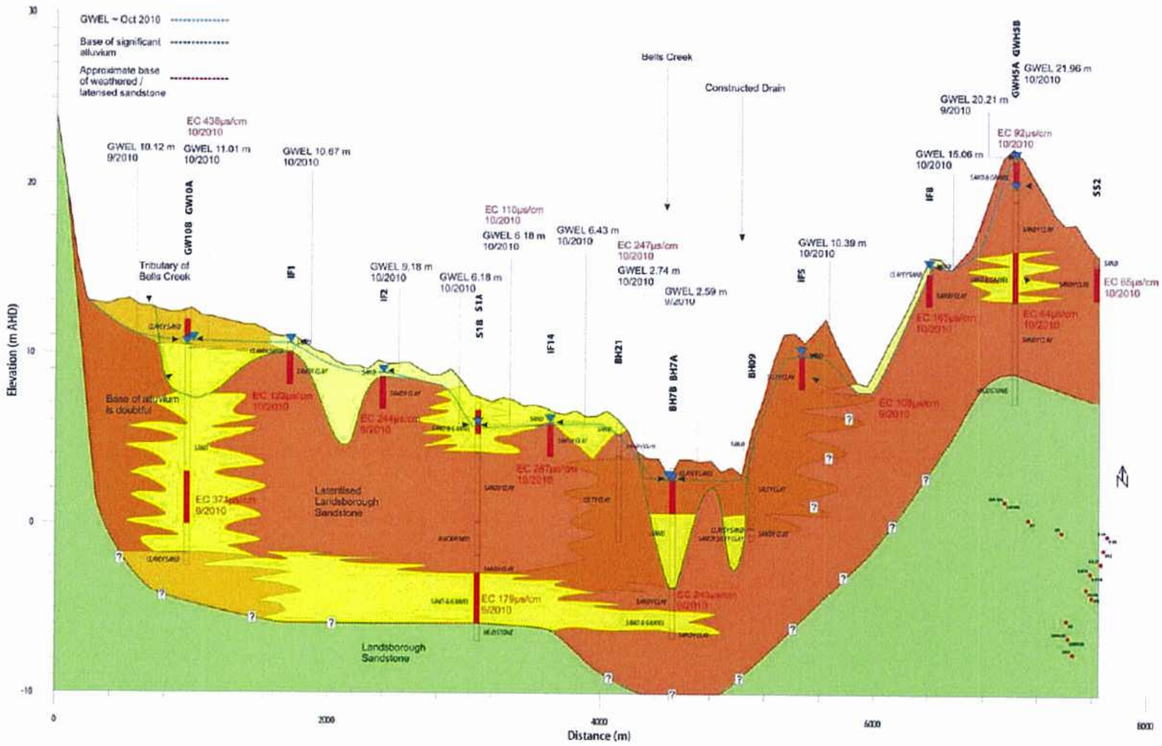
This section clearly illustrates the presence of Landsborough Sandstone deeply weathered to what has generally been described as sandy clay in the west and to a clayey sand in the east. This section indicates the presence of some narrow sandy alluvial channel fills and the presence of some shallow surficial sands in some locations. On the basis of recent extensive shallow drilling, these shallow surficial sands would be more extensive than indicated in this section.

Groundwater levels indicated on Section B – B' are also relatively shallow and are interpreted to largely reflect the topographic relief.

The most recent available spot values of groundwater electrical conductivity illustrates the presence of generally low salinity groundwater in the Landsborough Sandstone to the east of bore SS13 (deep). The exception to this is relatively brackish groundwater (electrical conductivity 3,266 µS/cm) recorded for bore GW8 (vs), notwithstanding that the salinity of the Landsborough Sandstone in deeper bores GW8 (deep) is quite low (electrical conductivity 773 µS/cm). This data suggests that a spot soil salinisation process is taking place whereby low salinity groundwater is being evaporated in the near surface environment to create more saline water. It is possible that other such localised salinity phenomena could occur on the Caloundra South site), although it appears that there would not be widespread. These groundwater electrical conductivity data also indicate poorer quality groundwater in the Landsborough Sandstone at depth to the east. Bores SS13A and H3 both recorded groundwater electrical conductivities exceeding 2,200 µS/cm. This might represent diffusion from the toe of the coastal seawater wedge, but more likely it simply reflects poorer quality water due to increased residence time in the aquifer. The data also indicate the presence of relatively saline groundwater at depth site BHH6 with the salinity increasing from very low values at shallow depth to brackish quality (6,186 μS/cm) at depth in bore BHH6 (deep).

It is also noted that on Section B – B' the groundwater hosted in the alluvial channel in the Halls Creek catchment at bore H4 is of relatively low salinity (720 μS/cm) at depth.

5.3.3.3 Discussion of Schematic Section C – C'



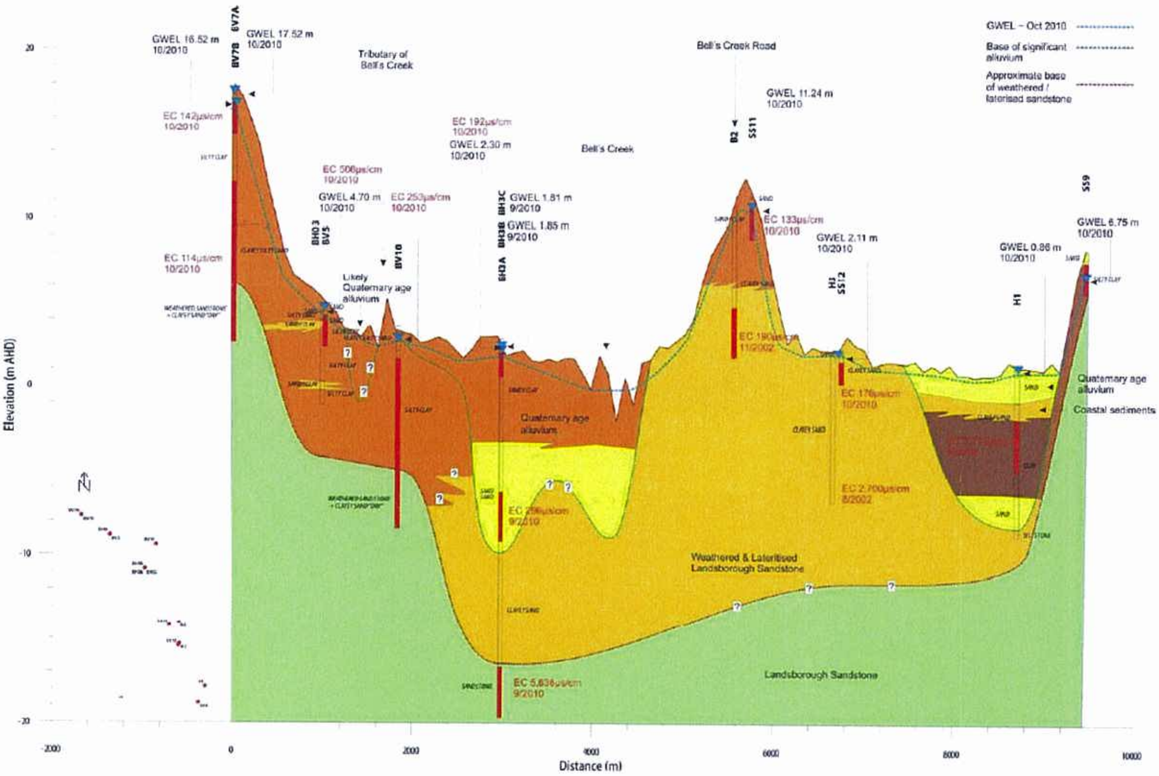
Schematic Section C – C' extends from just east of the Bruce Highway in an area north of the Caloundra South site, in a generally southerly direction across the site and terminates in now cleared former plantation pine land to the south of the site.

This section clearly illustrates the presence of Landsborough Sandstone deeply weathered to what has generally been described as silty clay and sandy clay but which also hosts some sections described as sand and sand and gravel. This section also indicates the presence of some narrow sandy alluvial channel fills and the presence of some shallow surficial sands in some locations.

Groundwater levels indicated on Section C – C' are also relatively shallow and are interpreted to largely reflect the topographic relief.

The most recent available spot values of groundwater electrical conductivity illustrates the presence of generally low salinity groundwater in the Landsborough Sandstone.

5.3.3.4 Discussion of Schematic Section D – D'



Schematic Section D – D' is located to the east of Section C – C'. Section D – D' extends from north of the Caloundra South site in a generally southerly direction across the site and terminates in native vegetation near Hall's Creek.

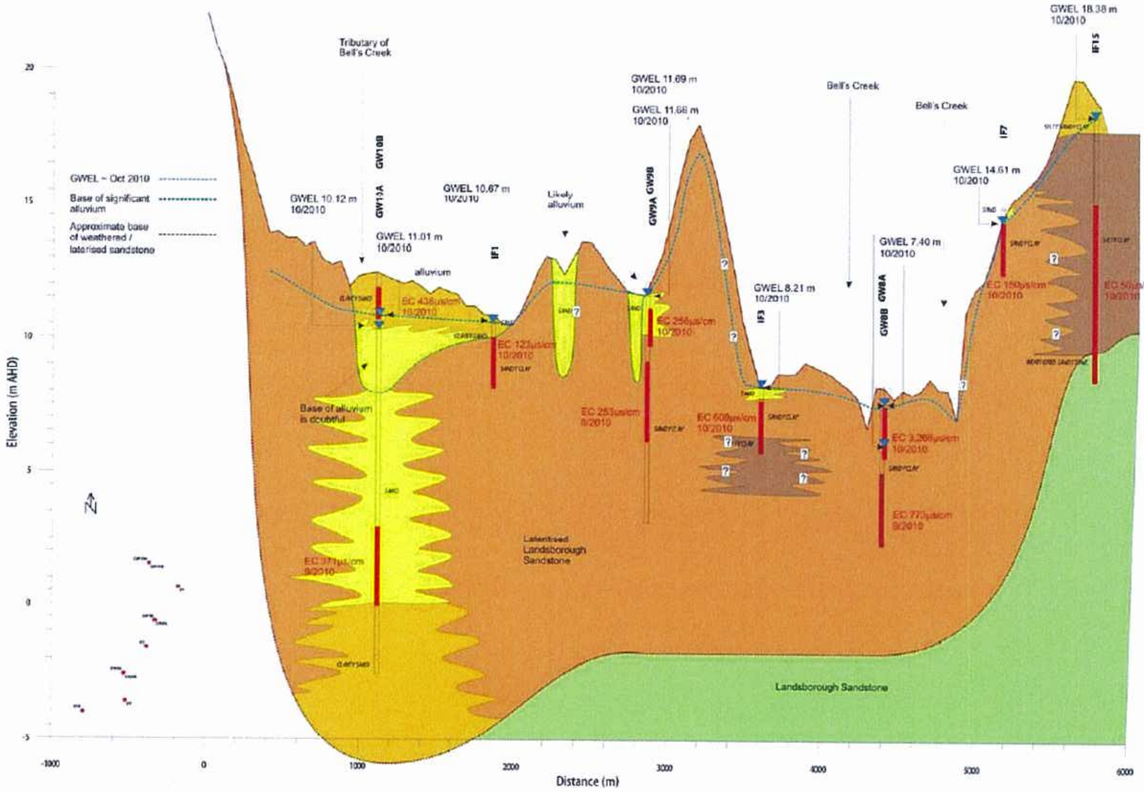
This section clearly illustrates the presence of Landsborough Sandstone deeply weathered to sandy clay, clayey sand and silty clay. This section also indicates the presence of some significant alluvial channel fills and the presence of some shallow surficial sands in some locations. There are two major alluvial channels indicated on Section D – D'. The southernmost of these channels is in the Halls Creek area and the log of bore H1 indicates that it hosts a basal layer of sand overlain by significant clay and then a surficial layer of sand and clayey sand. The northernmost of these alluvial channels is located around Bells Creek and to its north and bore BH3 indicates that this channel hosts a basal layer of sand overlain by sandy floodplain clays.

Groundwater levels indicated on Section D – D' are also relatively shallow and again are interpreted to largely reflect topographic relief. From Section D – D' it can be seen that Bells Creek is indicated to be a drain in the landscape and that groundwater from the alluvium would flow towards it. Similarly Halls Creek would act as a drain, however on this section it has a broad flood plain and very shallow groundwater levels across it.

Groundwater electrical conductivity data illustrates the presence of generally low salinity groundwater in the Landsborough Sandstone, except at depth in bores BH3 (deep) (electrical conductivity of 5,636 µS/cm) and H3 (electrical conductivity of 2,700 µS/cm). The more saline value for bore BH3 (deep) would reflect the influence of the seawater wedge in the aquifer formed by the unconsolidated sediments at this location. The less saline value for bore H3 might reflect poorer quality water due to increased residence time in the aquifer.

The presence of the coastal seawater wedge is evident in the electrical conductivity value of 7,770 µS/cm recorded for bore H1 at depth in the alluvial channel fill associated with Halls Creek.

5.3.3.5 Discussion of Schematic Section E – E'



Schematic Section E – E' commences in the same location as schematic Section C – C' and extends in a southerly direction across the Caloundra South site and terminates at the southern boundary of the Caloundra South site, approximately 600 m east of the Bruce Highway.

This section clearly illustrates the presence of Landsborough Sandstone deeply weathered to what has generally been described as silty clay and sandy clay but which also hosts some sections described as sand and sand and gravel. This section also indicates the presence of some narrow sandy alluvial channel fills and the presence of some shallow surficial sands in some locations.

It is notable that the geology at bore site GW10 is somewhat contentious. QUT researchers indicated the presence of a paleochannel incised to a depth of 14 m bGL at this location, although this was at variance with their ground penetrating radar work. It is interpreted herein that there is a sandy channel present at bore GW10, however beneath it there is deeply weathered sandy Landsborough Sandstone.

Groundwater levels indicated on Section D – D' are also relatively shallow and are again interpreted to largely reflect topographic relief.

Groundwater electrical conductivity data illustrates the presence of generally low salinity groundwater in the Landsborough Sandstone, with the exception of relatively brackish groundwater (electrical conductivity 3,266 µS/cm) recorded for bore GW8 (vs) as discussed previously.

It is also noted that on Section E – E' the groundwater hosted in alluvial channel at bore GW10 is also of relatively low salinity (438 µS/cm).

5.3.4 Groundwater Level Behaviour

It is important to understand the linkages between groundwater level, rainfall, evaporation and land use. In this regard, the extensive data set collected by the various researchers and for this project from the extensive network of boreholes placed across the site was interrogated and the following generalised conclusions can be drawn:

- The analysis of groundwater levels conducted by this study suggests that the groundwater elevations across the site decline over a period of several months when rainfall is below average. The data suggest that the groundwater elevations respond rapidly, over the course of a single month, when rainfalls increase or are above average.
- Available groundwater level and land use data also appears to suggest a strong link between rising groundwater levels and vegetation clearing. Specifically, it is noted that plantation pine was substantially clear felled prior to QUT initiating their study and groundwater levels rose during the period of their observation activities. The groundwater levels were noted to continue their rise following the QUT study, during a period of time when much of the Caloundra South site was open or cleared land.

5.3.5 Groundwater Flow Directions

The key matters pertaining to the pattern of groundwater flow that have also been derived based on the data collected by this study were as follows:

- Groundwater flows in a generally easterly direction from a series of hills and ridges formed by the Landsborough Sandstone towards the coastline of Pumicestone Passage to the east of the site and its fringing wetlands;
- Bells Creek forms a drain in the landscape for groundwater discharge, particularly its southern branch;
- Lamerough Creek would form a drain in the landscape for groundwater discharge; and
- The broad and shallow valley that hosts Hall's Creek also acts as a drain in the landscape for groundwater discharge.

It is noted that to the south of the site, groundwater would also flow towards Coochin Creek.

5.3.6 Depth to Groundwater

The presence of shallow groundwater at the Caloundra South site has previously been recognised by QUT researchers who noted that the unsaturated zone above the watertable could be clearly identified in ground penetrating radar profiles throughout the site and that this work had indicated the water table to be at very shallow depth, typically 0 to 2 m below the surface.

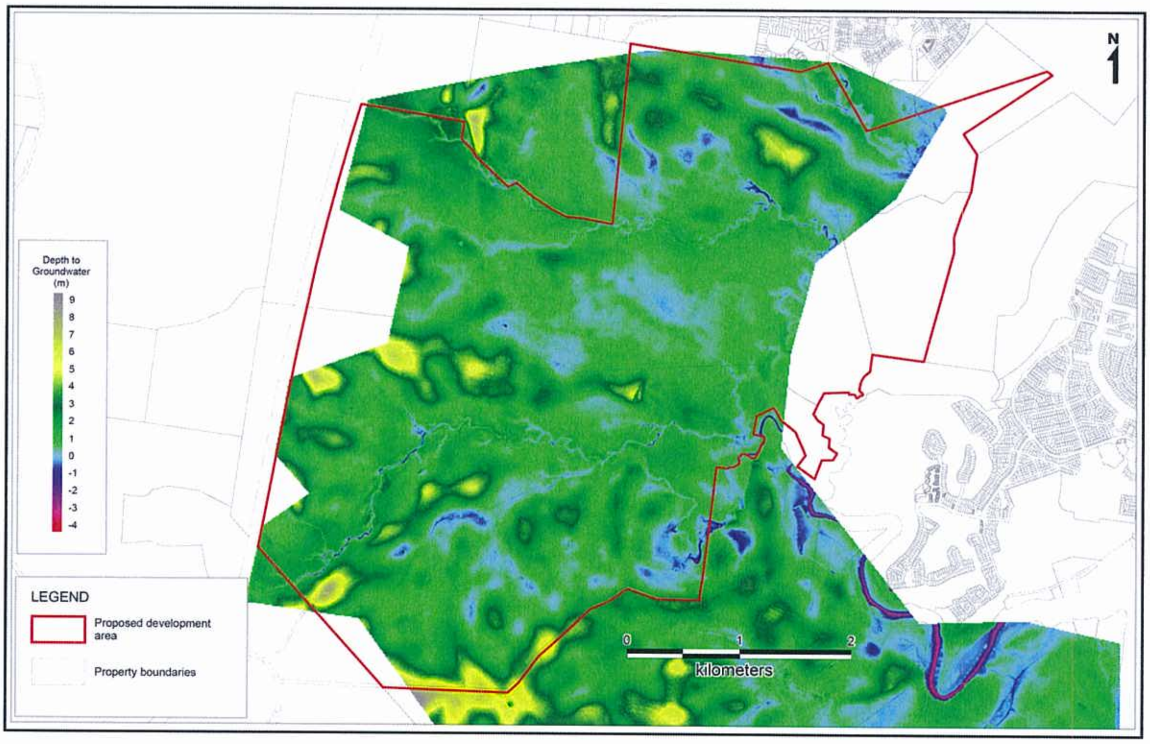


Figure 5-10 Composite Depth to Groundwater Plan for July-August 2010

Figure 5-10 provides a depth to groundwater plan for the Caloundra South site and its surrounding area for July / August 2010. Key matters to note in this figure are:

- There are generally greater depths to groundwater in the more elevated sections of the terrain, however shallow groundwater is not restricted to the lower slopes of the site.
- Some of the mid-slope areas and areas at the base of slopes host shallow groundwater.
- In its current, largely cleared state before any drainage works or earth works that would ameliorate shallow groundwater levels, there are some significant areas where groundwater is close to the ground surface (approximately 184 ha within Caloundra South site or approximately 7.7%).
- As would be expected, the depths to groundwater adjacent to key watercourses are very low, reflecting the role of the surface drainage in groundwater discharge phenomena.

Table 5-2 provides a summary of the depths to groundwater within the Caloundra South site at July / August 2010.

Table 5-2 Summary of Depths to Groundwater Across Caloundra South Property at July / August 2010

Depth to groundwater (m bGL)	Area (ha)	Proportion of property (%)
Above ground	80.20	3.39
0 - 0.25	103.94	4.39
0.25 - 0.5	171.43	7.24
0.5 - 0.75	229.19	9.68
0.75 - 1.0	252.10	10.65
1.0 - 1.5	414.80	17.52
1.5 - 2.0	280.93	11.87
> 2.0	416.42	17.59
Not categorised	418.00	17.66

From Table 5-2 it is evident that at July/August 2010, approximately 25% of the Caloundra South site had depths to groundwater less than 0.75 m. This would reflect the existing state of the site now that plantation pine has substantially been removed.

5.3.7 Groundwater Quality

There is a considerable body of shallow groundwater chemistry data available for the Caloundra South site. This data includes:

- Historical observations of QUT researchers;
- Routine observations since December 2005 by Cardno Bowler for the majority of the bores established by QUT researchers; and
- Recent October September 2010 observations by Cardno Bowler and laboratory analyses for recently installed shallow groundwater monitoring bores.

Based on these data, the following groundwater quality summaries can be presented. No major groundwater quality issues emerged from these assessments.

5.3.7.1 Physicochemical Data

Shallow groundwater has a groundwater electrical conductivity range of 92 to 3,266 μS/cm with a median value of 236 μS/cm and a mean value of 502 μS/cm. Shallow groundwater sampled across the site had relatively low to moderate salinity only. Shallow groundwater samples had a pH range of 3.82 to 6.86 with a median of 5.07 and mean of 5.15.

5.3.7.2 Nutrient Data

Available data indicates slightly elevated concentrations of nitrogenous compounds in the shallow groundwater. The total nitrogen data had a mean of 0.59 mg/L as N and a median of 0.52 mg/L as N. Similarly, total Kjeldahl nitrogen data had a mean of 0.56 mg/L and median of 0.465 mg/L. Ammonia values had a mean of 0.14 mg/L and a median of 0.019 mg/L. Nitrate data had a mean of 0.18 mg/L and a median value of 0.015 mg/L.

Total phosphorus data had a mean of 0.184 mg/L as P and a median of 0.054 mg/L as P. Reactive phosphorus data had a mean of 0.006 mg/L and a median of 0.002 mg/L.

5.3.7.3 Metals Data

- The peak recorded dissolved iron level was 9.36 mg/L with mean and median values of less than 2.33 and 0.33 mg/L respectively;
- The peak recorded aluminium level was 2.04 mg/L with mean and median values of less than 0.2 and 0.02 mg/L respectively;
- No arsenic concentrations were recorded above the detection limit of 0.001 mg/L;
- The peak recorded cadmium level was only 0.0012 mg/L with mean and median values less than 0.0003 and 0.0002 mg/L respectively;
- The peak recorded chromium level was only 0.0004 mg/L with the other bores all recording values less than the detection limit of <0.001 mg/L;
- The peak recorded copper level was only 0.007 mg/L with mean and median values less than 0.0038 and 0.004 mg/L respectively;
- No mercury values were recorded above a detection limit of 0.0001 mg/L;
- The peak recorded nickel level was only 0.021 mg/L with mean and median values less than 0.0067 and 0.006 mg/L respectively;
- The peak recorded lead level was 0.08 mg/L with mean and median values less than 0.014 and 0.0015 mg/L respectively;
- The peak recorded manganese level was 0.159 mg/L with mean and median values of 0.08 and 0.089 mg/L respectively; and
- The peak recorded zinc level was 0.159 mg/L with mean and median values of 0.038 and 0.034 mg/L respectively.

5.3.7.4 Organic Carbon and Iron

Bio-available iron has been implicated in the development of *Lyngbya* cyanobacterial algal blooms in Pumicestone Passage. Bio-available iron is iron bound to organic complexes. In order to assess the potential for the presence of bio-available/organically complexed iron in the shallow groundwater, dissolved organic carbon was measured along with dissolved iron. Where iron is present, but not dissolved organic carbon, organically complexed iron cannot be present in the groundwater.

The data collected shows a range of dissolved iron levels with a mean concentration of 2.33 mg/L and a median concentration of 0.33 mg/L. At one site only a detectable dissolved organic carbon concentration of 12 mg/L was recorded. These results indicate that the presence of organically complexed iron in the groundwater at that site is unlikely.

5.3.8 Existing and Historical Groundwater Use

A DERM groundwater database search was undertaken to assist in the location of water bores on the Caloundra South site and its surrounding area. It is noted that as the Caloundra South area is not located within a declared groundwater area (i.e. not a proclaimed sub-artesian district), until April 2003 there was no statutory requirement for the notification of water bores to DERM. However since that time an amendment to Queensland legislation requires that water bore drillers notify DERM of the locations and details of all water bores constructed to depths of 6 m or greater.

There are three main groupings of DERM recorded water bores as follows:

- A group of four water bores and a well located on rural properties between Bells Creek Road and Bells Creek to the immediate south east of the Caloundra South site;
- A group of seven water bores located on domestic properties to the immediate north of the Caloundra South site; and
- A group of three water bores located on rural residential properties between Coochin Creek and Roys Road approximately 4.5 km south of the Caloundra South site.

The group of four water bores and a well located on rural properties between Bells Creek Road and Bells Creek is notable for the recorded very poor yields from the Landsborough Sandstone with the exception of bore 120133 which has a reported yield of 1.1 L/s from 25 m. These bores appear to be small-scale domestic or farm supplies. It would be expected that the overall water extraction from these facilities would be very small. Although turf farming and other farming activity is present in this area, it appears almost certain that irrigation for these activities is supplied by surface water, rather than groundwater, sources.

The group of seven water bores located on domestic properties to the immediate north of the Caloundra South site tap the Landsborough Sandstone and have recorded spot yields ranging from 0.1 to 1.4 L/s with a median of 0.77 L/s. All of these bores are located on residential blocks and these residences have access to reticulated town water supply. Casing diameter records for these bores indicate a maximum casing size of 125 mm. Given the access to town water supply, the relatively small individual yields and the restricted casing size it would be expected that the overall water extraction from these facilities would be very small.

The limited records for the group of three water bores located on rural residential properties between Coochin Creek and Roys Road suggest that that they tap the Landsborough Sandstone. Of the three bores, two recorded poor yields of 0.1 and 0.2 L/s respectively whilst bore 121522 recorded a yield of 0.92 L/s. The two low yield bores have 100 mm diameter casings whilst bore 121522 has a 125 mm diameter casing. The relatively small individual yields and the restricted casing sizes would suggest that the overall water extraction from these facilities would be very small. Although farming activity (horticulture) is present in this area, it appears most likely that irrigation for these activities is supplied by surface water sources rather than groundwater sources.

5.4 Water Balance Discussion

5.4.1 Recharge

Recharge to the groundwater system at the Caloundra South site would be expected to consist of:

- Direct infiltration of incident rainfall to surface soils, with this being the dominant mechanism, with subsequent vertical drainage from the soil profiles to the underlying weathered Landsborough Sandstone or to underlying alluvium or coastal sediments; and
- Some infiltration of ephemeral stream flow to the Landsborough Sandstone in the very upper sections of the hills surrounding the site.

The major relevant hydrological processes at play at the Caloundra South site are evapotranspiration and groundwater seepage resulting from interflow from shallow sandy soils. Accordingly the recharge to the Landsborough Sandstone is relatively limited, and this in part reflects that the storage in the Landsborough Sandstone is small and also is generally full in the mid to lower slope areas.

It is noted that some of the lower sections of the coastal plain have clayey sediments overlying deeper sandy waterbeds. In these areas vertical leakage of groundwater from the soils would be slower.

5.4.2 Groundwater Discharge to Surface Water

The reaches of the main streams of the area from mid-slope positions down the catchment act primarily as drains during periods of high aquifer storage. Accordingly groundwater discharge provides baseflow to Bells Creek, Lamerough Creek and the lower reaches of Halls Creek. Drains incised into the weathered Landsborough Sandstone presumably to assist in the establishment of plantation pine also discharge groundwater.

5.4.3 Evapotranspiration and Pine Plantations

Water balance studies over the past decade have increasingly begun to recognise the importance of canopy interception. The canopy captures and temporally stores significant quantities of incident precipitation, allowing a portion of the rainfall to evaporate before reaching the ground. Studies in coastal rainforests in northern Queensland found that up to 30 percent of incident precipitation is captured and lost to evaporation.

This interception rate is for significantly wetter conditions than experienced at Caloundra South and applies to complex mesophyll vine forests. Furthermore, this interception rate is higher than reported for other broadleaf evergreen forests. Direct measurement of interception by needle-leafed forests has reported intercept rates between 10 and 40 percent with an average of 22.4 percent. A more recent study which examined interception rates using satellite observations found that needle-leafed forests intercept 22 percent of incoming rainfall.

For subsequent modelling, interception rates for needle-leaf forests were adopted.

5.4.4 Evapotranspiration and Natural Wetlands

Melaleuca sp. wetlands would be expected to capture a significant portion of incident rainfall in their canopies and then evaporate this back to the atmosphere.

A slightly different approach was taken to model canopy interception for wetlands. Needle-leaf forests have significantly more surface area than broad-leafed forests. Therefore, the ability of a broad-leafed forest canopy to intercept incoming rainfall is lower. Interception was modelled using a literature based approach which found that the *Melaleuca* sp. wetland capture and re-evaporate the first 3.5 mm of incoming rainfall before allowing any additional rainfall to fall through the canopy and reach the ground.

5.5 Groundwater Modelling

5.5.1 Approach

5.5.1.1 Model Domain and Model Boundaries

The groundwater model domain needs to be sufficiently broad to allow adequate investigation of the impact on groundwater levels from the proposed development and relevant land use changes and address a need for supportable model boundary conditions, sufficiently distant from the site to limit the reliability of simulations at the site.

In order to achieve these aims, a model domain of 106.2 km^2 as indicated in Figure 5-11 was required.

The majority of the model boundaries indicated in Figure 5-11 coincide with key surface water catchment boundaries and were assigned as "no flow" conditions. At the south eastern boundary of the model domain along Coochin Creek there was a no-flow boundary. Groundwater discharge towards Pumicestone Passage in the south eastern section of the domain was simulated with a general head boundary condition in this location.

5.5.1.2 Model Layers, Grid and Cell Size

Although the Landsborough Sandstone at the Caloundra South site is hundreds of metres in thickness, the majority of the key relevant groundwater phenomena that require consideration and simulation for the project could be expected to be restricted to the upper section of the sandstone. It is of particular note that much of the groundwater recharge/discharge phenomena at the site appear to be very much near surface phenomena.

The key for the ability to simulate relevant groundwater flow processes is to incorporate:

- A thin surficial layer to allow examination of very shallow groundwater level dynamics in the relatively ubiquitous layer of sandy surface soils present across the site;
- A middle layer of sufficient depth to accommodate the alluvium and coastal sediments at the site and hence allow lateral variations in model hydraulic conductivity to discretise the alluvium and coastal sediments against the Landsborough Sandstone; and
- A lower layer of sufficient depth to allow simulation of groundwater level dynamics in the deeply weathered/lateritised Landsborough Sandstone and the upper section of the less weathered sandstone.

The choice of model cell size is a trade-off between the ability to discretely simulate hydrological phenomena with close resolution and model run times and numerical stability. For the current project, a model cell size of 100m x 100m was considered suitable to provide both reasonable resolution and also acceptable model run times and stability.

5.5.1.3 Model Code

The United States Geological Survey (USGS) groundwater flow model MODFLOW is the most popular software code in the groundwater modelling industry for simulating groundwater level behaviour in porous media. MODFLOW is a block-centred finite difference code and it views the three-dimensional system as a sequence of layers of porous material, though transmissivity within a layer may vary due to spatial variations in aquifer thickness and/or hydraulic conductivity.

During normal MODFLOW operation when groundwater levels in some model cells fall below the base of those cells, these cells are declared as "dry" and rendered inactive. Even though they can "re-wet" at a later stage of the simulation process if necessary, numerical solution convergence difficulties can be experienced due to the use of certain thresholds in the re-wetting process. Because of the limited implementation of drying-re-wetting functionality in MODFLOW, MODFLOW is not efficiently utilised where groundwater level behaviour is mainly influenced by the wetting and drying processes. Earlier sections of this report have highlighted that parts of the Caloundra South site are covered in relatively thin sections of alluvium. This and the consequent need for adoption of a thin surficial sand layer in the model potentially predispose a standard MODFLOW model for the Caloundra South area to potential model cell "drying / wetting" stability problems. Accordingly the use of a standard MODFLOW model was identified as being problematic for the required simulations at Caloundra South site.

As such an alternative model, MODFLOW SURFACT V3.0, was applied. This is a comprehensive 3D finite-difference flow and contaminant transport model based on the USGS MODFLOW code and was developed by HydroGeologic Inc. to improve MODFLOW's robustness and increase its physical simulation capabilities to include complex saturated and unsaturated flow conditions in porous media. Through its new flow packages, MODFLOW-SURFACT enhances the scheme for performing unconfined simulations to rigorously model de-saturation/re-saturation of aquifers and overcome numerical difficulties encountered in the USGS MODFLOW simulations.

5.5.1.4 Model Calibration Targets

Calibration involves determination of the magnitude and spatial distribution of the parameter set which allows it to reproduce the observed/estimated groundwater levels within the model area.

A transient state calibration is required for the period from 1 January 2000 to 23 October 2010 such that the fit between simulated and observed groundwater levels on site is acceptable and reasonable. It is noted that groundwater levels over this period included some profound impacts due to substantial changes in land use due to land clearing activity. Accordingly the model had to incorporate these transient land use changes in temporal recharge simulation.

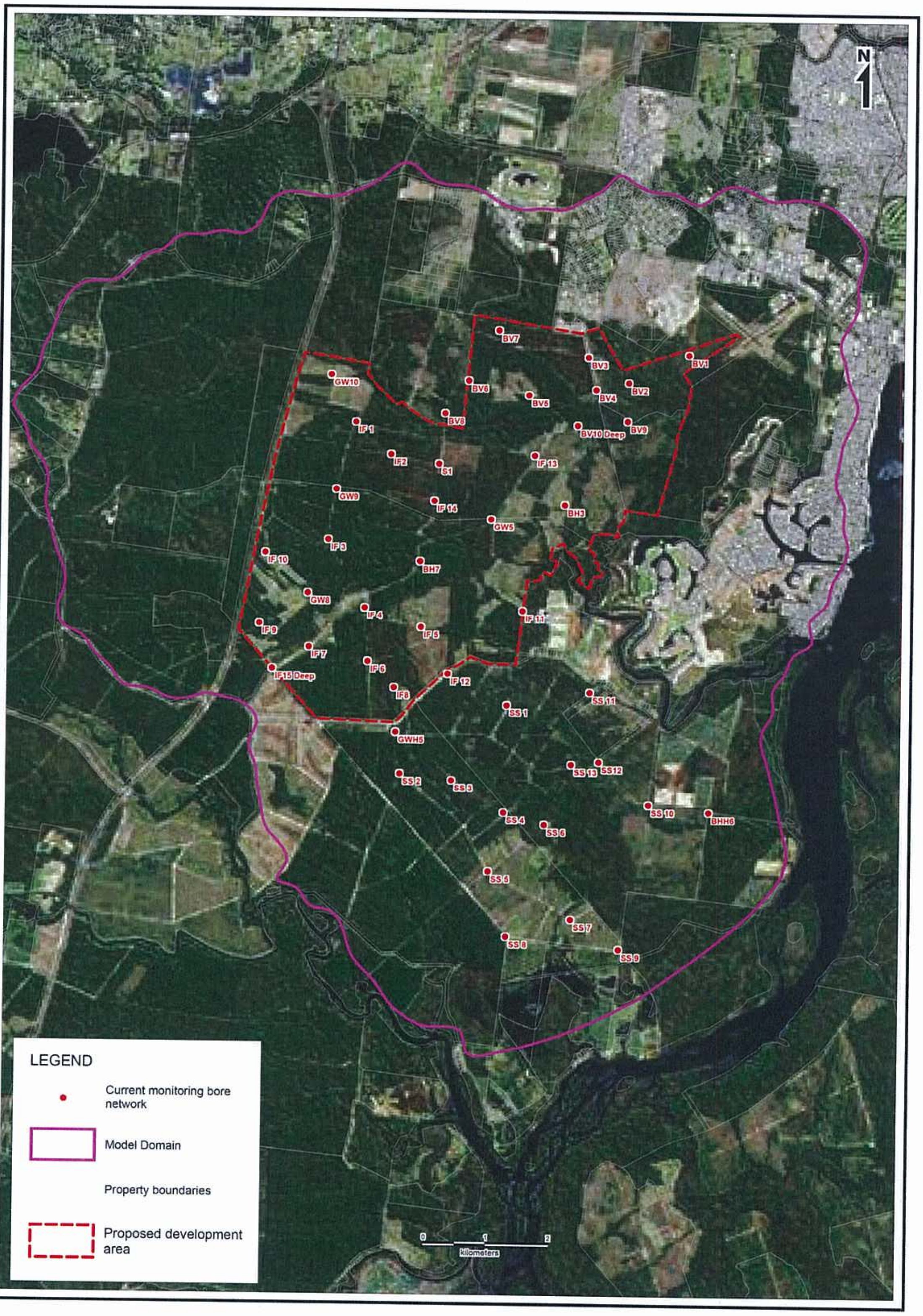


Figure 5-11 Groundwater Model Domain

5.5.2 Groundwater Model Development

5.5.2.1 Model Layers

The model area was discretised with a uniform finite difference grid of 100m x 100m with the following layers:

- A shallow surface Layer 1 of uniform 0.75m thickness;
- An intermediate Layer 2 including both weathered Landsborough Sandstone and unconsolidated alluvial and coastal sediments; and
- A lowermost Layer 3 including weathered Landsborough Sandstone.

As the predominant groundwater flow direction is seaward, from west to east towards Pumicestone Passage the model grid was oriented north – south/east – west.

The model grid comprises 127 rows, 121 columns and 3 layers. The model area was discretised with a uniform finite difference grid of 100 m x 100 m and covers 10,883 active cells.

The top elevation of Layer 1 was interpolated from the high resolution DEM. The elevation of the base of Layer 1 was assigned at 0.75m less than the layer top elevation. The elevation of the base of Layer 3 was set at 40 m below the ground elevation defined by the DEM. Model Layer 2 varies spatially in thickness to largely reflect the thickness of alluvium and coastal sediments. Where alluvium is not present, Layer 2 thickness is restricted to approximately 1 m and in these locations with the alluvium is not present the hydraulic conductivity of Layer 2 is the same as for the underlying Layer 3.

Figure 5-12 provides the final model set up grid for the model. The upper model layer was modelled as an unconfined type aquifer.

5.5.2.2 Model Boundary Conditions

Figure 5-12 indicates the adopted model domain. The model boundary to the north is a no flow boundary set at the top of the catchment and a similar boundary condition exists to the west, with this condition extending around the model domain to the south until approximately 2.5 km from the southern intersection of the Bruce Highway with the model domain. To the south east, the model domain borders Coochin Creek and a no-flow boundary was established for this area. Further around to the east the model incorporates a general head boundary set at 0 m AHD up to the canals of Pelican Waters Estate. This allows groundwater to leave the model in subsurface flow towards Pumicestone Passage.

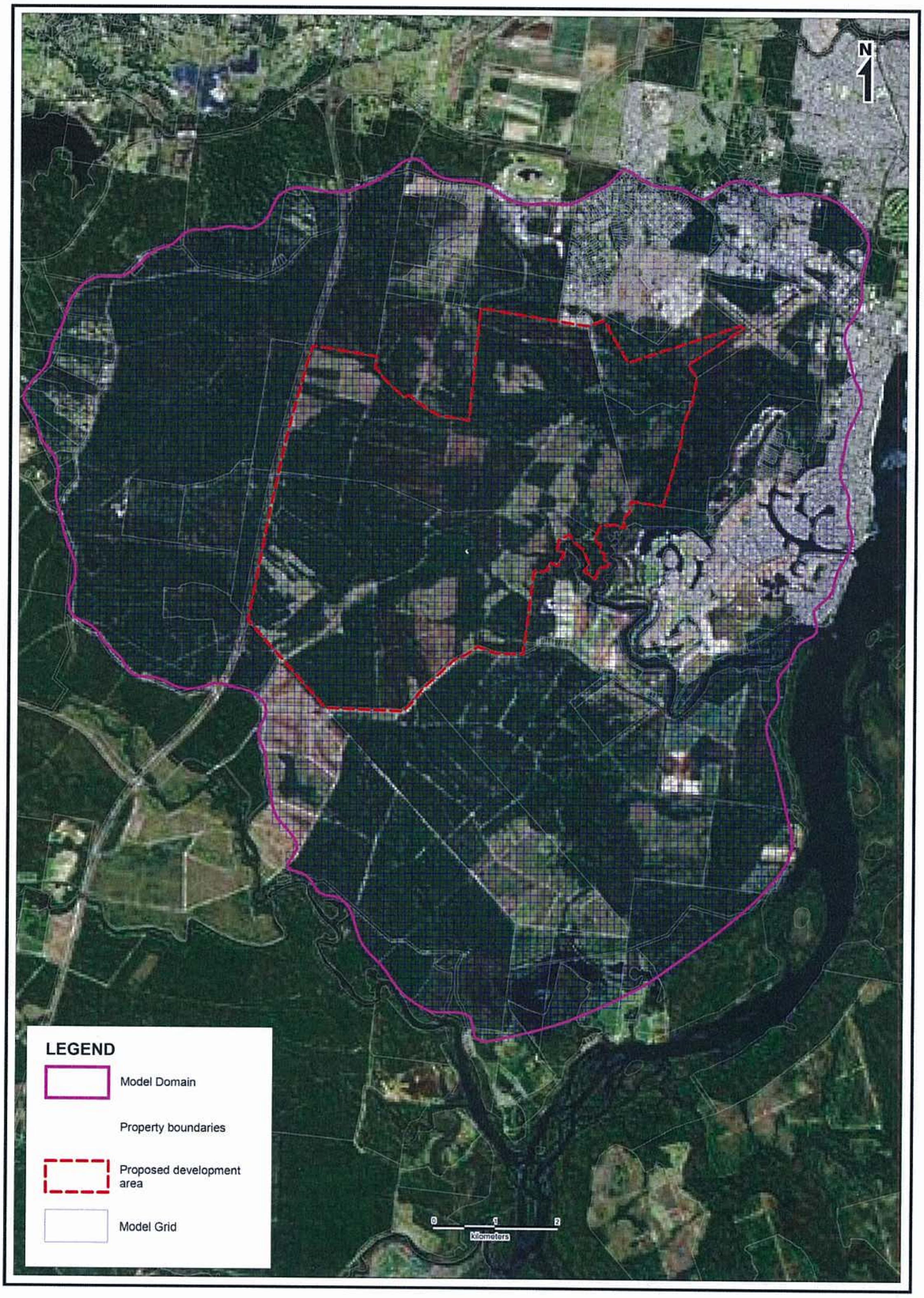


Figure 5-12 Adopted Groundwater Model Grid

5.5.2.3 *Simulation of Recharge*

A simple water balance model was developed to simulate the daily water balance components using the Soil Conservation Services (SCS) Curve Number (CN) method for each land use (cropping area, native forest, cleared land, plantation pine, urban areas and wetlands). The water balance model included evaporation from the canopy as interception, rainfall runoff and a soil moisture balance in the rooting zone. Drainage from the water balance model was linked to the groundwater model as recharge to the groundwater system.

Table 5-3 summarises the mean recharge rates adopted for the groundwater modelling.

Table 5-3 Mean Recharge Rates Adopted for Groundwater Modelling

Land use	SCS curve number	Mean recharge rate (% of incident rainfall)
Cropping	70	27.4%
Native Forest	75	3.0%
Cleared land	80	30.7%
Plantation pine	80	7.2%
Urban	90	10.6%
Wetland	70	8.7%

5.5.2.4 *Simulation of Evapotranspiration*

In addition to evapotranspiration simulated by the water balance model which includes the canopy evaporation, evapotranspiration from the rooting zone and from the groundwater system was simulated by the MODFLOW-SURFACT ET package.

5.5.2.5 *Groundwater Pumping*

Available data for private bores in the vicinity of the Caloundra South site indicate quite poor yielding bores tapping groundwater from the Landsborough Sandstone. Such bores would not be expected to be providing significant supplies. More specifically, although turf farming and other farming activity is present to the south east of the site; it appears almost certain that irrigation for these activities is supplied by surface, rather than groundwater, sources. Accordingly no groundwater pumping was included in the model set up.

5.5.3 Groundwater Model Calibration

PEST version 11.8 was used to automatically adjust model parameters until the fit between outputs and observations was optimised in the weighted least square sense. PEST is an automated calibration program used to expedite the determination of best fit parameter values and quantify the quality of calibration in comparing the alternative models. PEST also provides the calibrated parameter sensitivities, confidence intervals and correlations to manage the model calibration processes. The "pilot-points" parameterisation scheme was used to distribute the hydraulic conductivity values in layers 2 and 3 to the model cells using the geo-statistical methods available within PEST. During the automated calibration process, the model parameters were allowed to vary between prescribed lower and upper bounds whilst the objective function was minimised. The objective function was formulated as the sum of squares of residuals between the target groundwater levels and the model simulated groundwater levels.

Figure 5-13 plots of calibrated model groundwater elevations compared with manual observations of groundwater elevation at relevant site bores.

From it can be seen that in general the model does not simulate incidents of relatively sharp groundwater level decline that occur during drier periods. The most likely reason for this is that the geometry of the alluvial layer does not capture the presence of additional narrow palaeochannels incised into the Landsborough Sandstone and filled with permeable sandy alluvium in the mid-slope areas. Such channels could act to rapidly drain groundwater from the adjacent Landsborough Sandstone during low rainfall periods. This predictive deficiency is not significant from the perspective of prediction of changes to shallow groundwater levels in the proposed development area, or further afield, as it would tend to foster conservative predictions (i.e. groundwater levels in the development footprint would be simulated as being higher than would otherwise be expected and groundwater levels to the east in the native forest and wetland areas would be simulated as being lower than would otherwise be expected).

5.6 Groundwater Model Impact Assessments

A series of four impact assessment simulations were performed to assess groundwater level response to various development and land use change cases at Caloundra South as follows:

- Year 2000 land use with current topography and drainage (with land use in the Caloundra South site being dominated by plantation pine);
- Current land use at 2010 with current topography and drainage;
- Proposed future land use for development with current topography and drainage; and
- Proposed future land use for development inclusive of topographic surface revised for proposed cut and fill and the implementation of major surface drains.

These simulations used rainfall for the period 1 January 2000 through 23 October 2010.

Figure 5-14 indicates the land use distribution incorporated into the groundwater model to simulate the proposed land use changes. Figure 5-15 indicates the associated cut and fill pattern proposed for the development at this time to provide appropriate levels of drainage and flood immunity.

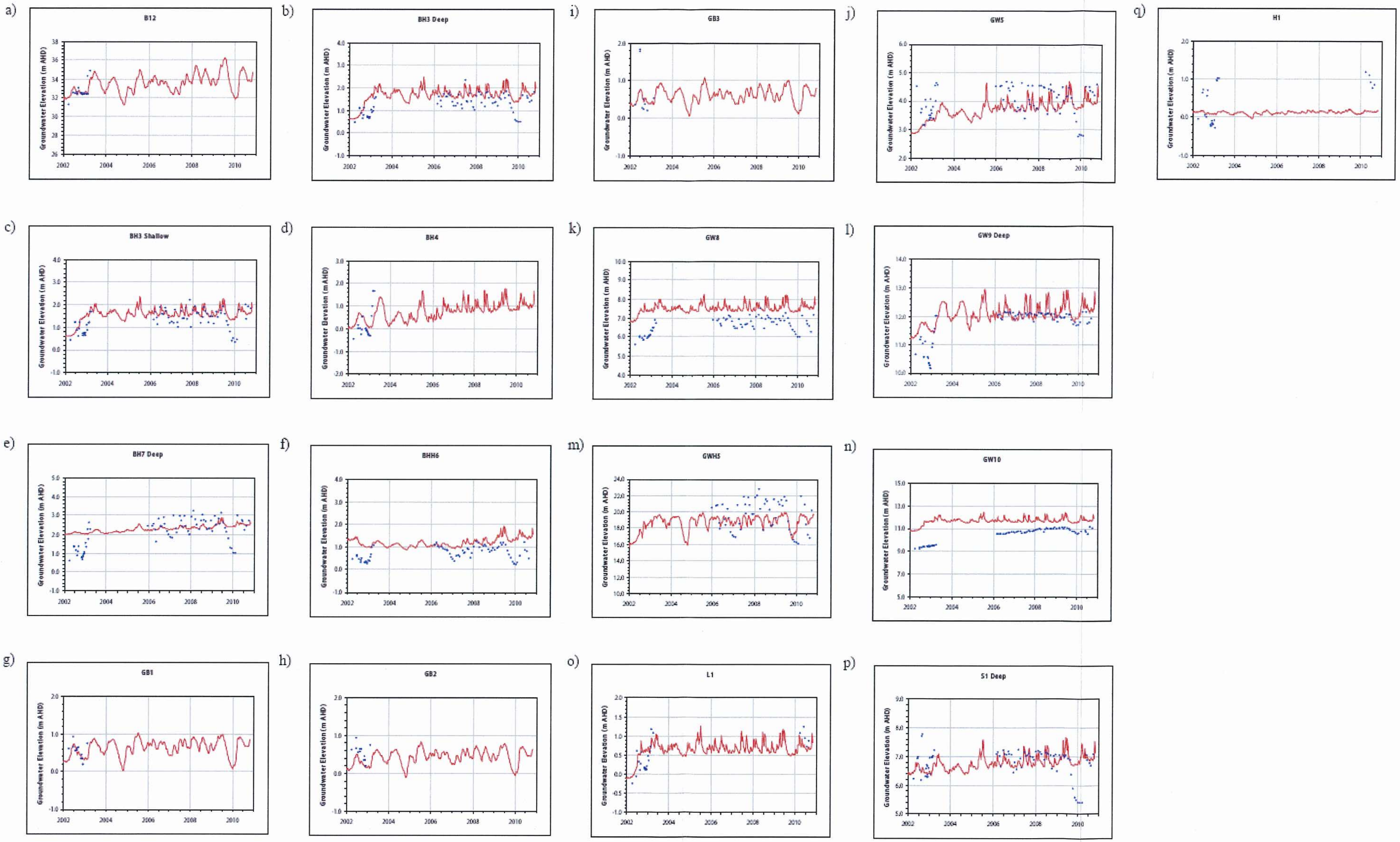


Figure 5-13 Groundwater Model Calibration Results

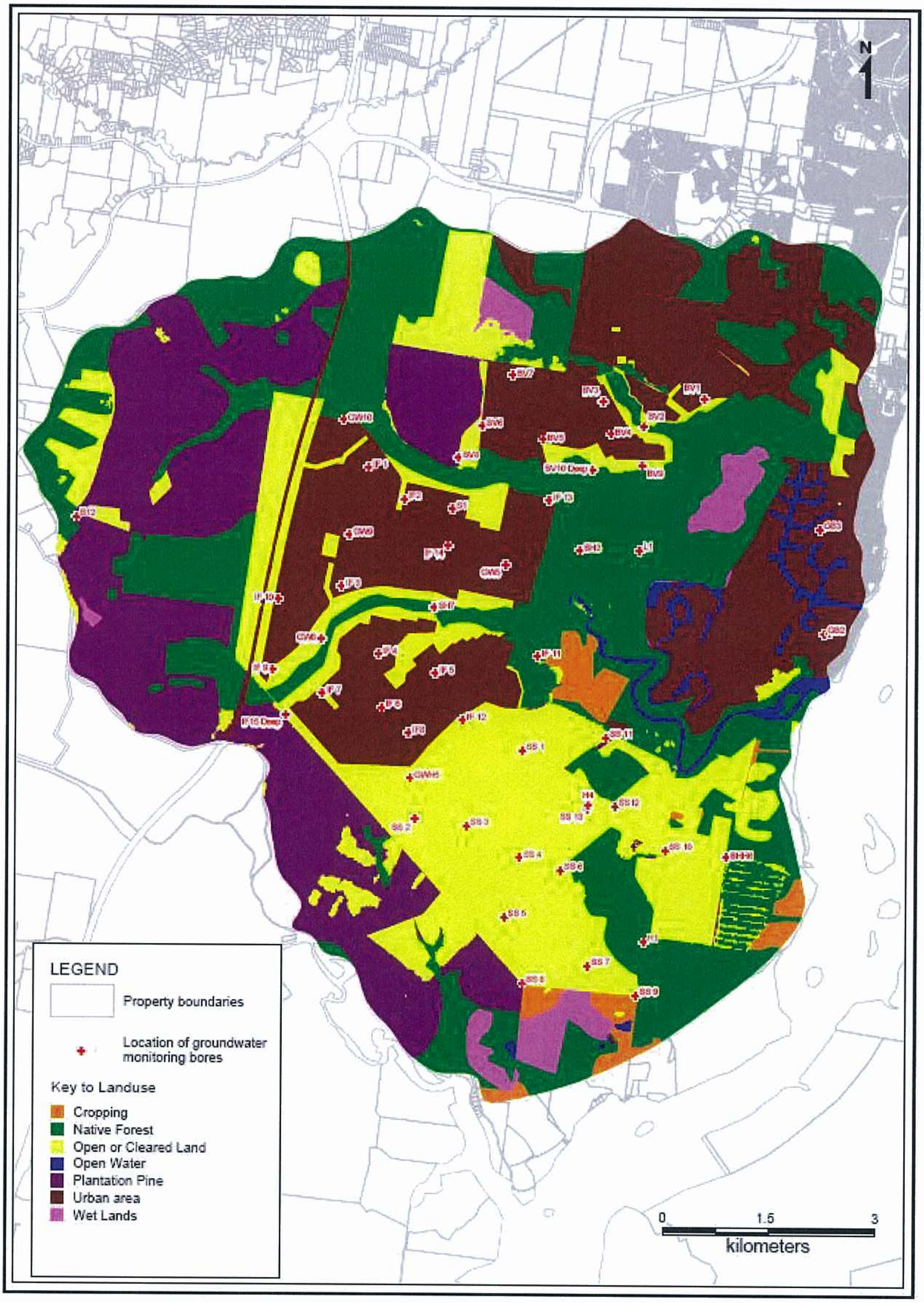


Figure 5-14 Land Use Distribution for Proposed Development

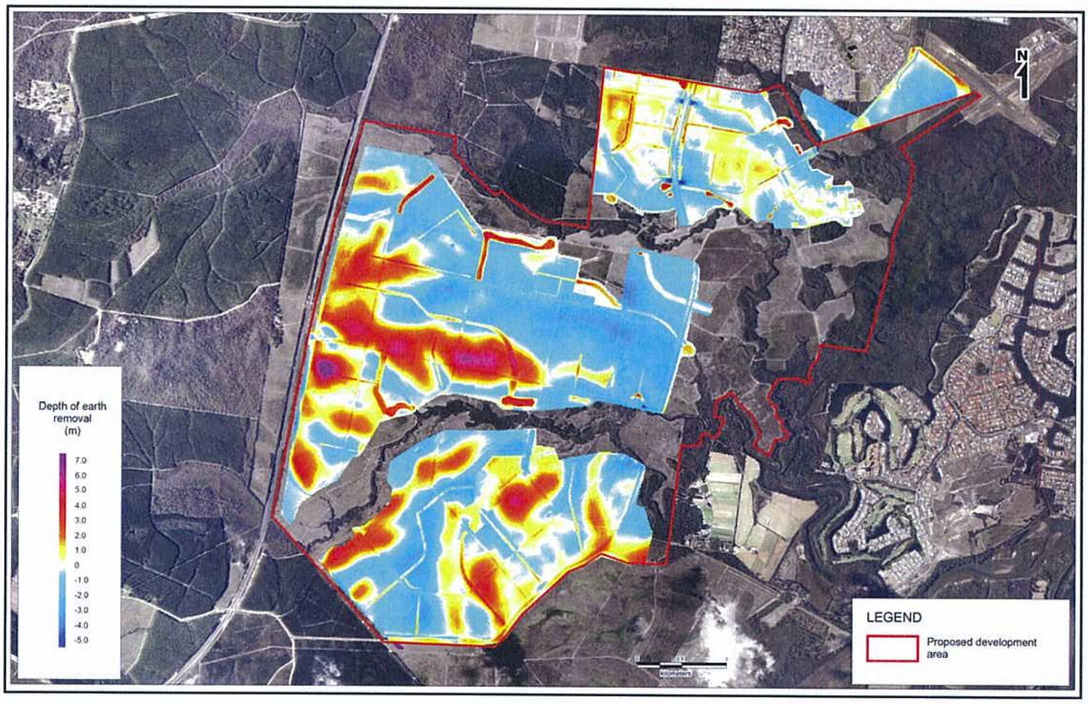


Figure 5-15 Simulated Pattern of Cut and Fill for the Proposed Development

5.6.1.1 Year 2000 Land Use Simulation

Table 5-4 provides a summary of the depths to groundwater for the year 2000 land use simulation.

Table 5-4 Summary of Depths to Groundwater for Year 2000 Land Use Simulation

Depth to groundwater (m bGL)	Area (ha)	Proportion of property (%)
Above ground	285.54	12.06
0 - 0.25	299.16	12.64
0.25 - 0.5	260.76	11.02
0.5 - 0.75	250.93	10.60
0.75 - 1.0	348.08	14.71
1.0 - 1.5	607.40	25.66
1.5 - 2.0	205.25	8.67
> 2.0	109.88	4.64
Not categorised	0.00	0.00

Table 5-4 indicates that with the land use at year 2000, approximately **35%** of the site would have been subject to groundwater levels within 0.5 m of the land surface. By contrast the corresponding data for a simulation with continuation of current land use at the site (see Table 5-5) suggests that approximately **71%** of the site would have been subject to groundwater levels within 0.5 m of the land surface. This reflects the profound impact on groundwater recharge of the clearing of plantation pine.

5.6.1.2 Year 2010 Land Use Simulation

Table 5-5 provides a summary of the depths to groundwater within the Caloundra South site for the simulation with current year 2010 land use.

Table 5-5 Summary of Depths to Groundwater for Year 2010 Land Use Simulation

Depth to groundwater (m bGL)	Area (ha)	Proportion of property (%)
Above ground	333.07	14.07
0 - 0.25	664.24	28.06
0.25 - 0.5	686.93	29.02
0.5 - 0.75	383.69	16.21
0.75 - 1.0	200.92	8.49
1.0 - 1.5	86.18	3.64
1.5 - 2.0	9.59	0.41
> 2.0	2.39	0.10
Not categorised	0.00	0.00

5.6.1.3 Proposed Development Land Use Simulation without Modification to Landform or Surface Drainage

Table 5-6 provides a summary of the depths to groundwater within the Caloundra South site for the simulation with the proposed land use but with no modification to the landform or surface drainage.

Table 5-6 Summary of Depths to Groundwater for Proposed Land Use with No Modification to Landform or Drainage

Depth to groundwater (m bGL)	Area (ha)	Proportion of property (%)
Above ground	62.24	2.63
0 - 0.25	103.78	4.38
0.25 - 0.5	245.15	10.36
0.5 - 0.75	536.79	22.68
0.75 - 1.0	801.33	33.85
1.0 - 1.5	529.16	22.36
1.5 - 2.0	66.60	2.81
> 2.0	21.94	0.93
Not categorised	0.00	0.00

Comparison of the results of Table 5-5 and Table 5-6 indicates a dramatic reduction in the area of the Caloundra South site subject to groundwater levels within 0.75 m of the ground from a simulation with continuation of current land use (i.e. 87% of site) to a simulation with changed land use for the proposed development (i.e. 40%). This effectively captures the reduced groundwater recharge applied to the site due to the capture and reuse of roofwater on site, and the reestablishment of deeply rooted vegetation.

The simulation data suggests that for the period of rainfall used in the simulations, implementation of the proposed development land use alone without changes to land form or the construction of additional major surface drains at the Caloundra South site would improve the shallow groundwater level situation. However, through land use alone, achievement of management of shallow groundwater levels would not be able to be achieved right across the development.

Importantly, the simulation indicates that the proposed development land use changes will not induce unacceptable changes to groundwater levels beneath native vegetation to the east of the Caloundra South site.

5.6.1.4 Proposed Development Land Use Simulation with Modification to Landform and Surface Drainage

Table 5-7 provides a summary of the depths to groundwater within the Caloundra South site for the simulation with the proposed land use modification to the landform and surface drainage.

Comparison of the data in Table 5-6 and Table 5-7 indicates an increase in the proportion of the area with groundwater levels above ground. This is because significant reaches of the major surface drains become groundwater drains. It is noted that although the cut and fill plan presented in Figure 5-15 was substantially designed to alleviate the depth to groundwater in some key areas, the implementation of the filling resulted in groundwater rising into the fill in many areas.

Table 5-7 Summary of Depths to Groundwater for Proposed Land Use with Modification to Landform and Drainage

Depth to groundwater (m bGL)	Area (ha)	Proportion of property (%)
Above ground	203.77	8.61
0 - 0.25	109.32	4.62
0.25 - 0.5	186.69	7.89
0.5 - 0.75	332.81	14.06
0.75 - 1.0	1036.74	43.80
1.0 - 1.5	417.45	17.64
1.5 - 2.0	56.06	2.37
> 2.0	24.15	1.02
Not categorised	0.00	0.00

The simulation data suggests that for the period of rainfall used in the simulations, the implementation of the proposed development land use, land form and major surface drains at the Caloundra South site should be able to produce reasonable management of shallow groundwater levels. The effective drainage impact of subsurface service trenches (i.e. permeable bedding materials) would be expected to further enhance control of shallow groundwater levels within the development area. It should however be noted that some localised areas of shallow groundwater may occur across the development areas, and these may require more site specific engineering interventions to achieve adequate control of groundwater.

5.6.1.5 Changes to Groundwater Levels Beneath Adjacent Native Vegetation

Importantly, the simulations indicate that the proposed development land use changes will not induce unacceptable changes to groundwater levels beneath the native vegetation to the east of the Caloundra South site. These results are highlighted in Figure 5-17.

- Groundwater levels beneath native vegetation sites 1 through 4 to the east of the Caloundra South site are predicted to not alter from simulated values with either current land use or a land use on the site dominated by plantation pine; and
- Groundwater levels beneath native vegetation site 5 to the east of the Caloundra South site are predicted to fall slightly (approximately 0.2 m) from levels for the current land use, yet they will remain slightly higher (also approximately 0.2 m) than levels which would have resulted had the land use continued to be dominated by plantation pine. As such, the groundwater levels will

be neither lower than those were the site fully vegetated, nor higher than those for the site in its existing condition. As such, they are predicted to be approximately midway between the extremes of groundwater levels that this site has already experienced between the time period from 2000 (when the site was vegetated) and now (when the site is unvegetated). As such, we can safely predict that there will be adverse groundwater related impacts on vegetation at this site.

5.6.1.6 Changes to Major Water Balance Items

Table 5-8 provides a summary of the major water balance items for the modelled scenarios over the model domain.

Table 5-8 Summary of Major Water Balance Items for Modelled Scenarios

Scenario	Mean recharge rate	Proportion of rainfall evapotranspired	Proportion of rainfall as drainage of groundwater	Proportion of recharge as drainage of groundwater
	(% of incident rainfall)			
Calendar year 2000 land use condition	8.4%	8.2%	0.1%	1.7%
Current land use condition 2010	15.6%	15.3%	0.2%	1.0%
Proposed developed land use without modification to landform or surface drainage	12.2%	11.9%	0.1%	1.2%
Proposed developed land use with modification to landform & surface drainage	12.1%	11.8%	0.5%	4.3%

From Table 5-8 it can be seen that the proposed development land use changes result in an appreciable decrease in recharge from the current land use, however the recharge would still be appreciably greater than with plantation pine cover.

It is noted that implementation of the proposed development land form with major surface drains will result in an appreciable increase in drainage of groundwater from the model domain.

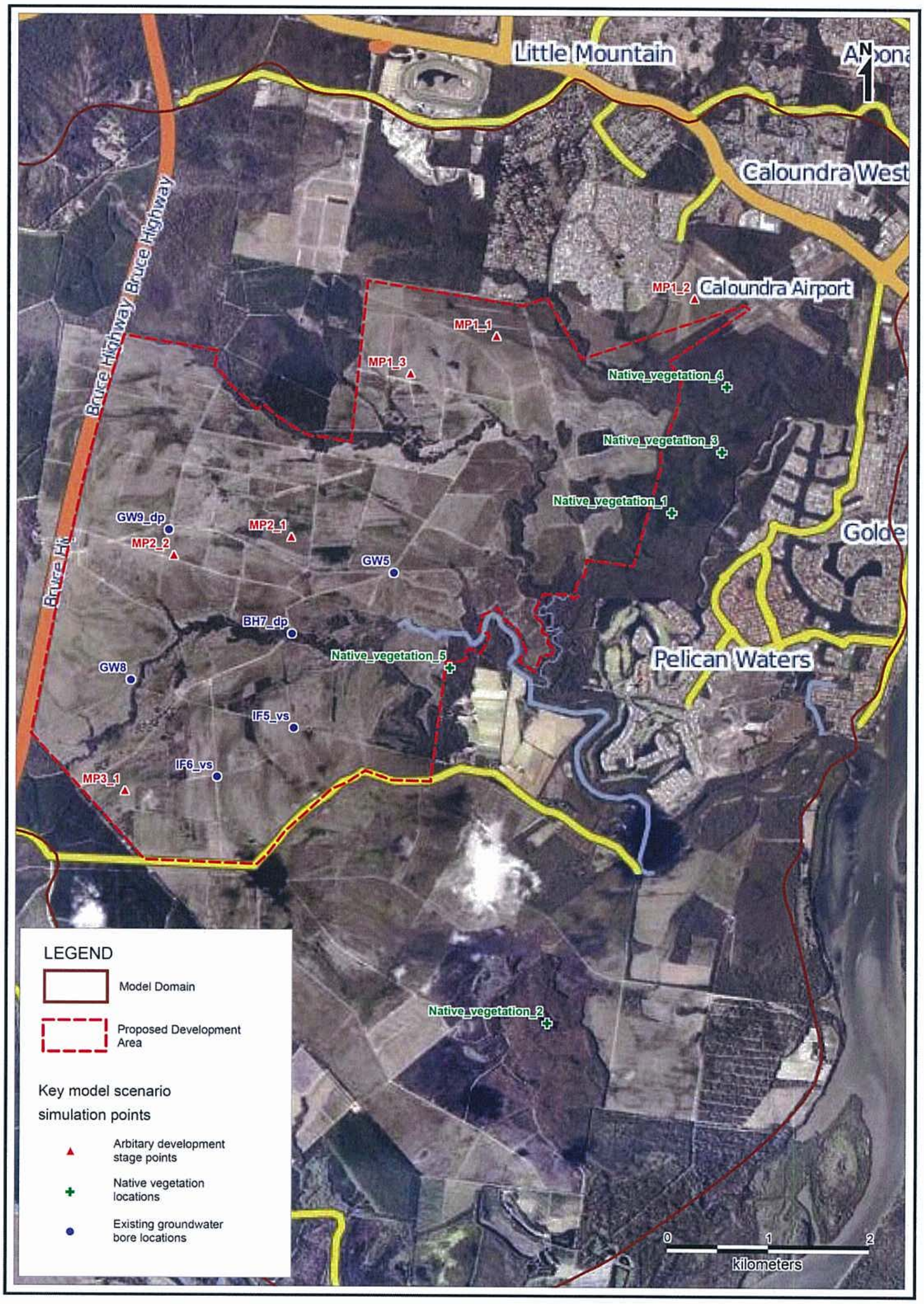


Figure 5-16 Key Locations at which Groundwater Model Predictions were Extracted

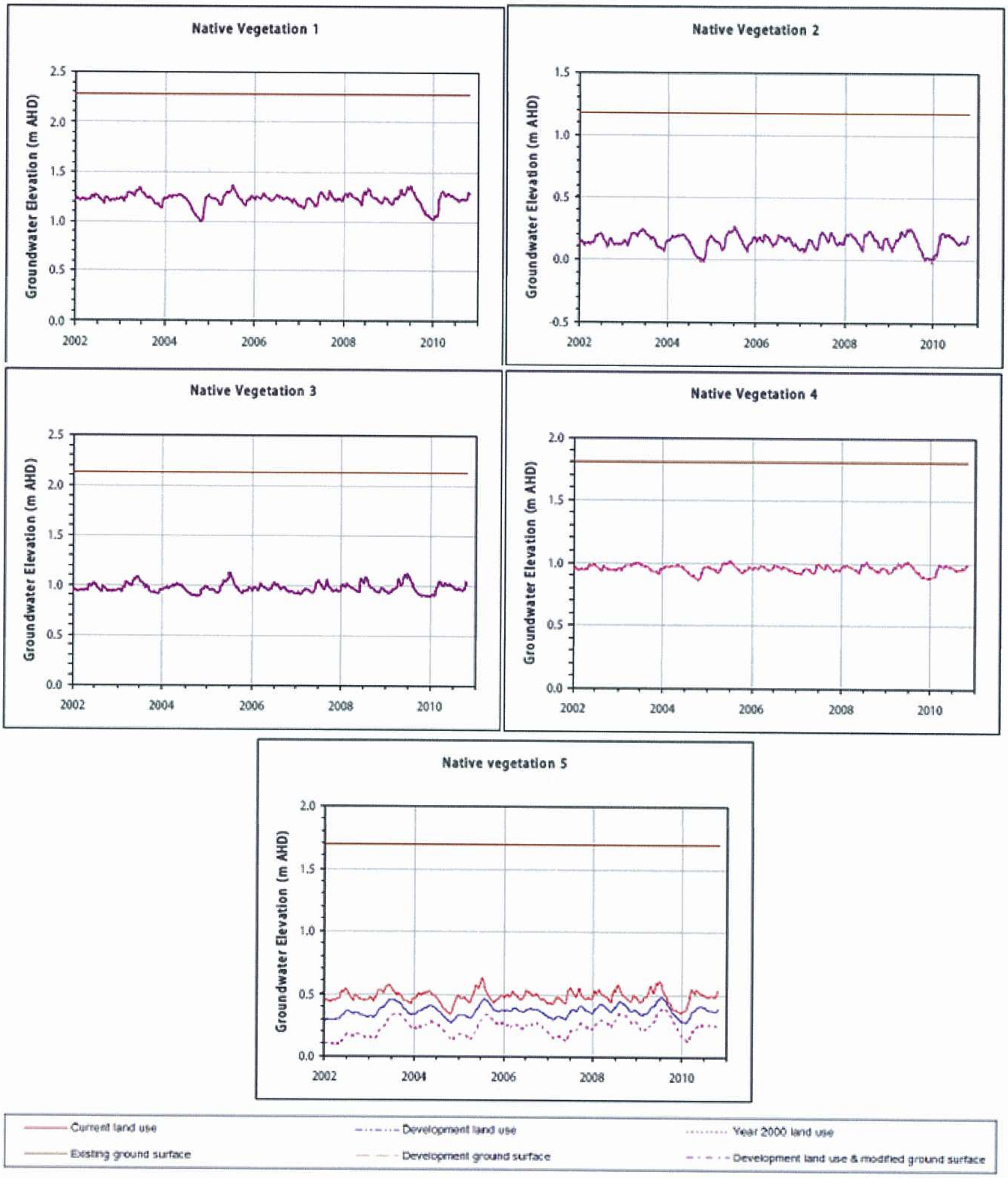


Figure 5-17 Groundwater Model Predictions Beneath Native Vegetation

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APPENDIX A: RAFTS-XP SUBCATCHMENT INPUTS

Table A-1 RAFTS-XP Pervious Areas and Manning's 'n' Values

	Existing			Developed		
Subcatchment ID	Pervious Area	Impervious Area	Pervious N	Pervious Area	Impervious Area	Pervious N
BC01	288.7	58.1	0.078	87.3	259.6	0.094
BC02	390.4	30.3	0.082	396.6	24.2	0.078
BCN1	98.2	17.6	0.088	72.7	43.1	0.086
BCN2	78.9	2.3	0.091	78.9	2.3	0.1
BCN3	638.3	0	0.092	417.1	221.2	0.073
BCN4	356.5	0	0.098	242.8	113.6	0.078
BCN5	224	0	0.1	224	0	0.1
BCN6	550	0	0.099	550	0	0.1
BCN7	497.5	0	0.096	497.5	0	0.097
BCS1	54.2	1.2	0.093	52.5	2.9	0.092
BCS2	345.4	0	0.099	79.5	265.9	0.075
BCS3	605.3	0	0.098	238.4	366.8	0.068
BCS4	419.4	0	0.1	200.4	219	0.068
BCS5	478.2	0	0.1	478.2	0	0.1
BCS6	139.1	0	0.1	139.1	0	0.1
DC01	226	67.2	0.057	226	67.2	0.057
DC02	70.6	24.6	0.061	70.6	24.6	0.061
DC03	59.2	63.9	0.022	59.2	63.9	0.022
HC01	733.2	0	0.093	716.1	17.1	0.093
HC02	314.9	0	0.087	243.5	71.4	0.087
HC03	305.4	0	0.096	89.3	216.1	0.096
HC04	396	0	0.099	394.9	1.1	0.058
LC01	189.1	218.7	0.038	407.8	0	0.015
LC02	223.7	8.3	0.09	179.5	52.5	0.09
LC03	180.1	0	0.095	180.1	0	0.1
LC04	123.9	0	0.067	99.8	24	0.083
LC05	126.8	0.1	0.07	64	80.3	0.064
LC06	199.8	115.8	0.043	74.3	241.3	0.087
LC07	158.3	91.7	0.051	64	168.6	0.049
LC08	112.6	0	0.085	112.6	0	0.075
LC09	112.8	0	0.086	73.1	39.7	0.098
LC10	271.5	0	0.087	271.5	0	0.085
LC11	96.8	0	0.1	96.8	0	0.1
TOTAL	**9064.8**	**699.8**		**7178.1**	**2586.4**	

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APPENDIX B: RAFTS-XP PEAK FLOW SUMMARY

Table B-1 RAFTS-XP Peak Inflows without Climate Change Allowance (m^3/s)

Event Magnitude	5 Year ARI				50 Year ARI				100 Year ARI			
Event Duration	6 Hour		12 Hour		6 Hour		12 Hour		6 Hour		12 Hour	
Subcatchment ID	EXG	DEV	EXG	DEV	EXG	DEV	EXG	DEV	EXG	DEV	EXG	DEV
BC01	46.8	46.8	47.7	47.6	69.6	69.6	73.3	73.3	79.9	79.9	84.4	84.4
BC02	9.9	9.9	11.4	11.4	21.0	21.0	23.6	23.6	25.1	25.1	28.0	28.0
BCN1	8.3	8.3	8.5	8.5	12.3	12.3	13.0	12.9	14.2	14.1	14.9	14.8
BCN2	1.4	1.2	1.7	1.5	2.9	2.5	3.7	3.2	3.5	3.0	4.4	3.9
BCN3	23.7	46.4	23.9	47.2	46.5	70.3	45.2	73.2	55.5	81.5	52.6	84.9
BCN4	17.0	25.8	15.2	25.9	31.6	39.6	29.5	42.0	37.7	46.1	36.0	49.2
BCN5	13.6	13.6	13.8	13.8	24.4	24.4	25.7	25.7	28.7	28.7	30.5	30.5
BCN6	35.3	35.3	37.1	37.1	62.6	62.6	67.3	67.3	73.8	73.8	79.6	79.6
BCN7	34.5	34.5	37.1	37.1	60.0	60.0	64.7	64.7	70.9	70.9	76.0	76.0
BCS1	1.3	1.1	1.5	1.3	2.7	2.4	3.0	2.8	3.2	2.8	3.6	3.4
BCS2	15.8	50.4	13.9	52.4	29.7	74.3	27.2	78.8	35.2	85.4	32.7	90.4
BCS3a	29.4	69.3	26.4	70.9	54.6	103.1	51.9	108.6	65.2	118.8	62.4	124.9
BCS3b		6.0		7.0		10.6		12.5		12.6		14.8
BCS4	23.7	46.2	23.2	47.1	43.6	70.0	44.6	72.8	51.4	81.0	53.0	84.4
BCS5	28.7	28.7	28.8	28.8	51.7	51.7	54.2	54.2	60.8	60.8	64.5	64.5
BCS6	9.9	9.9	10.7	10.7	17.4	17.4	18.6	18.6	20.5	20.5	21.6	21.6
DC01	20.4	20.4	23.5	23.5	33.4	33.4	40.5	40.5	39.4	39.4	47.6	47.6
DC02	13.2	13.2	12.7	12.7	21.2	21.2	21.1	21.1	24.8	24.8	24.8	24.8
DC03	22.2	22.2	23.1	23.0	32.7	32.7	34.9	34.9	37.5	37.5	40.0	40.0
LC01	47.8	38.0	44.3	36.8	79.4	79.4	76.6	76.6	93.7	93.7	90.5	90.5
LC02	10.8	10.8	11.1	11.1	16.4	16.4	17.1	17.1	18.9	18.9	19.7	19.7
LC03	3.0	2.6	3.7	3.3	6.6	5.6	8.3	7.5	8.1	7.0	10.0	9.1
LC04	6.1	6.5	5.6	7.1	11.3	11.1	10.8	13.1	13.6	13.1	13.2	15.4
LC05	7.4	16.7	7.3	17.0	13.4	25.1	13.8	26.3	15.7	29.1	16.6	30.3
LC06	44.2	49.1	44.6	50.1	67.5	73.7	69.7	77.1	78.5	85.0	80.9	88.8
LC07	31.8	36.0	32.4	36.5	47.8	54.4	50.1	56.8	55.1	62.8	57.6	65.4
LC08	6.0	6.0	5.8	5.8	11.2	11.2	11.2	11.2	13.3	13.3	13.5	13.5
LC09	9.6	9.6	9.6	9.6	15.1	15.1	16.3	16.3	17.7	17.7	19.1	19.1
LC10	13.6	13.6	12.5	12.5	25.4	25.4	24.4	24.4	30.2	30.2	29.3	29.3
LC11	11.3	11.3	10.4	10.4	19.3	19.3	18.6	18.6	22.7	22.7	22.1	22.1

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Table B-2 RAFTS-XP Peak Inflows with Climate Change Allowance (m^3/s)

Event Magnitude	100 Year ARI			
Event Duration	6 Hour		12 Hour	
Subcatchment ID	EXG	DEV	EXG	DEV
BC01	96.335	96.335	102.068	102.068
BC02	32.238	32.238	36.008	36.008
BCN1	17.127	16.982	18.029	17.903
BCN2	4.639	3.941	5.708	5.194
BCN3	70.711	99.049	65.092	103.183
BCN4	47.656	56.369	46.502	60.868
BCN5	35.815	35.815	38.741	38.741
BCN6	91.56	91.56	99.112	99.112
BCN7	87.945	87.945	93.522	93.522
BCS1	4.171	3.671	4.687	4.223
BCS2	44.506	103.227	42.786	109.395
BCS3a	82.334	143.691	80.714	151.061
BCS3b		15.675		18.475
BCS4	63.637	98.433	67.129	102.44
BCS5	75.785	75.785	81.296	81.296
BCS6	25.103	25.103	26.205	26.205
DC01	49.75	49.75	59.123	59.123
DC02	30.491	30.491	30.66	30.66
DC03	45.02	45.02	48.053	48.053
HC01	30.442	30.67	41.55	41.597
HC02	29.162	34.602	30.058	37.326
HC03	33.47	84.934	31.067	90.437
HC04	57.504	57.513	58.168	58.181
LC01	115.983	115.983	112.768	112.768
LC02	22.986	22.986	23.896	23.896
LC03	10.422	9.168	12.718	11.669
LC04	17.113	16.617	17.028	19.508
LC05	19.687	35.489	21.04	36.969
LC06	95.683	102.932	98.765	107.328
LC07	66.929	76.489	69.964	79.562
LC08	16.645	16.645	17.274	17.274
LC09	21.803	21.803	23.556	23.556
LC10	38.121	38.121	38.254	38.254
LC11	27.928	27.928	27.327	27.327

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APPENDIX C: EXISTING HYDRAULIC STRUCTURES

Table C-1 Structure Details of Bruce Highway Culvert Crossings

Structure Name	Type	No. of	Width (m)	Height (m)	Length (m)	U/S Invert (mAHD)	D/S Invert (mAHD)
BH19	Rectangular	3	2.6	3.8	22	11.064	10.854
BH20	Rectangular	3	2.6	3.8	22	10.854	10.836
BH21	Circular	1	0.75	-	27	12.831	12.646
BH22	Circular	1	0.75	-	27	12.646	12.474
BH_BCS6_1	Circular	5	1.3	-	18	13.7	13.5
BH_BCS6_2	Circular	5	1.3	-	18	13.5	13.3
BH36_37	Circular	3	1.3	-	42	12.097	11.949
BH38	Rectangular	3	3.3	3.2	40	10.758	10.607
BH40	Circular	4	0.825	-	18	23.997	23.667
BH41	Circular	4	0.825	-	22	23.667	23.369
BH42_43	Rectangular	3	2.1	1.5	38	24.234	24.108

APPENDIX D: EXISTING SCENARIO MUSIC PROPERTIES

The methodology to derive values for each of these is described below.

As described in Section 4.3.2, rainfall-runoff and pollutant export characteristics for the existing (pre developed) site have been developed based on the data collected as part of BMT WBM's baseline monitoring program at the Caloundra South site. Further information in relation to this program is provided in BMT WBM's (2011) "*Caloundra Downs Baseline Monitoring Program Final Report*".

To develop MUSIC properties for the existing site, data from Site 1 was excluded from the analysis as the catchment contributing to this site is partially urbanised. Therefore, only data from Sites 2 and 3 was used.

Rainfall Runoff Properties

To determine suitable rainfall-runoff properties for the site, a meteorological template of the monitoring period (using the recorded pluviometer data and average monthly PET for Caloundra WTP obtained from the Bureau of Meteorology) was developed. Volumetric Runoff Coefficients (VRCs) were calculated for 'Agricultural' and 'Forest' land usage classifications – using rainfall-runoff properties as given in Water By Design's (2010) "MUSIC Modelling Guidelines". These VRCs were subsequently compared to the values given in BMT WBM's (2010) "*Caloundra Downs Baseline Monitoring Program Final Report*". These VRCs are given in Table D-1.

Table D- 1 Calculated Volumetric Runoff Coefficients for Various Scenarios

Site/ Land Usage	VRC	Methodology
Site 2	0.51	Based on recorded rainfall and flow data (see aforementioned BMT WBM (2010) report).
Site 3	0.39	
'Agricultural'	0.48	Using rainfall-runoff properties given in Water By Design (2010b)
'Forest'	0.42	

As shown above, the VRC for 'Agricultural' is similar to the calculated VRC for Site 2 (and between the calculated VRC for sites 2 and 3). 'Agricultural' is also anticipated to be the land usage that most closely qualitatively describes the existing site. Therefore, the rainfall runoff properties for the 'Agricultural' land usage classification (as given by Water By Design (2010b)) has been applied to describe the existing site.

Pollutant Export Characteristics

As described in BMT WBM (2010) recorded pollutant concentration data was separated into 'storm flow' and 'ambient' (or baseflow) categories. Log values of recorded Total Suspended Solids, Total Phosphorus and Total Nitrogen were subsequently calculated and (as required in MUSIC), mean and standard deviations of these log values was calculated for stormflow and baseflow conditions. These calculated values are given in Table D-2.

Table D- 2 Calculated MUSIC Pollutant Export Characteristics for the Existing Site

Pollutant	Stormflow		Baseflow	
	Mean	*St.dev.*	*Mean*	*St.dev.*
TSS Log^{10} values	0.895	0.265	0.935	0.393
TP Log^{10} values	-1.426	0.096	-1.476	0.242
TN Log^{10} values	-0.013	0.084	-0.075	0.150

APPENDIX E: FILTER MEDIA TEST RESULTS

As described in Section 4.4, the proposed rain gardens and ephemeral wetlands will include ('bioretention') filter media. As outlined in Section 4.7, these systems will need to be constructed and established in accordance with Water By Design (2010a) *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands*. This guideline states that filter media must meet the requirements as given in FAWB's "*Adoption Guidelines for Stormwater Biofiltration Systems*".

As outlined in Table 4-3, assumptions have been made about the properties of the filter media (for the MUSIC modelling used to predict their treatment performance). Values have been assumed for the following properties:

- TN content of the filter media; and
- Orthophosphate content of the filter media.

These assumed values are based on laboratory test results for a potential filter media, as supplied by Southern Pacific Sands. The laboratory test results for a sample of this media is provided on the following page.

As outlined by Water By Design (2010a), the filter media supplier and contractor are responsible for ensuring the filter media meets the specifications outlined in these guideline and that the correct material is delivered to site. If significant variations occur between the parameter values assumed in this report (and associated modelling) and that of the media available, then it is recommended that MUSIC modelling be undertaken to confirm whether the strategy will still achieve the given pollutant load removal targets.

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BIORETENTION SAND ANALYSIS

Client	Southern Pacific Sands	**Job No.**	J11/04
Project	Bioretention Sand – Sample No: 2825	**Date Tested**	30/06/11
Test Procedures	FAWB Specifications	**Date Sampled**	Supplied

TEST RESULTS

Particle Size Distribution

Fraction	Sieve Size (mm)	Acceptable Range (%)	Actual (%)
Silt & Clay	< 0.05	< 3	0.1
Very Fine Sand	0.05 – 0.15	5 – 30	12.5
Fine Sand	0.15 – 0.25	10 – 30	20.1
Medium – Coarse Sand	0.25 – 1.00	40 – 60	49.9
Coarse Sand	1.00 – 2.00	7 – 10	7.4
Fine Gravel	2.00 – 3.4	< 3	0
Gravel	> 3.4	0	0

Drainage Properties

Property	Acceptable Range (mm/hour)	Actual (mm/hour)
Hydraulic Conductivity	> 100	195

Chemical Properties

Property	Acceptable Range	Actual
Organic Content	> 3% (w/w)	2.5
pH Value	5.5 – 7.5	6.9
Electrical Conductivity	< 1.2 dS/m	0.25
Orthophosphate (PO_4^3)	< 80mg/kg	19
Total Nitrogen (TN) Content	< 1000mg/kg	125

Notes: The supplied sample has passed the requirements of the FAWB specifications. Samples will be retained in laboratory storage for one (1) month after report date in case further analysis and or examinations are required. For technical support please contact the undersigned operative. This is not a NATA endorsed report.

JL

Jimmy Liddell
Laboratory Manager
Wagner Soil Testing

APPENDIX F: MAINTENANCE PLANS FOR PROPOSED RAIN GARDENS AND EPHEMERAL WETLANDS

This appendix includes an indicative maintenance plan for the proposed rain gardens and ephemeral wetlands. In this appendix, we have used the technical term 'bioretention system' to describe both the rain gardens and ephemeral wetlands.

SCHEDULE OF SITE VISITS													
Purpose of Visit	Frequency	J	F	M	A	M	J	J	A	S	O	N	D
Routine inspection	6/year	√		√		√		√		√		√	
Annual inspection	1/year					√							
Routine Maintenance	4/year	√			√			√			√		

The above schedule is a guideline only. Inspection and maintenance activities during the plant establishment period (first two years) of the bioretention systems is likely to be more frequent when frequent weed removal and replanting may be required. Inspections should also be performed after large rainfall events to check for damage or significant pollutant accumulation. Maintenance within the bioretention system should only occur after a reasonably rain-free period when the soil in the bioretention system is dry. Inspections are also recommended following large storm events to check for scour and other damage. Resetting (i.e. complete reconstruction) of the bioretention systems will be required if the system fails to drain adequately after tilling of the surface.

INSPECTION	
1	**Routine Inspection**
1.1	Routine inspection should be carried out on a regular bi-monthly basis. The purpose of the inspection is to check for weed invasion, litter accumulation and any damage/vandalism.
1.2	The bioretention system (including floor and batters) should be inspected for weed growth.
1.3	The bioretention system (including inflow points, overflow pits, under-drains and vegetation) should be checked for litter accumulation.
1.4	Identify areas of obvious sediment deposition, damage from vehicles and/ or clogging within the bioretention system (evident by ponding and/ or 'boggy' filter media surface). If there is shallow ponding or evidence of clogging, firstly ensure that cause is not a build-up of sediment. Investigate effect of "turning over" or "tilling" filter media soil, and inspect outflow pipes for clogging.
1.5	Identify areas of erosion, including scouring from storm flows and rill erosion of the batters from lateral inflows.
1.6	Any structures such as maintenance accesses, weirs, piping and access restrictions (eg. lock-rails, fencing) should be inspected for damage and or vandalism.
2.	**Annual Inspection**
2.1	Once per year, the condition of the bioretention system should be closely inspected. Any damage or problems should be noted on the inspection form for action by the property owner.
ROUTINE MAINTENANCE	
3	**Purpose**
3.1	Routine maintenance of the bioretention system involves weed control and the collection of any litter and minor remedial works if required.
4	**Weed Management**
4.1	If weeds have been observed within the bioretention system during routine inspection, these weeds should be removed by hand.
4.2	Where physical removal has been specified, the aim is to remove the weed including the roots when the weeds are less than 3 months old.
4.3	Herbicides should not be used.
4.4	The weeds should be disposed of offsite at an appropriate waste management facility.
4.5	Replant plant species as necessary in areas that have been extensively weeded.
4.6	*In general, the planted species should not be harvested. Harvesting plants has little, if any, benefit for treatment performance.*
5	**Litter Management**
5.1	Remove and dispose of any accumulated litter/debris within the bioretention basin.
6	**Surface Tilling**
6.1	If there is evidence of clogging of the bioretention system, tilling the bioretention basin surface or remove of the surface layer.

7	**Sediment Removal**
7.1	Removal of sediment from the bioretention system where it is smothering the bioretention basin vegetation. Remove accumulated sediments by surface scraping (if it does not damage the vegetation too much) or reforming of the bio-retention system.
8	**Under-Drainage Cleaning**
8.1	(For streetscape bioretention systems only) If the bioretention system is not draining, a reason may be due to the under-drainage being blocked by sediment or litter/ debris. This blockage should be removed by 'rodding' or 'jetting' (using high pressure water) of the under-drainage. As a result, 'rodding' points should be provided at the upstream ends of all under-drainage.
9	**Remedial Works**
9.1	Routine inspection may detect minor damage to the bioretention system after storms, which should be repaired. This may include erosion on the bioretention system or scouring at the inlet and/or outlet. This damage should be repaired as part of the routine maintenance of the bioretention system. Measures to reduce future damage (eg. erosion) from occurring should also be investigated and, if possible, implemented.
9.2	Resetting (i.e. complete reconstruction) of the bioretention system will be required if the system fails to drain adequately after tilling of the surface and no evidence of sediment accumulation or under-drainage blockage can be identified.

BIORETENTION SYSTEM MAINTENANCE CHECKLIST			
Asset I.D.			
Inspection Frequency:	1 to 6 monthly	Date of Visit:	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	Y	N	ACTION REQUIRED (DETAILS)
Sediment accumulation at sediment forebay?			
Litter within bioretention system?			
Erosion at inlet or other key structures?			
Traffic damage present?			
Evidence of dumping (building waste)?			
Vegetation condition satisfactory (density, weeds etc.)?			
Watering of vegetation required?			
Weed removal required?			
Mowing/slashing required?			
Pruning and/ or removal of dead or diseased vegetation required?			
Replanting required?			
Damage/vandalism to structures present?			
Set down from kerb still present (if road-side bioretention swale)?			
Evidence of ponding?			
Surface clogging visible?			
Drainage system inspected?			
Clogging of drainage points (sediment or debris)?			
Resetting of system required?			

COMMENTS

APPENDIX G: LAKE (AND SHALLOW WETLAND) MAINTENANCE PLAN

This appendix includes an indicative maintenance plan for the proposed lake systems (including the shallow, densely vegetated macrophyte zones and recirculation wetlands). The maintenance requirements for the recirculation infrastructure has not been included at this stage.

SCHEDULE OF SITE VISITS													
Purpose of Visit	**Frequency**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Routine inspection	26/year	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN
Routine clean up of litter	26/year	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN	FN
Sediment accumulation monitoring	1/ 5 years					✓							
Clean out of sediment	1/ 20 years						✓						

'FN': Fortnightly

The above schedule is a guideline only. Inspection and maintenance frequencies should be adjusted according to site and weather conditions.

INSPECTION	
1.	**Routine Inspection**
1.1	Routine inspection should be carried out on a regular bi-weekly basis. The purpose of the inspection is to check the condition of the lake system and associated infrastructure, and can be combined with the weekly litter and debris clean up.
1.2	Routine inspection involves visually checking Lake edges, shallow areas and embayments for litter or other debris accumulation. Associated lake infrastructure such as the rock walls, signage and boardwalks should also be inspected for signs of damage, vandalism or deterioration.
1.3	The amount of submerged macrophytes (eg. water weeds such as hydrilla) should be noted if growth is excessive so that harvesting can be arranged. Also, any accumulation of floating macrophytes (eg duckweed and salvinia) should be noted.
1.4	Any domestic fauna found to be on or around the Lake, such as ducks and geese should be noted for removal.
1.5	The recirculation system should be checked to ensure it is operating correctly and no blockages have occurred.
1.6	The destratification unit should be checked to ensure it is operating correctly and no blockages have occurred.
1.7	Complete the attached Maintenance Form and forward to relevant maintenance coordinator.

ROUTINE MAINTENANCE	
2	**Purpose**
2.1	Routine maintenance of the lake areas involves weed control and the collection of any litter and minor remedial works if required.
3	**Weed Management**
3.1	If weeds have been observed during routine inspection, these weeds should be removed from the wetland. Common weed species that have been associated with constructed wetlands and suggested removal techniques are given below:

Species	Typical locations	Suggested Removal Technique
Typha domegensis (Cumbungi)	Planted aquatic areas	Cut stems to below water level (remove all cut plant material)
Duckweed	Open water zones	Physical removal (eg. netting)
Salvinia molesta (Salvinia)	Open water zones	Biological control (weevil), Chemical, Physical removal, refer DNRM Pest Fact Sheet
Eichhornia cassipes (Water hyacinth)	Planted aquatic areas	Biological control, Chemical, Physical removal, refer DNRM Pest Fact Sheet
Brachiaria mutica (Paragrass)	Wetland edges, planted aquatic areas	Physical removal in planted aquatic areas. Herbicide (glyphosate) in wetland edges
Myriphyllum aquaticum (Parrot's feather)	Planted aquatic areas	Physical removal, see DNRM Pest Fact Sheet
Rumex spp. (Curled dock)	Planted aquatic areas	Physical removal
Baccharis halimifolia (Groundsel)	Wetland edges and adjacent areas	Physical removal of seedlings, Adults cut stump treatment with Herbicide (glyphosate)

3.2	Where physical removal has been specified, the aim is to remove the weed including the roots when the weeds are less than 3 months old, otherwise infestation can rapidly occur and may be difficult to control. Perennial weeds such as *Typha* can be drowned if cut below the water level in late autumn.
3.3	Herbicides should not be used where they may contaminate water in the lake system (and wetland areas).
3.4	The weeds should be disposed of offsite at an appropriate waste management facility.
3.5	Replant wetland species as necessary in areas that have been extensively weeded.
3.6	*In general, the planted wetland species should not be harvested unless encroachment into open water zones is excessive. Harvesting wetland plants has little, if any, benefit for treatment performance.*

4	**Litter Management**
4.1	A small motorised boat or punt should be used to perform the clean up. Pool scoops or simple manual removal are the best options for litter and debris removal. The boat or punt should have a reasonably shall draft to allow access into the inshore areas of the lake.
4.1	Floating macrophytes such as duckweed and *Salvinia* can be manually removed from the Lake using pool scoops. These weeds must be regularly removed to prevent excessive growth.
4.2	Contact with sharp objects, including hypodermic needles, is a risk when removing litter. All workers must be made aware of this risk, wear appropriate protective gear and use caution.
4.3	The collected litter and debris should be loaded into the back of a tip-truck. If the load includes loose material that is able to be blown off or fall from the truck, the load should be covered prior to leaving the Lake.
4.4	Tidy the site of any debris prior to leaving.
4.5	Proceed to landfill for disposal of trash.
5	**Remedial Works**
5.1	Routine inspection may detect minor damage to the lake after storms that should be repaired. This damage should be repaired as part of the routine maintenance of the lake.
SEDIMENT ACCUMULATION MONITORING	
3.1	On a biannual basis, the amount of sediment accumulation needs to be monitored. The most accurate process for doing this is by undertaking a survey of bathymetry of the Lake and comparing it to previous bathymetry measurements.
CLEANOUT OF SEDIMENT	
4.1	The cleanout of sediment from the lake system will be a major operation that will require specific technical input. Sediment removal should only be performed if absolutely necessary due to possible negative impacts on Lake water quality, aesthetics and ecology.

LAKE MAINTENANCE CHECKLIST			
Asset I.D.			
Inspection Frequency:	1 to 6 monthly	**Date of Visit:**	
Location:	Caloundra Downs		
Description:			
Site Visit by:			

INSPECTION ITEMS	Y	N	ACTION REQUIRED (DETAILS)
Litter within lake?			
Sediment accumulation at inflow points?			
Revetment walls in satisfactory condition ?			
Boardwalks in satisfactory condition ?			
Glory hole spillway in satisfactory condition and free of debris ?			
Signage around lake present and in satisfactory condition ?			
Damage/vandalism to structures present?			
Is recirculation system operating correctly ?			
Is destratification unit operating correctly ?			
Terrestrial vegetation condition satisfactory (density, weeds etc)? (Specify areas for future harvesting/ weed control)			
Aquatic vegetation condition satisfactory (density, weeds etc)?			
Replanting required?			

COMMENTS

APPENDIX H: PRELIMINARY LAKE DESIGN

As described in Section 0, potential constructed lakes are proposed at three locations within the site. The potential lakes are anticipated to add significant value to the master-planned community, by improving site amenity and enhancing the community's understanding, experience and engagement with the water cycle.

The potential lakes will be designed and operated with careful consideration to best practice design guidelines and experience to maximise their sustainability and minimise any risk of operational problems.

This is important as numerous operational problems (eg. excessive weed growth, algal blooms) have been observed in several lakes (and similar water-bodies) previously constructed within Queensland. These problems are commonly due to poor water quality inflows, long residence times, low abundance of emergent macrophytes and inadequate mixing (or stratification) within lakes (Mackay City Council, 2008).

This appendix describes some of the proposed design and management features of the potential lakes, including:

- Design intent;
- General description;
- Amenity and recreation;
- Lake functional design, including:
  - Pre-treatment of inflows;
  - Sustainable water levels;
  - Organic carbon loads;
  - Flushing of lake;
  - Mixing of lake;
- Management;
- Monitoring;
- Maintenance; and
- Hand-over.

These proposed features have been developed based on our experience in constructed and natural lakes (and similar water-bodies) with consdieration outlined in relevant lake guidelines, including (but not limited to)

- Mackay City Council's (2008) "*Engineering Design Guidelines: Constructed Lakes – Planning Policy No. 15.15*".
- Melbourne Water's (2005) "*Constructed Shallow Lake Systems – Design Guidelines for Developers* (Version 2).

It should be noted that proposed design and management features should be considered preliminary only. As described further in this appendix, further planning, design and assessment is required to maximise the sustainability of the potential lakes.

General Description

Three areas are proposed for constructed lakes within the master-planned community. The location of the potential lake systems are illustrated in Figure 4-6.

Potential lake system A is located within the gully area immediately south of Bells Creek South. It is proposed that this lake system will consist of a combination of open water and densely vegetated macrophyte zones. The proposed indicative configuration of this lake system is illustrated in Figure H-1.

Potential lake system B is located near the CBD area. Potential lake system C is located immediately west of the Lamerough Creek waterway buffer. It is anticipated that both lake systems B and C will be predominantly open water. The proposed indicative configuration of lake systems B and C is shown in Figures H-2 and H-3.

It is anticipated that each lake potential system may be fringed with emergent macrophytes or a hard edge.

Design Intent

The intended purposes of the potential constructed lakes include the following:

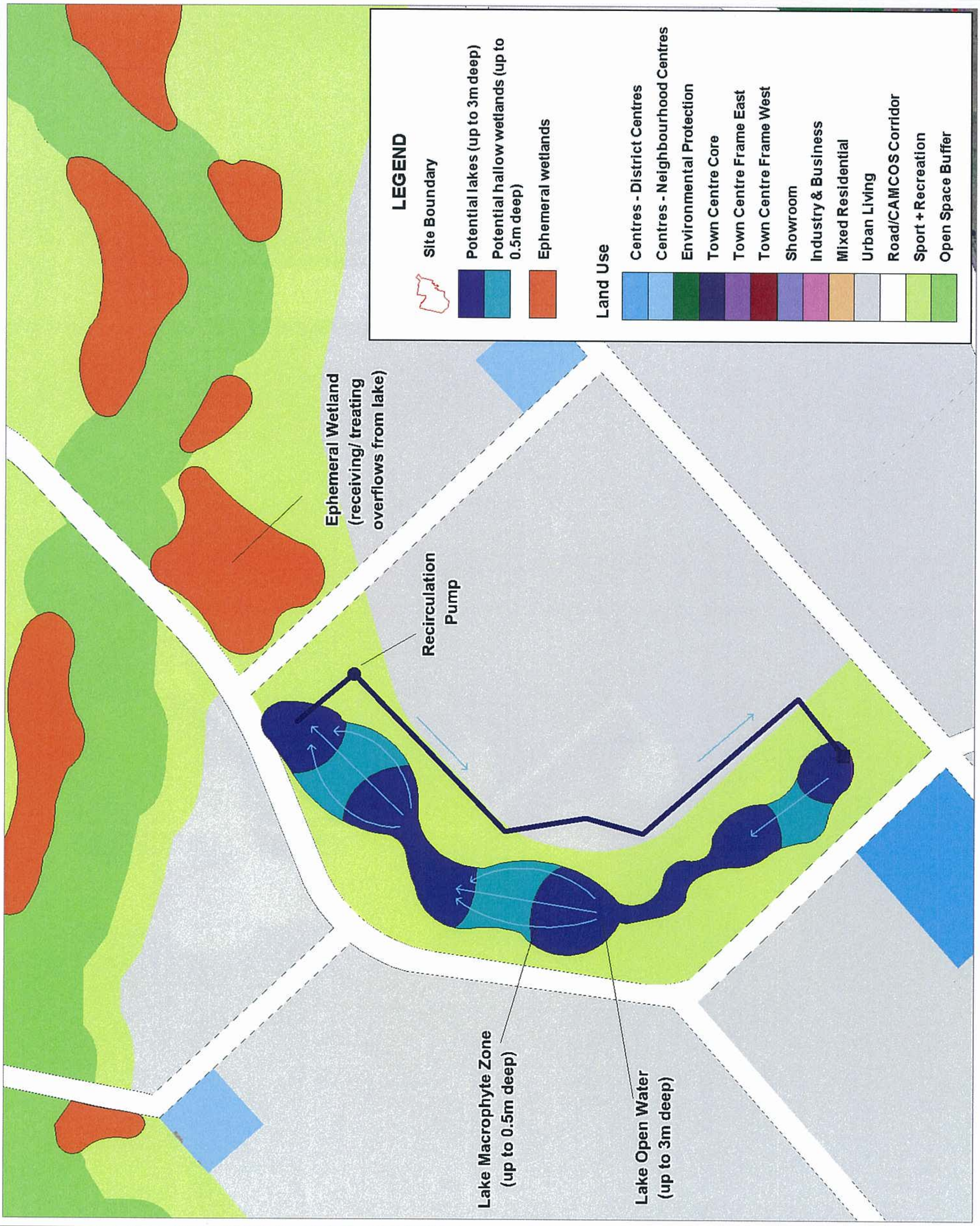
- Amenity;
- Enhancing the community's understanding, experience and engagement with the water cycle;
- Fill requirements. The excavated material from the lakes will be used to supplement fill requirements within the master-planned community. It is anticipated that the lakes may be able to provide approximately 280 000 m^3 of fill; and
- Secondary contact recreation (eg. model boat usage, canoeing).

None of the potential lake systems are located within any natural waterway (so will result in no disturbance to the passage of aquatic fauna or fish). Each lake system is also located external to the waterway buffer areas proposed within the site.

Recreation

The potential lake systems will be suitable for secondary contact usage (eg. model boat usage, canoeing), and will not be suitable for primary contact usage (eg. swimming).

Linkages between the potential lake systems and recreational master plans for the area will be provided at subsequent design stages.



Title:
Indicative Configuration of Potential Lake System A

Figure: H-1

Rev: A

N

0 200 400m

Approx. Scale

BMT WBM

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Filepath : I:\B18176_I_AMB_Caloundra_Downs\DRG\IWMP_Rev_5\UW_009_120524_LakeA.wor

Title:
Indicative Configuration of Potential Lake System B

Figure: **H-2**

Rev: **A**

N

0 100 200m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B18176_I_AMB_Caloundra_Downs\DRG\IWMP_Rev_5\UW_010_120524_LakeB.wor