2. OPEN SPACE CORRIDOR WATERWAYS

2.1 DGR Item References

The following DGR items are addressed in this section:

RAINBOW BEACH CONCEPT PLAN (CP) – MP06-0085

Item	Topic
CP2.1	Justify the constructed wetland in the context of the IWCM plan proposed for the site (refer to CP3.2).
CP2.2	Consider the functioning of the wetland including the responsibility for ongoing management, any potential risk to public safety and potential environmental impacts such as groundwater, water quality and hydrology.
CP3.1	Address potential impacts on water quality of both surface and groundwater.
CP7.1	Describe the potential impacts of the proposal on existing native vegetation (including areas of SEPP 26 littoral rainforest) both within and adjacent to the site and identify measures to minimise impacts on this vegetation (eg. appropriate buffers).
CP7.2	Describe the potential impacts of the proposal on existing aquatic flora and fauna and habitats both within and adjacent to the site and identify measures to minimise impacts on these habitats with consideration of Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 1999.
CP7.3	Outline measures for the conservation of flora and fauna and their habitats within the meaning of the Threatened Species Conservation Act 1995.
CP7.4	Outline measures for the conservation or enhancement of existing wildlife corridors and / or the connective importance of any vegetation on the subject land.

PROJECT APPLICATION – OPEN SPACE CORRIDOR & CONSTRUCTED WETLAND (PA) – MP07-0001

Item	Topic
PA4.1	Outline potential impacts on flora and fauna and their habitats (within the meaning of the Threatened Species Conservation Act 1994) across the site and, where relevant, provide conservation measures. Specifically address the impact of the constructed wetland on fish and their habitats. Note: The Department of Primary Industries states that constructed wetlands are inappropriate habitat for fish.
PA4.2	Provide a vegetation management plan that describes the proposed vegetation and regeneration works across the site. Consider the role of the revegetation in the provision of habitat for threatened species including the Koala (with reference to Hastings Council's Area 14 Koala Plan of Management).
PA4.3	Address the potential for the constructed wetland to harbour aquatic weeds and where necessary, identify measures for their management.
PA5.2	Assess the impacts of the proposal on surface and groundwater hydrology and quality. Specifically address any impacts on Duchess Gully and the ongoing management of the waterway and its riparian zone. Describe any potential impacts to the existing exfiltration system attached to the Bonny Hills Sewerage Treatment Plant.

2.2 Existing Waterway Features

The watercourses of Duchess Gully and its tributaries are the central features of the Open Space Corridor which extend through the site. Most reaches of Duchess Gully have been extensively modified by man-made drainage channel improvements and additions. Parts of the lower reaches of Duchess Gully, particularly along the eastern boundary of the site, retain areas of original forested habitat.

The existing water features of this area are shown in Figure 5 and Figure 6. Significant catchments west of Ocean Drive drain into the “upper” reach of Duchess Gully and into the Upper Tributary entering from the north. The man-made elements then direct flows into a large existing man-made lagoon which was constructed during previous development south of the site. Flows from this lagoon bypass the original “middle” reach flow path of Duchess Gully via a man-made culvert discharging to an overflow channel connected directly to the “lower” reach of Duchess Gully.

2.3 Proposed Development Waterway Features

The main proposed development features of the waterways within this open space corridor are highlighted in Figure 7 and Figure 8. The most prominent added feature is the 10.5 hectare constructed wetland located adjacent to the “middle” reaches of Duchess Gully. Flows will be re-directed from the existing lagoon through the new constructed wetland by means of a new culvert connecting the two water bodies.

The new constructed wetland will be provided with a culvert outlet discharging into the defined “middle” reach channel of Duchess Gully as shown in Figure 8 and the existing lagoon overflow culvert will be upgraded to better handle larger flows. The banks of the both the existing lagoon and the new constructed wetland will be regraded in selected areas to allow major storm event flows to discharge over the banks in a safe controlled fashion.

The development strategy aims to provide an area of coastal freshwater lagoons and marshes and non-tidal freshwater forested constructed wetlands with habitats for a diverse range of animals throughout all seasons including water birds, frogs, invertebrates, fish and with aquatic plants including sedges, rushes and various tree species native to the area.

Additional plantings will enhance the landscape, biodiversity, hydrology and natural processes of the site. A mosaic of plant communities has significant value for biodiversity. Melaleuca swamps provide nesting and roosting habitat for egrets, herons and ibis. Reedy margins provide breeding areas for native waterfowl. Vegetation in shallow pond margins provides foraging sites for shorebirds.

This vegetation plays a vital role in hydrological processes. Wetland plants stabilise shorelines, reducing soil erosion. They filter and trap sediment from stormwater inflows, reducing turbidity and sedimentation in the receiving waters of Duchess Gully.

The waterways will be flanked by riparian habitats incorporating facilities suitable for visitors and passive recreation.

2.4 Development Options

Three alternative options for development were examined across a range, evaluating the trade-offs between:

- Balancing earthworks within the site to avoid importing fill;
- Achieving the residential capacity desired under Council’s preferred planning scenario;
- Minimising disturbance of acid sulfate soils; and
- Minimising excavation in areas with rock strata.

while satisfying all regulatory requirements.

Table 6 Development Options

Evaluation Parameter	Option 1	Option 2	Option 3
Development features	Wetlands stormwater treatment	Bioinfiltration stormwater treatment	Bioinfiltration stormwater treatment
Residential area (ha)	67.8	67.8	45
Total earthworks volume (m3)	400,000	800,000	400,000
Volume imported fill (m3)	0	250,000	0

The proposed development using wetlands for stormwater treatment (see Section 1.4.3 and Figure 4) was adopted as the most advantageous overall because it is the only option satisfying all the above aims. Option 2 (using bioinfiltration treatment) is not economically feasible because of the increased volume of earthworks required involving additional cut from hill slope areas of the site and large volumes of imported material. Option 3 does not provide the desired residential capacity.

2.5 Potential Development Impacts

Potential impacts on watercourses which have been raised in the DGR items and which are investigated in this section of the report include:

- Potential impacts on hydrology including groundwater systems;
- Potential impacts of development control policies including water cycle management and stormwater runoff treatment;
- Potential impacts on native riparian flora and fauna;
- Viability of proposed aquatic habitats;
- Management and maintenance requirements of the watercourses including weed management;
- Impacts and risks arising from inundation; and
- Potential impacts of the construction phase including acid sulfate soils.

2.6 Hydrology - Surface Water Budget and Water Levels

This investigation has been carried out to determine the likely behaviour of the proposed constructed wetland lagoons under changed catchment hydrological conditions resulting from the proposed development.

2.6.1 Catchment Description and Areas

The catchment area of Duchess Gully at its outlet to the ocean is 782 hectares (7.8 km^2). The boundaries of the catchment are shown in Figure 9.

The western boundary of the catchment is formed by a ridge approximately 2 km west of Ocean Drive with elevations varying from about 80 mAHD to 200 mAHD. The drainage is fairly well defined west of Ocean Drive, but poorly defined on the low-lying area east of Ocean Drive. A number of shallow drains have been constructed east of Ocean Drive to drain this area.

West of Ocean Drive, the catchment is generally timbered and uncleared, except for a rural residential subdivision which occupies around 33 hectares. East of Ocean Drive, primarily the subject site, is generally cleared. There are areas of residential subdivision of about 28 hectares near the southern boundary of the catchment east of Ocean Drive.

The catchment sub-areas are listed in Table 7. Total catchment areas at key locations are summarised in Table 8.

The catchment upstream of Ocean Drive (that is, external to the site) is 538 hectares. Downstream of Ocean Drive, the catchment area is 243 hectares.

The catchment area of the existing lake is 662 hectares (6.6 square kilometres).

The catchment area draining to the proposed constructed wetland is 708 hectares.

With the proposed development of the site, 77.6 ha of will be developed from the existing undeveloped state to community facilities and residential subdivision including associated drainage easements (see Table 3).

Table 7 Catchment Subarea Components

Subarea	Area (Ha)	Subarea	Area (Ha)
1	5.98	27	0.797
2	10.944	28	1.824
3	0.951	29	2.934
4	0.43	30	0.393
5	0.575	31	3.151
6	0.314	32	0.29
7	8.495	33	0.858
8	251.3	34	0.906
9	0.779	35	0.564
10	1.587	36	0.77
11	3.048	37	0.9
12	3.481	38	1.855
13	4.086	39	1.801
14	2.831	40	6.425
15	0.535	41	3.93
16	2.057	42	0.561
17	17.361	43	4.882
18	12.267	44	6.626
19	6.289	45	287
20	9.372	46	7.6
21	3.802	47	17.4
22	1.093	48	11.28
23	22.134	49	10.25

Subarea	Area (Ha)	Subarea	Area (Ha)
24	1.04	50	11.28
25	1.602	51	15.23
26	1.319	52	23.2
		Total	781.5

Table 8 Total Catchment Area at Selected Locations

Location	Area (hectares)
Ocean Road	538.3
Existing Lagoon	661.6
Constructed Wetland Outlet	708.5
"Middle" Reach Duchess Gully	747.0
Duchess Gully at "Overflow" Confluence	758.3
Duchess Gully Outlet	781.5

2.6.2 Description of Water Bodies

2.6.2.1 Existing Lagoon

There is an existing lagoon adjacent to the upper reaches of Duchess Gully (see Figure 5 and Figure 6) which has a surface area of 6.3 hectares. The average bed level of this lagoon is RL 0.7 varying from RL 1.4 mAHD to RL-0.6 mAHD. Currently there is no outlet spillway for this lagoon. The water level is controlled by an outlet pipe culvert discharging to on "overflow" channel connecting to Duchess Gully.

This lagoon has an average depth of 2.7 metres deep at its normal top water level of RL 3.4 m AHD and has a stored volume of 132 ML.

2.6.2.2 Proposed Constructed Wetland

A new constructed wetland is proposed as part of the development. A surface area of 10.5 ha is proposed, and the position of the constructed wetland is indicated in Figure 8. The new constructed wetland will connect with the existing lagoon at its upstream end (connection S3) and will discharge to the "middle" reach of Duchess Gully via a base flow outlet (S4) and a high flow outlet (S5).

The average bed level of the new constructed wetland is RL 1.0 m AHD, and the normal top water level 3.0 mAHD. The capacity of the lake at its normal top water level is approximately 165 ML.

2.6.3 Water Body Water Balance Modelling

A water balance of the water bodies was carried out to determine their likely behaviour, given their dimensions, and their catchment areas. Catchment runoff volumes were determined using the USDA Soil Conservation Service rainfall runoff model.

2.6.3.1 Climate Data

Rainfall and evaporation records are required at the site for the water balance. The Queensland Department of Natural Resources and Water (DNRW) SILO database was used to extract interpolated daily rainfall and daily evaporation records for the site for the 51-year historical period 1957 to 2007. The SILO database uses an interpolation procedure to derive records at any site in Australia from available nearby climate data records.

The mean monthly values of rainfall and evaporation for the site were derived from the daily data, and are summarised in Table 9.

Table 9 Mean Rainfall and Pan Evaporation for Bonny Hills from SILO Data

Month	Mean Rainfall (mm)	Mean Pan Evaporation (mm)
Jan	144	158
Feb	155	131
Mar	181	120
Apr	161	93
May	126	67
Jun	140	60
Jul	68	67
Aug	66	91
Sep	58	118
Oct	101	140
Nov	116	147
Dec	115	170
Whole Year	**1440**	**1361**

The above figures indicate that mean rainfall and evaporation are comparable for this locality, and that mean monthly evaporation exceeds mean monthly evaporation for 6 months of the year.

2.6.3.2 Catchment Runoff Estimation

Runoff was estimated for the different land uses in the catchment area, which included forested and cleared open areas, and urban development.

The USDA Soil Conservation Service daily rainfall runoff model was used for determining the runoff from the catchment area of the lakes. A K_2 index is required for this model. The index is chosen according to the soil type, vegetation, condition and land use of the catchment. Guidance as to the selection of the index is given in the 1984 Qld Water Resources Commission “Farm Water Supplies Design Manual”.

The following K2 factors were chosen for this catchment:
Forested and open areas – K_2 = 74
Urban and proposed urban areas – K_2 = 90

The following average annual runoff depths were predicted by the USDA model for the catchment areas.

Table 10 Catchment Runoff – USDA Model

Land Use	K_2	Estimated Mean Annual Runoff Depth 1957-2000 (mm)	Mean Annual Rainfall 1957-2000 (mm)	RO/RF %
Forest/Open	74	230	1403	16
Urban	90	496	1403	35

2.6.3.3 Water Body Water Balance

The behaviour of the two water bodies was modelled for the period 1970 to 2007 for which there are evaporation records. This thirty-eight-year period is adequate to obtain a picture of the likely performance. The following assumptions have been made:

- There is some interchange of flow between the existing lagoon and the constructed wetland because the culvert discharging to the constructed wetland is at a lower invert level (RL 3.4) than the culvert discharging to the bypass "overflow" (RL 3.5). Low flows will flow from the existing lagoon through the constructed wetland. During more severe runoff events, the "overflow" culvert will also operate and catchment runoff will be divided equally between the constructed wetland and the overflow. It was assumed in the water balance model that monthly flows out of the existing lagoon up to 85 ML will all flow through the constructed wetland. Monthly flows out of the existing lagoon greater than 85 ML were assumed to be divided equally between the constructed wetland and the overflow flow path.
- Dimensions and capacities of the lakes were as described in 2.6.2.
- A nominal seepage allowance of 25 mm/month from the water bodies was assumed. Seepage is not likely to be significant because the water level at normal top water level is approximately the same level as the surrounding water table.
- No water use was assumed from the water bodies. A dual-reticulated town water supply will be available incorporating recycling and some water tank adoption is assumed. As a result there is no need for lawn and park watering supplies to be drawn from the water bodies.

Storage behaviour for the two water bodies and for two catchment development conditions are shown in Table 11.

Table 11 Water Body Storage Behaviour

Water Body	Development scenario	Lake Capacity (ML)	Minimum Stored Volume (ML)	Maximum Drawdown * (metres)
Existing Lagoon	Existing	132	82	0.94
Existing Lagoon	Developed	132	86	0.86
Constructed wetland	Developed	165	59	0.84

(Note: * "Drawdown" is the reduction in water level below normal top water level.)

From the water body behaviour simulation, statistics of the water levels in the water bodies were calculated. The percentage of time that the water levels lie within specified ranges below top water level (that is the spillway level of 3.4 m AHD) are listed in the table below.

Table 12 Statistics of Water Levels - % Time in Specified Ranges

	Existing Lagoon		Constructed wetland
Drawdown (metres)	**Existing Catchment**	**Developed Catchments**	**Developed Catchments**
0 – 0.01	51%	53.7%	50%
0.01 – 0.1	14%	14.3%	20%
0.1 – 0.2	15%	14.5%	13%
0.2 – 0.3	7%	6.8%	7%
0.3 – 0.4	5%	3.9%	5%
0.4 – 0.6	4%	4.6%	3%
0.6 – 0.8	3%	2.0%	2%
0.8 – 1.0	1%	0.2%	0%

Figure 10 is a plot of the above table showing the probability of exceeding specified drawdowns.

These results show that:

- For existing conditions, the lagoon stays reasonably full with a maximum drawdown of 0.94 metres and drawdowns of less than 0.3 metres for 87% of the time. This agrees with site conditions where the existing lagoon has been a permanent feature of the landscape for some years.
- After development, the existing lagoon will continue to stay reasonably full with reduced drawdown because of the increased runoff from the catchment.
- The constructed wetland will also stay reasonably full most of the time with a maximum drawdown of 0.84 metres and drawdowns of less than 0.3 metres for 90% of the time.
- Drawdowns greater than 0.3 metres are likely to be relatively temporary in duration.

The water balance model also shows that the total outflow from the existing lagoon divides equally between the constructed wetland and the “overflow” flow path direct to Duchess Gully. This indicates that the bulk of the flows maintaining the water levels in water bodies derive from heavy rainfall events rather than from the low base flow in the system.

2.6.4 Initial Filling

The time for the proposed constructed wetland to fill initially after construction was estimated from the statistics of the water balance model results.

The probability of filling within one year of construction is estimated as 98% and the probability of filling within 2 years of construction is estimated as 100%.

The estimated median time for the constructed wetland to fill after construction is three months and the probability of filling within six months of construction is estimated as 78%.

These results indicate that the constructed wetland should become established within a short period after construction and artificial filling of the constructed wetland should not be necessary.

2.6.5 Summary – Average Water Body Levels

The storage behaviour analyses indicate that the existing lagoon generally stays full but may be temporarily drawn down by approximately 0.8 to 0.9 metres very infrequently during drought periods such as 1980, 1991 and 2002. This result is borne out by site information which shows that the existing lagoon is a permanent feature with a well-established habitat.

The new constructed wetland (with the development in place) will also generally stay full but may be temporarily drawn down by approximately 0.8 metres during drought periods

For the majority of the time the levels of both water bodies are expected to be within 0.3 metres of their spillway levels.

In summary, the water balance indicates that the water level in both lakes will for most of the time vary between spillway level and 0.3 metres below spillway level, with very infrequent drawdowns to about 0.8 metres below spillway level.

The constructed wetland should fill within a short time after construction.

2.7 Water Level and Flow Controls

Following construction of the proposed development the flow path of Duchess Gully will be altered to direct low flows from the existing lagoon through the constructed wetland and then into the “middle” reach of Duchess Gully at the north of the site instead of discharging flows to the “overflow” channel. This redirection re-establishes the original flow path of the stream. This flow path is indicated in Figure 7 and Figure 8.

The standing water level in the existing lagoon will be unchanged being maintained by new weir structures at RL 3.4.

The standing water level in the constructed wetland will be maintained at RL 3.0 by a new channel connection to Duchess Gully at the northern end of the constructed wetland.

The locations of these structures are also shown in Figure 7 and Figure 8.

The new flow path will ensure that there is adequate exchange of water in the water bodies and will establish fish migration pathways throughout the length of Duchess Gully. The proposed weir structures will be designed to enhance fish migration. Details of these structures are shown in Figure 28 to Figure 33.

2.8 Major Storm Event Runoff

The Open Space Corridor will also be subjected to occasional severe runoff events which will cause inundation and heightened flow conditions throughout the waterway system of Duchess Gully and the adjacent riparian zone.

These conditions are dealt with in detail in a later section (see Section 4.3).

2.9 Climate Change

Possible impacts on the development arising from climate change are:

- sea level rises
- catchment runoff flow rates
- catchment runoff volumes
- coastal erosion

2.9.1 Sea Level Rise

The critical hydraulic control structures incorporated into the lagoon and wetland systems within the development site are located at levels of RL 3.0 mAHD and above. These devices (weirs) control the water levels upstream of the structures and isolate the water bodies from the influence of sea levels.

The present average sea level is about RL 0.0. Published estimates of sea level rise over the next 90 years as a result of climate change are of the order of 0.6 metres (CSIRO 2007). The same study indicates that storm surges will not increase. An increase in the mean sea level to RL 0.6 mAHD would not materially alter the behaviour of the hydraulic systems in the development site because the higher sea level plus accompanying storm surge would still be well below the control structure levels. In October 2009, the NSW government adopted a policy in relation to sea level rise resulting from climate change (DECCW 2009d). The policy statement establishes sea level rise planning benchmarks of 40 cm (400 mm) by 2050 and 90 cm (900 mm) by 2100 above 1990 mean sea levels.

The inundation study described in a later Section 4.3 shows that sea level increases of this order do not change inundation levels at the site (see Section 4.3.9.2). It was estimated that a 1.0 metre sea level rise could occur without increasing inundation levels at the site. In essence, sea level rise does not affect the St Vincents property.

2.9.2 Catchment Rainfall Runoff Flow Rates

Catchment runoff rates are directly affected by rainfall intensities. Runoff rates will change by about the same percentage as any change in rain intensities. Flood levels in the streams bordering the development are in turn affected by runoff rates.

The risk and hazards associated with increased inundation runoff in conjunction with sea level rise are assessed in detail in Section 4.3.9.4. It was found that adequate inundation immunity for reclamation areas and housing floor levels can be maintained even with projected climate change conditions.

2.9.3 Catchment Runoff Volumes

Catchment runoff volumes could also be affected by climate changes.

Decreasing runoff volumes pose some environmental risk for the development because the Open Space Corridor proposals are based on a series of permanent water bodies. Reduced runoff volumes would reduce the flow through these water bodies and might increase the frequency of the water bodies "drying up".

This effect was evaluated by re-running the water balance model (see Section 2.6.3) with a 10% reduction in the historically-recorded rainfall totals over the period 1957 to 2007. The results in terms of the frequency of various levels of drawdown are shown in Figure 10. The reduction in rainfall does not materially change the water level behaviour in either the existing lagoon or the proposed constructed wetland.

Although there are no firm indications at this time that rainfall totals will actually decrease by 10%, this calculation shows that the proposed water bodies are not sensitive to a reduction of this order.

Conversely, increasing runoff volumes do not affect standing water levels because the water bodies are provided with overflows which rapidly discharge any excess runoff. The standing water levels in the water bodies are strictly limited by these overflows. Increasing runoff volumes could lead to some slight increased accumulation of erosion damage in the water courses and streams in the Open Space Corridor.

The Bureau of Meteorology "trend maps" of rainfall totals from 1970 to the present for New South Wales show a decrease in wet days and heavy rain days. Other published trends show declines in average rainfall totals in several regions of Australia including NSW.

On balance there appears to be a trend towards a decrease in overall rainfall totals.

2.9.4 Coastal Erosion

Increasing sea levels and ocean storm surge along with more severe storm conditions have the potential to increase coastal erosion and coastline recession. This could potentially endanger the stability of the coastal dune system and the stability of the lower reach of Duchess Gully which runs north-south behind the dunes. Any changes to the west bank of this reach of Duchess Gully could in turn threaten the stability of the constructed wetlands outlet control structure (see Figure 28).

A recent study was commissioned to address this issue (SMEC 2010). The study found that the dune system is not overtopped or threatened by increased storm activity under projected climate change conditions or by coastline recession. In that case, the outlet control structure is not threatened either.

2.10 Water Quality

2.10.1 Existing Water Quality Regime

2.10.1.1 Existing Water Body Features

The existing lagoon at the site is comparable in size and depth to the proposed constructed wetlands. This lagoon is shown on Figure 2. It is located on the “upper” reach of Duchess Gully and overflows into the “lower” reach of Duchess Gully via a constructed diversion drain during storm events.

A comparison of relevant features of the existing and proposed waterways is given in the following table.

Table 13 Water Body Features

Feature	Existing Lagoon	Proposed Constructed Wetlands
Surface area (ha)	6.9	10.5
Average water depth m	2.7	2.0
Catchment area (ha)	662	708
Surface area per hectare of catchment (m2/ha)	103	150
Catchment type and land use	Natural terrain with limited development	Natural terrain with urban development
Runoff control	Nil	Engineered stormwater treatment devices
Underlying soil	Sand and clay	Predominantly sand
Salinity range	Fresh	Fresh

It is expected that the water quality of the existing lagoon will be a good indicator to the water quality in the proposed constructed wetlands because of the similarity of the two water bodies in location and configuration.

The main difference between the two water bodies is the fact that the catchment draining to the existing lagoon is largely natural terrain but uncontrolled whereas the catchment draining to the proposed constructed wetlands will include developed residential areas with stormwater treatment devices incorporated in the drainage system.

2.10.1.2 Recorded Water Quality

The following tables show physical and bacteriological water quality in the existing lagoon measured during 2005 and 2007.

Table 14 Recorded Water Quality (PHYSICAL PARAMETERS)

Location	Centre of Existing Lagoon					DATE	29 Sept 2005
						Time	13:00
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	22.0	120.1	6.83	0.44	0.02	200.0	0.165
0.5	21.5	116.7	6.80			211.7	0.164
1.0	21.2	117.7	6.72			222.0	0.165
1.5	19.85	104.0	6.6			261.2	0.165
2.0	18.75	88.8	6.44			287.1	0.165
2.5	17.45	63.5	6.34			310.6	0.165

Location	Centre of Existing Lagoon					DATE	13 Oct 2005
						Time	12:00
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	23.42	128.0	7.00	0.47	0.02	185.8	0.169
0.5	23.44	129.5	7.01			186.0	0.169
1.0	23.42	127.5	7.00			185.1	0.169
1.5	23.36	129.1	6.99			186.8	0.169
2.0	23.20	127.2	6.94			186.5	0.169
2.5	19.72	78.4	6.40			197.2	0.169

Location	Centre of Existing Lagoon					DATE	25 Oct 2005
						Time	15:42
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	25.55	128.5	7.09	0.56	0.03	141.3	0.203
0.5	25.52	128.3	7.10			141.8	0.199
1.0	25.47	128.2	7.08			141.0	0.199
1.5	25.26	127.4	7.07			139.6	0.201
2.0	21.31	88.4	6.50			143.7	0.218
2.5	19.97	74.5	6.49			139.8	0.200

Location	Centre of Existing Lagoon					DATE	17 Nov 2005
						Time	-
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	22.3	121.3	7.18	0.46	0.02	106.1	0.242
0.5	22.3	122.3	7.16			108.1	0.242
1.0	22.3	121.2	7.24			111.1	0.242
1.5	22.3	120.8	7.34			114.0	0.242
2.0	22.3	120.6	7.46			116.4	0.242
2.5	22.3	122.2	7.72			121.1	0.242

Location	Centre of Existing Lagoon					DATE	1 Dec 2005
						Time	-
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	26.6	122.3	7.28	0.41	0.02	99.2	0.27
0.5	26.6	122.0	7.16			100.5	0.27
1.0	26.5	120.9	7.23			101.3	0.27
1.5	26.5	119.7	7.14			104.0	0.27
2.0	24.5	56.6	6.61			116.1	0.263
2.5	22.7	16.6	6.48			121.0	0.259

Location	Centre of Existing Lagoon					DATE	16 Dec 2005
						Time	-
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	26.6	124.2	7.28	0.43	0.01	89.9	0.27
0.5	26.6	122.4	7.26			89.3	0.269
1.0	26.5	120.1	7.20			90.1	0.27
1.5	26.4	116.9	7.05			95.2	0.27
2.0	24.5	43.6	6.64			97.7	0.266
2.5	23.2	17.9	6.63			72.4	0.265

Location	Centre of Existing Lagoon					DATE	17 Feb 2006
						Time	-
Depth m	Temp (deg C)	Dissolved Oxygen (%Sat.)	pH	Total N (mg/L)	Total P (mg/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0				0.62	0.02		
0.5	24.7	74.4	6.96			53.0	0.221
1.0	24.7	81.2	7.07			82.1	0.216
1.5	24.7	70.6	6.91			50.9	0.221
2.0	24.7	72.1	7.40			76.2	0.217
2.5	24.6	45.5	7.01			74.3	0.219

Location	Centre of Existing Lagoon							DATE	3 Aug 2007
								Time	-
Depth m	Temp (deg C)	D.O. (%sat)	pH	TN (mg/L)	TP (mg/L)	Turb idity (NTU)	Chlor 'a' (ug/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	15.0		9.0	0.53	<0.05	15.6	2	68.3	0.125
0.5	15.0		8.2					81.3	0.124
1.0	14.5		8.1					83.9	0.125
1.5	14.5		7.8					89.6	0.126
2.0	14.0		7.6					94.2	0.126
2.5	13.0		7.4					99.0	0.126
3.0	13.0		7.2					102.2	0.131
3.5	13.0		6.9					107.3	0.158

Location	**Centre of Existing Lagoon**							**DATE**	**22 Aug 2007**
								Time	**-**
Depth m	**Temp (deg C)**	**D.O. (%sat)**	**pH**	**TN (mg/L)**	**TP (mg/L)**	**Turb idity (NTU)**	**Chlor 'a' (ug/L)**	**ORP (Oxidation Reduction Potential)**	**Conductivity (mS/cm)**
0.0	15.5		7.8	0.64	<0.05	30.8	2	68.3	0.125
0.5	15.5		7.2					81.3	0.124
1.0	15.5		6.9					83.9	0.125
1.5	15.5		6.8					89.6	0.126
2.0	15.5		6.7					94.2	0.126
2.5	15.0		6.6					99.0	0.126
3.0	15.0		6.6					102.2	0.131
3.5	15.0		6.5					107.3	0.158

Location	**Centre of Existing Lagoon**							**DATE**	**7 Sept 2007**
								Time	**-**
Depth m	**Temp (deg C)**	**D.O. (%Sat)**	**pH**	**TN (mg/L)**	**TP (mg/L)**	**Turb idity (NTU)**	**Chlor 'a' (ug/L)**	**ORP (Oxidation Reduction Potential)**	**Conductivity (mS/cm)**
0.0	17.0		8.6	0.67	<0.05	17.5	4	108.5	0.125
0.5	17.0		8.1					111.2	0.124
1.0	17.0		7.7					117.0	0.125
1.5	17.0		7.6					114.0	0.126
2.0	16.0		7.4					117.0	0.126
2.5	16.0		7.2					119.5	0.126
3.0	16.0		6.9					123.8	0.131
3.5	16.0		6.7					114.7	0.158

Location	Centre of Existing Lagoon							DATE	11 Nov 2007
								Time	-
Depth m	Temp (deg C)	D.O. (%Sat)	pH	TN (mg/L)	TP (mg/L)	Turbidity (NTU)	Chlor 'a' (ug/L)	ORP (Oxidation Reduction Potential)	Conductivity (mS/cm)
0.0	26.0	86	7.7			*		123.0	0.162
0.5	26.0	79	7.2					114.7	0.162
1.0	25.9	77	7.1					114.0	0.162
1.5	24.3	41	6.7					125.6	0.160
2.0	22.5	12	6.3					138.9	0.147
2.5	19.9	7	6.3					113.9	0.130
3.0	18.5	7	6.6					81.0	0.150
3.5	18.4	7	6.6					21.0	0.146
4.0	bottom								

(Note: * Lake water was observed as "brown and murky" at all depths.)

Table 15 Recorded Water Quality (BACTERIOLOGICAL PARAMETERS)

		DATE	31 May 2007
Lab ID	Location		Faecal Coliforms (presumptive cfu/100mL)
H07 2011	A	Existing lagoon (dam)	100
H07 2012	B	Duchess Gully	100

		DATE	14 Jun 2007
Lab ID	Location		Faecal Coliforms (presumptive cfu/100mL)
H07 2202	A	Existing lagoon (Dam)	60
H07 2203	B	Duchess Gully	70

		DATE	21 Jun 2007
Lab ID	Location		Faecal Coliforms (presumptive cfu/100mL)
H07 2325	A	Existing lagoon (Dam)	<10
H07 2324	B	Duchess Gully	60
H07 2323	C	Overflow from Existing Lagoon (Dam)	30

		DATE	28 Jun 2007 (*)
Lab ID	**Location**		**Faecal Coliforms (presumptive cfu/100mL)**
H07 2448	A	Existing lagoon (Dam)	2340 approx.
H07 2447	B	Duchess Gully	120
H07 2446	C	Overflow from Existing Lagoon (Dam)	2100 approx.

(* Rainfall totalling 54 mm was recorded at this time.)

		DATE	5 Jul 2007
Lab ID	**Location**		**Faecal Coliforms (presumptive cfu/100mL)**
H07 2553	A	Existing lagoon (Dam)	10
H07 2552	B	Duchess Gully	30
H07 2551	C	Overflow from Existing Lagoon (Dam)	10

		DATE	19 Jul 2007
Lab ID	**Location**		**Faecal Coliforms (presumptive cfu/100mL)**
H07 2553	A	Existing lagoon (Dam)	20
H07 2552	B	Duchess Gully	10
H07 2551	C	Overflow from Existing Lagoon (Dam)	<10

2.10.1.3 Desirable Water Quality Criteria

Appropriate water quality objectives for the site were adopted from:

- *"Australian Water Quality Guidelines for Fresh and Marine Waters"* (ANZECC 2000)
- *"Hastings Council Aus-Spec Design Specification"* (PMHC AUSPEC 2003)

The ANZECC and AUSPEC category parameters shown in Table 16 are applicable to the site.

Table 16 Water Quality Management Parameters

Ecosystem type	• Freshwater lakes, reservoirs and wetlands • Lowland Rivers
Environmental values	• Aquatic ecosystem viability • Passive recreation use • Potential irrigation use
Ecosystem condition	• Slightly to moderately disturbed systems (ANZECC) • Highly modified Ecosystems (AUSPEC)
Location	• South-east Australia (including NSW)

The water quality objectives from ANZECC and AUSPEC for this range of physical and chemical indicators are summarised in Table 17.

Table 17 Key Indicators and Water Quality Objectives

FRESHWATER LAKES, RESERVOIRS AND WETLANDS

Key Indicator	Water Quality Objective	
	ANZECC	AUSPEC
pH	6.5 to 8.0	6.2 -8.6
Turbidity (ntu)	1 – 20	Ns
SS (mg/L)	ns	Ns
Chlorophyll a (ug/L)	5	Ns
Salinity (mS/cm)	0.02 – 0.03	Ns
Dissolved Oxygen % saturation	90 – 110	80 – 120
Total Nitrogen (mg/L)	0.35	0.44
Total Phosphorus (mg/L)	0.01	0.01
E. coli (cfu/100 mL median value)	<1000	Ns

(ns = not specified)

LOWLAND RIVERS

Key Indicator	Water Quality Objective	
	ANZECC	AUSPEC
pH	6.5 to 8.0	6.2 – 8.6
Turbidity	6 – 50 ntu	Ns
SS (mg/L)	ns	62
Chlorophyll a	5 ug/L (0.005 mg/L)	Ns
Salinity (mS/cm)	0.125 – 2.2	Ns
Dissolved Oxygen (% saturation)	85 – 110	75 – 110
Total Nitrogen (mg/L)	0.5	0.62
Total Phosphorus (mg/L)	0.05	0.06
E. coli (cfu/100 mL median value)	<1000	Ns

These objective values may be used as trigger values which, if exceeded for any significant period, should initiate investigative and possibly remedial actions.

The ANZECC and AUSPEC Guidelines suggests this range of indicators and trigger values as suitable to monitor potential ecosystem impacts in lieu of more specific biological indicators which are significantly more difficult to apply. In particular it is expected that achievement of these performance criteria will avoid adverse effects from other ecosystem factors such as –

- Eutrophication (excess growth of algae and aquatic plants)
- Reduction of photosynthesis and optical clarity
- Reduction in biodiversity
- Excess temperature variation

The ANZECC and AUSPEC Guidelines also discuss the potential impact of specific toxic substances but these are not considered to be relevant to the current proposal which is limited to residential use. Routine monitoring for specific toxins is not recommended.

2.10.1.4 Summary of Existing Water Quality Regime Conditions

In summary, water quality is good. It can be seen that the existing lagoons generally satisfy the desirable water quality objectives to ensure sustainability of an appropriate freshwater coastal ecosystem capable of providing a suitable recreation environment and potential habitat resources.

Conductivity values (indicating the degree of salinity) in the existing lagoon are higher than the objective but are still considered low. For comparison, the ANZECC guidelines suggest a trigger value in the range of 0.125 – 2.2 mS/cm for fresh lowland rivers (in comparison to freshwater lakes and wetlands) with NSW coastal freshwater rivers having typical values of 0.2 – 0.3 mS/cm. In addition, the low salinity limit of 0.02 – 0.03 mS/cm given by the ANZECC Guidelines for freshwater lakes are based on pristine Tasmanian mountain lakes. These conditions are not considered appropriate for the development site. A further comparison may be made to the limit of 1.5 mS/cm recommended for conductivity in water recycling guidelines (NRMMC 2006) levels in order to protect sensitive crops.

Nitrogen levels are also slightly higher than the objective but again are lower than the ANZECC figure of 0.5 mg/L TN recommended for fresh NSW coastal lowland rivers.

The consistent positive high values for oxidation-reduction potential within the existing lagoon are indicative of fully aerobic conditions suitable for aquatic fauna. Dissolved oxygen levels are consistently high, often exceeding 100% in upper levels. This indicates some degree of algal activity.

Recorded conditions in the existing lagoon also show gradual variation with depth. This indicates that the water body is well-mixed and not subject to persistent stratification. This ensures that aerobic conditions are maintained throughout the depth of the water column.

The mixing regime can also indicated by the theoretical Lake Number ($L_{N;}$ Robertson et al 1990). Values of L_N greater than 1.0 indicate stable stratification and values of L_N less than 1.0 indicate increasing degree of vertical mixing due to wind stress. The theoretical Lake Number L_N for the existing lagoon is -6.4, assuming a wind speed of only 10 km/hr and a typical pattern of thermal stratification similar to that recorded in Table 14. This value shows that the existing lagoon will be very well-mixed and is not liable to persistent stratification. This is to be expected given the shallow water depth, the moderate climate and the large surface area exposed to consistent coastal winds.

Bacteriological results also satisfy desirable water quality objectives. Occasional “spikes” of higher bacterial concentration occur apparently associated with wet weather events. These events are to be expected and are unlikely to raise median results above the desirable limit. The results show no impacts from the Sewage Treatment Plant (STP) located further downstream on Duchess Gully.

2.10.2 Proposed Constructed Wetlands Development

The general features of the proposed development are described in Section 2.3.

Construction Phase

The development will involve reclamation earthworks which will be carried out in accordance with comprehensive site management controls specified in an Erosion and Sediment Control Plan complying with Port Macquarie-Hastings Council Aus-Spec Specification’s requirements forming part of the development application. This ensures that sediment runoff from the construction site is controlled to a minimum. The proposed Erosion and Sediment Control Plan is included as Appendix D.

Treatment of any disturbed potential acid sulfate will be in accordance with an Acid Sulfate Soils Management Plan specific to this site (see Appendix A) which will ensure that any runoff from the works areas and any future leachate will be neutral in terms of the adopted water quality criteria listed in the table below.

Areas affected by earthworks activities, including watercourses and riparian corridors will be comprehensively rehabilitated and planted in accordance with the Open Space Corridor Environmental Land Use Management Plan (including vegetation management) complying with Council’s requirements which is shown in Figure 20.

The proposed constructed wetlands will be rehabilitated and planted in accordance with a comprehensive Aquatic Rehabilitation Plan which is shown in Figure 21.

Operational Phase – Residential Use Areas

After development, storm runoff from the residential areas will be treated using a treatment “train” including grassed swales, bio-infiltration areas and end-of-line bioinfiltration and wetland areas to ensure satisfactory water quality prior to discharge to the constructed wetlands flow-through zone. These features are indicated on Figure 23. The stormwater treatment trains have been sized in accordance with Port Macquarie-Hastings Council’s WSUD design guidelines (see Section 3.4).

The main through flow areas of the constructed wetlands will have a water depth of 2.0 metres corresponding to the difference between the permanent standing water level of RL 3.0 mAHD and the average bed level of RL 1.0 mAHD (see Figure 13). The depth varies between 1.25 metres at the western limit to 2.75 metres deep at the northern end of the constructed wetlands.

Catchment Runoff Flow Paths

As part of the development program, flows in the “upper” reach of Duchess Gully will be diverted through the flow zone of the constructed wetlands by means of a new control weir located between the two water bodies (see S2 in Figure 23).

It is expected that the “middle” reaches of Duchess Gully will benefit from this redirection of base flows which re-establishes the original flow path of the watercourse.

During major rainfall events, at higher water levels, part of the total runoff flow will still overflow direct to Duchess Gully via the "overflow" downstream of the existing lagoons (S3).

2.10.3 Expected Water Quality Conditions for the Constructed Wetlands

2.10.3.1 Methodology

As stated in Section 2.10.1.1, it is expected that the water quality in the proposed constructed wetlands flow through zone will be similar to the high standard water quality of the existing lagoon.

This was confirmed by –

- (A) A comparison of the hydraulic detention (or "residence") times in the water bodies before and after development. Hydraulic detention time is the most important parameter influencing the settling and removal of sediment and nutrients and therefore the clarity and water quality of water in the wetlands and in overflows out of the wetlands (ACT 2006).
- (B) Demonstrating that the constructed wetlands are similar in hydraulic characteristics and mixing regime to the existing lagoon.
- (C) POND modelling.
- (D) Comparison with recorded data from Gold Coast water bodies.

2.10.3.2 (A) Catchment Runoff Volumes and Detention Times

The detention times for the existing lagoon and for the development condition including the constructed wetlands in the flow path are shown in Table 18.

Annual runoff depths were calculated using the USDA catchment model and local climate data and allowing for changes in catchment runoff characteristics caused by the proposed urbanisation of parts of the catchment (Cardno 2001).

Estimated sediment and nutrient removal rates are based on PRSC (2005), Figure 3.6.19, Section 3, Part 2 Stormwater Drainage).

Table 18 Wetlands Hydraulic Detention Times

	Existing Lagoon		Constructed Wetlands
Parameter	**Existing Conditions**	**Developed Conditions**	**Developed Conditions**
Total Catchment Area (ha)	662	662	708
Effective Catchment Area with overflow diversions (Sect. 2.6.3.3) (ha)	662	662	354
Average annual runoff (mm)	237	240	240
Water volume (ML)	132	132	165
Detention (residence) time (days)	31	30	61
Surface area (m^2)	63,000	63,000	105,000
	Existing Lagoon		**Constructed Wetlands**
Parameter	**Existing Conditions**	**Developed Conditions**	**Developed Conditions**
Surface area per hectare effective catchment (m^2/ha)	95	95	297
Sediment removal rate (%)	77%	77%	85%
TP (phosphorous) removal rate (%)	54%	54%	63%

2.10.3.3 (B) Water Quality Regime in the Constructed Wetlands

The comparisons above show that the water quality of the constructed wetlands (and of overflows discharging into Duchess Gully) will be at least as good as the existing lagoons or better. Water quality is expected to exceed the desirable criteria given in Section 2.10.1.3. The constructed wetlands flow zone will provide valuable additional treatment of stormwater runoff.

2.10.3.4 (C) CRC-FE POND Modelling

Methodology

The CRC-FE Pond model, developed by the Cooperative Research Centre for Freshwater Ecology, is a model for simulating the pollutant interception processes and water quality responses of ponds. The model computations are based on a daily time step for inflows, discharges, internal mixing, transformations and transfers. The POND model allows for the simulation of sediment and nutrient movement and interaction in typical shallow water bodies. POND simulates the oxygen uptake of BOD in the water column and the settling and remobilisation of bed sediments. The model also simulates the growth of algal population in the water body.

The CRC-FE has also produced a wetland model for modelling the performance of vegetated water bodies. The existing lagoon (E2 plus E3) and the constructed wetland (W1) are large water bodies with only partial vegetation and hence are suitably represented by the POND model.

Water Body Configuration for POND

A relatively small weir length of 15m was chosen for each water body. However, it can be noted that trials with a range of weir lengths determined that the results were relatively insensitive to the selected weir width. This was most likely due to small catchment area and small runoff events generated over the period of simulation.

Measured water quality parameters as presented in Table 14 were used to represent the initial conditions with the water bodies. Default parameters were used where no measured data was available.

Climatic Input

Measured seasonal meteorological parameters were taken from the Bureau of Meteorology monthly climate statistics for Australian Locations. The site location was Bellevue Gardens, Port Macquarie (Latitude 31.44° South, Longitude 152.91° East) were used to represent the meteorological conditions for the site. Default parameters were used where no measured data was available. Parameters used in the model are presented in Table 19.

Table 19 POND Model Meteorological Parameters

Season	Mean air temp oC	Mean wind speed m/s	Solar heat flux W/m^2
Summer (Dec-Feb)	25.43	2.91	270.06
Autumn (Mar - May)	22.93	2.65	183.64
Winter (Jun-Aug)	18.40	2.59	129.24
Spring (Sep - Nov)	21.80	3.30	221.84

Catchment Runoff Inputs – Sediment and Nutrients

The daily volumes and daily mean concentrations of Suspended Solids, Total Nitrogen and Total Phosphorus entering each water body from the catchment draining to the modelled water bodies for existing and proposed stages of development were taken from the MUSIC model of the contributing catchments described in Section 3.4. The MUSIC model was extended for this purpose to represent all the existing parts of the catchments over and above those areas to be developed as residential, commercial and associated land uses under the proposals.

POND Modelling Scenarios

The following scenarios were modelled:

- Existing Lagoon Conditions
- Existing Lagoon Conditions after Proposed Development
- Constructed Wetlands Conditions after Proposed Development

Results for POND Modelling

The results of the POND modelling in terms of the median concentration of principal water quality determinants over the eleven year simulation period are shown in Table 20.

Table 20 POND Model Results - Water Quality Indicators – Median Concentrations

Scenario	TSS (mg/L)	TN (mg/L)	TP (mg/L)	DO Sat. (%)	Algae (µg/L)
Existing Lagoon	2.8	0.56	0.025	79%	4
Existing Lagoon after Development	2.3	0.57	0.025	80%	4
Constructed Wetland after Development	0.25	0.4	0.007	84%	4

The response of the water bodies to varying conditions over the period of the simulation is shown plotted in Figure 11 and Figure 12.

These results show that:

- The POND model reproduces the behaviour of the existing lagoon reasonably well and confirms that water quality in the lagoon is good.
- After development, the existing lagoon and the constructed wetland should continue to maintain similar levels of good water quality conditions.
- There will be occasional episodes of disturbed water quality associated with some storm runoff events but these episodes are expected to be temporary with water bodies returning to conditions of good water quality.

2.10.3.5 (D) Comparison of Predicted Water Quality with Existing Gold Coast Lakes

The predictions by the MUSIC and POND models of the proposed final lakes may be compared with water quality data recorded over a number of years in other similar lakes within the Gold Coast City area.

The results of regular water quality measurements in a number of existing lakes are available in the 2002 report "Health of the Gold Coast Waterways" (GCCC 2002). Water quality is rated in terms of the ANZECC standard (ANZECC 1992).

These results are summarised in Table 21.

Table 21 Water Quality Summary - Existing Gold Coast Lakes

Lake	Approx. Size (ha)	Depth (m)	Catchment (km2)	Catchm Elev'n	Land Use		Ex-Change	Water quality; vegetation; algal blooms
					Upper	Lower		
Clear Island Waters	105	7	120	High	RR	U	No; fresh	Good WQ; significant vegetation; some blooms
Coombabah Lake	150	0.5	~100	High	U	U	Yes; saline	High nutrients; some blooms; good WQ
Royal Palm Lake	<5	4	<0.5	Low	U	U	Yes; saline	Good WQ
Runaway Bay Lake	<5	4	<0.25	Low	U	U	Yes; brackish	Good WQ
Lake Rosser	<5	4	<0.25	Low	U	U	Yes; saline	High E.coli; good WQ
Lake Hugh Muntz	20	8	<1.0	Low	U	U	No; fresh	High TP; good WQ
Pizzey Park Lake	<5	7	<1.0	Low	U	U	Yes; brackish	High TN; good WQ
Silvabank Lake	25	7	~4	Low	U	U	Yes; brackish	High E.coli; good WQ
Heron Lake	25	7	~1.5	Low	U	U	Yes; brackish	Some turbidity; good WQ
Burleigh Lake	40	7	~1.5	Low	U	U	Yes; brackish	Good WQ
Swan Lake	20	7	~1.2	Low	U	U	Yes; brackish	Some TN, TP, E.coli; good WQ
Cyclades lake	<5	7	<0.25	Low	U	U	Yes; saline	Good WQ
Lake Murtha	~20	7	~1.2	Low	U	U	Yes; saline	Some TP, E.coli; good WQ
19th Ave Lake	~20	7	~1.2	Low	U	U	Yes; saline	Some TN, TP, E.coli; good WQ
Pelican lake	~20	7	~1.2	Low	U	U	Yes; brackish	Good WQ

These results indicate:

- All the existing lakes show consistently good water quality in terms of the ANZECC criteria.
- Some lakes occasionally showed poorer conditions ranging from turbidity to excessive plant growth and algal blooms though none of these detracted significantly from the overall quality of the water bodies. There were some instances of measured elevated levels of nutrients and bacteria.
- The main factors influencing water quality appear to be :
  - Catchment size relative to the lake size. Lakes with large catchments are more likely to experience runoff causing poorer conditions.
  - Catchment elevation; episodes of poorer water quality occurred more often in catchments with elevated areas. This is probably related to the greater erosive power of runoff in these catchments with greater volumes of pollutants entering the lakes as a result.
- Water quality does not appear to be influenced greatly by whether or not the lake has any natural or mechanical exchange mechanism and some salinity or brackishness as a result. Both saline/brackish and freshwater lakes show good water quality provided their catchment is relatively small and low-lying. The lack of exchange appears to result in some measured elevated levels of nutrients but these have not been sufficient to result in algal blooms.
- The lake size and depth do not appear to influence water quality.

It can be concluded that the POND modelling is supported by the recorded data from existing lakes.

These two analyses indicate that the proposed final rehabilitated lakes should experience very good water quality with little likelihood of algal blooms or significant disturbance during runoff events.

The efficiency of the lake as a settling basin combined with the proposed development of a mature natural aquatic ecosystem within the littoral zone of the lake will ensure that nutrient levels in the water column remain low into the future. The lake will therefore remain oligotrophic and will not develop excessive vegetation indicative of eutrophication.

2.10.4 Circulation and Stratification in Water Bodies

The theoretical Lake Number L_N (Robertson et al 1990) for the constructed wetlands is -2.5 indicating that the wetlands will also be very well-mixed. This is to be expected since the constructed wetlands also have a shallow water depth and a large surface area exposed to consistent coastal winds.

The proposed constructed wetlands will have an average depth of about two metres.

It is expected that circulation within the water bodies will be good because of their relatively shallow depth in relation to their area, their compact shape and their exposure to prevailing coastal winds.

It is unlikely that anaerobic conditions will develop in the deeper parts of the lakes because the lakes will have low levels of nutrients and are expected to remain oligotrophic without excessive vegetation growth.

2.10.5 Stratification in Existing Gold Coast Lakes

A good indication of the likelihood of stratification occurring may be obtained from data recorded over a number of years in other similar lakes within the Gold Coast City area.

The results of regular water quality measurements over the vertical depth profile in a number of existing lakes was obtained from the Gold Coast City Council Catchment Management Section (GCCC 2007).

A number of physical parameters including conductivity, dissolved oxygen, pH and temperature were measured at close vertical intervals to depths of up to 7 metres at least several times per year and as frequently as monthly in the following lakes:

- Clear Island Waters
- Lake Hugh Muntz
- Royal Palms Lake
- Pizzey Park Lake
- Robina Lakes
- Burleigh Lakes
- Cyclades Lake

The recorded data show the following trends:

- Vertical profiles show no stratification in the form of thermo-clines (distinct boundary marked by temperature drop) or iso-clines (marked change in salinity) irrespective of the season, the average temperature or the average salinity.
- The range of lakes measured show that the lack of stratification is not influenced by the lake size, the catchment size or the brackishness of the lake. Uniform conditions occur over the vertical profile whether the lake is fresh or saline overall.
- Clear Island Waters and Burleigh Lakes show some instances of low DO near the bed but the profile otherwise indicates that conditions are well-mixed vertically.
- Clear Island Waters shows some increase in conductivity with depth on some occasions.
- The measured lakes show well-mixed conditions to depths of up to 8 metres.

The Gold Coast City Council data indicate that the proposed constructed wetlands should be well-mixed with little vertical stratification throughout the year because the proposed water bodies are comparable to the Gold Coast lakes having:

- Similar depths or shallower;
- Similar areas;
- Similar prevailing winds from a coastal location;
- Zero salinity.

It is expected that the constructed wetland will remain well-mixed vertically and free of stratification because the wetland will be fresh with no salinity exchange so that there is no tendency for denser saline water to limit vertical mixing.

2.10.6 Summary of Surface Water Impacts

- The surface water quality in existing lagoons at the site has been shown to be of a high standard and it is expected that the water quality in the proposed constructed wetlands flow zone will be similarly of a high standard.
- Re-direction of overflows from the existing lagoons in the “upper” reaches of Duchess Gully into the proposed constructed wetlands will re-establish the original flow path and is expected to improve conditions in the “middle” reaches of Duchess Gully.
- The constructed wetlands are expected to establish and maintain an attractive mature freshwater coastal aquatic ecosystem in the long term.

2.10.7 Surface Water Management

2.10.7.1 Operational Management Procedures

There are no specific recommended surface water management procedures to be followed in the long-term operation of the wetlands except for regular monitoring as set out in Section 2.10.7.2 and Appendix C (Surface Water Monitoring Plan).

Occasional desilting of the deep inlet basins of the treatment zones may be required.

Recreation and visitor park areas surrounding the wetlands should be maintained in accordance with normal Council practice.

2.10.7.2 Surface Water Monitoring

It is proposed that surface water conditions be monitored on a regular basis in each water body within the creek and wetlands system.

Monitoring should include physical and chemical constituent testing as set out in Appendix C (Surface Water Monitoring Plan).

2.10.7.3 Construction Management

Monitoring of surface water conditions will also be carried out during the construction phase of the development (see Section 6.6).

2.11 Groundwater Systems

Note: This study was completed in 2006 prior to additional data collection and groundwater modelling by the University of New South Wales Water Research Laboratory (WRL 2010). The findings described in this section of the document are generally in agreement with these later more detailed WRL investigations.

2.11.1 Existing Site Features

Subsurface information is available from the geotechnical investigations listed in Section 4.8.1. The bore logs show that the proposed constructed wetland area consists of sedimentary material ranging from clay to sands originally derived from both riverine sources (surface runoff) and marine sources (material deposited by the action of coastal dune movements).

Surface features of the site are described in Section 1.4.2 and illustrated in Figure 2.

2.11.2 Potential Development Impacts on Groundwater Systems

Potential impacts on groundwater systems which have been raised in the DGR documents and which are investigated in this section of the report include:

- Groundwater resources
- Construction phase excavation dewatering water table drawdown
- Exposure of acid sulfate soil

- Maintenance of frog habitat
- Seepage losses from constructed wetland water body
- Dispersion of STP effluent

2.11.3 Subsurface Stratigraphy

An examination of the borehole data reveals the following subsurface conditions –

- Sediments in the low-lying areas form coherent layers of relatively homogeneous material which are characteristic of their alluvial origin (riverine and marine respectively).
- Layers are generally several metres deep.
- Riverine material from land catchments is generally clay derived from the weathering of underlying serpentine rock. This material is evident in boreholes from the hillier parts of the site where several holes terminate in either dense clays or weathered rock. In western parts of the site (that is, the western tributary of Duchess Gully), clay material occurs over the whole depth of the sedimentary column. In central parts of the site these riverine clays overlie coastal sand strata. The limit of the extrusion of riverine clays over the coastal sands is indicated on Figure 16 by the dashed line marked "limit of riverine clay". A typical cross section is shown in Section – 1.
- Marine material in the form of fine to medium sand is evident in upper strata over the eastern parts of the site and is probably the result of recent coastal dune movement. At the coastline this sand occurs from the surface to considerable depth in the form of coastal dunes which may in places be indurated to form "coffee rock". In central parts of the floodplain the coastal sands intrude under the riverine clay resulting in two distinct deep strata in these areas. The limit of intrusion of coastal sands beneath the clay upper layer is indicated on Figure 16 by the dashed line marked "limit of lower marine sand".
- Older marine sediments are also found at depth in eastern parts of the site in the form of dark, sandy marine clays. This deeper marine clay stratum extends inland only to the extent indicated on Figure 16 by the dashed line marked "limit of deep marine clay". These deeper marine clays may contain significant potential acid sulfate material (PASS) whereas the upper strata show only very low levels of PASS not requiring treatment.
- Sediments are deepest in the low-lying areas. In the higher ridge areas in western and northern parts of the site, the strata consist only of shallow clays derived from weathered rock.

2.11.4 Recorded Groundwater Levels

2.11.4.1 Site Data

Groundwater levels have been recorded on various dates between 1993 and 2003 at the sites of the investigative boreholes listed in Table 59 (see Section 4.8.1).

Groundwater levels within the site are summarised in Holmes & Holmes (2003a) as follows:

Table 22 Recorded Groundwater Levels

Date	Range of Groundwater Levels mAHD
1993	RL 3.5 – RL 4.0
Dec 2002	RL 3.2 – RL 3.7
Jan 2003	RL 3.3 – RL 3.7
Mar 2003	RL 4.0 – RL 4.7

Other observations derived from bore logs are –

- Seasonal variation appears to be of the order of 0.5m to 1.0m.
- Levels are relatively uniform over the site; there is some evidence of a slight gradient from the west along the line of the “upper” reaches of Duchess Gully but this is not pronounced and is only evident in higher seasonal levels.

2.11.4.2 STP Exfiltration Data

There are also records of groundwater levels in the frontal dune system on the ocean (eastern) side of “lower” Duchess Gully which are reported in ERM (2001) and AWACS (1996).

These levels are influenced by the exfiltration groundwater recharge system associated with the STP (Sewerage Treatment Plant). This system injects up to 1 ML of effluent per day into the dune system via a series of ponds and an extended buried pipeline distributor (see Figure 16).

Groundwater levels within the exfiltration system zone vary between RL 3.0 and RL 6.0.

2.11.5 Existing Groundwater Regime

The terrain, the stratigraphy and recorded groundwater levels indicate that significant groundwater reserves occur within the sediments in low-lying areas, particularly in the marine sands located within the eastern parts of the system.

It is expected that the groundwater will be fresh with little saline intrusion from the ocean except perhaps within the channel of the “lower” reaches of Duchess Gully.

Groundwater levels are maintained by rainfall recharge. Subsurface inflow (as distinct from surface drainage) from the western catchments into the low-lying sediments within the site is expected to be small because sediments in the "upper" reaches of Duchess Gully are entirely low-permeability clays. Subsurface inflow from the other surrounding elevated areas to the west and north may also be small because soils in these areas are also clays.

There will be significant inflow to the coastal dunes east of "lower" Duchess Gully from the STP exfiltration system but this is likely to be contained within the dune zone by the Duchess Gully drainage feature and is not likely to affect the development site.

2.11.6 Development Proposal and Impacts

The development proposals involve filling some parts of future residential areas of the site to raise the surface levels above inundation level. These residential areas are shown in Figure 4. The required fill material will be obtained by excavation of the proposed constructed wetlands zone.

The potential groundwater impacts resulting from the construction and on-going operation of the constructed wetlands which need to be addressed in this study can be summarised as follows –

- Long-term effects on water table levels (and available groundwater resource volumes).
- Long-term changes in groundwater flow patterns.
- Changes in surface base flows and flow patterns from groundwater interaction.
- Potential impacts on flora and fauna resulting from these groundwater changes.
- Changes in the performance of the adjoining wastewater treatment plant exfiltration system.
- Potential salinity and contaminant intrusions into groundwater systems within the site.
- Temporary drawdown impacts during the construction phase.

Change to the groundwater regime as a result of settlement beneath fill areas is not considered a significant issue because geotechnical surveys (Holmes & Holmes 1993) show that soils on the site are not likely to settle under the fill depths proposed.

2.11.7 Methodology for Modelling Impacts

2.11.7.1 Model Platform

The groundwater system of the floodplain sediments was modelled mathematically using the standard MODFLOW groundwater modelling system. This computer package simulates the groundwater system as a series of adjoining cells arranged in a rectangular grid. The grid can simulate a series of horizontal soil layers of varying thickness and characteristics. Groundwater flows, levels and storages are modelled across a finite-size grid of limited area with remote influences simulated by setting boundary conditions (usually the water levels) along the edges of the grid and at selected cells within the grid.

2.11.7.2 Model Configuration

The MODFLOW model used for this study is 180 cells wide by 160 cells high, each cell being 10 metres square, giving the model an active area of approximately 196 hectares. The layout of the model and the configuration of the model boundaries are shown in Figure 16.

The area represented extends over the zone of sand sediments of the low-lying areas of Duchess Gully including the coastal dunes.

2.11.7.3 Model Boundary Conditions

The south and west boundaries are defined as “no-flow” boundaries across which there are expected to be no horizontal groundwater flows.

At the southern boundary this applies because the boundary is transverse to the dune ridges and the terrain has an approximately zero gradient in the north-south direction. In addition, the STP exfiltration pipeline has an approximately zero gradient across this boundary.

At the western edge the boundary is also approximately transverse to the western tributary terrain ridge and valley lines which are here nearly level. Also, as noted in Section 2.11.5, groundwater flows in the sediment across this boundary will be small because of the low permeability of the clay soils.

The north boundary was set to correspond to the terrain catchment ridge line which was assumed to correspond also to the groundwater divide. Cells beyond this line are set “inactive”.

The eastern boundary coincides with the ocean shoreline where outflows are expected and the boundary condition is therefore set to a constant piezometric head of RL 0.0 mAHD, equal to the average tide level or Mean Sea Level (MSL).

In addition to these edge boundary conditions, internal boundary conditions are specified in the form of surface overflow “drains” which allow outflow from the groundwater system at low points in the terrain and at levels corresponding to the overflow crest levels controlling the standing water levels in lagoons and other water bodies. Only outflows can occur at “drains”. It is assumed that all outflows at drains are collected in surface channels and do not re-enter the groundwater system.

Internal boundary conditions are also set within the STP exfiltration system by specifying a constant water level (i.e. a fixed piezometric level) at cell locations corresponding to the exfiltration ponds and exfiltration pipeline.

2.11.7.4 Scenarios for Modelling Development Impacts

The MODFLOW model was run to solve for “steady-state” conditions; that is, for constant flow conditions representing average persistent conditions. This was accepted as appropriate for the comparative studies required in evaluating the impacts of the proposed constructed wetlands. There may be some seasonal variation in rainfall recharge which will cause a variation in the predicted groundwater levels but this is not expected to alter the general trend of potential impacts. This approach is also appropriate for this site where seasonal rainfall variations are moderate.

Three scenarios were examined, namely –

- Existing Conditions
- Constructed Wetlands Conditions
- Excavation "Mid Construction" Conditions

The "Existing Conditions" case is used to establish a realistic model of the current groundwater regime as a basis for comparison with conditions after the proposed development.

The "Constructed Wetlands" case represents the long-term average groundwater conditions resulting from the permanent constructed wetlands water body of some 10.5 hectares with a controlled constant water level of RL 3.0 mAHD.

The "Excavation Mid Construction" case simulates the maximum short-term effect on groundwater conditions during the construction phase by calculating conditions during excavation and dewatering of the southernmost stage of the constructed wetlands.

2.11.8 "Existing Conditions" Groundwater Model

2.11.8.1 Model Configuration and Soil Conditions

The general extent of the model is described in Section 2.11.7.2.

The low-lying area sediments were represented as two continuous layers one above the other extending over the model area. This was done so as to represent the marked vertical changes in soil type between riverine clay and marine sands within the upper soil strata in the central areas of the site. Towards the eastern and western edges of the model the soil type does not vary vertically but the two layers were retained for convenience.

Layer 1 (the upper layer) and Layer 2 (the lower layer) both vary in thickness from as little as 0.5 metres in hilly areas to as much as five metres in the areas of deeper alluvium in the eastern parts of the site.

The soil layers and the layers in the mathematical model are illustrated in a typical cross-section shown in Figure 16.

The transition to dark marine clays in the eastern areas of the model was taken as the effective bottom boundary of the model since these soils have very low permeability and are unlikely to provide an effective groundwater flow path. That is, these materials were excluded from the mathematical model and inactive.

Hydraulic conductivities for materials within the coastal dune system are reported in AWACS (1996) as follows –

Table 23 Reported Soil Hydraulic Conductivities

Material Type	Hydraulic Conductivity "K" (m/day)
Clayey sands	0.01
Fine sands	0.8 – 2.8
Fine to medium sands	2.5 – 29

The values adopted for the present study (based on Table 23 and CGS 1999) are shown in the following table –

Table 24 Adopted Conductivities for Model

Material Type	Hydraulic Conductivity "K" m/day	
	Horizontal	Vertical
Clay	0.1	0.1
Sand	5.0	1.0

2.11.8.2 Boundary Conditions & Inflows

The boundary conditions adopted are generally described in Section 2.11.7.3.

Groundwater levels are generally controlled by –

- The fixed ocean level;
- The overflow levels set for the "drains". (These correspond to the terrain surface levels or to standing water levels in the existing water bodies. For the existing lagoons, this level is RL 3.4. For the "lower" reaches of Duchess Gully, this level was assumed to be RL 1.5 mAHD which is the level of the controlling sand bar at the mouth of the creek); and
- The hydraulic gradients required to convey the rainfall recharge to drainage points.

The inflows to the model consist of –

- Exfiltration into the coastal dune system from the STP
- Rainfall recharge to groundwater over the entire model area

Exfiltration inflows are calculated by the model based on the constant head level set for the cells located at the effluent ponds and the pipeline. This was assumed to be RL 4.5 m AHD (the average of the reported groundwater level range of RL 3.0 to RL 6.0).

The average annual rainfall for Bonny Hills is 1440 mm/year and the annual average evaporation is 1361 mm/year (SILO 2001). Rainfall is well-distributed throughout the year.

Based on catchment analyses for other similar catchments, a recharge rate to groundwater of 365 mm/year (or 0.001 m/day) was adopted for the present model. This equates to 24% of the rainfall.

2.11.8.3 Calibration Results – "Existing" Groundwater Levels & Flow Patterns

The "Existing Conditions" Model was solved for steady-state conditions using the adopted parameter values described in Section 2.11.8.2.

The calculated "steady-state" conditions are illustrated in Figure 17 which shows that -

- Groundwater levels within the low-lying areas (see "GROUNDWATER LEVELS" diagram) agree reasonably with recorded levels described in Section 2.11.4.1. Agreement could be improved by adjusting soil permeabilities and recharge rates but the agreement obtained was considered adequate for comparative studies.

- The calculated average groundwater levels adjacent to the existing lagoon in the marshy area of a known frog habitat are at least a metre below surface level at this location. This is well below the base of the marshy habitat. Since this area is known to retain standing water most of the time, it was concluded that the habitat is a perched water body isolated from the underlying aquifer by impermeable material.
- Drainage outflow zones are illustrated in the diagram “DRAINAGE OUTFLOW ZONES”. Outflows occur to low points of the site including the main drain lines, depressions and into the existing lagoon and Duchess Gully. Outflow is also shown discharging along the ocean shoreline as expected.
- Drainage outflow zones are also predicted across the hilly areas in western parts of the model. These areas correspond to steep terrain with clay soils. The results indicate that surface seepage is likely to occur in these areas during wet weather which agrees with site observations.
- Net groundwater outflows from the various subcatchments of interest are shown in the diagram “FLOW PATHS”. Groundwater generally drains into Duchess Gully but there is significant outflow to the ocean. The flow in the “lower” reach of Duchess Gully is significantly augmented by seepage from the STP exfiltration system.

- The net inflow from the STP exfiltration system totals 660 m3/day or 0.66 Ml per day. This compares well with the estimate of 1 Ml per day (from ERM 2001) given in Section 2.11.4.2 for the whole exfiltration system, since only part of the exfiltration pipeline is represented within the model limits. The behaviour of the exfiltration system is adequately represented by assigning constant head values to model cells in this area.

2.11.9 “Constructed Wetlands” Groundwater Model

2.11.9.1 Amending the Model Configuration for Constructed wetlands Conditions

The constructed wetlands were represented by amending the “Existing Conditions” model by –

- Adjusting the surface “drain” overflow levels within the area of the constructed wetland to RL 3.0 mAHD which is the proposed permanent standing water level.
- Increasing the horizontal permeability of cells in Layer 1 within the constructed wetland area to a high value. This represents the free flow of water within the open water body which corresponds approximately in depth to the excavated depth of the water body.

The model was again run for “steady-state” conditions.

2.11.9.2 Results – “Constructed Wetlands” Development Impacts

The calculated “steady-state” conditions are illustrated in Figure 18.

- The predicted groundwater levels are plotted in the diagram “GROUNDWATER LEVELS”.

- Groundwater levels are reduced in some areas near the constructed wetlands. Drawdown effects (that is, lowering of the water table) are limited and localised to near the constructed wetlands as illustrated in the diagram “DRAWDOWN”. The amount of drawdown is governed mainly by the water level adopted for the constructed wetlands. The maximum drawdown is 2.1 metres which only occurs at the south-west corner of the constructed wetlands where the constructed wetland encroaches on the hill slope. The extent of drawdown in this area is limited by the clay nature of the soils in the upper strata. Drawdown extends further beyond the constructed wetland around the northern edges of the constructed wetlands because the upper strata material in these areas is sand.
- Adjoining areas are not affected except for some drawdown between the constructed wetlands and the existing lagoon. The drawdown in this area is close to the eastern edge of a known froglet breeding habitat. However, it is concluded elsewhere (see Section 2.11.8.3 and Section 4.3.8.8) that water levels and moisture in the depression forming this habitat are mainly dependent on local runoff and the habitat is isolated from the groundwater system by a surface layer of clay. As a result the habitat breeding functionality will not be affected by the groundwater drawdown.
- There is little change in the groundwater levels at the northern boundary of the model corresponding to the catchment divide. This indicates that the position of the groundwater divide does not change and the assumed boundary condition still applies.
- A more recent assessment of the groundwater system (WRL 2010) came to similar conclusions regarding drawdown although the estimates of the amount of drawdown are somewhat less in that assessment than in the study reported here.
- The drawdown in groundwater levels does not expose high-PASS material to potential oxidation. This material remains well below the water table. There are very low levels of PASS material in the upper layers along the north-west edge of the constructed wetlands where drawdown of the order of 0.5 metres or less is expected. Oxidation of this material does not pose any risk to ecosystems or water quality because the PASS concentrations are so low that soil treatment is not required under the acid sulfate soil management guidelines (ASSMAC 1998). Soils in this category can be dewatered and excavated without restriction.
- Net groundwater outflows from the various subcatchments are not significantly affected (see the diagram “FLOW PATHS”). There is some diversion of flow from the “upper” reaches of Duchess Gully into the constructed wetland; that is, the lower water level in the constructed wetland tends to “capture” more of the groundwater drainage. This diverted flow enters the “middle” reaches of Duchess Gully further upstream as a result, which re-establishes the original flow path before the lagoon overflow was constructed bypassing flows direct to the lower reach of Duchess Gully.
- The construction of the constructed wetland does not affect the operation of the STP exfiltration system where flows are not changed.

Overall, it was concluded that there are no significant adverse groundwater effects caused by the constructed wetlands. There are expected to be ecological benefits from the diversion of base flows back into the original flow path through the “middle” reaches of Duchess Gully.

2.11.9.3 Impact on Groundwater Resource Volumes

The drawdown of groundwater levels in soil strata surrounding the constructed wetlands represents some loss of available groundwater reserves. The loss of volume was calculated and amounts to only 7.2% of the total groundwater reserves within the site.

This loss is more than offset by the increase in available freshwater reserves represented by the conversion of the constructed wetland area from saturated soils to open water. This increase in water volume amounts to 44% of the original groundwater reserves.

This minor change in groundwater resource volumes does not have any immediate impacts on potential groundwater users. These changes do not affect any future planned uses of groundwater since Port Macquarie Hastings Council "has previously reviewed and discarded the potential for coastal aquifers within the LGA as a source of potable water" (PMHC 2009).

2.11.10 "Mid Construction" Groundwater Model

2.11.10.1 Amending the Model Configuration for Excavated Conditions

The "Existing Conditions" model was then amended to represent the most severe drawdown conditions which will occur for a limited period during constructed wetlands construction.

The constructed wetlands will be constructed "in the dry" by reducing the water table locally to allow excavation of the constructed wetlands using standard machinery. The excavation will be done in stages to limit the drawdown occurring at any time. Excavated stages will then be flooded to RL 3.0 mAHD to restore the water table and prevent exposure of PASS materials to oxidation.

Assuming that the excavation will be done in several stages, the final stage was simulated on the groundwater model. This stage assumes that the northern portion of the constructed wetlands is complete and allowed to fill. The remaining southernmost portion of the constructed wetlands is then dewatered and excavated to the bed level of RL 1.0 mAHD. This is the maximum drawdown condition because groundwater levels will be drawn down over most of the constructed wetlands and dewatering will be occurring adjacent to the highest ground at the south-west corner of the constructed wetland and the area closest to the adjoining existing lagoon.

The excavated areas were again represented by –

- Adjusting the surface "drain" overflow levels within the area of the completed constructed wetland to RL 3.0 mAHD and within the excavated area to the excavation bed level of RL 1.0mAHD.
- Increasing the horizontal permeability of cells in Layers 1 and 2 within the constructed wetland area and the excavation stage to a high value. This represents the free flow of water within the open water body and excavated areas.

2.11.10.2 Results – "Mid Construction" Impacts

The calculated "steady-state" conditions for this case are illustrated in Figure 19.

- The diagram "GROUNDWATER LEVELS" shows the predicted levels.
- The water table drawdown is increased but still relatively localised to near the excavated area.

- There are likely to be significant seepage flows into the excavation from the two adjacent water bodies (the existing lagoon to the south-west and the part-completed constructed wetlands to the north) through the separating bunds which will increase the dewatering pump rate.
- The diagram labelled “FLOW PATHS” indicates that the diversion of base flow into the “middle” reaches of Duchess Gully system is increased slightly but, since part of this flow represents the dewatering of the excavation, the actual diversion will depend on the discharge point for the dewatering operation.
- There are no groundwater cross-flows between the STP exfiltration area and the development site.

Overall, there are no significant adverse groundwater effects during the dewatering operation as a result of the construction.

2.11.11 Sensitivity to Parameter Values and Model Configuration

Predicted groundwater levels will vary depending on the values adopted for the controlling parameters in the model, principally soil hydraulic conductivity and rainfall recharge. In this case, the values adopted have been calibrated by comparison of predicted and recorded groundwater levels. Variation of one of these parameters would require adjustment of the other to maintain the calibration. Since both of these parameters provide a linear response in the groundwater model, there is little practical value in considering different parameter values in isolation.

Rainfall recharge will vary seasonally and this is likely to result in some variation of the groundwater level throughout the year. This variation does not invalidate comparisons based on changes produced by the proposed development.

Recharge will also vary somewhat within the catchment because of variations in soil type. Recharge in clayey soils in higher upstream parts of the catchment will be less than the adopted value of 365 mm per year. However the calibrated model showed that the contribution to groundwater reserves from these clay soils is minor with much of the groundwater recharge discharging onto the steeply-sloped surface and being removed via surface drainage. A variation in the recharge rate in these areas would not materially alter the predicted calibration groundwater levels.

The groundwater model adopts a constant recharge rate across the site. Where parts of the site are replaced by the open water constructed wetlands (and for the existing lagoons) the recharge rate is likely to be greater since all rainfall is captured directly by the water body, only offset by direct evaporation. It was considered that the comparative studies are still valid since there is a predicted net outflow from the water bodies which would only be increased by the greater recharge rate.

2.11.12 Groundwater Quality

There is little information recorded on groundwater quality within the low-lying areas of the site. Based on the gradients and flow patterns calculated in this study, it is expected that all groundwater within the low-lying areas will be fresh, since the calculations show a consistent base flow from the catchment towards the ocean and groundwater levels in the low-lying areas are generally well above tide level.

There is a considerable amount of published data for the frontal dune system at the STP exfiltration system. This indicates that the groundwater in these dunes is also generally fresh (only becoming brackish below 4.0 metres depth). This low salinity may be a direct effect of the exfiltration flows but in other dune systems rainfall recharge results in fresh groundwater close to the ocean shoreline. There are no reported results from the area closest to the STP exfiltration but it is expected that will be no significant groundwater flow from the STP exfiltration into the site because flows are intercepted by the Duchess Gully drainage line. The groundwater records from the STP exfiltration system are therefore irrelevant to the constructed wetlands system.

Recorded surface water quality in the existing lagoon is described in Section 2.10.1. These waters are fresh with relatively low nutrient levels. Because the groundwater analysis shows that this water body is connected to the groundwater system and interacts with the upper aquifer, it is probable that the groundwater water quality is similar to this surface quality except during storm runoff events when the surface runoff will carry higher loads of sediment and pollutants.

There are no published specific water quality criteria for groundwater but ANZECC (1995) suggests that surface water quality criteria, such as those published in ANZECC (2000), could be adopted for groundwater with similar environmental values and potential uses.

These criteria are discussed in the next section of the document (see 2.10.1.3). They indicate that the water quality in the existing lagoons is acceptable for the passive recreation use proposed for these areas and would be suitable for irrigation purposes.

2.11.13 Impacts on Groundwater of Settlement under Fill

The settlement caused by the pressure of fill material on existing soil strata is not expected to have any significant impact on the groundwater regime because the amount of settlement will be small as reported in the geotechnical investigation reports (see Holmes & Holmes 1993).

2.11.14 Summary of Groundwater Impacts

- The proposed constructed wetlands causes some drawdown of groundwater levels which is localised to near the constructed wetlands and limited in extent; the drawdown effect is not detrimental to the regional groundwater regime and will not affect the known froglet habitat.
- The limited area of reduced groundwater levels does not expose any significant acid sulfate material to oxidising conditions and will not increase acid seepage.
- Groundwater base flow patterns are not materially affected. There is some diversion of base flow away from the overflow drain of the existing lagoon into the constructed wetlands zone and hence into the “middle” reach of Duchess Gully. This diversion restores the original flow pattern in the low-lying areas with beneficial effects for the creek system.
- The constructed wetlands do not affect the operation of the STP effluent exfiltration system. The STP effluent discharge will not affect the groundwater regime of the development site.
- Creation of the permanent constructed wetland waterway may slightly reduce stored groundwater reserves in localised drawndown areas near the constructed wetland but freshwater reserves are greatly increased overall by the large volumes stored in the constructed wetlands water body itself.

- Short-term dewatering during excavation of the constructed wetlands does not result in significant detrimental groundwater drawdown.
- Settlement of soils under fill zones will not affect groundwater systems because the amount of settlement is very small.

2.11.15 Groundwater Management

2.11.15.1 Operational Management Procedures

There are no specific recommended groundwater management procedures to be followed in the long-term operation of the constructed wetlands except for regular monitoring as set out in Section 2.11.15.2 and Appendix B.

2.11.15.2 Groundwater Monitoring

It is proposed that groundwater conditions be monitored on a regular basis at four locations surrounding the constructed wetlands. Suitable locations are shown in Figure 18.

Monitoring will include physical and chemical constituent testing as set out in Appendix B (Groundwater Management Plan).

2.11.15.3 Construction Management

Groundwater levels in the area of the constructed wetlands will be closely monitored by the construction manager during construction using the network of established bores (WRL 2010) in addition to temporary bores at locations to suit the construction program to confirm that drawdown effects do not exceed those predicted in this report.

Monitoring of groundwater conditions may be required by other management procedures. Monitoring of this nature is included in Appendix A (the Acid Sulfate Soil Management Plan) and the Groundwater Management Plan (GMP) recommended in recent additional groundwater assessments (WRL 2101) and adopted by the proponent.

All monitoring recommended by these various investigations will be incorporated in a detailed Construction Environment Management Plan (CEMP) to be submitted and approved by Port Macquarie Hastings Council prior to the issue of a construction certificate.

2.12 Open Space Corridor Habitats

2.12.1 Terrestrial Flora and Fauna

The majority of the site currently supports degraded pastoral woodland and sedge land that has been subject to broad-scale vegetation clearance and livestock grazing. As such the majority of the site is in a disturbed and degraded state and supports a variety of weed species common to agricultural landscapes. A number of wooded vegetation communities have also been identified on the site (refer Darkheart 2008) including a variety of eucalypt woodlands and forests, Swamp oak swamp forest, disturbed/regrowth Swamp forest and dry shrubland. The majority of these vegetation communities will be encompassed by the Open Space Corridor. While no threatened flora species have been identified within the site, three vegetation communities are considered to support elements of Endangered Ecological Communities recognised by the Threatened Species Conservation Act 1995 (refer Darkheart 2008). More specifically:

- part of the Forest red gum dominated pastoral woodland occurring on the floodplain is considered to be a very low quality example of the 'Subtropical coastal floodplain forest of the NSW north coast bioregion;
- disturbed/regrowth Swamp forest communities are considered to constitute low to medium quality 'Swamp sclerophyll forest on Coastal floodplains' EEC; and
- the mixed wet sclerophyll forest is considered to marginally constitute the 'River flat eucalypt forest on Coastal floodplains of NSW north coast, Sydney basin and south east corner bioregions' EEC.

With regard to the above, the Mixed wet sclerophyll community and the majority of the disturbed Swamp forest community will be retained and protected within the Open Space Corridor. However, the Remnant Forest red gum community is situated wholly within the development footprint and will be removed as a result of the site development.

The availability of habitat resources for native fauna on the site has been reduced by a prolonged history of disturbance associated with such as vegetation clearance and livestock grazing. The relatively open nature and low floristic diversity of vegetation communities such as the pastoral woodland and disturbed sedgeland communities that constitute the majority of vegetation on the site is likely to exclude:

- cryptic and/or secretive species;
- species that are specialist foragers; and
- species that require a range of forage resources.

As such, these areas are more likely to be utilised by more cosmopolitan and highly mobile fauna such as macropods, birds and bats that are more adapted to highly modified rural environments.

By contrast, the intact, native vegetation communities encompassed by the Open Space Corridor provide a greater range of habitat resources for native fauna and some communities are known to support threatened fauna species such as the Koala (*Phascolarctos cinereus*), Wallum froglet (*Crinia tinnula*), Eastern Chestnut mouse (*Pseudomys gracilicaudatus*) and Common planigale (*Planigale maculata*) (refer Darkheart 2008).

2.12.1.1 Corridor Values

The UIA 14 Structure Plan identifies the following parts of the site as contributing to local corridors in the locality:

- Duchess Gully and associated vegetation in the upper reaches as forming a link between vegetation around the STP (STP) in the south and a corridor to be incorporated into future urban development to the north; and
- The southern portion of the site as forming a link between habitat in the Queens Lake State Conservation Area (SCA) and surrounding rural land to the west and vegetation associated with the STP and complex dune vegetation to the east.

Both areas identified as forming part of a broader fauna movement corridor will be incorporated within the Open Space Corridor. However, it should be noted that riparian corridor associated with Duchess Gully is intercepted by Ocean Drive in its northern extent, which may present a barrier to fauna dispersing in this direction. Furthermore, land to the north of the site has an urban land use designation which will inevitably further reduce the ecological values and functions of the north-south corridor.

Vegetation within the Open Space Corridor identified as forming part of the east-west corridor is in a highly fragmented and degraded state and as such provides tenuous link at best, particularly to smaller ground dwelling fauna that are at higher risk of predation by avian predators and domestic animals once they move out into open environments. The western extent of this corridor is also dissected by Ocean Drive which may result in increased mortality of native fauna attempting to move into and out of the site in this direction. However, the presence of the Queens Lake SCA to the west of the site provides greater ecological benefit to dispersing fauna than land that is ear-marked for urban development.

2.12.1.2 Impacts of the Development on Terrestrial Flora and Fauna

The orderly development of the site in general accordance with the Concept Plan (refer Figure 4) will necessitate direct physical impact on some of the site’s vegetation communities and fauna habitat in the form of vegetation clearance and development works (e.g. excavation of fill, modification of the low-lying areas, establishment of a residential subdivision and business/retail centre and associated infrastructure etc). The majority of this disturbance will be take place within areas of the site that have relatively low ecological values (ie. cleared pastoral land and disturbed sedge communities). The Open Space Corridor is a prominent feature of the Concept Plan given that it will encompass approximately 80.9 ha or 46% of the site’s area and will include the majority of existing, intact native vegetation communities and expanses of regenerating vegetation that will be rehabilitated. The extent of disturbance to vegetation and fauna habitat within the Open Space Corridor is to be limited to the loss and/or modification of the following areas of vegetation:

- Approximately 7.7 hectares of degraded native vegetation for the purposes of establishing the District Sporting Fields; and
- Approximately 10.5 hectares of pastoral woodland which supports a few scattered native trees for the purposes of excavating fill for the development and establishing the proposed constructed wetland.

Vegetation identified as forming part of broader fauna movement corridors (refer Section 2.12.1.1) will be retained and protected within the Open Space Corridor. The extensive rehabilitation works proposed for the Open Space Corridor will enhance the structure and function of these currently degraded communities and hence higher quality fauna movement corridors will be created (refer Section 2.13).

It is relevant to note that development of the site will not have any direct impact on adjoining areas of SEPP 26 Littoral Rainforest to the east. However, it is intended to utilise an existing dirt track adjacent to the southern end of the SEPP 26 Littoral Rainforest as a means of controlled access from the proposed development to the beach. This track is currently an informal pathway subject to potential erosion. It is proposed to upgrade the track to a floating board walk along its existing alignment. The establishment of this formal walkway will not necessitate the removal of any existing vegetation and will essentially reduce the occurrence of degrading processes (e.g. aimless meanderings) by creating a more formal and controlled public access way to the beach.

2.12.2 Aquatic Habitats

The Open Space Corridor currently supports a number of exiting aquatic habitats, namely:

- an existing lagoon system in the central portion;
- two small wetlands constructed for the purposes of receiving and treating stormwater from the residential development to the south;
- Duchess Gully which extends along the eastern boundary of the site; and
- constructed drainages channels in the western and northern portions.

The location and extent of aquatic features within the Open Space Corridor are illustrated in Figure 5 and Figure 6.

As part of the Rainbow Beach Development, a proposed constructed wetland will be created in the middle reaches of Duchess Gully within the Open Space Corridor (see Figure 8). This constructed wetland will form an integral part of the proposed stormwater treatment train that will service the development and re-instate the natural flow path of Duchess Gully through the central portion of the site.

The proposed constructed wetland will have a surface area of 10.5ha, an average bed level of RL 1.0 m AHD and a normal top water level 3.0 m AHD. The capacity of the lake at its normal top water level is approximately 165 ML. While the primary purpose of the constructed wetland will be the treatment of storm water runoff generated by the adjoining development, revegetation and rehabilitation of the wetland will be aimed at high quality habitat for aquatic and terrestrial fauna whilst providing visual amenity and passive recreational pursuits for future residents.

2.12.2.1 Aquatic Vegetation

The existing lagoon system supports a variety of native macrophyte species including populations of Jointed twig rush (*Baumea articulata*), Bare twig rush (*Baumea juncea*), Sag (*Eleocharis equisitina*), Sea rush (*Juncus krausii*), Water primrose (*Ludwigia peploides ssp montevidensis*), Water ribbons (*Triglochin sp.*). Large expanses of the littoral or marginal zone of the existing lagoon system support infestations of the introduced Torpedo grass (*Panicum repens*). The landowner (St Vincents Foundation) and staff of ‘Wild Things Native Gardens’ have been actively trialling means of controlling this pest species and have successfully removed the majority of its biomass from the lagoon littoral/marginal zone. This has created an opportunity for the revegetation and rehabilitation of the existing lagoon to enhance its biodiversity values and inhibit regrowth of Torpedo grass. No threatened aquatic flora species have been recorded within or adjacent to the lagoon system.

Although the water quality regime shows that the constructed wetlands will lie in the oligotrophic range, it is expected that the shallow shoreline zone will develop significant areas of freshwater littoral and emergent macrophyte vegetation. It is likely that freshwater aquatic species will also grow readily in the water body.

This vegetation is a normal part of the development of a mature freshwater ecosystem and should be maintained. Vegetation is an integral part of the wetlands stormwater treatment process. The wetlands treatment zones will be planted with appropriate emergent and aquatic species as part of the construction phase (refer Section 2.13).

2.12.2.2 Aquatic Fauna

An initial survey of the existing lagoon indicated that it is in a relatively healthy condition with only some minor concerns surrounding the low abundance and diversity of benthic fauna (refer Ecology Lab 2008). A variety of aquatic organisms were found to inhabit the lagoon including Sea mullet (*Mugil cephalus*), Freshwater mullet (*Myxus petardi*), Snake-necked tortoise (*Chelodina longicolis*), Empire gudgeon (*Hypseleotris compressus*), Striped gudgeon (*Gobiomorphus australis*), Flathead gudgeon (*Philypnodon grandiceps*), and Shortfin eel (*Anguilla australis*). The only introduced species detected in the lagoon was the Mosquito fish (*Gambusia holbrooki*). A number of cosmopolitan waterbird species such as Chestnut teal (*Anas castanea*), Cormorants (*Phalacrocorax spp*), Pacific Black duck (*Anas superciliosa*) and Purple swamphen (*Porphyrio porphyrio*) utilise the existing lagoon for habitat resources on a regular basis.

The presence of juvenile Snake-necked tortoise (*Chelodina longicolis*) and Short-finned eels also demonstrates the existing lagoon system is providing breeding and/or nursery resources to aquatic organisms.

No threatened aquatic fauna species have been recorded within or adjacent to the lagoon system.

2.12.2.3 Impacts of the Development on Aquatic Habitats

The extent of direct physical disturbance to existing aquatic habitats within the site will be limited to:

- Realignment of a small section of a constructed drainage line in the western portion of the site for the purposes of establishing the district sporting fields; and
- The removal of a constructed drainage line associated with the north-eastern portion of Duchess Gully for the purposes of establishing the proposed residential subdivision.

The remaining aquatic habitats within the site are to be retained and protected within the Open Space Corridor.

Fish species such as Sea mullet (*Mugil cephalus*), and Shortfin eels (*Anguilla australis*) have a marine life-cycle and hence their presence in the existing lagoon indicates connectivity to the ocean via Duchess Gully.

During major storms, when high water levels occur, flow will also continue to discharge from the existing lagoon via the existing "overflow" channel direct to Duchess Gully. The outlet structure will be reconstructed to increase its capacity (see Section 2.7 and Section 4.4).

2.12.2.4 Aquatic Weeds

Many recognised aquatic weed species have been bought into Australia for ornamental purposes (i.e. water features, aquariums etc) and have escaped into natural and constructed waterbodies as direct result of seed/propagule dispersal and/or irresponsible disposal of plants into storm water drains. In this regard, wetlands constructed to manage storm water run-off, such as the proposed constructed wetland, have the potential to support high levels of nutrients and hence can provide ideal conditions for the invasion of aquatic weed species.

In the first instance, consideration must be given to the fact that existing waterbodies do not currently support any significant aquatic weed infestations even though:

- They have been receiving run-off from surrounding pastoral land for at least 20 years;
- Storm-water run-off from residential development to the south has also been directed into the waterbodies; and
- Substantial numbers of water birds, which are important dispersal agents for aquatic plants, utilise the waterbodies on a regular basis.

The above facts and circumstances suggest that:

- the existing waterbodies do not support conditions that are favourable to the growth of aquatic weeds;
- there are no source populations of aquatic weeds within dispersal distance of the water bodies; and
- residents in the locality have not been disposing of aquatic weed material in an inappropriate fashion.

Notwithstanding the above, aquatic weed infestation is a serious issue and the potential for the constructed and existing waterbodies to harbour aquatic weeds has been given due consideration in the design of the wetland system and on-going management of the Open Space Corridor.

The storm water “treatment train” that will include bioretention basins, wetlands and vegetated swales will also serve as preventative weed management system in that the majority of escaped or dumped weed material should be “collected” within these structures prior to entering the waterbodies. As such, regular monitoring and maintenance of the “treatment train”, during growing seasons and after rainfall events, will function as an effective weed prevention system. Specifications pertaining to the control and management of aquatic weeds species have been detailed in the Open Space Management Strategy (Cardno 2008) prepared for the site.

2.12.2.5 Algal Blooms

The analysis of water quality described in Section 2.10 shows that the existing lagoon and the proposed constructed wetland are expected to establish an oligotrophic regime with low levels of nutrients. As such, these water bodies are not expected to experience nuisance blooms of algae. Some temporary increases in algal concentrations may occur during wet weather with heavy runoff as a result of increased nutrient runoff but the water quality simulations show that these incidents will be rare and temporary in nature.

2.13 Open Space Corridor Establishment

2.13.1 Rehabilitation and Revegetation of Terrestrial Habitats

It is intended to revegetate and rehabilitate the majority of the Open Space Corridor, which will effectively offset the loss of degraded vegetation and fauna habitat resulting from development of the site. In this regard an integrated Open Space Management Strategy (OSMS) has been prepared that seeks to provide management specifications that will protect and enhance the ecological values and functions of the Open Space Corridor whilst facilitating public access and use of designated recreational areas. More specifically, the Open Space Management Strategy aims to:

- Enrich the current native biodiversity of existing vegetation within the Open Space Corridor;
- enhance the existing corridor values of vegetation along Duchess Gully;
- create better movement opportunities in an east-west direction for native wildlife;
- reduce the extent of existing weed infestations within the Open Space Corridor;
- protect and enhance aquatic habitat values within existing and to be constructed waterbodies within the Open Space Corridor; and
- provide an appropriate interface between native vegetation and wildlife habitats within the Open Space Corridor and adjacent areas of urban development.

Some of the vegetation communities encompassed by the Open Space Corridor are known to support threatened fauna species such as the Koala (*Phascolarctos cinereus*), Wallum froglet (*Crinia tinnula*), Eastern Chestnut mouse (*Pseudomys gracilicaudatus*) and Common planigale (*Planigale maculata*). In addition, some vegetation communities have also been identified a low to medium quality Endangered Ecological Communities (EECs) including 'Swamp sclerophyll on coastal plains' and 'River flat eucalypt forest on coastal floodplains'. In this regard, the Open Space Management Strategy has been prepared with a focus on retaining and enhancing Endangered Ecological Communities and habitat for threatened fauns species that occur within the Open Space Corridor. The Open Space Management Strategy aims to revegetate and manage the Open Space Corridor in a manner that conserves biodiversity values through:

- o the protection and improvement to the wetland area that supports a relatively large Wallum froglet population;
- o increasing the prevalence of known Koala food trees and other plants with multiple-species values throughout the Open Space Corridor;
- o restoring the floristic and structural elements of degraded EECs;
- o providing structural complexity and cover for ground-dwelling fauna such as the Eastern chestnut mouse and Common planigale;
- o reinstating degraded fauna movement corridor values throughout the Open Space Corridor; and
- o removing and managing weed infestations.

The manner in which the Open Space Corridor will be rehabilitated and revegetated is summarised in the Environmental Land Use Management Plan (ELUMP) provided as Figure 20 (sheets A and B). The substantial revegetation and rehabilitation works and on-going management measures that are outlined in the Open Space Management Strategy and ELUMP have been specifically designed to off-set for any loss or modification of terrestrial ecosystems that will result from the proposed plan of development (refer Figure 4).

In addition to rehabilitating degraded vegetation and fauna habitat within the Open Space Corridor, implementation of the Open Space Management Strategy will benefit surrounding adjoining areas of SEPP 26 Littoral Rainforest given that:

- the establishment of the Open Space Corridor will provide appropriate vegetated spatial buffers between residential development and Littoral rainforest vegetation to the east;
- stormwater control devices will be implemented within the development footprint and Open Space Corridor in order to control the quality and quantity of storm water run-off generated by the development and minimise its potential impact on surrounding environments; and
- source populations of weed species such as Lantana (*Lantana camara*) will be managed as part of a comprehensive weed management program.

2.13.2 Management and Revegetation of Aquatic Habitats

The most prominent aquatic habitats included in the Open Space Corridor are the existing lagoon and proposed constructed wetland. Overall, the extensive revegetation and rehabilitation works proposed for the Open Space Corridor combined with on-going management as detailed in the Open Space Management Strategy are expected to enhance values of existing and proposed aquatic habitats through:

- the removal and management of weed species from the littoral/marginal zone (i.e. Torpedo grass);
- implementing supplementary planting programs that will provide a diversity of native macrophyte species within and around aquatic habitats;
- the provision of supplementary habitat features such as logs and snags (to be sourced from areas of the site to be cleared) as breeding, roosting and feeding areas;
- increasing the coverage of woody vegetation around the edges of the water bodies to provide cover, litter and debris for aquatic organisms;
- increasing public surveillance of the waterbodies which will reduce degrading activities such as refuse dumping and construction of "cross-overs" using dumped refuse; and
- controlling human and domestic animal access to the waterbodies.

The manner in which the existing lagoon and proposed constructed wetland will be managed and revegetated is summarised in the Wetlands Revegetation Plan provided as Figure 21 (sheets A and B).

It should be noted that the proposed urban development of the northern portion of the site is expected to increase the:

- quantity and nutrient/sediment loading of stormwater runoff;
- the rate of runoff response; and
- peak discharges from developed area for flood events.

As detailed in Section 3.4 herein, the proposed development will include a stormwater "treatment train" that will incorporate the following measures to reduce the impact of runoff from the development on receiving environments:

- buffer strips for the removal of sediment and nutrients from impervious surfaces such as foot paths and driveways;
- grassed swales to convey storm flow and provide adequate flow detention prior to downstream devices such as wetlands and bioretention systems;

- establishment of bioretention systems (generally in the upper reaches of the catchment) for the removal of sediments and nutrients; and
- wetland systems in the downstream end of the catchment and immediately upstream of receiving lakes.

The various components of the proposed stormwater "treatment train" will minimise any impacts of run off on receiving environment given that they will:

- convey and/or contain water that meets adopted water quality objectives as required by Port Macquarie-Hastings Council;
- not have any significant impacts on the hydrology and groundwater levels of the Open Space Corridor and surrounding locality;
- not result in the exposure of high Potential Acid Sulfate Soils material to potential oxidation;
- be constructed in accordance with an approved Erosion and Sediment Control Plan and Acid Sulfate Soil Management Plan;
- be revegetated in a manner that enhances the diversity and connectivity of fisheries habitat within and adjacent to the site.

In summary, the proposal will have minimal impact on the existing aquatic features within and adjacent to the site and generally accords with the purpose and intent of Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 1999 (DPI 1999) in that due consideration have been given to the following:

- increasing the quality and diversity of fisheries habitat associated with existing and constructed waterbodies within the Open Space Corridor;
- providing appropriate vegetated buffers between aquatic features and conflicting land uses such as residential development;
- sediment and erosion control; and
- water pollution control.

2.13.3 Benefits of Constructed Wetland Habitat

Constructed wetlands are often referred to as 'artificial wetlands' but this terminology can be misleading as it suggests that constructed wetlands are comprised of 'artificial components'. Constructed wetlands when designed, constructed and vegetated in an appropriate manner with due consideration given to the hydrology, ecology and other landscape features of the surrounding area can contribute to valuable ecosystem functions and processes.

The constructed wetland system to be incorporated into the Open Space Corridor has been specifically designed to provide a number of ecological values and functions including:

- Increased aquatic habitat for migratory and wader birds, amphibians (including the threatened Wallum froglet which is known to occur on the site), fish and invertebrates;
- Effective onsite and offsite stormwater quality improvement through the retention and treatment of nutrients, organic waste and sediment;
- Storm runoff peak flow mitigation;
- Improved aesthetic and intrinsic values within the landscape; and
- Increased passive recreational opportunities (e.g. bird watching and other nature appreciation pursuits).

Given the above, the inclusion of constructed wetlands within the Open Space Corridor will provide a net ecological benefit to the site and surrounding locality.

2.13.4 Access and Public Safety

There will be controlled public access within the Open Space Corridor during the occupational stage of the development and as such the safety of the exiting lagoons and proposed constructed wetland is a major issue in regard to the management of the Open Space Corridor. The Open Space Management Strategy addresses public safety issues associated with the waterbodies with a risk minimisation approach based on the principles of not inviting people to danger and ensuring risk is minimised through reasonable provision of safety measures. In addition, a detailed assessment of public access and safety risk issues is described in Section 5.6 which deals with operational procedures for the Open Space Corridor.

Safety measures presented in the Opens Space Management Strategy include the following:

- Vegetative barriers – the revegetation program has been specifically designed to create impenetrable vegetative barriers to the existing lagoon and proposed constructed wetland. Around the existing lagoon, the vegetative barrier will commence from the terrestrial fringe into the submerged zone of the lagoon. The extent of the barrier has been specifically designed to prevent public access to the water from at least 2 -3 m back from the Normal Top Water Level (NTWL) mark to reduce the likelihood of unexpected entry into the waterbody.

- Physical Barriers – no formal access to either the existing lagoon or proposed constructed waterbody will be provided unless there are appropriate barriers and/or safety benching installed. This will apply to areas where viewing platforms or shared cycle/pathways are situated along the edge of the existing lagoon or proposed constructed water body.

- Signage – Signage that complies with Australian standards (AS1742) and is non-obtrusive and highly resistant to vandalism will be installed in appropriate locations around the existing lagoon and proposed constructed waterbody. Signage will incorporate the following elements:
  - the purpose of the wetland (i.e. stormwater treatment and wildlife habitat);
  - significant environmental features (e.g. waterbird nesting habitat);
  - appropriate safety warnings; and
  - prohibition of domestic animals such as dogs within the wetland.

Under the proposed development, the existing lagoon and the constructed wetland will be provided with water level and flow control structures in the form of simple fixed weirs and overflow embankments.

The weirs will discharge storm runoff for all storms up to and including the 5 Year ARI events with these flows confined to scour-protected channels separated from all pedestrian walkways so as to maintain public safety during these events. Where necessary, pedestrian walkways will span these channels via bridges.

The overflow embankments will discharge storm runoff in excess of the 5 Year ARI events. Although the embankments are designed to carry these flows with minimal erosion damage, flow conditions on the embankments during these major runoff events will represent high hazard conditions for pedestrians because of the water velocities created. Some pedestrian walkways are located on these embankments. Appropriate signage should be installed at these locations to warn pedestrians and prevent access to these sections of the walkways during major runoff events when embankments are overtopped.

The locations of these flow structures are described in more detail in Section 4.3.

2.14 DGR Item Responses

RAINBOW BEACH CONCEPT PLAN (CP)

DGR Item	Topic
CP2.1	Justify the constructed wetland in the context of the IWCM plan proposed for the site (refer to CP3.2).
Response: • The proposed development incorporating end-of-pipe wetlands for stormwater treatment was adopted as the most advantageous overall because it is the only option providing the required residential areas along with satisfactory WSUD solutions whilst remaining economically feasible in terms of minimising total earthworks which avoids the necessity for imported fill (Section 2.4). • WSUD stormwater treatment using bioinfiltration (as favoured by Council's IWCM strategy) is not feasible because of the increased volume of earthworks required including large volumes of imported material. • The proposed wetland stormwater treatment was a feasible acceptable option under Council's IWCM assessment which was only discarded on the basis of cost. These costs are avoided under the current development proposals.	
CP2.2	Consider the functioning of the wetland including the responsibility for ongoing management, any potential risk to public safety and potential environmental impacts such as groundwater, water quality and hydrology.
Response: Responsibility for ongoing management The Open Space Management Strategy provides the framework within which the Open Space Corridor is to be managed by the Land Owner as part of the Rainbow Beach Development. Details are provided concerning strategies that have been developed and which are to be implemented by the Land Owner to ensure the construction and occupation of the urban development component of the Rainbow Beach development does not adversely impact upon the values of the Open Space Corridor including the constructed wetland. Risk to public safety The Open Space Management Strategy addresses issues associated with public access and safety within the Open Space Corridor, in respect of providing (Section 2.13.4 and 5.6): • appropriate mechanisms to restrict unauthorised and inappropriate forms of access into the Open Space Corridor by contractors involved in the construction phase of the Rainbow Beach development; • appropriate infrastructure to facilitate controlled public access to and within the Open Space Corridor for passive recreational pursuits compatible with the area's environmental values; and • appropriate infrastructure to facilitate Council access to and within the Open Space Corridor for environmental management purposes. A risk minimisation approach based on the principles of not inviting people to danger and ensuring risk is minimised through reasonable provision of safety measures is to be implemented on the site. The safety measures to be implemented on the site in relation to the wetland areas include the following: • Vegetative barriers – the revegetation program has been specifically designed to create impenetrable vegetative barriers to the existing lagoon and proposed constructed wetland. Around the existing lagoon, the vegetative barrier will commence from the terrestrial fringe into the submerged zone of the lagoon.	

The extent of the barrier has been specifically designed to prevent public access to the water by reducing the likelihood of unintentional entry into the waterbody.

- Physical barriers – no formal access points to either the existing lagoon or proposed constructed waterbody will be provided unless there are appropriate barriers and/or safety benching installed. This will apply to areas where viewing platforms or shared cycle/pathways are situated along the edge of the existing lagoon or proposed constructed water body.
- Signage – signage that complies with Australian standards (AS1742) and is non-obtrusive and highly resistant to vandalism will be installed in appropriate locations around the existing lagoon and proposed constructed waterbody. This signage will incorporate the following elements:
  - the purpose of the wetland (i.e. wildlife habitat and stormwater treatment);
  - significant environmental and ecological features (e.g. waterbird nesting habitat);
  - appropriate public safety warnings; and
  - prohibition of domestic animals such as dogs within the wetland areas.

The overflow embankments will discharge storm runoff in excess of the 5 Year ARI events. Although the embankments are designed to carry these flows with minimal erosion damage, flow conditions on the embankments during these major runoff events will represent high hazard conditions for pedestrians because of the water velocities created. As some pedestrian walkways are located on these embankments, appropriate signage will be installed at these locations to warn pedestrians and prevent access to these sections of the walkways during major runoff events.

<u>Potential environmental impacts such as groundwater, water quality and hydrology</u>

Potential environmental impacts of the wetland on hydrology, water quality and groundwater are shown to be inconsequential (section 2.6.5) or beneficial (Section 2.10.6)

CP3.1	Address potential impacts on water quality of both surface and groundwater.

Response:

- Historical recorded data show that water quality in the existing lagoon is good and satisfies desirable water quality limits given in Council and ANZECC guidelines to ensure a sustainable appropriate freshwater coastal ecosystem. The data show the existing lagoon is well-mixed and not liable to stratification (Section 2.10.1.4
- The recorded data show that the Sewage Treatment Plant (STP) does not affect existing water bodies on the site (Section 2.10.1.4).
- Water quality in proposed water bodies was predicted by a variety of methods (namely, comparison with existing water bodies, mathematical modelling and comparison with water bodies at other similar sites). The results show that the proposed constructed wetland will exhibit good water quality similar to the existing water bodies (Section 2.10.3). The results also show that conditions in the existing water bodies will not be affected by the proposed development (Section 2.10.3.4).
- The proposed re-direction of flows from the existing lagoons in the “upper” reaches of Duchess Gully into the proposed constructed wetlands will re-establish the original flow path and is expected to improve surface water quality conditions in the “middle” reaches of Duchess Gully (Section 2.10.2
- The effects of the proposed development on groundwater systems were predicted using a calibrated groundwater model (Section 2.11.7). The results show that the proposed constructed wetland does not materially affect the regional groundwater regime or groundwater flow patterns. Groundwater levels are reduced only in some areas local to the constructed wetlands (Section 2.11.9.2).
- The local drawdown in groundwater levels does not expose high-activity potential acid sulfate soils to oxidation. This material remains below the water table (Section 2.11.9.2)
- The proposed constructed wetland does not affect the operation of the STP exfiltration system where groundwater flows are not changed and are not re-directed into the site (Section 2.11.9.2).
- There are no significant adverse groundwater effects during the dewatering operations for the proposed constructed wetland (Section 2.11.10.2). Drawdown is temporarily increased but still confined to areas close to the excavation (Section 2.11.10.2)

DGR Item	Topic
CP7.1	Describe the potential impacts of the proposal on existing native vegetation (including areas of SEPP 26 littoral rainforest) both within and adjacent to the site and identify measures to minimise impacts on this vegetation (eg. appropriate buffers).

Response:

The orderly development of the site will necessitate direct physical impact on some of the site's vegetation communities and fauna habitat in the form of vegetation clearance and development works (e.g. excavation of fill, modification of the low-lying areas, establishment of a residential subdivision and business/retail centre and associated infrastructure etc). The majority of this disturbance will take place within areas of the site that have relatively low ecological values (i.e. previously cleared pastoral land and disturbed sedge communities). The Open Space Corridor is a prominent feature of the Concept Plan given that it will encompass approximately 80.9 ha or 46% of the site's area and will include the majority of existing, intact native vegetation communities and expanses of regenerating vegetation which will be rehabilitated. The extent of disturbance to vegetation and fauna habitat within the Open Space Corridor is to be limited to the loss and/or modification of the following areas of vegetation:

- approximately 7.7 ha of degraded native vegetation for the purposes of establishing the District Sporting Fields; and
- approximately 10.5 ha of pastoral woodland which supports a few scattered native trees for the purposes of excavating fill for the development and establishing the proposed constructed wetland.

Vegetation identified as forming part of broader fauna movement corridors will be retained, rehabilitated and protected within the Open Space Corridor. The extensive rehabilitation works proposed for the Open Space Corridor will enhance the structure and function of these currently degraded communities and hence higher quality fauna movement corridors will be created. The manner in which the Open Space Corridor is to be rehabilitated and managed to enhance its ecological values and function is detailed within the Open Space Management Strategy.

It is relevant to note that development of the site will not have any direct impact on adjoining areas of SEPP 26 Littoral Rainforest located to the east. However, it is intended to utilise an existing dirt track adjacent to the southern end of the SEPP 26 Littoral Rainforest as a means of controlled access from the proposed development to the beach. This track is currently an informal pathway subject to potential erosion. It is proposed to upgrade the track to a floating board walk along its existing alignment. The establishment of this formal walkway will not necessitate the removal of any existing vegetation and will essentially reduce the occurrence of degrading processes (e.g. aimless meanderings) by creating a more formal and controlled public access way to the beach.

DGR Item	Topic
CP7.2	Describe the potential impacts of the proposal on existing aquatic flora and fauna and habitats both within and adjacent to the site and identify measures to minimise impacts on these habitats with consideration of Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 1999.

Response:

The extent of direct physical disturbance to existing aquatic habitats within the site will be limited to:

- realignment of a small section of a constructed drainage line in the western portion of the site for the purposes of establishing the district sporting fields; and
- the removal of a constructed drainage line associated with the north-eastern portion of Duchess Gully for the purposes of establishing the proposed residential subdivision.

The remaining water features on the site are to be retained and protected within the Open Space Corridor. A preliminary assessment of the existing lagoon has been completed and the results indicate that the lagoon is currently in a healthy condition as reflected by:

- low density and diversity of introduced aquatic fauna;
- acceptable levels of water quality parameters;
- the diversity of native species in the macrophyte and submerged zones; and
- the diversity of waterbirds utilising the waterbodies for habitat diversity.
- The only major issues associated with the existing lake system is the predominance of the introduced Torpedo grass (Panicum repens) inspections of the macrophyte and submerged zones of the waterbody and a low diversity of benthic fauna.

Overall, the extensive revegetation and rehabilitation works proposed for the Open Space Corridor combined with on-going management as detailed in the Open Space Management Strategy are expected to enhance existing fisheries habitat value of aquatic features within the site through:

- the removal of weed species from the macrophyte zone (i.e. Torpedo grass);
- increasing the density and diversity of native plant species in the macrophyte zone;
- the provision of supplementary habitat features such as logs and snags (to be sourced from areas of the site to be cleared) as breeding, roosting and feeding areas;
- increasing the coverage of woody vegetation around the edges of the water bodies to provide cover, litter and debris for aquatic organisms;
- increasing public surveillance of the waterbodies which will reduce degrading activities such as refuse dumping and construction of "cross-overs" using dumped refuse; and
- controlling human and domestic animal access to the waterbodies.

It is intended for the existing lagoon to connect to the proposed constructed wetland by a control weir. During major storms, when high water levels occur, flow will also continue to discharge from the existing lagoon via the existing "overflow" channel direct to Duchess Gully. The outlet structure will be reconstructed to increase its capacity.

CP7.3	Outline measures for the conservation of flora and fauna and their habitats within the meaning of the Threatened Species Conservation Act 1995.

Response:
Some of the vegetation communities encompassed by the Open Space Corridor are known to support threatened fauna species such as the Koala (*Phascolarctos cinereus*), Wallum froglet (*Crinia tinnula*), Eastern Chestnut mouse (*Pseudomys gracilicaudatus*) and Common planigale (*Planigale maculata*). In addition, some vegetation communities have also been identified as low to medium quality Endangered Ecological Communities ("EEC's") In this regard, the Open Space Management Strategy has been prepared with a focus on retaining and enhancing EEC's and habitat for threatened fauna species that occur within the Open Space Corridor. The Open Space Management Strategy aims to revegetate and manage the Open Space Corridor in a manner that conserves biodiversity values through:

- the protection and improvement to the wetland area that supports a relatively large Wallum froglet population;
- increasing the prevalence of known Koala food trees and other plants with multiple-species values throughout the Open Space Corridor;
- restoring the floristic and structural elements of degraded EECs;
- providing structural complexity and cover for ground-dwelling fauna such as the Eastern chestnut mouse and Common planigale;
- reinstating degraded fauna movement corridor values throughout the Open Space Corridor; and
- removing and managing weed infestations.

CP7.4	Outline measures for the conservation or enhancement of existing wildlife corridors and / or the connective importance of any vegetation on the subject land.

Response:
The Open Space Corridor is a prominent feature of the Concept Plan given that it will encompass approximately 80.9 ha or 46% of the site's area and will include the majority of existing, intact native vegetation communities and expanses of regenerating vegetation. In addition to the ongoing protection offered to these areas by their incorporation into the Open Space Corridor, substantial revegetation and rehabilitation works and on-going management measures are proposed to enhance the ecological values of these areas. These revegetation and rehabilitation measures have been specifically designed to more than off-set any loss or modification of terrestrial ecosystems that will result from the proposed plan of development. The Open Space Management Strategy provides details of management actions that have been designed to:

- ensure the preservation of native fauna species and their associated habitats that currently exist within the Open Space Corridor during both the construction and occupational phases of development;
- enhance vegetated corridors and linkages to improve movement opportunities for native fauna residing within or dispersing through the Open Space Corridor; and
- minimise the potential for mortality and/or harm to be inflicted on native fauna as a consequence of domestic pets and vehicular traffic associated with the proposed urban development.

PROJECT APPLICATION – OPEN SPACE CORRIDOR & CONSTRUCTED WETLAND (PA)

DGR Item	Topic
PA4.1	Outline potential impacts on flora and fauna and their habitats (within the meaning of the Threatened Species Conservation Act 1994) across the site and, where relevant, provide conservation measures. Specifically address the impact of the constructed wetland on fish and their habitats. Note: The Department of Primary Industries states that constructed wetlands are inappropriate habitat for fish.

Response:

The orderly development of the site will necessitate direct physical impact on some of the site's vegetation communities and fauna habitat in the form of vegetation clearance and development works (e.g. excavation of fill, modification of the low-lying areas, establishment of a residential subdivision and business/retail centre and associated infrastructure etc). The majority of this disturbance will take place within areas of the site that have relatively low ecological values (i.e. previously cleared pastoral land and disturbed sedge communities). The Open Space Corridor is a prominent feature of the Concept Plan given that it will encompass approximately 81 ha or 46% of the site's area and will include the majority of existing, intact native vegetation communities and expanses of regenerating vegetation which will be rehabilitated. The extent of disturbance to vegetation and fauna habitat within the Open Space Corridor is to be limited to the loss and/or modification of the following areas of vegetation:

- approximately 7.7 hectares of degraded native vegetation for the purposes of establishing the District Sporting Fields; and
- approximately 10.5 hectares of pastoral woodland which supports a few scattered native trees for the purposes of excavating fill for the development and establishing the proposed constructed wetland.

It is intended to revegetate and rehabilitate the majority of the Open Space Corridor, which will effectively offset the loss of degraded vegetation and fauna habitat resulting from development of the site. In this regard an integrated Open Space Management Strategy has been prepared that seeks to provide management specifications that will protect and enhance the ecological values and functions of the Open Space Corridor whilst facilitating public access and use of designated recreational areas. More specifically, the Open Space Management Strategy aims to:

- enrich the current native biodiversity of existing vegetation within the Open Space Corridor;
- enhance the existing corridor values of vegetation along Duchess Gully;
- create better movement opportunities in an east-west direction for native wildlife;
- reduce the extent of existing weed infestations within the Open Space Corridor;
- protect and enhance aquatic habitat values within existing and to be constructed waterbodies within the Open Space Corridor; and
- provide an appropriate interface between native vegetation and wildlife habitats within the Open Space Corridor and adjacent areas of urban development.

As part of the Open Space Management Strategy it is intended to revegetate and manage the existing and proposed waterbodies in a manner that provides high quality aquatic habitat through:

- the removal of weed species from the macrophyte zone (i.e. Torpedo grass)
- increasing the density and diversity of native plant species in the macrophyte zone;
- the provision of supplementary habitat features such as logs and snags (to be sourced from areas of the site to be cleared) as breeding, roosting and feeding areas;
- increasing the coverage of woody vegetation around the edges of the water bodies to provide cover, litter and debris for aquatic organisms;
- increasing public surveillance of the waterbodies which will reduce degrading activities such as refuse dumping and construction of "cross-overs" using dumped refuse; and
- controlling human and domestic animal access to the waterbodies.

DGR Item	Topic
PA4.2	Provide a vegetation management plan that describes the proposed vegetation and regeneration works across the site. Consider the role of the revegetation in the provision of habitat for threatened species including the Koala (with reference to Hastings Council's Area 14 Koala Plan of Management).

Response:
An Vegetation Management Plan entitled "Environmental Land Use Management Plan" (ELUMP) has been prepared in conjunction with the Open Space Management Strategy. A key focus of the ELUMP and Open Space Management Strategy is the reinstatement of the ecological values and functions of degraded vegetation contained within the Open Space Corridor. As such, due consideration has been given to floristic and structural elements of vegetation communities to be rehabilitated within the Open Space Corridor, in particular the following measures have been included:

- the use of trees species that provide a variety of forage (i.e. foliage, pollen, nectar, fruits) nesting and roosting resources to a range of native fauna species;
- providing for a minimum percentage (i.e. 50%) of known Koala habitat trees to be used within revegetation areas;
- identifying potential fauna movement corridors and enhancing vegetation in these areas to facilitate fauna movement in a north-south and east-west direction;
- enhancing existing aquatic habitats through the removal of existing weed infestations and increasing the coverage of native aquatic vegetation;
- creating a diversity of aquatic habitats in the proposed waterbody to encourage colonisation (i.e. the provision of snags, logs, boulders etc within submerged environments);
- structural complexity of vegetation to facilitate the survival of ground dwelling organisms, with specific reference to the habitat requirement of the Eastern chestnut mouse and Common planigale that have both been recorded within the Open Space Corridor;
- protection and enhancement of known Wallum froglet habitat within the Open Space Corridor.

Given the above, the revegetation works proposed for the Open Space Corridor have been designed to reinstate habitat values with a particular emphasis on improving habitat of threatened fauna species as well creating new habitat fauna movement opportunities.

DGR Item	Topic
PA4.3	Address the potential for the constructed wetland to harbour aquatic weeds and where necessary, identify measures for their management.

Response:
Many recognised aquatic weed species have been bought into Australia for ornamental purposes (i.e. water features, aquariums etc) and have escaped into natural and constructed waterbodies as direct result of seed/propagules dispersal and/or irresponsible disposal of plants into storm water drains. In this regard, wetlands constructed to manage storm water runoff, such as the proposed constructed waterbody, have the potential to support high levels of nutrients and hence can provide ideal conditions for the proliferation of aquatic weed species.

In the first instance, consideration must be given to the fact that existing waterbodies on the site do not currently support any significant weed infestations even though:

- they have been receiving run-off from surrounding pastoral land for at least 20 years;
- storm-water run-off from residential development to the south has also been directed into the waterbodies; and
- substantial numbers of water birds, which are important dispersal agents for aquatic plants, utilise the waterbodies on a regular basis.

The above facts and circumstances suggest that:

- the existing waterbodies do not support conditions that are favourable to the growth of aquatic weeds;
- there are no source populations of aquatic weeds within dispersal distance of the water bodies; and
- residents in the locality have not been disposing of aquatic weed material in an inappropriate fashion.

Notwithstanding the above, aquatic weed introduction and infestation is a serious issue and the potential for the constructed and existing waterbodies to harbour weed infestations has been given due consideration in the design of the wetland system and on-going management of the Open Space Corridor.

The storm-water "treatment train" that will include vegetated swales and retention areas will also serve as preventative weed management system in that the majority of escaped or dumped weed material should be "collected" within these structures prior to entering the waterbodies. As such, regular monitoring and maintenance of the "treatment train", especially after rainfall events, will function as an effective weed prevention system. The Open Space Management Strategy provides specifications for the control and management of aquatic weed infestations should they develop within the waterbodies.	
PA5.2	Assess the impacts of the proposal on surface and groundwater hydrology and quality. Specifically address any impacts on Duchess Gully and the ongoing management of the waterway and its riparian zone. Describe any potential impacts to the existing exfiltration system attached to the Bonny Hills Sewerage Treatment Plant.
Response: • Catchment runoff will be maintained after the proposed development with some small increases in runoff volumes (Section 2.6.3). • The existing lagoon will be maintained as a continuing permanent feature of the surface water system with water levels close to full most of the time except for occasional drought periods when water levels may be reduced by up to 0.9 metres (Section 2.6.3). • The proposed constructed wetland will similarly become a continuing permanent feature of the surface water system with water levels close to full most of the time except for occasional drought periods when water levels may be reduced by up to 0.9 metres (Section 2.6.3). • Low flows will be re-directed through the original flow path of the middle reaches of Duchess Gully with benefits to the ecosystems of Duchess Gully. (Section 2.6.3) • The proposed constructed wetland is expected to be filled by catchment runoff within one year after construction (Section 2.6.4). • Potential climate change effects will not materially affect the surface water hydrology or stream characteristics (Section 2.9). • Potential climate change sea level rises will not affect the proposed surface water flow control structures (Section 2.9) • The effects of the proposed development on groundwater systems were predicted using a calibrated groundwater model (Section 2.11.7). The results show that the proposed constructed wetland does not materially affect the regional groundwater regime or groundwater flow patterns. Groundwater levels are reduced only in some areas local to the constructed wetlands (Section 2.11.9.2). • The local drawdown in groundwater levels does not expose high-activity potential acid sulfate soils to oxidation. This material remains below the water table (Section 2.11.9.2) • The proposed constructed wetland does not affect the operation of the STP exfiltration system where groundwater flows are not changed and are not re-directed into the site (Section 2.11.9.2). • There are no significant adverse groundwater effects during the dewatering operations for the proposed constructed wetland (Section 2.11.10.2). Drawdown is temporarily increased but still confined to areas close to the excavation (Section 1.11.10.2)	

FIGURES SECTION 2

LEGEND

Site Boundary

+B Existing wetlands surface water sampling locations

40 0 40 80 120 160 200m 1:4000

Scale 1:4000 (A3)

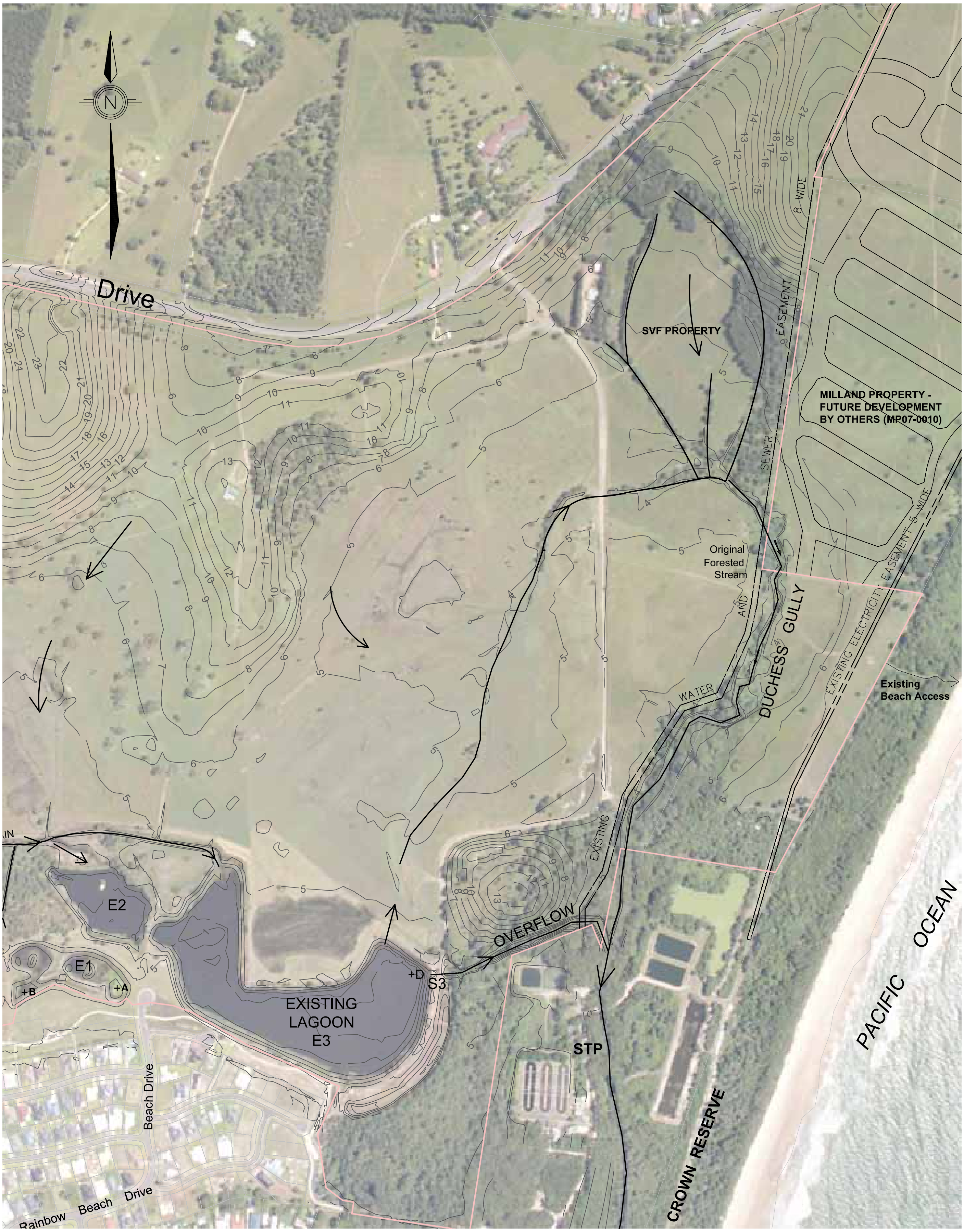
FIGURE 5
OPEN SPACE CORRIDOR PLAN - EXISTING WATER FEATURES (WEST)

Ver 2 Date: 19 MArch 2010

St. Vincents Foundation Pty Ltd

CAD FILE: L:\7135-01\Acad\Water Engineering & Env DGR Assessments\Figure 5&6 - Open space Corridor & Existing Water Features.dwg
XREF's: Contours for weirs 21-2-08; wetland outline

PRINT DATE 17 March, 2010 - 6:48am



LEGEND

Site Boundary

+B Existing wetlands surface water sampling locations

Scale 1:5000 (A3)

FIGURE 6
OPEN SPACE CORRIDOR PLAN - EXISTING WATER FEATURES (EAST)

LEGEND

Site Boundary

Open Space Corridor Boundary

40 0 40 80 120 160 200m 1:4000

Scale 1:4000 (A3)

FIGURE 7

OPEN SPACE CORRIDOR PLAN - PROPOSED DEVELOPMENT WATER FEATURES - WEST

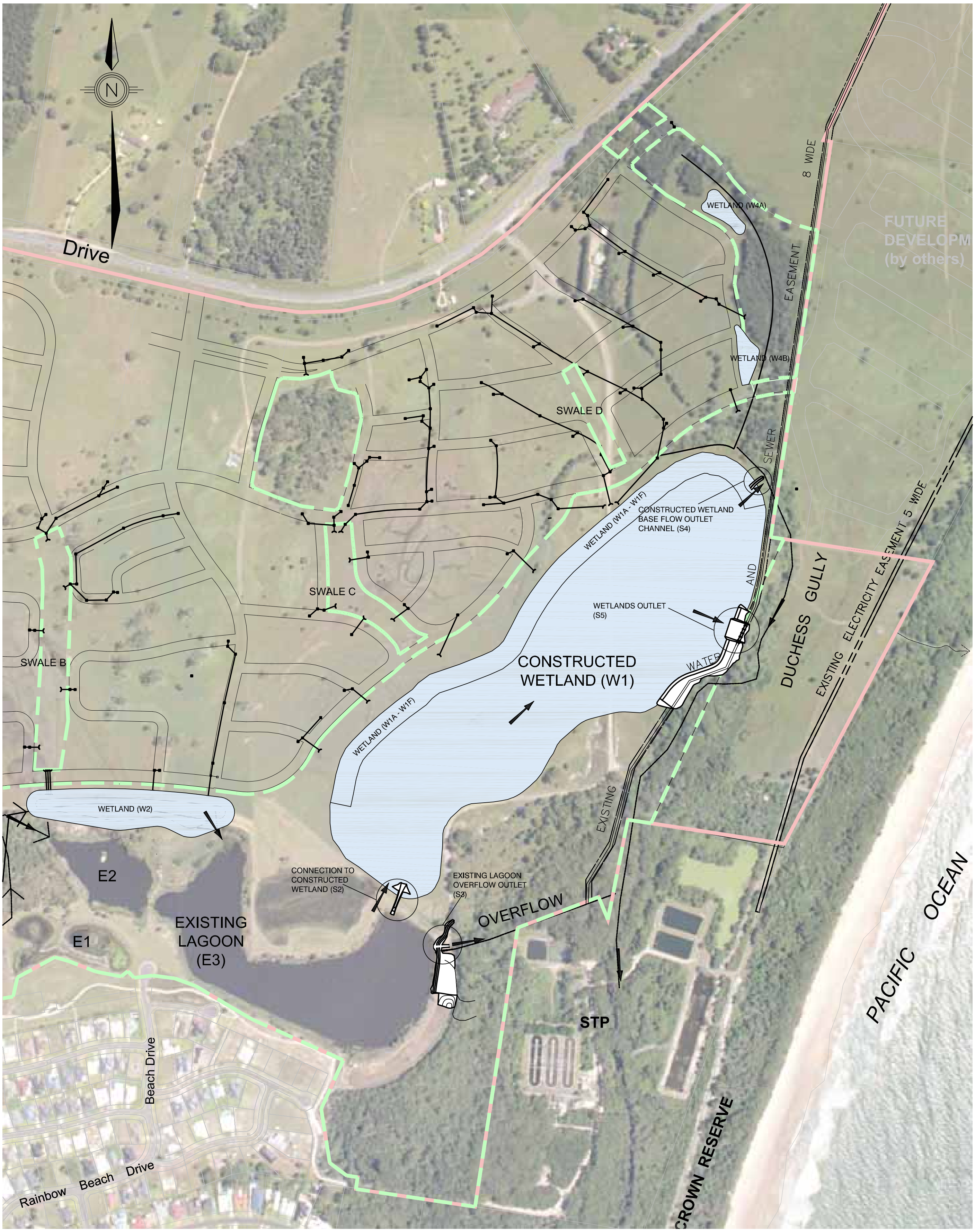
PRINT DATE: 17 March, 2010 - 11:19am

Ver 2 Date: 19 March 2010

St. Vincents Foundation Pty Ltd

CAD FILE: L:\7135-01\Acad\Water Engineering & Env DGR Assessments\Figure 7&8 Open space Corridor Plan - Proposed Dev Conditions.dwg
XREF's: wetland outline

Cardno



LEGEND

- Site Boundary
- Open Space Corridor Boundary

Scale 1:5000 (A3)

FIGURE 8

OPEN SPACE CORRIDOR PLAN - PROPOSED DEVELOPMENT WATER FEATURES - EAST

Ver 2 Date: 19 March 2010

St. Vincents Foundation Pty Ltd

CAD FILE: L:\7135-01\Acad\Water Engineering & Env DGR Assessments\Figure 7&8 Open space Corridor Plan - Proposed Dev Conditions.dwg
XREF's: wetland outline

PRINT DATE: 17 March, 2010 - 11:19am

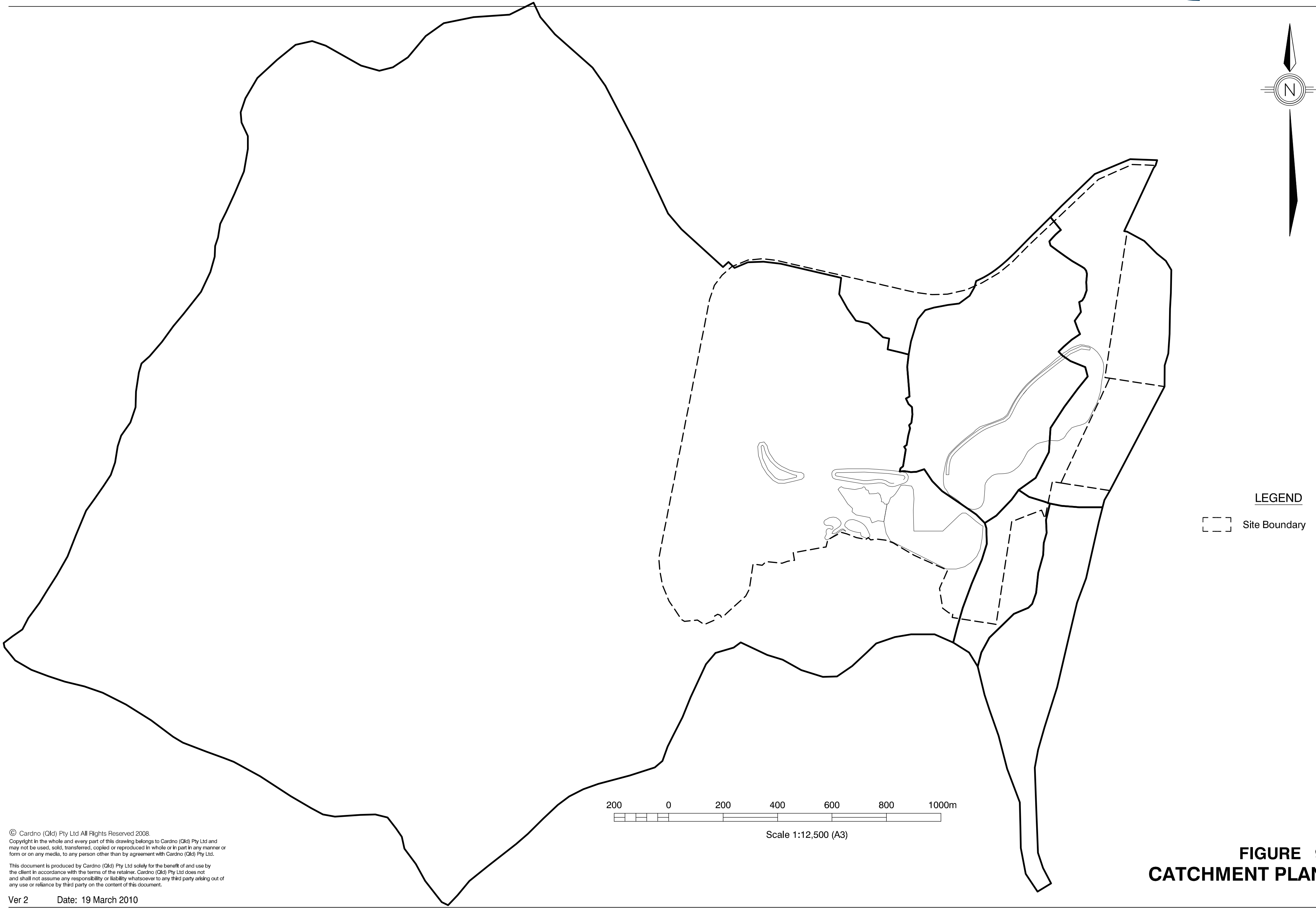
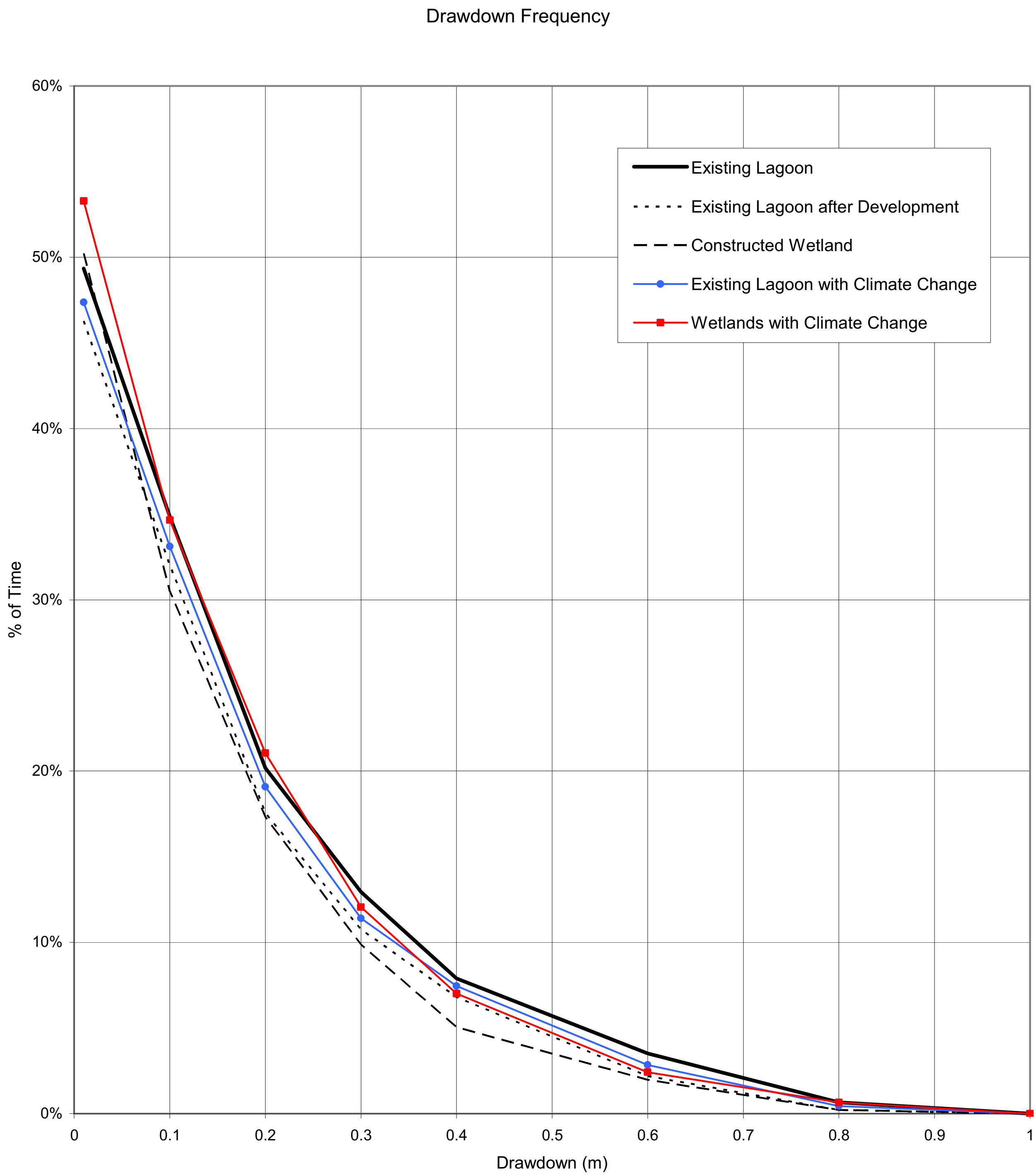


FIGURE 9
CATCHMENT PLAN

Ver 2 Date: 19 March 2010

St. Vincents Foundation Pty Ltd
CAD FILE: L:\7135-01\Acad\Water Engineering & Env DGR Assessments\Figure 9 - Catchment Plan_190808.dwg
XREF's: BASE DESIGN DRAINAGE

PRINT DATE: 16 March, 2010 - 4:39pm



L:\7135-01\Water Balance Jan 08\Lake level frequency.xls\Plot

Figure 10 Constructed Wetland Water Levels – Probability of Exceedance of Drawdown

FIGURE 10

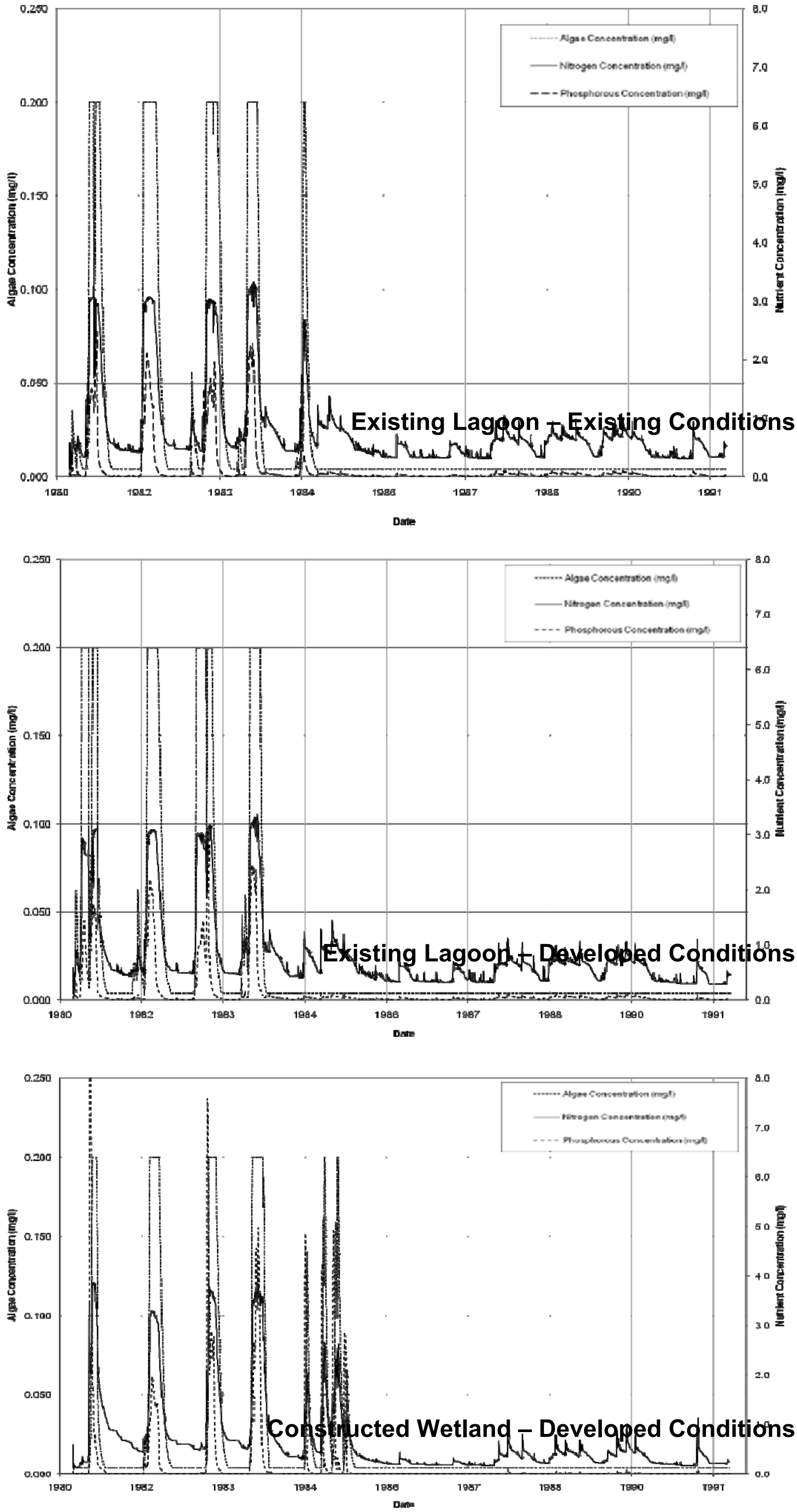


Figure 11 POND Model – Water Bodies Water Quality Response – Nutrients

FIGURE 11

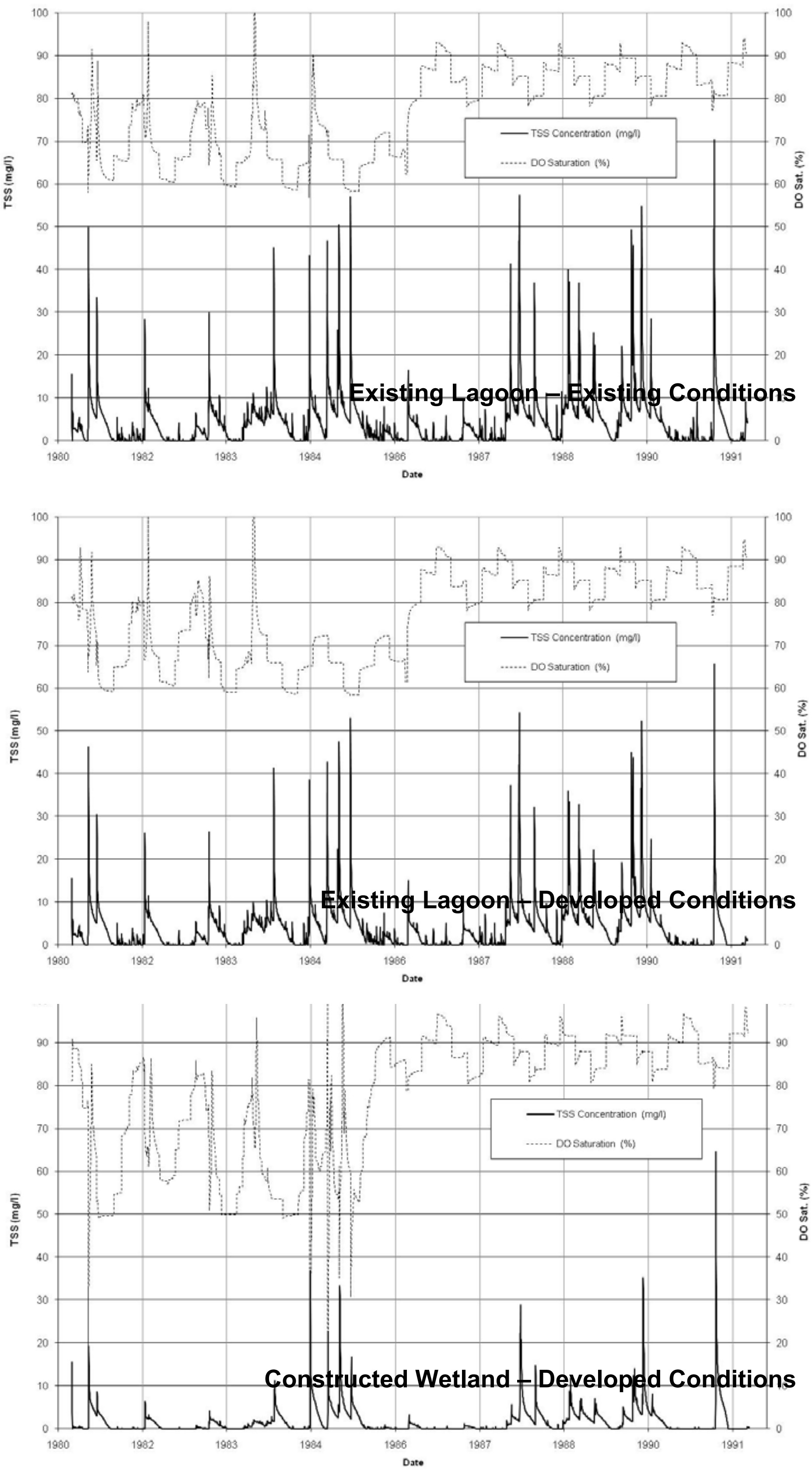
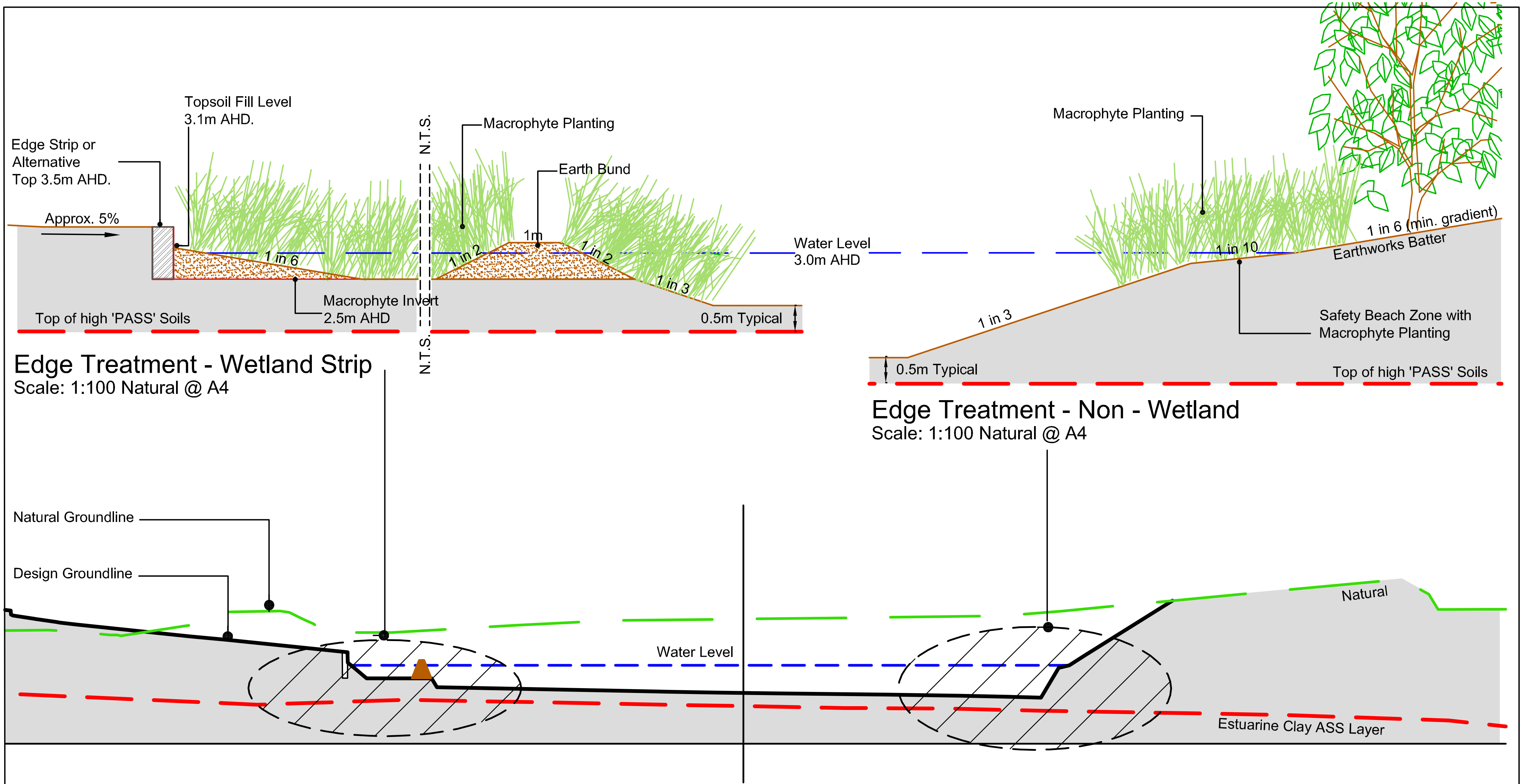


Figure 12 POND Model – Water Bodies Water Quality Response – Physical Parameters

FIGURE 12



Typical Section

Scale Horizontal 1:1000 Vertical 1:200 @ A4

NOTE: Typical Section is **Vertically Exaggerated.**

Rainbow Beach Estate
Wetland Sections - Application Set
Job. No. 4509:ND Dwn: CM/BAC
Luke and Company Pty Ltd

REVISIONS:

A	5.2.08	
B	10.3.08	BT comments 4.3.08
C	12.3.10	EARTH BUND - CARDNO

WETLAND EDGE TREATMENT
TYPICAL SECTION
SECTION W10

FIGURE 13A CONSTRUCTED WETLAND SECTION

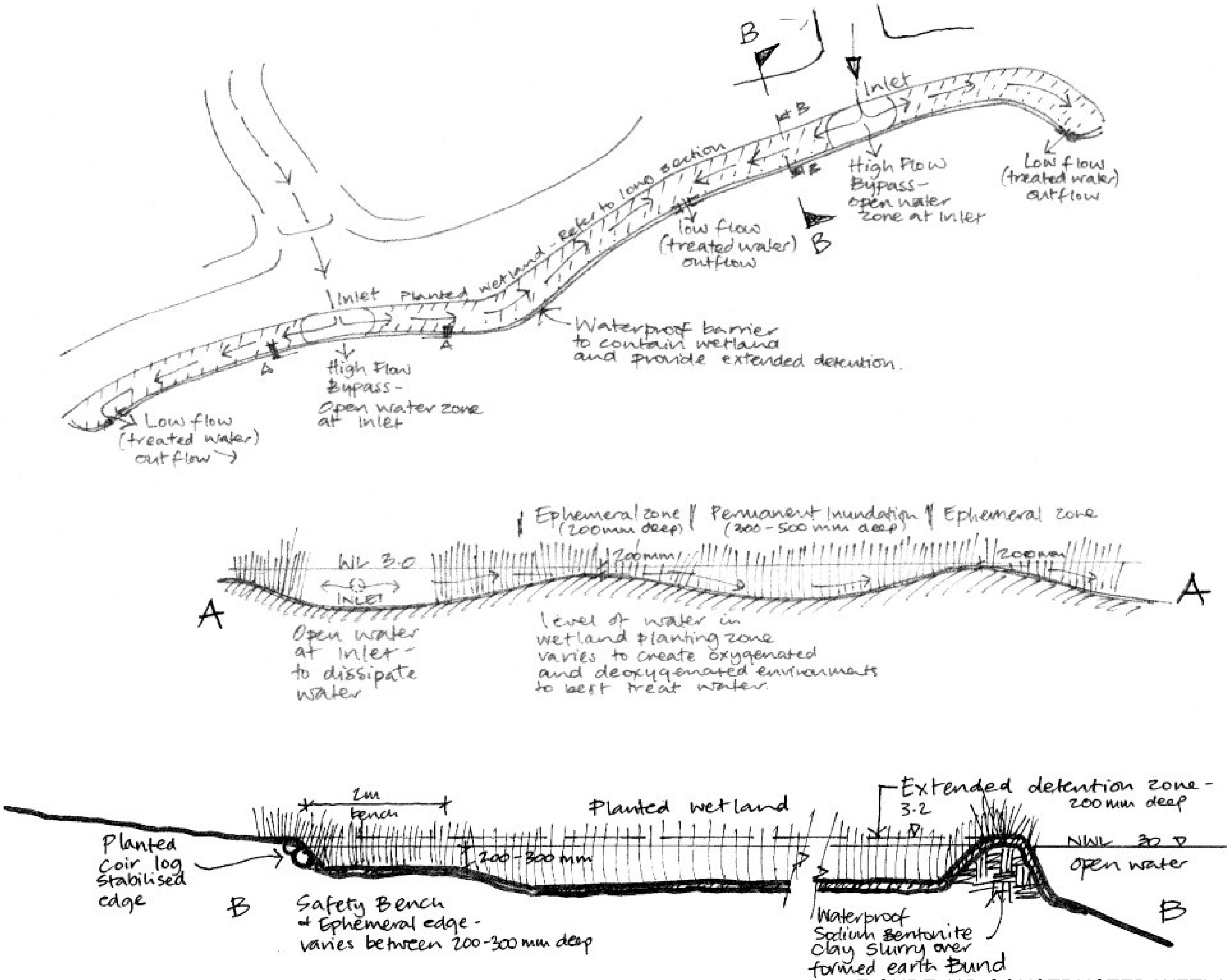
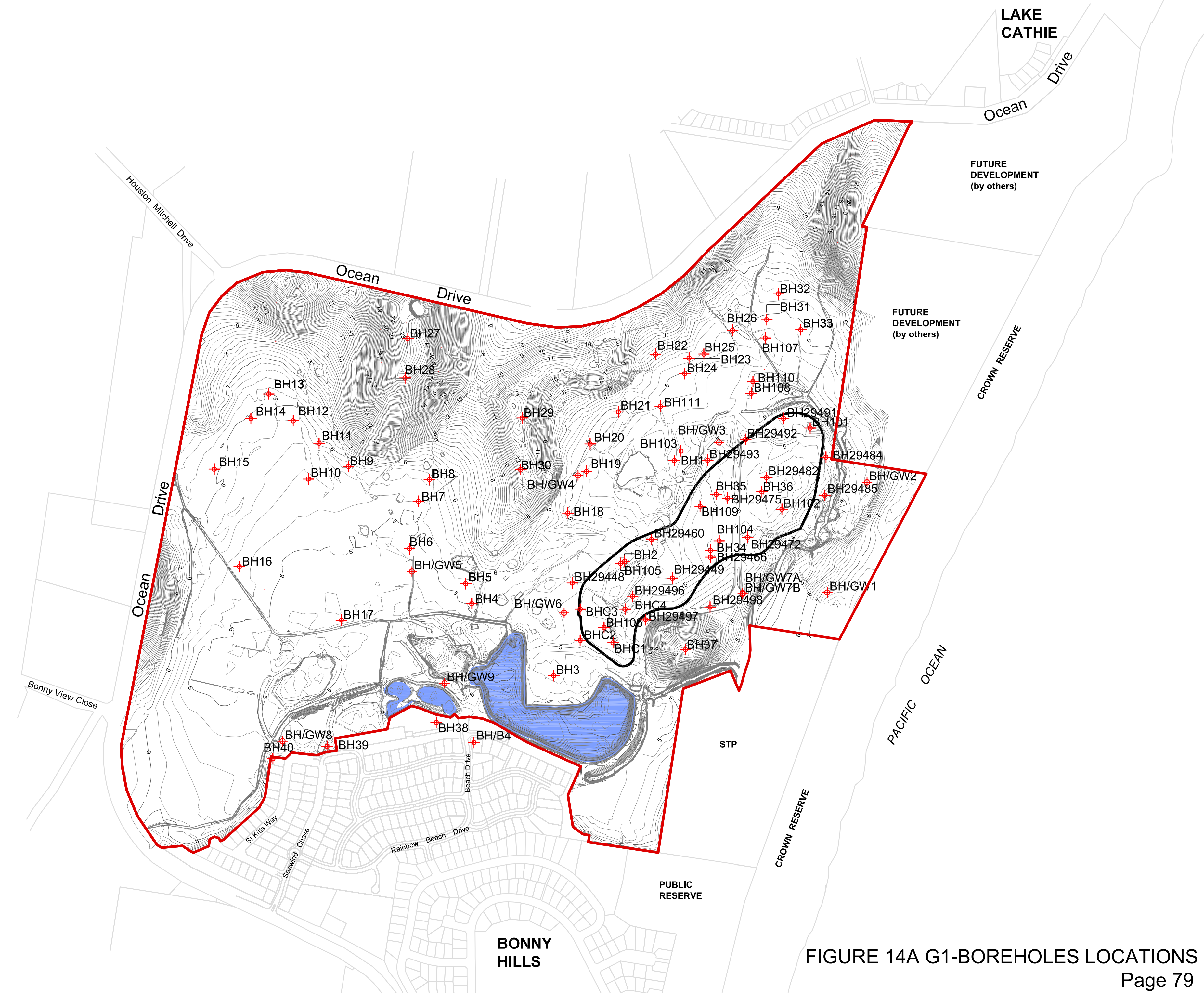


FIGURE 13B CONSTRUCTED WETLANDS DETAILS



BOREHOLE LOCATIONS
Plan G1

SUBJECT LAND

EXISTING CONTOURS 0.20METRE INTERVALS

BH 23 BOREHOLE LOCATIONS AND REFERENCE NUMBERS

REVISIONS
A: 15.1.08
D: 22.4.08
E: 23.9.08
F: 29.10.09

Rainbow Beach Estate
Concept Plan Application Set
Job. No. 4509:ND Dwn: CM
Luke and Company Pty Ltd

Scale:
1:8000@A3 1:4000@A1
The stated scale of this drawing maybe altered by copying.
The scale should be verified prior to deriving measurements from this drawing

0 20 40 100 200 400(M)

FIGURE 14A G1-BOREHOLES LOCATIONS