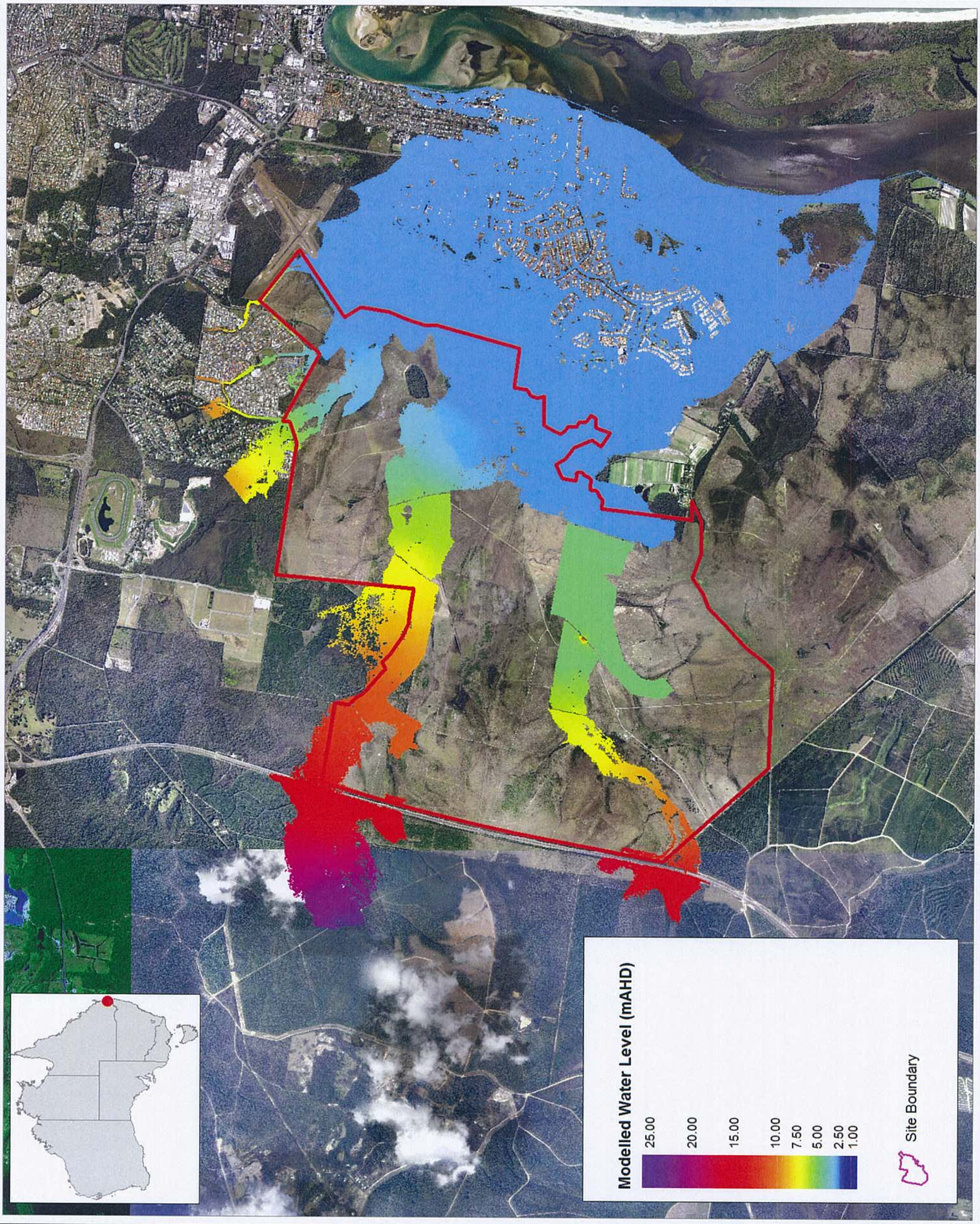


Title:

# Q100 Peak Flood Levels For Developed Case (with Climate Change)

Figure: 3-38

Rev: B



N 0 1.5 3km

Approx. Scale

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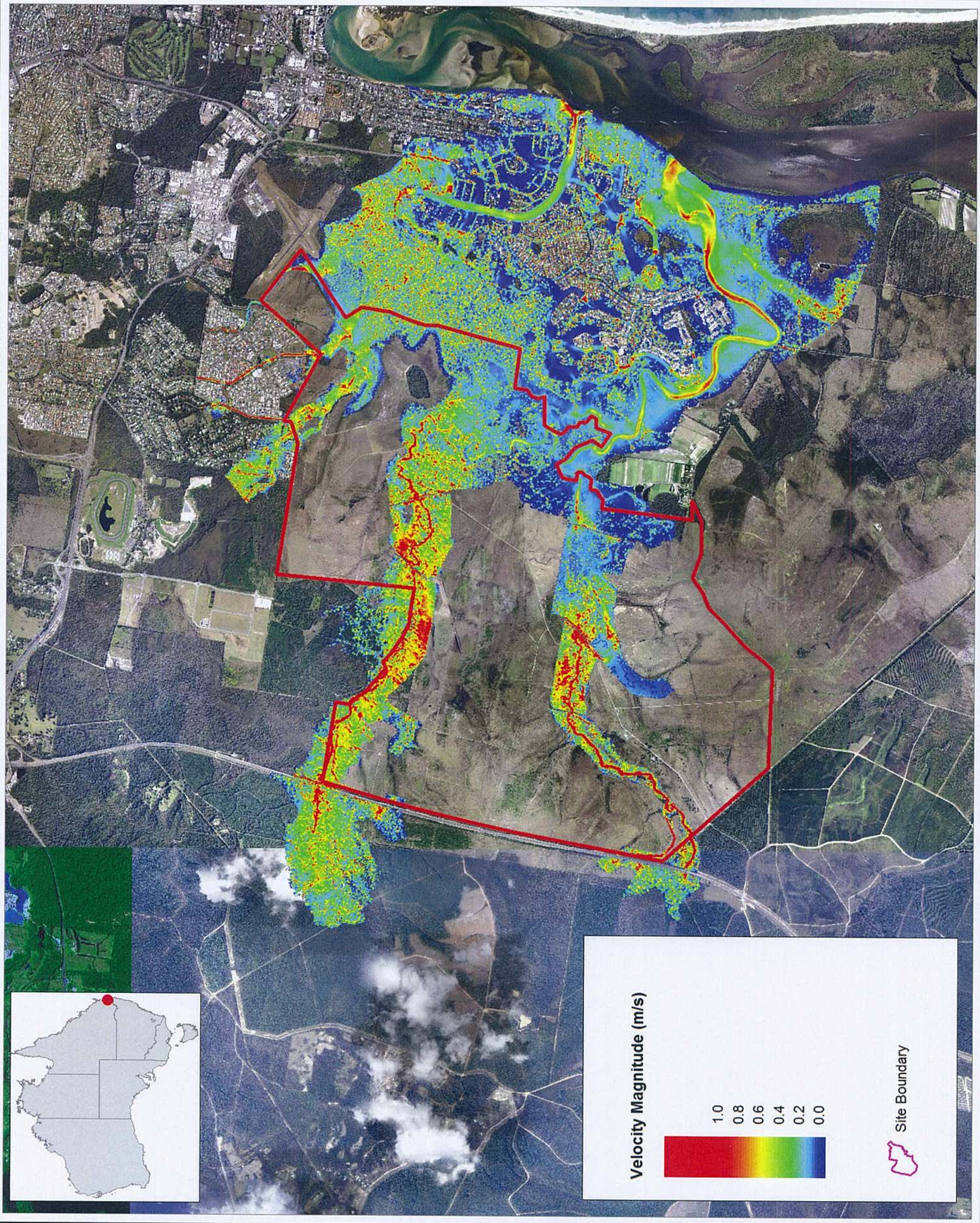


Title:

**Q100 Peak Flow Velocities for Developed Case (with Climate Change)**

Figure: 3-39

Rev: B



N 0 1.5 3km

Approx. Scale

BMT WBM

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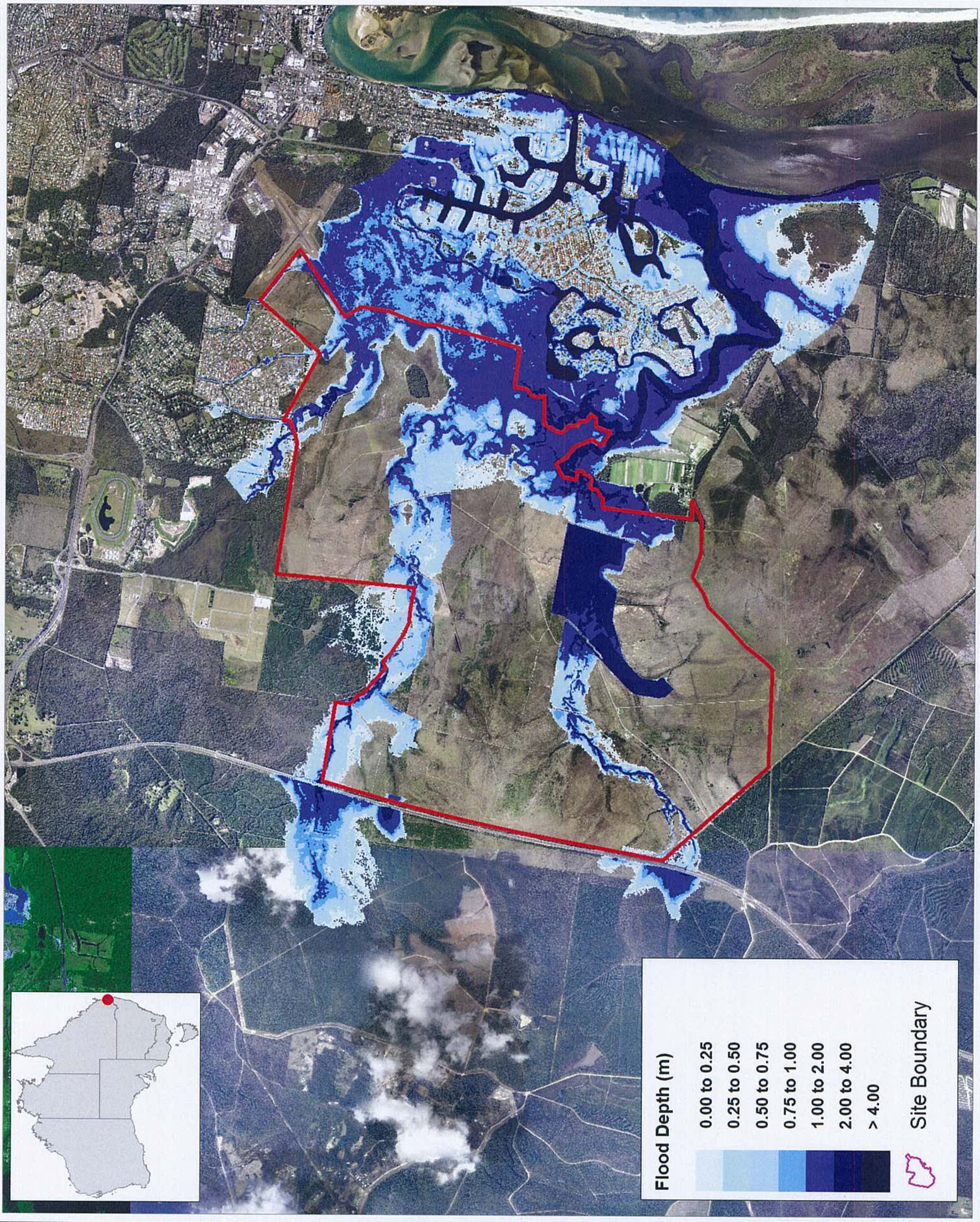


Title:
## Q100 Peak Flood Depth For Development Case (with Climate Change)

Figure: 3-40

Rev: B



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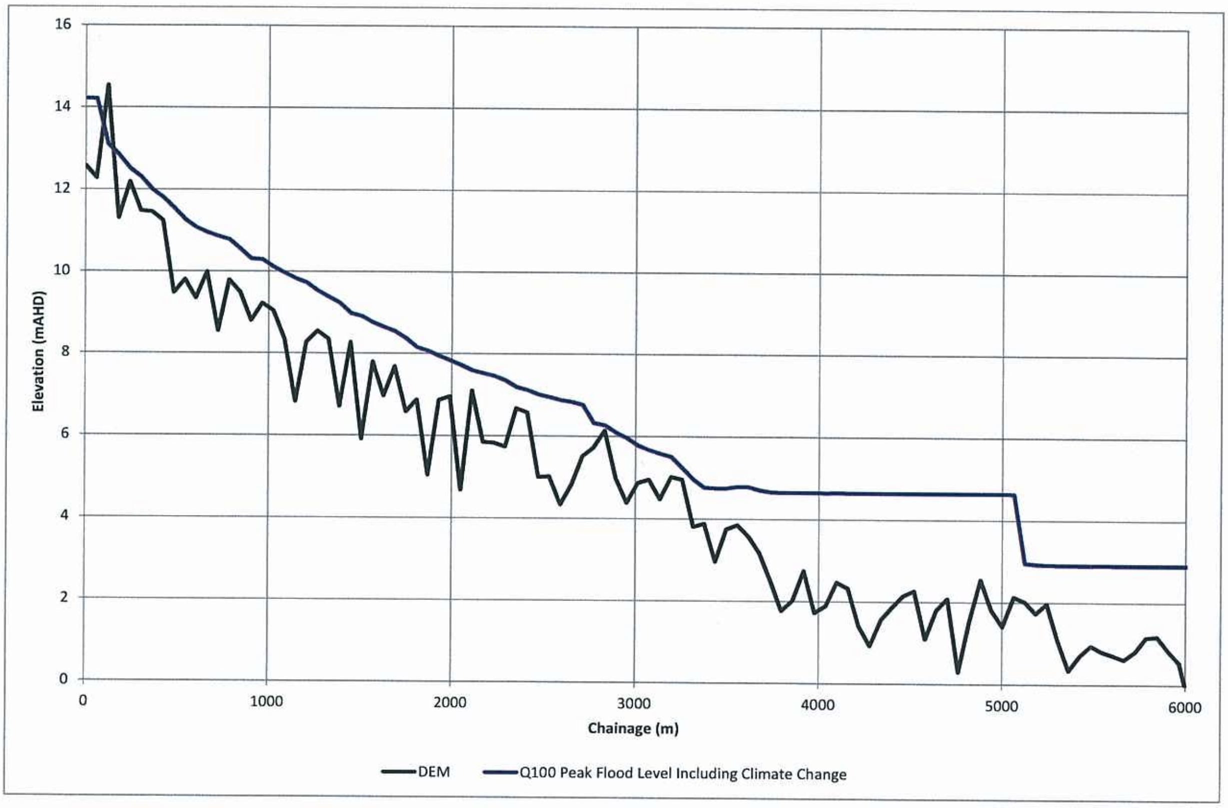



**Figure 3-41 Design Flood Levels (with Climate Change Allowance) along Bells Creek South**

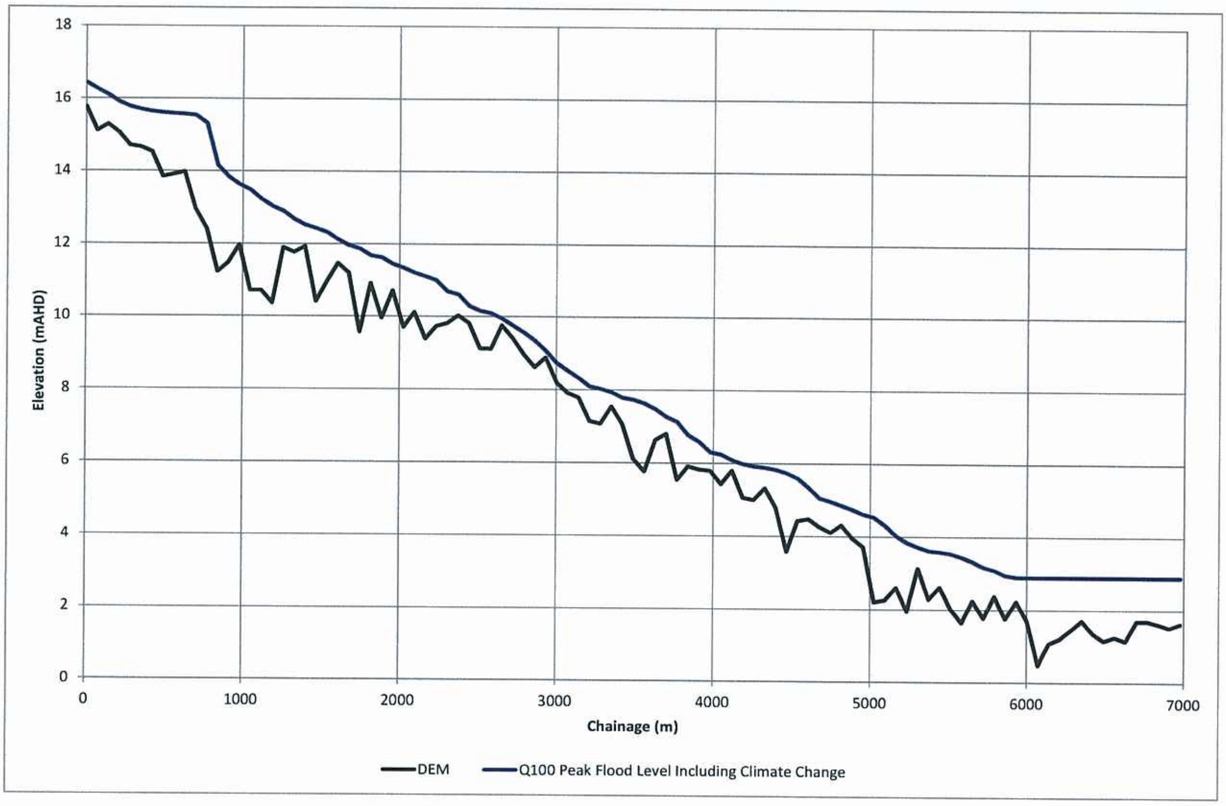



**Figure 3-42 Design Flood Levels (with Climate Change Allowance) along Bells Creek North**

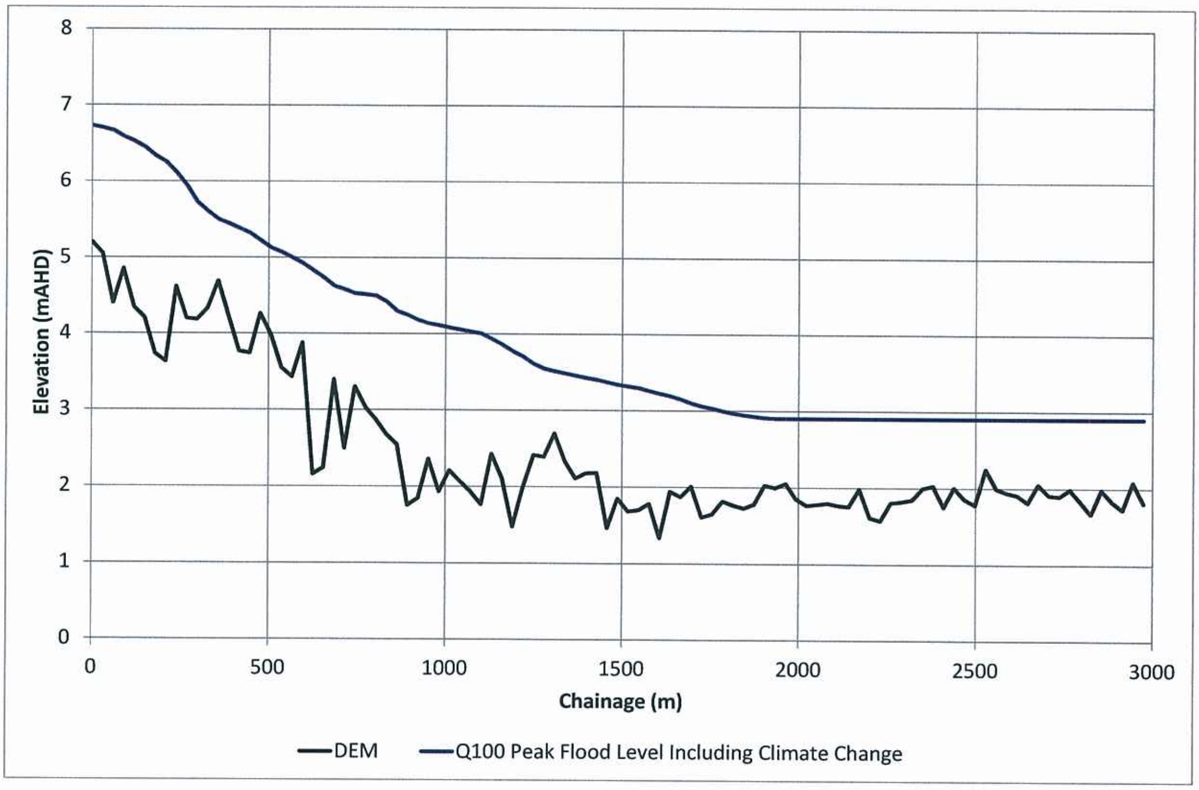
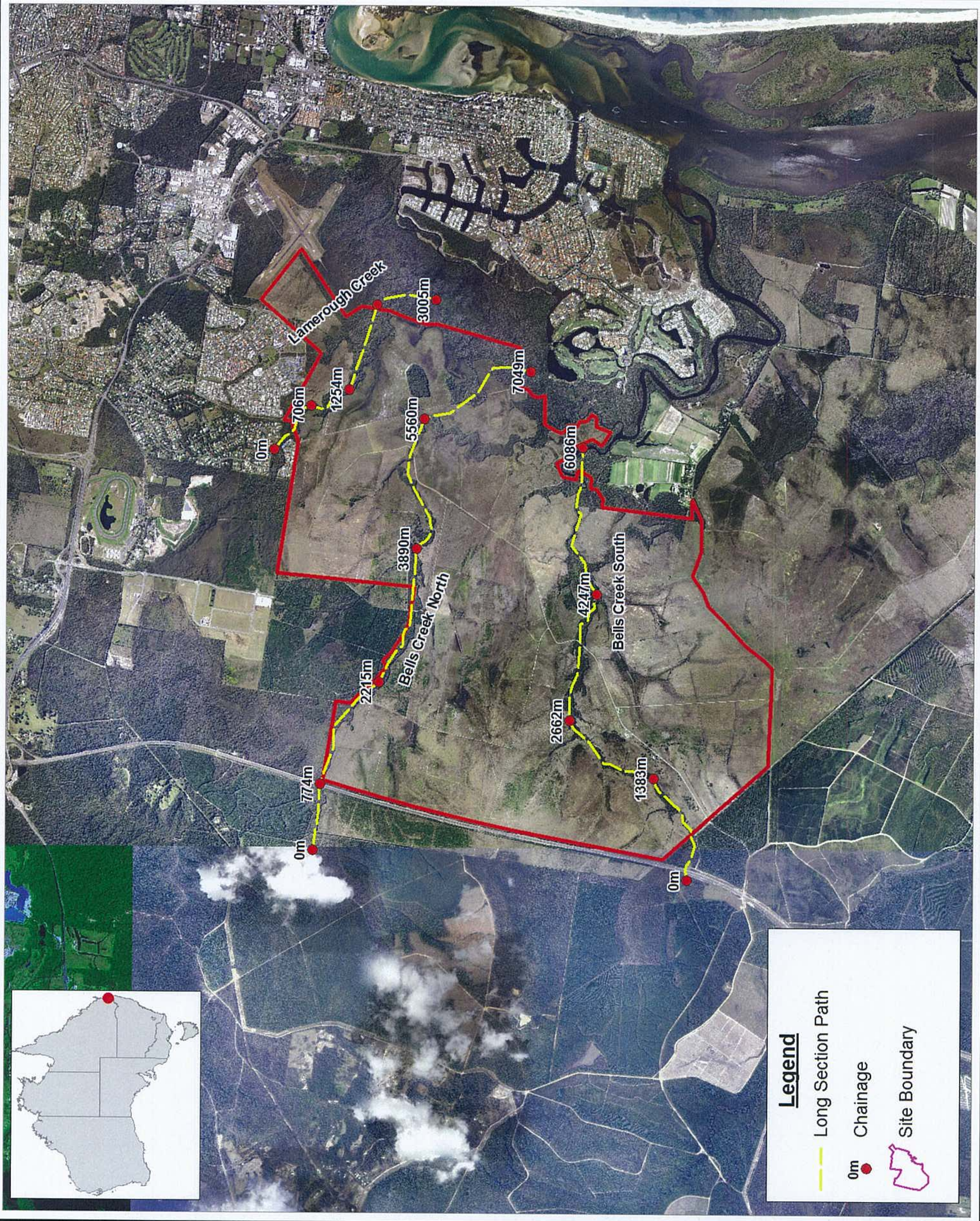



**Figure 3-43 Design Flood Levels (with Climate Change Allowance) along Lamerough Creek**




Title:

**Locations of Long Section Plots along Major Streams**

Figure: 3-44

Rev: A

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N 0 1.5 3km
Approx. Scale

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## 3.7 Conclusions and Recommendations

Flood risk on the Caloundra South site has been investigated by developing hydrology and hydraulic models of the site pre and post development. A flood risk management strategy has been developed incorporating a series of mitigation measures into the proposed development design. The following additional recommendations are drawn from this study:

- The hydraulic model has not been calibrated to historical flood events due to the absence of reliable data. It is therefore recommended that following a significant flood event on site, a set of flood data is recorded and used for model calibration. The current form of the hydraulic model is considered conservative. Thus calibration may result in reduced flood levels which would in turn reduce the planning levels and amount of filling required on the site.
- Post development flood levels have been determined considering climate change and a planning horizon of 2100. These flood levels should be used to determine the planning levels on site thereby mitigating the flood risk to the proposed development.

# 4 STORMWATER MANAGEMENT PLAN

## 4.1 Preamble

This section provides a conceptual assessment and plan relating to the runoff from the site and how it will achieve the given stormwater management objectives during the operational (post-construction) phase of the master-planned community.

## 4.2 Stormwater Management Objectives

From a surface water quality and quantity perspective, there are four (4) key objectives that the development of the Caloundra South site will satisfy, the first two being more water quality focussed and the second two more water quantity focussed. These objectives are as follows:

- The Queensland Department of Environment and Resource Management (DERM) has defined adjacent sections of Pumicestone Passage as having High Ecological Value (HEV) status in the Environmental Protection Policy (EPP) – Water (2009). The commensurate Water Quality Objective (WQO) which accompanies this designation is of the nature of 'no change', but more specifically is quantified as:

  *"maintain existing water quality (20$^{th}$, 50$^{th}$ and 80$^{th}$ percentiles[2])".*

- The Federal Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), with others, has defined large sections of Pumicestone Passage and associated waterways as having Ramsar wetland status. The associated significance criteria which accompany this designation are as follows:
  - Areas of the wetland being destroyed or substantially modified;
  - A substantial and measurable change in the hydrological regime of the wetland (e.g. volume, timing, duration and frequency of surface and groundwater flows);
  - The habitat or lifecycle of native species being seriously affected;
  - A substantial and measurable change in the water quality of the wetland (e.g. salinity, pollutants, nutrients and water temperature) which may adversely impact on biodiversity, ecological integrity, social amenity or human health; and
  - An invasive species that is harmful to the ecological character of the wetland becoming established, or an existing invasive species spreading.
- The development should achieve contemporary water cycle performance objectives as follows:
  - A stretch goal for 2016 of reducing potable water consumption rates across the site to 140 L/p/day, or a 55% reduction on the pre 'Millennium' drought water supply usage rates in the region of 300 L/p/day.
- The development should have acceptable levels of flood immunity, in particular realising the possible long term impacts of climate changes and sea level rise, and also not have any adverse flooding impacts on adjacent inhabited properties.

[2] A **percentile** is the value of a variable below which a certain percent of observations fall. For example, the 20th percentile is the value below which 20 percent of observations may be found.

For the purposes of this report, we have applied that the first objective will require a commensurate objective of 'no increase' in the load of pollutants exiting the site, as diffuse load/stormwater runoff.

## 4.3 Modelling Methodology

### 4.3.1 Software

The eWater CRC *MUSIC* software (Version 5) has been used in this assessment.

### 4.3.2 Source Nodes

Within MUSIC, the user is required to specify source nodes. The source nodes represent the pollutant generating areas of the site.

Rainfall-runoff and pollutant export characteristics for the existing (pre developed) site have been developed based on the data collected as part of BMT WBM's baseline monitoring program at the Caloundra South site (documented in BMT WBM's "*Caloundra Downs: Baseline Monitoring Program Final Report*"). The MUSIC source node properties (ie. rainfall-runoff and pollutant export characteristics) applied for the 'existing site' (and the methodology used to derive them) are described in Appendix A.

Land usage classifications for the proposed site have been based on development layout plans provided by Stockland, which are very similar to the proposed development layout illustrated in Figure 2-3.

The MUSIC source node properties for the existing site have been applied to areas classified as 'conservation', 'linear park drainage corridor', 'waterway corridor', and 'open space' areas. Rainfall-runoff and pollutant export characteristics as given by Water By Design's (2010b) "*MUSIC Modelling Guidelines*" have been applied for the other land usage classifications (see Figure 2-3) as follows:

- *Industrial*: for the 'industry and business' areas.
- *Residential*: for 'mixed residential' and 'urban living' areas.
- *Residential Ground Level*: for 'small park', 'district park' and 'major sport' areas.
- *Residential Road*: for all major 'road' areas.
- *Commercial*: for all 'centres', all 'community', health hub and showroom.

Each of the industrial, residential and commercial land usages were further separated into lot, road reserve and ground level areas, based on the land usage breakdown as recommended by Water By Design (2010b). Pollutant export properties for these land use types were also applied from Water By Design (2010b).

An effective impervious percentage of 0% was assumed the existing site and all 'conservation', 'linear park drainage corridor', 'waterway corridor', 'open space', 'small park', 'district park' and 'major sport' areas. Effective impervious percentages for the other areas were based on recommended values given in Water By Design (2010b).

For the purposes of this conceptual study, the site has not been separated into individual sub-catchments.

### 4.3.3 Meteorological Data

Modelling was performed for a period of ten years (from 1st January 1997 to 31st December 2006), using recorded pluvio data from Caloundra WTP (Station 40496) and monthly aerial PET. The application of this meteorological data is in accordance with Water by Design's (2010) "*MUSIC Modelling Guidelines*".

While some years were "dry", it is more important in the MUSIC model to ensure that a reasonable spread of individual rainfall events is represented, rather than just whether the annual rainfall was low or high. For these reasons, the Caloundra WTP data is the best available given its proximity to the site and the period of time (10 years) of data available.

### 4.3.4 Results

Table 4-1 provides a comparison of the predicted flows and pollutant loads from the existing site and the developed site (without stormwater quality management).

**Table 4-1 Predicted Annual Pollutant Loads (1997-2006) – Existing Site v Developed Site (With No Treatment)**

| Parameter | Existing Site | Developed Site With No Treatment | % Increase |
|---|---|---|---|
| **Flow (ML/yr)** | 10 600 | 17 400 | 64% |
| **TSS (kg/yr)** | 96 900 | 2 370 000 | 2346% |
| **TP (kg/yr)** | 408 | 5 170 | 1167% |
| **TN (kg/yr)** | 10 700 | 33 900 | 217% |
| **Gross Pollutants (kg/yr)** | 0 | 311 000 | - |

As shown by the results in Table 4-1, in its existing (mostly cleared) condition, the site contributes surface water runoff to relevant receiving waters. The results also show that the proposed development (without stormwater treatment) would be predicted to result in a significant increase in stormwater pollutant loads (relative to the existing site).

Extremely high rates of stormwater pollutant removal will be required to achieve a 'no increase' in stormwater pollutant loads. It will be necessary to achieve stormwater pollutant load reductions significantly greater than that considered 'best practice' (ie. 80% removal for Total Suspended Solids loads, 60% for Total Phosphorus and 45% for Total Nitrogen as outlined in Queensland Government's (2009) "*Implementation Guideline No. 7*".).

## 4.4 Proposed Strategy

A 'beyond best practice' stormwater management strategy consisting education, rainwater harvesting tanks, rain gardens, ephemeral wetlands, lakes, shallow wetlands and environmental protection and rehabilitation has been proposed for the site of the proposed development. The 'treatment train' is illustrated in Figure 4-1. Details of the SMMs proposed for use on the site and how they will be configured are presented in the following sub-sections.

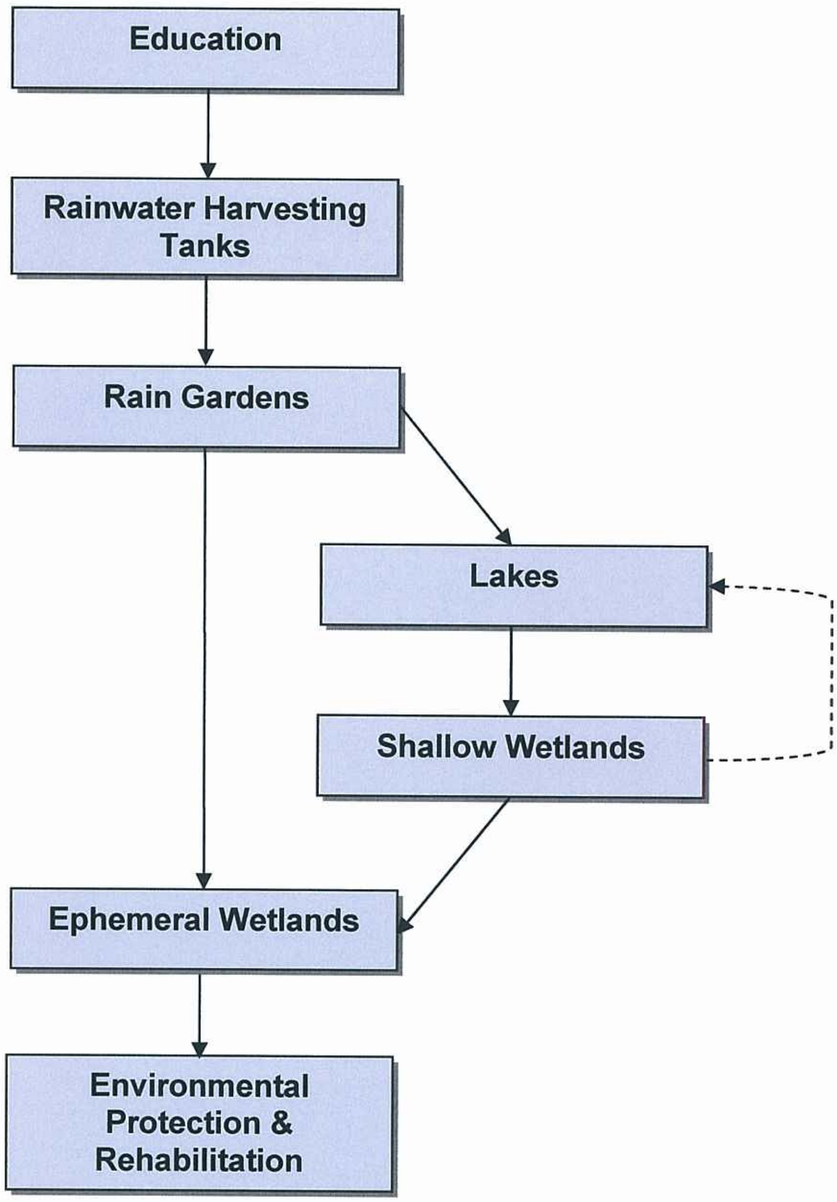



**Figure 4-1 Proposed Stormwater Treatment Train for the Site**

These stormwater management measures are described in the following sub-sections.

### 4.4.1 Education

Education has significant potential to decrease pollutant loads at the source and increases people's understanding and acceptance of water quality issues and stormwater treatment devices. It is proposed that signage be installed at appropriate locations (eg. adjacent to proposed bioretention systems).

It should also be noted that education will need to be ongoing, and relate to pre- and post-development for all stakeholders.

An example of educational signage to improve understanding of water quality issues is given in Figure 4-2. While the potential for pollutant load reduction due to education is noted, it has not been assumed within the MUSIC model.


**Figure 4-2 Examples of Signage to Improve Understanding of Water Quality Issues**

### 4.4.2 Rainwater Tanks

It is proposed that every allotment will be required to install a rainwater tank to collect roof runoff, in order to supplement non-potable water demands and comply with Queensland Development Code (QDC) MP4.2 and MP4.3. The rainwater tanks for each land usage classification (eg. 'mixed residential') in each subcatchment have been represented in the MUSIC model as a single 'Rainwater Tank' for each of the classifications.

For this assessment, it has been assumed that all residential lots are detached lots with 5kL rainwater tanks for all residential lots. The rainwater tank requirements (outlined in Queensland Development Code (2009) for 'small buildings' (of a rainwater tank volume of 1500 litres for every 50m$^2$ of roof area) have been applied for areas designated as 'industrial' and 'commercial'. Rainwater tank demands have been modelled in accordance with Water By Design (2010b). The entire roof area was assumed to drain to a rainwater tank – for residential, commercial and industrial land usages.

The use of rainwater tanks to supplement potable water demands will significantly reduce peak and volumetric stormwater discharges from the site and substantially reduce mains water demand.

### 4.4.3 Rain Gardens

A 'rain garden' (or 'bioretention system') is a soil and plant-based stormwater management measure. A typical system consists of a porous medium such as sandy loam. Vegetation is also established within the rain garden to promote evapotranspiration, maintain soil porosity, encourage biological activity, and promote uptake of some pollutants. Run-off is directed into the rain garden and infiltrates through the plant/mulch/soil environment. Figure 4-3 provides examples of streetscape (or similar 'ground level') rain gardens.


**Figure 4-3 Examples of Streetscape Rain Gardens**

It is anticipated that the rain gardens will be integrated into the streetscape and/ or linear drainage corridors within the development. It is anticipated that the majority of the rain gardens will be integrated into the streetscape, and receive stormwater flows from adjacent surface areas prior to discharging into the piped drainage system.

For the purposes of this conceptual report, we have provided an estimate of the approximate filter area (and, of less importance in terms of overall treatment effectiveness, surface area) as a percentage of development area (excluding conservation areas) required for rain gardens within the proposed development. The configuration, size and number of the individual rain gardens required to satisfy the given WQOs will be determined during subsequent design stages. However, it is anticipated that the rain gardens will be included in the road reserve (or, if present, adjacent open space areas) of the developed areas at numerous locations.

All rain gardens has been assumed to have a filter depth of 0.6m and an extended detention depth of 0.2m. The filter media for the rain garden has been modelled as a sandy loam media of effective diameter 0.45 mm and a saturated hydraulic conductivity of approximately 200 mm/hr.

Figure 4-4 provides a conceptual cross section of a rain garden, illustrating the modelled properties of the system.

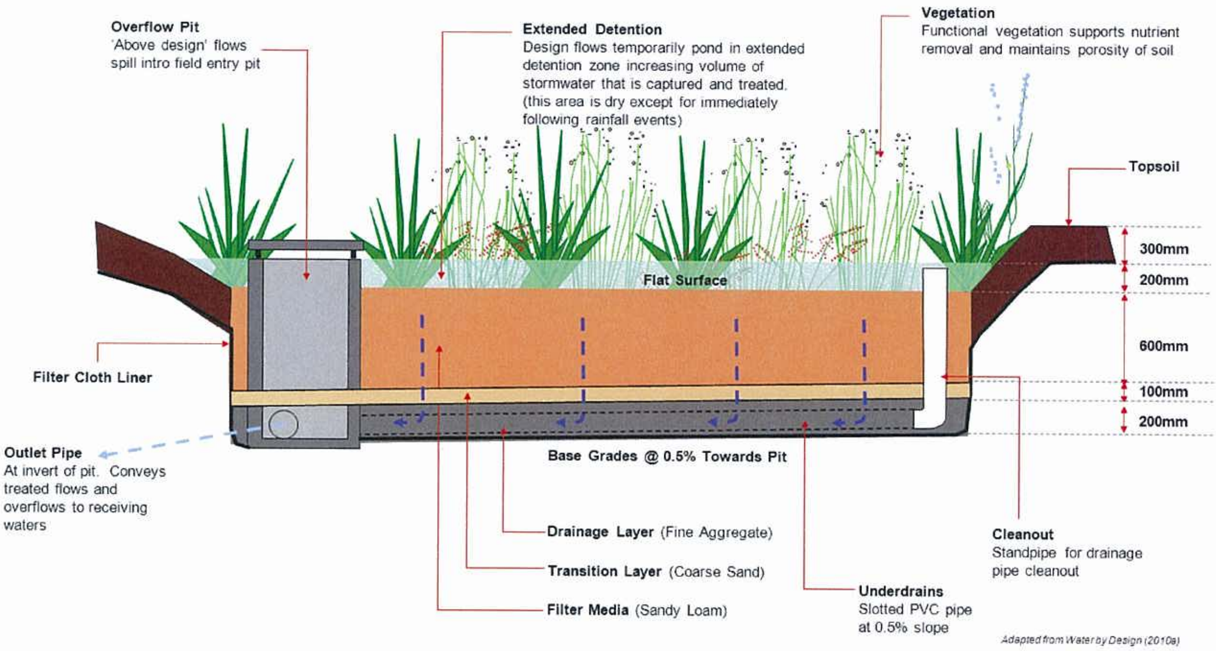



**Figure 4-4 Conceptual Cross Section of Rain Garden Properties**

### 4.4.4 Potential Lakes

A constructed lake is "*an artificial body of permanent open water with either an edge that may be fringed with emergent macrophytes or a hard edge. While submerged macrophytes may occur throughout the water column, the dominant feature is open water*" (Mackay City Council, 2008).

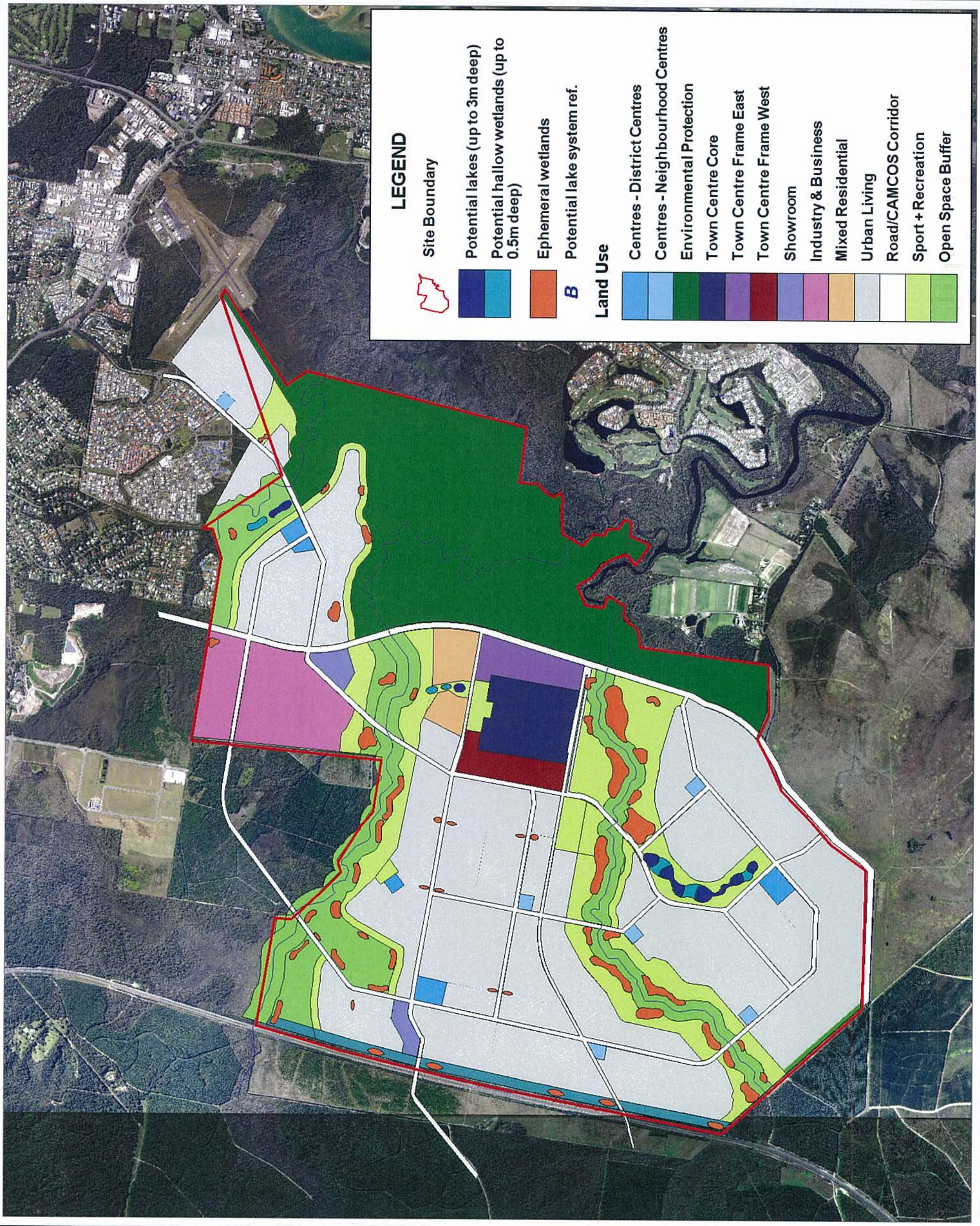
Examples of lakes are provided in Figure 4-5.


**Figure 4-5 Examples of Lakes**

Potential constructed lakes are proposed at three locations within the site. Figure 4-6 illustrates the proposed location and extent of the proposed lakes.

Potential lake system A is located within the gully area immediately south of Bells Creek South and is proposed to extend over an area of approximately 19 hectares. It is proposed that this potential lake system will consist of a combination of open water and densely vegetated macrophyte zones (or 'shallow wetland areas'). The proposed indicative configuration of this potential lake system is illustrated in Figure G-2.

Potential lake system B is located near the CBD area and is proposed to extend over approximately 0.6 hectares. Potential lake system C is located immediately west of the Lamerough Creek waterway buffer and will extend over approximately 1.2 hectares. It is anticipated that both potential lake systems B and C will be predominantly open water.




Title:
**Indicative Location of Potential Wetlands & Lakes**

Figure: 4-6

Rev: C

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The potential lakes will be primarily created for visual amenity, but will also allow enhance the community's understanding, experience and engagement with the water cycle. The potential lakes will be designed and operated with careful consideration to best practice design guidelines and experience to maximise their sustainability and minimise any risk of operational problems.

It is anticipated that 'polishing' of lake waters will be provided by recirculation of lake waters through 'shallow wetland areas' (see Section 4.4.5). Appendix H provides further information in relation to the design, operation and management of the potential lakes.

Although considered part of the 'stormwater treatment train' for the site, their stormwater treatment performance has not been included within the MUSIC modelling for the site.

### 4.4.5 Shallow Wetlands

Potential shallow wetland areas are proposed at three separate areas within the site. Potential shallow wetland areas are proposed to be integrated within Lake System A. Two other potential shallow wetland areas will be integrated in to site adjacent to Lake Systems B and C.

It is proposed that these potential wetland areas be shallow (up to 0.5m maximum permanent depth of water) and densely vegetated – similar to typical macrophyte zones in conventional stormwater wetland systems. Examples of constructed shallow wetlands are provided in Figure 4-7.


**Figure 4-7 Examples of Shallow Wetlands**

These shallow wetlands will perform two key water quality improvement functions:

- *Treatment of stormwater flows*: The wetland areas will receive (and provide additional treatment to) stormwater flows from upstream catchment areas (following treatment by upstream 'rain gardens').
- *Treatment of recirculated lake waters*: As outlined in the previous section, lake waters will be recirculated through the 'shallow wetland areas' for 'polishing' (removal of pollutants and to limit algal growth). 'Polished' waters from the shallow wetland areas will then discharge (by gravity drainage or pumping) to the downstream or adjacent open waters of the lake system.

Further information in relation to the wetlands and their role in the treatment of recirculated lake waters is provided in Appendix H.

### 4.4.6 Ephemeral Wetlands

'Ephemeral wetlands' (or 'bioretention basins') are proposed to provide treatment to flows pre-treated by rainwater tanks and rain gardens (and, where present upstream, shallow wetlands).

These ephemeral wetlands will be incorporated at multiple locations throughout the site, downstream of the rain gardens (but external to the waterway buffer and environmental protection areas). Figure 4-6 provides an indicative location of the proposed ephemeral wetlands.

The ephemeral wetlands have been modelled as bioretention systems for several reasons, including:

- It is proposed that the ephemeral wetlands will be predominantly dry and densely vegetated (similar to bioretention systems);
- It is proposed that the ephemeral wetlands will be planted with vegetation with effective nutrient removal plants (e.g. melaleuca *spp*). The additional treatment provided by these types of vegetation can be modelled in 'bioretention' treatment nodes (but not 'wetland' treatment nodes);
- It is proposed that the ephemeral wetlands be constructed with sandy loam filter media (like a bioretention system, as shown in Figure 4-9 of the IWMP), augmenting additional treatment of stormwater flows prior to infiltrating into the surrounding soil profile; and
- In effect, these systems will operate identically to a biofilter though without an underflow drain. They are not specifically infiltration systems, as infiltration systems only facilitate water movement into the soil and are not typically designed to provide significant treatment. The ephemeral wetlands will ensure that the water that is infiltrated into the subsoil is effectively treated and hence the bioretention node in MUSIC best simulates this.

Of significance, when the development proceeds the wetlands provide the opportunity to be used for regional stormwater harvesting purposes and such use will totally prevent any pollutants in the water which is extracted from them reaching receiving waters. This process was simulated in MUSIC via the use of infiltration whereas in reality stormwater reuse will occur. This is a highly conservative assumption within the catchment pollutant export modelling.

For the purposes of this master planning report, we have provided an estimate of the approximate filter area (and, of less importance in terms of overall treatment effectiveness, surface area) as a percentage of development area (excluding conservation areas) required for ephemeral wetlands within the proposed development. The configuration, size and number of the individual ephemeral wetlands required to satisfy the given WQOs will be determined during subsequent design stages. However, it is anticipated that ephemeral wetlands will be integrated into the site as 'end-of-pipe' SMMs within open space (and similarly landscaped) areas.

Examples of bioretention basins are provided in Figure 4-8. Figure 4-9 provides a conceptual cross section of an ephemeral wetland, illustrating the modelled properties of the system.

The ephemeral wetlands will not be lined, and will be allowed to infiltrate/ seep incoming stormwater inflows into the in-situ soil (and underlying groundwater). Therefore, in addition to the treatment mechanisms that the areas will provide above the ground surface, a portion of the flows that enter the ephemeral wetlands have assumed to infiltrate/ seep into the in-situ soil (and underlying groundwater). A seepage rate of 25mm/ hour has been assumed within each of the ephemeral wetlands.

It should be noted that Water By Design (2010b) states that it is not appropriate to incorporate seepage/exfiltration into treatment nodes (eg. bioretention basin treatment nodes) when demonstrating compliance with load removal targets. We believe that it is reasonable to include a seepage rate – provided certain site requirements are present. It should be stressed, however, that soil investigations will be required to determine the feasibility of the basins (and their capacity to infiltrate incoming stormwater flows).


**Figure 4-8 Examples of Bioretention Basins**

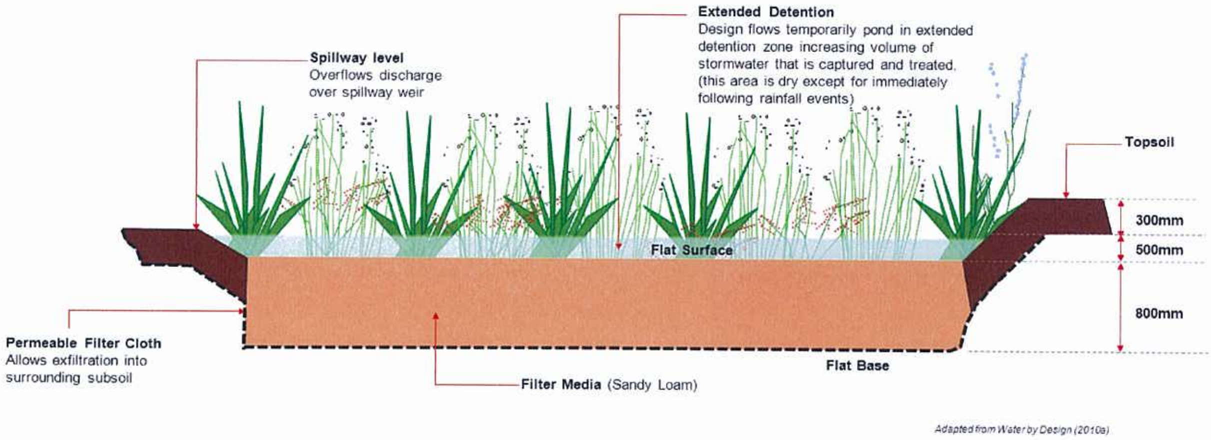


**Figure 4-9 Conceptual Indicative Cross Section of Ephemeral Wetland Properties**

### 4.4.7 Environmental Protection and Rehabilitation

As illustrated in Figure 2-3, a large portion of the site is designated for 'environmental protection' and 'waterway buffers'. These conservation and waterway corridor areas extend over an area of 135 and 443 hectares respectively, which is over 24% of the site area.

It is understood that these areas will be protected and rehabilitated (with extensive revegetation to remediate existing and historical land usage practices, including cattle grazing and pine plantation activities).

It is anticipated that the protection and rehabilitation of these areas will significantly improve the health of downstream waterway areas, through improved catchment hydrology and reduced pollutant loads. Furthermore, the linear drainage corridors are also anticipated to provide additional stormwater treatment. However, the benefits of these activities/areas has not been modelled as part of our assessment. As described in Section 4.3.2, these areas have been modelled with MUSIC source nodes properties identical to the existing site.

This approach is expected to be conservative and likely to under-estimate the stormwater-related benefits of the proposed stormwater management strategy for the site.

### 4.4.8 Treatment Node Properties

The properties of the various stormwater management measures (as modelled in MUSIC) are summarised in Table 4-2.

**Table 4-2 Summary of Modelled Properties for Rainwater Tanks**

| Area Receiving Treatment | Volume Below Overflow (m³) | Surface Area (m²) | Equivalent pipe diameter (mm) | Total annual external demand (kL/year) | Daily internal demand (kL/day) |
|---|---|---|---|---|---|
| **All** | Rainwater tanks for each of the above areas have been modelled using a single 'Rainwater tank' node (for each of the below areas). With 0.2m depth above overflow and annual (external) demand scaled by 'PET – Rain'). See Section 4.4.2 for further information. | | | | |
| **Roof Areas of 'Centres – District Centres' Areas** | 1 679 | 933 | 1738 | 17 888 | 49 |
| **Roof Areas of 'Centres – Neighbourhood Centre' Areas** | 12 148 | 633 | 1433 | 12 148 | 33 |
| **Roof Areas of 'Centres – Retail' Areas** | 2 657 | 1 476 | 2 187 | 28 316 | 78 |
| **Roof Areas of 'Commercial & Office' Areas** | 947 | 526 | 1 305 | 10 089 | 28 |
| **Roof Areas of 'Community' Areas** | 4 821 | 2 678 | 2 946 | 51 368 | 141 |
| **Roof Areas of 'Showroom' Areas** | 13 162 | 7 312 | 4 867 | 14 960 | 51 |
| **Roof Areas of 'Industry & Business' Areas** | 12 701 | 7 056 | 4 781 | 108 268 | 371 |
| **Roof Areas of 'Mixed Residential' Areas** | 3 166 | 1 759 | 2 387 | 30 359 | 93 |
| **Roof Areas Of 'Residential' Areas** | 64 451 | 35 806 | 10 771 | 1 556 660 | 1 885 |

Note: It should be noted that rainwater tank modelling properties are approximate only.

**Table 4-3 Summary of Modelled Properties for Rain Gardens & Ephemeral Wetlands**

| Parameter | Rain Gardens | Ephemeral Wetlands | Comments |
|---|---|---|---|
| Area receiving treatment | All areas (excluding park, open space, major sport, linear drainage corridor, waterway corridor and environmental protection areas) | All areas (excluding waterway corridor and environmental protection areas) | |
| Treatment Node Type | Bioretention | | |
| Filter Area ($m^2$) | 300 000 (1.7% of total development area) | 730 000 (4.1% of total development area) | 'Total development area' excludes 'waterway corridor' and 'environmental protection' areas |
| Extended Detention Depth (m) | 0.20 m | 0.5m | |
| Saturated Hydraulic Conductivity (mm/hr) | 200 | | In accordance with Water By Design (2010b) |
| Filter Media Soil Type | Loamy Sand | | |
| Filter Depth (m) | 0.60 | 0.80 | |
| Submerged Zone Depth (m) | 0 | | |
| Surface Area / Filter Area ratio | 1 | | Approximation for modelling purposes in accordance with Water By Design (2010b) |
| Overflow weir width | Filter area/ 10 | | |
| TN Content of Filter Media (mg/kg) | 125* | | Filter media properties based on media test results (see Appendix B) |
| Orthophosphate Content of Filter Media (mg/kg) | 19* | | |
| Vegetation Properties | Vegetated with Effective Nutrient Removal Plants | | See FAWB (2009) |
| Exfiltration Rate (mm/hr) | 0.00 | 25 | See section 1.1.1 for ephemeral wetlands. |

## 4.5 Model Results

Total annual flow and pollutant loads from the site for each scenario are presented in Table 4-4. These values represent the flow and loads that are predicted to discharge from the Caloundra South site.

**Table 4-4 Predicted Annual Pollutant Loads (1997-2006)**

| Parameter | Existing Site | Developed Site with No Treatment | Developed Site With Treatment | % Removal | % Decrease from Existing Site |
|---|---|---|---|---|---|
| Flow (ML/yr) | 10 600 | 17 400 | 5 550 | 68% | 48% |
| TSS (kg/yr) | 96 900 | 2 370 000 | 93 900 | 96% | 3% |
| TP (kg/yr) | 408 | 5 170 | 406 | 92% | 0% |
| TN (kg/yr) | 10 700 | 33 900 | 6 200 | 82% | 42% |
| Gross Pollutants (kg/yr) | 0 | 307 000 | 0 | 100% | - |

As shown by the results presented above, with the integration of the proposed stormwater management strategy, significant reductions in stormwater pollutant loads can be achieved. A 'no worsening' in stormwater pollutant loads from the site can be achieved with the proposed development (and associated stormwater management strategy).

## 4.6 Maintenance Plans

Indicative maintenance plans for the rain gardens and ephemeral wetlands are provided in Appendix C. Appendix G includes an indicative maintenance plan for the lake (and shallow wetlands).

## 4.7 Construction and Establishment

The rain gardens and ephemeral wetlands will need to be constructed and established in accordance with Water By Design (2010b) *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands.*

A construction and establishment plan for the lakes (and shallow wetlands) will be prepared at a later design stage.

## 4.8 Asset Hand-over

It is expected that the proposed rain gardens, lakes, shallow wetlands and ephermal wetlands (including responsibility for all ongoing maintenance requirements) will eventually be 'handed over' to Sunshine Coast Regional Council.

## 4.9 Summary

This stormwater management plan has provided a conceptual stormwater management strategy for the proposed development. A stormwater 'treatment train' consisting of rainwater tanks, rain gardens, lakes, shallow wetlands, ephemeral wetlands and protection and rehabilitation of environmental areas has been proposed for the site.

The modelling results show that with the integration of the proposed stormwater management strategy, the pollutant export loads from the site can be significantly reduced compared to the unmitigated scenario – and achieve a 'no worsening' in pollutant loads (relative to the existing site).

# 5 GROUNDWATER QUANTITY AND QUALITY ASSESSMENT

## 5.1 Preamble

This section provides an assessment of groundwater quantity and quality for the Caloundra South site. The assessment has included a hydrogeological conceptualisation of the site and the development of a robust and defensible groundwater model for the site.

## 5.2 Aim of Groundwater Modelling

The Caloundra South site is characterized by poor drainage and shallow groundwater levels. To the east of the site there are natural landscapes that include groundwater dependent wetland systems. Any hydrological interventions at the site to manage groundwater should not result in adverse groundwater level impacts beneath the wetland systems to the east of the site.

Successful development of the site will require an integrated development planning process that would be expected to include (but not be limited to) works to:

- Achieve an earthworks balance to fill development areas currently subject to inundation;
- Drain areas of shallow groundwater in areas proposed to be developed; and
- Achieve management of groundwater recharge rates through strategic retention of deep rooted vegetation and potentially strategic revegetation with deep rooted plant species.

A groundwater flow model was therefore required to simulate:

- Spatial/temporal changes in groundwater levels across the site in response to altered land uses and land profiles (i.e. cut and fill) including the implementation of major surface drains; and
- Changes to discharge of groundwater seepage to the catchment to support further consideration of surface water quality management.

The aim of the groundwater modelling was to provide a tool to allow the development of successful planning and the iterative development of integrated hydrological solutions to address both groundwater and surface water issues.

## 5.1 Previous Investigations

The hydrogeological system at the Caloundra South site has been extensively investigated since 2002 and has been well documented. All relevant data and reports were obtained and reviewed in the process of undertaking this study.

## 5.2 Background Data

### 5.2.1 Climate

There are a number of sources of climate data for the Caloundra South site. These include:

- Formal Bureau of Meteorology climate and rainfall sites;

- A pluviograph installed at the site for this project; and
- Interpolated climatic data drawn from the SILO data drill facility.

For the purposes of the groundwater modelling exercise, interpolated climatic data from the SILO data drill were adopted.

#### *5.2.1.1 SILO Data*

The SILO Data Drill facility was used to obtain long-term rainfall data for the site. Over a 121 year period, the following annual rainfall statistics were generated for the site:

- Average annual rainfall – 1,521 mm;
- Minimum annual rainfall (year 1902) – 460 mm;
- Median annual rainfall – 1,458 mm;
- Maximum annual rainfall (year 1893) – 3,183 mm; and
- Standard deviation in annual rainfall – 421 mm.

From this data, it is evident that annual rainfall at the site is highly variable.

Figure 5-1 provides a plot of annual rainfall at the site drawn from the SILO data. From Figure 5-1 it is readily apparent that there had been a series of largely below mean and median rainfall years between 2000 and 2008 with the exception of 2003 when average rainfall (1,521 mm of rainfall) occurred. Rainfall since this time has been above mean and median annual rainfall with 1,683 mm of rain recorded for 2009 and very significant wet weather being recorded during 2010. To November 2010, the SILO data drill indicates that 1,680 mm of rain had fallen at the site and significant early wet season rainfall occurred since this time. Figure 5-2 provides a plot of cumulative residuals of monthly rainfall from mean monthly rainfall, and monthly rainfall, to the end of October 2010. Such plots provide an indication of the state of the groundwater storage where groundwater storages are most strongly influenced by rainfall recharge and where there is no immediately adjacent groundwater discharge site that might otherwise act as a control on maximum groundwater elevations.

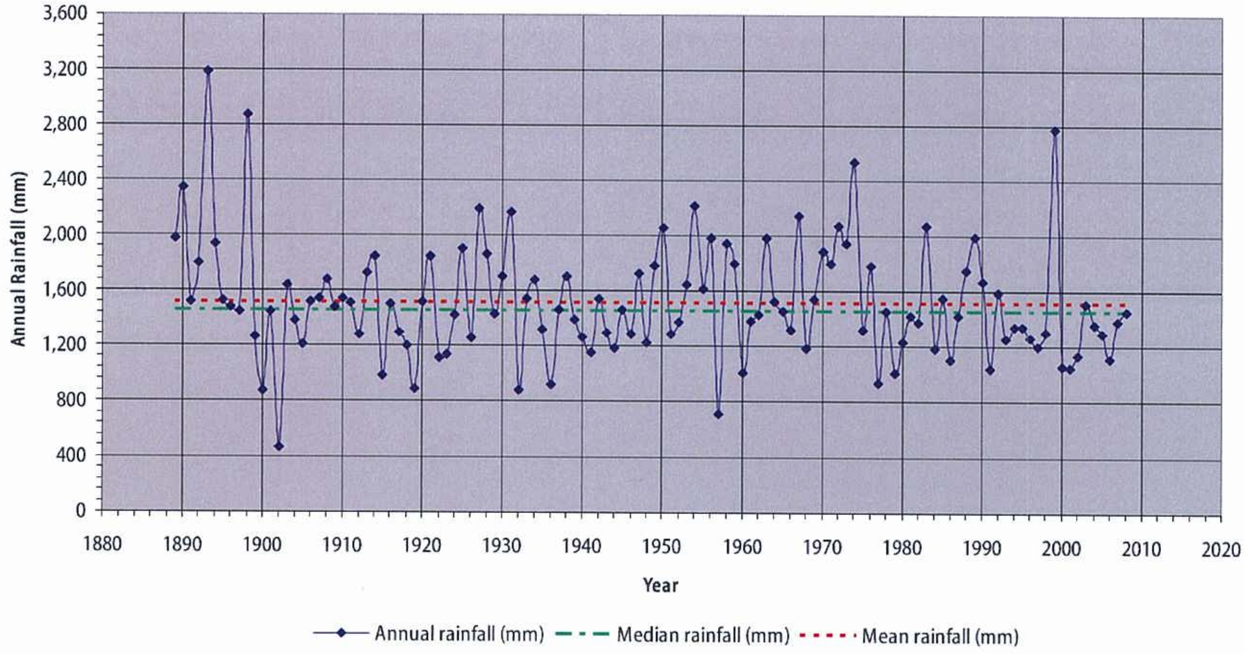


**Figure 5-1 Plot of Annual Rainfall at Site Drawn from SILO Data**

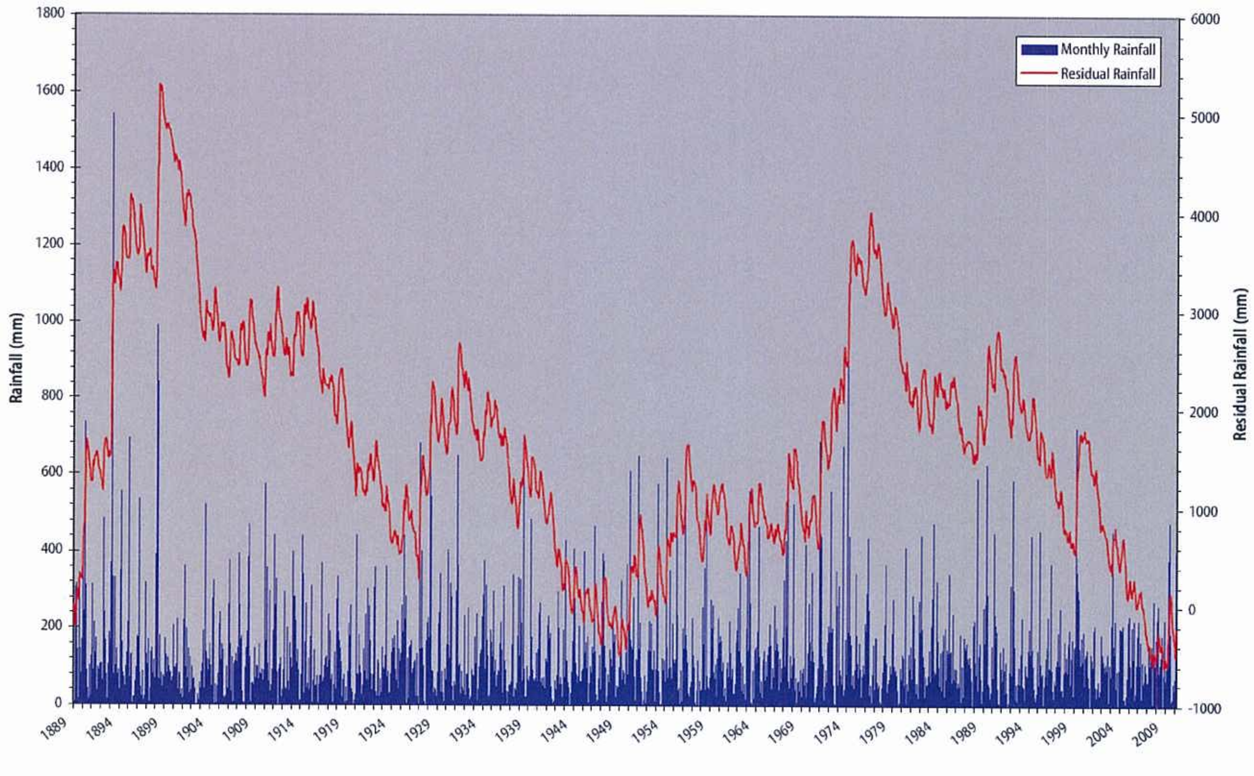


**Figure 5-2 Plot of Cumulative Residuals of Monthly Rainfall from Mean Monthly Rainfall, and Monthly Rainfall to the End of October 2010**

The trace of cumulative residuals from mean monthly rainfall indicated in Figure 5-2 displays a marked decline from the mid 1970's to near historical lows by November 2008. This would normally suggest that the groundwater levels in the system should also currently be close to historical lows by November 2008 and would have peaked in the mid 1970's. However, at Caloundra South there is an intimate relationship between groundwater and surface water, with local water courses (and constructed drains) acting to convey groundwater out of the landscape as does seepage and evapotranspiration processes. Accordingly it appears reasonable that the groundwater system response would tend to be more related to near term antecedent rainfall than long-term rainfall patterns.

Table 5-1 provides mean monthly values for maximum and minimum temperature, rainfall, pan evaporation and potential evapotranspiration for the site also drawn from the SILO data drill. From Table 5-1 it can be seen that at the Caloundra South site, on average:

- There is a marked wet season from November through May during which 76.7% of the rainfall occurs; and
- Monthly rainfall exceeds monthly pan evaporation from January through June.

**Table 5-1 Summary of Mean Monthly Values for Maximum and Minimum Temperature, Rainfall, Pan Evaporation & Potential Evapotranspiration**

| Month | Maximum temperature (°C) | Minimum temperature (°C) | Mean rainfall (mm) | Mean pan evaporation (mm) | Mean excess of pan evaporation over rainfall (mm) | Mean FAO-56 potential evapotranspiration |
|---|---|---|---|---|---|---|
| January | 28.7 | 20.5 | 198.5 | 178.3 | -20.1 | 148.0 |
| February | 28.3 | 20.4 | 220.8 | 142.8 | -78.0 | 121.0 |
| March | 27.3 | 19.2 | 220.1 | 140.2 | -79.9 | 116.5 |
| April | 25.5 | 16.3 | 138.4 | 109.7 | -28.7 | 92.2 |
| May | 23.0 | 13.2 | 130.0 | 84.6 | -45.4 | 74.3 |
| June | 20.6 | 10.5 | 90.7 | 72.9 | -17.8 | 60.5 |
| July | 20.2 | 9.2 | 72.3 | 79.8 | 7.5 | 68.5 |
| August | 21.5 | 9.8 | 51.6 | 100.9 | 49.3 | 86.3 |
| September | 23.6 | 12.4 | 50.0 | 129.9 | 80.0 | 108.1 |
| October | 25.6 | 15.3 | 89.6 | 157.7 | 68.1 | 131.6 |
| November | 27.1 | 17.6 | 109.8 | 169.1 | 59.2 | 142.1 |
| December | 28.4 | 19.5 | 149.2 | 186.2 | 37.0 | 154.1 |
| Totals | | | 1,521.1 | 1,552.1 | 31.1 | 1,303.2 |

## 5.2.2 Topography and Landscape

### *5.2.2.1 Digital Elevation Model*

The most relevant topographic data for the site is an airborne laser scanner (ALS) digital elevation model (DEM) which covers the entire Caloundra South site and also a significant area outside of the Caloundra South site. This DEM was used to interpolate natural surface elevations at historical drill holes across the site. Figure 5-3 presents the location of the Caloundra South site over the ALS DEM. The DEM indicates the following regarding the relief of the Caloundra South site:

- The sharp ridges on the west of the site boundary reach elevations of 65 m AHD;

- The lower ridges to the south of the site reach elevations of 21 m AHD;
- The coastal plain to the east of the site has elevations that fall from approximately 9 m AHD to the east where at the site boundary ground elevations are in the order of 1.5 m AHD; and
- The coastal plain associated with Hall's Creek has elevations of the order of 1.5 to 2.5 m AHD.

#### *5.2.2.2 Surface Drainage*

Figure 5-4 provides key surface drainage lines over the DEM and the surface catchment boundaries. The key surface drainage features in the Caloundra South area are from north to south:

- Lamerough Creek which drains ultimately to the Pelican Waters canal estate and thence to Pumicestone Passage; and
- Bells Creek (including north and south branches) which drains to Pumicestone Passage to the south of Pelican Waters.

It is noted that in addition to these natural drainage features there is a network of numerous minor surface drains that appear to have been historically constructed to support the establishment of plantation pine across and adjacent to the Caloundra South site.

### 5.2.3 Soils and Landscape

There are four main land resource units across the site, with two of these being predominantly developed over Landsborough Sandstone (i.e. J2 and J3) and the other two (Q1 and Q2) being predominantly developed over alluvium and coastal sediments.

In land resource unit J2 developed over Landsborough Sandstone, the dominant soil types are gleyed podzolic soils with some lateritic podzolic soil. Podzolic soils are characterised by a fine sandy loam A horizon (the upper layer), changing rapidly at depth into more clayey soils. Gleyed soils generally exhibit grey and blue-green colour due to wetland conditions. Gleying may be caused by water being held up on a slowly permeable layer. The gleyed podzolic soils are poorly drained acid soils with texture contrast profiles of brownish-grey A horizons, pale A2 horizons and grey and yellow mottled clay B horizons.

Many of the shallow boreholes constructed on the Caloundra South site intersected soils with very sandy A horizons over clayey subsoil layers at depths generally in the order of 0.75 m.

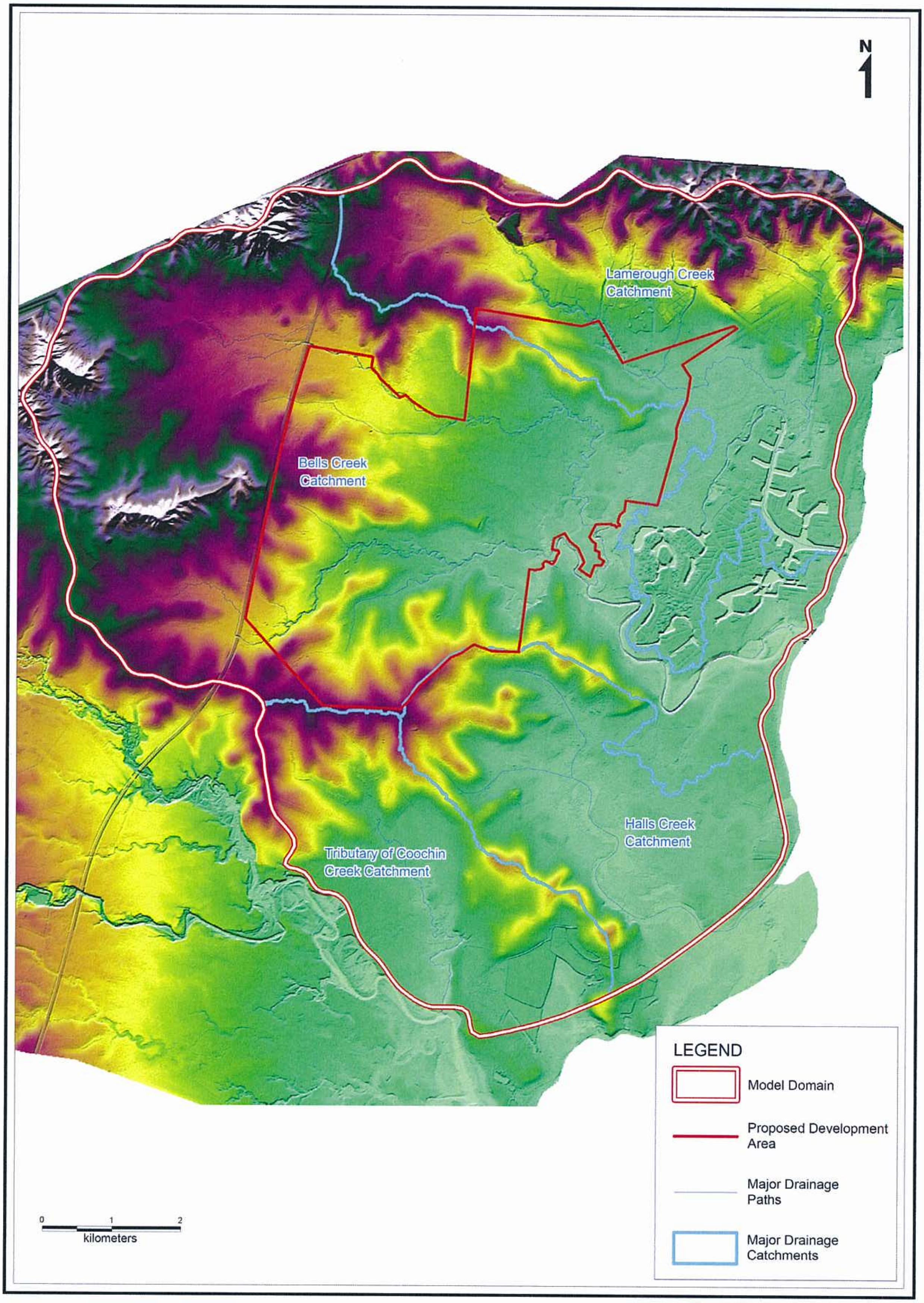


**Figure 5-4 Key Drainage Traces Over High Resolution DEM with Catchment Boundaries**

In land resource unit J3 developed over Landsborough Sandstone, the dominant soil types are yellow podzolic soils and gleyed podzolic soil. The clays at depth may be red, yellow or brownish grey depending on landscape position. Red coloured clays generally indicate better drainage (usually at the top of hills), and grey coloured clays indicate poorer drainage (near the base of hills).

In land resource unit Q1 developed over alluvium and coastal sediments, the dominant soil types can mainly be divided into soils developed over tidal deposits and estuarine deposits. The soils developed over the tidal deposits are solonchak soils. Typically solonchak soils have high soluble salt accumulation within 0.3 m of the surface and have little distinct subsurface layering. The soils developed over the estuarine deposits are dominated by gleyed podzolic soil with some humus podzols and humic gley soils. Some humus podzols have a cemented subsoil layer known as "coffee rock".

In land resource unit Q2 developed over flood plain and river terraces, soil types are dominated by humic gley soils. Humic gley soils are generally are loamy or clayey, with a humose or peaty topsoil. Typically they also occupy low-lying sites or depressions. The humic gley soils are acid to neutral soils with a dark organic A horizon grading into grey mottled heavy clay B horizons.

The key matters to note arising from the review of the available soils data are the relatively widespread development of podzolic soils with sandy A horizons over the Landsborough Sandstone landscape, and the development of gleying in many of the soils due to waterlogging.

### 5.2.4 Land Use

A key issue with the simulation of groundwater for Caloundra South is that it has experienced profound land use changes that have significantly influenced the hydrogeological regime at the site. In order to characterize the site for the purposes of groundwater modelling, consideration of land use, and more specifically the temporal pattern of land use changes, was required.

#### *5.2.4.1 Available Aerial Photography Coverage*

A series of aerial photography coverages are available for the site and these were used to assess land-use and vegetation cover change over time for the modelling. These data alone were insufficient to provide enough temporal discretisation of land use given that major clearing of plantation pine commenced in 2002 and that by 2007 the majority of the site had been cleared of plantation pine. Data were available for the following dates:

- 19 July 1972;
- 24 May and 11 July 1981;
- 18 June 1995;
- 25 July 2003;
- 23, 24, 31 October 2008; and
- 21 July 2010.

### 5.2.4.2 Temporal Land Use Changes

**Assessment of temporal land use changes using available aerial photography**

Land-use changes were assessed for the site and the surrounding area required to be incorporated in the domain of a regional groundwater model. The required groundwater modelling domain covers the upland groundwater recharge areas located to the west and north of the main site and the groundwater discharge areas located to the south adjacent to Pumicestone Passage.

Aerial photographs indicated that the majority of the site was originally open forest and woodland on sand plains. The native cover was largely *Melaleuca sp.* forest (*Melaleuca quinquenervia* or *M. viridiflora*). The majority of the native forests at the site were removed prior to the capture of the 19 July 1972 aerial photographs.

There is evidence of recent ground disturbance in the 1972 aerial photographs, accordingly the native forests (including *Melaleuca sp.* forest) were likely to have been cleared during the late 1960s or early 1970s. The felled areas were subsequently converted to plantation pine in the early 1970s. The majority of the land area that would be converted to pine plantation had been converted by July 1972. A few small stands of *Melaleuca sp.* were felled subsequent to 1972, however the area added to the plantation pines did not increase appreciably. Notwithstanding that there were some additions to the area of plantation pine, large areas of *Melaleuca sp.* forest were subsequently cleared for urban development to the north east of the Caloundra South site.

By the time of the 1981 aerial photography, growth of the plantation pine was evident. Planting of this plantation pine was concentrated to the south and west of the Caloundra South site. By 1981, some planting of pine had occurred on the Caloundra South site, however the majority of the site remained open land at that time. In the 1981 photography, the Caloundra airport and associated urban development areas were under development.

There is only one aerial photo available for 1995, and this photo shows strong growth in the plantation pine in the western portion of the Caloundra South site.

The eastern side of the site was photographed again in July 2003. The July 2003 photography recorded a significantly expanded urban area directly to the east of the site. This urban area contained both open and closed channels. The open channels connect to Pumicestone Passage to the east and the closed channels were landlocked. It is evident in the July 2003 photography that the plantation pine areas had experienced strong growth since 1981. However the south western corner of the site remained open at July 2003. The available aerial photography does not confirm that plantation pine achieved maturity in the south west section of the site, notwithstanding that the photograph does suggest that it was prepared to host plantation pine.

QUT groundwater level monitoring at the site commenced in early 2002, a relatively short period before capture of July 2003 photography. Anecdotal advice from the QUT researchers was that some clearing of plantation pine at the site occurred during the period of QUT monitoring (i.e. March 2002 through March 2003), although available imagery suggests that most of the clearing had occurred prior to March 2002.

Between the photographic capture on July 2003 and October 2008, there appears to have been relatively little land use change in areas covered by the groundwater model domain. By October 2008, the majority of the site had been cleared, except for the remnant riparian and wetland areas that were not cleared in the late 1960s or early 1970s. The footprint of the urban development to the east and north east of the site did not change significantly between July 2003 and October 2008, however by October 2008 the canals had been extended, especially the open canal system, and the area appeared to be reaching full build out.

Between October 2008 and July 2010 there were relatively few land use changes. By July 2010 areas cleared for urban development between 1981 and 2003 appeared to have reached full build out. Harvesting of plantation pine between October 2008 and July 2010 appeared to be largely confined for the areas to the east of the Bruce Highway.

The July 2010 aerial photography effectively provided current site conditions as land use on the site has not changed significantly since July.

**Assessment of temporal land use changes using additional data from SLATS imagery**

As previously discussed the temporal distribution of aerial photography for the study area was insufficient for a sufficient temporal land-use discretisation to support groundwater flow modelling for the site. In order to support this process, data from the Queensland Department of Environment and Resource Management (DERM) Statewide Landcover and Trees Study (SLATS) were used. These data were used to assist in interpretation of the land use at the site and its catchment (i.e. an area sufficiently wide to cover a suitable domain for regional groundwater flow modelling) for periods covering the available groundwater level record and to provide a yearly land use pattern from the end of 2001 through to the current period.

The key land-use types that were determined for this analysis were:

- Native forest (excluding major wetlands);
- Wetlands;
- Open / cleared land (including land cleared of plantation pine);
- Plantation pine;
- Urban areas;
- Cropping (mainly turf farming); and
- Open water.

Figure 5-5 provides time series land use classifications for each calendar year from 2000 through to 2007 and Figure 5-6 provides same for the current period as at July 2010.

### *5.2.4.3 Surface Water Hydrology*

Because drainage/discharge of shallow groundwater to surface water is a major feature of the Caloundra South site, predictive groundwater models need to be able to emulate the baseflow component of observed groundwater discharge. Accordingly information pertaining to stream flow is important in the overall conceptualisation of the groundwater system.

There are no DERM surface water gauging sites within the catchments of Bell's, Lamerough or Halls Creeks. The closest DERM gauging stations are at Coochin Creek well to the south west of the Caloundra South site and at the Mooloolah River located well to the north east of the site.

However a series of 3 stream gauging sites was established for the project in the catchments of Bell's Creek and Lamerough Creek. Site 1 was initially established on Lamerough Creek and Site 2 was initially established on a northern tributary of Bells Creek. Subsequently, the surface water gauging equipment at Site 1 was relocated onto the main body of Bell's Creek near observation bore BH7 (Site 3). Data from these sites were collated and reviewed and used to inform the groundwater modelling.

During site inspections in late October 2010, it was noted that there was appreciable baseflow discharge occurring in some unnamed tributaries of Bell's Creek. In order to obtain some data regarding the magnitude of surface flows in some of these surface water bodies, a program of spot gauging was also undertaken.

### 5.2.5 Geology

#### *5.2.5.1 Regional Geological Framework*

Regional geological mapping indicates that the basement rocks of the Caloundra South site consist of the Landsborough Sandstone of the Nambour Basin. The Late Triassic age to early Jurassic age Nambour Basin is a small, frontier, intracratonic basin in southeastern Queensland. This basin extends from approximately Sandgate in the south to Mudjimba in the north and west. To the south it is contiguous with the Moreton Basin and to the north it is contiguous with the Maryborough Basin. The western boundary of the basin abuts Palaeozoic age rocks of the D'Aguilar Block (to the northwest) and the Beenleigh Block (to the southwest). The southern basin overlies Palaeozoic basement and mid-Triassic sediments of the Ipswich Basin.

Structures in the Nambour Basin trend mainly north-northwest. The Nambour Basin consists of Late Triassic to Middle Jurassic continental fluviatile sediments with generally sub-horizontal strata. The sandstones of this basin are usually massive and well jointed and north west trending folds which plunge gently to the southeast have been mapped between Mooloolah and Palmwoods.

#### *5.2.5.2 Available Sources of Drilling Information for Site*

The primary sources of drilling information available to assist in geological and hydrogeological characterisation of the site are shown in Figure 5-7, and are as follows:

- Boreholes constructed by QUT;
- A series of 45 shallow (2 – 3 m deep) monitoring bores constructed by Cardno Bowler for the current investigation;
- A series of 6 deeper (10.1 to 15 m deep) groundwater monitoring bores constructed by Cardno Bowler for the current investigation; and
- A series of 31 acid sulphate soil investigation boreholes (4 to 7 m deep) constructed by Cardno Bowler for the current investigation.

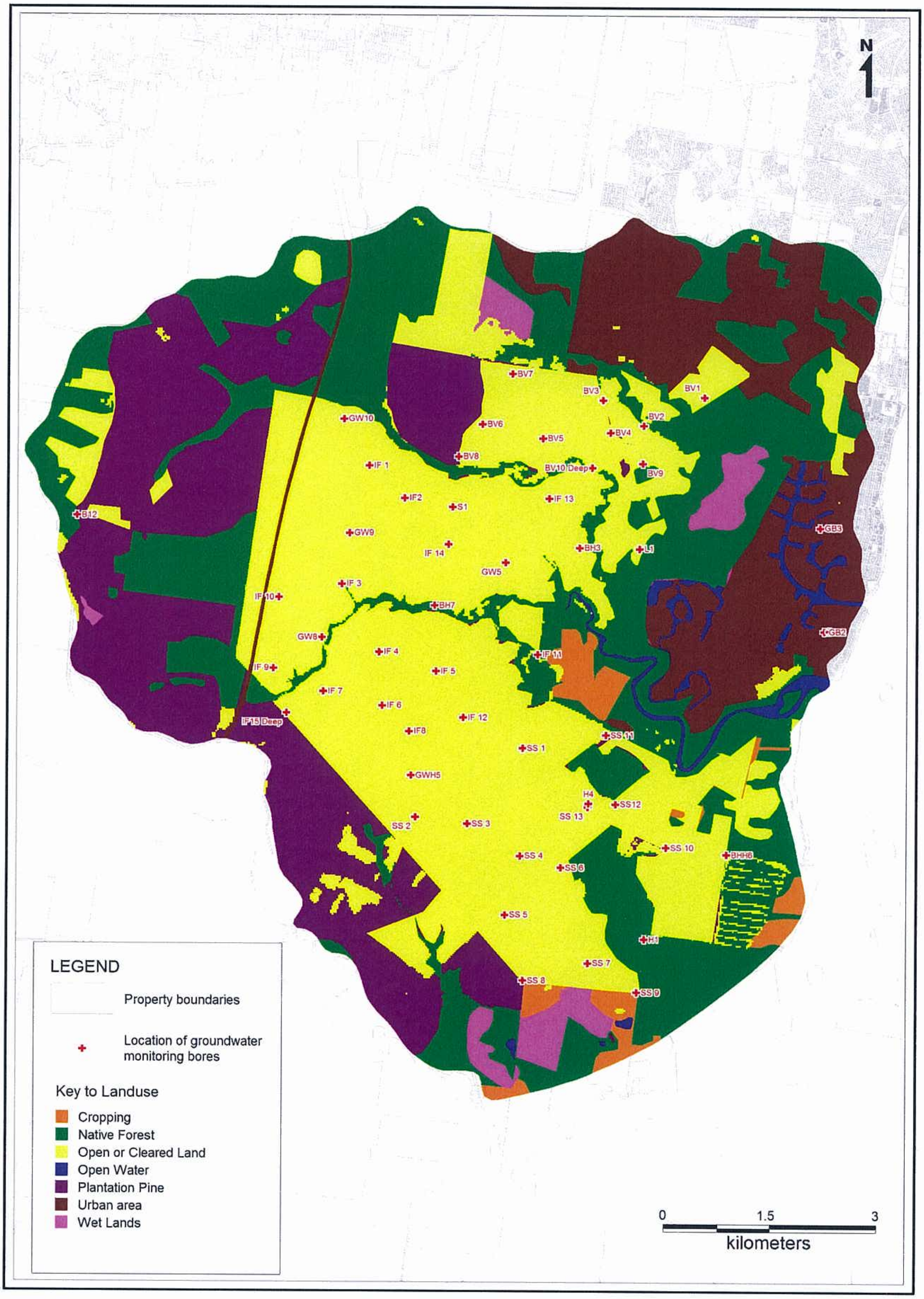


**Figure 5-6 Interpreted Current (July 2010) Land Uses for the Caloundra South Area**

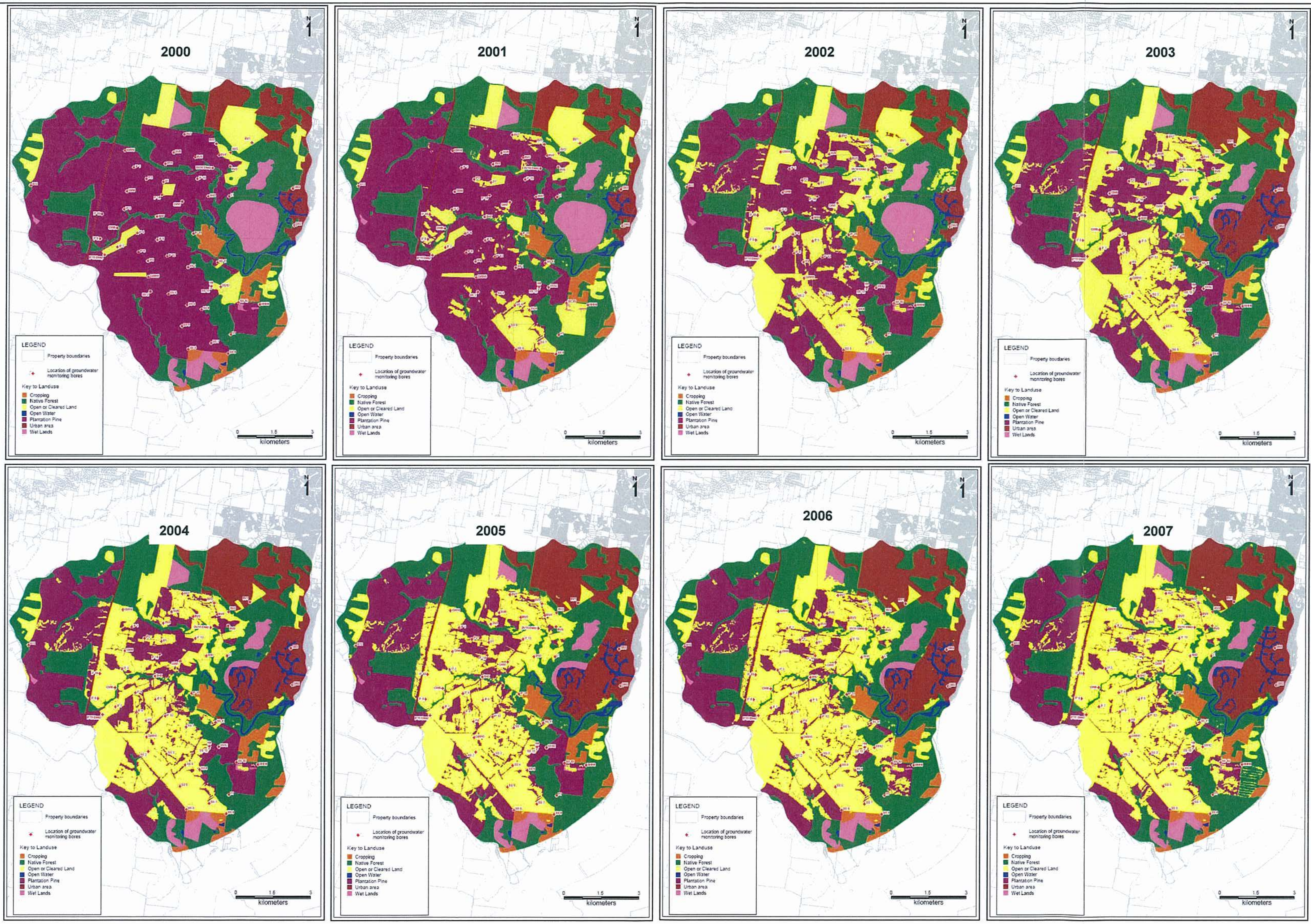


**Figure 5-5 Interpreted Land Uses for the Caloundra South Area: 2000 through 2007**

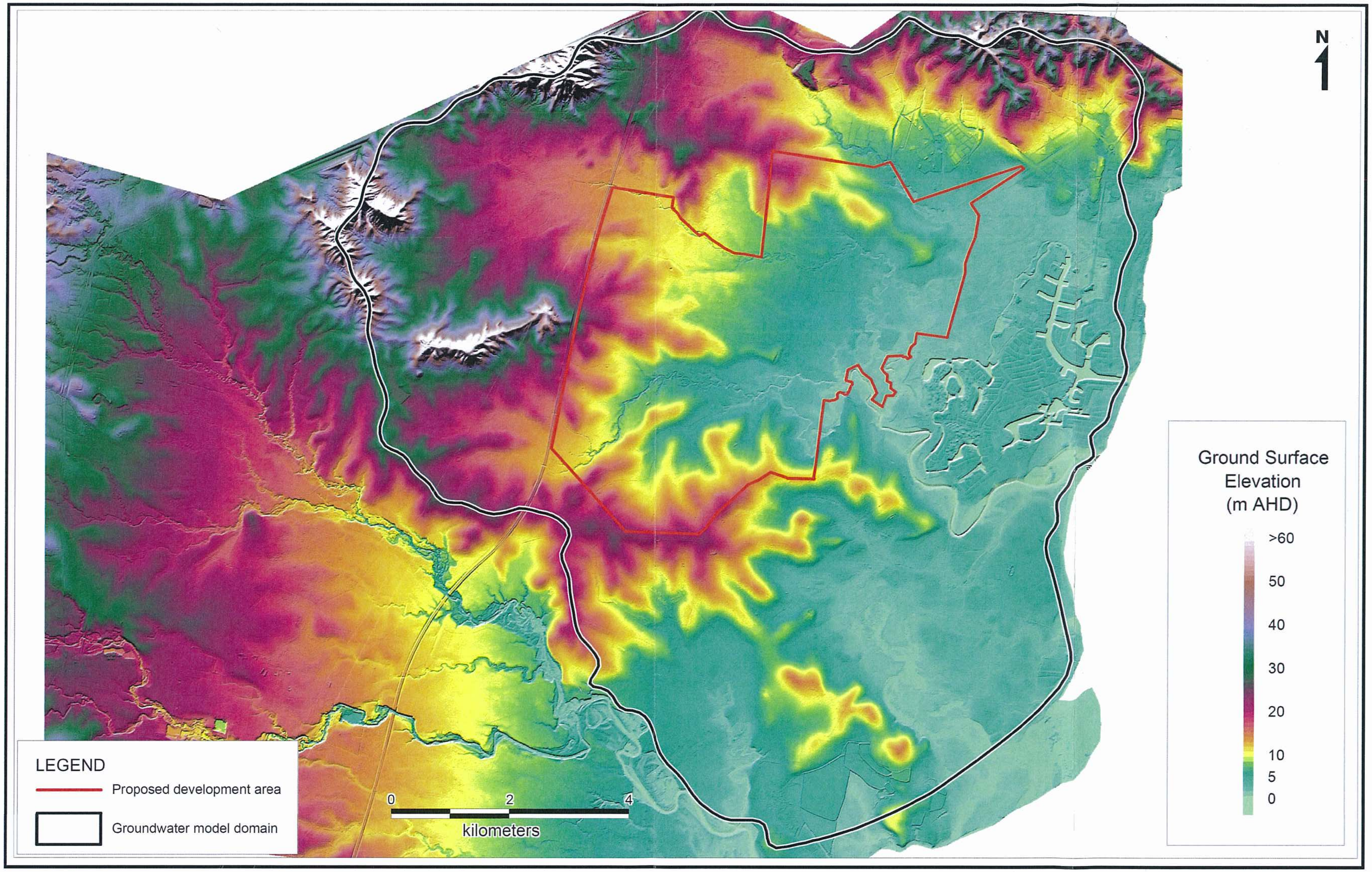


**Figure 5-3 Location of Caloundra South Site Over ALS DEM**


**Figure 5-7 Relevant Borehole and Acid Sulphate Soil Investigation Sites**