Project: Muirhead Residential Development

Buffalo Creek Water Quality Improvement Plan

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Executive Summary

Executive Summary

Introduction

Defence Housing Australia (DHA) is proposing to develop a 1,350 dwelling residential subdivision (the Muirhead development) on a 167.6 ha land parcel (the Project Area) within Buffalo Creek's catchment (part of the greater Darwin Harbour catchment) The Muirhead development is an action on Commonwealth land and is being undertaken by a Commonwealth Agency. It therefore requires assessment under the *Environmental Protection and Biodiversity Conservation Act* 1999 (EPBC Act). The development was referred to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) on 3 June 2010 for assessment. The outcome of this referral was the declaration of the Muirhead development as a Controlled Action on the 2 July 2010. The development was assessed on the Preliminary Documents by SEWPaC. On the 30 March 2011 a *Decision on Approval* (the Decision) was issued. Condition 1 of the Decision identified the need to prepare a water quality improvement plan (WQIP) for Buffalo Creek for approval by the Minister before any works beyond Muirhead Stage 2 could commence.

Purpose

As per Condition 1 of the Decision, the purpose of the Buffalo Creek WQIP is to ensure *<u>no further impact</u>* on the water quality of Buffalo Creek occurs as a consequence of the Muirhead Subdivision. This allows for only two possible outcomes in relation to the management of Buffalo Creek water quality:

- The water quality at Buffalo Creek gets no worse; or
- The water quality at Buffalo Creek improves.

Objectives

The objectives of the Buffalo Creek WQIP are to (as per Condition 1 of the Decision):

- Detail the planned stages and timeline of the Muirhead Subdivision
- Define the milestones of upgrades to be undertaken by Power and Water Corporation (PWC) at the Leanyer Sanderson Sewage Treatment Plant (LSSTP)
- Demonstrate that upgrades at the LSSTP waste stabilisation ponds are sufficient to ensure that the Muirhead Subdivision does not contribute to the decline of water quality at Buffalo Creek
- Details of water quality monitoring undertaken at Buffalo Creek prior to and post treatment upgrades at Leanyer-Sanderson waste stabilisation ponds in order to demonstrate water quality improvements at Buffalo Creek
- Clearly identify key actions that need to be undertaken to ensure Buffalo Creek water quality improves, and assign those actions to specific agencies and organisations that are best positioned to ensure the various actions are implemented

Strategic Approach

The NT Government has already established a Strategic Plan for Darwin Harbour (SPDH). This plan is being overseen by the Darwin Harbour Advisor Committee (DHAC), and includes the rolling out of a number of water quality improvement initiatives such as the Water Quality Protection Plan for Darwin Harbour (WQPP) and the water quality "Report Cards". The DHAC is now well established, and has a number of key government agencies, institutions and organisations as sitting members (e.g., Darwin City Council, PWC, the Australia Institute of Marine Science, and Charles Darwin University).

Given the close alignment between the Terms of Reference of the DHAC and the Buffalo Creek WQIP, the overarching strategic approach is to align this WQIP with the current DHAC initiatives (particularly the Report Cards programs), and to appoint the DHAC to steward its implementation. If adopted, this approach should see the Buffalo Creek WQIP implemented successfully.

Current Condition of Buffalo Creek

Buffalo Creek is known to be in poor condition. This is verified by the Shoal Bay and Buffalo Creek Report Cards for 2010 and 2011 (NRETAS). Both Report Cards gave the Creek an overall water quality rating of 'E' (the lowest possible score) which translates to "*very poor water quality*", where <30% of the indicators comply with water quality objectives.

Key Polluting Activities with the Buffalo Creek Catchment

An analysis of landuse within the Buffalo Creek catchment undertaken as part of this WQIP has identified the following activities that are likely to be key contributors to the current condition of the creek (in likely order of impact):

- The LSSTP
- Existing Urban development
- Current and future construction works / urban development
- Existing and historic landfills
- Historic quarry mine
- Recreational boating

Environmental Values of Buffalo Creek

Environmental Values (EV) are those qualities of the waterway that make it suitable to support particularly aquatic ecosystems and human uses, also known as beneficial uses. Human use EVs are divided into a variety of categories reflecting the types of human use while aquatic ecosystem EVs are divided into condition classes reflecting the degree of modification from natural conditions.

Environmental values of high significance in relation to Buffalo Creek (particularly if water quality was to improve) include its role as an aquatic ecosystem, source of seafood for human consumption, secondary recreation (indirect contact with water via activities such as boating), and cultural and spiritual values. Other values such as a source of irrigation waters, aquaculture and industrial issues may also apply.

Potential Impact of Muirhead Development on Buffalo Creek (Nutrient Fate Modelling)

The main objective of this WQIP is to demonstrate how the current condition of Buffalo Creek (including water quality) can be maintained or improved with the proposed development proceeding. In order to demonstrate this, a nutrient fate model was developed that took into account the likely effects that the Muirhead Development would have on Buffalo Creek water quality. This model then was used to model the following scenarios:

1. Current condition of the creek without the development (no change).
2. Muirhead Development with current nutrient generation rates i.e. business as usual.
3. Development with stormwater quality control measures in place as per the developments stormwater management plan

4. Development with stormwater quality control measure in place and tertiary treatment upgrade in place at the LSSTP.

Within the limitations of the data available, modelling shows that the Muirhead Development will not lead to further degradation of Buffalo Creek's water quality, providing the LSSTP is upgraded to include tertiary treatment and that the strategies identified in the Stormwater Management Plan (Appendix K) are implemented.

Specific Actions

The WQIP has identified a number of specific water quality improvement actions to reduce the amount of key pollutants entering receiving waters in the Buffalo Creek catchment. There are specific actions for different pollutant sources and types including; point source (LSSTP), existing urban areas and land development and construction sites/works. The actions associated with local pollutant sources and types are listed below.

LSSTP

- increasing treatment to tertiary standards;
- using aerated rock filters to reduce nutrient and algal blooms;
- Constructing an ocean outfall to eliminate discharge into Buffalo Creek; and
- Increasing wastewater recycling in the Northern suburbs, reducing the volume of treated effluent discharged

Existing Urban Areas

- Establish Water Sensitive Urban Design (WSUD) principles as guiding principles for existing and future urban developments that fall within the CLA jurisdiction.
- Developing a stormwater management plan focussing on existing urban development within the Buffalo Creek catchment
- Establish a sub-committee within the DHAC specifically for Buffalo Creek to oversee the development and implementation of the above Buffalo Creek Stormwater Management Plan.
- Incorporate the improvement of urban stormwater quality within the Buffalo Creek catchment as a specific line item in CLA and DCC business plans and financial reporting.

Future Development

- Use the monitoring data collected as per this WQIP in relation to the construction of the Muirhead development and the implementation of its CEMP and SMP to report on the degree of success, lessons learned, and recommendations for future development.
- Based on the findings and conclusion of the aforementioned report;
  - update the WSUD Design Objectives for Darwin Harbour in Darwin (Dept. of Planning and Infrastructure, 2009),
  - ensure improvements are considered when assessing Development Applications for future developments within Buffalo Creek catchment and the wider Darwin Harbour watershed.
- Establish WSUD principles as guiding principles for future CLA stormwater related planning and projects.
- Following effective completion of future developments (i.e. 80% or more of the housing constructed), initiate a 10 year monitoring programed designed to assess the long term success / appropriateness of the WSUD infrastructure incorporated into the Muirhead development's stormwater management system. Such a program will provide important information concerning how to deliver effective WSUD infrastructure not just for Darwin Harbour, but for the northern latitudes of Australia collectively

Action Plan

In order for any plan to be successful, it is crucial to attribute rolls and responsibilities for the delivery of specific actions. Having identified the players who will implement this WQIP the next step is to for the various players to agree to deliver specific actions within the nominated timelines. Chapter 6 of this WQIP sets out an Action Plan for the delivery of this WQIP with the cooperation of the various people and organisations through their nominated (and accepted) roles and responsibilities.

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Glossary

Term	Definition
CEMP	Construction Environment Management Plan
CLA	Crown Land Administration
CDU	Charles Darwin University
DCC	Darwin City Council
DHA	Defence Housing Australia
DHAC	Darwin Harbour Advisor Committee
EPA	Environmentally Relevant Activity
LSSTP	Leanyer-Sanderson Sewerage Treatment Plant
NRETAS	Northern Territory Government Department of Natural Resource, Environment, The Arts and Sport
NT	Northern Territory
PWC	Power and Water Corporation
SEWPaC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
SMP	Stormwater Management Plan
SPDH	Strategic Plan for Darwin Harbour
WQIP	Water Quality Improvement Plan for Buffalo Creek
WQPP	Water Quality Protection Plan for Darwin Harbour
WSUD	Water Sensitive Urban Design

1 Background & Purpose

1.1 Background

1.1.1 Buffalo Creek

Buffalo Creek is located approximately 14 km north north-east of Darwin's CBD and forms part of the Darwin Harbour Watershed (Figure 1-1). This tidal influenced creek flows into Shoal Bay (receiving waters). Shoal Bay is listed by the Northern Territory (NT) Government as a *Site of International Significance* (NRETAS, 2007) for a number of reasons including the following (NT, 2007):

- Extensive tidal flats providing important feeding and roosting area for migratory shorebirds
- Small inland freshwater wetlands frequented by up to 5,000 waterbirds
- Patches of rainforest around the margin of the tidal flats
- Threatened species including three plants, ten vertebrates and one invertebrate.

Buffalo Creek consists of a long, narrow channel that grades into a few large meandering bends near its confluence with Shoal Bay (Haese, et al., 2009). It is the most polluted tributary discharging into Darwin Harbour (Drewry, 2010). This is due to a number of past and present land uses, including:

- The Leanyer-Sanderson Sewerage Treatment Plant (LSSTP) that continues to discharge secondary treated sewage directly into Buffalo Creek since 1971 (point source)
- The discharge of untreated urban stormwater directly into the creek from existing urban development to the south and south-east (urban defuse)
- Intermittent ongoing urban development (land development and construction works – spike then urban diffuse)
- Transport infrastructure (spike then urban diffuse)
- Existing and historic landfills (ERA)
- Recreational activities (including a caravan park, a water park and recreational boating)
- A historic quarry mine (Extractive Industry, ERA)
- Historical use as a military training range.

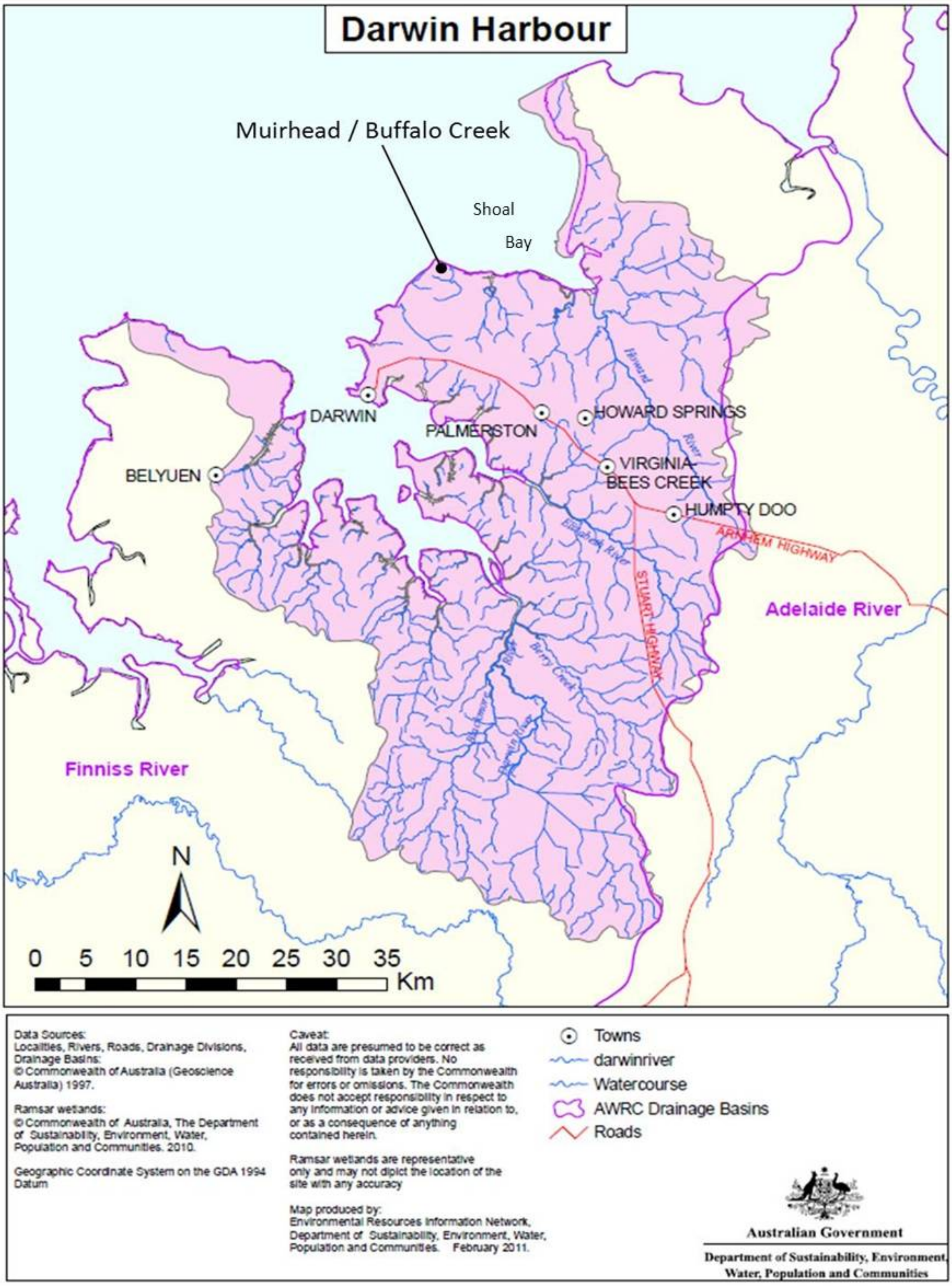

Figure 1-1 | **Buffalo Creek as it occurs within the Darwin Harbour Catchment**

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1.1.2 Muirhead residential development

Defence Housing Australia (DHA) is proposing to develop a 1,350 dwelling residential subdivision (the Muirhead development) on a 167.6 ha land parcel (the Project Area) within Buffalo Creek's catchment (Figure 1-2). The average density of housing is proposed to be 10 dwelling units per hectare of which 55% will be open market housing, 30% defence housing, 10% affordable housing and 5% community housing.

The Muirhead development has the potential to further impact on an already stressed Buffalo Creek in two primary ways:

1. Municipal water generated by this development will be directed to the LSSTP, which discharges directly into Buffalo Creek
2. Alteration to stormwater quality and hydrology due to increased hard surfaces and potential sources of pollution.

The Muirhead development is an action on Commonwealth land and is being undertaken by a Commonwealth Agency. It therefore requires assessment under the *Environmental Protection and Biodiversity Conservation Act* 1999 (EPBC Act). The development was referred to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) on 3 June 2010 for assessment. The outcome of this referral was the declaration of the Muirhead development as a Controlled Action on the 2 July 2010.

The development was assessed on the Preliminary Documents by SEWPaC. On the 30 March 2011 a *Decision on Approval* (the Decision) was issued (Appendix B). Condition 1 of the Decision identified the need to prepare a water quality improvement plan (WQIP) for Buffalo Creek for approval by the Minister before any works beyond Muirhead Stage 2 could commence.

1.2 Purpose

As per Condition 1 of the Decision, the purpose of the Buffalo Creek WQIP is to ensure *no further impact* on the water quality of Buffalo Creek occurs as a consequence of the Muirhead Subdivision. This allows for only two possible outcomes in relation to the management of Buffalo Creek water quality:

- The water quality at Buffalo Creek gets no worse; or
- The water quality at Buffalo Creek improves.

1.3 Objectives

The objectives of the Buffalo Creek WQIP are to (as per Condition 1 of the Decision):

- Detail the planned stages and timeline of the Muirhead Subdivision (Section 1.6.3)
- Define the milestones of upgrades to be undertaken by Power and Water Corporation (PWC) at the Leanyer Sanderson Sewage Treatment Plant (LSSTP) waste stabilisation ponds (Section 5.4.1).
- Demonstrate that upgrades at the LSSTP waste stabilisation ponds are sufficient to ensure that the Muirhead Subdivision does not contribute to the decline of water quality at Buffalo Creek (Section 4)
- Detail water quality monitoring undertaken at Buffalo Creek prior to and post treatment upgrades at Leanyer-Sanderson waste stabilisation ponds in order to demonstrate water quality improvements at Buffalo Creek (Sections 2.2 and 5.3)
- Clearly identify key actions that need to be undertaken to ensure Buffalo Creek water quality improves, and assign those actions to specific agencies and organisations that are best positioned to ensure the various actions are implemented (Sections 5 and 6)

1.4 Strategic Approach

Setting up and maintaining momentum for strategic documents such as WQIPs can be very difficult and is often prone to failure. The key challenge lies in striking a balance between what is both practically possible and meaningful. This requires developing a plan that is able to achieve real, measureable outcomes, but is not so convoluted, complex and/or costly, that it becomes unmanageable. It is also important that mechanisms are in place to ensure the plan is implemented, i.e., that responsibilities and accountabilities are assigned, and that these responsibilities and accountabilities are monitored and followed up through effective Project Managment.

The NT Government has already established a Strategic Plan for Darwin Harbour (DHAC, 2010). This plan, the SPDH, is being overseen by the Darwin Harbour Advisor Committee (DHAC), and includes the roll out of a number of water quality improvement initiatives such as the Water Quality Protection Plan for Darwin Harbour (WQPP) and the Report Cards. The DHAC is now well established with a number of key government agencies, institutions and organisations as sitting members (e.g., Darwin City Council, PWC, the Australia Institute of Marine Science, and Charles Darwin University).

Given the close alignment between the Terms of Reference of the DHAC and the Buffalo Creek WQIP, the over-arching strategic approach is to align this WQIP with the existing DHAC initiatives (particularly the Report Cards programs), and to appoint the DHAC to steward its implementation. If adopted, this approach should see the Buffalo Creek WQIP implemented successfully.

It should be noted that this WQIP should be treated as a “living document”, i.e., a document designed to be adapted as new information becomes available. This approach is required as decisions such as the upgrade of the LSSTP had not been finalised at the time of the development of this document. Further, as actions identified in this plan are implemented and new data becomes available, it may be appropriate to adjust priorities to suit the situation and / or introduce new strategies and actions.

1.5 WQIP Area

This WQIP applies to Buffalo Creek and its catchment. This includes its estuary and its receiving waters, Shoal Bay / Darwin Harbour. The creek itself consists of a long, narrow channel with meandering becoming more pronounced moving downstream (Smith, 2009). Upstream the creek is fresh water, but becomes increasingly estuarine towards its confluence with Shoal Bay. The majority of the creek channel has straight-sided banks with the exception of intertidal mudflats on the meander bends and parts of the main channel (Smith, 2009).

Aerial imagery of the Buffalo Creek catchment and its receiving waters (Shoal Bay) is provided in Figure 1-2. A vegetation map for the area is provided in Appendix C. The aerial imagery and vegetation map reveal the following features of the catchment:

Creek channel and riparian zone

- The confluence of Buffalo Creek with Shoal Bay is heavily distorted by a large intertidal sand bar (the effect of this sandbar is to dampen tidal movement).
- In its mid to lower reaches, Buffalo Creek is fringed by mangroves in its intertidal zone, consisting mostly of *Rhizophora stylosa*, *Bruguiera exaristata* and *Camptostemon schultzii* closed to open forest
- In its upper reaches, Buffalo Creek splits into two tributaries, both of which are fed by stormwater drains connected to urban drainage systems that currently have no associated water quality improvement infrastructure (Jones, 2012). This part of Buffalo Creek is dominated by salt flats and fringing closed grassland / sedgeland.

Catchment

- Established urban development in south-eastern quadrant of the catchment
- A mixture of cleared and vegetative land in the north-eastern quadrant consisting of Eucalyptus and Paperbark communities, Monsoon Rainforest, regenerative woodland / shrubland, a small patch of Pandanus and a small patch of development (a caravan park)
- The northeast quadrant is predominately undeveloped and is dominated by hyper-saline salt flats. Small elongated areas of mangroves also occur at the Shoal Bay side of this quadrant
- The south-eastern quadrant is also mostly undeveloped except for some urban development at its southern end. Otherwise this quadrant is dominated by salt flats fringed by grasslands and sedgeland as well as regenerating very low open woodland and shrubland of mixed species (including grasslands and disturbed areas)
- The series of constructed ponds visible in Figure 2 are the LSSTP treatment ponds.

A detailed analysis of land use within the Buffalo Creek catchment is provided in Section 2 of this report.

Figure 1-2 | Buffalo Creek catchment

(Source: John Drewry, NRETAS, 2011)

1.6 Muirhead Development

1.6.1 Location

The development that triggered the requirement to for this WQIP is the Muirhead residential subdivision (the Muirhead development) being developed by DHA. The Project Area (Figure 1-3) is located off Lee Point Road, Muirhead, is legally described as Lot 9737 Town of Nightcliff (Survey Plan L2001/071). The land is owned by the Commonwealth and covers an area of 167.6 ha.

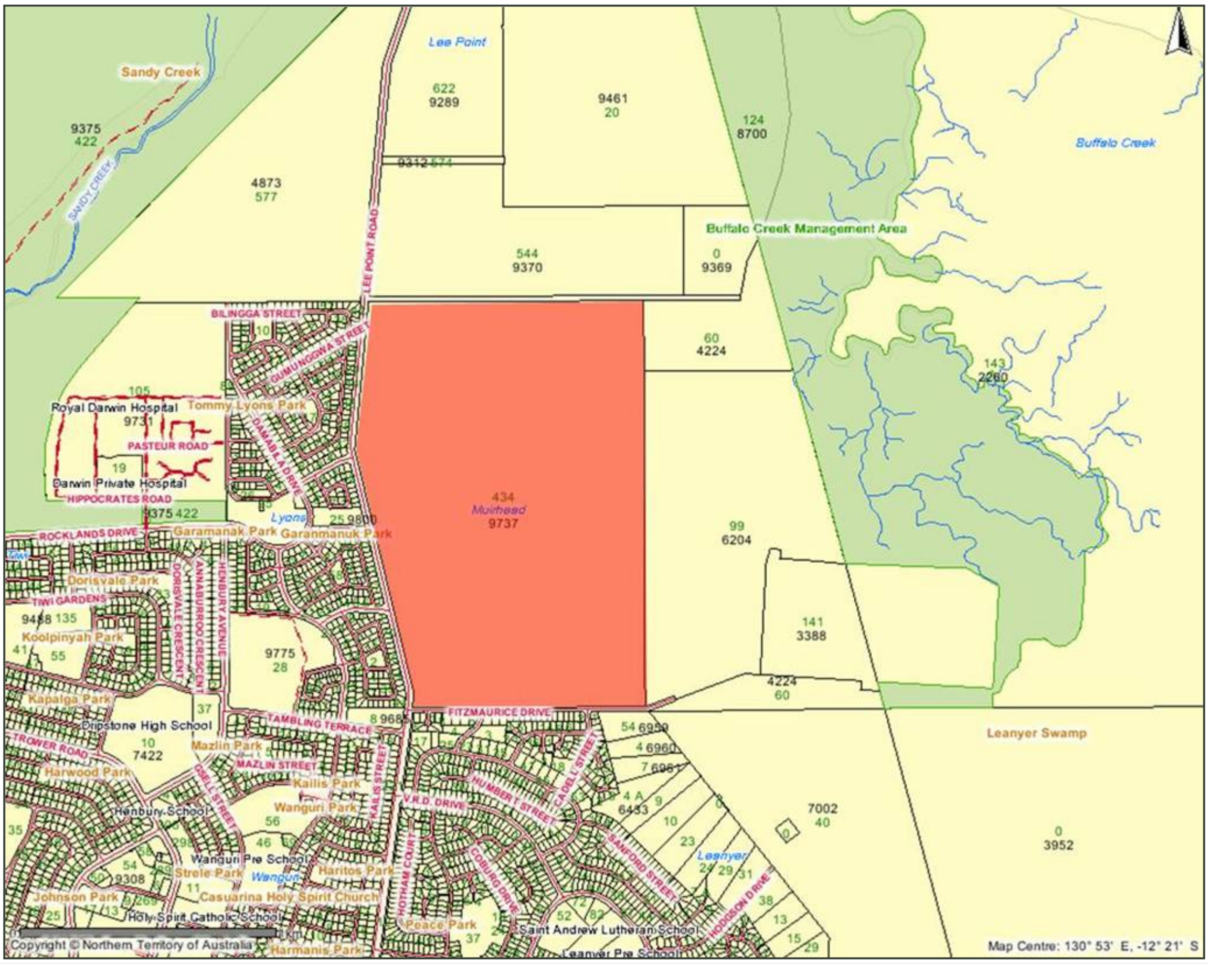


Figure 1-3 | Cadastral map showing the Muirhead development

1.6.2 Subdivision Design

The Muirhead development is designed to be an economically viable, diverse, sustainable and affordable master planned community and is to provide a diversity of housing options through a range of lot sizes and house designs.

The three key elements informing the Muirhead residential subdivision are:

1. Providing a climatically responsive design for the tropical environment
2. Providing a range of housing product, including a dispersed mixture of single dwelling houses on conventional sized allotments, affordable community housing and defence housing; and

3. Linking Muirhead to neighbouring residential communities through an extensive open space network, forming an integral part of a framework servicing the northern suburbs of Darwin.

Note that the development does not include any commercial or industrial land uses, nor any other landuse other than residential and open space.

The average density of housing is proposed to be 10 dwelling units per hectare of which 55% will be open market housing, 30% defence housing, 10% affordable housing and 5% community housing. A breakdown of dwellings based on lot size and dwelling type is provided in Table 1.1.

Table 1.1 | Dwellings by Lot Size and Type

Lot Size	Dwellings	%
450 – 499 m^2	114	10
500 – 599 m^2	278	25
600 – 699 m^2	422	39
700 – 799 m^2	184	17
800 m^2 +	30	3
4,000 m^2 +	68	6
Total	**1,096**	**100**
Single dwelling sites	981	81
Multiple dwelling sites (Duplex)	115	19
Total potential dwelling units	**1,211**	**100**

1.6.3 Milestones and Timelines for the Muirhead development

The Muirhead development is to be constructed over a number of stages as illustrated on the Preliminary Staging Plan provided in Appendix D. Stage 1 is already complete and was publically launched on the 29 November 2011 (DHA & Investa Property Group, November 2011). The starting time of the future stages is dependent, in part, on the approval of this WQIP.

Once SEWPaC has granted approval for the remaining stages of the Muirhead development to proceed, the roll out of Stages 2 and 3 are expected to begin together (DHA & Investa Property Group, September 2011). The stages are expected to be completed six months after construction begins, whereas the timing of Stage 4 is likely to be dependent on the completion dates for Stages 2 and 3.

2 Buffalo Creek

2.1 General Description

The Muirhead development falls within the Buffalo Creek catchment, approximately 1 km east of the creek's closet bank (Figure 1-2). The creek is a freshwater grading to estuarine tidal system which flows into Shoal Bay approximately 13 km north north-east of Darwin's CBD, on the northern outer reaches of Darwin Harbour. It consists of a long, narrow channel with a few large meander bends at the downstream end (Haese, et al., 2009). There is a large intertidal sand bar across the mouth which dampens tidal movement. Moving upstream, the channel narrows and meanders through a dense mangrove environment and the majority of the creek has straight-sided banks with occasional intertidal mudflats on the meander bends and parts of the main channel (Haese, et al., 2009). The main channel splits into two approximately 5 km upstream. These two main tributaries ultimately connect with two urban stormwater drains connected to urban drainage networks that currently have no associated water quality improvement infrastructure (Jones, 2012). Given the nature of urban development (i.e. increased hard surfaces preventing infiltration and increasing run-off), these drains are likely to provide a significant proportion of the water feeding into Buffalo Creek during wet weather..

2.2 Current Water Quality

Buffalo Creek is known to be in poor condition (Drewry, 2010). This is exemplified by the Shoal Bay and Buffalo Creek Report Cards for 2010 and 2011, both of which gave the Creek an overall water quality rating of 'E', the lowest possible score, which translates to "*very poor water quality*", where <30% of the indicators comply with water quality objectives. The Report Card results for Buffalo Creek are summarised in Table 2.1. and provided in full in Appendix E.

The results provided in Table 2.1 illustrate multiple compliance failures relative to the defined water quality objectives, and that the water quality may have worsened over time. According to the Northern Territory Government Department of Natural Resource, Environment, The Arts and Sport (NRETAS), the most likely candidate for this situation is the LSSTP (Section 2.3.1), the outfall for which discharges directly into Buffalo Creek (NRETAS, 2010). It should be noted, however, that there are other potential sources of pollution for Buffalo Creek. Chief amongst these is the direct discharge of untreated urban runoff directly into the creek.

The creek also has a low denitrification efficiency (used to provide an indication of ecosystem health), meaning the majority of inorganic nitrogen is released back into the water column as ammonia and nitrate (Burford, et al., 2009). It has been suggested that significant respiration occurs as a result of organic carbon and nutrient inputs resulting in low dissolved oxygen concentrations in the creek, which is likely to have major effects on the ecosystem functioning of the creek (Haese, et al., 2009). Generally, it is considered that Buffalo Creek has poor ecosystem health due to long residence times of sewage discharge, a larger nutrient load, low denitrification efficiency, and poor tidal flushing (Haese, et al., 2009).

Table 2.1 | Water quality results for Buffalo Creek as reported in the Shoal Bay and Buffalo Creek Report Card **(NRETAS, 2010)**

Indicator (units)	Water Quality Objective	Reported Condition – 2010 (9 Samples)	Reported Condition – 2011 (4 Samples)
Electrical Conductivity (µS/cm)	NSO	49800	NR
Turbidity (NTU)	NSO	17	NR
pH	6-8.5	7.3-8.0	7.3-7.8
Dissolved oxygen (%)	80-100 (under revision)	**38-66**	NR
Total suspended solids (mg/L)	<10 (under revision)	**28**	NR
Chlorophyll a (µg/L)	<4	**29**	**45**
NOx (µg N/L)	<20	**76**	**40**
Ammonia (µg N/L)	<20	**533**	**1775**
Total nitrogen (µg N/L)	<300	**1510**	**2735**
Total phosphorus (µg N/L)	<30	**375**	**548**
Filterable reactive phosphorus (µg P/L)	<10	**318**	**326**

Table notes:

NR – nor reported by NRETAS (no reason given)
NSO – No set objective
Red Bold – Water Quality Objective exceeded

It should be noted that the exposure of Buffalo Creek to pollution over an extended period of time suggests that sediments may have reached, or are approaching, sorption saturation (i.e., the process of attachment and inclusion of pollutants such as nutrients and metals onto sediment particles). Consequently, there may be lag time between reducing pollutant inputs into the creek, and when a noticeable improvement in water quality is measured.

2.3 Buffalo Creek Catchment – Potential Sources of Pollution

Landuse within the Buffalo Creek water catchment ranges from relatively undisturbed riparian and littoral vegetation to highly urbanized (Figure 2-1 and Appendix C). This range of activities brings with it a number of potential pollution sources, including:

- The LSSTP
- Existing Urban development
- Current and future construction works / urban development
- Existing and historic landfills
- Historic quarry mine
- Recreational boating.

Figure 2-1 | Catchment map of Buffalo Creek showing potential pollutant sources.

Note that the red boundary delineates Buffalo Creek catchment boundary

2.3.1 Leanyer-Sanderson Sewage Treatment Plant

Whilst a number of potential pollutant sources have been identified for Buffalo Creek (Figure 2-1), the LSSTP is likely having the greatest adverse impact on the water quality of the creek. The LSSTP is owned and operated by the PWC. According to Drewry et al., (2010), the LSSTP's treatment ponds' are the largest in the NT, and have been discharging secondary treated effluent into Buffalo Creek since 1971.

The LSSTP treatment catchment is now approaching maximum development, with about 70% of its design capacity already committed. This is expected to rise to 80% following the completion of developments at Muirhead and Lyons, with the rest committed to new suburbs and increases in residential density in the existing treatment catchment. This expansion in demand will likely see an increase in water quality stressors for Buffalo Creek unless effort is made to upgrade the existing plant (Drewry, 2010).

2.3.2 Urban Stormwater Runoff

Many of the articles and reports referenced for this WQIP focus on the LSSTP. Given the aging technology and the level of treatment currently operating at this STP, such focus is understandable. The presence of the LSSTP, however, may have over-shadowed another important potential stressor on Buffalo Creek, i.e. the untreated stormwater runoff generated from the urban development identified in Figure 2-1.

Urban development is known to significantly impact on catchment hydrology and the water quality of stormwater runoff (Egodawatta, et al., 2007; USEPA, 2002). Urban development results in a fundamental change to the landscape and introduces sources of pollution above natural background levels. These pollutants may then enter nearby water bodies within the affected catchments. The resultant impact of these pollutants can be severe due to the multitude of pollutants stormwater can introduce to aquatic ecosystems, including (Lawrence, et al., 2006; Bolto, et al., 2011):

- Toxicants (heavy metals, hydrocarbons, ammonia)
- Nutrients (phosphorus, nitrogen, carbon)
- Oxygen depleting substances (organic material, ammonia, hydrocarbons, sulphides).
- Physical contaminants (suspended solids, colloidal material)
- Trace organic compounds (pharmaceutically active compounds, insecticides, herbicides, personal care products)
- Gross pollutants (plastics products, cigarette butts, cartons, glass, vegetation etc.)
- Altered hydrology (e.g. stream levels, stream flow frequency, stream flow energies).

As shown in Figure 2-1, the Buffalo Creek catchment includes a large proportion of predominately residential development, particularly in its southern and south eastern reaches. This includes two large urban stormwater network drainage outlets that flow directly into Buffalo Creek. This outlet, along with other smaller contributors, is likely to be having a significant impact on the current water quality of Buffalo Creek (Barnard, 2011), as there is currently no stormwater quality improvement infrastructure associated with these urban stormwater networks (Jones, 2012). Further, development within the Buffalo Creek catchment is set to continue, which will compound this problem unless best management practice strategies are incorporated into current and future urban developments.

2.3.3 Current and Future Construction Works

Construction works can result in significant short term impacts on water quality, primarily through the introduction of large sediment loads via stormwater runoff. This increased mobilisation of sediment is due to the removal of vegetative surface covers and the stockpiling of soil and fill materials on construction sites that are not properly managed. Construction works also increase the potential for environmental incidents such as petrochemical spills associated with the refuelling of plant and equipment or leakage from fuel storage levels.

Construction works are currently underway within the Buffalo Creek catchment in the form of the Muirhead development (Figure 2-1). Hence, the appropriate management of these construction sites, including the establishment of a Construction Environment Management Plan (CEMP) and the enforcement of construction regulations, will be essential in managing this issue. It is also important that planning conditions are in line with current industry standards for post development stormwater runoff management practices. This could include facilitating the integration of water quality improvement infrastructure into the existing stormwater drainage system and preparing conditions and protocol associated with the hand over to Council of water quality improvement infrastructure for future developments.

2.3.4 Existing and Historic Landfills

Landfills can impact on the water quality of nearby water bodies through two main vectors, i.e., surface runoff and groundwater flows (Figure 2-2). Surface runoff and groundwater flows impacted by landfills can contain a wide range of pollutants, depending on the types of wastes disposed of at the given site, and the length of time that has passed since a given landfill cell has been in place (i.e., the stage of decomposition currently underway). The age of a given landfill site is also important because it has a strong bearing on the types of technologies and landfill management practices implemented at the site during its construction and operation (this has implications for the ingress of leachate into the local groundwater system, as well as the off-site movement of contaminated runoff). That is, older landfills, due to available technology and less stringent legislative controls, tend to be a greater risk to water quality than newer landfills.

The issue of landfills particularly applies to the Buffalo Creek catchment as it contains two know landfill sites, one of which is no longer operational (i.e. historic landfill), as shown in Figure 2-1. Further, given the catchments historical association with the Australian Defence Force, the potential also exists for the presence of smaller, uncontrolled landfills that may contain undocumented waste, including ordinance. Consequently, there is a risk of landfill affected groundwater impacting on the water quality at Buffalo Creek.

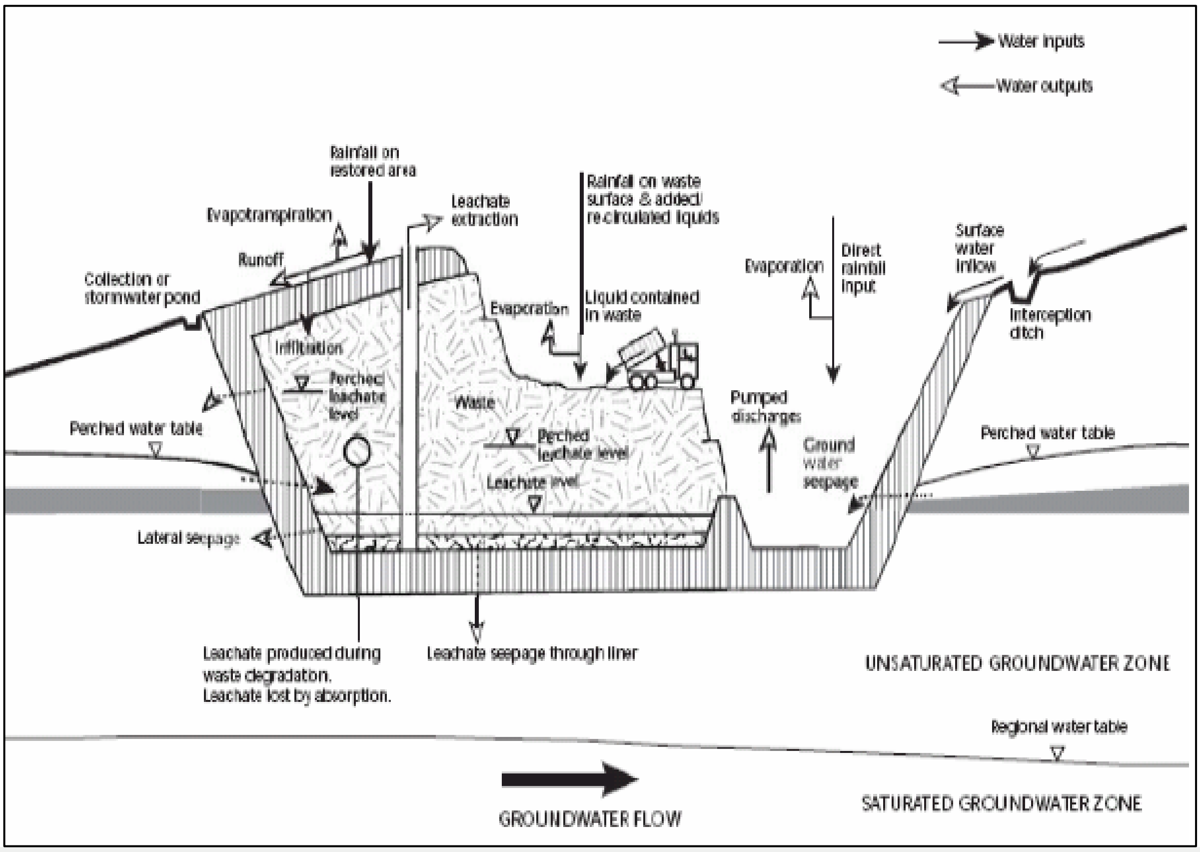


Figure 2-2 **|** Conceptual diagram of water movement into and out of a landfill site (EPA, 2008)

3 Environmental Values of Buffalo Creek

3.1 What are Environmental Values?

Environmental Values (EV) are those qualities of the waterway that make it suitable to support particularly aquatic ecosystems and human uses, also known as beneficial uses. Human use EVs are divided into a variety of categories reflecting the types of human use while aquatic ecosystem EVs are divided into condition classes reflecting the degree of modification from natural conditions (Gunn, et al., 2010). These values can be categorised as follows (NWQMS, 1998; Gunn, et al., 2010):

- High conservation / ecological value systems (HCV or HEV), often found within national parks, conservation reserves or inaccessible locations
- Slightly to moderately disturbed systems (SMD). These systems have undergone some changes but are not considered so degraded as to be highly disturbed.
- Highly disturbed system (HD). These are degraded systems likely to have lower levels of naturalness. These systems may still retain some ecological or conservation values that require protecting. Targets for these systems likely less stringent and may be aimed at remediation and recovery or retaining a functional but highly modified ecosystem that supports other environmental values also assigned to it.

- Irrigation – Irrigation of crops such as cotton, Lucerne, citrus, grapes or hay or watering lawn
- Farm use – for milking sheds, vehicle and equipment wash-down and protection, piggeries, feedlots or fruit packing
- Stock watering – Drinking water for stock
- Aquaculture – water used in operational aquaculture farms
- Human consumer of aquatic foods – e.g. fish or crustaceans
- Primary recreation – Direct contact with the water, e.g., swimming, snorkelling, skiing (Includes bathing, i.e., bath and showers)
- Secondary recreation – Indirect contact with water through fishing, boating, sailing, rafting or wading
- Visual appreciation – Aesthetic values of maintaining clean waterways, e.g., free of algal blooms and pollution.
- Drinking water – raw water for humans' drinking, e.g. local town supply, hikers, camping grounds, mine sites.
- Industrial – Power generation, manufacturing plants, mines
- Cultural and Spiritual Values – scar trees, middens, burial sites and historical features.

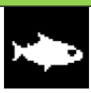
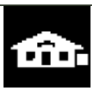
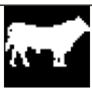
3.2 Inferred Environmental Values for Buffalo Creek

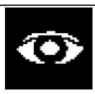
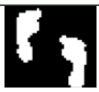
Water systems are variable, interconnected systems. Freshwater systems typically become estuary systems which discharge into marine systems. Any upstream issues will inevitably impact downstream. For example, estuaries, which are the buffer zone between fresh and marine systems, are known to provide breeding; shelter; and / or feeding habitat for marine species. Water quality issues that occur upstream can have flow on effects for downstream aquatic health and beneficial values. Hence, the assignment of environmental values to a given water system must be done in the context of its connectivity with its downstream systems. In the case of Buffalo Creek, the environmental values (Table 3.1) have been assigned taking into account its estuarine component and its connectivity with Shoal Bay.

It should also be noted that the environmental values of Buffalo Creek have been assigned under the supposition that the water quality of Buffalo Creek is unaffected by pollution. This assumption is important, especially within context of this WQIP; because it allows for the inclusion of the potential utility of Buffalo Creek should water quality improve. For example, given the current condition of Buffalo Creek, it is unlikely that it could be safely used for irrigation. However, should Buffalo Creek be returned to a reasonable condition, this situation could be reviewed.

Table 3.1 | Buffalo Creek - Environmental values.

This table identifies if a given value applies (yes or no), and provides a qualitative assessment of the likely importance of the value (H = high, M = medium, and L = low). The values are assigned under the supposition that Buffalo Creek does not currently suffer from high levels of pollution, taking into account existing and likely future utility.

Value		Applicable	Comments
	Aquatic Ecosystem	Yes (H)	Despite its polluted state, Buffalo Creek does provide an important aquatic habitat, including habitat for two fish species of regional significance (*Pristis clavata* and *P. Zijsron*). Further, Buffalo Creek discharges into Shoal Bay, which is listed as being of *International Significance* (Section 1.1).
	Irrigation	Yes (M)	It appears that currently Buffalo Creek is not being used for irrigation purposes, and this is likely due to its poor water quality. However, should the quality improve, Buffalo Creek should present a potential future source of irrigation water to supplement potable supplies (e.g. irrigating of public facilities).
	Farm use	No	There is currently no commercial farming, nor is there likely to be in the future.
	Stock watering	No	There is currently no commercial farming, nor is there likely to be in the future.
	Aquaculture	Yes (L)	There is currently no commercial aquaculture; however opportunities may be possible in the future should water quality improve.
	Human consumption	Yes (H)	Due to the high levels of pollution, the consumption of fish and other aquatic food sources from Buffalo Creek and its estuary is not recommended (despite the popularity of fishing in the lower reaches). However, improvements in water quality may eventually see this change.

			Note also that water flowing from Buffalo Creek has the potential to impact on consumable species in Shoal Bay
	Primary recreation	No	While the creek, particularly towards the outlet, occasionally is used for this purpose (swimming), primary recreation is discouraged due to the presence of crocodiles.
	Secondary recreation	Yes (H)	Boating and fishing are currently common activities, particularly towards the outlet where a public boat ramp is situated. Improvements in the condition of Buffalo Creek are likely to see this increase.
	Visual appreciation	Yes (H)	Buffalo creek is a known and often used as a recreation area, and is a known bird watching location.
	Drinking water	No	Pollution issues notwithstanding, it is unlikely that Buffalo Creek will be used as a drinking water supply in foreseeable future due to its urban runoff headwaters and marine water confluence.
	Industrial use	Yes (L)	Currently there is no known industrial usage of Buffalo Creek's water or other features. Improvements in water quality might make this a viable source in the future, however no specific industrial uses have been identified.
	Cultural and spiritual values	Yes (H)	There is a recorded sacred site, under the *Northern Territory Sacred Sites Act* at Buffalo Creek. A World WWII observation post is situated at Buffalo Creek and is listed on the Register of the National Estate. However it is in poor condition.

3.3 Summary

Table 3.1 helps resolve the importance of Buffalo Creek as both a resource in-itself and as an important contributor to the utility and environmental health of Shoal Bay. It also demonstrates the economic and social importance of the creek and how these values might be enhanced by improving its current condition. This is particularly the case where recreational activities are concerned, which has flow on benefits to the local community in the form of tourism. For example, improving the generally condition of the creek should improve issues such as water clarity, fish numbers, and the general appearance of the creek and its estuary, which in turn should see an increase in its use for recreational purposes such as fishing and boating. This in turn should improve the local economy, and improve general quality of life for current and future residence.

Table 3.1 also reveals the importance of Buffalo Creek as an aquatic habitat. For example, despite its degraded condition, it is known to contain two species of regional significance, namely the Dwarf Sawfish (*Pristis clavata*) and the Green Sawfish (*P .zijsron*). Both of these species of sawfish are listed as follows:

- Critically Endangered worldwide (Larson, et al., 2006; Stirrat, et al., 2006)
- Vulnerable in accordance with the EPBC Act; and
- Vulnerable by the NRETAS (Larson, et al., 2011)

It is also likely to contain the Freshwater Sawfish and Northern River Shark, and may also be frequented by the Speartooth Shark, all of which are also Critically Endangered worldwide (Larson et al. 2006, Ward and Larson 2006). Further, Buffalo Creek is also a known bird watching location. McCrie and Watson (2003) observe that the Chestnut Rail, Great-billed Herron, and Azure Kingfisher are often seen at the mouth of the creek. Additionally, a large number of Great Knot and Bar-tailed Godwit roost near the mouth (McCrie & Watson 2003). The Little Bronze-Cuckoo, Mangrove Gerygone and the Yellow White-eye and Red-headed Honeyeaters are frequently seen in the mangroves upstream towards the LSSTP (Haese & Smith 2009). Overall, Buffalo Creek has important Aquatic Ecosystem value as it drains into Shoal Bay, which is listed by the NT Government as being of *International Significance* (Section 1.1 of this report).

4 Nutrient Fate Modeling

4.1 Purpose

The Muirhead Nutrient Fate Model was developed to provide predicted outcomes based on known scientific principles using Buffalo Creek water quality data to facilitate improvements in waste management infrastructure.

This document sets out the methodology used to develop the model and the results of the initial model simulations. It also includes recommendations for further options to improve the accuracy of the model predictions.

4.2 Project Overview

The approval for the first stage of the Muirhead Residential Subdivision was granted under the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) on 30 March 2011 and includes a range of conditions that Defence Housing Australia (DHA) must satisfy before further developments can commence (Section 1.1.2).

These conditions specifically state any development beyond Muirhead Stage 2 can only take place once the following conditions have been met. This includes the:

- Delivery of a nutrient fate modelling study for Buffalo Creek

This report outlines the results of this modelling study for Buffalo Creek.

4.3 Limitations

All care has been taken in the preparation of this report and the model that it refers to however the accuracy of the model is dependent on the information which was used in the validation process. The water quality data that was used for the development of the model was from existing monitoring programs. These programs were not designed to be used for model development so they are limited in both temporal and spatial dimensions.

Furthermore the impact of sediments on water quality was not investigated within the model. Given the history of the catchment (Section 2), it is likely that the levels of nutrients in sediments are high and this may impact on the water quality.

The model does not take into account the impact of evaporation or seepage on the nutrient levels within Buffalo Creek. In reality water would be both lost and gained from the system through evaporation, precipitation and seepage to and from groundwater. Water loss from evaporation occurs from the ponds of the LSSTP and the water body of Buffalo Creek. Both water loss and gain from seepage occurs from both the LSSTP ponds and Buffalo Creek (note that groundwater seepage may also be providing a vector for leachate to find its way into Buffalo Creek for both the existing and historic landfills).

Due to both the complexity of defining suitable levels of seepage to the model and the lack of local groundwater data, this parameter was not used.

4.4 Objectives

The objectives of this project are to:

- Develop a nutrient fate model using the Contaminant Transport module of the simulation software GoldSim
- Undertake a workshop to confirm the assumptions and data to be used prior to the set-up of the model
- Develop the model in such a way that various dispersion rates and likely end fates from nutrients entering the creek from the existing LSSTP can be modelled
- Develop the model to allow for future upgrades and to provide a basis for on-going planning and impact estimation for the upgraded LSSTP.

4.5 Workshop

A workshop was held on the 20th October 2011 to discuss the nutrient model with potential stakeholders. The purpose of this meeting was to identify information sources for the model and determine the basic structure of the model. A copy of the Workshop Presentation and minutes is included in Appendix F. The workshop included representatives from Power and Water Corporation (PWC) whom own and operate the LSSTP; the Department of Natural Resources; Environment; The Arts and Sport (NRETAS) and Charles Darwin University (CDU). The Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) was invited to attend but declined.

4.6 Nutrient Fate Model

4.6.1 Goldsim – Model Platform

GoldSim is simulation software that allows the user to carry out dynamic, probabilistic simulations.

The GoldSim Contaminant Transport Module is a program extension to GoldSim which allows users to probabilistically simulate the release, transport and fate of mass (e.g. contaminants) within complex engineered and/or natural environmental systems.

A mass transport model is a mathematical representation of an actual system (e.g. the subsurface environment near a waste disposal site) which can be used to simulate (and hence predict) the release, transport (movement) and ultimate fate of mass within the system. The “mass” that is typically simulated is that of chemical contaminants that have been accidentally released or intentionally disposed of within the system. As a result, such models are often referred to as contaminant transport models.

The fundamental outcome produced by the Contaminant Transport Module consists of predicted mass fluxes at specified locations within the system and predicted concentrations within environmental media (e.g. groundwater, soil, air) throughout the system.

The model has been designed using a ‘top down’ approach. The theory of ‘top down’ design is that a model is defined in its most simplistic terms or elements at the highest level (see Figure 4-1). Each element can be thought of as a ‘black box’ which can be opened up to reveal another level of detail. This approach allows for varying levels of detail in a model where there is uncertainty in the processes occurring. Assumptions can be made at varying levels and where additional information is available extra levels of detail can be documented. This allows for the model to be updated overtime without having to completely rebuild the model.

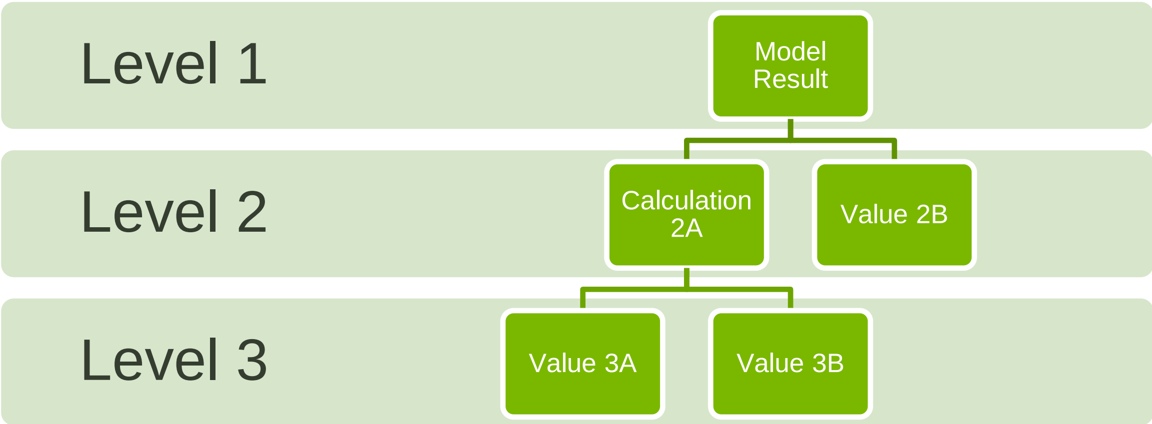


Figure 4-1 | Example of ‘top down’ model

4.6.2 Model Overview

The model of Buffalo Creek is a simplified conceptual model of the processes that occur within the creek Figure 4-2. The model simulates the input of nutrients from the LSSTP, and stormwater runoff from the urban area.

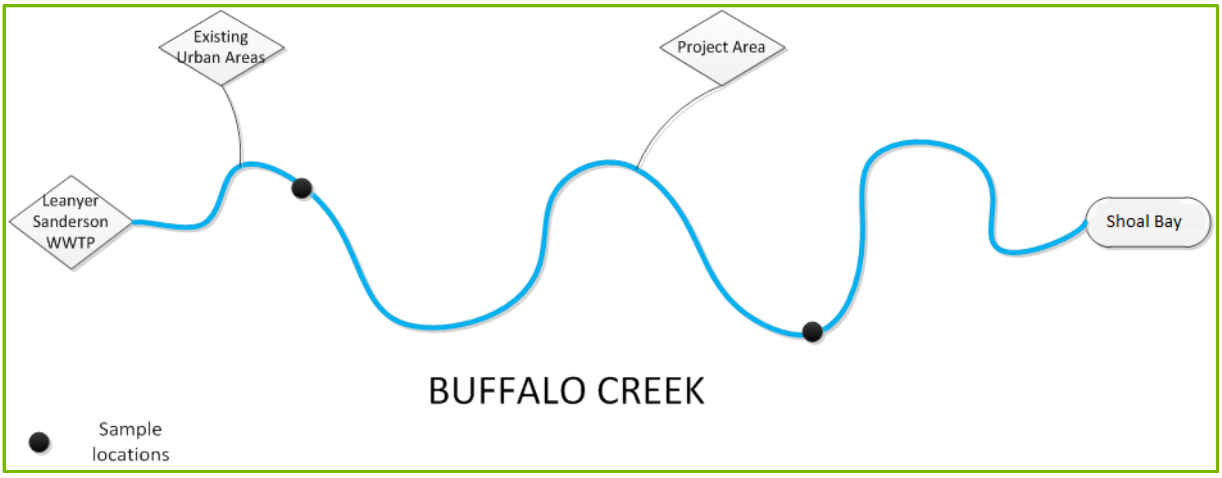


Figure 4-2 | Simplified view of Buffalo Creek system

The model was developed to trace the flow of nutrients through Buffalo Creek. The following nutrients were selected to be traced based on the impact to the aquatic ecosystem:

- Total nitrogen
  - Total nitrogen is the sum of total kjeldahl nitrogen (organic and reduced nitrogen), ammonia and nitrate – nitrite. It is an essential nutrient for plant and animals. Excess quantities of

nitrogen can lead to leaching into ground and surface waters, altered plant morphology and stimulation of aquatic plant and algal growth in surface water (ANZECC, 2000).

- Total phosphorous
  - The total phosphorous content includes all phosphorus that is bound to suspended particles as well as the phosphorous that is dissolved in the water. It is a major nutrient for plant growth. Environmentally significant concentrations of phosphorous (i.e. concentrations which could cause algal blooms in water bodies) may be transported in dissolved or particulate forms. The availability of phosphorus to be taken up by algae varies depending on the form of the phosphorous in solution (ANZECC, 2000)

A number of the model variables have been defined in terms of a mean and standard deviation. This has been done to simulate the natural variability of the system. These variables are referred to as stochastic variables and are calculated (or resampled) by the model at defined intervals during the simulation. Stochastic variables include:

- Monthly LSSTP discharge rates
- Nutrient levels in both LSSTP discharge and urban runoff
- Nutrient levels in tidal inflows

There are several model inputs which can be changed to model changes to the urban area. The values used for these inputs is outlined Section 4.6.7.

The components of model are described in more detail in the following sections. The description includes the variables used, how they are calculated and the possible ranges for inputs.

The model was developed to run using a 15 minute time step from 1/01/2000 to 31/12/2009. The model was run for 10 realisations. This allowed for a better representation of the model results.

4.6.3 Leanyer Sanderson Sewage Treatment Plant

The Leanyer Sanderson Sewage Treatment Plant (LSSTP) is located wholly within the Buffalo Creek Catchment. The plant currently treats approximately 46,000 EP with an overall capacity of 68,000 EP. The entire Muirhead Development can be accommodated with the current spare capacity of 22,000 EP.

The treatment process at the Leanyer Sanderson sewerage plant is a secondary treatment process via Waste Stabilisation Ponds (WSP) utilising aerobic and anaerobic bacteria for purification and algae for oxygen production. The ponds treat most of the sewage from the northern suburbs of Darwin. Two sets of five ponds each operate in parallel.

Most of the secondary treated water is then discharged directly into Buffalo Creek (some of the treated water is pumped to Northlakes Water Reclamation Plant where it is treated to tertiary level before being used to irrigate the Darwin Golf Course and the Marrara sporting ovals (PowerWater, 2004)).

Discharge data supplied from PWC for the LSSTP was analysed to determine the mean and standard deviation for the flow rate and discharge quality for use in the model. This is shown in Table 4.1. The data was for monthly outflows between 2000 and 2011. There were some gaps in the supplied data for the above parameters but there was sufficient information (greater than 50 records) for a statistical analysis

Table 4.1 | Typical outfall quality from the LSSTP-

Parameter	Discharge Quality	
	Mean	Standard Deviation
Total Nitrogen (mg/L)	17	6
Total Phosphorous(mg/L)	5.3	3
Discharge Volume (ML/mon)	370	260

Monthly discharge is shown in Figure 4-3. A line of best fit has been plotted showing that the monthly discharge has been gradually increasing over the measurement period. Peak discharge is also correlated to the summer months, when Darwin receives the majority of its rainfall. This correlation between rainfall and discharge from the LSSTP has not been included in the model.

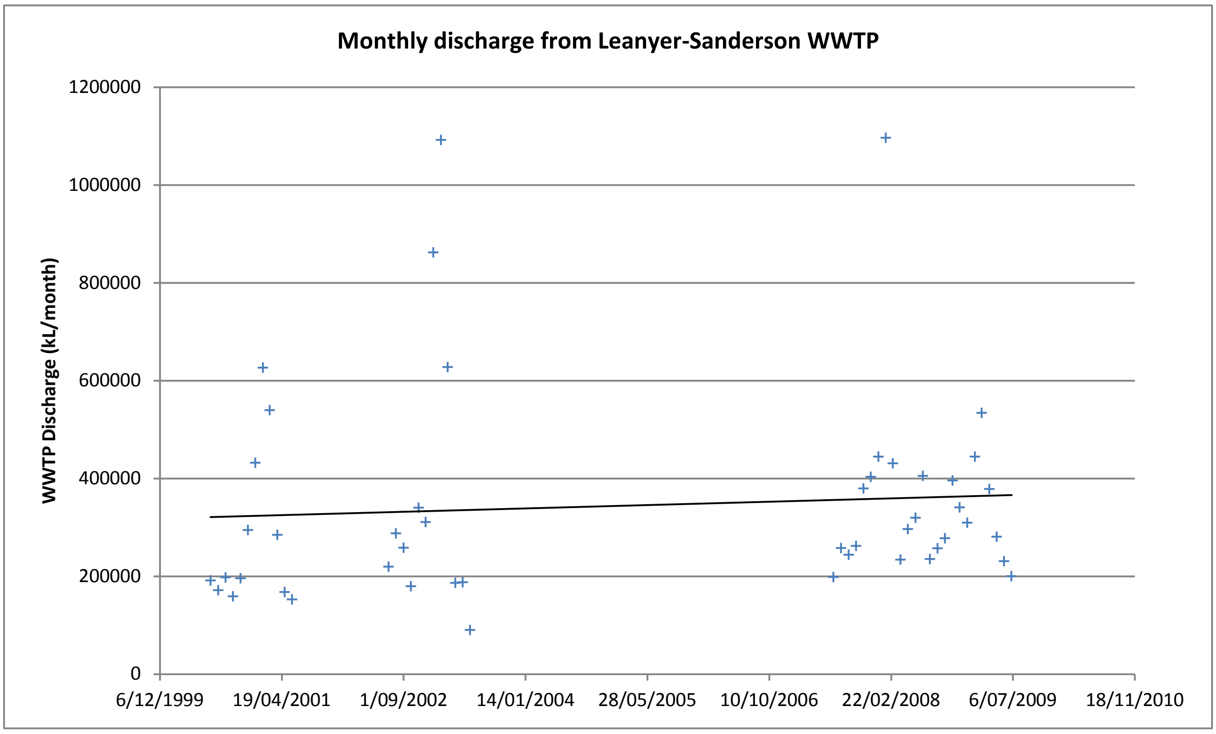


Figure 4-3 | Monthly Discharge to Buffalo Creek from LSSTP showing line of best fit

Power and Water are investigating a number of options to improve the quality of effluent being released from the Leanyer-Sanderson LSSTP.

While short term options have been identified and implemented to assist performance optimisation, longer term options are also being investigated, including:

- Increasing treatment to tertiary standards
- Using an aerated rock filter to reduce nutrients and algal blooms
- Constructing an ocean outfall to eliminate discharge into Buffalo Creek

- Increasing wastewater recycling in the northern suburbs reducing the volume of treated effluent discharged

The National Water Quality Management Strategy (1997) produced Table 4.2 to outline the typical effluent quality following some of the various levels of treatment available.

Table 4.2 | Typical effluent quality for various levels of treatment

Treatment	BOD mg/L	Total Suspended Solids mg/L	Total Nitrogen mg/L	Total Phosphorous mg/l	Oil and Grease mg/L	Examples of Treatment Process
Raw Wastewater	150-500	150-450	35-60	6-16	50-100	
Pre Treatment	140-350	140-350				Screening
Primary Treatment	120-250	80-200	30-55	6-14	30-70	Primary Sedimentation
Secondary Treatment	20-30	25-40	20-50	6-12		Biological treatment, chemically assisted treatment, lagoons
Nutrient Removal	5-20	5-20	10-20	<2	<5	Biological, chemical precipitation
Disinfection						Lagooning, ultraviolet, chlorination
Advance wastewater treatment	2-5	2-5	<10	<1	<5	Sand filtration, microfiltration

The dashboard which controls the LSSTP variables is shown in Figure 4-4 and Figure 4-5. A screen capture of the LSSTP container in the model is in Appendix G

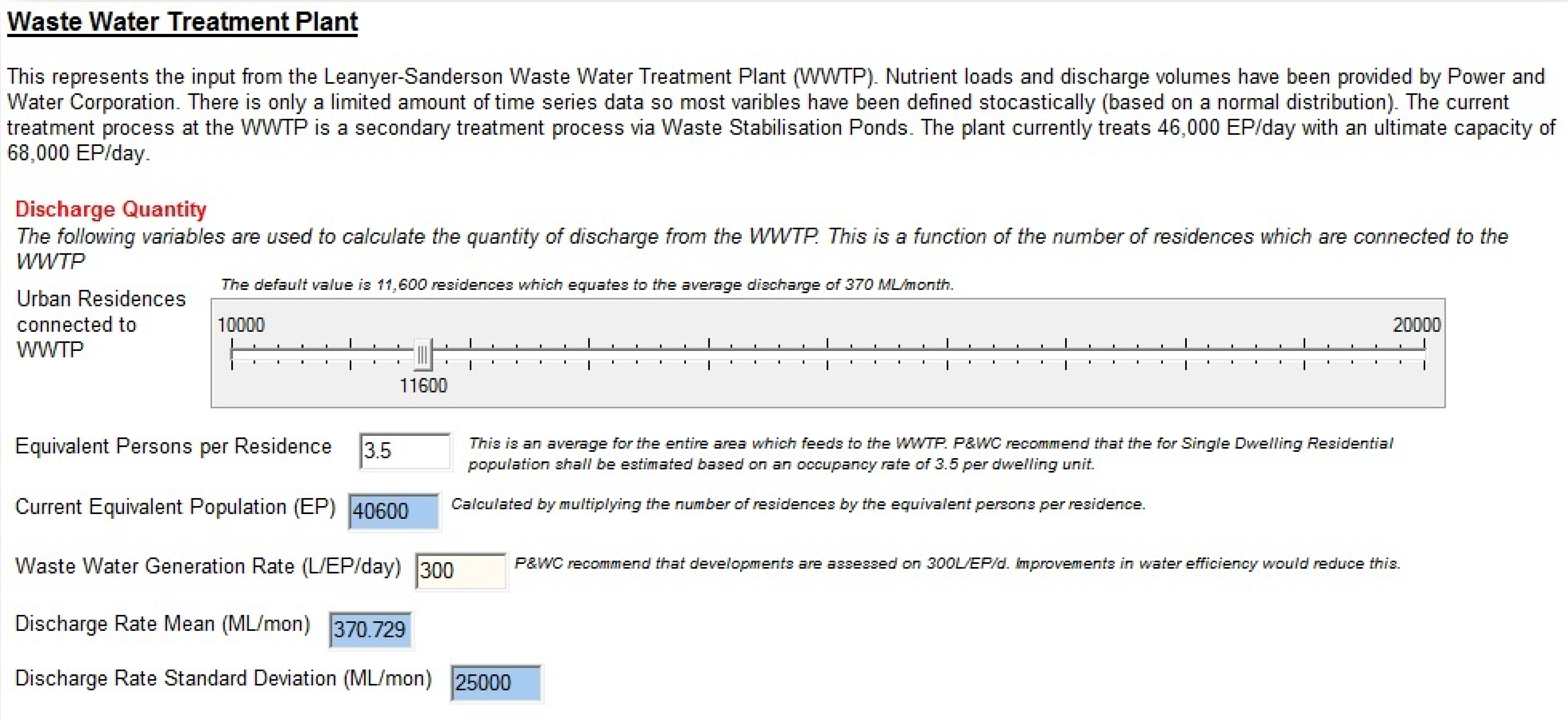
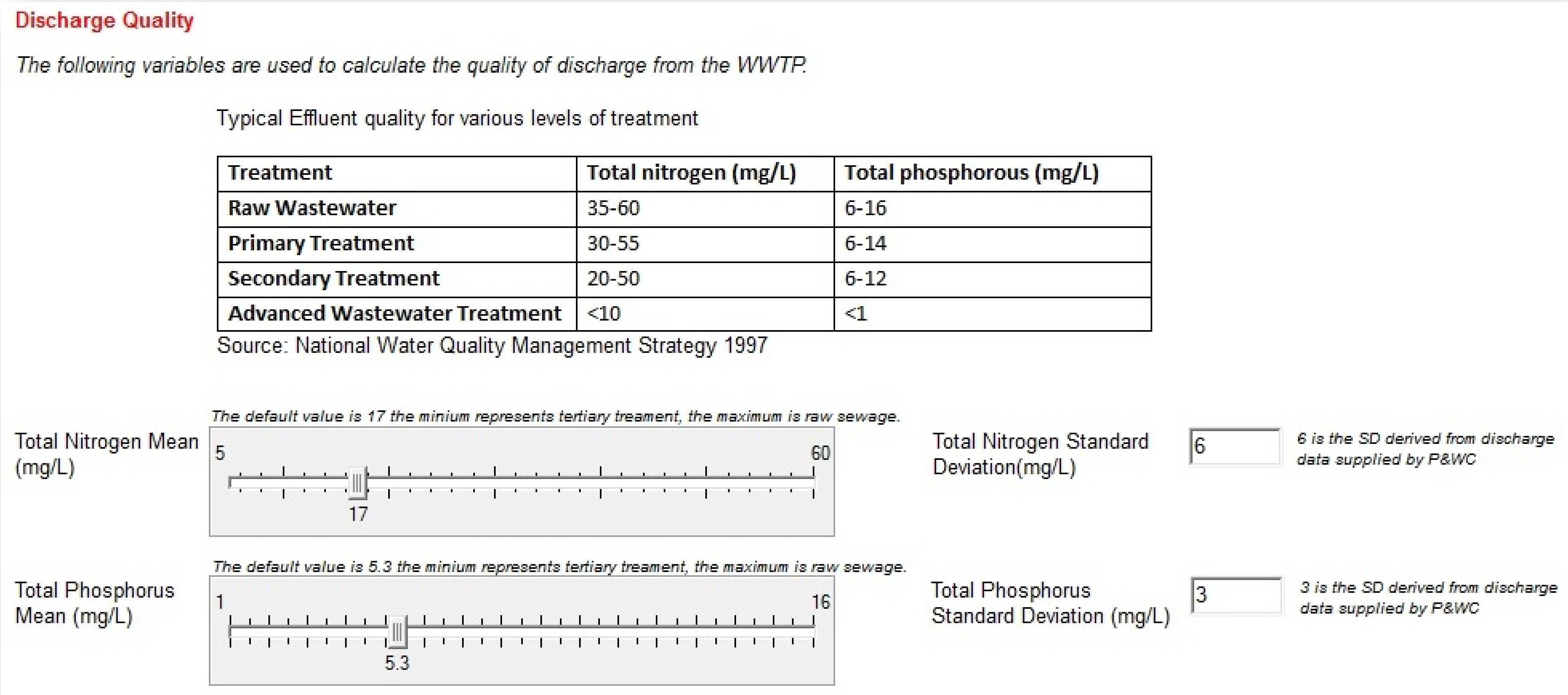


Figure 4-4 | LSSTP dashboard in model – Part 1



Discharge Quality

The following variables are used to calculate the quality of discharge from the WWTP.

Typical Effluent quality for various levels of treatment

Treatment	Total nitrogen (mg/L)	Total phosphorous (mg/L)
Raw Wastewater	35-60	6-16
Primary Treatment	30-55	6-14
Secondary Treatment	20-50	6-12
Advanced Wastewater Treatment	<10	<1

Source: National Water Quality Management Strategy 1997

Figure 4-5 | LSSTP dashboard in model – Part 2

4.6.4 Existing Urban Area

A 980 ha existing urban catchment is located to the south west of Buffalo Creek. This catchment is predominantly residential development and includes two large urban stormwater network drainage outlets that flow directly into Buffalo Creek. There are currently no water quality improvement devices or other infrastructure associated with the urban stormwater networks (Jones, 2012)

Runoff volumes and water quality data from the existing urban area are not recorded and therefore typical values (NT DPI 2009) were used to model the impact of urban areas on Buffalo Creek. The majority of stormwater runoff in urban catchments is generated from the impervious surfaces (eWater 2009). Analysis by Duncan (1999) found event mean concentrations of TSS, TP and TN to be approximately log-normally distributed for a range of different urban land-use.

The pollutant levels used to define urban runoff are outlined in Table 4.3.

Table 4.3 | Nutrient load of Urban Runoff (NT DPI, 2009)

Parameter	Unit	Mean	Standard Deviation
Total Nitrogen	mg/L	1.52	1.209
Total Phosphorous	mg/L	0.676	1.284

The mean rainfall for Darwin is 1733.7 mm[1] and assuming that 75 % of rainfall from the urban area within the Buffalo Creek catchment ends up as runoff in Buffalo Creek, this equates to approximately 12,743 ML/a.

The dashboard which controls the urban catchment variables is shown in Figure 4-6. A screen capture of the urban catchment container in the model is in Appendix G.

The runoff co-efficient was investigated during the calibration of the model but changes to it had little impact on the calibration results therefore it has been assumed to be 0.75

[1] http://www.bom.gov.au/climate/averages/tables/cw_014015.shtml

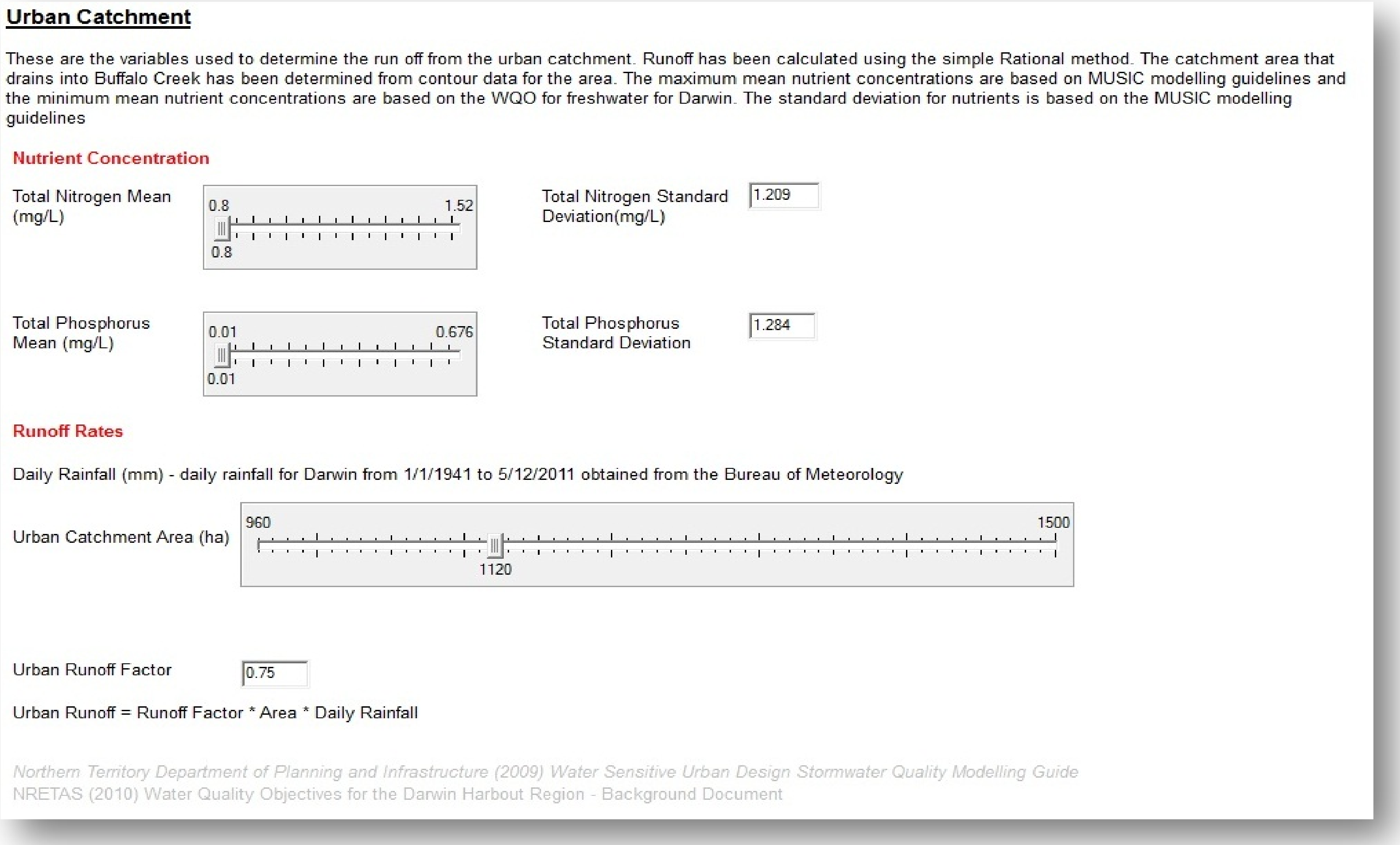


Figure 4-6 | Urban catchment dashboard in model

4.6.5 Buffalo Creek

Buffalo Creek consists of a long, narrow channel with meandering becoming more pronounced moving downstream (Smith2009). Upstream the creek is fresh water, but becomes increasingly estuarine towards its confluence with Shoal Bay. The majority of the creek channel has straight-sided banks with the exception of intertidal mudflats on the meander bends and parts of the main channel (Smith, 2009)

The confluence of Buffalo Creek with Shoal Bay is heavily distorted by a large intertidal sand bar (the effect of this sandbar is to dampen tidal movement).

In its mid to lower reaches, Buffalo Creek is fringed by closed to open mangrove forest consisting of *Rhizophora stylosa*, *Bruguiera exaristata* and *Camptostemon schultzii*. This part of Buffalo Creek is dominated by salt flats and fringing closed grassland / sedgeland.

In its upper reaches, Buffalo Creek splits into two tributaries, both of which are fed by stormwater drains connected to urban drainage systems that currently have no associated water quality improvement infrastructure (Jones, 2012). This part of Buffalo Creek is dominated by salt flats and fringing closed grassland/sedgeland.

Tides are semi-diurnal, with a 7.65 m mean highest water level and 0.47 m mean lowest low water level with a 4.22 m mean sea level (MSL). Poor tidal flushing has been attributed to the elevated concentrations of chlorophyll in Buffalo Creek estuary. Burford et al (2009) found that the sediments in Buffalo Creek contain a large concentration of dissolved nutrients.

The dashboard which controls the Buffalo Creek variables is shown in Figure 4-8. A screen capture of the Buffalo Creek container in the model is in Appendix G.

The creek was divided into five reaches, which are assumed to be of the same dimensions. In the model each of these reaches is simulated as a cell in which the concentration of nutrient is uniform.

The LSSTP and urban catchment both flow into Reach 1. The model simulates inflows from the tide such that each reach can flow either upstream or downstream depending on the depth of water in the reach. A 15 minute time step has been used to simulate the lag in movement of water between each reach which would be the result of drag.

The assumed dimensions of creek reaches were calibrated against nutrient sampling data for the points indicated in Figure 4-7.

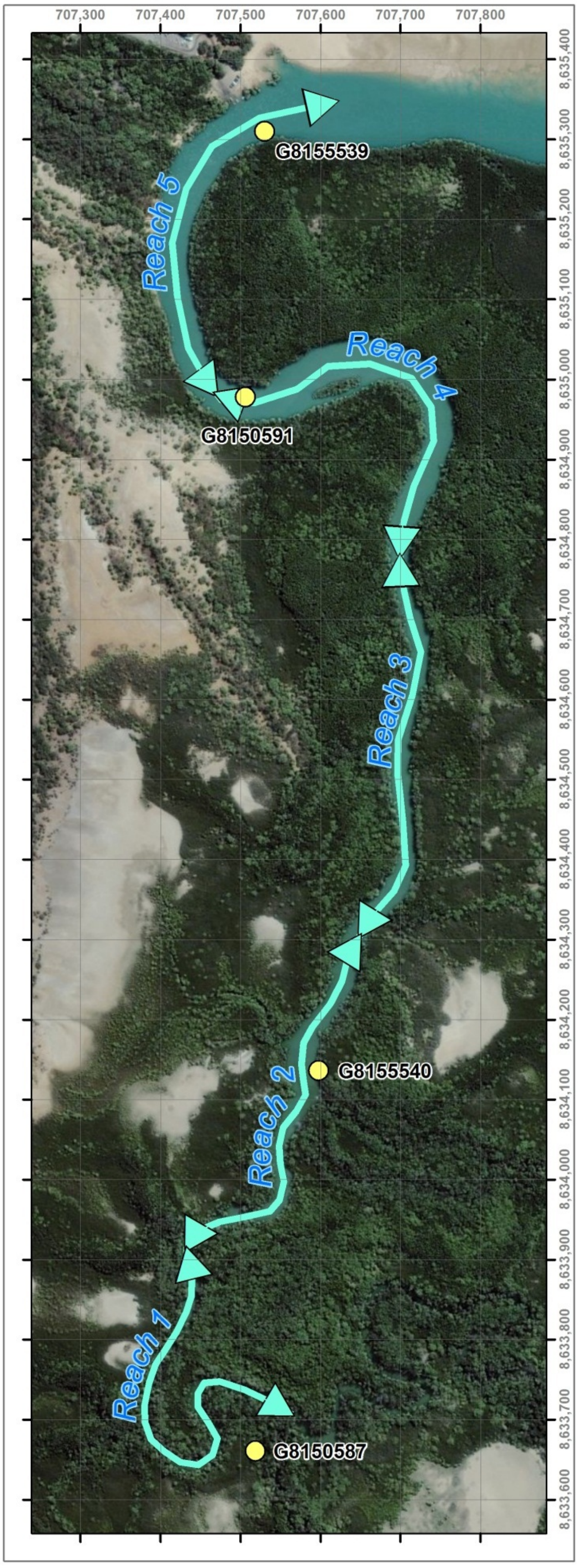


Figure 4-7 | Buffalo Creek reaches and monitoring points.

Buffalo Creek

The following are the variables for Buffalo Creek. The model currently assumes that the creek is a series of uniform boxes as shown in the figure. If accurate topographic data was collected the actual dimensions of each reach could be defined, however the flow formulas would also need to be adjusted.

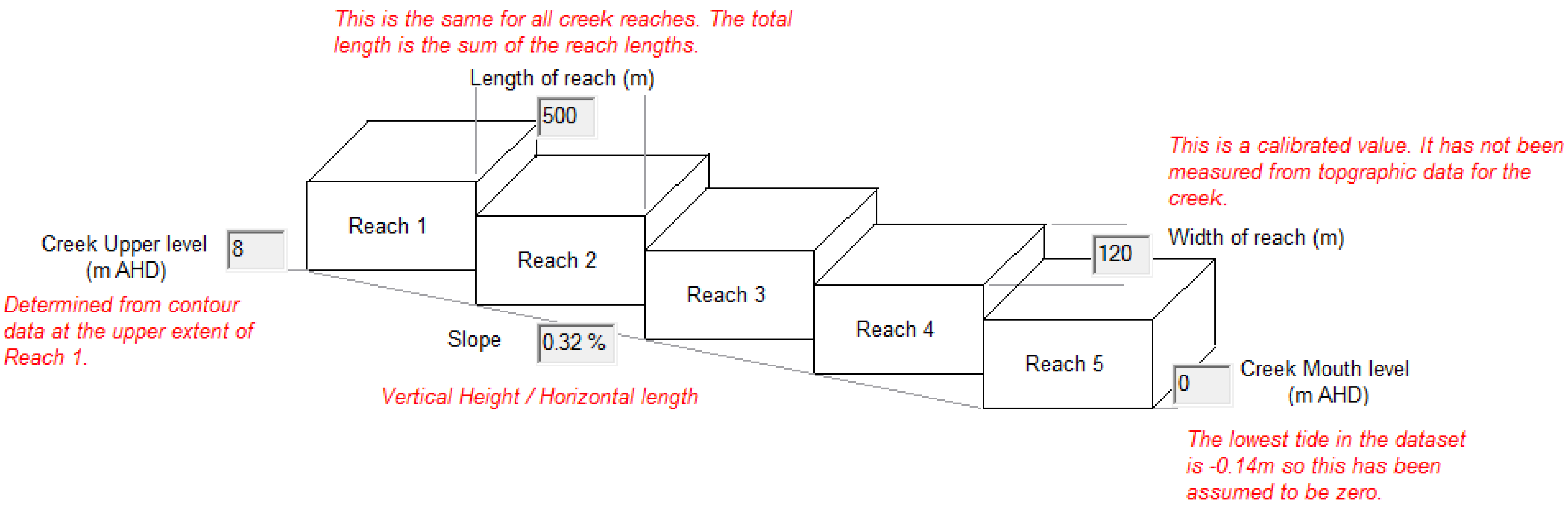


Figure 4-8 | Buffalo Creek dashboard

4.6.6 Darwin Harbour

Buffalo Creek discharges into Darwin Harbour (Shoal Bay).In the model Darwin Harbour acts as a sink, 'collecting' nutrients being discharged from Buffalo Creek. The concentration of nutrients in Darwin Harbour is assumed to be independent of the outflows from Buffalo Creek and has been defined using the values in Table 4.4.

The tide times for Darwin Harbour for the modelled period have been obtained from the Bureau of Meteorology.

The container for Darwin Harbour is shown in Appendix G.

Table 4.4 | Darwin Harbour Variables

Variable	Total Nitrogen	Total Phosphorus
Distribution	Beta (generalized)	Beta (generalized)
Mean	0.22 mg/L	0.02 mg/L
Standard Deviation	0.01 mg/L	0.001 mg/L
Minimum	0.14 mg/L	0.01 mg/L
Maximum	0.35 mg/L	0.05 mg/L

4.6.7 Muirhead Development

Defence Housing Australia (DHA) is proposing to develop a 1,350 dwelling residential subdivision (the Muirhead Development) on a 167.6 ha land parcel in the northern suburbs of Darwin (the Project Area). The Muirhead Development will involve the construction of approximately 20km of roads, 18.8 km of piped drainage and three (3) stormwater attenuation basins (SMEC Urban Consulting Group, 2009).

The majority of the Muirhead Development is within the Buffalo Creek catchment. Two of the three sub-catchments (148.6 ha) will drain towards Buffalo Creek while the third sub catchment (19.0 ha) will drain towards the Lyons Development drainage channel.

To reduce the impact of urban runoff on Buffalo Creek as a consequence of the Muirhead Development, SMEC Urban Consulting Group developed a Stormwater Management Plan (SMP) that proposes stormwater management measures to be implemented within the Muirhead Development (Appendix I). This SMP recommended that the following measures be included in the Project Area:

- Structural measures
  - Rainwater harvesting
  - Gross Pollutant Traps
  - Surface protection/lining as appropriate to prevent erosion
  - Treed and grassed drainage reserves for additional sediment and nutrient capture
  - Retention and infiltration of first flush runoff
- Non-structural measures proposed include:
  - Rehabilitation and maintenance of disturbed areas until sustainable ground cover is established
  - Public education programmes relating to the use of fertilizers and the disposal of pet wastes, litter etc
  - Regular street sweeping programmes

If there were no in-system control measures put in place, post development loads and concentrations of sediment, nutrients and the gross pollutants would increase significantly. However by implementing an appropriate suite of water quality management measures, pollutant levels can be retained at target levels (SMEC Urban Consulting Group, 2009)

The sewage load from the Muirhead Development will be treated in the LSSTP.

4.6.8 Scenarios

4.6.8.1 General

Four scenarios were modelled to investigate the impact of the Muirhead Development on the nutrient loads into Buffalo Creek. The model inputs are shown in the following section with a short description of the scenario modelled.

4.6.8.2 Business as Usual (BAU)

This scenario is the current situation for the catchment (Table 4.5). This represents the baseline against which the impact of the project will be compared.

Table 4.5 | Scenario 1 – BAU inputs

Input	Value
Urban Catchment	
Total Nitrogen Mean (mg/L)	1.52
Total Nitrogen Standard Deviation (mg/L)	1.209
Total Phosphorus Mean (mg/L)	0.676
Total Phosphorus Standard Deviation (mg/L)	1.284
Urban Catchment Area (ha)	960
Urban Runoff Factor	0.75
LSSTP	
Urban Residences	11600
Equivalent Persons per residence	3.5
Waste Water Generation Rate (L/EP/day)	300
Total Nitrogen Mean (mg/L)	17
Total Nitrogen Standard Deviation (mg/L)	6
Total Phosphorus Mean (mg/L)	5.3
Total Phosphorus Standard Deviation (mg/L)	3

4.6.8.3 Development with current nutrient generation

This scenario includes the impact of the Muirhead development but assumes that the concentration of nutrient in stormwater and from the LSSTP will be the same as is currently generated (Table 4.6).

Table 4.6 | Scenario 2 – Development with current nutrient generation inputs

Input	Value
Urban Catchment	
Total Nitrogen Mean (mg/L)	1.52
Total Nitrogen Standard Deviation (mg/L)	1.209
Total Phosphorus Mean (mg/L)	0.676
Total Phosphorus Standard Deviation (mg/L)	1.284
Urban Catchment Area (ha)	1120
Urban Runoff Factor	0.75
LSSTP	
Urban Residences	12960
Equivalent Persons per residence	3.5
Waste Water Generation Rate (L/EP/day)	300
Total Nitrogen Mean (mg/L)	17
Total Nitrogen Standard Deviation (mg/L)	6
Total Phosphorus Mean (mg/L)	5.3
Total Phosphorus Standard Deviation (mg/L)	3

4.6.8.4 Development with reduced stormwater concentration

This scenario includes the impact of the Muirhead development but assumes that the concentration of nutrient in stormwater has been reduced such that the mean concentrations are consistent with the water quality objectives for freshwater (NRETAS, 2010). This would be the case if stormwater quality improvement devices were retrofitted to the existing stormwater catchments and were installed in the new development (Table 4.7).

Table 4.7 | Scenario 3 – Development with reduced stormwater concentrations

Input	Value
Urban Catchment	
Total Nitrogen Mean (mg/L)	**0.8**
Total Nitrogen Standard Deviation (mg/L)	1.209
Total Phosphorus Mean (mg/L)	**0.01**
Total Phosphorus Standard Deviation (mg/L)	1.284
Urban Catchment Area (ha)	1120
Urban Runoff Factor	0.75
LSSTP	
Urban Residences	12960
Equivalent Persons per residence	3.5
Waste Water Generation Rate (L/EP/day)	300
Total Nitrogen Mean (mg/L)	17

Input	Value
Total Nitrogen Standard Deviation (mg/L)	6
Total Phosphorus Mean (mg/L)	5.3
Total Phosphorus Standard Deviation (mg/L)	3

4.6.8.5 Development with reduced stormwater concentrations and tertiary treatment at the LSSTP

This scenario includes the impact of the Muirhead development but assumes that the concentration of nutrient in stormwater has been reduced such that the mean concentrations are consistent with the water quality objectives for freshwater (NRETAS, 2010). It also assumes that the LSSTP has been upgraded to include tertiary treatment (Table 4.8).

Table 4.8 | Scenario 4 – Development with reduced stormwater concentrations and tertiary treatment at the LSSTP.

Input	Value
Urban Catchment	
Total Nitrogen Mean (mg/L)	0.8
Total Nitrogen Standard Deviation (mg/L)	1.209
Total Phosphorus Mean (mg/L)	0.01
Total Phosphorus Standard Deviation (mg/L)	1.284
Urban Catchment Area (ha)	1120
Urban Runoff Factor	0.75
LSSTP	
Urban Residences	12960
Equivalent Persons per residence	3.5
Waste Water Generation Rate (L/EP/day)	300
Total Nitrogen Mean (mg/L)	**10**
Total Nitrogen Standard Deviation (mg/L)	6
Total Phosphorus Mean (mg/L)	**2.5**
Total Phosphorus Standard Deviation (mg/L)	3

4.7 Results

The primary output from the model is the annual nutrient loads for each of the inflows (the LSSTP, urban runoff and tidal inflows) and the outflow from the lowest reach (BF5). Tables of these results for each scenario have been included in Appendix H.

The results of the model confirm that mixing or dilution is the primary mechanism occurring in Buffalo Creek. This result is consistent with studies that show that the sediment is saturated with nutrients. The system has no capacity to treat any of the inflows and therefore all inflows loads will end up in Darwin Harbour.

The scenarios modelled were:

1. Business As Usual
2. Development with current nutrient generation
3. Development with reduced stormwater concentrations
4. Development with reduced stormwater concentrations and tertiary treatment of wastewater

The maximum, minimum and average annual load for Total Nitrogen and Total Phosphorus are shown in Figure 4-9 and Figure 4-10 (respectively). These graphs demonstrate that the range in the annual loads is quite variable and that the difference between the first three modelled scenarios is not statistically significant. The variation in the annual loads is largely due to the variability in the stormwater and LSSTP discharges into the creek.

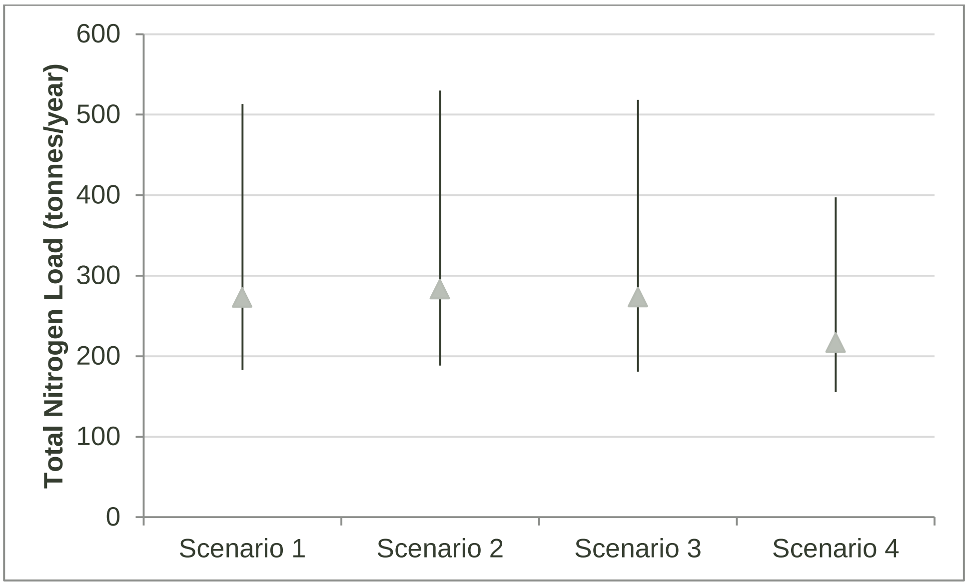


Figure 4-9 | Comparison of annual load of total nitrogen for scenarios modelled

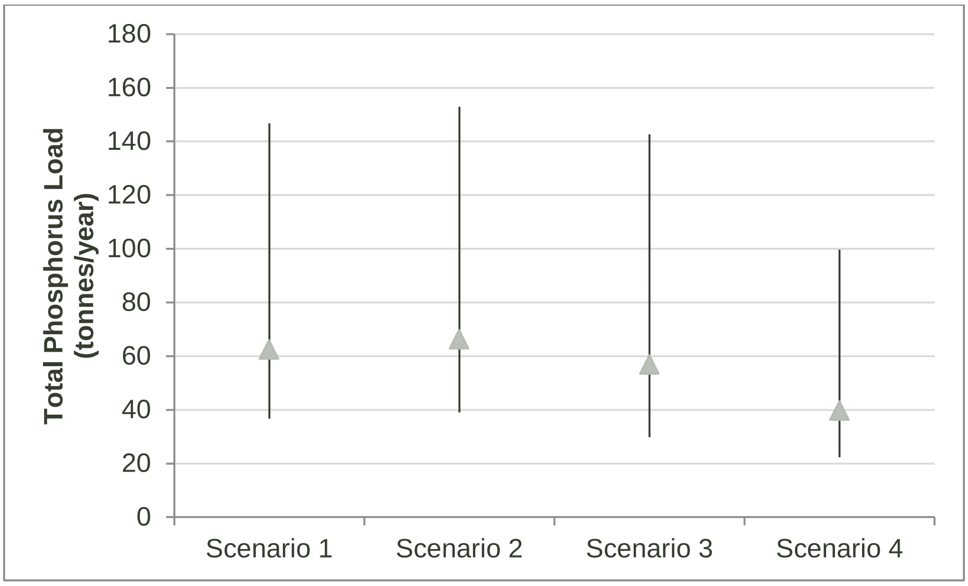


Figure 4-10 | Comparison of annual load of Total Phosphorus for scenarios modelled

In Figure 4-11 the mean annual loads for each scenario are compared. This demonstrates that if the impact of the development on stormwater and the LSSTP were not mitigated then there is the potential for annual loads into Buffalo Creek to increase. The most effective way to reduce the annual loads into Buffalo Creek is to improve the quality and quantity of water discharged from the LSSTP. This would require an upgrade to the LSSTP and sewage transport system along with a community awareness campaign to reduce stormwater inflows to the sewage system.

If the LSSTP were upgrade to include tertiary treatment then the increase in load from the Muirhead Development would be mitigated and the water would potentially be available for re-use.

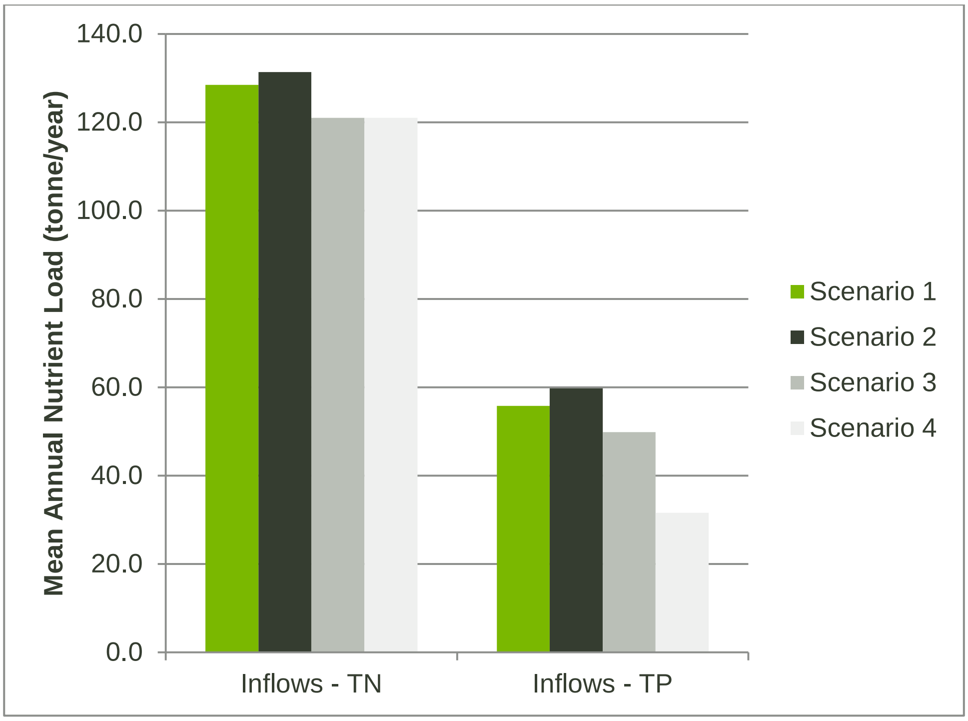


Figure 4-11 | Comparison of nutrient loads for inflows (LSSTP and urban runoff) for scenarios modelled

4.8 Recommendations

The recommendations in this report are based on the data availability for the development of the model and the outcomes of the modelling exercise.

The following are recommendation to improve the accuracy of the model:

- Undertake flow measurement within Buffalo Creek to enable a full understanding of tidal influence on the creek
- Increase water quality sampling of Buffalo Creek (including event water quality sampling) to determine the influence of seasonal changes on water quality
- Undertake sampling of sediments along Buffalo Creek to identify and quantify pollutant levels in the sediments
- Install an automatic sampler within the urban drainage channel to enable measurement of nutrient loads being discharged to Buffalo Creek from the urban catchment during rainfall events. This will also assist in targeting nutrient load reduction within the same area.

The following are recommendations to reduce the impact of the Muirhead Development

- Install Water Sensitive Urban Design (WSUD) infrastructure within the Muirhead Development area to minimise runoff and increase water quality
- Increase level of treatment of LSSTP discharge to reduce overall nutrient loads being discharged

Further development of the model should be undertaken as more data becomes available. This will also enable the complexity of the model to increase, enabling a better representation of real life processes.

4.9 Conclusions

Within the limitations of the data available, modelling shows that the Muirhead Development will not lead to further degradation of Buffalo Creek's water quality, providing the LSSTP is upgraded to include tertiary treatment and that the strategies identified in the Stormwater Management Plan (Appendix K) are implemented.

5 Strategic Plan for Buffalo Creek

5.1 Purpose

The purpose of this chapter is to identify potential actions that could be undertaken to protect the quality of water flowing through Buffalo Creek within the context of the objectives set out in Section 1.3 of this report and Condition 1 of the Decision (Appendix B). Specifically, this means determining a meaningful and practical set of actions that a can be used to demonstrate that *no further impact* on the water quality of Buffalo Creek occurs as a consequence of the Muirhead Subdivision.

5.2 Approach

The development of a WQIP can be broken down into the following strategic steps:

- Define and describe the catchment, including the identification of potential pollution sources (Section 1.5 and 2.3 of this report)
- Establishment of Beneficial Uses of the subject waterway (Section 3)
- Establish water quality objectives (Section 5.3)
- Develop strategic actions for improving water quality (Section 5.4)
- Establish a monitoring Strategy (Section ❑)
- Identify mechanisms and accountabilities for the ongoing implementation of the WQIP (Section 6).

Defining the catchment and identifying its major sources of pollution was the first step towards developing an effective strategy to protect Buffalo Creek from further degradation. This included examination of aerial photography, research of published materials, and conversations with representatives from the LSSTP, NRETAS Aquatic Health Unit, Darwin City Council (DCC) and the Crown Land Administration (CLA). This enabled likely sources of pollution to be identified and prioritised (Section 2.3). An evaluation of Buffalo Creek's Environmental Values was also undertaken to assist in this process (Section 3).

In order to provide a mechanism for benchmarking water quality moving forward, it is necessary to have a baseline to compare against in order to establish water quality performance over time. For this WQIP, the 2010 Report Card for Buffalo Creek (NRETAS, 2010) was used to establish a set of Water Quality Objectives for Buffalo Creek (Section 5.3). This determination was made on the basis that the source of information is trusted (i.e. report cards are produced by NRETAS Aquatic Health Unit). Further, it also consistent with the overarching strategy of this WQIP, i.e., strategic alignment with the aquatic ecology initiatives of the Darwin Harbour Strategy (DHAC, 2010) and the Terms of Reference of the DHAC.

The term "strategic actions" refers to the determination of specific actions for protecting Buffalo Creek water quality that are prioritised to maximise benefit. In the case of this WQIP, the objective is to improve water quality at Buffalo Creek. Hence, actions were chosen based on their relative impact on water quality and their likelihood of being undertaken. Consequently, actions for the LSSTP are given highest priority as LSSTP is likely to be the major contributor to pollution in Buffalo Creek (particularly nutrients), hence any improvements achieved at the LSSTP are likely to provide a high return on water quality (and therefore, a high return on investment).

Monitoring is an extremely important source of performance feedback. The strategy employed for this WQIP extends beyond monitoring water quality to the inclusion of mechanisms to monitor the progress of actions identified in this plan (Section 5.5). By monitoring both water quality and the progress of various actions identified in this report, it is possible to infer the degree to which a given action has on the quality of water flowing through Buffalo Creek, which in turn can be used to inform future actions. If, for example, upgrading a given operation at the LSSTP provides significant improvements in outfall water quality, but overall water quality indicates further need for improvement, this would signal a need to shift focus from the LSSTP to other potential sources (e.g. urban runoff, landfill leachate and / or sediment sinks).

Plans can fail for one or more reasons including available resources, logistics, lack of practical solutions, lack of accountability and confusion of roles. Chapter 6 addresses these issues by:

- identifying a specific organisation best equipped to steward the plan;
- identifying a forum for stakeholders to discuss ideas and track progress;
- identifying specific organisations or agencies (“Actors”) against specific actions; and
- identifying governance arrangements and mechanisms for overseeing the plan as a whole.

5.3 Water Quality Objectives

Phase 1 of the WQPP for Darwin Harbour was completed in 2009. This included the development of water quality objectives (Aquatic Health Unit, 2010) based on Beneficial Use Declarations (similar process to that described in Section 3) for a number of waterways within the Darwin Harbour watershed, including Buffalo Creek. Phase 2 of this initiative is currently underway (January 2011 - June 2013) with the aim of finalising the WQPP for Darwin Harbour. An important outcome of this initiative was the development and implementation of the Darwin Harbour Region Report Cards. These Report Cards provide a snap shot of Darwin Harbour’s stream, estuarine and beaches (NRETAS, 2010; NRETAS, 2010). This includes the development and implementation of a Report Card for Buffalo Creek, the latest results for which are provided in Section 2.2.

As covered in Section 1.2, the purpose of this WQIP is to ensure *no further impact* on the water quality of Buffalo Creek occurs as a consequence of the Muirhead Subdivision. In order to be able to establish that this purpose is being met, a reliable set of Water Quality Objectives are needed to establish a baseline that reflects the current condition of Buffalo Creek that can also be readily compared to monitoring undertaken in the future. The Buffalo Creek Report Card (NRETAS, 2010) already identifies water quality objectives for Buffalo Creek. The Report Card initiative currently being undertaken as part of the WQPP provides an excellent bases for establishing both a set of Water Quality Objectives and a means of providing highly comparable data into the future. Reasons for this are:

1. The data comes from a reliable source
2. The program is already underway and was established independent of this WQIP
3. The Report Card program is part of the separate and ongoing WQPP initiative that is administered and monitored by the NT Government (i.e., the program is likely to continue into future).

Hence, this WQIP has adopted the Buffalo Creek Report Card process to inform its specific water quality objectives (Table 5.1) and as a means of tracking the overall performance of this WQIP and its actions moving forward.

The Buffalo Creek Water Quality Objectives discussed in Section 2.2 and provided in Table 5.1 are based on the most recent results available Report Card data (Table 2.1). Note that Table 5.1 includes an "upper maximum" not provided in the Report Card to account for variation for some indicators where appropriate (e.g. conductivity). These upper maximums have been set by adding 10% to the stated water quality objective (insufficient data was available to reliably determine ranges based on statistical methods). The value stated the "upper maximum" column applies providing that ongoing monitoring does not demonstrate an ongoing upward trend. That is, should reported values continue to fall between the stated Water Quality Objective and its upper maximum for three consecutive years then consideration should be given to the possibility that a further decline in water quality is likely to have occurred (as opposed to natural variation).

Table 5.1 | Water Quality Objectives for Buffalo Creek.

In order for the purpose and objectives of the Buffalo Creek WQIP to meet, all future report cards water quality results should met the water quality objectives presented in this table (adjustments to water quality objectives by NRETAS notwithstanding).

Indicator	Water Quality Objective	Upper Maximum	Further requirements / clarifications
Electrical Conductivity (µS/cm)	49800	54780	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
Turbidity (NTU)	17	18.7	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
pH	6 – 8.5	None.	Range must be met.
Dissolved oxygen (%)	35-100	None	Range must be met
Total Suspended Solids (mg/L)	≤28	<30.8	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
Chlorophyll a (µg/L)	≤29	<31.9	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If electrical conductivity results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
NOx (µg N/L)	≤76	<83.6	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
Ammonia (µg N/L)	≤533	<586	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
Total nitrogen (µg N/L)	≤1510	<1661	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by more than three consecutive Report Cards exceed the water quality objective but

Indicator	Water Quality Objective	Upper Maximum	Further requirements / clarifications
			remain below the upper maximum.
Total phosphorus (µg N/L)	≤375	<413	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by <u>more than</u> three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.
Filterable reactive phosphorus (µg P/L)	≤318	<350	An exceedance is considered to have occurred if: • The upper maximum is exceeded • If results reported by <u>more than</u> three consecutive Report Cards exceed the water quality objective but remain below the upper maximum.

5.4 Specific Actions for Improving Water Quality in Buffalo Creek

As discussed in Section 2.3, a number of potential pollution sources have been identified for Buffalo Creek. The three thought to be most important are as follows:

- LSSTP
- Existing urban development
- Construction Works

The three pollutant sources listed above are not the only potential sources of pollution within the Buffalo Creek catchment; however they are likely to be poses the biggest threat to water quality. Hence, any gains made in these three areas will likely see a significant return on effort with regards to the protection and improvement of water quality conditions at Buffalo Creek. This Section focuses on specific actions associated with these potential pollution sources.

5.4.1 Leanyer-Sanderson Sewage Treatment Plant

As discussed in Section 2.3.1, the LSSTP is likely to be the main source of pollution entering Buffalo Creek. In response to this situation, and the poor performance recorded in the Buffalo Creek Report Cards, the owner and operator of the LSSTP, PWC, has budgeted for major treatment upgrades for the plant within a five year period (refer to letter in Appendix I). Engineering investigations have already commenced to determine which options are preferred for implementation over this five year period, including:

- increasing treatment to tertiary standards;
- using aerated rock filters to reduce nutrient and algal blooms;
- Constructing an ocean outfall to eliminate discharge into Buffalo Creek; and
- Increasing wastewater recycling in the Northern suburbs, reducing the volume of treated effluent discharged

Note that, other than the general target of completion of selected options within the next five years, there is currently no detailed timeline or milestones established, and won't be until a preferred option(s) are established. Such information should be available around mid to late 2012 (George, 2011).

PWC has also committed to a number of short term strategies in order to reduce their impact on Buffalo Creek. These include (PWC, 2010; Drewry, et al., 2010):

- Modifying the channels to improve the hydraulics of the ponds (completed).
- Accelerating the de-sludging program, with at least one pond already completed.
- Issuing tenders for aeration equipment to be installed to the outfall channel during the 2011 - 2012 wet seasons.
- Inclusion of LSSTP's catchment in the 20 year sewer re-lining program to reduce the amount of stormwater entering the sewerage system during the wet season.

Impetus for this change is also being driven by the NT Government via the recent issuing of a new two year Waste Discharge Licence for the LSSTP. This includes a commitment from PWC to develop a long term augmentation plan (yet to be released) and improve water quality consistent with the *National Water Quality Management Strategy*.

5.4.2 Existing Urban Areas (Urban Stormwater Runoff)

While the focus of attention is currently on the LSSTP regarding the water quality issues within Buffalo Creek, the LSSTP is not the only potentially significant source of pollution. As discussed in Section 2.3.2, stormwater runoff from urban developments can present a significant source of pollution for receiving water bodies. As illustrated in Figure 2-1, a significant proportion of the southern end of the Buffalo Creek catchment has been urbanised, with at least two major stormwater drainage systems discharging directly into Buffalo Creek. Further, based on discussions with the CLA (Jones, 2012), the stormwater systems associated with these existing developments have no water quality improvement infrastructure (i.e., gross pollutant traps, constructed wetlands, biofiltration or similar infrastructure designed to improve the water quality of runoff prior to discharge). Hence, the impact of urban runoff on Buffalo Creek is likely to be significant. After the upgrades to the LSSTP become effective the focus of water quality improvement in Buffalo Creek will need to shift to urban (diffuse) stormwater runoff.

The urban stormwater networks that feed into Buffalo Creek come under the jurisdiction of the CLA and any improvements in urban stormwater quality will require the involvement and support of the CLA. The CLA currently has no specific strategies in relation to addressing the water quality issues currently facing Buffalo Creek. Further, the CLA does not appear to have a seat on the DHAC. Hence, the first step would be to approach the CLA to join the DHAC (this might be best done by the Chair of the DHAC). Once the CLA has a sitting member on the DHAC, the DHAC should work together to establish strategies and funding sources to begin addressing the status of existing urban development, as well as development controls to ensure future developments meet minimum stormwater runoff quality targets like those stipulated in the SMP for the Muirhead development (Appendix K). This might include:

- Establish WSUD principles as guiding principles for existing and future urban developments that fall with the CLA jurisdiction.
- Developing a stormwater management plan focussing on existing urban development within the Buffalo Creek catchment that:
  - Assess current status of existing stormwater infrastructure within the existing urban areas within the Buffalo Creek
  - Identifies specific actions in the areas of infrastructure, education, governance / policy, advocacy and monitoring to improve urban stormwater runoff discharging into Buffalo Creek
  - Identifies potential sources of funding
  - Identifies stakeholder relationships
  - Identifies timelines and accountabilities.
- Establish a sub-committee within the DHAC specifically for Buffalo Creek to oversee the development and implementation of the above Buffalo Creek Stormwater Management Plan.

- Incorporate the improvement of urban stormwater runoff within the Buffalo Creek catchment as a specific line item in CLA and DCC business plans and financial reporting.

5.4.3 Current and Future Construction Works

5.4.3.1 Muirhead development

Without the adoption and incorporation of appropriate stormwater management measures the Muirhead development will further adversely impact the condition of Buffalo Creek worsening an already stressed system. Initially, this threat comes from the earthmoving activities associated with land development. Removal of vegetation, excavation, stockpiling, surface profiling and disruption to natural stormwater drainage systems increases the potential for erosion and subsequent mobilisation of sediments. Potential petrochemical and other chemical spills may also be a concern for water quality. Following construction the long term water quality impacts of urban development need to be managed. With an appropriate design approach these stormwater management measures are built into the development at the concept stage and carried through to the operational stage of newly established urban areas.

In order to address the initial threat of the Muirhead development, a Construction Environmental Management Plan (CEMP) has been developed (Appendix J) which covers issues such as erosion and sediment control and stormwater management. Similarly, in order to address the longer term issues associated with a newly established urban development, a Stormwater Management Plan (SMP) has also been developed for the Muirhead development identifying Stormwater Management Infrastructure options that will minimise the long term impacts of this development on Buffalo Creek (Appendix K). This SMP includes site specific objectives and criteria for water quality and stormwater management derived from the WSUD Planning Guide (Dept. of Planning and Infrastructure, 2009) which are also consistent with the NT WSUD Planning Guide (McAuley, et al., 2009). A summary of these site specific criteria are provided in Table 5.2 below.

Table 5.2 | Muirhead development site specific Stormwater Management Plan Summary

(Extracted from the Stormwater Management Plan (SMP) for Lee Point Road, Appendix K)

Objective	Proposed Measures
Water quality – *to maintain or improve* *the surface and groundwater quality within the development areas relative to pre development conditions*	• Gross pollutant traps will be provided throughout the piped drainage network to trap litter and sediments close to source. • Public Open Space and Drainage Reserve fronting Buffalo Creek will be landscaped, including deep rooted native trees indigenous to the area, for nutrient removal. • The Public Open Space for the outflow that crosses Lee Point Road will be landscaped, including deep rooted native trees indigenous to the area, for nutrient removal.
Water quantity - *to maintain the total water cycle balance within development areas relative to pre development conditions.*	• Post development peak discharge flows will be attenuated within detention basins to approximate pre- development flows for specific design storm events.
Water conservation - *to maximise the reuse of stormwater / rainfall*	• Rain water harvesting – residents will be encouraged to capture and store rainwater to supplement mains water supply. This could also assist in mitigating the impact of the sub-division development on flow regimes, thus reducing potential stormwater runoff into receiving environments • Grey water re-use systems – residents will be encouraged to install grey water re-use systems (e.g. for toilet flushing) to decrease water supply demand. • Provision of a non-potable water reticulation network for irrigation purposes.
Ecosystem health - *to retain natural drainage*	• The proposed discharge points for stormwater coincide with the existing natural discharge locations on site.
Economic Viability – *to implement stormwater management systems that are economically viable in the long term*	• The stormwater management methods proposed for the site have reasonably low maintenance requirements.

Public Health – *to minimise public risk, including the risk of injury or loss of life to the community*	• All drainage, including basins are designed to drain completely to avoid public health and safety issues relating to standing water. • All drainage areas where detained water depths exceed 750 mm will be fenced to restrict public access.
Protection of Property – *to protect the built environment from flooding and water logging*	• Piped drainage and culvert crossings to convey runoff from minor storm events of 2 years Average Recurrence Interval (ARI) minimum. • Overland flow paths, including roads, public open spaces and drainage reserves to convey runoff from major storm events of 100 years ARI.
Social Values – *to ensure that social, aesthetic and cultural values are recognised and maintained when managing stormwater*	• The ecological value of Buffalo Creek and its foreshore area have been considered. A green buffer is proposed along the creek frontage to provide protection from potential negative effects of land development. • The attenuation basins will be designed to be visually aesthetic and to blend in with the surrounding environment.
Development – *to ensure the delivery of best practise stormwater management through planning and development of high quality developed areas in accordance with sustainability and precautionary principles.*	• The cost effective and practical stormwater management controls proposed for this development are consistent with best practice stormwater management principles.

Because a site specific CEMP and SMP have been developed for the Muirhead development, the strategy adopted in this WQIP becomes one of ensuring the actions and initiatives in each of these plans are implemented. This should include:

- Ensuring that, as a minimum, the controls identified in the CEMP and SMP comply with local and State guidelines for Subdivision and Development, and WSUD Guidelines, e.g. the DCC Subdivision and Development Guidelines (DCC, 2005a) and the WSUD Planning Guide respectively (Dept. of Planning and Infrastructure, 2009) respectively.
- Ensuring that the controls identified in the final, approved CEMP are implemented correctly and independently verified by an appropriately qualified person (preferably an appropriately qualified and authorised NRETAS Environmental Officer). This action should be proactive, i.e. site visits at environmentally sensitive stages during (e.g. site levelling) and, ideally, random checks, particularly during wet periods.
- Ensuring that DCC and NRETAS staff are informed of the construction works such that any complaints made to either agency are acted on promptly (noting that most private citizens would not be aware that the Muirhead development comes under State and Federal jurisdiction, hence the DCC is likely to receive such complaints should they eventuate).
- Any incidents and non-compliance are adequately documented and reported to the DHAC, including any initial and follow up action taken.
- Ensuring WSUD features are installed as per design (suggested reference: *Construction and Establishment Guidelines* (Water by Design, 2010)), and that the design of these features are consistent with the findings of the Stormwater Management Plan (SMP) and best practice (e.g. *Technical Design Guidelines for South East Queensland* (Water By Design, 2006)).

5.4.3.2 Future Construction Works and Urban Expansion

It is likely that there will be further development within the Buffalo Creek catchment. This will put further pressure on Buffalo Creek and its catchment, which will also have flow on effects for Shoal Bay unless such development is managed appropriately. The Muirhead development's CEMP and SMP provide an excellent example for testing and establishing effective construction management requirements and long term stormwater infrastructure guidelines that will not only provide important information for the Buffalo Creek Catchment, but for the Darwin Harbour watershed generally. Hence, the strategy for this WQIP becomes one of assessment of the success of CEMPs and SMPs for any future development within the Buffalo Creek catchment, as well as the effectiveness of various agencies and organisations to deliver positive outcomes. Specific Actions should include

- Compilation of monitoring data associated with the construction of the Muirhead development and its WSUD infrastructure (e.g. degree of compliance with CEMP, number of environmental incidents, complaints, etc.).
- Review and analysis of this data with the objective of providing a report on the implementing the CEMP and SMP, including the provision of a gap analysis and suggested improvements.
- Based on the findings and conclusion of the aforementioned report, update the WSUD Design Objectives for Darwin Harbour in Darwin (Dept. of Planning and Infrastructure, 2009), and ensure improvements are considered when assessing Development Consents for future developments within Buffalo Creek catchment and the wider Darwin Harbour watershed.
- Following effective completion of future developments (i.e. 80% or more of the housing constructed), initiate a 10 year monitoring programed designed to assess the long term success / appropriateness of the WSUD infrastructure incorporated into the Muirhead development's stormwater system. Such a program will provide important information concerning how to deliver effective WSUD infrastructure not just for Darwin Harbour, but for the northern latitudes of Australia collectively. This should include::
  - Bioretention functional species rate of die-back / disease

- Bioretention system filter media hydraulic infiltration rates
- GPT rubbish removal – frequency and amount of material removed (including costs).
- Bioretention maintenance – type, frequency and annual costs.
- Swale maintenance – type, frequency and annual costs
- Water quality performance monitoring
- Record keeping of any design failure / underperformance associated with the treatment train and why.

5.5 Develop and Implement a monitoring program

Monitoring provides the primary governance tools for ensuring this WQIP is being implemented and that it is achieving its purpose. In order to do this, the monitoring program must be able to provide information that clearly demonstrates that actions are being implemented, and that these actions are indeed having a positive impact on the water quality status of Buffalo Creek. Further, this outcome needs to be achieved within the constraints imposed by the logistical, administrative and financial realities associated with development projects of this nature.

In order to meet these needs and constraints, a pragmatic, cost-effective strategy is needed that provides information on the progress of actions identified in this WQIP and the effect that such actions actual have on the quality of water in Buffalo Creek, whilst maintaining a level of flexibility that allows for the gathering of information for investigative / adaptive purposes. This involves delineating monitoring into three interdependent areas.

- WQIP action progress monitoring
- Routine water quality monitoring program
- Investigative monitoring

5.5.1 WQIP Action Progress Monitoring

There are a number of governance and administrative reasons why monitoring the progress of specific actions identified in Table 6.1 (Section 6.2) is important. These include:

- Reporting progress to project partners and administrative authorities
- Provide an impetus for ensuring target deadlines are met
- Provide information that can be used to assess the effectiveness of the implementation of actions
- Identify potential problems / barriers early to facilitate early development and implementation of adaptive actions
- Ensure actions are being implemented correctly.

Progress monitoring will need to be undertaken for a range of activities including the upgrade of LSSTP, the implementation and effectiveness of the Muirhead CEMP (Appendix J), and the validation of stormwater quality measures installed as per the Muirhead SMP (Appendix K). It will also need to monitor the progress of routine water quality monitoring as well as investigative monitoring (Section when and if such monitoring is required.

5.5.2 Routine Water Quality Monitoring Program

Routine water quality monitoring is also an important tool for achieving the purpose and objectives of this WQIP as it:

1. Enables the establishment of baseline data to track changes in water quality as the WQIP is rolled out, and
2. Provides feedback information on the impact of specific actions on water quality as they take effect.

Establishing an effective routine water quality monitoring program to track the effectiveness of actions requires specific skills and an administrative system that is able to ensure sampling and data analysis is undertaken in a timely manner, often over several years. Time is needed to determine appropriate parameters and then gather enough data to establish a meaningful baseline, and resources are needed to develop an effective program; collect samples; analyse samples; and collate and analyse data. Resources also need to be devoted to cross referencing results against other forms of data (Section 5.5.1) and making sure actions derived from such analysis are implementation (governance). This kind of program requires a robust, specialised administrative and governance systems that are not typical incorporated into development agencies and organisations.

Fortunately, the catchment within which this WQIP applies, the NT Government has already established the Darwin Harbour WQPP, which includes the Report Cards, stewarded by the DHAC with the support of the NRETAS Aquatic Health Unit. This established administration and governance system represents a significant opportunity for establishing and implementing the Buffalo Creek WQIP. This includes adopting the Report Card program for Shoal Bay and Buffalo Creek as the primary means of ongoing monitoring and reporting of Buffalo Creek's water quality moving forward. Adopting this program as the routine water quality monitoring program for the Buffalo Creek WQIP is highly recommended for the following reasons:

- It has been designed by appropriately qualified personal through the NRETAS Aquatic Health Unit.
- It is an established monitoring program that is scheduled to continue for the foreseeable future (Drewry, 2011).
- It facilitates a relationship between this WQIP and the WQPP for Darwin Harbour which has important strategic implications for both initiatives.
- Financial advantages by avoiding duplication of the existing program
- Administrative and Governance frameworks are already in place and functioning.

5.5.3 Investigative Monitoring

Routine water quality monitoring of Buffalo Creek described in Section 5.5.2 provides a means of monitoring overall water quality at Buffalo Creek, which provides a useful basis for assessing the overall impact of the WQIP. However, it may not always be focused enough to pinpoint and assess specific issues that may arise as the WQIP rolls out. If, for example, the LSSTP implements all of its proposed improvements yet routine water quality monitoring of Buffalo Creek still reveals relatively poor water quality outcomes, it may be necessary to establish more focused monitoring to identify and prioritise other sources of pollution such as the stormwater outlets or groundwater seepage from the historic Landfill (**Figure 2-1**).

This type of monitoring, referred to as "Investigative Monitoring", is reactive, and depends on feedback obtained from monitoring undertaken as per Sections 5.5.1 and subsequent cross-analysis with the routine water quality monitoring results described in Section 5.5.2. Hence, it is not currently possible to identify specific investigative monitoring actions. Rather, the action at this stage must be to ensure progress monitoring and routine water quality monitoring actions are implemented, and that the necessary analysis and reporting is undertaken so that the need for investigative monitoring can be identified if / when needed. Details on actions and the responsible parties are incorporated into Table 6.1 (Section 6.2).

6 WQIP Rollout: Roles, Responsibilities and Timelines

6.1 Introduction

In order for any plan to be successful, it is crucial to attribute rolls and responsibilities for the delivery of specific actions. The first step is to identify who the key / major actors are in relation to the delivery of this WQIP. The next is to assign specific actors to specific tasks and for the delivery of specific actions. The purpose of this section is to address these issues, action by action, and provide an indicative timeline for the delivery of specific actions where such information is available.

6.2 Action Plan: What, When, and Who

This section provides clear and specific actions that will be necessary in order to see no further impact on Buffalo Creek water quality. Further, if followed diligently, it is likely that these actions will see a significant improvement in water quality over the next ten years (timing based on Approval by SEWPaC and implementation by the DHAC). It is designed to make the most of existing agencies, organisations (collectively “actors”), and programs so that, wherever possible, the goals, objectives and actions of the Buffalo Creek WQIP are given the maximum chance to succeed. When assigning different actions to various actors, careful consideration has been given to ensuring the particular action is a good fit with regard to the actor’s own aspirations, purpose, goals and resources. Consideration has also been given to the actor’s jurisdiction were appropriate (e.g., assigning actions to the CLA in relation to urban runoff is consistent with their ownership of the stormwater network within existing urban development).

Table 6.1 | Specific actions and responsibilities for agencies and organisations ("actors").

Note that most start and finish dates have been left blank as this is a matter of negotiation between relevant actors, stakeholders and the DHAC.

Action Area	Action	Start	Finish	Actor	Role	Comments
Over-arching Governance	Stewardship			DHAC	Oversee the rollout of this WQIP	In order for this WQIP to be successful, a recognised body needs to oversee the overall intent and actions contained within the WQIP. The DHAC is already doing this in relation to the Darwin Harbour Strategy and WQIPP, which includes Buffalo Creek.
	Regulation			SEWPaC	Consent Authority.	SEWPaC is the Consent Authority for the Muirhead development and, in this role, the governing body that determined the need for this WQIP. Consequently, it has the authority to enforce the various components of this WQIP (once approved).
Key Stakeholders	Identify and recruit			DHAC	Identify and recruit	The current membership of the DHAC may not include all the key stakeholders necessary to facilitate the improvement of water quality at Buffalo Creek. For example, it would appear that the CLA is not represented (Section 5.4.2).
WQIP review and approval	Review			SEWPaC	Stakeholder – review and submit comments	SEWPaC is the consent authority, and has ultimate approval power. At this stage, however, feedback is being sort prior to submission for approval.
				DHA	Stakeholder (Developer) – review and submit comments	DHA is the Developer that is ultimately responsible for the Muirhead development, including the submission of this WQIP

Action Area	Action	Start	Finish	Actor	Role	Comments
				Aurecon	Respond to comments and update WQIP	Aurecon is developing the WQIP and is responsible for advising DHA regarding feedback from other stakeholders, and updating the WQIP accordingly.
				PWC	Stakeholder – review and submit comments	PWC is the owner and operator of the LSSTP. Actions identified for improving the quality of the outflow discharge from the LSSTP will fall to them to implement.
				Aquatic Health Unit - NRETAS	Stakeholder – review and submit comments	As the administrator of the WQPP for Darwin Harbour initiative, the Aquatic Health Unit has a vested interest in seeing the water quality at Buffalo Creek protected.
				DHAC	Stakeholder – review and submit comments	The DHAC provides advice to the NT Government on land use, planning, and development and the use of natural resources within the Darwin Harbour region. This includes overseeing the implementation of the WQPP for Darwin Harbour.
				DCC	Stakeholder – review and submit comments	As the Local Government Authority, the cooperation of the DCC would be beneficial to the role out of the WQIP.
	Approval			SEWPaC	Approval of the WQIP.	The land on which the Muirhead development is to take place is Commonwealth land, hence SEWPaC is the government agency responsible for approving this WQIP.

Action Area	Action	Start	Finish	Actor	Role	Comments
WQIP Operation	Implementation governance			SEWPaC	Consent Authority	In relation to matters outlined in Condition 1 of the *Decision on Approval*, it is SEWPaC's role to ensure this Condition is met.
				Aquatic Health Unit - NRETAS	Lead Agency	The Aquatic Health Unit of NRETAS is the lead agency heading up the WQPP for Darwin Harbour and its associated initiatives. Given that the Buffalo Creek WQIP fits neatly within the goals and objectives of the Darwin Harbour Strategy, the Aquatic Health Unit is the obvious choice to oversee the administration of the implementation of Buffalo Creek WQIP
	Progress monitoring and review			DHAC	Overseeing implementation Reviewing progress and advising NRETAS and SEWPaC accordingly Reviewing WQIP	The DHAC provides the ideal forum for overseeing the implementation of the Buffalo creek WQIP as the WQIP fits neatly within its terms of reference and existing functions. Further, the DHAC is made up of representatives that have a key role in the roll out of specific actions in this WQIP (e.g. the PWC and DCC)
	Administration and implementation			DHA	Responsible organisation	With regards to actions derived from Condition 1 of the *Decision on Approval*, the DHA has a responsibility to ensure that the actions associated with the Muirhead development are implemented.
				Aquatic Health Unit - NRETAS	Responsible organisation	Over-arching administration and implementation of the Buffalo Creek WQIP as part of its existing role in implementing aspects of the Darwin Harbour Strategy (DHAC, 2010) and the WQPP for Darwin Harbour.

Action Area	Action	Start	Finish	Actor	Role	Comments
Technological and Operational improvements – LSSTP (Refer to Section 5.4.1)	Develop a long term augmentation plan			PWC	Responsible organisation	Condition of the existing two-year Waste Discharge Licence for the LSSTP.
	Select engineering options for major treatment upgrades			PWC	Responsible organisation	As detailed in Section 5.4.1, PWC is currently considering a number of options
	Establish timeline and milestones for major treatment upgrades			PWC / DHA.	Responsible organisation	The PWC is responsible for the establishment of timeline and milestones. The communication of these timelines to SEWPaC (Consent Authority) is the responsibility of DHA as per *Decision on Approval* conditions for the Muirhead development.
	Implement major treatment upgrades			PWC	Responsible organisation and funding body.	PWC has budgeted for upgrades (Appendix I), however a decision on which solutions will be implemented is yet to be decided.
	Modify channels to improve hydraulics of the ponds		Complete	PWC	Responsible organisation	
	Accelerating the de-sludging program			PWC	Responsible organisation	
	Installing aeration equipment at the outfall channel		season	PWC	Responsible organisation	

Action Area	Action	Start	Finish	Actor	Role	Comments
	Re-lining sewer network to reduce amount of stormwater entering LSSTP sewerage network during wet season			PWC	Responsible organisation	Involves the asset condition assessment and repairs as necessary.
	Install baffles in ponds to increase pond retention times			PWC	Responsible organisation	
	Install aerators in ponds			PWC	Responsible organisation	Aeration is undertaken to improve biochemical nutrient removal processes
	Design inlet works			PWC	Responsible Organisation	Tendering process should now be complete
	Report on progress of works			PWC	Responsible organisation	Update reports to be made at each DHAC meeting. Update reports also need to be made to NRETAS in accordance with the Discharge Licence for the LSSTP

Action Area	Action	Start	Finish	Actor	Role	Comments
	Continue outfall monitoring			PWC	Responsible organisation	When providing update reports on the progress of works at each DHAC meeting, it is recommended that PWC also provide updates on water quality trends from, as a minimum, the discharge into Buffalo Creek. Results should be reported as both concentration and loads (to compensate for expected increase in the volume of discharge). By cross checking this against Report Cards for Shoal Bay / Buffalo Creek Report Card will allow both the performance of the STP and its overall effect on Buffalo Creek's water quality to be assessed.
Urban stormwater runoff	Advocate for legislative regulator enhancement		Ongoing	DCC / Aquatic Health Unit - NRETAS	Lead agency / responsible organisation	DCC has identified this as an ongoing strategy to address water quality through administrative, command and control processes (DCC, 2011). DCC to provide updates on progress at DHAC meetings. Note: while the DCC does not have specific jurisdiction over the urban development within the Buffalo Creek catchment, it is the most appropriate organisation to represent the greater Darwin community in this regard.

Action Area	Action	Start	Finish	Actor	Role	Comments
	Investigate opportunities to install GPT in strategic locations within existing urban development occurring within the Buffalo Creek catchment			CLA	Responsible organisation	The first step to improving water quality improvement of urban runoff entering Buffalo Creek is the installation of GPTs. New generation units such as continuous deflection separation devices are very effective at removing gross pollutants (> 5 mm), and have been shown to provide some capacity to trap particulate phosphorus and some heavy metals (Watkins, et al., 2003). CLA to update progress at DHAC meetings.
	Lobby DCC / CLA to develop an education program that specifically targets residents in the Buffalo Creek catchment			DHAC	Lobbying	DCC has identified education in relation to water quality enhancement as an area of ongoing commitment (DCC, 2011a; DCC, 2005). Given the poor condition of Buffalo Creek, it is suggested that special consideration be given to developing education programs specifically targeting residents within the Buffalo Creek Catchment. Consider also a Council sponsored / support Buffalo Creek Revitalization program
	Lobby DCC / CLA to establish specific research and development projects aimed at protecting the water quality (e.g. WSUD initiatives).			DHAC	Lobbying	DCC has identified a general commitment to initiating, participating, facilitating and encouraging research and development projects that focus on improving water quality (DCC, 2011a). Given the poor state of Buffalo Creek, it is recommended that the DHAC lobby council to identify and / or support programs that are focus on improving the water quality in Buffalo Creek.

Action Area	Action	Start	Finish	Actor	Role	Comments
	Incorporate WSUD principles into DCC and CLA Subdivisions and Development Guidelines			DCC	Delivery	DCC has committed to the incorporation of WSUD into Council Subdivisions and Development Guidelines (DCC, 2011b). The CLA does not appear to have a similar commitment at this stage. Hence, the first step would be to establish such a commitment.
	Progress monitoring			DCC / CLA	Report	Provide report on progress, including recent wins and discussion on barriers to implementation where applicable.
				DHAC	Facilitation.	Forum for reporting, tracking and workshopping issues as they arise.
Construction works	Muirhead development CEMP compliance			SEWPaC	Consent Authority	Ensure the CEMP for the Muirhead development complies with existing legislation and regulation
	Implement the Muirhead development CEMP			DHA	Governance	DHA to ensure construction site managers are ultimately responsible for ensuring the CEMP is implemented correctly
				NRETAS	Audit	Pro-active and complaint response auditing. Pro-active auditing should include on-site inspection at critical phases during construction (e.g. site levelling), and random audits, particularly during or just after rain events.

Action Area	Action	Start	Finish	Actor	Role	Comments
	Performance monitoring			DHA	Report	Provide reports on level of conformance to CEMP in relation to sediment and stormwater runoff management on the Muirhead development site at DHAC meetings. This should include information on any incidents and subsequent follow up action(s).
				NRETAS / DCC / CLA	Report	Provide report on any audits, incidents, and complaints in relation to the management of sediment and surface runoff at the Muirhead development site. This should include information on any incidents and subsequent follow up action.
				DHAC	Facilitation	Forum for reporting, tracking and workshopping issues as they arise.
	Ensure that the proposed WSUD features are designed and installed such they are consistent with the Muirhead developments Stormwater Management Plan (Appendix K)			SEWPaC	Approval	SEWPaC, as the Consent Authority, is to give ultimate approval to the Stormwater Management Plan (Appendix K), taking into account best practice design and construction principles (Healthy Waterways, 2006; Water by Design, 2010; McAuley, et al., 2009)
				DHA	Delivery	DHA, as the developer, is ultimately responsible for ensuring designs are consistent with the SMP (Appendix K), and that design and construction remains consistent with the SMP. Suggest that DHA, or their representative, review designs and monitor their physical construction in line with best practice (Water by Design, 2010).

Action Area	Action	Start	Finish	Actor	Role	Comments
				NRETAS	Certifier / Audit	NRETAS to oversee the inspection and final certification of WSUD infrastructure. This should include working with DHA to ensue inspections are conducted in accordance with best practice (Water by Design, 2010).
Water Quality Monitoring	Routine monitoring of Buffalo Creek	2009	Indefinite	NRETAS Aquatic Health Unit	Delivery & reporting	As per existing Shoal Bay and Buffalo Creek Report Cards (NRETAS, 2010). Annual Report Card results to be submitted at next DHAC meeting following publication of results
				DHAC	Assess Report Card results against other monitoring data streams	Discussion and assessment of the results of new Report Card for Buffalo Creek in the context of previous results and the completion of activities in other Action Areas (e.g. Construction Works, LSSTP and Urban Stormwater Runoff).
	Investigative Monitoring			DHAC	Facilitation / Decision	Provides flexibility to address unforseen issues. Based on the assessment of Buffalo Creek Report Card results, DHAC to workshop decision as to whether or not additional monitoring is needed, what this should include, and why (Section 5.5.3).
				NRETAS Aquatic Health Unit	Administration / Delivery	Provide technical support and project management of specific monitoring program

Action Area	Action	Start	Finish	Actor	Role	Comments
	Mitigation action			DHAC	Facilitation / Decision	Provide forum to workshop any issues with key stakeholders and determine action(s) to address issues.
				NRETAS Aquatic Health Unit	Administration / Delivery	Provide technical support and project management of specific mitigation action.
Post Construction Monitoring (nominal 10 consecutive years)	Monitoring of GPTs			DHA	Data collection, collation and reporting	Monitoring should include frequency of emptying each GPT, the level at the time of emptying (i.e., full or a proportion thereof), the structural condition of the GPT, and, if practical, the weight and type of material removed. This information will provide important information on the effectiveness of these systems in terms of the environmental benefit, expected life span, and operational costs that can be used to inform future developments within Muirhead (and northern Australia generally).
				DHAC	Facilitation	Provide an impetus for the completion of monitoring programs by providing a forum for annual reports to the committee. Given the timeline of 10 years, the DHAC will have an important role in ensuring continuity of data collection and overall delivery.
				SEWPaC	Consent Authority	As the consent Authority, SEWPaC will have ultimate responsibility regarding ensuring monitoring is carried out for the duration.

Action Area	Action	Start	Finish	Actor	Role	Comments
				NRETAS Aquatic Health Unit	Convert results into policy	As the Territory's representative on the DHAC, the responsibility of ensuring reported results are considered when updating policy documents such as the Water Sensitive Urban Design Planning Guide (Dept. of Planning and Infrastructure, 2009).
	Monitoring of Swales			DHA	Data collection, collation and reporting	Monitoring should include periodic (e.g. quarterly) inspections for vegetative die-back, weed infestation, and erosion. Monitoring should also include keeping records of types of maintenance undertaken, when, and how much cost was involved. This information will provide important information on the effectiveness of these systems in terms of the environmental benefit, expected life span, and operational costs that can be used to inform future developments within Muirhead (and northern Australia generally).
				DHAC	Facilitation	Provide an impetus for the completion of monitoring programs by providing a forum for annual reports to the committee. Given the timeline of 10 years, the DHAC will have an important role in ensuring continuity of data collection and overall delivery.
				SEWPaC	Consent Authority	As the consent Authority, SEWPaC will have ultimate responsibility regarding ensuring monitoring is carried out for the duration.

Action Area	Action	Start	Finish	Actor	Role	Comments
				NRETAS Aquatic Health Unit	Convert results into policy	As the Territory's representative on the DHAC, the responsibility of ensuring reported results are considered when updating policy documents such as the Water Sensitive Urban Design Planning Guide (Dept. of Planning and Infrastructure, 2009).
	Monitoring Bioretention			DHA	Data collection, collation and reporting	Monitoring should include periodic (e.g. quarterly) inspections for vegetative die-back, weed infestation, hydraulic conductivity and erosion. Monitoring should also include keeping records of types of maintenance undertaken, when, and how much cost was involved. This information will provide important information on the effectiveness of these systems in terms of the environmental benefit, expected life span, and operational costs that can be used to inform future developments within Muirhead (and northern Australia generally).
				DHAC	Facilitation	Provide an impetus for the completion of monitoring programs by providing a forum for annual reports to the committee. Given the timeline of 10 years, the DHAC will have an important role in ensuring continuity of data collection and overall delivery.
				SEWPaC	Consent Authority	As the consent Authority, SEWPaC will have ultimate responsibility regarding ensuring monitoring is carried out for the duration.

Action Area	Action	Start	Finish	Actor	Role	Comments
				NRETAS Aquatic Health Unit	Convert results into policy	As the Territory's representative on the DHAC, the responsibility of ensuring reported results are considered when updating policy documents such as the WSUD Planning Guide (Dept. of Planning and Infrastructure, 2009).
	Treatment Train effectiveness			DHA	Design, implement and report on water quality performance	The DHA will need to design a water monitoring program that is able to demonstrate that water quality is being improved by the treatment train constructed.
				DHAC	Facilitation / technical assistance	Provide an impetus for the completion of monitoring programs by providing a forum for annual reports to the committee. Given the timeline of 10 years, the DHAC will have an important role in ensuring continuity of data collection and overall delivery. The DHAC should also act as a forum to assist the DHA design an appropriate monitoring program.
				SEWPaC	Consent Authority	As the consent Authority, SEWPaC will have ultimate responsibility regarding ensuring monitoring is carried out for the duration.
				NRETAS Aquatic Health Unit	Convert results into policy	As the Territory's representative on the DHAC, the responsibility of ensuring reported results are considered when updating policy documents such as the Water Sensitive Urban Design Planning Guide (Dept. of Planning and Infrastructure, 2009).

Appendices

Appendix A Bibliography

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Appendix B
Decision on Approval

Letter from the Consent Authority, Department of Sustainability, Environment, Water, Population and Communities (SEWPaC)

Appendix C
Remnant Vegetation Map

Appendix D
Preliminary Staging Plan

Appendix E
Shoal Bay and Buffalo Creek Report Cards

Appendix F
Nutrient Fate Modelling Workshop Presentation and Minutes

Appendix G
Nutrient Fate Model Setup

Appendix H
Scenario Results

Appendix I
Letter from Power Water Corporation

Appendix J
Draft Construction Environmental Plan (CEMP)

Appendix K
Stormwater Management Plan (SMP)

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