# A Business Case for Best Practice Urban Stormwater Management: Case Studies

Version 1.1 – September 2010

*A companion document to A Business Case for Best Practice Urban Stormwater Management*

water by design

Water by Design is a program of the South East Queensland Healthy Waterways Partnership

HEALTHY WATERWAYS
*Because we're all in the same boat*

Version 1.1, September 2010

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## Disclaimer



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Water by Design welcomes feedback on this publication, which can be directed to info@waterbydesign.com.au.

## Water by Design

Water by Design is a program of the South East Queensland Healthy Waterways Partnership. Water by Design builds the capacity of the water and urban development sectors to help successfully implement sustainable urban water management.

## South East Queensland Healthy Waterways Parntership

The South East Queensland Healthy Waterways Partnership is a collaboration between government, industry, researchers and the community. The Partnership was created in 2001. The partners work together to improve catchment management and waterway health in Moreton Bay and the rivers of South East Queensland between Noosa and the Queensland–New South Wales border. The South East Queensland Healthy Waterways Partnership developed and implemented the *South East Queensland Regional Water Quality Management Strategy* (2001) and its successor, the *South East Queensland Healthy Waterways Strategy 2007–2012* (2008). The Partnership also manages the Ecosystem Health Monitoring Program, which produces an annual report card on the health of the region's waterways, estuaries and bays.

Further information in the SEQ Healthy Waterways Partnership and the Water by Design Program, is available from www.healthywaterways.org and www.waterbydesign.com.au.

This document is available for download from www.waterbydesign.com.au

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# 1 Introduction

To build the business case for water sensitive urban design (WSUD) in Queensland, and to support the adoption of the stormwater management objectives defined by the draft *State Planning Policy for Healthy Waters* (DERM, 2009), the practicality and cost of applying WSUD at a development scale to achieve the objectives was assessed.

Case studies of typical urban developments have been assessed for their ability to support the practical application of the stormwater management[1] objectives (being stormwater quality, waterway stability and frequent flow management objectives) using WSUD. The case studies investigated as part of this project:

- are based on real urban developments in Queensland
- include a mixture of 'greenfield' and 'infill' urban development
- include a range of landuses (residential of varying densities, commercial and industrial)
- are captured by Queensland's 'Integrated Development Assessment System'
- trigger the new State Planning Policy for Healthy Waters and the associated Urban Stormwater Code and Best Practice Environmental Management Guidelines — Urban Stormwater (DERM, 2009)
- include the alternative water source (rainwater tank) requirement as defined by the Queensland Development Code.

In most of the case studies, the *Queensland Development Code* requires an alternative water source (other than reticulated potable supply) for uses such as toilet flushing and garden irrigation applies. This requirement was met in the case study assessments in the form of rainwater tanks. The costs associated with the tanks are presented separately (i.e. in the base case scenarios) to ensure the discrete costs associated with meeting the alternative water source requirement of the *Queensland Development Code* are separated from the discrete costs associated with meeting the stormwater management objectives defined through the *State Planning Policy for Healthy Waters* (DERM, 2009) (i.e. the WSUD case scenarios).

The case studies build on case studies completed as part of the document *WSUD: Developing Design Objectives for Urban Development in South East Queensland* (SEQ HWP, 2007).

This Case Study Report:

- describes the process used to select the case studies (section 2.1) and climatic regions (section 2.2)
- outlines the stormwater management objectives and the alternative water source requirement (section 2.3)
- describes the development cases in which the stormwater management objectives and the alternative water source requirement were applied (section 2.4)
- defines the relevant WSUD solutions adopted for each case study (section 2.5) and the base case and WSUD case scenarios (section 2.6)
- describes the performance assessment method and assumptions (section 3)
- outlines the costing method and assumptions (section 4)
- summarises the details and results of each case study (i.e. modelling results and costs) (section 5)
- presents a summary of the case study results (section 6).

[1] These objectives are explained in *Best Practice Environmental Management Guidelines — Urban Stormwater* (DERM, 2009) and in further detail in section 2.3 of this appendix.

# 2 General case study information

## 2.1 Selection of case studies

A range of case studies were needed to assess how the stormwater management objectives can be met given varying development landuse, size, layout, site coverage, landscaping and water demand scenarios. The selected case studies were chosen as typical examples of 'greenfield' and 'infill' development that would be captured by the *Integrated Development Assessment System*, the new *State Planning Policy for Healthy Waters* and the associated *Urban Stormwater Code and Best Practice Environmental Management Guidelines — Urban Stormwater*. That is, the developments in each case study are:

- subject to development approval
- 6 lots or more
- 2500 m2 or greater
- 25% or more impervious surfaces on the site.

The development case studies are summarised in Table 1. Each case study is a real development that has either been designed or built somewhere in Queensland, with or without WSUD elements. Choosing case studies based on real developments ensures the developments' characteristics are consistent with current town planning scheme provisions and reflect current stakeholder and market expectations in Queensland. For some of the case studies, minor design amendments have been made in order to make them comply with stormwater management objectives.

## 2.2 Climatic regions

To test the influence of climate variability on the practicality and cost of achieving the stormwater management objectives, each case study was hypothetically assessed as though it was built in four climatic regions:

- South East Queensland (represented by Brisbane as the climatic 'mean' of SEQ)
- Central Coast North (Mackay)
- Dry Tropics (Townsville)
- Wet Tropics (Cairns).

These regions were selected because they include the coastal zones in South East Queensland and the regional areas of Queensland that are expected to support the projected 50% increase in Queensland's population in the next 25 years.

For modelling purposes, historical rainfall data and evapotranspiration data was used. Each model used a minimum ten years of rainfall data, at a six-minute time intervals as shown in Table 2. The ten years' data series used for this assessment were selected as they provide a similar average annual rainfall to the long-term average climatic conditions in each region.

Table 1: Case study development scenarios

| CASE STUDY | DEVELOPMENT TYPE | KEY ELEMENTS |
|---|---|---|
| 1 | Residential greenfield (large scale) on sloping topography | • 76 ha of detached residential<br>• 951 detached houses (400–700 m2/lot)<br>• 5.5 ha of active and passive parkland<br>• 8.75 ha drainage and restored waterway (vegetated)<br>• 47% impervious surfaces on site. |
| 2 | Residential greenfield on flat topography | • 6.4 ha of detached residential<br>• 84 detached houses (400–500m2 p/lot)<br>• 56% impervious surfaces on site. |
| 3 | Residential townhouse development | • 0.67 ha of attached residential<br>• 25 townhouse dwellings<br>• 61% impervious surfaces on site<br>• 15% pervious landscaped areas on site. |
| 4 | Urban renewal development | • Conversion of 14 ha of light industrial area to high-density residential<br>• 7 ha high rise residential towers<br>• 5 ha five-storey residential apartment buildings<br>• 2000 + dwellings (units and apartments)<br>• 40 m-wide road reserve and substantial promenades<br>• 81% impervious surfaces on site. |
| 5 | Commercial development | • 0.42 ha neighbourhood shopping centre<br>• 15–20 ground-level shops<br>• 95–98% impervious surfaces on site. |
| 6 | Industrial development | • 1.0 ha factory and warehouse<br>• 86% impervious surfaces on site. |

Table 2: Climate data

| REGION | PERIOD OF MODELLING | RAINFALL STATION | LONG-TERM MEAN ANNUAL RAINFALL (MM)* | MEAN ANNUAL RAINFALL FOR MODELLING PERIOD (MM) | ANNUAL EVAPO-TRANSPIRATION (MM) |
|---|---|---|---|---|---|
| South East Queensland | 10 years (1980–1989) | 40223 Brisbane | 1,186 | 1,155 | 1,539 |
| Central Coast North | 10 years (1990–1999) | 33119 Mackay | 1,576 | 1,566 | 1,834 |
| Dry Tropics | 14 years (1970–1983) | 32040 Townsville | 1,130 | 1,165 | 1,856 |
| Wet Tropics | 10 years (1975–1984) | 31011 Cairns | 2,010 | 1,937 | 1,872 |

* www.bom.gov.au /climate/averages

## 2.3 Stormwater management objectives and alternative water source requirement

The case studies focus on achieving the draft stormwater management objectives outlined in the *Best Practice Environmental Management Guidelines—Urban Stormwater* (DERM, 2009) as referenced by the *State Planning Policy for Healthy Waters* (DERM, 2009) and *Urban Stormwater Code*. The objectives for South East Queensland are consistent with those contained in the *South East Queensland Regional Plan 2009 to 2026: Implementation Guideline No. 7*.

Developments that trigger the draft *State Planning Policy for Healthy Waters* are likely to trigger the *Queensland Development Code*. Therefore the case study assessments also considered compliance with the alternative water source requirement of the *Queensland Development Code*.

The following sections summarise each objective by outlining its intent and target. Section 2.4 summarises the application of the objectives.

### 2.3.1 Stormwater quality objective

**Intent:** This objective aims to protect receiving water quality by limiting the quantity (loads) of stormwater pollutants discharged into receiving waters.

**Target:** Minimum reductions in total pollutant loads, compared to untreated stormwater runoff, are set for total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN) and gross pollutants. The objectives vary across Queensland because they are set based on a best practice treatment approach for each climatic region.[2] The stormwater quality objectives for the four climatic regions relevant to the case study assessment are summarised in Table 3.

Table 3: Stormwater quality objectives for the case study regions

| STORMWATER POLLUTANT | MINIMUM PERCENTAGE LOAD REDUCTION COMPARED TO UNMITIGATED DEVELOPMENT | | | |
|---|---|---|---|---|
| | SOUTH EAST QUEENSLAND (BRISBANE) | CENTRAL QUEENSLAND — NORTH (MACKAY) | DRY TROPICS (TOWNSVILLE) | WET TROPICS (CAIRNS) |
| Total Suspended Solids (TSS) | 80% | 75% | 80% | 80% |
| Total Phosphorus (TP) | 60% | 60% | 65% | 65% |
| Total Nitrogen (TN) | 45% | 35% | 40% | 40% |
| Gross pollutants | 90% | 90% | 90% | 90% |

### 2.3.2 Frequent flow objective

**Intent:** The frequent flow objective aims to protect in-stream ecosystems from the effects of increased runoff frequency. Capturing the initial portion of runoff from impervious areas ensures the frequency of disturbance to in-stream ecosystems in developed catchments is similar to predevelopment conditions.

**Target:** The frequent flow objective requires a specific depth (mm/day) of runoff from all impervious surfaces to be captured and managed. The depths are:

- for developments with <=40% impervious surfaces: runoff capture depth => 10 mm/day
- for developments with >40% impervious surfaces: runoff capture depth => 15 mm/day.

[2] Refer to Best Practice Environmental Management Guidelines—Urban Stormwater (DERM, 2009) for an explanation of best practice.

'Management' of the frequent flow management volume (i.e. 15 mm multiplied by the impervious area on the site) can occur by either infiltration, evapotranspiration or discharge via bioretention (or a combination of these). The management volume is to be fully available each day i.e. the storage volume needs to be drawn down in 24 hours.

### 2.3.3 Waterway stability objective

Intent: This objective aims to prevent in-stream erosion downstream of urban development by controlling the size and duration of sediment transporting flows.

Target: Limit the post-development peak 1-year Average Recurrence Interval (ARI) event discharge within the receiving waterway to the pre-development peak 1-year ARI event discharge.

### 2.3.4 Alternative water source requirement (*Queensland Development Code*)

The *Queensland Development Code Mandatory Parts 4.2 and 4.3* requires the use of an alternative (other than the reticulated potable supply) water source for most new dwellings and buildings. Alternative water sources include individual or communal rainwater tanks, greywater reuse, dual reticulation or stormwater reuse. The use of the alternative water source depends on the building type, but it can generally be used for toilet flushing, laundry, and outdoor use.

Rainwater tanks are the most common solution used to achieve the alternative water source requirement. Therefore, rainwater tanks form part of the WSUD solution for each case study. However, tanks are a relatively costly part of the WSUD solution and are not necessary to achieve the stormwater management objectives. Other more cost-effective WSUD solutions can be adopted to achieve these objectives. Given this, rainwater tanks are presented separately in the findings for each case study. Note, however, that using rainwater tanks does change the required bioretention size — the bioretention size can be reduced when the tanks are in place. This also affects the costs of the WSUD solutions.

## 2.4 Applying the objectives and requirements

The stormwater management objectives are not applicable to every development situation:

- The stormwater quality objective applies to all new urban developments, except those that are less than 25% impervious.
- The frequent flow objective applies only in catchments that drain to waterways and wetlands classified as High Environmental Value (HEV) systems or if the local council intends to rehabilitate a modified system. The frequent flow objective does not apply to developments that drain to tidal waterways or to waterways that are deemed by a local or regional authority as having limited potential for future rehabilitation.
- The waterway stability objective applies to developments within catchments that contribute to un-lined freshwater waterways or where the local council intends to decommission a lined waterway and re-instate a natural channel system. The waterway stability objective does not apply to developments that drain to tidal waterways or to waterways that are deemed by a local or regional authority as having limited potential for future rehabilitation.
- When the waterway stability design objective does apply, a flood management objective will usually apply too (i.e. no increase in peak flows from the development for a range of storm events). Compliance with either objective requires detention storage. These storages can be co-located with the storage outlet structure designed to cater for separate functions (i.e. stage outlet).
- The alternative water source requirement applies to boarding houses, detached and attached accommodation, commercial and industrial buildings. It does not apply to multi-storey residential buildings (i.e. case study 4) and compliance is voluntary in the Townsville region.

Table 4 clarifies when the alternative water source requirement and each stormwater management objective applies for typical developments in Queensland. For the purpose of the case studies, WSUD solutions have been developed to cover the following scenarios:

- Scenario 1: Only the alternative water source requirement and the stormwater quality objective apply to the case studies. This is considered typical of most urban developments in Queensland.

- Scenarios 2: The alternative water source requirement plus all three stormwater management objectives apply. This scenario demonstrates how practical it is to meet all three stormwater management objectives and shows the costs associated with WSUD on developments upstream of a waterway or wetland of HEV.

Table 4: Applicability of the stormwater management objectives and alternative water source requirement to development situations

| OBJECTIVE | DEVELOPMENT SITUATION | | | | |
|---|---|---|---|---|---|
| | SCENARIO 1 | | SCENARIO 2 | | |
| | Greenfield or infill<br>- coastal or tidal | Greenfield or infill<br>- freshwater but poor stream health | Infill<br>- freshwater with high stream or wetland health (unlikely scenario) | Greenfield<br>- freshwater with high stream or wetland health | Greenfield or infill<br>- freshwater with high stream or wetland health (but flooding not a concern) |
| Alternative water source (*Queensland Development Code*) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Stormwater quality | ✓ | ✓ | ✓ | ✓ | ✓ |
| Waterway stability | | | ✓* | ✓* | ✓ |
| Frequent flow | | | ✓ | ✓ | ✓ |

* Waterway stability detention storage requirement co-located with flood detention (minimises extra cost for providing waterway stability).

## 2.5 WSUD solutions

To meet the draft stormwater management objectives and the alternative water source requirement, the WSUD solution for the case studies include a combination of elements:

- Rainwater tanks — The primary role of the rainwater tanks is to satisfy the alternative water source requirement of the *Queensland Development Code* Mandatory Parts 4.2 and 4.3. Tanks can also help achieve the WSUD objectives. Tanks are not necessarily required to meet the stormwater management objectives (i.e. the stormwater management objectives could be achieved with bioretention systems and detention storage alone).
- Bioretention systems — Bioretention systems ensure compliance with the stormwater quality and frequent flow objectives.
- Detention storage — Detention storage detains or retards the 1-year ARI flow for the waterway stability objective. As highlighted in section 2.4, the waterway stability objective will not apply in many development situations and detention storage will not be required. Where the waterway stability objective does apply, it is likely flood storage will also be required and the waterway stability detention storage will be integrated into the flood storage at minimal cost. Therefore, the cost of the detention storage does not form part of the WSUD case costs, but it still presented in the case study results for illustration purposes.

Table 5 shows the role each WSUD element plays in meeting the stormwater management objectives and alternative water source requirement. Each of these elements and how they were used in the case studies is described in more detail in sections 2.5.1 to 2.5.3.

Selecting the preferred WSUD solution is site- and development-specific and is dependent on topography, receiving drainage and waterway levels, land availability and landscape intent. The design process for each case study was undertaken in accordance with *Concept Design Guidelines for Water Sensitive Urban Design* (Water by Design, 2009), *Deemed to Comply Solutions –*

*Stormwater Quality* (Water by Design, 2010) and the *WSUD Technical Design Guidelines for South East Queensland* (SEQ Healthy Waterways Partnership, 2006).

Table 5: Role of WSUD solutions in achieving stormwater management objectives and alternative water source requirement

| WSUD ELEMENT | ALTERNATIVE WATER SOURCE REQUIREMENT | STORMWATER QUALITY OBJECTIVE | WATERWAY STABILITY OBJECTIVE* | FREQUENT FLOW OBJECTIVE* |
|---|---|---|---|---|
| Rainwater tanks | ✓ | ☑ | | ☑ |
| Bioretention systems | | ✓ | ☑ | ✓ |
| Detention storage | | | ✓ | |

* The objective is to be applied at the discretion of the local authority
✓ Primary role
☑ Secondary role

### 2.5.1 Rainwater tanks

The rainwater tank sizes adopted for each case study are the minimum required by the *Queensland Development Code Mandatory Parts 4.2 and 4.3* to meet the alternative water source requirement. The rainwater tank requirements are shown in Table 6.

For the residential development case studies, water use (demand) from the tanks was assumed (as adopted by the Queensland Water Commission based on recent research on the Gold Coast[3]) as:

- indoor demand (toilets and laundry cold) = 43.4 litres / person / day
- outdoor demand (garden irrigation and pool top-up) = 60 litres / household per day (for the purposes of this assessment, conservatively low outdoor demands were adopted to account for water restrictions and to avoid undersizing of stormwater treatment systems).

This demand was also based on occupancy assumptions for residential case studies:

- Case study 1 (detached houses): 2.5 people per household
- Case study 2 (detached houses): 2.5 people per household
- Case study 3 (townhouses): 2.0 people per household
- Case study 4 (units): 1.8 people per household.

The outdoor demand for case study 4 was estimated at 5000 kL/yr, based on an irrigated area of 1 ha and an application rate of 500 mm/yr. For case study 5 and case study 6 rainwater tank demands were case-specific. For all case studies, it was assumed that the overflow from the rainwater tanks is directed to a bioretention system.

[3] Willis, et al. (2009).

Table 6: Minimum rainwater tank requirements as defined in *Queensland Development Code Mandatory Parts 4.2 and 4.3*

| BUILDING TYPE (BUILDING CODE OF AUSTRALIA CLASS) | DEFINITION[1] | RAINWATER TANK REQUIREMENTS[2] | | |
|---|---|---|---|---|
| | | MINIMUM CONNECTIONS TO TANK | MIN RAINWATER TANK VOLUME | MINIMUM ROOF AREA CONNECTED TO TANK |
| Detached buildings (Class 1ai) | A single detached dwelling (i.e. free-standing house) | Toilets, washing machine (cold water) and an external use | 5 kL | The lesser of 50% of total roof area or 100 $m^2$ |
| Attached buildings (Class 1aii) | One or a group of attached dwellings (i.e. row houses, townhouses, terraces, villas) | | 3 kL | |
| Boarding house (Class 1b) | A boarding house, hostel, guest house or similar with <300 $m^2$ floor space and <12 residents | | 3 kL | |
| Units or apartments (Class 2) | A building containing 2 or more sole occupancy units | n/a | n/a | n/a |
| Accommodation buildings (Classes 3, 9a/c) | Commercial buildings with > 50% space classified as Classes 3, 9a or 9c | Swimming pools, required toilets, an external use, and washing machine (cold water) | Pools: refer Appendix B *Queensland Development Code* MP4.3 Toilets: 1.5 kL per required toilet | 50 $m^2$ per toilet (or total area if less) |

[1] Building code definitions obtained from the Building Services Authority of Queensland.

[2] Additional requirements may be stipulated by local council planning schemes, policies or codes.

## 2.5.2 Bioretention systems

Bioretention systems treat stormwater by filtering runoff through densely planted vegetation and percolating the runoff through a filter media, such as sandy loam. As stormwater percolates through the soil, pollutants are captured by fine filtration, adsorption and biological uptake. Figure 1 shows a typical cross-section through a bioretention system and identifies the functional elements of the system. A comprehensive description of bioretention system function and design is provided in *WSUD Technical Guidelines for South East Queensland* (South East Queensland Healthy Waterways Partnership, 2006).

For the case studies, bioretention systems were assumed to have the following configuration:

- extended detention depth 0.2 m
- filter media depth 0.6 m
- saturated hydraulic conductivity 200 mm/hr
- batters to surrounds 1 in 4 preferably (1 in 2 max vegetated).

This size of the bioretention system required to meet the stormwater quality objectives varies between climatic regions.

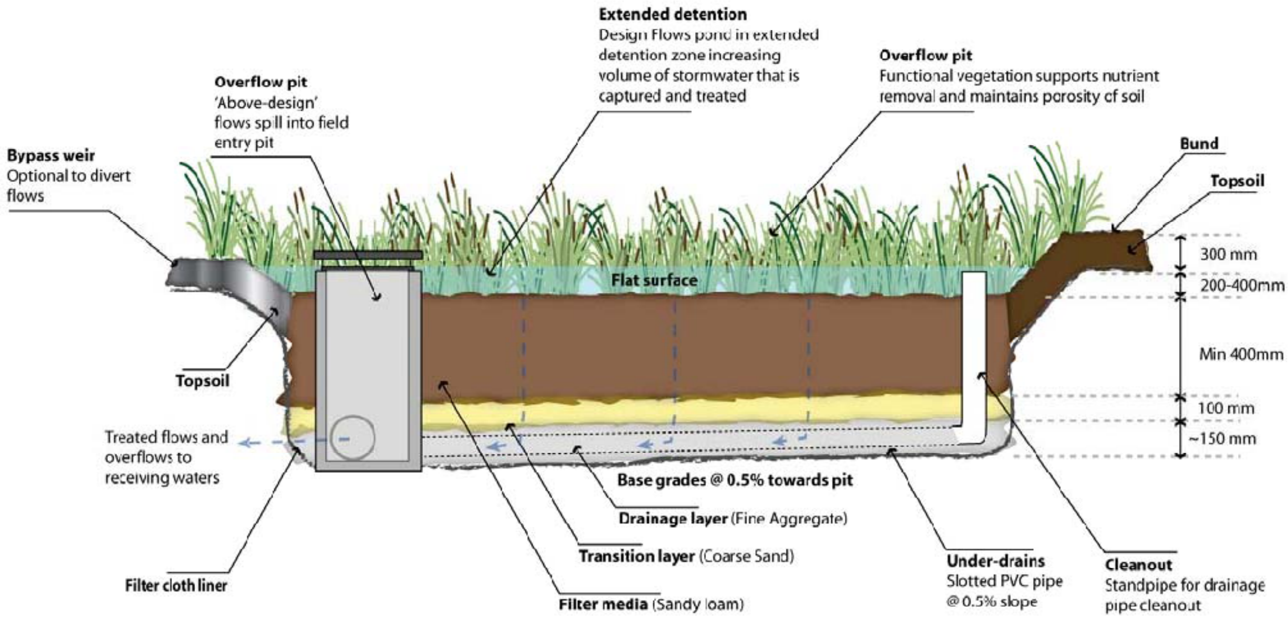


Figure 1: Typical cross-section through a bioretention system

### 2.5.3 Detention storage

If the waterway stability objective is applicable, storage is required to detain and retard the 1-year ARI flow. The key elements of detention are a storage volume and a choked outlet designed to restrict the outflow rate. Detention storage options considered for the case studies include:

- within and above the bioretention systems — storage over the bioretention system above the overflow pit crest (allowing for 10% of the extended detention)
- above ground open detention basin — typically a shallow, vegetated area surrounded by earth bunds
- informal surface ponding — where relatively small storage volumes are required, it may be appropriate to allow temporary ponding over landscaped or car park areas
- above ground tanks — rainwater tanks which do not retain water for reuse but drain down fully after each storm event
- underground storages — tanks located underground as either reinforced tanks, sealed stormwater pipes or voids filled with rocks or gravel.

It is usually possible to design bioretention systems so they double as detention storage by providing a choked outlet and storage above this outlet. The detention volume can also be provided as multiple storages distributed throughout a site, although the individual storages must be sized appropriately based on the local catchment area.

In many instances, particularly greenfield sites, detention is also required for floods or drainage protection. The storage volume for flood detention is typically larger than that required for the waterway stability objective. If flood detention storage is appropriately designed, it may also meet the requirements of the waterway stability objective, removing the need for separate dedicated detention storage for waterway stability.

## 2.6 Scenarios

One of the aims of the business case is to determine what additional costs, if any, are generally added to developments as a result of meeting the stormwater management objectives. To do this, the 'WSUD case' (where the development meets the draft stormwater management objectives and the alternative water source requirement of the *Queensland Development Code*) are compared to a 'base case' (where the development only meets the alternative water source requirement).

The base case development assumes:

- conventional stormwater drainage management
- flood management (where required)
- application of the alternative water source requirement (i.e. rainwater tanks).

The WSUD case development assumes:

- As per base case PLUS
- WSUD elements (bioretention systems, detention storage etc) to meet the stormwater management objectives (As outlined in sections 2.4 and 2.5, where the waterway stability objective does apply, it is likely flood storage will also be required and the waterway stability detention storage will be integrated into the flood storage).

The stormwater management outcomes and costs for each option are presented separately to allow interpretation of the incremental cost of the base case (meeting the alternative water source requirements) and WSUD case (meeting the stormwater management objectives).

# 3 Compliance methodology

This chapter provides a description of the methods used to assess how the case studies comply with each stormwater management objective. As noted above, the use of a rainwater tank of a minimum specified size demonstrates compliance with the *Queensland Development Code* requirement for alternative water use.

## 3.1 Stormwater quality objective

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC version 3.01) was used to assess stormwater quality treatment performance for each case study. MUSIC is the preferred assessment tool for stormwater quality objectives in Australia. The Cooperative Research Centre for Catchment Hydrology (CRCCH) developed MUSIC to model the industry's current best understanding of:

- the transformation of rainfall to runoff (surface and baseflow) in urban environments
- the generation of key stormwater pollutants (stressors) in surface flows and base flows from various land surfaces
- the removal of key pollutants (stressors) from urban stormwater runoff by contemporary best practice stormwater treatment technologies.

A number of assumptions underpin the MUSIC modelling undertaken for the case studies:

- A minimum 10 years of 6-minute rainfall for the rainfall stations described in section 2.2, Table 2.
- Table 7 shows the rainfall–runoff parameters used in the case study modelling. These parameters are based on the MUSIC default parameters for Brisbane as provided in the MUSIC Manual.
- The storm pollutant generation parameters are presented in Tables 8–10. These parameters are from *Gold Coast City Council's Stormwater Quality Management Guidelines*, (GCCC 2006), which is the best available information for Queensland. The baseflow pollution generation parameters are based on *Guidelines for Pollutant Export Modelling in Brisbane Version 8*, April 2006 (BCC 2006).
- The rainwater tank volumes are defined by the requirements of the *Queensland Development Code* and the demands as summarised in section 2.5.1.
- The bioretention system design assumptions provided in section 2.5.2 were adopted. The MUSIC default stormwater quality treatment performance parameters for bioretention were used. These were derived from performance monitoring data collected from across Australia and internationally by the CRCCH (refer to MUSIC Version 3.01 User Manual, Appendix F). Insufficient local stormwater treatment performance data was available for bioretention systems to allow for local performance data sets to be used for each climatic region.

Table 7: Rainfall–runoff parameters used in MUSIC

| PARAMETER | VALUE |
|---|---|
| Impervious area properties | |
| Rainfall threshold | 1 mm/d |
| Pervious area properties | |
| Soil storage capacity | 120 mm |
| Initial storage (% of capacity) | 30 % |
| Field capacity | 80 mm |
| Infiltration capacity coefficient — a | 200 |
| Infiltration capacity coefficient — b | 1 |
| Groundwater properties | |
| Initial depth | 10 mm |
| Daily recharge rate | 25 % |
| Daily base flow rate | 0 % |
| Daily deep seepage rate | 5 % |

Table 8: Stormwater pollutant concentrations used in MUSIC — residential

| PARAMETER | BASE FLOW CONCENTRATION | | STORM FLOW CONCENTRATION | |
|---|---|---|---|---|
| | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L |
| Roof | | | | |
| Total Suspended Solids | 1.00 | 0.34 | 1.30 | 0.39 |
| Total Phosphorus | - 0.97 | 0.31 | - 0.89 | 0.31 |
| Total Nitrogen | 0.20 | 0.20 | 0.26 | 0.23 |
| Road/driveway/car park | | | | |
| Total Suspended Solids | 1.00 | 0.34 | 2.43 | 0.39 |
| Total Phosphorus | - 0.97 | 0.31 | - 0.30 | 0.31 |
| Total Nitrogen | 0.20 | 0.20 | 0.26 | 0.23 |
| Other areas | | | | |
| Total Suspended Solids | 1.00 | 0.34 | 2.18 | 0.39 |
| Total Phosphorus | - 0.97 | 0.31 | - 0.47 | 0.31 |
| Total Nitrogen | 0.20 | 0.20 | 0.26 | 0.23 |

Table 9: Stormwater pollutant concentrations used in MUSIC — commercial

| PARAMETER | BASE FLOW CONCENTRATION | | STORM FLOW CONCENTRATION | |
|---|---|---|---|---|
| | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L |
| Roof | | | | |
| Total Suspended Solids | 0.78 | 0.39 | 1.30 | 0.38 |
| Total Phosphorus | - 0.60 | 0.50 | - 0.89 | 0.34 |
| Total Nitrogen | 0.32 | 0.30 | 0.37 | 0.34 |
| Road/driveway/car park | | | | |
| Total Suspended Solids | 0.78 | 0.39 | 2.43 | 0.38 |
| Total Phosphorus | - 0.60 | 0.50 | - 0.30 | 0.34 |
| Total Nitrogen | 0.32 | 0.30 | 0.37 | 0.34 |
| Other areas | | | | |
| Total Suspended Solids | 0.78 | 0.39 | 2.18 | 0.38 |
| Total Phosphorus | - 0.60 | 0.50 | - 0.47 | 0.34 |
| Total Nitrogen | 0.32 | 0.30 | 0.37 | 0.34 |

Table 10: Stormwater pollutant concentrations used in MUSIC — industrial

| PARAMETER | BASE FLOW CONCENTRATION | | STORM FLOW CONCENTRATION | |
|---|---|---|---|---|
| | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L | MEAN $LOG_{10}$ MG/L | STD DEV $LOG_{10}$ MG/L |
| Roof | | | | |
| Total Suspended Solids | 0.78 | 0.45 | 1.30 | 0.44 |
| Total Phosphorus | - 1.11 | 0.48 | - 0.89 | 0.36 |
| Total Nitrogen | 0.14 | 0.20 | 0.25 | 0.32 |
| Road/driveway/car park | | | | |
| Total Suspended Solids | 0.78 | 0.45 | 2.43 | 0.44 |
| Total Phosphorus | - 1.11 | 0.48 | - 0.30 | 0.36 |
| Total Nitrogen | 0.14 | 0.20 | 0.25 | 0.32 |
| Other areas | | | | |
| Total Suspended Solids | 0.78 | 0.45 | 2.18 | 0.44 |
| Total Phosphorus | - 1.11 | 0.48 | - 0.47 | 0.36 |
| Total Nitrogen | 0.14 | 0.20 | 0.25 | 0.32 |

## 3.2 Frequent flow objective

The frequent flow objective requires the first 10 or 15 mm of rainfall (depending on the imperviousness of the catchment) that falls on impervious surfaces to be captured and managed. The capture and storage volume must be available each day (drained within 24 hours) through a combination of management approaches:

- reuse
- diversion
- infiltration
- evapotranspiration
- discharge via bioretention.

For most development situations in Queensland, reuse, diversion, infiltration and evapotranspiration of this volume of water is not practically possible without connection to external locations (e.g. piped to other high water users, pipe diversion or connection to an aquifer system). This requires a strategic planning approach such as locating 'thirsty industries' within, or adjacent to, catchments draining to HEV waterways. A strategic planning approach will rarely be able to be implemented on individual parcels of land being developed privately.

Therefore, discharge via a bioretention system is the primary practical way of complying with the frequent flow objective at the development scale. Discharge via a bioretention system was adopted as the compliance method for the case studies. This approach approximately matches the frequency of overflows from a bioretention system to the natural frequency of surface runoff, but does not necessarily preserve the natural baseflow regime [4].

Using the bioretention compliance approach requires that a volume of water, equivalent to the first 10 or 15mm runoff from impervious areas in a day, pass through the filter media of the bioretention system. This requires extended detention, which provides ponding (storage) above the bioretention system's surface.

Bioretention systems drain rapidly because the saturated hydraulic conductivity of bioretention filter media is generally around 180 mm/hour. This is faster than the draw-down rate required to drain the frequent flow volume in 24 hours. If the volume can be drained faster than over 24 hours, the storage size can decrease to achieve a comparable outcome.

Modelling was undertaken for the three climatic regions to determine how a bioretention system, sized to meet the stormwater quality objectives for its catchment, would perform in meeting the frequent flow objective. The following steps were used in the modelling:

1. The percentage of annual runoff accounted for in the first 10/15 mm of runoff per day from impervious surfaces was calculated.
2. The proportion of annual runoff that passed through the filter media of a bioretention system sized to meet best practice stormwater quality objectives was calculated.

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[4] Note that the management method involving disposal of the capture volume by discharge through a bioretention system to the receiving waterway is an acceptable solution as defined by *WSUD: Developing design objectives for urban development in South East Queensland* (SEQ HWP, 2006), *Queensland Best Practice Environmental Management Guidelines—Urban Stormwater Technical Note: Derivation of Design Objectives* (DERM and EDAW, 2009). Recent research indicates that discharging the capture volume through a bioretention system does provide some level of hydrologic management but may not provide a suitable level of management to ensure protection of certain high environmental value ecosystems which may be highly sensitive to frequent flows (Walsh et al., 2009). Further technical investigation of frequent flow objective and compliance requirements is underway. There are emerging approaches in the literature (Walsh et al., 2009) that suggest throttling the outflow of a bioretention system to match predevelopment baseflow conditions may more closely reflect the retention capacity of natural catchments. This approach is likely to require a modification to contemporary bioretention system design and the costs of such modifications have not been costed as part of this project as the approach is purely theoretical at this stage. For particularly high value ecosystems, customised approaches to development may need to be adopted to preserve the key sustaining hydrology of the relevant ecosystem (Wong and Breen 2006). Assessing the costs and benefits of such approaches can only be done on a case-by-case basis.

3. If the percentage of annual runoff that passed through the bioretention system filter media was greater than the volume calculated in step 1, the frequent flow management objective was considered to be met.
4. If the frequent flow objective was not met, additional storage above the bioretention system must be provided.

Hypothetical catchments were set up to simulate a range of different development types for the three regions. Catchments were created with impervious surfaces ranging from 25% to 100%, to represent different development situations. Bioretention systems were then sized to treat the catchment runoff to meet the stormwater quality objectives. The proportion of average annual runoff treated by bioretention systems was then extracted from the model. The results are provided in Table 11.

The modelling indicates that when a bioretention system is sized to meet stormwater quality objectives, the frequent flow objective is also achieved for all development scenarios. The frequent flow volume passes through bioretention filter media using extended detention above the bioretention system (0.2–0.3 m) without the need for additional storage.

Table 11: Frequent flow management assessment

| REGION | % CATCHMENT IMPERVIOUSNESS | AVERAGE ANNUAL RUNOFF (ML/YEAR) | AVERAGE ANNUAL RUNOFF AFTER THE FIRST 10 OR 15 MM RAINFALL FROM IMPERVIOUS AREAS IS DIVERTED (ML/YEAR) | % REDUCTION IN ANNUAL AVERAGE FLOWS, OR PORTION OF ANNUAL RUNOFF TO PASS THROUGH BIORETENTION | BIORETENTION SIZE (AS % OF CATCHMENT AREA) | CALCULATED PROPORTION OF AVERAGE ANNUAL FLOW THAT PASSES THROUGH BIORETENTION |
|---|---|---|---|---|---|---|
| Brisbane | 25% | 4.17 | 3.47 | 17% | 1.8% | 75% |
| | 50% | 6.55 | 3.7 | 44% | 1.5% | 70% |
| | 80% | 8.93 | 4.37 | 51% | 1.5% | 68% |
| | 100% | 10.5 | 4.82 | 54% | 1.5% | 56% |
| Mackay | 25% | 7.8 | 7 | 10% | 1.5% | 55% |
| | 50% | 10.3 | 7.17 | 30% | 1.5% | 54% |
| | 80% | 12.8 | 7.81 | 39% | 1.5% | 51% |
| | 100% | 14.5 | 8.23 | 43% | 1.5% | 48% |
| Cairns | 25% | 11 | 9.87 | 10% | 2.5% | 65% |
| | 50% | 13.6 | 9.6 | 29% | 1.8% | 60% |
| | 80% | 16.3 | 9.82 | 40% | 1.8% | 58% |
| | 100% | 18 | 9.97 | 45% | 1.5% | 50% |

## 3.3 Waterway stability objective

The waterway stability objective aims to limit the post-development peak 1-year ARI event discharge within the receiving waterway to the pre-development peak 1-year ARI event discharge. In most situations, this requires storage to detain or retard the 1-year ARI flows. The *Design Objectives for Water Sensitive Developments in SEQ, Appendix C (SEQ Healthy Waterways Partnership, 2007)* outlines two methods for defining the detention storage requirements:

- Method A: Simple 'Hydrograph Method'
- Method B: Runoff Routing Model Method.

Method A was adopted for these case studies. Details of this method can be found in *Design Objectives for Water Sensitive Developments in SEQ (SEQ Healthy Waterways Partnership, 2007)*. The detention storage was then allocated in the case studies according to the options outlined in section 2.5.4. Site layout and topography dictated the final location for detention storage and the following general hierarchy was used:

- Storage within and above bioretention systems: refers to storage that is already built into the bioretention systems as a result of the design. The already available storages are assumed to be:
- storage above the extended detention volume of the bioretention in the zone between the level of the low-flow outlet (typically an overflow pit or culvert) and the level of the high-flow outlet (typically a weir)
- 10% of the extended detention volume above the bioretention and 10% of the pore space available in the bioretention5*
- Surface ponding within car parks and other areas.
- Above-ground detention storage in drainage reserves, landscape areas and parklands (often co-located with bioretention systems).
- Additional roofwater tanks.
- Underground storage tanks.

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[5] It is reasonable to credit 10% of the storage volume within the bioretention system. This water ultimately discharges, via infiltration, through the filter media because the infiltration rate is typically 10–15% of the target outflow rate from waterway stability storage (i.e. pre-development 1-year ARI 60 minute flow).

# 4 Costing method and assumptions

## 4.1 Overview

Cost estimates were prepared for the WSUD solutions developed for each case study. The following cost components were calculated:

- acquisition costs (including design and capital costs for construction and establishment)
- typical annual maintenance costs
- renewal costs (i.e. corrective maintenance costs)
- decommissioning costs.

These costs were used to determine a total lifecycle cost for the WSUD solution for each case study, as well the lifecycle cost of the individual components of the solution (e.g. rainwater tanks, bioretention systems, detention storages). Details of the cost estimates are presented in the case study summaries in section 5.

The cost assessment evaluates a net cost difference between a development that incorporates a WSUD solution and a 'traditional', or 'business-as-usual' development.

## 4.2 Component costs

Unit rates were prepared to estimate the acquisition costs and the typical annual maintenance costs for each WSUD element. These unit rates are presented and discussed in the following sections. Given the limited information about renewal and decommissioning costs for WSUD infrastructure, these costs were estimated as a fraction of the acquisition costs. The following assumptions were applied to the renewal and the decommissioning costs:

- renewal cost (bioretention systems) 40% of acquisition cost
- renewal cost (other WSUD infrastructure) 30% of acquisition cost
- decommissioning cost (bioretention systems) 40% of acquisition cost
- decommissioning cost (other WSUD infrastructure) 20% of acquisition cost

### 4.2.1 Rainwater tanks

The unit rates adopted for rainwater tanks and shown in Table 12 are based on review of recent reference material and advice from rainwater tank suppliers. The operation and maintenance costs include an annualised cost to cover pump replacement. This is typically a large component of the annual maintenance cost and is heavily influenced by the assumed pump life. A pump life of 10 years has been assumed for this assessment.

Table 12: Unit rates adopted for rainwater tanks (acquisition and maintenance)

| COST | DESCRIPTION | UNIT RATE | SOURCE OF UNIT RATE |
|---|---|---|---|
| 3 kL rainwater tank (above ground) | | | |
| Acquisition cost | Cost of supply and installation, including pump and internal pipework | $2,500 | Advice from rainwater tank suppliers |
| Annual maintenance cost | Ongoing operation and maintenance, including power and pump replacement | $90/yr | Advice from rainwater tank suppliers |
| 5 kL rainwater tank (above ground) | | | |
| Acquisition cost | Cost of supply and installation, including pump and internal pipework | $3,000 | Advice from rainwater tank suppliers |
| Annual maintenance cost | Ongoing operation and maintenance, including power and pump replacement | $90/yr | Advice from rainwater tank suppliers |
| 9 kL rainwater tank (below ground) | | | |
| Acquisition cost | Cost of supply and installation, including pump and internal pipework | $9,000 | Advice from rainwater tank suppliers |
| Annual maintenance cost | Ongoing operation and maintenance, including power and pump replacement | $175/yr | Advice from rainwater tank suppliers |
| 21 kL rainwater tank (above ground) | | | |
| Acquisition cost | Cost of supply and installation, including pump and internal pipework | $6,000 | Advice from rainwater tank suppliers |
| Annual maintenance cost | Ongoing operation and maintenance, including power and pump replacement | $175/yr | Advice from rainwater tank suppliers |
| 32 kL rainwater tank (within building) | | | |
| Acquisition cost | Cost of supply and installation, including pump and internal pipework | $20,000 | Advice from rainwater tank suppliers |
| Annual maintenance cost | Ongoing operation and maintenance, including power and pump replacement | $300/yr | Advice from rainwater tank suppliers |

### 4.2.2 Bioretention systems

The unit rates adopted for bioretention systems, shown in Table 13, are based on actual costs incurred in recent projects and on data from related research projects. Due to the significant effort required to ensure the bioretention plants establish, which usually takes up to two years, the maintenance costs in the first two years were estimated as three times the long-term annual maintenance costs.

Bioretention systems typically occupy areas that would otherwise be landscaped as turf or garden beds. Therefore, the net cost (acquisition and maintenance) of bioretention systems was calculated as the cost of the bioretention system less the cost of typical landscaping. It was assumed that half the area occupied by a bioretention system would otherwise be covered with turf and the other half would be covered with garden beds.

The unit cost of bioretention systems ($\$/m^2$) decreases as size increases. This is because the costs for infrastructure such as overflow pits and site establishment is spread across a larger area as the bioretention size increases.

Table 13: Unit rates adopted for bioretention systems (acquisition and maintenance)

| COST | DESCRIPTION | UNIT RATE | SOURCE OF UNIT RATE |
|---|---|---|---|
| Landscape (garden bed) | | | |
| Acquisition cost | Cost of design and construction of typical garden bed | $\$55/m^2$ | Advice from landscape architects<br>Actual costs from recent projects |
| Annual maintenance cost | Ongoing maintenance | $\$2.5/m^2/yr$ | Advice from landscape architects<br>Actual costs from recent projects |
| Landscape (turf) | | | |
| Acquisition cost | Cost of design and construction of turf area | $\$ 15/m^2$ | Advice from landscape architects Actual costs from recent projects |
| Annual maintenance cost | Ongoing maintenance | $\$ 1/m^2/yr$ | Landscape architects and local authorities |
| Bioretention system (large) — protection required during subdivision construction | | | |
| Gross acquisition cost | Cost of design and construction, including landscaping | $\$ 300/m^2$ | Actual costs from recent projects |
| Net acquisition cost | Gross acquisition cost less landscape cost | $\$ 265/m^2$ | n/a |
| Bioretention system (large) — no protection required during subdivision construction | | | |
| Gross acquisition cost | Cost of design and construction, including landscaping | $\$ 270/m^2$ | Actual costs from recent projects |
| Net acquisition cost | Gross acquisition cost less landscape cost | $\$ 235/m^2$ | n/a |
| Bioretention system (medium) | | | |
| Gross acquisition cost | Cost of design and construction, including landscaping | $\$ 365/m^2$ | Actual costs from recent projects |
| Net acquisition cost | Gross acquisition cost less landscape cost | $\$ 330/m^2$ | n/a |
| Bioretention system (small or complex) | | | |
| Gross acquisition cost | Cost of design and construction, including landscaping | $\$ 400/m^2$ | Actual costs from recent projects |
| Net acquisition cost | Gross acquisition cost less landscape cost | $\$ 365/m^2$ | n/a |

| COST | DESCRIPTION | UNIT RATE | SOURCE OF UNIT RATE |
|---|---|---|---|
| Bioretention system (all) | | | |
| Gross annual maintenance cost (first 2 years) | General maintenance (e.g. weeding, replanting, sediment removal) | $ 15/m²/yr | Actual costs from recent projects |
| Gross annual maintenance cost (ongoing) | General maintenance (e.g. weeding, replanting, sediment removal) | $ 5/m²/yr | Actual costs from recent projects |
| Net annual maintenance cost (first 2 years) | Gross maintenance cost less landscape cost | $ 13.25/m²/yr | n/a |
| Net annual maintenance cost (ongoing) | Gross maintenance cost less landscape cost | $ 3.25/m²/yr | n/a |

Table 14: Unit rates adopted for detention storages

| COST | DESCRIPTION | UNIT RATE | SOURCE OF UNIT RATE |
|---|---|---|---|
| Above-ground detention storage | | | |
| Gross acquisition cost | Cost of design and construction, including landscaping | $40/m³ | Actual costs from recent projects* |
| Gross annual maintenance cost | General maintenance (e.g. weeding, replanting, sediment removal) | $2.5/m³/yr | Actual costs from recent projects* |
| Net acquisition cost | Gross acquisition costs minus landscape cost | $25/m³ | |
| Net annual maintenance cost | Gross acquisition costs minus landscape cost | $1.0/m³/yr | |
| Below ground detention storage | | | |
| Acquisition cost | Cost of supply and installation | $ 300/m³ | Actual costs from recent projects* |
| Annual maintenance cost | General maintenance | $ 1/m³/yr | Actual costs from recent projects* |

* Development projects include Coomera Waters, North Lakes, Fernbrooke Estate, North Shore. Information also provided by Gold Coast City Council.

## 4.3 Lifecycle costs

For each case study, the lifecycle cost for the overall WSUD solution, as well as the individual components of the solution, have been calculated. A lifecycle cost period of 25 years has been used as this is the typical period used for public benefit–cost analysis. A discount rate of 5.5% has been used in the lifecycle cost calculations, which is supported by Queensland Treasury who suggest a real discount rate of between 5% and 6%. Due to the discounting, impacts after 25 years rarely have a material impact on benefits or costs.

# 5 Case studies

## 5.1 Case study 1: residential greenfield (sloping topography)

### 5.1.1 Development type

Case study 1 is a residential greenfield development that consists of numerous stages, or land releases, within a large-scale, mixed-use subdivision. The case study site covers an area of 76 ha within an overall subdivision of approximately 1000 ha. The site is focused around a creek corridor, with residential areas covering the ridges that flank the creek. The ridge crests are approximately 10 m higher than the creek, resulting in moderate slopes (5%–10%) throughout the residential areas. There are 951 detached houses, with a typical lot size of between 400–700 m². The remainder of the site comprises an internal road network to service the lots and 5.5 ha of creditable open space parklands. The drainage reserve containing the creek is not included in the case study site area. Overall, the site is approximately 47% impervious. Table 15 shows a breakdown of the site areas and Figure 2 illustrates the layout of the development.

Table 15: Case study 1 site breakdown

| SITE AREA BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 191,600 | 100% |
| Road/driveway | 215,000 | 60% |
| Other areas<br>- landscape<br>- pavement | 350,900 | 11% |
| Total site area | 757,500 | 47% |

#### 5.1.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is located on moderately sloping ground, with typical slopes of 5%–10%. Civil designs for sloping sites usually aim to work with the existing topography and minimise the amount of earthworks required. While some degree of cut and fill may be required, the developed site typically has similar slopes to the pre-developed site.

The moderate slopes generally limit the design of stormwater drainage to conventional drainage and the associated WSUD solutions to precinct scale or end-of-line. With the exception of rainwater tanks and on-site detention tanks, lots and roads with moderate slopes are not conducive to lot-scale or streetscape stormwater management systems. A typical design for a sloping site incorporates conventional pit and pipe stormwater drainage networks feeding to end-of-line stormwater treatment and detention systems. End-of-line stormwater management systems are integrated into open space areas between the edge of the lots or roads and the ultimate receiving waterway or stormwater drainage network.

Case study 1 follows this standard approach, with a pit and pipe stormwater drainage system collecting stormwater runoff from the residential lots, roads and open space areas. Stormwater is conveyed to end-of-line stormwater management systems located within the creek corridor. The topography of the site and the earthworks' design dictate approximately twelve separate locations for stormwater to be discharged from the piped drainage network. This provides some flexibility regarding the overall number and configuration of the stormwater management systems.

The site design for case study 1 incorporates substantial flood detention storage. Two dry detention basins are located within the creek corridor. This flood detention storage totals approximately 20,000–25,000 m³ to meet the local council's stormwater design requirements.

Development Type: Large residential - Moderate to steep
Building Type: Detached Houses
Number of Dwellings: 951

**Site Breakdown**

| | Area | % Impervious |
|---|---|---|
| Roof | 19.2 ha | 100% |
| Road | 21.5 ha | 60% |
| Other | 35.1 ha | 11% |
| Total | 75.8 ha | 47% |

**Development Characteristics**

- Typical lot size of between 400 and 700 $m^2$
- Site is focused around a creek corridor, with residential areas covering the ridges on either side of the creek

- Catchment Extent
- Catchment Boundary
- Rehabilitated Waterway

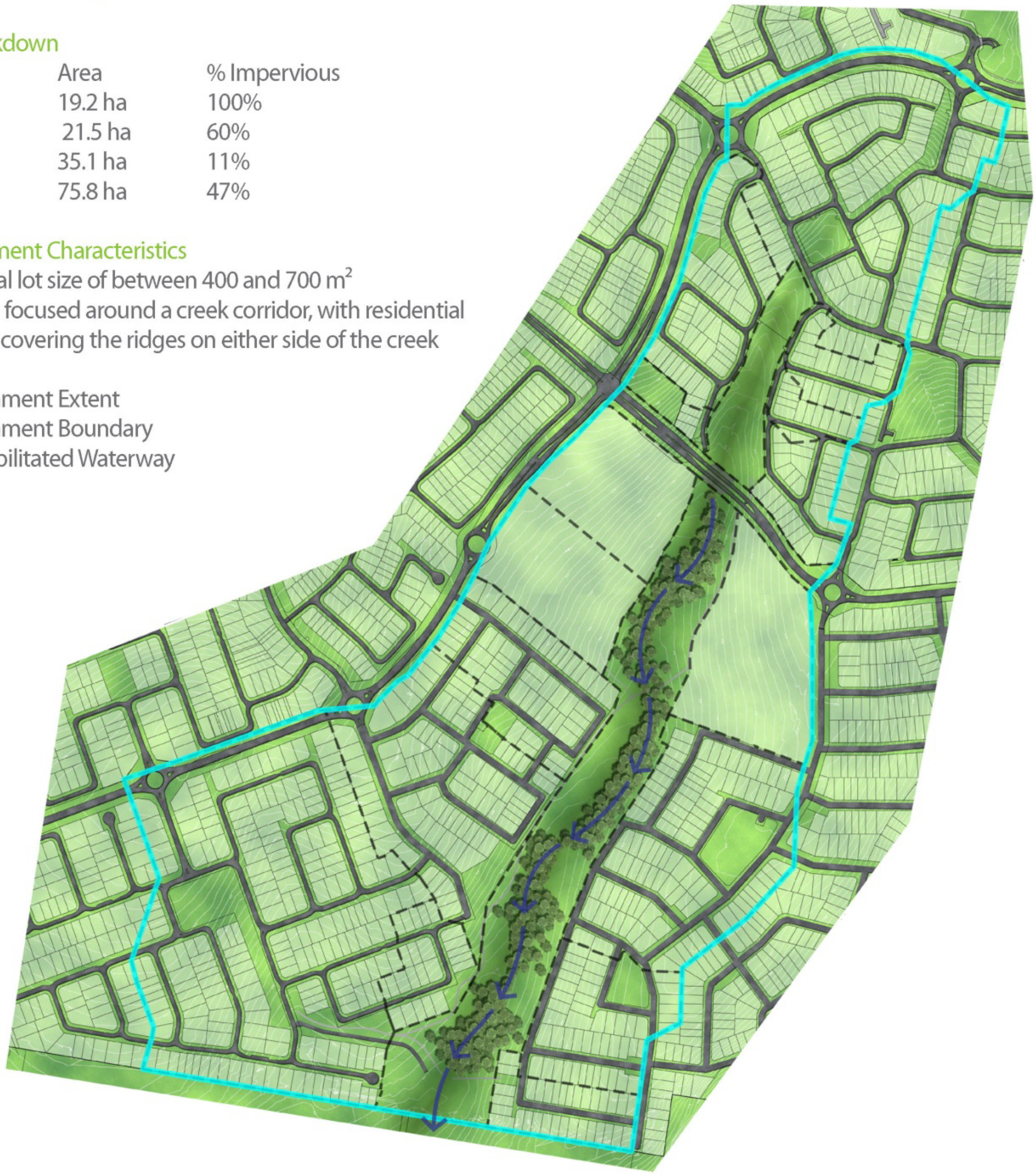

Figure 2: Case study 1 — development plan

### 5.1.2 WSUD solution

The base case includes rainwater tanks as required by the *Queensland Development Code* and flood detention.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks as required by the Queensland Development Code
- end-of-line bioretention systems to deliver the stormwater quality and frequent flow objectives
- above-ground detention storage to manage the 1-year ARI flow to deliver the waterway stability objective (assumed to form part of flood storage in base case).

Figure 3 shows the treatment train and the location of the WSUD solutions.

#### 5.1.2.1 RAINWATER TANKS

As required by the *Queensland Development Code*, each detached house has a 5 kL rainwater tank to supply toilet flushing, laundry cold and outdoor demands. The overflow from the rainwater tanks discharges to the drainage system, which is directed towards a bioretention system.

#### 5.1.2.2 BIORETENTION SYSTEMS

Twelve precinct-scale bioretention systems treat water quality for the remainder of the site, including half of the roof area plus overflows from the rainwater tanks. The bioretention systems are located along the edge of the drainage corridor with discharge directed into the drainage corridor. The total bioretention area required to deliver best practice stormwater quality for the site, as developed in each test region, is shown in Table 16.

Table 16: Case study 1 — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 6,060 | 0.8% |
| Mackay | 9,090 | 1.2% |
| Townsville | 9,848 | 1.3% |
| Cairns | 11,363 | 1.5% |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements outlined in section 3.2.

#### 5.1.2.3 DETENTION STORAGE

The waterway stability objective applies to this case study. The detention volume required for sites within each climatic region is shown in Table 17 and is incorporated in the flood storage element of the base case.

Table 17: Case study 1— waterway stability storage requirement

| REGION | TOTAL STORAGE VOLUME REQUIRED ($M^3$) | STORAGE VOLUME UNIT RATE ($M^3$/HA) |
|---|---|---|
| Brisbane | 13,100 | 173 |
| Mackay | 15,259 | 201 |
| Townsville | 14,792 | 195 |
| Cairns | 16,627 | 219 |

The detention storage is provided within the site three ways:

- In bioretention systems: 10% of the bioretention systems with an extended detention depth and pore space volume in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 0.6 m depth across the bioretention surface area.
- Above-ground storage: the site design incorporates substantial flood detention storage with two dry detention basins. The additional storage required to meet the waterway stability objective can be provided by these detention storages, without compromising the flood detention function. Therefore, no additional detention basins are required.

A breakdown of the storages required for each region is shown in Table 18.

Table 18: Case study 1 — detention storage allocation for the waterway stability objective

| REGION | PORTION OF BIORETENTION SYSTEM EXTENDED DETENTION AND PORE SPACE ($M^3$) | ABOVE BIORETENTION SYSTEMS ($M^3$) | ABOVE-GROUND STORAGE WITHIN FLOOD STORAGE ($M^3$) | TOTAL($M^3$) |
|---|---|---|---|---|
| Brisbane | 236 | 3,636 | 9,228 | 13,100 |
| Mackay | 355 | 5,454 | 9,450 | 15,259 |
| Townsville | 384 | 5,909 | 8,499 | 14,792 |
| Cairns | 443 | 6,818 | 9,366 | 16,627 |

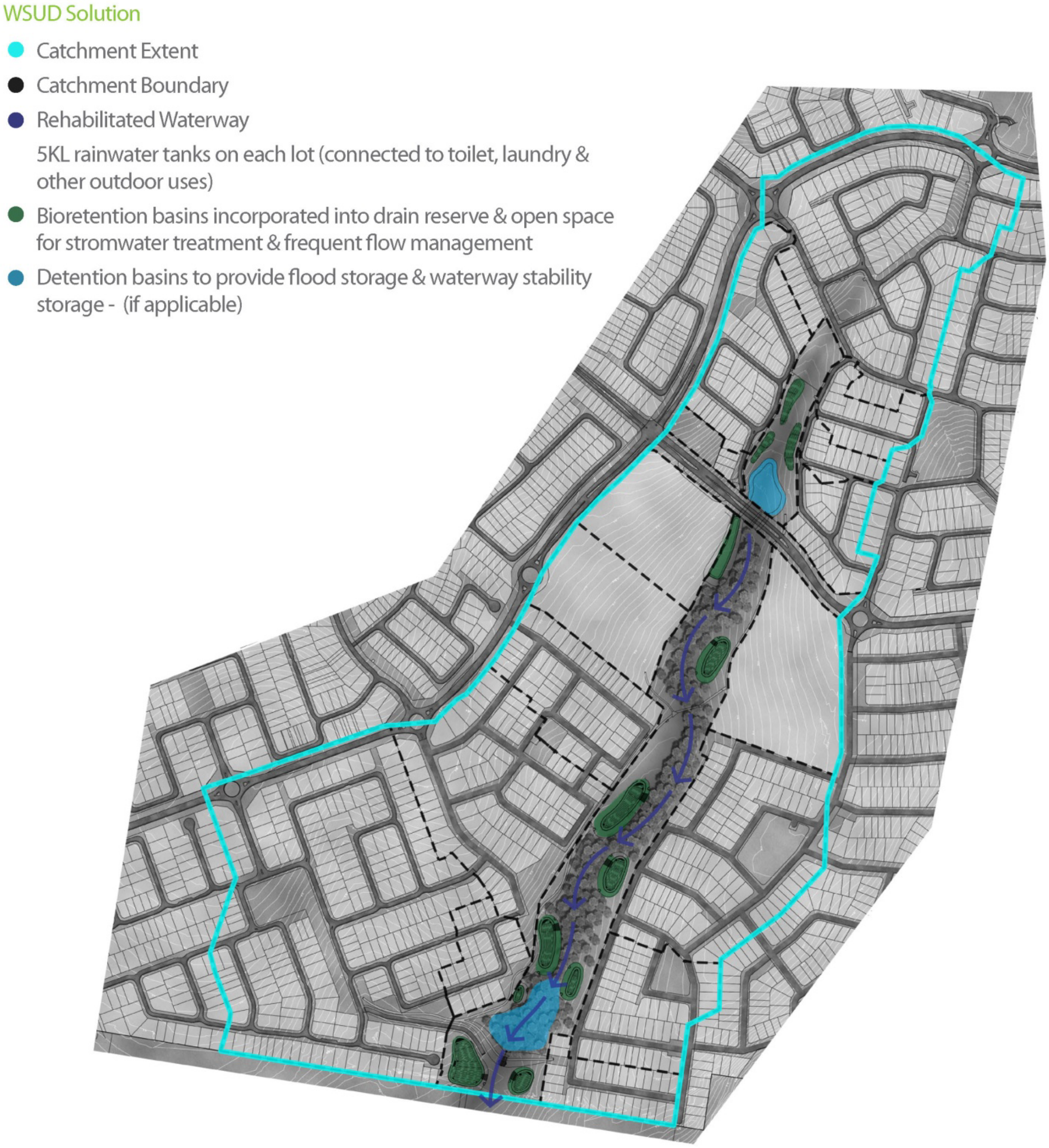


Figure 3: Case study 1 — WSUD solution

### 5.1.3 Performance

The MUSIC results for the WSUD solution for each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 19 shows the MUSIC results for case study 1.

Table 19: Case study 1 — MUSIC results

| | | | BASE CASE | | WSUD CASE | | STORMWATER QUALITY OBJECTIVE |
|---|---|---|---|---|---|---|---|
| | | UNMITIGATED | AVERAGE ANNUAL LOADS | % REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | |
| Brisbane | Flow (ML/yr) | 438 | 384 | 12% | 385 | 12% | - |
| | Total Suspended Solids (kg/yr) | 87,000 | 84,960 | 2% | 17,300 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 169 | 159 | 6% | 56 | 67% | 60% |
| | Total Nitrogen (kg/yr) | 921 | 802 | 13% | 490 | 47% | 45% |
| Mackay | Flow (ML/yr) | 700 | 651 | 7% | 651 | 7% | - |
| | Total Suspended Solids (kg/yr) | 144,000 | 141,880 | 1% | 35,400 | 75% | 75% |
| | Total Phosphorus (kg/yr) | 279 | 270 | 3% | 109 | 61% | 60% |
| | Total Nitrogen (kg/yr) | 1,460 | 1,349 | 8% | 906 | 38% | 35% |
| Townsville | Flow (ML/yr) | 509 | 473 | 7% | 474 | 7% | - |
| | Total Suspended Solids (kg/yr) | 104,000 | 102,400 | 2% | 19,300 | 81% | 80% |
| | Total Phosphorus (kg/yr) | 200 | 193 | 3% | 65 | 68% | 65% |
| | Total Nitrogen (kg/yr) | 1,070 | 988 | 8% | 603 | 44% | 40% |
| Cairns | Flow (ML/yr) | 912 | 862 | 5% | 862 | 5% | - |
| | Total Suspended Solids (kg/yr) | 188,000 | 185,580 | 1% | 37,300 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 361 | 351 | 3% | 122 | 66% | 65% |
| | Total Nitrogen (kg/yr) | 1,900 | 1,784 | 6% | 1,100 | 42% | 40% |

### 5.1.4 Costs

Table 20 shows the costs of the base case and WSUD case for each region. The table also identifies the incremental cost of the WSUD case when compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the costs of meeting the *Queensland Development Code* (rainwater tanks) requirements is the dominant cost, accounting for between 55%–73% of the overall cost of the WSUD case, depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $2300 per lot in Brisbane to $4400 per lot in Cairns.

Table 20: Case study 1 — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 4,214,208 | 2,853,000 | 85,590 | 855,900 | 570,600 |
| | Bioretention systems (incremental cost) | 2,247,698 | 1,605,900 | 19,695 | 642,360 | 642,360 |
| | - per hectare | 29,673 | 21,200 | | | |
| | - per lot | 2,364 | 1,689 | | | |
| | Detention storages* | 395,314* | 230,700 | 9,228 | 69,210 | 46,140 |
| | Overall (WSUD CASE) | 6,461,906 | 4,458,900 | | | |
| | - per hectare | 80,774 | 55,736 | | | |
| | - per lot | 6,795 | 4,689 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 4,214,208 | 2,853,000 | 85,590 | 855,900 | 570,600 |
| | Bioretention systems (incremental cost) | 3,371,547 | 2,408,850 | 29,543 | 963,540 | 963,540 |
| | - per hectare | 44,509 | 31,800 | | | |
| | - per lot | 3,545 | 2,533 | | | |
| | Detention storages* | 404,867* | 236,275 | 9,451 | 70,883 | 47,255 |
| | Overall (WSUD CASE) | 7,585,755 | 5,261,859 | | | |
| | - per hectare | 94,822 | 65,773 | | | |
| | - per lot | 7,977 | 5,532 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 4,214,208 | 2,853,000 | 85,590 | 855,900 | 570,600 |
| | Bioretention systems (incremental cost) | 3,652,509 | 2,609,588 | 32,004 | 1,043,835 | 1,043,835 |
| | - per hectare | 48,218 | 34,450 | | | |
| | - per lot | 3,841 | 2,744 | | | |
| | Detention storages* | 364,085* | 212,475 | 8,499 | 63,743 | 42,495 |
| | Overall (WSUD CASE) | 7,866,717 | 5,462,588 | | | |
| | - per hectare | 103,851 | 72,113 | | | |
| | - per lot | 8,272 | 5,744 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 4,214,208 | 2,853,000 | 85,590 | 855,900 | 570,600 |
| | Bioretention systems (incremental cost) | 4,214,433 | 3,011,063 | 36,928 | 1,204,425 | 1,204,425 |
| | - per hectare | 55,636 | 39,750 | | | |
| | - per lot | 4,432 | 3,166 | | | |
| | Detention storages* | 401,226* | 234,150 | 9,366 | 70,245 | 46,830 |
| | Overall (WSUD CASE) | 8,428,641 | 5,864,063 | | | |
| | - per hectare | 105,358 | 73,301 | | | |
| | - per lot | 8,862 | 6,166 | | | |

***** This item is associated with detention storage to meet the waterway stability objective. In this case study, the storage is incorporated into the flood detention storage for the site, therefore, the costs for this item have not been included in the overall costs. The costs are still presented for illustration purposes.

## 5.2 Case study 2: residential greenfield (flat topography)

### 5.2.1 Development type

Case study 2 consists of several residential stages, or land releases, within a large-scale residential subdivision. The case study site covers an area of 6.3 ha within an overall subdivision of approximately 100 ha. There are 84 detached houses within the site, with typical lot sizes of between 400–500 $m^2$. There is an internal road network to service the houses, but no significant park areas or communal buildings within the site. The site is located on flat, low-lying ground close to the coast. Small created drainage waterways flow along two sides of the site and are the ultimate discharge locations for stormwater. Overall, the site is 56% impervious. Table 21 breaks down the site areas. Figure 4 shows the development layout.

Table 21: Case study 2 — site breakdown

| SITE BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 19,400 | 100 |
| Road/driveway | 24,660 | 50 |
| Other areas<br>- landscape<br>- pavement | 19,340 | 20 |
| Total site area | 63,400 | 56 |

#### 5.2.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is located on flat ground, with slopes of less than 1%. Civil designs for flat sites typically incorporate substantial re-profiling to create gentle undulations with sufficient grade for surface drainage (within kerb and gutter).

Flat sites present significant challenges for stormwater drainage design and associated WSUD solutions. Underground stormwater pipes must be laid at flat grades and need to be relatively large to convey the required flow. Conventional design approaches to flat site can result is very large drainage and earthworks costs (refer section 5.3.4 of main report). The development layout for case study 2 has been designed to avoid these drainage and earthworks issues. Much of the site incorporates stormwater management systems into the road reserves with stormwater runoff from the remainder of the site directed to stormwater management systems via short lengths of small pipes.


Figure 4: Case study 2 — development plan

## 5.2.2 WSUD solution

The base case included rainwater tanks as required by the *Queensland Development Code*.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks as required by the *Queensland Development Code*
- bioretention systems to deliver the stormwater quality and frequent flow objectives
- detention storage to manage the 1-year ARI flow in accordance with the waterway stability objective.

Figure 5 shows the locations of the WSUD solutions.

### 5.2.2.1 RAINWATER TANKS

Each lot has a 5 kL rainwater tank as required by the *Queensland Development Code* connected to half the roof, which will service the toilet, laundry, and outdoor uses. The overflow from the tank is directed to the stormwater drainage network and, ultimately, to one of the bioretention systems.

#### 5.2.2.2 BIORETENTION SYSTEMS

Nine bioretention pods are integrated into road reserves to treat stormwater runoff from half of the site and six bioretention systems incorporated into open space areas at end-of-line locations to treat stormwater runoff from the other half of the site.

The total bioretention area required to deliver best practice stormwater quality on the site, as developed in each test region, is shown in Table 22.

Table 22: Case study 2 — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 634 | 1.0 |
| Mackay | 824 | 1.3 |
| Townsville | 824 | 1.3 |
| Cairns | 1,014 | 1.6 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements outlined in section 3.2.

#### 5.2.2.3 DETENTION STORAGE (IF APPLICABLE)

The case study assumes the waterway stability detention storage is not required or is incorporated into flood storage (base case). If the waterway stability objective did apply and there is no flood storage requirement, the detention volume required is shown in Table 23. Table 23: Case study 2 — waterway stability storage requirement

| REGION | TOTAL STORAGE VOLUME REQUIRED ($M^3$) | STORAGE VOLUME UNIT RATE ($M^3$/HA) |
|---|---|---|
| Brisbane | 1,132 | 179 |
| Mackay | 1,318 | 208 |
| Townsville | 1,278 | 202 |
| Cairns | 1,437 | 227 |

The detention storage is provided within the site four ways:

- In bioretention systems: 10% of the bioretention systems' extended detention depth and pore space volume is in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 0.3 m depth across the bioretention surface area.
- Underground storage: an underground detention tank is provided within the road reserve at each of the six end-of-line locations. These underground detention tanks are sealed stormwater pipes and provide 450 $m^3$ of the additional storage requirement.
- The remaining storage volume is achieved by expanding the footprint of five of the six end-of-line bioretention systems so that they provide additional storage volume between the level of the low-flow outlet and the high-flow outlet.

A summary of the storages required for the four regions is shown in Table 24.

Table 24: Case study 2 — detention storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION EXTENDED DETENTION AND PORE SPACE VOLUME (M³) | VOLUME ABOVE BIORETENTION (M³) | UNDERGROUND DETENTION TANK VOLUME (M³) | ADDITIONAL DETENTION SYSTEM VOLUME ABOVE END-OF-LINE SYSTEMS (M³) |
|---|---|---|---|---|
| Brisbane | 26 | 190 | 450 | 466 |
| Mackay | 34 | 247 | 450 | 587 |
| Townsville | 34 | 247 | 450 | 547 |
| Cairns | 41 | 304 | 450 | 642 |


Figure 5: Case study 2 — WSUD solution

### 5.2.3 Performance

The MUSIC results for the WSUD solutions in each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 25 shows the MUSIC results for case study 2.

Table 25: Case study 2 — MUSIC results

| | | | BASE CASE | | WSUD CASE | | |
|---|---|---|---|---|---|---|---|
| | | UNMITIGATED | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | STORMWATER QUALITY OBJECTIVE |
| Brisbane | Flow (ML/yr) | 42 | 37 | 12% | 37 | 12% | - |
| | Total Suspended Solids (kg/yr) | 7,900 | 7,704 | 2% | 1,420 | 82% | 80% |
| | Total Phosphorus (kg/yr) | 16 | 15 | 6% | 5 | 69% | 60% |
| | Total Nitrogen (kg/yr) | 87 | 76 | 13% | 45 | 49% | 45% |
| Mackay | Flow (ML/yr) | 64 | 60 | 7% | 60 | 7% | - |
| | Total Suspended Solids (kg/yr) | 12,900 | 12,706 | 2% | 3,030 | 77% | 75% |
| | Total Phosphorus (kg/yr) | 25 | 24 | 3% | 10 | 62% | 60% |
| | Total Nitrogen (kg/yr) | 135 | 125 | 7% | 83 | 38% | 35% |
| Townsville | Flow (ML/yr) | 47 | 44 | 7% | 44 | 7% | - |
| | Total Suspended Solids (kg/yr) | 9,490 | 9,341 | 2% | 1,870 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 18 | 18 | 3% | 6 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 99 | 91 | 8% | 57 | 43% | 40% |
| Cairns | Flow (ML/yr) | 83 | 78 | 6% | 78 | 6% | - |
| | Total Suspended Solids (kg/yr) | 16,800 | 16,572 | 1% | 3,280 | 81% | 80% |
| | Total Phosphorus (kg/yr) | 33 | 32 | 3% | 11 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 173 | 163 | 6% | 99 | 43% | 40% |

### 5.2.4 Costs

Table 26 shows the costs of the base case and WSUD case as developed in each region. The table also identifies the incremental cost of the WSUD case compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the cost of meeting the *Queensland Development Code* (rainwater tanks) requirements is the dominant cost, accounting for between 45 and 57% of the overall cost depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $3400 per lot in Brisbane to $5400 per lot in Cairns.

Table 26: Case study 2 — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 372,233 | 252,000 | 7,560 | 75,600 | 50,400 |
| | Bioretention systems (incremental cost) | 284,189 | 209,220 | 2,061 | 83,688 | 83,688 |
| | - per hectare | 44,825 | 33,000 | | | |
| | - per lot | 3,383 | 2,491 | | | |
| | Detention tanks* | 154,533 | 135,000 | 450 | 40,500 | 27,000 |
| | Detention storages* | 19,963 | 11,650 | 466 | 3,495 | 2,330 |
| | Overall (WSUD CASE) | 656,422 | 461,220 | | | |
| | - per hectare | 103,537 | 72,748 | | | |
| | - per lot | 7,815 | 5,491 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 372,233 | 252,000 | 7,560 | 75,600 | 50,400 |
| | Bioretention systems (incremental cost) | 369,356 | 271,920 | 2,678 | 108,768 | 108,768 |
| | - per hectare | 58,258 | 42,890 | | | |
| | - per lot | 4,397 | 3,237 | | | |
| | Detention tanks* | 154,533 | 135,000 | 450 | 40,500 | 27,000 |
| | Detention storages* | 25,189 | 14,700 | 588 | 4,410 | 2,940 |
| | Overall (WSUD CASE) | 741,589 | 523,920 | | | |
| | - per hectare | 116,970 | 82,637 | | | |
| | - per lot | 8,828 | 6,237 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 372,233 | 252,000 | 7,560 | 75,600 | 50,400 |
| | Bioretention systems (incremental cost) | 369,356 | 271,920 | 2,678 | 108,768 | 108,768 |
| | - per hectare | 58,258 | 42,890 | | | |
| | - per lot | 4,397 | 3,237 | | | |
| | Detention tanks* | 154,533 | 135,000 | 450 | 40,500 | 27,000 |
| | Detention storages* | 23,433 | 13,675 | 547 | 4,103 | 2,735 |
| | Overall (WSUD CASE) | 741,589 | 523,920 | | | |
| | - per hectare | 116,970 | 82,637 | | | |
| | - per lot | 8,828 | 6,237 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 372,233 | 252,000 | 7,560 | 75,600 | 50,400 |
| | Bioretention systems (incremental cost) | 454,523 | 334,620 | 3,296 | 133,848 | 133,848 |
| | - per hectare | 71,691 | 52,779 | | | |
| | - per lot | 5,411 | 3,984 | | | |
| | Detention tanks* | 154,533 | 135,000 | 450 | 40,500 | 27,000 |
| | Detention storages* | 27,460 | 16,025 | 641 | 4,808 | 3,205 |
| | Overall (WSUD CASE) | 826,756 | 586,620 | | | |
| | - per hectare | 130,403 | 92,527 | | | |
| | - per lot | 9,842 | 6,984 | | | |

***** This item is associated with detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

## 5.3 Case study 3: townhouses

### 5.3.1 Development type

Case study 3 is a townhouse development located within a large master-planned residential community. The case study site comprises 25 two-storey townhouses. As well as the townhouse dwellings, the site has landscaped areas, an internal road network, visitor parking spaces and a loading bay. The total site area is 6660 $m^2$. Overall, the site is 61% impervious. Table 27 shows the breakdown of the site areas. Figure 6 shows the development layout.

Table 27: Case study 3 — site breakdown

| SITE BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 2,200 | 100 |
| Road/driveway | 1,830 | 100 |
| Other areas<br>- Landscape<br>- pavement | 2,630 | 0 |
| Total site area | 6,660 | 61 |

#### 5.3.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is flat with an average slope of less than 1%. The ultimate discharge locations for stormwater are existing stormwater drainage networks. There is a level difference of 1.5–2 m from the surface of the site to the invert of the external drainage. This limits flexibility for the location and level of stormwater management systems. The central landscaped area provides a suitable location for vegetated stormwater treatment systems, such as bioretention systems. However, to enable piped roofwater drainage to discharge onto the surface of a bioretention system, surcharge pits are required in some instances. The compact nature of the site allows a stormwater management strategy that maximises the proportion of the site drained via surface flow paths and minimises the use of stormwater pits and pipes.

The areas to be treated are split into components. Twelve townhouses have roof areas of 92 $m^2$ and thirteen have roof areas of 84 $m^2$. It is assumed that half the area of each roof will drain to a rainwater tank to meet the minimum requirements of the *Queensland Development Code*. Runoff from the other half of the roof, combined with overflow from the tanks, and will enter the shallow drainage system to the stormwater management systems.

Development Type: Residential Townhouse Development
Building Type: Attached 2 storey townhouses
Number of Dwellings: 25

### Site Breakdown

| | Area | % Impervious |
|---|---|---|
| Roof | 0.22ha | 100% |
| Roads/Driveway | 0.18ha | 100% |
| Other Areas | 0.26ha | 0% |
| Total | 0.66ha | 61% |

### Development Characteristics

- Internal circular driveway to service lots
- Central landscaped common area
- Four visitor car parking spaces & loading bay


Figure 6: Case study 3 — development plan

### 5.3.2 WSUD solution

The base case included rainwater tanks as required by the *Queensland Development Code*.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks as required by the *Queensland Development Code*
- bioretention systems to deliver the stormwater quality and frequent flow objectives
- detention storage to manage the 1-year ARI flow to deliver the waterway stability objective if it applies.

Figure 7 shows the location of the WSUD solutions.

#### 5.3.2.1 RAINWATER TANKS

As required by the *Queensland Development Code*, each townhouse has a 3 kL rainwater tank for toilet flushing, laundry and outdoor demands. The overflows from the rainwater tanks discharge to the drainage system, which is directed towards a bioretention system.

#### 5.3.2.2 BIORETENTION SYSTEMS

Bioretention systems accept surface runoff from the road and ground level areas, together with piped flows from the roof areas and tank overflows.

It is assumed that the majority of the bioretention systems are incorporated into existing landscaped areas on common ground. The total bioretention area required to deliver best practice stormwater quality on the site, as developed in each test region, is shown in Table 28.

Table 28: Case study 3 — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 59.9 | 0.9 |
| Mackay | 73.3 | 1.1 |
| Townsville | 79.9 | 1.2 |
| Cairns | 93.2 | 1.4 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements as outlined in section 3.2.

#### 5.3.2.3 DETENTION STORAGE (IF APPLICABLE)

The case study assumes the waterway stability detention storage is not required or can be incorporated into flood storage (base case). If the waterway stability objective did apply and there is no flood storage requirement, the detention volume required is shown in Table 29.

The detention storage can be provided within the site four ways:

- In bioretention systems: 10% of the bioretention systems' extended detention depth and pore space volume in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 0.4 m depth across the bioretention surface area.

- Underground storage: provided as underground storage beneath the landscape area with the invert level of the storage above the level of the discharge point from the site (i.e. flat 1350 mm or 1500 mm pipe).
- Surface storage: temporary ponding within a portion of the landscape areas adjacent to the bioretention systems.

Stormwater will preferentially fill the underground storage, so surface ponding is restricted to relatively infrequent, high-intensity storm events. Stormwater that temporarily ponds in the landscaped areas is ultimately drained into the underground tanks. Therefore, the outflow from the underground tanks is choked to ensure the target flow rate is achieved.

A summary of the storages required for the four regions is shown in Table 30.

Table 29: Case study 3 — waterway stability detention storage requirements

| REGION | TOTAL DETENTION STORAGE ($M^3$) | DETENTION STORAGE VOLUME ($M^3$/HA) |
|---|---|---|
| Brisbane | 121.5 | 182.4 |
| Mackay | 141.4 | 212.3 |
| Townsville | 137.1 | 206.0 |
| Cairns | 154.1 | 231.4 |

Table 30: Case study 3 — detention storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION SYSTEM EXTENDED DETENTION AND PORE SPACE $M^3$ | ABOVE BIORETENTION SYSTEMS $M^3$ | UNDERGROUND STORAGE $M^3$ | SURFACE STORAGE $M^3$ | TOTAL $M^3$ |
|---|---|---|---|---|---|
| Brisbane | 2.3 | 24.0 | 59.8 | 35.4 | 121.5 |
| Mackay | 2.8 | 29.3 | 73.3 | 36.0 | 141.4 |
| Townsville | 3.0 | 32.0 | 79.9 | 22.2 | 137.1 |
| Cairns | 3.5 | 37.3 | 93.2 | 20.1 | 154.1 |

WSUD Solution

- 3KL rainwater tank for each townhouse (connected to toilet, laundry & outdoor uses)
- Bioretention basins for treatment of stormwater
- Underground detention tanks for waterway stability storage (if applicable)
- Surface ponding over landscaped area for waterway stability storage (if applicable)
- ← Overflow from tanks via shallow 100-225mm PVC

Note: Road & ground level surface flow to bioretention


Figure 7: Case study 3 — WSUD solution

### 5.3.3 Performance

The MUSIC results for the WSUD solution for each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 31 shows the MUSIC results for case study 3.

Table 31: Case study 3 — MUSIC results

| | | UNMITIGATED | BASE CASE | | WSUD CASE | | STORMWATER QUALITY OBJECTIVE |
|---|---|---|---|---|---|---|---|
| | | | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | |
| Brisbane | Flow (ML/yr) | 4.64 | 3.79 | 18% | 3.79 | 18% | - |
| | Total Suspended Solids (kg/yr) | 916 | 889 | 3% | 169 | 82% | 80% |
| | Total Phosphorus (kg/yr) | 1.79 | 1.65 | 8% | 0.55 | 69% | 60% |
| | Total Nitrogen (kg/yr) | 9.75 | 7.95 | 19% | 4.79 | 51% | 45% |
| Mackay | Flow (ML/yr) | 7.03 | 6.17 | 12% | 6.18 | 12% | - |
| | Total Suspended Solids (kg/yr) | 1,450 | 1,419 | 2% | 364 | 75% | 75% |
| | Total Phosphorus (kg/yr) | 2.78 | 2.63 | 5% | 1.08 | 61% | 60% |
| | Total Nitrogen (kg/yr) | 14.80 | 12.95 | 13% | 8.92 | 40% | 35% |
| Townsville | Flow (ML/yr) | 5.16 | 4.57 | 11% | 4.57 | 12% | - |
| | Total Suspended Solids (kg/yr) | 1,060 | 1,036 | 2% | 206 | 81% | 80% |
| | Total Phosphorus (kg/yr) | 2.03 | 1.92 | 5% | 0.67 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 10.80 | 9.49 | 12% | 5.97 | 45% | 40% |
| Cairns | Flow (ML/yr) | 9.01 | 8.14 | 10% | 8.14 | 10% | - |
| | Total Suspended Solids (kg/yr) | 1,850 | 1,815 | 2% | 376 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 3.59 | 3.43 | 5% | 1.22 | 66% | 65% |
| | Total Nitrogen (kg/yr) | 18.9 | 16.97 | 10% | 10.7 | 44% | 40% |

### 5.3.4 Costs

Table 32 shows the costs of the base case and WSUD case as developed in each region. The table also identifies the incremental cost of the WSUD case when compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the cost of meeting the *Queensland Development Code* (rainwater tanks) requirements is the dominant cost, accounting for between 70% and 78% of the overall cost depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $1100 per lot in Brisbane to $1700 per lot in Cairns.

Table 32: Case study 3 — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 96,994 | 62,500 | 2,250 | 18,750 | 12,500 |
| | Bioretention systems (incremental cost) | 26,850 | 19,767 | 195 | 7,907 | 7,907 |
| | - per hectare | 40,315 | 29,680 | | | |
| | - per lot | 1,074 | 791 | | | |
| | Detention tanks* | 20,570 | 17,970 | 60 | 5,391 | 3,594 |
| | Detention storages* | 1,516 | 885 | 35 | 266 | 177 |
| | Overall (WSUD CASE) | 123,844 | 82,267 | | | |
| | - per hectare | 185,953 | 123,524 | | | |
| | - per lot | 4,954 | 3,291 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 96,994 | 62,500 | 2,250 | 18,750 | 12,500 |
| | Bioretention systems (incremental cost) | 32,857 | 24,189 | 238 | 9,676 | 9,676 |
| | - per hectare | 49,334 | 36,320 | | | |
| | - per lot | 1,314 | 968 | | | |
| | Detention tanks* | 25,172 | 21,990 | 73 | 6,597 | 4,398 |
| | Detention storages* | 1,542 | 900 | 36 | 270 | 180 |
| | Overall (WSUD CASE) | 129,851 | 86,689 | | | |
| | - per hectare | 194,971 | 130,164 | | | |
| | - per lot | 5,194 | 3,468 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 96,994 | 62,500 | 2,250 | 18,750 | 12,500 |
| | Bioretention systems (incremental cost) | 35,815 | 26,367 | 260 | 10,547 | 10,547 |
| | - per hectare | 53,776 | 39,590 | | | |
| | - per lot | 1,433 | 1,055 | | | |
| | Detention tanks* | 27,438 | 23,970 | 80 | 7,191 | 4,794 |
| | Detention storages* | 951 | 555 | 22 | 167 | 111 |
| | Overall (WSUD CASE) | 132,809 | 88,867 | | | |
| | - per hectare | 199,414 | 133,434 | | | |
| | - per lot | 5,312 | 3,555 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 96,994 | 62,500 | 2,250 | 18,750 | 12,500 |
| | Bioretention systems (incremental cost) | 41,777 | 30,756 | 303 | 12,302 | 12,302 |
| | - per hectare | 62,728 | 46,180 | | | |
| | - per lot | 1,671 | 1,230 | | | |
| | Detention tanks* | 32,005 | 27,960 | 93 | 8,388 | 5,592 |
| | Detention storages* | 861 | 503 | 20 | 151 | 101 |
| | Overall (WSUD CASE) | 138,771 | 93,256 | | | |
| | - per hectare | 208,365 | 140,024 | | | |
| | - per lot | 5,551 | 3,730 | | | |

* This item is associated with detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

## 5.4 Case study 4: urban renewal

### 5.4.1 Development type

Case study 4 is a large-scale urban renewal project involving conversion of an industrial area into a high-density residential development. The case study site comprises 14 ha located within a larger redevelopment site of approximately 100 ha. The development includes 7 ha of high-rise residential towers and 5 ha with 5-storey residential apartment buildings. There are 25 separate buildings within the site. An internal road network services the buildings and the central road is characterised by a 40 m-wide road reserve. The site also contains substantial promenade areas and has river frontage along one boundary. Overall, the site is 81% impervious. Table 33 shows a breakdown of the site areas. Figure 8 shows the development layout.

Table 33: Case study 4 — site breakdown

| SITE BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 72,860 | 100 |
| Road/driveway | 37,900 | 54 |
| Other areas<br>- landscape<br>- pavement | 29,240 | 66 |
| Total site area | 140,000 | 81 |

#### 5.4.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is located on flat ground, with slopes of less than 1%. Flat sites present challenges for stormwater drainage design and the associated WSUD solutions. The case study site incorporates stormwater management systems on the lots and within the road reserves, rather than at end-of-line locations. The generous road reserves are capable of accommodating relatively large stormwater treatment systems. Stormwater runoff from the site discharges at a single location into an adjacent stage of the larger redevelopment site.

At the time this case study was developed, the alternative water source requirements of the *Queensland Development Code* did not apply to multi-storey residential buildings. Given that the inclusion of rainwater tanks has a significant influence on the overall cost estimate, two potential WSUD solutions have been developed for the site: Option A and Option B.

The key difference between the two proposals is that Option A incorporates rainwater tanks to collect roof runoff and assumes reuse of this water for internal and external purposes. Additional roofwater detention tanks are used to provide a portion of the storage volume required for the waterway stability objective. Option B does not include rainwater tanks or roofwater detention tanks. All stormwater treatment is provided in bioretention systems and underground detention tanks are used to provide a portion of the storage volume required for the waterway stability objective.

Development Type: Large scale urban renewal project involving conversion of industrial area into high density residential development

Building Type: High rise residential towers & 5 storey apartment buildings

Number of Dwellings: 2000 + (Approx) Apartments

Site Breakdown

| | Area | % Impervious |
|---|---|---|
| Roof | 7.29ha | 100% |
| Roads | 3.79ha | 54% |
| Other Areas | 2.92ha | 66% |
| Total | 14.00ha | 81% |

Development Characteristics

- Road network to service buildings
- East/West roads have 450m wide road reserve incorporating open space corridor & WSUD
- Substantial promenade areas

Figure 8: Case study 4 — development plan

## 5.4.2 WSUD solution — option A

The base case includes rainwater tanks.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks
- bioretention systems to deliver the stormwater quality and frequent flow objectives
- roofwater detention tanks to manage the 1-year ARI flow to deliver the waterway stability objective if it applies.

Figures 9 and 10 show the locations of the WSUD solutions.

#### 5.4.2.1 RAINWATER TANKS

Centralised rainwater tanks are provided for each building. Runoff from 75% of the roof area is diverted to the rainwater tanks, while runoff from the remaining 25% is diverted to the bioretention systems.

Collected rainwater is reused for toilet and laundry uses in the dwellings located on the bottom five storeys. The total rainwater tank volume is based on a unit rate of 1 kL per dwelling, with a total of 800 dwellings. Overflows from the rainwater tanks are directed to bioretention systems via shallow drainage pipes.

#### 5.4.2.2 BIORETENTION SYSTEMS

Linear bioretention systems are incorporated into the road reserves. The 40 m-wide road reserve for the central boulevard provides substantial space (15–20 m) on one side of the road pavement for a linear park that incorporates stormwater treatment infrastructure. The road reserves for the side streets are sufficiently wide to incorporate a bioretention system either within the centre median or on one side of the road pavement.

Stormwater runoff from the internal road pavements drains via sheet flow onto the surface of the bioretention systems. Roofwater is conveyed via a shallow underground pipe network to the bioretention systems. The total bioretention area required to deliver best practice stormwater quality on the site in each region is shown in Table 34.

Table 34: Case study 4A — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 1,540 | 1.1 |
| Mackay | 1,820 | 1.3 |
| Townsville | 2,100 | 1.5 |
| Cairns | 2,240 | 1.6 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements outlined in section 3.2.

#### 5.4.2.3 DETENTION STORAGE (IF APPLICABLE)

The case study assumes the waterway stability detention storage is not required or is incorporated into flood storage (base case). If the waterway stability objective did apply and there was no flood storage requirement, the detention volume required is shown in Table 35.

Table 35: Case study 4A — waterway stability detention storage requirements

| REGION | TOTAL STORAGE VOLUME REQUIRED (M³) | STORAGE VOLUME UNIT RATE (M³/HA) |
|---|---|---|
| Brisbane | 2,781 | 199 |
| Mackay | 3,239 | 231 |
| Townsville | 3,140 | 224 |
| Cairns | 3,530 | 252 |

The detention storage can be provided within the site three ways:

- In bioretention systems: 10 % of the bioretention systems' extended detention depth and pore space volume in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 1.0 m depth across the bioretention surface area.
- Roofwater detention tanks: The additional required storage is provided by roofwater detention tanks. Each building will have a detention tank, sized based on the roof area and runoff from the entire roof that is directed to the tank.

A summary of the storages required for the four regions is shown in Table 36.

Table 36: Case study 4A — detention storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION EXTENDED DETENTION AND PORE SPACE VOLUME (M³) | VOLUME ABOVE BIORETENTION (M³) | ROOFWATER DETENTION TANK VOLUME (M³) |
|---|---|---|---|
| Brisbane | 68 | 1,540 | 1,173 |
| Mackay | 80 | 1,820 | 1,339 |
| Townsville | 92 | 2,100 | 948 |
| Cairns | 99 | 2,240 | 1,191 |

WSUD Solution

- Large rainwater tanks on allotments with volume equivalent to 1KL per dwelling for bottom 5- storeys (Connected to toilet, laundry & irrigation of public open space)
- Bioretention basins within road reserves for treatment of stormwater
- Roof water detention tanks to provide waterway stability storage (If applicable)

Figure 9: Case study 4A — WSUD solution

### WSUD Solution - Detail

- Large rainwater tanks on allotments with volume equivalent to 1KL per dwelling for bottom 5- storeys (Connected to toilet, laundry & irrigation of public open space)
- Roof water detention tanks to provide waterway stability storage (If applicable)
- Bioretention basins within road reserves for treatment of stormwater
- Underground detention tanks for waterway stability storage (if applicable)

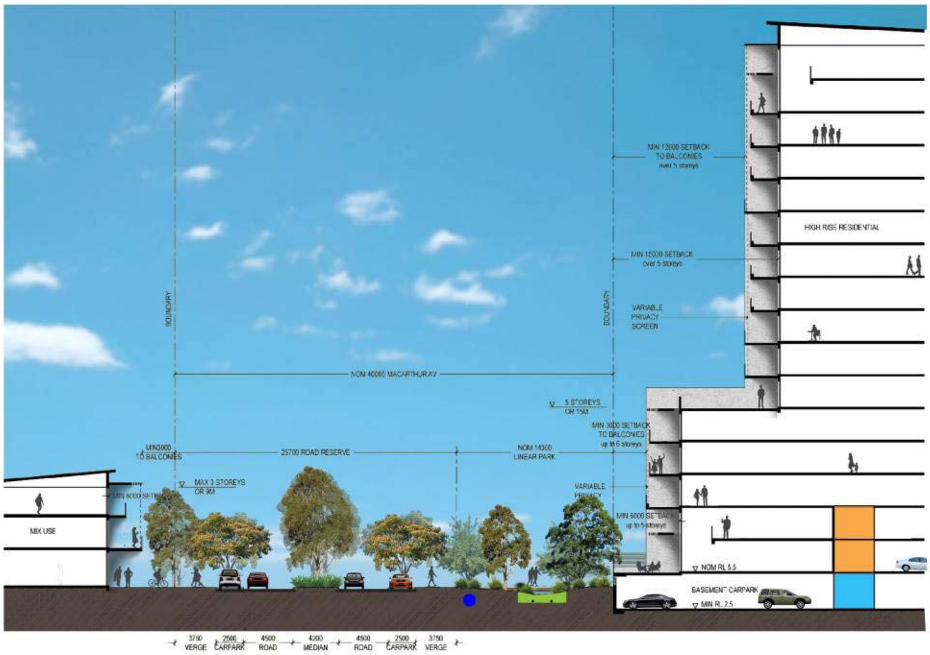


Figure 10: Case study 4A — WSUD solution in detail

## 5.4.3 Performance — option A

The MUSIC results for the WSUD solution in each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 37 shows the MUSIC results for case study 4A.

Table 37: Case study 4A — MUSIC results

| | | UNMITIGATED | BASE CASE | | WSUD CASE | | STORMWATER QUALITY OBJECTIVE |
|---|---|---|---|---|---|---|---|
| | | | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | |
| Brisbane | Flow (ML/yr) | 123 | 103 | 16% | 103 | 16% | - |
| Brisbane | Total Suspended Solids (kg/yr) | 16,900 | 16,200 | 4% | 3,170 | 81% | 80% |
| Brisbane | Total Phosphorus (kg/yr) | 37.7 | 34.3 | 9% | 12.1 | 68% | 60% |
| Brisbane | Total Nitrogen (kg/yr) | 255 | 213 | 16% | 130 | 49% | 45% |
| Mackay | Flow (ML/yr) | 176 | 157 | 11% | 157 | 11% | - |
| Mackay | Total Suspended Solids (kg/yr) | 25,500 | 24,750 | 3% | 6,190 | 76% | 75% |
| Mackay | Total Phosphorus (kg/yr) | 56.2 | 52.7 | 6% | 22.2 | 61% | 60% |
| Mackay | Total Nitrogen (kg/yr) | 366 | 325 | 11% | 219 | 40% | 35% |
| Townsville | Flow (ML/yr) | 130 | 117 | 10% | 117 | 10% | - |
| Townsville | Total Suspended Solids (kg/yr) | 18,600 | 18,060 | 3% | 3,520 | 81% | 80% |
| Townsville | Total Phosphorus (kg/yr) | 41.3 | 38.8 | 6% | 13.8 | 67% | 65% |
| Townsville | Total Nitrogen (kg/yr) | 273 | 245 | 10% | 151 | 45% | 40% |
| Cairns | Flow (ML/yr) | 221 | 201 | 9% | 201 | 9% | - |
| Cairns | Total Suspended Solids (kg/yr) | 33,100 | 32,240 | 3% | 6,590 | 80% | 80% |
| Cairns | Total Phosphorus (kg/yr) | 71.1 | 67.3 | 5% | 24.1 | 66% | 65% |
| Cairns | Total Nitrogen (kg/yr) | 463 | 418 | 10% | 256 | 45% | 40% |

## 5.4.4 Costs — option A

Table 38 shows the costs of the base case and the WSUD case as developed in each region. The table also identifies the incremental cost of the WSUD case when compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the cost of providing rainwater tanks is a substantial portion of the overall cost, accounting for between 39% and 48% of the overall cost depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $350 per dwelling in Brisbane to $500 per dwelling in Cairns. This is substantially lower than the cost per dwelling compared to a low- or medium-density residential development, i.e. compared to case studies 1, 2 and 3. The higher the density of development, the lower the cost of the WSUD solution per dwelling.

Table 38: Case study 4A — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 645,062 | 500,000 | 7,500 | 150,000 | 100,000 |
| | Bioretention systems (incremental cost) | 690,301 | 508,200 | 5,005 | 203,280 | 203,280 |
| | - per hectare | 49,307 | 36,300 | | | |
| | - per dwelling | 345 | 254 | | | |
| | Detention storages* | 402,815 | 351,900 | 1,173 | 105,570 | 70,380 |
| | Overall (WSUD CASE) | 1,335,363 | 1,008,200 | | | |
| | - per hectare | 95,383 | 72,014 | | | |
| | - per dwelling | 668 | 504 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 645,062 | 500,000 | 7,500 | 150,000 | 100,000 |
| | Bioretention systems (incremental cost) | 815,811 | 600,600 | 5,915 | 240,240 | 240,240 |
| | - per hectare | 58,272 | 42,900 | | | |
| | - per dwelling | 408 | 300 | | | |
| | Detention storages* | 459,820 | 401,700 | 1,339 | 120,510 | 80,340 |
| | Overall (WSUD CASE) | 1,460,873 | 1,100,600 | | | |
| | - per hectare | 104,348 | 78,614 | | | |
| | - per dwelling | 730 | 550 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 645,062 | 500,000 | 7,500 | 150,000 | 100,000 |
| | Bioretention systems (incremental cost) | 941,320 | 693,000 | 6,825 | 277,200 | 277,200 |
| | - per hectare | 67,237 | 49,500 | | | |
| | - per dwelling | 471 | 347 | | | |
| | Detention storages* | 325,549 | 284,400 | 948 | 85,320 | 56,880 |
| | Overall (WSUD CASE) | 1,586,382 | 1,193,000 | | | |
| | - per hectare | 113,313 | 85,214 | | | |
| | - per dwelling | 793 | 597 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | **Rainwater tanks (BASE CASE)** | **645,062** | **500,000** | 7,500 | 150,000 | 100,000 |
| | Bioretention systems (incremental cost) | 1,004,075 | 739,200 | 7,280 | 295,680 | 295,680 |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per dwelling | 502 | 370 | | | |
| | Detention storages* | 408,966 | 357,300 | 1,191 | 107,190 | 71,460 |
| | **Overall (WSUD CASE)** | **1,649,137** | **1,239,200** | | | |
| | - per hectare | 117,795 | 88,514 | | | |
| | - per dwelling | 825 | 620 | | | |

* This item is associated with detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

## 5.4.5 WSUD solution — option B

The base case does not include rainwater tanks.

To meet the stormwater management objectives, the WSUD case includes:

- bioretention systems to deliver the stormwater quality and frequent flow objectives
- underground detention tanks to manage the 1-year ARI flow in accordance with the waterway stability objective if it applies.

### 5.4.5.1 BIORETENTION SYSTEMS

As with Option A, linear bioretention systems are incorporated into the road reserves. However, because Option B does not include rainwater tanks, all of the stormwater treatment is provided by the bioretention systems. The total bioretention area required to deliver best practice stormwater quality on the site, as developed in each test region, is shown in Table 39. Figure 11 shows the WSUD solution for Option 4B.

Table 39: Case study 4B — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 2,240 | 1.6 |
| Mackay | 2,100 | 1.5 |
| Townsville | 2,240 | 1.6 |
| Cairns | 2,240 | 1.6 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements as outlined in section 3.2.

#### 5.4.5.2 DETENTION STORAGE (IF APPLICABLE)

The case study assumed the waterway stability detention storage is not required or is incorporated into flood storage (base case). If the waterway stability objective did apply and there was no flood storage requirement, the detention volume required is shown in Table 35.

For Option B, the detention storage can be provided within the site three ways:

- In bioretention systems: 10 % of the bioretention systems' extended detention depth and pore space volume in the filter media
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 1.0 m depth across the bioretention surface area.
- Underground detention tanks: additional storage required is provided by underground detention tanks. The detention tanks are located within the road reserve, underneath the verge.

A summary of the storages on the site, developed for the four regions, are shown in Table 40.

Table 40: Case study 4B — detention storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION EXTENDED DETENTION AND PORE SPACE VOLUME (M³) | VOLUME ABOVE BIORETENTION (M³) | UNDERGROUND DETENTION TANK VOLUME (M³) |
|---|---|---|---|
| Brisbane | 99 | 2,240 | 442 |
| Mackay | 92 | 2,100 | 1,047 |
| Townsville | 99 | 2,240 | 802 |
| Cairns | 99 | 2,240 | 1,191 |


Figure 11: Case study 4B — WSUD solution

## 5.4.6 Performance — option B

The MUSIC results for the WSUD solution in each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 41 shows the MUSIC results for case study 4B.

Table 41: Case study 4B — MUSIC results

| | | | BASE CASE | | WSUD CASE | | |
|---|---|---|---|---|---|---|---|
| | | UNMITIGATED | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | STORMWATER QUALITY OBJECTIVE |
| Brisbane | Flow (ML/yr) | 123 | 123 | 0% | 123 | 0 | - |
| | Total Suspended Solids (kg/yr) | 17,000 | 17,000 | 0% | 2,630 | 85 | 80% |
| | Total Phosphorus (kg/yr) | 38.4 | 38.4 | 0% | 11.8 | 69 | 60% |
| | Total Nitrogen (kg/yr) | 254 | 254 | 0% | 138 | 46 | 45% |
| Mackay | Flow (ML/yr) | 176 | 176 | 0% | 176 | 0 | - |
| | Total Suspended Solids (kg/yr) | 25,700 | 25,700 | 0% | 5,890 | 77 | 75% |
| | Total Phosphorus (kg/yr) | 56.3 | 56.3 | 0% | 22.0 | 61 | 60% |
| | Total Nitrogen (kg/yr) | 371 | 371 | 0% | 238 | 36 | 35% |
| Townsville | Flow (ML/yr) | 130 | 130 | 0% | 130 | 0 | - |
| | Total Suspended Solids (kg/yr) | 18,600 | 18,600 | 0% | 3,480 | 81 | 80% |
| | Total Phosphorus (kg/yr) | 41.2 | 41.2 | 0% | 14.1 | 66 | 65% |
| | Total Nitrogen (kg/yr) | 274 | 274 | 0% | 163 | 41 | 40% |
| Cairns | Flow (ML/yr) | 221 | 221 | 0% | 221 | 0 | - |
| | Total Suspended Solids (kg/yr) | 32,900 | 32,900 | 0% | 6,610 | 80 | 80% |
| | Total Phosphorus (kg/yr) | 71.4 | 71.4 | 0% | 24.9 | 65 | 65% |
| | Total Nitrogen (kg/yr) | 462 | 462 | 0% | 275 | 41 | 40% |

## 5.4.7 Costs — option B

Table 42 shows the costs of the WSUD solution for case study 4B implemented in each region. Option 4B ranges from 33%–64% more cost-effective than option 4A, due to the absence of rainwater tanks. This solution, however, does not benefit from being able to use the water that the tanks provide, which means annual water charges are higher for this development.

Table 42: Case study 4B — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | **Rainwater tanks (BASE CASE)** | **0** | **0** | 0 | 0 | 0 |
| | Bioretention systems (incremental cost) | 1,004,075 | 739,200 | 7280 | 295,680 | 295,680 |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |
| | Detention storages* | 151,785 | 132,600 | 442 | 39,780 | 26,520 |
| | **Overall (WSUD CASE)** | **1,004,075** | **739,200** | | | |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |
| Mackay | **Rainwater tanks (BASE CASE)** | **0** | **0** | 0 | 0 | 0 |
| | Bioretention systems (incremental cost) | 941,320 | 693,000 | 6825 | 277,200 | 277,200 |
| | - per hectare | 67,237 | 49,500 | | | |
| | - per lot | 471 | 347 | | | |
| | Detention storages* | 359,546 | 314,100 | 1047 | 94,230 | 62,820 |
| | **Overall (WSUD CASE)** | **941,320** | **693,000** | | | |
| | - per hectare | 67,237 | 49,500 | | | |
| | - per lot | 471 | 347 | | | |
| Townsville | **Rainwater tanks (BASE CASE)** | **0** | **0** | 0 | 0 | 0 |
| | Bioretention systems (incremental cost) | 1,004,075 | 739,200 | 7,280 | 295,680 | 295,680 |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |
| | Detention storages* | 275,412 | 240,600 | 802 | 72,180 | 48,120 |
| | **Overall (WSUD CASE)** | **1,004,075** | **739,200** | | | |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 0 | 0 | 0 | 0 | 0 |
| | Bioretention systems (incremental cost) | 1,004,075 | 739,200 | 7280 | 295,680 | 295,680 |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |
| | Detention storages* | 408,996 | 357,300 | 1191 | 107,190 | 71,460 |
| | Overall (WSUD CASE) | 1,004,075 | 739,200 | | | |
| | - per hectare | 71,720 | 52,800 | | | |
| | - per lot | 502 | 370 | | | |

* This item is associated with detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

## 5.5 Case study 5: commercial

### 5.5.1 Development type

Case study 5 is a small-scale commercial development comprising a neighbourhood shopping centre on a 0.42 ha site. Two buildings are separated by a central arcade and 15–20 ground-level shops. The remainder of the site contains an internal driveway and car park with approximately 60 car parking spaces. Overall, the site is 98% impervious. A breakdown of site areas is shown in Table 43. Figure 12 shows the development layout.

Table 43: Case study 5 — site breakdown

| SITE BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 1,700 | 100 |
| Driveway/car park | 2,000 | 100 |
| Other areas<br>- landscape<br>- pavement | 500 | 80 |
| Total site area | 4,200 | 98 |

#### 5.5.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is very flat with an average slope of less than 1%. The site design includes small landscaped areas dispersed throughout the car park. These areas are the only practical location for vegetated stormwater treatment systems such as bioretention systems. To enable piped roofwater drainage to discharge onto the surface of the bioretention system, surcharge pits were adopted in some cases. Retail shops have a relatively low demand for water; therefore the opportunities for on-site reuse of stormwater are limited.

The ultimate discharge location for stormwater is the existing stormwater drainage networks. This limits the flexibility for the location of the stormwater management systems.

| | |
|---|---|
| Development Type: | Small scale commercial development comprising a neighbourhood shopping centre |
| Building Type: | Retail Shops |
| Number of Dwellings: | 2 |

## Site Breakdown

| | Area | % Impervious |
|---|---|---|
| Roof | 0.17ha | 100% |
| Carpark/Drive | 0.20ha | 100% |
| Other Areas | 0.05ha | 80% |
| Total | 0.42ha | 98% |

## Development Characteristics

- Two buildings with retain shops separated by a central arcade
- 15-20 retail shops
- Internal driveway and car park with approximately 60 parking spaces


Figure 12: Case study 5 — development plan

### 5.5.2 WSUD solution

The base case include rainwater tanks as required by the *Queensland Development Code*.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks as required by the *Queensland Development Code*
- bioretention systems to deliver the stormwater quality and frequent flow objectives
- detention storage to manage the 1-year ARI flow to deliver the waterway stability objective if it applies.

Figure 13 shows the locations of the WSUD solutions.

#### 5.5.2.1 RAINWATER TANKS

As required by the *Queensland Development Code*, a 9 kL rainwater tank collects roof runoff from one of the buildings. This water is reused for toilet and outdoor uses. It is assumed six toilets are provided within the building with a combined demand of 1.3 kL/d. There is no guaranteed outdoor demand for collected rainwater due to the relatively small area of landscaping. The overflow from the rainwater tank is diverted to one of the bioretention systems via a stormwater pipe.

#### 5.5.2.2 BIORETENTION SYSTEMS

Bioretention systems provide water quality treatment for the remainder of the site, including the roof areas that are not directed to the tank and overflow from the tank. Six bioretention systems are dispersed throughout the car park and incorporated into the more substantial landscaped areas. Stormwater runoff from the driveway and car park drains onto the surface of the bioretention systems. Roofwater is conveyed via a shallow underground pipe network to the bioretention systems.

The total bioretention area required to deliver best practice stormwater quality on the site in each region is shown in Table 44.

Table 44: Case study 5 — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA ($M^2$) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 58.8 | 1.4 |
| Mackay | 50.4 | 1.2 |
| Townsville | 63.0 | 1.5 |
| Cairns | 63.0 | 1.5 |

It may be necessary to use ‘hard’ edges and vertical walls in the design of the bioretention systems due to the limited available space.

#### 5.5.2.3 DETENTION STORAGE (IF APPLICABLE)

The case study assumes the waterway stability detention storage is not required or is incorporated into flood storage (base case). If the waterway stability objective did apply and there is no flood storage requirement, the detention volume required is shown in Table 45.

Table 45: Case study 5 — waterway stability detention storage requirements

| REGION | TOTAL STORAGE VOLUME REQUIRED ($M^3$) | STORAGE VOLUME UNIT RATE ($M^3$/HA) |
|---|---|---|
| Brisbane | 88.7 | 211 |
| Mackay | 103.4 | 246 |
| Townsville | 100.2 | 239 |
| Cairns | 112.6 | 268 |

The detention storage can be provided within the site three ways:

- In bioretention systems: 10 % of the bioretention systems' extended detention depth and pore space volume in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 0.4 m depth across the bioretention surface area.
- Above ground storage: Additional storage is proposed in landscaped and car park areas adjacent to the bioretention systems.

Stormwater preferentially fills the storage volume available in the landscaped areas, so surface ponding within the car park is restricted to relatively infrequent, high intensity storm events.

The breakdown of storage available on the site as developed in the three regions is shown in Table 46.

Table 46: Case study 5 — storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION EXTENDED DETENTION AND PORE SPACE VOLUME ($M^3$) | VOLUME ABOVE BIORETENTION ($M^3$) | STORAGE VOLUME IN LANDSCAPED AREAS AND CAR PARK ($M^3$) |
|---|---|---|---|
| Brisbane | 2.2 | 23.5 | 62.9 |
| Mackay | 1.9 | 20.2 | 81.3 |
| Townsville | 2.4 | 25.2 | 72.6 |
| Cairns | 2.4 | 25.2 | 85.0 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements as outlined in section 3.2.

### WSUD Solution

- 9KL rainwater tank connected to toilets, urinals & outdoor taps
- Bioretention basins/pods for treatment of stormwater
- Surface ponding over landscaped areas and carpark for waterway stability storage (if applicable)


Figure 13: Case study 5 — WSUD solution

## 5.5.3 Performance

The MUSIC results for the WSUD solution in each region demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 47 shows the MUSIC results for case study 5.

Table 47: Case study 5 — MUSIC results

| | | UNMITIGATED | BASE CASE | | WSUD CASE | | STORMWATER QUALITY OBJECTIVE |
|---|---|---|---|---|---|---|---|
| | | | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | |
| Brisbane | Flow (ML/yr) | 4.33 | 4.15 | 4% | 4.15 | 4% | - |
| | Total Suspended Solids (kg/yr) | 982 | 976 | 1% | 161 | 84% | 80% |
| | Total Phosphorus (kg/yr) | 1.95 | 1.92 | 2% | 0.58 | 70% | 60% |
| | Total Nitrogen (kg/yr) | 13.8 | 13.2 | 4% | 7.6 | 46% | 45% |
| Mackay | Flow (ML/yr) | 6.00 | 5.81 | 3% | 5.81 | 3% | - |
| | Total Suspended Solids (kg/yr) | 1,360 | 1,353 | 0% | 356 | 74% | 75% |
| | Total Phosphorus (kg/yr) | 2.73 | 2.69 | 1% | 1.09 | 60% | 60% |
| | Total Nitrogen (kg/yr) | 18.9 | 18.3 | 3% | 12.2 | 35% | 35% |
| Townsville | Flow (ML/yr) | 4.47 | 4.34 | 3% | 4.34 | 3% | - |
| | Total Suspended Solids (kg/yr) | 1,010 | 1,005 | 0% | 198 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 2.02 | 1.99 | 1% | 0.66 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 14.0 | 13.6 | 3% | 8.2 | 42% | 40% |
| Cairns | Flow (ML/yr) | 7.45 | 7.24 | 3% | 7.24 | 3% | - |
| | Total Suspended Solids (kg/yr) | 1,690 | 1,683 | 0% | 331 | 80% | 80% |
| | Total Phosphorus (kg/yr) | 3.35 | 3.31 | 1% | 1.11 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 23.6 | 22.9 | 3% | 13.7 | 42% | 40% |

## 5.5.4 Costs

Table 48 shows the costs of the base case and WSUD case as developed in each region. The table also identifies the incremental cost of the WSUD case when compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the cost of meeting the *Queensland Development Code* (rainwater tanks) requirements is a substantial portion of the overall cost, accounting for between 28% and 30% of the overall cost depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $69,000 to $73,000 per hectare.

Table 48: Case study 5 — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 12,110 | 9,000 | 175 | 2,700 | 1,800 |
| | Bioretention systems (incremental cost) | 28,806 | 21,462 | 191 | 8,585 | 8,585 |
| | - per hectare | 68,585 | 51,100 | | | |
| | - per lot | 14,403 | 10,731 | | | |
| | Detention storages* | 2,695 | 1,573 | 63 | 472 | 315 |
| | Overall (WSUD CASE) | 40,915 | 30,462 | | | |
| | - per hectare | 97,418 | 72,529 | | | |
| | - per lot | 20,458 | 15,231 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 12,110 | 9,000 | 175 | 2,700 | 1,800 |
| | Bioretention systems (incremental cost) | 24,691 | 18,396 | 164 | 7,358 | 7,358 |
| | - per hectare | 58,787 | 43,800 | | | |
| | - per lot | 12,345 | 9,198 | | | |
| | Detention storages* | 3,483 | 2,033 | 81 | 610 | 407 |
| | Overall (WSUD CASE) | 36,800 | 27,396 | | | |
| | - per hectare | 87,620 | 65,229 | | | |
| | - per lot | 18,400 | 13,698 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 12,110 | 9,000 | 175 | 2,700 | 1,800 |
| | Bioretention systems (incremental cost) | 30,863 | 22,995 | 205 | 9,198 | 9,198 |
| | - per hectare | 73,484 | 54,750 | | | |
| | - per lot | 15,432 | 11,498 | | | |
| | Detention storages* | 3,110 | 1,815 | 73 | 545 | 363 |
| | Overall (WSUD CASE) | 42,973 | 31,995 | | | |
| | - per hectare | 102,317 | 76,179 | | | |
| | - per lot | 21,486 | 15,998 | | | |

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 12,110 | 9,000 | 175 | 2,700 | 1,800 |
| | Bioretention systems (incremental cost) | 30,863 | 22,995 | 205 | 9,198 | 9,198 |
| | - per hectare | 73,484 | 54,750 | | | |
| | - per lot | 15,432 | 11,498 | | | |
| | Detention storages* | 3,641 | 2,125 | 85 | 638 | 425 |
| | Overall (WSUD CASE) | 42,973 | 31,995 | | | |
| | - per hectare | 102,317 | 76,179 | | | |
| | - per lot | 21,486 | 15,998 | | | |

* This item is associated with detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

## 5.6 Case study 6: industrial

### 5.6.1 Development type

Case study 6 is a medium-scale industrial development comprising a factory and warehouse on a 1 ha site. The single building is surrounded by an internal driveway and car park with approximately 100 car parking spaces. Offices and general amenities are incorporated into the building. There are significant landscaped areas, both active and passive, distributed throughout the site. Overall, the site is approximately 86% impervious. Table 49 shows the breakdown of the site areas. Figure 14 shows the development layout.

Table 49: Case study 6 — site breakdown

| SITE BREAKDOWN | AREA (M²) | % IMPERVIOUS |
|---|---|---|
| Roof | 3,970 | 100 |
| Road/driveway | 3,890 | 100 |
| Other areas<br>- landscape<br>- pavement | 2,140 | 34 |
| Total site area | 10,000 | 86 |

#### 5.6.1.1 SITE CONDITIONS AND CONSTRAINTS

The site is very flat with an average slope of less than 1%. The site design includes significant passive landscaped areas, most of which are suitable locations for stormwater management infrastructure. Industrial warehouses have a relatively low demand for water; therefore the opportunities for on-site reuse of stormwater are limited.

The ultimate discharge location for stormwater is the existing stormwater drainage network. This limits the flexibility for the location of stormwater management systems.

| | |
|---|---|
| Development Type: | Medium scale industrial development comprising a factory warehouse |
| Building Type: | Factory / Warehouse |
| Number of Dwellings: | 1 |

### Site Breakdown

| | Area | % Impervious |
|---|---|---|
| Roof | 0.40ha | 100% |
| Roads/Driveway | 0.39ha | 100% |
| Other Areas | 0.21ha | 34% |
| Total | 1.00ha | 86% |

### Development Characteristics

- Single large building surrounded by internal driveway and car park with approximately 100 car spaces
- Offices and general amenities incorporated into building
- Significant landscaped areas, both active and passive


Figure 14: Case study 6 — development plan

## 5.6.2 WSUD solution

The base case includes rainwater tanks as required by the *Queensland Development Code*.

To meet the stormwater management objectives, the WSUD case includes:

- rainwater tanks as required by the *Queensland Development Code*
- bioretention systems to deliver the stormwater quality and frequent flow objectives
- above-ground detention storage to manage the 1-year ARI flow to deliver the waterway stability objective if it applies.

Figure 15 shows the location of the WSUD solutions.


Figure 15: Case study 6 — WSUD solution

#### 5.6.2.1 RAINWATER TANKS

As required by the *Queensland Development Code*, a 21 kL rainwater tank collects roof runoff from the building. Collected water is reused for toilet and outdoor uses. Fourteen toilets are provided within the building with a combined demand of 1.5 kL/d. A typical landscape design for an industrial site is assumed that uses native species requiring minimal irrigation. Therefore, there is no guaranteed outdoor demand for collected rainwater. The overflow from the rainwater tank is diverted to one of the bioretention systems via a stormwater pipe.

#### 5.6.2.2 BIORETENTION SYSTEMS

Bioretention systems will provide water quality treatment for the remainder of the site, including the roof areas that are not directed to the tank and for overflow from the tank. Two bioretention systems are incorporated into landscaped areas at strategic locations. Stormwater runoff from the roof, driveway and car park is collected in a shallow pit and pipe drainage network and conveyed to one of the two bioretention systems. Where possible, runoff is conveyed in surface drainage systems such as swales and dish drains.

The total bioretention area required to deliver best practice stormwater quality on the site in region is shown in Table 50.

Table 50: Case study 6 — size of bioretention systems

| REGION | BIORETENTION SURFACE AREA (M2) | BIORETENTION SURFACE AREA (% OF SITE AREA) |
|---|---|---|
| Brisbane | 140 | 1.4 |
| Mackay | 130 | 1.3 |
| Townsville | 150 | 1.5 |
| Cairns | 150 | 1.5 |

If the frequent flow objective applies, the extended detention zone of the bioretention system provides sufficient storage to meet the frequent flow requirements as outlined in section 3.2.

#### 5.6.2.3 DETENTION STORAGE (IF APPLICABLE)

The case study assumes the waterway stability detention storage is not required or is incorporated into flood storage (base case). If the waterway stability objective did to apply and there is no flood storage requirement, the detention volume required is shown in Table 51.

Table 51: Case study 6 — waterway stability detention storage requirements

| REGION | TOTAL STORAGE VOLUME REQUIRED ($M^3$) | STORAGE VOLUME UNIT RATE ($M^3$/HA) |
|---|---|---|
| Brisbane | 201.9 | 202 |
| Mackay | 235.2 | 235 |
| Townsville | 227.9 | 228 |
| Cairns | 256.2 | 256 |

The detention storage can be provided within the site three ways:

- In bioretention systems: 10% of the bioretention systems' extended detention depth and pore space volume in the filter media.
- Above the bioretention systems: storage volume above the bioretention systems in the zone between the level of the low-flow outlet and the level of the high-flow outlet. This volume is estimated as the equivalent of 0.45 m depth across the bioretention surface area.
- Above ground storage: it is proposed to provide the additional storage required in landscaped and car park areas adjacent to the bioretention systems.

Stormwater will preferentially fill the storage volume available in the landscaped areas, so surface ponding within the car park is restricted to relatively infrequent, high intensity storm events.

The breakdown of storage available on the site as developed in the four regions is shown in Table 52.

Table 52: Case study 6 — storage allocation for waterway stability objective

| REGION | PORTION OF BIORETENTION EXTENDED DETENTION AND PORE SPACE VOLUME ($M^3$) | VOLUME ABOVE BIORETENTION ($M^3$) | STORAGE VOLUME IN LANDSCAPED AREAS AND CAR PARK ($M^3$) |
|---|---|---|---|
| Brisbane | 5.3 | 63.0 | 133.6 |
| Mackay | 4.9 | 58.5 | 171.8 |
| Townsville | 5.7 | 67.5 | 154.7 |
| Cairns | 5.7 | 67.5 | 183.0 |

### 5.6.3 Performance

The MUSIC results for the WSUD solution for each of the regions demonstrate that the proposed stormwater treatment train meets the stormwater quality objectives. Table 53 shows the MUSIC results for case study 6.

Table 53: Case study 6 — MUSIC results

| | | UNMITIGATED | BASE CASE | | WSUD CASE | | STORMWATER QUALITY OBJECTIVE |
|---|---|---|---|---|---|---|---|
| | | | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | AVERAGE ANNUAL LOADS | REDUCTION IN LOADS | |
| Brisbane | Flow (ML/yr) | 9.25 | 8.86 | 4% | 8.86 | 4% | - |
| | Total Suspended Solids (kg/yr) | 2,230 | 2,213 | 1% | 345 | 85% | 80% |
| | Total Phosphorus (kg/yr) | 4.16 | 4.08 | 2% | 1.22 | 71% | 60% |
| | Total Nitrogen (kg/yr) | 21.5 | 20.6 | 4% | 11.7 | 46% | 45% |
| Mackay | Flow (ML/yr) | 13.1 | 12.7 | 3% | 12.7 | 3% | - |
| | Total Suspended Solids (kg/yr) | 3,210 | 3,192 | 1% | 785 | 76% | 75% |
| | Total Phosphorus (kg/yr) | 5.86 | 5.78 | 1% | 2.24 | 62% | 60% |
| | Total Nitrogen (kg/yr) | 30.7 | 29.8 | 3% | 19.9 | 35% | 35% |
| Townsville | Flow (ML/yr) | 9.73 | 9.47 | 3% | 9.47 | 3% | - |
| | Total Suspended Solids (kg/yr) | 2,340 | 2,327 | 1% | 441 | 81% | 80% |
| | Total Phosphorus (kg/yr) | 4.41 | 4.35 | 1% | 1.45 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 22.6 | 22.0 | 3% | 13.4 | 41% | 40% |
| Cairns | Flow (ML/yr) | 16.4 | 16.0 | 2% | 16.0 | 2% | - |
| | Total Suspended Solids (kg/yr) | 3,920 | 3,900 | 1% | 756 | 81% | 80% |
| | Total Phosphorus (kg/yr) | 7.28 | 7.19 | 1% | 2.41 | 67% | 65% |
| | Total Nitrogen (kg/yr) | 37.9 | 36.9 | 3% | 22.4 | 41% | 40% |

### 5.6.4 Costs

Table 54 shows the costs of the base case and WSUD case as developed in each region. The table also identifies the incremental cost of the WSUD case when compared to the base case (i.e. identifies the cost of the bioretention systems). The results show that the cost of meeting the *Queensland Development Code* (rainwater tanks) requirements is a minor portion of the overall cost, accounting for between 12% and 13% of the overall cost depending on the region. The incremental cost of meeting the stormwater management objectives is the bioretention cost with the lifecycle cost ranging from $58,000 per hectare in Brisbane to $67,000 per hectare in Cairns.

Table 54: Case study 6 — costs

| | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
| | | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Brisbane | Rainwater tanks (BASE CASE) | 8,800 | 6,000 | 175 | 1,800 | 1,200 |
| | Bioretention systems (incremental cost) | 62,755 | 46,200 | 455 | 18,480 | 18,480 |
| | - per hectare | 62,755 | 46,200 | | | |
| | - per lot | 62,755 | 46,200 | | | |
| | Detention storages* | 5,740 | 3,350 | 134 | 1,005 | 670 |
| | Overall (WSUD CASE) | 71,555 | 52,200 | | | |
| | - per hectare | 71,555 | 52,200 | | | |
| | - per lot | 71,555 | 52,200 | | | |
| Mackay | Rainwater tanks (BASE CASE) | 8,800 | 6,000 | 175 | 1,800 | 1,200 |
| | Bioretention systems (incremental cost) | 58,272 | 42,900 | 423 | 17,160 | 17,160 |
| | - per hectare | 58,272 | 42,900 | | | |
| | - per lot | 58,272 | 42,900 | | | |
| | Detention storages* | 7,368 | 4,300 | 172 | 1,290 | 860 |
| | Overall (WSUD CASE) | 67,073 | 48,900 | | | |
| | - per hectare | 67,073 | 48,900 | | | |
| | - per lot | 67,073 | 48,900 | | | |
| Townsville | Rainwater tanks (BASE CASE) | 8,800 | 6,000 | 175 | 1,800 | 1,200 |
| | Bioretention systems (incremental cost) | 67,237 | 49,500 | 488 | 19,800 | 19,800 |
| | - per hectare | 67,237 | 49,500 | | | |
| | - per lot | 67,237 | 49,500 | | | |
| | Detention storages* | 6,640 | 3,875 | 155 | 1,163 | 775 |
| | Overall (WSUD CASE) | 76,038 | 55,500 | | | |
| | - per hectare | 76,038 | 55,500 | | | |
| | - per lot | 76,038 | 55,500 | | | |

|  | ITEM | COSTS ($ 2009) | | | | |
|---|---|---|---|---|---|---|
|  |  | TOTAL LIFECYCLE | ACQUISITION | ANNUAL MAINTENANCE | RENEWAL | DECOMMISSION |
| Cairns | Rainwater tanks (BASE CASE) | 8,800 | 6,000 | 175 | 1,800 | 1,200 |
|  | Bioretention systems (incremental cost) | 67,237 | 49,500 | 488 | 19,800 | 19,800 |
|  | - per hectare | 67,237 | 49,500 |  |  |  |
|  | - per lot | 67,237 | 49,500 |  |  |  |
|  | Detention storages* | 7,839 | 4,575 | 183 | 1,373 | 915 |
|  | Overall (WSUD CASE) | 76,038 | 55,500 |  |  |  |
|  | - per hectare | 76,038 | 55,500 |  |  |  |
|  | - per lot | 76,038 | 55,500 |  |  |  |

* This item is associated with the provision of detention storage to meet the waterway stability objective. This objective is not applicable in all instances. Therefore, the costs for this item have not been included in the overall costs.

# 6 Summary

The case studies described in this Case Study Report have been developed to test the practicality and cost of using WSUD to meet the proposed stormwater management objectives for typical development types in Queensland. Case study developments were selected from actual developments (existing or proposed) in Queensland. WSUD solutions for contemporary 'best practice' stormwater 'treatment trains' were developed for each case study in order to meet the draft policy objectives. In each case, a WSUD solution was developed that integrates into the urban layout and landscape design, ensuring no loss of development yield. The cost of compliance for each development type was then calculated for four different climatic areas within Queensland.

Detailed summaries of the likely acquisition (capital + design) costs, annual maintenance costs and life cycle costs for each case study are provided in Tables 55 to 57[6]. These costs represent **additional** costs compared to relevant base case scenarios (i.e. incremental cost going from base case to WSUD case). From these cost data it can be concluded that:

- There is some variation in the cost of different WSUD solutions for different development types, different climatic and other site characteristics. Where rainfall is higher, treatment systems generally need to be slightly larger to achieve the stormwater quality objective when rainwater tanks are included in the treatment train. For example, a bioretention size (filter area) will need to increase from 1.1% in Brisbane to 1.6% (expressed as a portion of catchment area) in Cairns based on an urban renewal development type.
- Typically, in excess of 50% of the acquisition costs are attributable to rainwater tanks, which are not specifically required to meet the stormwater management objectives. Therefore, rainwater tanks do not therefore appear to be a cost-effective approach to achieving the stormwater management objectives compared to alternative WSUD solutions assessed, such as bioretention. Rainwater tanks are, however, the commonly used acceptable solution to the Queensland Development Code Mandatory Parts 4.2 and 4.3 requirement for alternative water use. It is acknowledged that rainwater tanks are primarily implemented as an alternative water use measure rather than a measure to protect the health of downstream waterways.
- The acquisition costs of implementing WSUD solutions range from approximately $250 per dwelling for units in large complexes to around $4000 for more complex WSUD solutions for detached houses in case study 2 in Cairns. These costs are typically less than 1% of the cost of a new dwelling (house and land package).
- The ongoing operation and maintenance costs of WSUD to meet the stormwater management objectives of the draft policy are typically less than 2%–3% of the cost of annual property rates charged by local governments.
- When designed and delivered effectively, WSUD requirements are relatively minor compared to other factors that influence costs (e.g. interest rates) of new urban developments.

The case studies illustrate that the stormwater management objectives can be practically achieved through the implementation of WSUD. In all of the case studies WSUD solutions could be effectively built into the developments and integrated into the development layout and landscape design with no loss of development yield. This assessment suggests that applying WSUD is both a practical and relatively cost-effective method of meeting the draft policy's stormwater management objectives for typical future development in Queensland.

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[6] Case study 4A incorporates rainwater tanks to collect roof runoff and assumes reuse of this water for internal and external purposes with roofwater detention tanks used to provide a portion of the storage volume required for the waterway stability objective. Case study 4B does not include rainwater tanks or roofwater detention tanks. All stormwater treatment is provided in bioretention systems and underground detention tanks are used to provide a portion of the storage volume required for the waterway stability objective.

Table 55: Acquisition (capital + design) costs (in A$2009)[7]

| CASE STUDY SUMMARY: ACQUISITION COSTS FOR WSUD MEASURES (ESTIMATES) | | | BRISBANE | | MACKAY | | TOWNSVILLE | | CAIRNS | |
|---|---|---|---|---|---|---|---|---|---|---|
| CASE STUDY | CASE STUDY DESCRIPTION | WSUD MEASURE | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT |
| 1 | Residential greenfield (large scale) on sloping topography | Bioretention systems | 21,200 | 1,689 | 31,800 | 2,533 | 34,450 | 2,744 | 39,750 | 3,166 |
| 2 | Residential greenfield on flat topography | Bioretention systems | 33,000 | 2,491 | 42,890 | 3,237 | 42,890 | 3,237 | 52,779 | 3,984 |
| 3 | Residential townhouse development | Bioretention systems | 29,680 | 791 | 36,320 | 968 | 39,590 | 1,055 | 46,180 | 1,230 |
| 4A | Urban renewal development | Bioretention systems | 36,300 | 254 | 42,900 | 300 | 49,500 | 347 | 52,800 | 370 |
| 4B | Urban renewal development | Bioretention systems | 52,800 | 370 | 49,500 | 347 | 52,800 | 370 | 52,800 | 370 |
| 5 | Commercial development | Bioretention systems | 51,100 | 10,731 | 43,800 | 9,198 | 54,750 | 11,498 | 54,750 | 11,498 |
| 6 | Industrial development | Bioretention systems | 46,200 | 46,200 | 42,900 | 42,900 | 49,500 | 49,500 | 49,500 | 49,500 |

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Table 56: Annual maintenance costs (excluding renewal and decommissioning costs) (in A$2009)

| CASE STUDY SUMMARY: ANNUAL MAINTENANCE COSTS OF WSUD MEASURES (ESTIMATES) | | | BRISBANE | | MACKAY | | TOWNSVILLE | | CAIRNS | |
|---|---|---|---|---|---|---|---|---|---|---|
| CASE STUDY | CASE STUDY DESCRIPTION | WSUD MEASURE | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT |
| 1 | Residential greenfield (large scale) on sloping topography | Bioretention systems | 260 | 21 | 390 | 31 | 423 | 34 | 488 | 39 |
| 2 | Residential greenfield on flat topography | Bioretention systems | 325 | 25 | 422 | 32 | 422 | 32 | 520 | 39 |
| 3 | Residential townhouse development | Bioretention systems | 292 | 8 | 358 | 10 | 390 | 10 | 455 | 12 |
| 4A | Urban renewal development | Bioretention systems | 358 | 3 | 423 | 3 | 488 | 3 | 520 | 4 |
| 4B | Urban renewal development | Bioretention systems | 520 | 4 | 488 | 3 | 520 | 4 | 520 | 4 |
| 5 | Commercial development | Bioretention systems | 455 | 96 | 390 | 82 | 488 | 102 | 488 | 102 |
| 6 | Industrial development | Bioretention systems | 455 | 455 | 423 | 423 | 488 | 488 | 488 | 488 |

Table 57: Life cycle costs (in A$2009)[8]

| CASE STUDY SUMMARY: LIFE CYCLE COSTS FOR WSUD MEASURES (ESTIMATES) | | | BRISBANE | | MACKAY | | TOWNSVILLE | | CAIRNS | |
|---|---|---|---|---|---|---|---|---|---|---|
| CASE STUDY | CASE STUDY DESCRIPTION | WSUD MEASURE | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT | $ / HA | $ / LOT |
| 1 | Residential greenfield (large scale) on sloping topography | Bioretention systems | 29,673 | 2,364 | 44,509 | 3,545 | 48,218 | 3,841 | 55,636 | 4,432 |
| 2 | Residential greenfield on flat topography | Bioretention systems | 44,825 | 3,383 | 58,258 | 4,397 | 58,258 | 4,397 | 71,691 | 5,411 |
| 3 | Residential townhouse development | Bioretention systems | 40,315 | 1,074 | 49,334 | 1,314 | 53,776 | 1,433 | 62,728 | 1,671 |
| 4A | Urban renewal development | Bioretention systems | 49,307 | 345 | 58,272 | 408 | 67,237 | 471 | 71,720 | 502 |
| 4B | Urban renewal development | Bioretention systems | 71,720 | 502 | 67,237 | 471 | 71,720 | 502 | 71,720 | 502 |
| 5 | Commercial development | Bioretention systems | 68,585 | 14,403 | 58,787 | 12,345 | 73,484 | 15,432 | 73,484 | 15,432 |
| 6 | Industrial development | Bioretention systems | 62,755 | 62,755 | 58,272 | 58,272 | 67,237 | 67,237 | 67,237 | 67,237 |

[8] A life cycle cost period of 25 years and real discount rate of 5.5% was used.