- PHASE 1 REPORT -

TOWARDS THE DEVELOPMENT OF A WATER QUALITY PROTECTION PLAN FOR THE DARWIN HARBOUR REGION

A biologically rich and diverse marine and terrestiral environment for our use and enjoyment today, and for our children tomorrow...

Aquatic Health Unit
April 2009

J. Fortune & G. Maly 2009

Australian Government

Department of Natural Resources, Environment, the Arts and Sport.
Environment, Heritage and the Arts.
Aquatic Health Unit.

This report describes activities undertaken in the development towards a Water Quality Protection Plan for the Darwin Harbour Region. The process was undertaken in consultation with the Ecosystem Monitoring Group, a technical advisory body of the Darwin Harbour Advisory Committee and a number of other key stakeholders. Broader public consultation was also undertaken to determine beneficial uses for the Darwin Region which is further described within this report.

The Department of Natural Resources, Environment the Arts and Sport kindly acknowledges the support of the Australian Government in the development of a Water Quality Protection Plan for the Darwin Region.

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CONTENTS

Acronyms

DAC	Darwin Aquaculture Centre
DCC	Darwin City Council
DHRWQM	Darwin Harbour Receiving Water Quality Model
DHAC	Darwin Harbour Advisory Committee
DPI	Department of Planning and Infrastructure
DRDPIFR	Department of Regional Development, Primary Industry, Fisheries and Resources.
MOS	Margin of Safety
NRETAS	Department of Natural Resources, Environment, the Arts and Sport
NWQMS	National Water Quality Management Strategy
PCC	Palmerston City Council
PWC	Power Water Corporation
STP	Sewerage Treatment Plant
TDML.	Total Daily Maximum Limit
TRaCK	Tropical Rivers and Coastal Knowledge Consortium
WAP	Water Allocation Plan
WQO's	Water Quality Objectives
WQPP	Water Quality Protection Plan
WSUD	Water Sensitive Urban Design

Section 1. Introduction

1.0 Overview

The Darwin Harbour region is the country of the Larrakia and other Aboriginal people, and is enjoyed by Territorians and tourists for its recreational opportunities. Most Territory residents live in the region, which is the centre for industrial and commercial activities. The region is also a major hub for road, rail, air and sea transport. Our use of the catchment, through urban, industrial and agricultural development in the region has increased the amount of pollutants entering Darwin Harbour.

Continued growth of urban and rural activities around Darwin Harbour will place increasing pressure on the Harbour's waterways. Currently, the assimilative capacity of the Harbour to receive pollutants from point and non-point sources is poorly known and improved monitoring and knowledge is required to ensure the recreational, social, environmental and economic values of our waterways are not degraded.

At present waters in the Darwin Harbour region are considered to be in good condition compared to those adjacent to highly populated areas in other regions of Australia. This is reflected in the good reputation that the Top End enjoys for its ecological diversity, recreational opportunities such as fishing and its distinctive tropical character.

There are, however, areas of concern, especially around some urbanised areas where sewage outfalls, stormwater, or pollution in the form of pathogens and nutrients, can affect the quality of the water. It is important to recognise that the environmental quality of these waters in the future will strongly depend on the decisions we make now.

It is vital that we maintain the harbours current 'good shape' and ensure that water quality is not degraded.

This report describes the development of Water Quality Objectives, Pollutant Load Targets and priority research undertaken to inform a Water Quality Protection Plan (WQPP) for the Darwin region. The development of this plan recognises that many of the Harbours waterways are ecologically intact and are important for the economic, social and spiritual benefits they provide. Striking the balance between these sometimes disparate values and ensuring resources that the region contains are utilised sustainably is an important underpinning goal in the development of current and future strategies for the region.

1.1 Development of a Water Quality Protection Plan

An action plan is to be developed for the Darwin region through the use of the Framework for Marine and Estuarine Water Quality Protection. This plan is called the Water Quality Protection Plan for Darwin Harbour (WQPP). The aim of the WQPP project is to ensure that Water Quality Objectives, a key component of the Plan, are maintained and that community's values associated with various waterways are protected. The development of this plan has been made possible through funds provided by the Australian Government under the Coastal Catchments Initiative.

The proposed framework for the WQPP (Figure 1) will provide the basis for which to progress beyond the first preparatory phase of the plan. Key components will include Modelling, Monitoring and Implementation strategies for the region which will support the approach outlined by the framework.

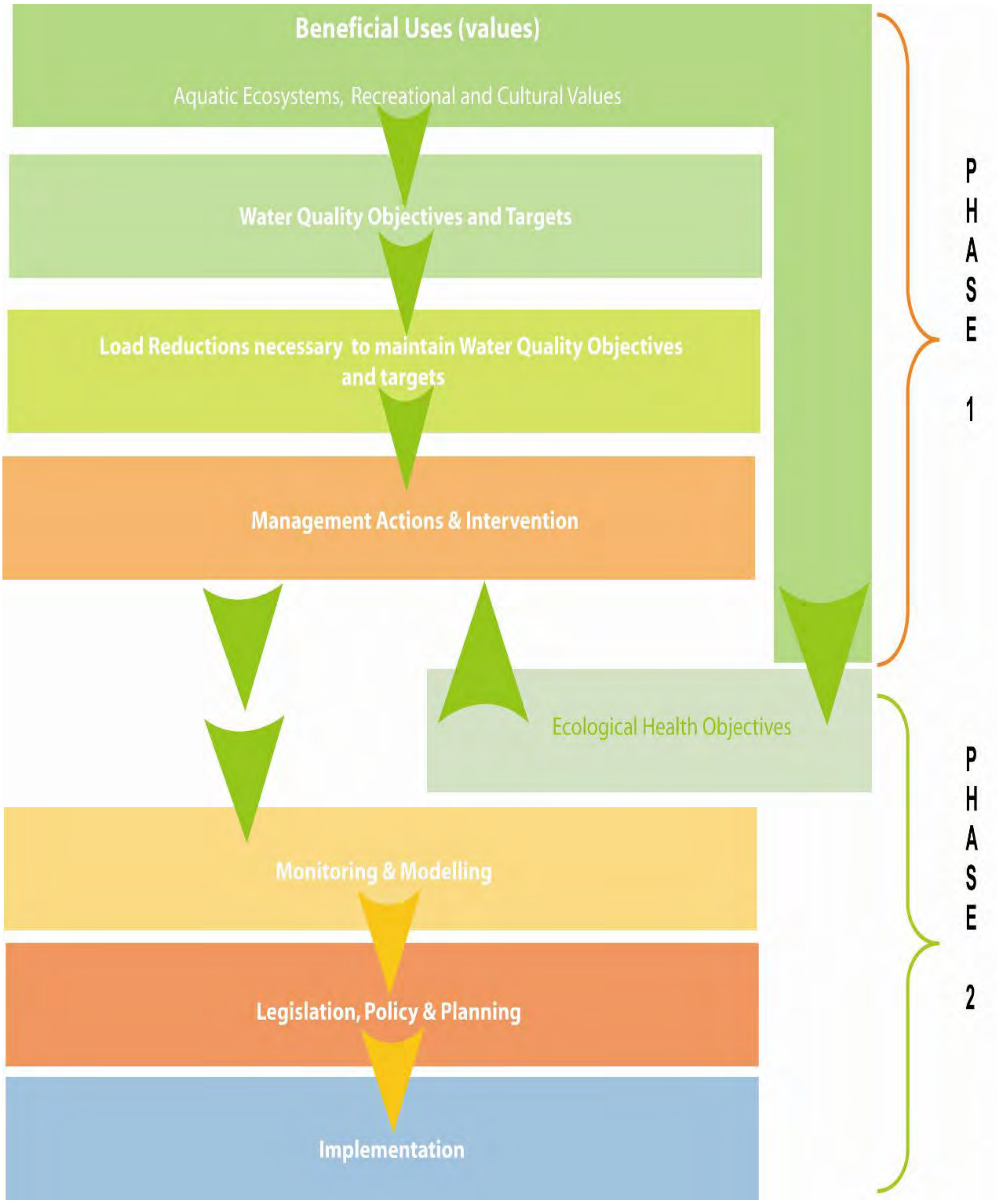


Figure 1.1 Proposed outline of the Water Quality Protection Plan for Darwin Harbour.

1.2 The Darwin Harbour Region

Compared to other Australian states and most other countries, our cities and towns are nestled amongst natural landscapes. There is no legacy of environmental decay or pollution in the region which has necessitated measures to rehabilitate aquatic ecosystems, restore rivers or wetlands. We do not have to spend considerable resources attempting to address water quality which from experience elsewhere in Australia and internationally is nearly always invariably expensive and often futile. This makes Darwin Harbour a special place which is prized by Territorians and visitors to the region.

Darwin Harbour and its catchment is defined by a line between Gunn and Charles Point, and includes Port Darwin and Shoal Bay (Figure 2). The 2010 km^2 terrestrial catchment, that being the land above the harbour's high water mark, comprises the cities of Darwin and Palmerston, a predominately rural hinterland and undeveloped areas. The major rivers flowing into the harbour are the Howard, Elizabeth and Blackmore Rivers.

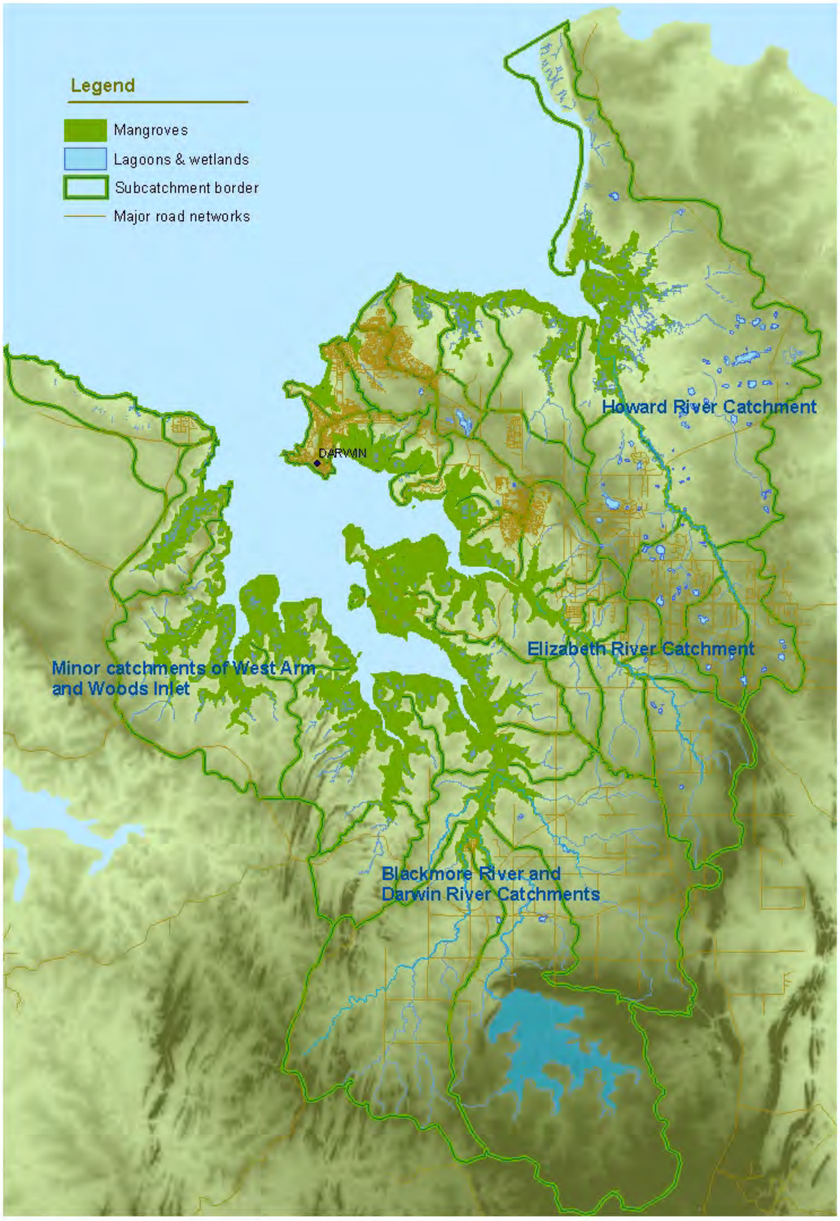


Figure 1.2: Major Subcatchments of the Darwin Harbour Region.

The area of the terrestrial catchment to the estuary ratio for Darwin Harbour is approximately 2:1, which is relatively small. This means that the areas than can generate potentially polluted run-off that flows into the harbour is less than for other proportionally large catchments, such as Brisbane's Moreton Bay or Sydney's Port Jackson (Darwin Harbour Advisory Committee, 2003). Darwin Harbour has naturally deep channels that are 10-12 m deep and extend into the three major arms: East Arm, Middle Arm and West Arm. The harbour is fringed by mangroves, mud flats, rocky foreshores, low cliffs and sandy beaches.

Darwin Harbour is a large macro-tidal estuary that experiences tidal variations up to 8 metres. The mean spring tidal ranges approximate 6 metres, whilst mean neap tidal ranges are around 3 metres. The harbour's tides are semi-diurnal, with two high tides and two low tides daily. These macrotides produce strong currents that can peak at speeds of up to 2-2.5m/second. Tidal flows between East point and Mandorah have been measured and found to be in the order of 120,000 cubic metres per second (Williams and Wolanski, 2003).

Figure 1.3: Turbid plumes resulting from macrotidal regime in the Darwin Harbour estuary.

The catchment's geology is ancient and highly weathered, consequently most soils in the region have poor fertility. The topography of the catchment is relatively low-lying with most land being less than 30 metres above sea level. Inland plains are flooded with fresh water to a depth of up to two meters each wet season.

Darwin city lies on the north eastern side of the Harbour and supports the largest concentration of the Northern Territory population. Growing urbanisation, industry and clearing in the catchment contribute to increasing diffuse and point source loads to the harbour. Impacts appear to be confined to localised areas of the harbour, whilst much of the region remains in a healthy state with some areas such as West Arm considered relatively pristine (Water Monitoring Branch, 2005).

Industry is located primarily in the suburb of Winnellie fringing the eastern margin of Port Darwin. However, a number of satellite industrial estates service the East Arm Port region at Hudson Creek, whilst others are located in the Berrimah and Pinelands areas. More recently, approximately 88 hectares of Wickham Point was cleared to establish an LNG plant and its associated infrastructure. Industrial and manufacturing land-use, including the port, constitutes 0.15% of land-use in the catchment or approximately 990 ha. Approximately two percent of land-use in the catchment has been developed for horticulture. These areas are located primarily in the Litchfield and Coomalie Shires.

1.3 Larrakia Country

The harbour has been home to the Larrakia people for thousands of years. For the Larrakia the region's environments are 'cultural landscapes' that are vital to their well-being. A rich oral history links land, sea and culture from generation to generation.

Larrakia still have ceremonies, walk their country, camp, hunt, fish and gather plant foods and materials as part of maintaining culture. Numerous Larrakia sacred and archaeological sites occur in the region's land and seascapes with many sites recorded and sacred sites registered within the region. Some of these are 'Dreaming sites' associated with animals, plants or people.

Favourite Larrakia sea foods include dugong *Damaldangala*, turtle *Dawudlirra*, sharks and rays, bream, barramundi, salmon, trevally, mackerel, mullet, mud crab, long-bum *Danijarra*, mud mussel *Damagula* and periwinkles (Darwin Harbour Advisory Committee, 2003). Coastal bush fruits include the Bush Peanut and Pandanus. Rotten Cheesefruit is used for coughs and colds and smoking pipes are made from beach hibiscus, *Larrwa,* timber and crab claw.

Burial sites are located around the coast, including Mindil Beach. Other archaeological sites include shell middens, camping sites and stone fish traps. Stone artefacts are also found around the coast. Popular campsites, past and present, often have freshwater and abundant food sources nearby.

Maintaining this natural asset for its highly regarded ecological, recreational and cultural values remains paramount. There is an ongoing need to monitor and model increasing pressures from the catchment to maintain water quality for Beneficial Uses of the region and aid decision making for the sustainable management of Darwin Harbour. The monitoring and modelling applications pursued as part of the Water Quality Protection Plan (WQPP) will enable us to not only inform decision making processes for sustainable development but to importantly understand the underpinning processes which characterise this estuary.

1.4 Water Quality Issues in the Region

Land use change including land clearing for irrigation, horticulture, agriculture and urban development can result in a range of impacts and pressures on waterways. Altering hydrology, increasing rates of erosion, water extraction, nutrients and chemical pollutants entering waterways, to weed and feral incursions which alter fire regimes are some of the impacts associated with increasing development pressures.

Urbanisation probably has one of the most dramatic effects of any land-use on catchment runoff. Urban and commercial developments have large areas of hard impervious surfaces such as roads and roofs that limit infiltration to the ground. This results in a greater volume of runoff. Existing developments have used efficient stormwater drainage designs to convey the runoff from these areas as quickly as possible to minimise the risk of flooding and inundation. This reduces the time it takes for water to leave the catchment and enter rivers and creeks and can lead to higher flow but shorter duration peaks in the stream flows. The increased flow velocities associated with this runoff can result in higher rates of erosion if urban drains and streams are not adequately stabilised. Contemporary urban drainage design seeks to return the runoff regime to a more natural setting.

On a whole of harbour scale, the contributions from diffuse runoff and point source sewage discharges to the overall nutrient status of the harbour are relatively minor. However, current research suggests that the effects of point and diffuse sources of nutrients may be significant at more local scales such as in the tidal creeks or the upper reaches of the estuary where point source nutrient are discharged. The hydrodynamic model developed for Darwin Harbour suggests that the upper reaches of the estuary experience extended residence times (Williams and Wolanski, 2003; WRL 2008). This understanding, coupled with the forecasted nutrient load contributions make these areas of extended residence time particularly vulnerable to localised nutrient impact.

Sources of nutrients include point-source discharges (particularly sewage discharges) and run-off from urban and rural areas. These pollutant sources present the greatest management issue for water quality in the region (Fig 4). Catchment areas that have been cleared of vegetation typically provide more nutrients than areas in their natural state. Potential consequences of increased nutrient loads to estuaries include eutrophication, algal blooms or excessive macrophyte growth, anoxic events due to decay of plant matter, and fish or animal kills from lack of oxygen.

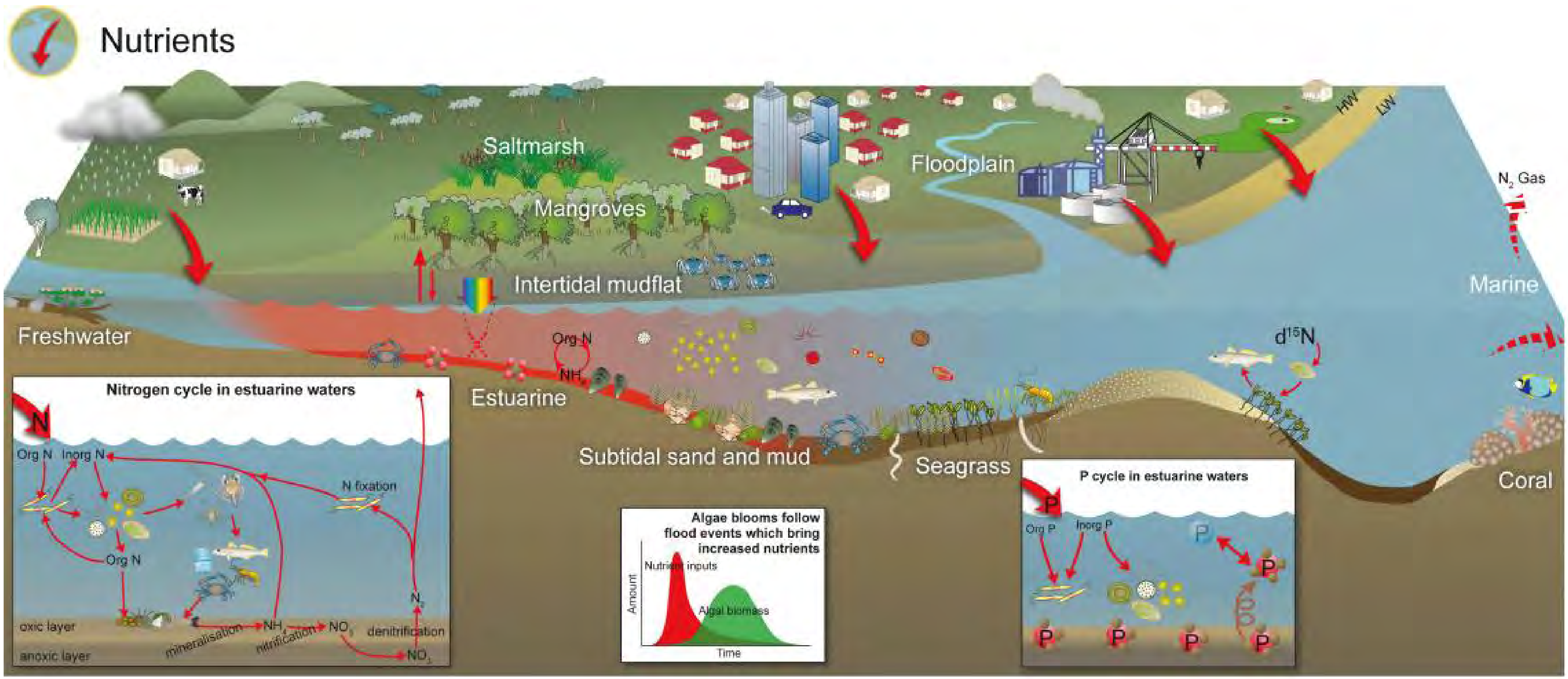


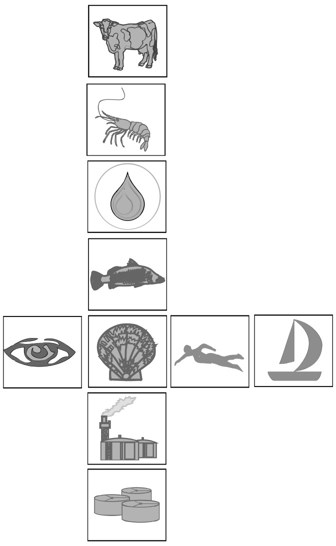
Figure 1.4: Conceptual diagram of nutrient pollutants entering a waterway and effects on receiving environments (Source Qld EPA).

Estuarine monitoring has continued since the early 1990's however there is a need to intensify effort and build on a program which incorporates other attributes such as biota and habitat indicators. Monitoring of freshwater rivers and streams at a series of sites across the broader Darwin region catchment has included water quality and biological assessments with particular focus on macroinvertebrates. Future research efforts will trial additional indicators of aquatic health including fish, amphibians, riparian health and river metabolism.

Achieving protection of aquatic ecosystems requires management of not only water quality but also other attributes of the system such as flow for environmental requirements and habitat condition as indicated above. Any assessment of ecosystem health needs to indicate the measurement of biological indicators as well as the indirect assessment of system modifiers such as water quality. Measurement of these modifiers is important in determining causes of detected changes to biological attributes. In the case of ecosystem protection there is a plethora of possible indicators to choose from. Monitoring all potential indicators is impractical and a process to select the most appropriate indicators was undertaken in conjunction with the preparation for a WQPP.

1.5 Beneficial Uses

Environmental values are particular values or uses of water that are conducive to a healthy ecosystem and/or contribute to public benefit, welfare, safety and health. These environmental values require protection from the effects (both on-going and potential) of pollution, waste discharges, and waste deposits. The Northern Territory *Water Act* defines these values or uses as Beneficial Uses and a given water body may have none, one, a number, or all of the following Beneficial Uses:



Agriculture – to provide irrigation water for primary production including related research;

Aquaculture – to provide water for commercial production of aquatic animals;

Public water supply – to provide water for drinking purposes;

Environment – to provide water to maintain the health of aquatic ecosystems;

Cultural – to provide water to meet aesthetic, recreational and cultural needs;

Industry – to provide water for industry; and

Rural stock and domestic – to provide water for specific use

A number of high conservational value ecosystems have been identified in the region. Many of these are protected zones and include important marine, estuarine and freshwater habitats and species. These include areas such as the Casuarina Coastal Reserve, Doctors Gully Aquatic Life Reserve and Berry Springs Nature Reserve. Areas of high conservational significance attract a higher level of protection and therefore no change to natural values would be determined for such zones.

Beneficial uses have now been established through community consultation for the subsequent determination of water quality objectives (WQO's) and targets. The underlying principle of the development of these Objectives and Pollutant Load Targets is the protection of beneficial uses, with particular emphasis on the preservation of aquatic ecosystems (environmental use), recreational and cultural values.

1.5.1 Consultation Process and Darwin Harbour Advisory Committee

Beneficial Uses for regional waters were first declared in 1996 as part of the National Water Quality Management Strategy, a long term plan of action developed by the Federal, State and Territory Governments in 1992 to ensure a sustainable and nationally consistent approach to water quality management. Since that time a significant portion of the catchment has been developed. It was therefore appropriate to review the nominated uses. To ensure that current Beneficial Use declarations still reflect values and uses of water by the community, a consultation process was undertaken which sought to determine how and for what purpose should water in the catchment be used. A detailed list of consultation objectives can be found in the project's consultation strategy.

The consultation process was facilitated by the Darwin Harbour Advisory Committee (DHAC) a key partner in the development of WQPP, whose members represent groups and organisations with an interest or responsibility for the management of all aspects of Darwin Harbour and its catchment. The Committee was established in 2002 to develop, review and oversee the implementation the Darwin Harbour Regional Plan of Management. Much of the Committee's and its technical reference groups early work and recommendations also inform the preparation of WQPP. The Committee's role in the WQPP project is to facilitate community consultation and engagement processes as outlined in the consultation strategy.

The public consultation process took place from April to June 2007. Over 400 information packs containing flyers, fact sheets, contact details for further information and feedback forms were distributed via mail, e-mail, at fairs, shows and at information sessions. DHAC database containing 200 individuals and organisations who expressed an interest in management of the Harbour was also utilised in relation to the consultation process in addition to a comprehensive media campaign which included media releases, interviews with DHAC Chair and project team members during prime time afternoon time slot and a number of newspaper articles.

Three public forums were held across the catchment (at Cox Peninsula, Darwin's rural area and in Darwin CBD) where experts presented information about Beneficial Uses and discussed the role of environmental values in the water quality management process with the participants. All of the information was also made available electronically on the WQPP website including an electronic feedback form.

1.5.2 Outcomes from the Consultation Process

A total of 64 submissions were received at the conclusion of the consultation period. A table showing distribution of preferences for various uses of water in 9 different areas is in Appendix A. Table 1 summarises the nominated beneficial uses for major catchments and systems in the Darwin region.

A key outcome from the consultation process was the community's preference for existing uses to be retained and for environment to be the highest ranking category of beneficial use for all waterways in the catchment.

The Darwin Harbour region is the country of the Larrakia and other Aboriginal people. Larrakia 'country' consists of both land and sea, and there is strong unbroken relationship to their land, sacred sites, stories and resources through oral and written history. Consultation with the Larrakia Harbour Committee (LHC) identified a number of values falling under one overarching principle – that all water is valued and that the traditional and cultural use of the Harbour is innately tied to an intact environment. The ongoing advice and development of water quality and ecological objectives which are culturally appropriate is continuing with the assistance of the LHC.

WATER REGIONS WATER USE CATEGORIES		1 Darwin Harbour & its marine reaches	2 Rapid Creek freshwater reaches	3 Elizabeth & Howard Rivers Region – surface water	4 Elizabeth & Howard Rivers Region - groundwater	5 Darwin & Blackmore Rivers Catchment- surface water	6 Darwin & Blackmore Rivers Catchment- groundwater	7 Shoal Bay & Vernon Islands	8 Hudson Creek & tributaries
AGRICULTURAL	Use of the water body for irrigation and livestock				✓		✓		
CULTURAL	Collecting food (e.g. fish, crabs, shellfish)	✓	✓	✓		✓			
	Spiritual values	✓	✓	✓		✓			
	Recreation (e.g. swimming, fishing)	✓	✓	✓		✓			
	Aesthetics (visual)	✓	✓	✓		✓			
AQUACULTURE	Aquatic food farming								
PUBLIC WATER SUPPLY	Drinking				✓		✓		
	Other domestic uses				✓		✓		
ENVIRONMENT	Habitat for plants and animals	✓	✓	✓	✓	✓	✓	✓	✓
RIPARIAN	Access to water body by people and livestock			✓		✓			
MANUFACTURING INDUSTRY	Water for industry								

Table 1.1. Nominated beneficial uses for major catchments and systems in the Darwin region.

1.6 Water Quality and Environmental Flows Management in the Darwin Region

Northern Territory's water resources are managed through a regulatory framework prescribed by the *Water Act* and *Water Regulations.* The key principle on which this legislation is based is that the management of water is guided by its value which is in turn determined by its use or its purpose. The Beneficial Uses and water bodies to which they apply are formally declared by the Administrator in the Gazette. The primary decision maker under the *Water Act* responsible for all other aspects of water management is the Water Controller.

Department of Health and Families has responsibility for the management of water quality if it becomes an issue of public health. Consequently the Chief Health Officer of the Department of Health and Families has the responsibility for maintaining and updating Water Quality Objectives for cultural or recreational uses. These are typically based on national standards and are implemented by Power and Water Corporation.

Other legislation and decision makers relevant to the management of water quality include:

- Advisory committees such as the Darwin Harbour Advisory Committee (DHAC) and the Rapid Creek Advisory Committee (RCAC) which have some influence over water quality in Darwin Harbour through the recommendations they provide to the Minister for Environment and Heritage on issues relating to the management of land and water in Darwin Harbour catchment.

- City and Shire Councils make decisions and undertake functions listed in Schedule 2 of the *Local Government Act* which includes provisions for the management and disposal of stormwater but does not specify any responsibility for its quality. Department of Planning and Infrastructure has similar responsibility under the *Control of Roads Act* for the management of stormwater in road corridors owned by NT or Australian Government

- Darwin Port Corporation operates under the provision of the *Darwin Port Corporations Act* which amongst other functions vests the control and regulation of the use of all waters of the Harbour's port and other marine activities to the Corporation. In this capacity Darwin Port Corporation is another important decision maker with a relative influence on water quality in the Darwin Harbour.

1.7 The Role of Natural Resource Management Board NT Inc. in preparation of a WQPP

The NRM Board (NT) Inc. has been established in order to implement a strategic approach to natural resource management through the Northern Territory Integrated Natural Resource Management (INRM) Plan and Regional Investment Strategy (RIS), as agreed from time to time by the Northern Territory and Commonwealth Governments. The NRMB (NT) is responsible and accountable for:

- identifying and integrating opportunities and priorities for the management of the natural resources of the Northern Territory particularly through review of the INRM Plan and RIS as appropriate;
- promoting and nurturing partnerships aimed at achieving the outcomes of the INRM Plan;
- managing investment funds made available to it by governments or other investors; and
- reporting to stakeholders (including managers of natural resources, community organisations and groups) on the processes for and outcomes of such investments.

A partnership in a form of an MoU was developed with the Board which will assist the integration of relevant elements of the WQPP into the regional NRM and Investment initiatives.

The Memorandum of Understanding commits the parties to:

- the delivery of Management Action Targets identified in the NRMBs Integrated Natural Resource Management Plan for the Northern Territory; and

- share information as it comes available because communication and co-operation between the Department, responsible for delivering project outcomes and the NRMB is essential to maximise the use of knowledge and resources and to assist the Board in revision of its INRM Plan.

1.8 The Project Steering Committee

The WQPP project is overseen by a steering committee chaired by the Executive Director Environment and Heritage from the Department of Natural Resources, Environment, the Arts and Sport (NRETAS), which has the principal contractual obligations to undertake the project. Other members of the committee are sourced from the Department of Planning and Infrastructure, Darwin Harbour Advisory Committee and the Australian Government Department of the Environment, Water, Heritage and the Arts. The Steering Committee considers and endorses reports, timeframes, communications and consultation strategies.

2.0 Ambient Estuarine Water Quality

The water quality of Darwin Harbour varies greatly with tides, season and location. Over the 12 hours of each tidal cycle, and between neap and spring tides, the clarity of the Harbour can change dramatically. This is most noticeable in the upper reaches of the Harbour, where there is an almost hourly change in water quality as water carrying sediment flows into and out of the mangroves. On a seasonal time scale, river inflows affect the salinity of the Harbour.

The first comprehensive water quality study of Darwin Harbour was undertaken during 1990-91 for the main body of the harbour and the entrances to East, West and Middle Arms. Recent water quality monitoring of the harbour, from 2001 to the present have expanded the range of locations, which now include the upper reaches of East and Middle Arms, tidal creeks and Shoal Bay. The monitoring program collects water samples at about the same time during the tidal cycle, which is within 2 hours of the tide's low water level on an outgoing tide. By standardising sample collection to account for the influence of the tides, comparisons of water quality between years are made easier and will be more likely to be able to detect water pollution. Water samples are collected during the wet and dry seasons.

Table 2.1 The average water quality of the main body of Darwin Harbour and Shoal Bay. *Minimum and maximum concentrations measured are shown in brackets.*

		1990-1991, Darwin Harbour	2001–2004, Darwin Harbour	2004, Shoal Bay
Dissolved oxygen (mg/L)	Dry	5.61 (5.25-5.84)	5.78 (4.02-6.55)	6.12 (6.01-6.23)
	Wet	5.57 (5.30-5.80)	5.72 (5.41-6.12)	5.91 (5.83-5.96)
Turbidity (NTU)	Dry	2.5 (1.7-3.7)	1.9 (1.0-7.0)	2.3 (1.9-2.7)
	Wet	5.6 (1.5-20)	3.1 (1.3-5.0)	3.4 (1.1-8.2)
Euphotic depth (m)	Dry	11.5 (8.4-16.4)	15.7 (6.5-22.6)	16.0 (11.6-27.1)
	Wet	10.0 (5.3-18.8)	10.7 (6.0-18.6)	13.8 (6.2-25.0)
Total Nitrogen (mg/L)	Dry	0.44 (0.25-1.23)	0.17 (0.05-0.37)	-
	Wet	0.55 (0.13-2.0)	0.15 (0.10-0.25)	0.18 (0.15-0.23)
Total Phosphorus (mg/L)	Dry	0.014 (0.012-0.017)	0.01 (0.01-0.02)	-
	Wet	0.013 (0.009-0.016)	0.01 (0.01-0.04)	0.01 (0.01-0.03)
Chlorophyll (µg/L)	Dry	1.36 (0.4-2.7)	0.59 (0.25-1.20)	-
	Wet	1.24 (0.3-2.1)	1.43 (0.40-3.00)	0.82 (0.20-2.00)

Additional to the typical suit of physico-chemical indicators monitored in Darwin Harbour is the parameter of euphotic depth. Euphotic depth is a measure of how deep light penetrates through the water, and is related to turbidity. It is the depth at which light intensity has decreased to 1% of the light entering the water at the surface. The clearer the water, the deeper light penetration is.

Table 2.2 The average water quality of the upper reaches of Darwin Harbour and Shoal Bay, and tidal creeks. *Minimum and maximum concentrations measured are shown in brackets.*

		Darwin Harbour, East and Middle Arms	Darwin Harbour tidal creeks modified catchments	Darwin Harbour tidal creek with largely unmodified catchments	Shoal Bay Howard River estuary	Shoal Bay Buffalo Creek, modified catchment.
Dissolved Oxygen (mg/L)	Dry	5.43 (4.02-6.32)	5.41 (4.90-6.06)	4.83 (3.83-5.94)	6.18 (6.02-6.33)	5.99 (5.71-6.27)
	Wet	5.81 (4.62-6.68)	-	-	5.33 (4.17-6.49)	3.91 (3.50-4.31)
Turbidity (NTU)	Dry	3.6 (1.5-7.7)	5.7 (3.9-8.1)	11.3 (7.2-21.0)	15.8 (14.0-17.5)	29.3 (27.5-31.0)
	Wet	20.9 (2.8-72.0)	-	-	15.0 (13.0-17.0)	30.5 (24.0-37.0)
Euphotic Depth (m)	Dry	8.5 (4.2-13.0)	5.5 (4.8-6.7)	3.7 (1.9-5.2)	2.9 (2.7-3.2)	1.4 (1.3-1.5)
	Wet	3.7 (0.8-7.2)	-	-	2.6 (2.5-2.6)	1.6 (1.6-1.6)
Total Nitrogen (mg/L)	Dry	-	0.209 (0.121-0.328)	-	-	-
	Wet	0.22 (0.14-0.35)	-	-	0.40 (0.31-0.49)	1.63 (1.63-1.63)
Total Phosphorus (mg/L)	Dry	0.02 (0.01-0.03)	0.021 (0.010-0.037)	-	-	-
	Wet	0.02 (0.01-0.05)	-	-	0.03 (0.03-0.04)	0.32 (0.31-0.32)
Chloro-phyll *a* (µg/L)	Dry	1.58 (0.30-3.80)	2.57 (0.60-4.60)	-	-	-
	Wet	3.06 (0.50-8.00)	-	-	4.5 (1.00-8.00)	40.00 (19.00-61.00)

Tables 2.1 and 2.2 summarise the results for nutrients (nitrogen and phosphorus), chlorophyll, dissolved oxygen and water clarity. The water quality of the main body of Darwin Harbour is similar between the 1990-91 survey and the 2001-04 survey, indicating no deterioration in water condition over that time. The water quality of the main body of Darwin Harbour is similar to that in Shoal Bay. These are both large and open bodies of water that are exchanged with the open sea.

Concentrations of nutrients are low and are similar throughout the Harbour, with the exception of Buffalo Creek which receives treated wastewater and urban stormwater. In the dry season Buffalo Creek water quality is impacted by wastewater effluent, and in the wet season by both urban run-off as well as wastewater effluent. The concentration of total phosphorus and chlorophyll *a* in the creek is approximately ten times higher than that measured elsewhere, and total nitrogen four times higher.

Levels of dissolved oxygen are much the same throughout all sites sampled, with the Harbour's waters being well oxygenated. There is a tendency for tidal creeks to have lower oxygen levels due to organic material present in the creeks from nearby mangroves which consumes oxygen. The exception again being Buffalo Creek in the Shoal Bay region where DO levels in the creeks upper reaches can become low resulting in anoxic conditions as a consequence of effluent inputs.

The concentration of heavy metals and arsenic are very low throughout the harbour. Concentrations measured in 2001-03 are similar to or less than those measured in 1994-95, suggesting no increase of metals in the Harbour over this period. The concentration of all metals in the main body of the harbour is similar between the wet and dry periods.

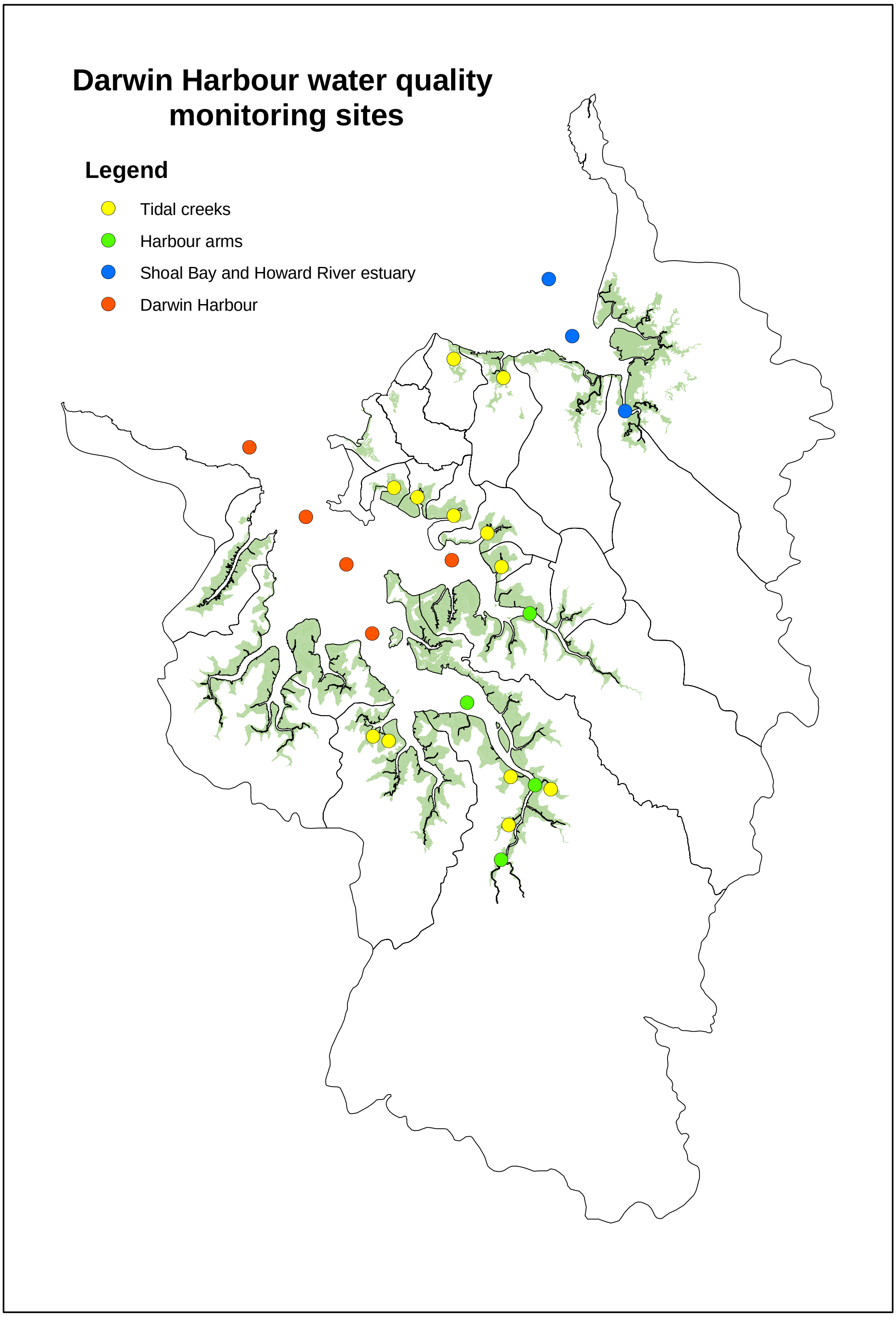


Figure 2.1: Ambient estuarine monitoring sites.

2.1 Ambient Freshwater Quality

Tropical rivers systems of northern Australia are recognised for their high ecological and cultural values. However, unlike their temperate Australian counterparts and many tropical systems elsewhere in the world and, these systems have largely unmodified flow regimes and are relatively free of impacts associated with intense development.

In the Darwin region the continued growth of urban and rural activities will place increasing pressure on the Harbour's waterways. Ongoing monitoring effort will need to inform waterway health assessment across the catchment and management actions to ensure beneficial uses are upheld. Further research and future trials of indicators for river health assessment in the wet/dry tropics is required. Any future assessment will need to be sensitive to the more subtle impacts that might be occurring within an ecosystem to enable early warning mechanisms and appropriate response.

The majority of river flow in the Darwin Harbour catchment is seasonal. Flow typically commences in December or January, peaks over the wet season, then declines during the early dry season months, ceasing to flow in the middle of the year (typically June). Wet season flow is principally supplied by surface runoff, whilst the remainder originates from groundwater. At this time of year, approximately 50% of the soils in the catchment become moderately to severely waterlogged, with low lying areas prone to flooding. As a result of waterlogging, up to 80% of rainfall during wet season months can be attributed to surface runoff.

The water quality of rivers and streams affects the types and the abundance of aquatic flora and fauna. There are many water quality parameters that could be monitored, but it is often not practical or cost-effective to monitor them all. The parameters monitored in the streams of the Darwin Harbour region are listed below, with explanations about their ecological significance.

Table 2.3. Water quality parameters monitored in the Darwin region.

Water Quality Parameter	Importance
Nitrogen	An important plant nutrient. Too much nitrogen in the form of oxidised nitrogen (nitrate and nitrite) and ammonia can lead to excessive plant growth. Total nitrogen is the sum of nitrite, nitrate and Total Kjeldhal Nitrogen, which is mainly organically bound nitrogen.
Phosphorus	An important plant nutrient. Too much phosphorus in the form of filterable reactive phosphate can lead to excessive plant growth.
Chlorophyll *a*	The green component of plants used in photosynthesis. Is used as an index of the amount (biomass) of algae.
Dissolved oxygen	Essential for all plant and animal processes. Prolonged periods of oxygen depletion can result in death of fish and other animals, and too much oxygen is a sign of increased plant/algal biomass due to nutrient enrichment.
Metals	Some are required at trace levels by organisms, but can be toxic at high levels. The concentration of metals may vary with local geology or anthropogenic sources (pollution).
Total suspended sediments	This is a measure of the amount of all material suspended in the water. This measure is sensitive to catchment erosion or disturbance of bottom sediments.
pH	The concentration of hydrogen ions, i.e. the acidity or alkalinity of water. A fundamental measure that determines metal solubility and toxicity, and affects an organisms ability to absorb minerals and nutrients.
Turbidity	A measure of the light scattering property of water as a result of material suspended in the water. Turbidity is correlated with suspended solids. It affects the amount of light available for photosynthesis by plants.
Conductivity	A measure of the amount of ionic materials (salts).

The water quality of streams is monitored at eight sites that drain catchments representing different land-uses (see Figure 2.2 showing hydrographic stations). This provides information about water quality that is typical over the period of flow and is used to calculate stream loads.

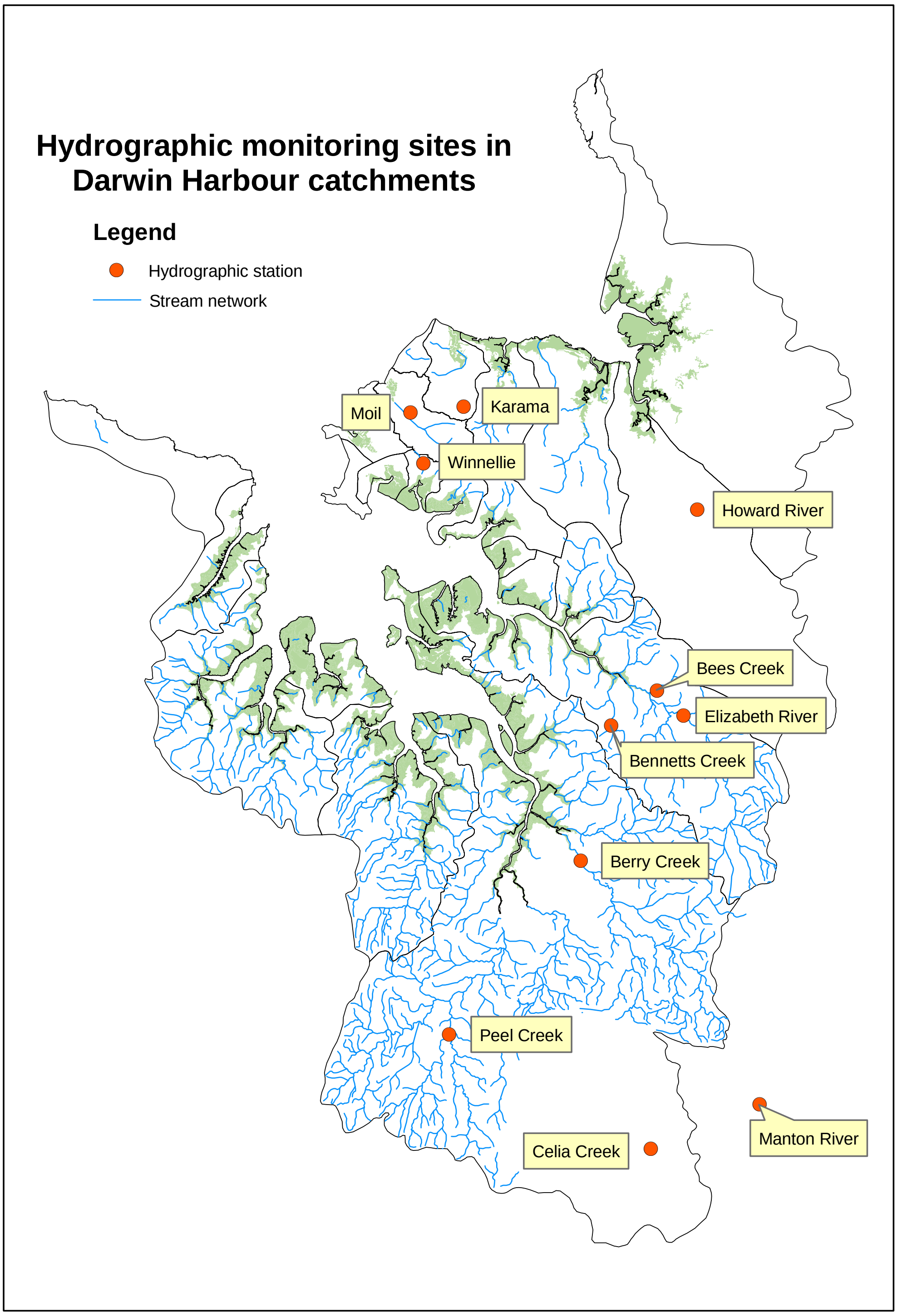


Figure 2.2: Hydrographic monitoring sites in the Darwin region catchment.

Table 2.4 summarises typical concentrations of nutrients, metals and suspended sediments measured in streams during the wet season. The undisturbed catchments are: Celia Creek and Manton River; rural catchments are Elizabeth River, Berry Creek and Bees Creek; the urban catchments are Moil and Karama drains; and the industrial catchment is Winnellie drain. There is little or no difference in concentrations between what is measured in the undisturbed and rural catchments. This may be due to the current level of rural development being insufficient to adversely affect streams.

Table 2.4. Typical concentrations* of nutrients, metals and suspended sediments measured in streams during the wet season. (Dash indicates that concentration was not measured, units explained below).

	Undisturbed	Rural	Urban	Industrial
Total Nitrogen (mg/L)	0.5	0.3	0.7	0.8
Total Phosphorus (mg/L)	0.03	0.01	0.07	0.21
Total Aluminium (μg/L)	-	357	-	684
Total Arsenic (μg/L)	0.3	0.3	0.6	2.2
Total Cadmium (μg/L)	0.1	0.1	0.2	0.4
Total Chromium (μg/L)	1	1	4	18
Total Copper (μg/L)	2	2	5	11
Total Iron (μg/L)	-	578	-	624
Total Manganese (μg/L)	-	13	-	19
Total Lead (μg/L)	1	1	27	16
Total Nickel (μg/L)	1	1	2	2
Total Zinc (μg/L)	1	9	54	167
Total Suspended Sediment (mg/L)	24	14	63	44
Organic Suspended Sediment (mg/L)#	5	3	20	9

**These concentrations are flow-weighted, meaning that they take into account the effect of flow volume on calculating average water quality.*

Table 2.5 summarises the water quality measures at these sites over a four-year period. The median values are presented, along with the range, to provide an indication of how water quality can fluctuate between years and sites. The concentrations of total nitrogen, phosphorus, metals and suspended sediment are low, with similar concentrations in urban and rural streams. Most metals are well within threshold limits recommended by Australian water quality guidelines. Some metals are naturally present at levels that exceed water quality guidelines (e.g. aluminium) but this is attributed to local geology rather than anthropogenic effects.

Table 2.5. Water quality at monitoring sites over a four-year period (2001-2004) during seasonal recession flow* (Source: Water Monitoring Branch, 2005).

Nutrients	Median (4 years)	Range (4 years) *
Total Nitrogen (mg/L)	0.22	0.074 – 1.72
Total Kjeldahl Nitrogen (mg/L)	0.23	<0.05 - 0.64
Oxidised Nitrogen (mg/L)	0.009	<0.001 - 0.35
Ammonia (mg/L)	0.008	<0.002 - 0.03
Total Phosphorus (mg/L)	0.007	0.001 - 0.040
Filterable Reactive Phosphate (mg/L)	<0.001	<0.001 - 0.003
Metals#		
Aluminium (μg/L)	85	4.8 - 180
Arsenic (μg/L)	0.5	<0.5 – 2.9
Cadmium (μg/L)	<0.1	<0.1
Chromium (μg/L)	0.5	<0.1 – 2.3
Copper (μg/L)	0.3	<0.5 – 5.4
Iron (μg/L)	470	230 – 6,400
Lead (μg/L)	0.3	<0.1 – 1.1
Manganese (μg/L)	13	1.9 – 190
Nickel (μg/L)	0.5	0.2 – 5
Zinc (μg/L)	0.9	<0.1 – 8.4
General		
Electrical conductivity (μS/cm)	35.2	6.8 – 451
pH (pH units)	6.6	5.1 – 7.8

Turbidity (NTU)	6.3	0.5 – 24
Dissolved oxygen (mg/L)	5.72	1.4 – 8.0
Chlorophyll *a* (μg/L)	2	0.1 – 19.0
Alkalinity (mg/L)	13.1	2.6 – 125
Bicarbonate (mg/L)	16	3.2 – 153
Calcium (mg/L)	2.7	0.2-22
Carbonate (mg/L)	0	0-2
Chloride (mg/L)	2	1-130
Fluoride (mg/L)	<0.1	0-0.1
Magnesium (mg/L)	1.1	0.2-16
Potassium (mg/L)	0.2	0-2.6
Sodium (mg/L)	2.3	1.0-65
Sulphate (mg/L)	1	0-17
Total hardness (mg/L)	10.6	1.8-121
Total suspended sediment (mg/L)	2	1-16

** Some samples were collected from large pools when the stream had stopped flowing. These samples sometimes had higher concentrations than samples collected when the stream was flowing. [#]Note: median metal concentrations for years 2001-2003.*

Wet season water quality is affected by urban land-use. It has higher nutrient, metal and sediment concentrations than the rural or other parts of the Darwin Harbour catchment. During recession flow in the streams at the end of the wet season, however, the water quality of the region's streams is typically good. It is low in nutrients, metals and sediment.

2.2 Ecological Health Monitoring

Further development of biological health indicators is required to determine the relationship between water quality and ecological health of ecosystems. Ecosystem health is inextricably linked to water quality and river flows. Water quality will continue to be used as a useful indicator of ecosystem health as it has important linkages with beneficial uses and water quality objectives.

The wet-dry tropical climate in the region is typified by a sequence of predictable periods of "flood" and "drought". These extremes pose both scientific and practical challenges for aquatic ecological health assessment. The nature of impacts on the aquatic environment are also fundamentally different from other parts of Australia. Large parts of the region have little intensive development, the regions catchment vegetation is reasonably well intact and only one regulated waterway exists. Waterway health can be threatened by more pervasive processes and identifying indicators which are capable of detecting early warning signs of degradation so that management action can focus on prevention will be important.

For freshwater systems in the Darwin region a series of water quality and biological monitoring sites have been established (Fig 2.3). These long term monitoring sites will be maintained and provide data for the assessment of ecological health in the region. In addition to the ongoing macroinvertebrate and water quality sampling, future monitoring effort will focus on trialling other potential bio-indicators such as fish, river metabolism and amphibians to name a few. Attributes of flow and habitat condition will also be incorporated into future monitoring effort and may include indicators such as riparian health and catchment disturbance.

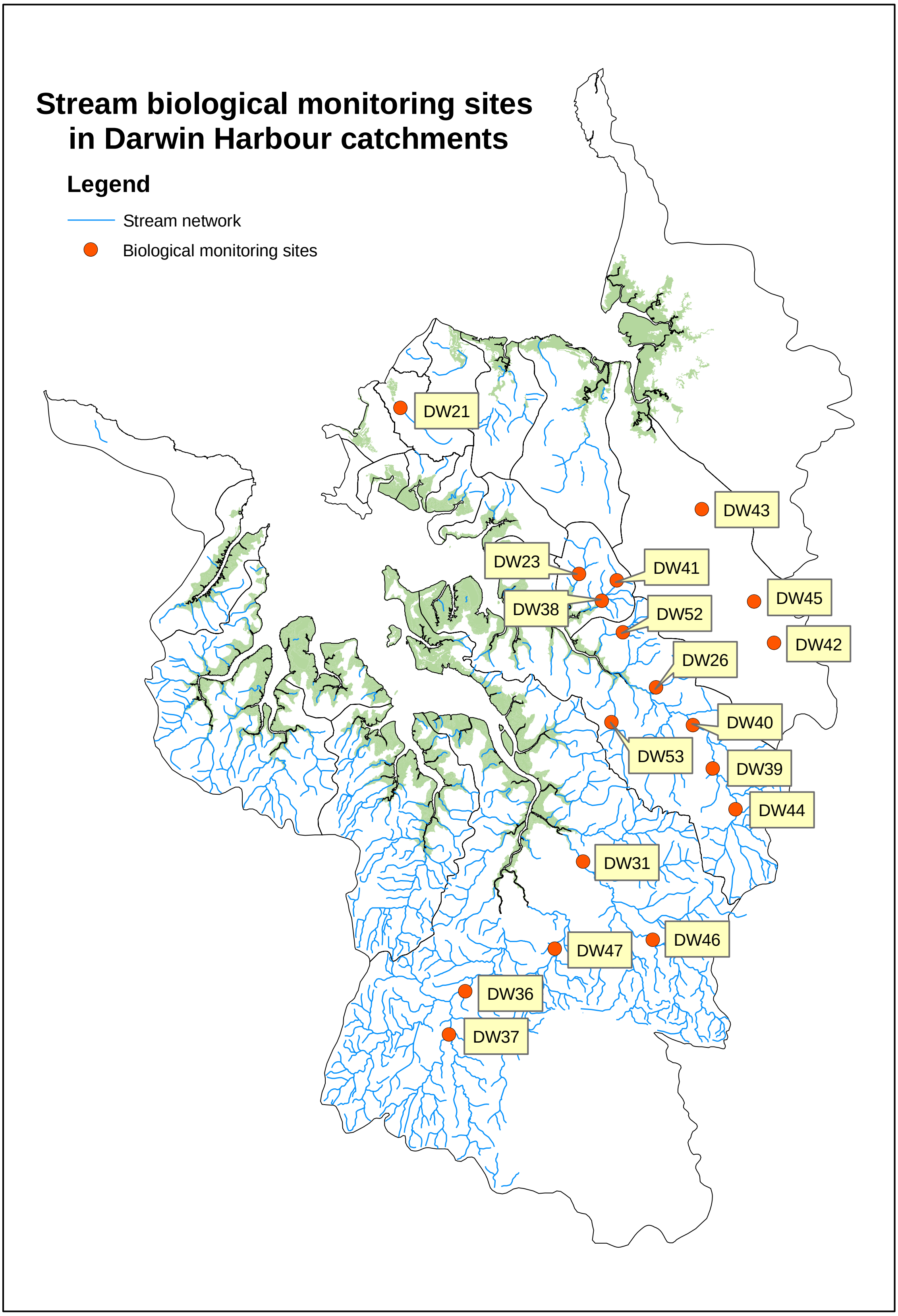


Figure 2.3: Biological Monitoring Sites in the Darwin Region.

Future trials of the Framework for Australian River and Wetland Health (FARWH) in the region present an opportunity to develop robust and efficient ecological health indicators which could be incorporated into freshwater monitoring programs for comparison across catchments, regions and utilised for national reporting and assessment.


Aquatic Health Unit staff undertaking macroinvertebrate sampling and electro-fishing in the urban catchment of Rapid Creek.

Currently there is no regular biological monitoring of the Darwin Harbour Estuary. Funds are being sought and collaborative partnerships developed to inform a trial project which will examine a suite of potential indicators for ongoing monitoring of aquatic ecosystems in the region.

2.2.1 Water Quality Mapping.

Chlorophyll-*a* (Chl *a*) is a pigment found in all photosynthetic organisms. It is an essential molecule for the process of photosynthesis. In surface waters Chl *a* is present in phytoplankton such as cyanbacteria, diatoms and dinoflagellates. Because it occurs in all phytoplankton it is commonly used as a measure of algal biomass.

Chl *a* is largely influenced by the availability of nutrients, light and optimal water temperature. Measuring Chl *a* provides an indication of nutrient and light conditions at the time of sampling and their resulting biological effect or biomass. Under conditions where nutrient concentration is high and light is available phytoplankton blooms can result. When these blooms decay, the resulting bacterial activity can reduce dissolved oxygen and in some cases result in fish kills.

Monitoring Chl *a* is an important and useful indicator for ongoing monitoring particularly in the vicinity of nutrient rich point source discharges where it can be exacerbated by limited mixing observed in the upper reaches of the estuary. Ongoing monitoring and the intensification of monitoring effort in these reaches will be undertaken to enable water quality mapping.

The use of spatial interpolation of water quality parameters will be used to estimate values for broader priority areas. This approach has advantages over just mapping point data. While it is not possible to monitor all locations, by undertaking spatial interpolation it is possible to estimate values across a region. The approach also allows us to measure the extent of human impact such as those associated with point or diffuse discharge and their expansion or contraction can inform ongoing management and the health of the waterway (Fig 2.4).

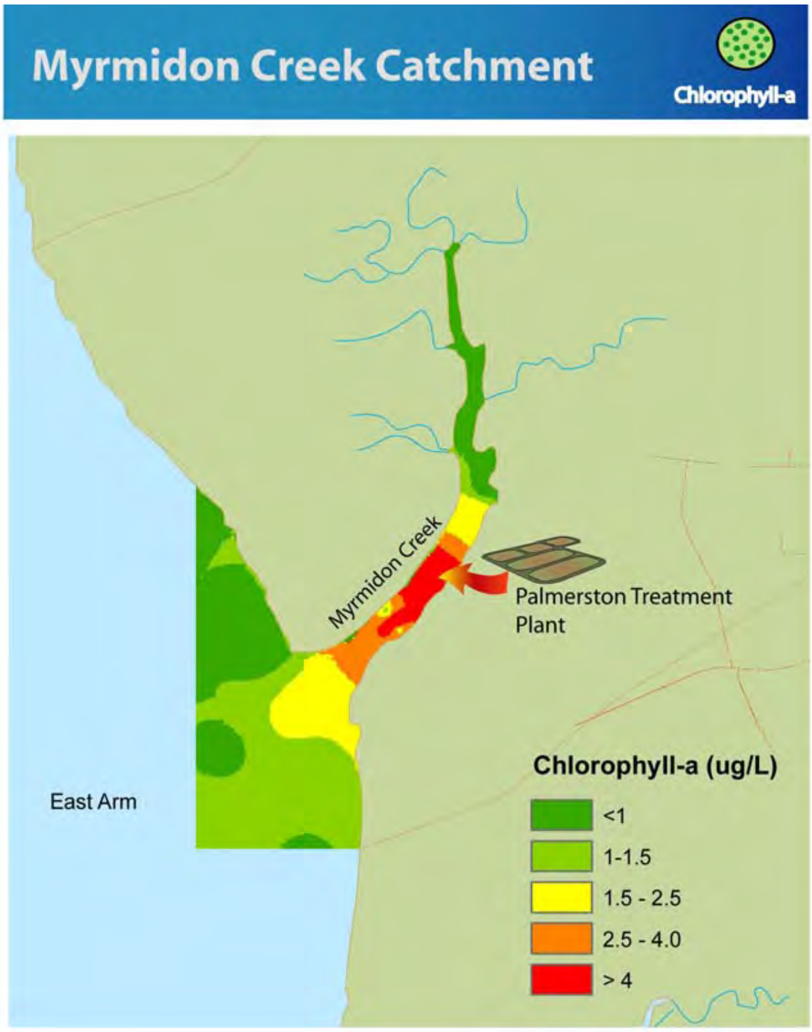


Figure 2.4: Use of spatial interpolation for Chlorophyll-a monitoring data of Myrmidon Creek.

Currently monitoring data for other priority zones such as Middle Arm and zones of the Blackmore River are being compiled for water quality mapping using water quality objectives as performance criteria to provide insight into estuarine health. The presentation of water quality maps will accompany future ecosystem health reporting in the region.

2.3 Priority Zones for Monitoring Focus

Although the waterways of the region are typically in good shape a number of zones show signs of localised impact. Future effort will focus on these systems and zones in the catchment to ensure WQOs are upheld and that any management measure is effectively maintaining water quality.

Priority estuary zones are highlighted below (Figure 2.5) and are typically associated with pressures from point source discharge, regions of limited flushing and more generally areas where data is limited. A number of priority freshwater systems are also identified for further monitoring effort.

2.3.1 Rationale for Priority Zones

Sources of nutrients include point-source discharges (particularly sewage discharges) and run-off from urban and rural areas present the greatest management issue for water quality in the region.

The key human activities which cause a change to the stressor ‘nutrients’, susceptibility factors, potential condition responses observed, indicators used to monitor changes in pressures on the system (i.e. the risk) and the condition of the system can be summarised below.

Table 2.6. Pressure-Stressor and Response to Nutrient Enrichment.

<table>
<tr><th>Pressure</th><th>Stressor</th><th colspan="2">Condition Response</th></tr>
<tr><td>Diffuse sources: catchment run-off (rural and urban)
Point sources: industrial/aquaculture discharge, sewage treatment plant discharge, dumping of wastewater
Sewage discharge from vessels</td><td>Nutrients</td><td>Physical-chemical condition</td><td>Biological condition</td></tr>
<tr><td colspan="2">Nutrients Loads
Increase in the amount of nutrients entering the system</td><td>↑ nutrient concentrations</td><td>↑ primary production → ↑ nuisance growth of aquatic plants or algae
→ ↑ algal blooms → ↑ anoxic and hypoxic events (eutrophication)
→ ↑ animal kills
→ ↑ toxic algal blooms → ↑ animal kills (due to toxins)
→ ↓ light penetration for plant growth (due to shading from algal blooms, macroalgae, macrophytes) → ↓ seagrass abundance
→ ↑ epiphyte growth → ↓ seagrass abundance</td></tr>
<tr><td colspan="4">Pressure indicators
Indicators of nutrient sources:
Pressure indicator 1: catchment land-use
Pressure indicator 2: % length of river system with no riparian vegetation
Pressure indicator 3 : ocurrence of sewage treatment plants
Pressure indicator 4: occurrence of sewage overflow events
Pressure indicator 5: presence of point sources (excluding STPs)

Indicators of direct pressure:
Pressure Indicator 1: total phosphorus load
Pressure Indicator 2: total nitrogen load</td></tr>
<tr><td colspan="4">Physical-chemical condition indicators

Condition indicator 1: ammonia
Condition indicator 2: organic nitrogen
Condition indicator 3: oxidised nitrogen
Condition indicator 4: total nitrogen
Condition indicator 5: filterable reactive phosphorus
Condition indicator 6: total phosphorus</td></tr>
<tr><td colspan="4">Biological condition indicators

Condition indicator 1: chlorophyll-a
Condition indicator 2: % epiphytic cover on seagrass or other benthic habitat.
Others to be developed.</td></tr>
<tr><td colspan="4">Susceptibility
Geomorphic setting (e.g. estuary type)
Estuary length and tidal range
Bioavailability, speciation of nutrient
Light availability
Residence times, flushing rates, dilution</td></tr>
</table>

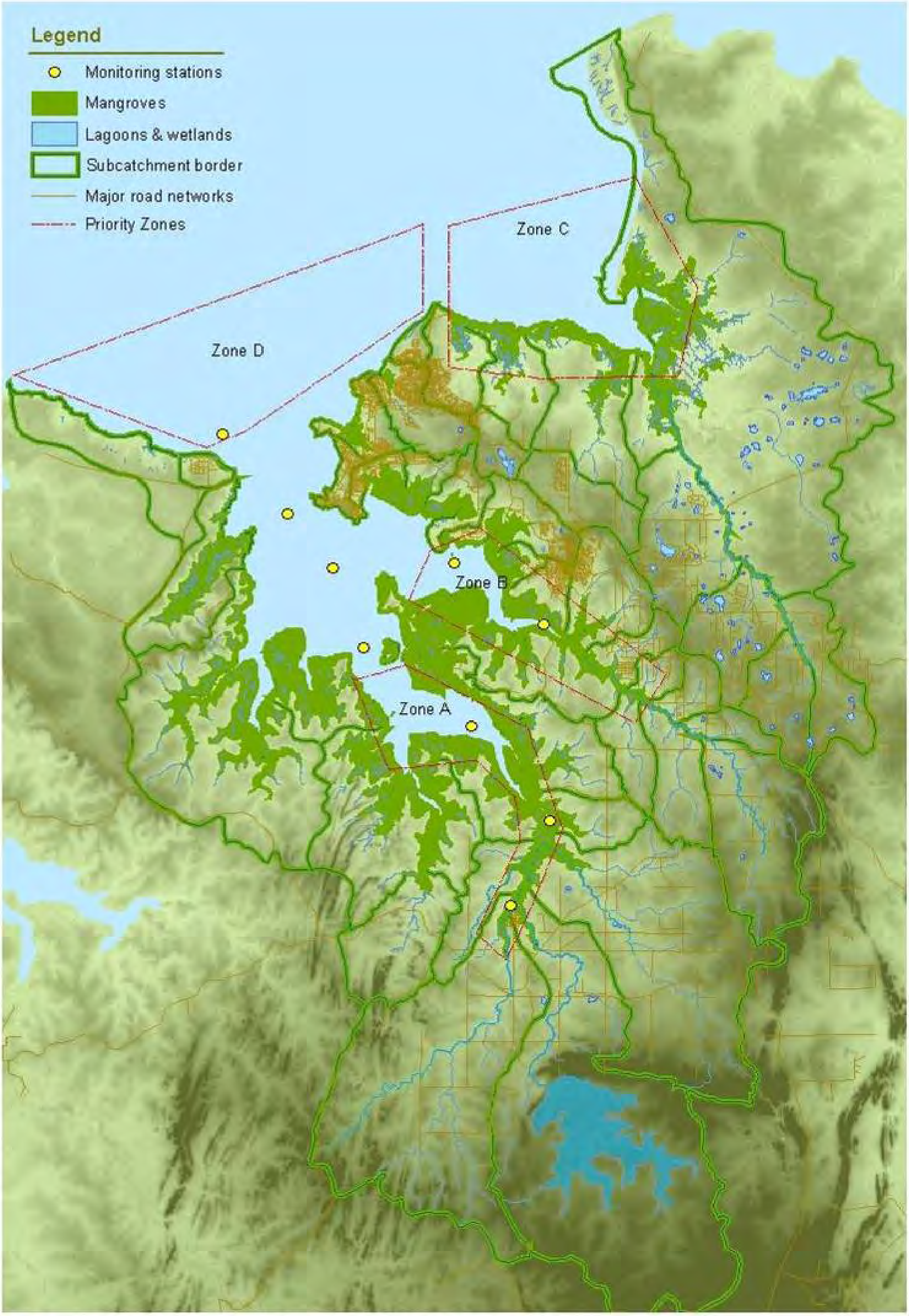


Figure 2.5: Priority zones for future monitoring and modelling effort.

2.3.2 Priority Zone Description.

Zone A: Middle Arm – Blackmore River

- Investigate modelling options within upper reaches where aquaculture discharge may be impacting the waterway.
- Ensure data collected under Waste Discharge Licensing is suitable for assessing loads.
- Chl-*a* mapping with a focus on wet and dry season variation.
- Water quality monitoring of priority indicators outlined in the Water Quality Objectives and report against these as performance indicators.
- Upper reaches likely to be immediately subject to nutrient and sediment inflows from the largest subcatchment.
- Monitoring over tidal and seasonal cycles.

Aquaculture operation

Zone B: East Arm – Elizabeth River

- Chl*a* mapping with a focus on wet and dry season variation.
- Water quality monitoring of priority indicators outlined in the Water Quality Objectives and report against these as performance indicators.
- Tidal Creeks receiving diffuse discharge over the wet season from urban developments in the Palmerston region.
- Tidal Creeks receiving point STP discharge (Myrmidon and Blesser Creek).
- Subject to increasing pressure from urban & industrial developments.
- Monitoring over tidal and seasonal cycles.

Treatment ponds

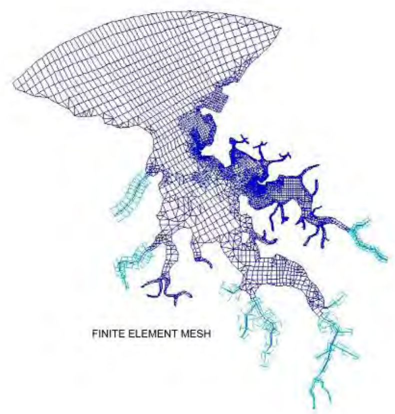
Zone C: Shoal Bay and its tributaries

- Intensify monitoring effort to build improved water quality dataset to inform water quality objectives.
- Tidal Creeks of Buffalo Creek (STP discharge),Micket Creek and Hope Inlet.

Zone D: Outer estuary

- Intensify monitoring effort to inform water quality objectives.

- Build on boundary condition dataset for modelling.



Targeted work for these priority areas will be explored further in future monitoring and modelling states.

Freshwater Priority Zones and Systems

- Howard River – aquifer subject to increasing pressure, groundwater dependent ecosystems, subject to Water Allocation Planning process (WAP).
- Berry Springs & Berry Creek – aquifer subject to increasing pressure, WAP process to be initiated.
- Elizabeth River – subject to greater rural residential development.
- Blackmore River – largest catchment, limited data available on some tributaries. Aquaculture based industry in the catchment.
- Rapid Creek – urban creek subject to increasing recreational pressures and urban/commercial development.
- Mitchell Creek catchment – location of show case WSUD implementation with Bellamack subdivision to be established.
- Effectiveness of bio-retention and wetland systems to be monitored. Provide scientific support for WSUD roll out for new 'greenfield' type developments.

Section 3. Water Quality Objectives for the region

3.0 Introduction

Water quality objectives (WQOs) and pollutant load targets have been developed and will be incorporated into ongoing monitoring programs as performance benchmarks for waterways across the catchment. WQOs have been derived for the environmental beneficial use of ecosystem protection and have been determined for a subset of physico-chemical indicators (Table 3.1).

3.1 Water Quality Indicators

It is expected that further amendments may address a wider range of indicators including biological and other habitat indicators. Data availability and relevance to the WQPP has restricted the range of indicators examined in this document however guideline values for toxicant indicators in water and sediment will continue to be sourced from ANZECC (2000) Guidelines. Local guidelines have been derived for physico-chemical indicators or stressors, and do not address toxicants (such as heavy metals). Health related indicators presented in the “The Development of Water Quality Objectives for the Darwin Harbour Region” document are sourced from the NT Dept of Health and Community Services Guidelines and/or the relevant National Guideline values.

Table 3.1: Physico-chemical Guideline indicators.

Guideline Indicators	
Dissolved Oxygen (DO)	O_2
pH	pH
Turbidity	
Nitrogen	N
Phosphorus	P
Chlorophyll-*a*	

WQOs have been generated from local reference catchments and sites and are based on the 20th and 80th percentiles for relevant water quality indicators. Current WQOs are based on ambient water quality and it is envisaged that event based WQOs will be developed as data becomes available. Further details of the approach to deriving WQOs are outlined in supporting documentation (Fortune & Maly, 2008).

3.2 Guidelines and Objectives

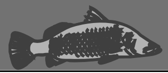
Water Quality Guidelines provide a threshold to assess whether a designated beneficial use or environmental value is being maintained. Water Quality Objectives are agreed between stakeholders as measures of management performance. Assuming the objective is to manage waters for their environmental beneficial use, then in most if not all waters it is logical that the water quality objective be set to equate the water quality guideline specific to the water type.

Currently water quality objectives are aligned with determined local guideline values for freshwater and estuarine systems in the Darwin Harbour region. However, in the case where a licensed point discharge exists and a corresponding mixing zone prevails the conditions and terms of the waste discharge licence (WDL) will administer requirements for water quality.

These proposed Water Quality Objectives should be used in conjunction with supporting information provided by the ANZECC Guidelines (ANZECC & ARMCANZ 2000).

Water Quality Guideline indicators proposed for each water body type is shown in Tables 3.2 - 3.4. The indicators monitored however, may be broader than those proposed to provide contextual information about the guideline indicator value (e.g. salinity, temperature).

Table 3.2: Proposed ambient guideline values and draft Water Quality Objectives for priority water quality indicators of the Darwin Harbour Region (Based on 80th and 20th percentiles of data from reference sites).

Indicator for Environmental Use: Aquatic Ecosystem Protection 	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams[b]	Aquifer Fed Springs	Lagoons	Groundwater
To maintain and protect the ecological condition of marine, estuarine and freshwater ecosystems of the Darwin Harbour Region.									
DO% saturation	Refer ANZECC (2000)	Refer ANZECC (2000)					To be determined	To be determined	-
Upper			100	100	100	100			
Lower			80	80	75	54			
Water Quality Objective	-	-	Maintain DO between 80-100% saturation	Maintain DO between 80-100% saturation	Maintain DO between 80-100% saturation	Maintain DO between 50-100% saturation	**-**	**-**	**-**
pH	Refer ANZECC (2000)	Refer ANZECC (2000)						To be determined	
Upper			8.5	8.5	8.5	7.5	8.0		8.0
Lower			7.0	7.0	6.0	6.0	7.0		7.0
Water Quality Objective	-	-	Maintain pH between 7.0-8.5	Maintain pH between 7.0-8.5	Maintain pH between 6-8.5	Maintain pH between 6.0-7.5	Maintain pH between 7.0 -8.0	**-**	Maintain pH between 7.0-8.0
Turbidity (NTU)	Refer ANZECC (2000)	Refer ANZECC (2000)	-	-	-	1-20	To be determined	1-4	-
Water Quality Objective	-	-	-	-	-	Maintain Turbidity <20 NTU	-	Maintain Turbidity <5 NTU	-
Conductivity (µS/cm)	Refer ANZECC (2000)	Refer ANZECC (2000)	-	-	-	20-200	320-390	n/a	350
Water Quality Objective	-	-	-	-	-	Maintain Conductivity <200 µS/cm	Maintain Natural Conductivity range	-	Maintain conductivity between 350-400 µS/cm

Indicator for Environmental Use: Aquatic Ecosystem Protection 	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams[b]	Aquifer Fed Springs	Lagoons	Groundwater
Nutrients (µg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)					To be determined	To be determined	-
Total N (µg N/L)			440[a]	270	300	80-225			
Water Quality Objective	-	-	Maintain TN<440µg/L	Maintain TN <270 µg/L	Maintain TN <300µg/L	Maintain TN <230 µg/L	-	-	-
NOx (µg N/L)			10	17	20	8	nd		nd
Water Quality Objective	-	-	Maintain NOx <10 µg/L	Maintain NOx <20µg/L	Maintain NOx <20 µg/L	Maintain NOx <8 µg/L	-	-	-
NH_3-N (µg/L)			20	20	20				
Water Quality Objective	-	-	Maintain Ammonia <20 µg/L	Maintain Ammonia <20 µg/L	Maintain Ammonia <20 µg/L	-	-	-	-
Total P (µg P/L)			16	20	26	10			
Water Quality Objective	-	-	Maintain TP <20 µg/L	Maintain TP <20 µg/L	Maintain TP <30µg/L	Maintain TP <10µg/L	-	-	-
FRP (µg P/L)			8[a]	5	9	5	To be determined	To be determined	
Water Quality Objective	-	-	Maintain FRP <10 µg/L	Maintain FRP <5 µg/L	Maintain FRP <10 µg/L	Maintain FRP <5 µg/L	-	-	-
Chla (µg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)	1	2	4	2	-	10	-
Water Quality Objective	-	-	Maintain Chl *a* <1 µg/L	Maintain Chl *a* <2 µg/L	Maintain Chl *a* <4 µg/L	Maintain Chl *a* <2 µg/L	-	Maintain Chl *a* <10 µg/L	-
TSS (mg/L)	-	-	6	6	10	5	-	-	-
Water Quality Objective	-	-	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <5mg//L	-	-	-

Indicator for Environmental Use: Aquatic Ecosystem Protection 	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams[b]	Aquifer Fed Springs	Lagoons	Groundwater
Possible Biological Indicators – Objectives yet to be determined									
Aquatic Macroinvertebrates						X	X	X	-
Fish						X	X	X	-
Algal biomass (Chlorophyll-a see above)	X	X	X	X	X	X	X	X	-
Polychaete/shellfish or other estuarine sp				X	X				-
Macrophyte/aquatic flora							X	X	-
Amphibians						X	X	X	
River Metabolism						X		X	
Mangrove intactness/extent				X	X				
Riparian Health						X	X	X	

[a]Limited data. [b] Derived from Fukuda & Townsend 2006.

Note A: Note that DO guidelines for freshwater should only be applied for flowing streams/waters. Stagnant pools in intermittent streams naturally experience low DO.

Note B: DO values less than 30% saturation is toxic to some fish species.

Note C: DO guidelines apply to daylight hours/conditions. Lower values occur at night.

Note D: Guidelines do not apply during high flow events associated with wet season conditions. ANZECC (2000) guidelines suggest that this is best addressed using load-based guidelines. These would be based on a reference approach and involve the assessment of loads in undisturbed catchments and using these as benchmarks for other catchments. Loads could be assessed through either direct measurement or through a calibrated model. Total Maximum Pollutant loads for N, P and TSS will be developed through the WQPP for the Darwin Harbour region using catchment loads data and modelling approaches.

Note E: The water quality objective will use the annual median as the performance measure for which indicators would be reported.

Note F: Biological indicators are yet to be developed. It is expected that pilot studies with a focus on potential indicators are explored for estuarine and marine ecosystems.

Table 3.3: Interim Recreational Guidelines and Objectives for Primary Contact.

Indicator for Protection of Cultural Use: Recreation Primary contact	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams	Aquifer Fed Springs	Lagoons	Groundwater
To maintain marine, estuarine and fresh water quality so that it is suitable for activities such as swimming and other direct water contact sports									
Biological									
Enterococci [a]	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	<50 Enterococci/ 100mL	NA
Water Quality Objective	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100mL	All samples to be less than or equal to 50 Enterococci/ 100 mL	All samples to be less than or equal to 50 Enterococci/ 100mL	
E.*coli*	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	<200 E.coli/100mL	NA
Water Quality Objective	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	No single sample greater than 200 E.coli/100mL	
Pathogenic Protozoans [b]	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/100mL	<10 pathogenic protozoans/100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	NA
Water Quality Objective	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/100mL	<10 pathogenic protozoans/100mL	<10 pathogenic protozoans/ 100mL	<10 pathogenic protozoans/ 100mL	
Toxicants	Refer to ANZECC & ARMCANZ Guidelines (2000)		Refer to ANZECC & ARMCANZ Guidelines (2000)			Refer to ANZECC & ARMCANZ Guidelines (2000)			NA

Note [a]: Enterococci is the preferred indicator, however until a robust enterococci data base is established in the NT, the use of E.coli is acceptable.
Note [b]: There is no generic test for pathogenic protozoans, however there may need to be specific testing for the following protozoans depending on the outcomes of a specific risk assessment process: Naegleria fowleri (preferred testing organism in fresh waters), Acanthamoeba spp, Entamoeba spp and Cryptosporidium.
Primary contact: Minimum of five samples taken at regular intervals for E.coli not exceeding one month, with four out of five samples containing less than 600 organisms/100mL (ANZECC 2000). The maximum number of enterococci organisms in any one sample: 450-700 organisms/100mL. According to the *Northern Territory Recreational Microbiological Water Quality Guidelines* action must be taken if Enterococci are detected above 50 organisms/100ml, but the water body remains open for swimming unless two consecutive samples within 24 hours detect >201 Enterococci/100ml.

The current National Health and Medical Research Council (NHMRC) *Guidelines for Managing Risks in Recreation Water,* do not consider waterborne infections a hazard for incidental (secondary) contact recreational use and therefore have not specified a microbiological indicator for this contact. Incidental contact is defined as boating, fishing and wading of adults, but excludes any recreational activities by children, these are always considered as primary contact.

Table 3.4: Proposed Guidelines and Objectives for Cultural Use of Aquatic Foods.

Indicator for Protection Cultural Use: Aquatic Foods	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams	Aquifer Fed Springs	Lagoons	Groundwater
To maintain water quality for the production and consumption of aquatic foods derived from aquaculture, recreational, commercial or indigenous food gathering.									NA
Biological (Applied to the consumption of aquatic foods)									
Guideline in shell fishing water									NA
Water Quality Objective	Median concentration of faecal coliform should not exceed 14 MPN/100mL (no more than 10% of the samples exceeding 43 MPN/100mL)					Median concentration of faecal coliform should not exceed 14 MPN/100mL (no more than 10% of the samples exceeding 43 MPN/100mL)			
Standard in edible tissue									NA
Water Quality Objective	Fish for human consumption should not exceed a limit of 2.3 MPN E.coli/g of flesh with a standard plate count of 100 000 organisms/g.					Fish for human consumption should not exceed a limit of 2.3 MPN E.coli/g of flesh with a standard plate count of 100 000 organisms/g.			
Toxicants [a]	Refer to ANZECC & ARMCANZ Guidelines (2000)		Refer to ANZECC & ARMCANZ Guidelines (2000)			Refer to ANZECC & ARMCANZ Guidelines (2000)			Refer to NHMRC Drinking Water Guidelines 2004

Note [a]: Toxicant guidelines indicated in ANZECC and ARMCANZ (2000) has been determined for the protection of aquaculture species. To protect the health of human consumers of aquatic foods the ANZECC & ARMCANZ Guidelines are intended to be used in conjunction with the Food Standards Code (FSANZ 2005). Updates available at www.anzfa.gov.au
MPN= Most probable number.

3.3 Risk based approach to Water Quality and Water Quality Objectives.

The recommended Water Quality Objectives for the defined estuarine segments and freshwater reaches within the Darwin region catchment are set to protect and maintain aquatic ecosystem health or environmental uses. The suggested use of the objectives is that their exceedance indicates a potential risk of adverse ecological effects. Exceedance of the objective indicates the requirement for further investigation or management action and can be summarised in the figure below.

The risk based approach is based on the recommendations of the NWQMS and focuses resources to where they are needed; to high risk situations for ecosystems. The package of Water Quality Objectives for assessing potential risks consists initially of a value (concentration/level) and a protocol to assess whether the objective is met. Where the objective is exceeded or impacts are unknown an adaptive decision-making framework determines further action initially commencing with further investigation that leads to an informed assessment of the potential risk (Fig 3.4).

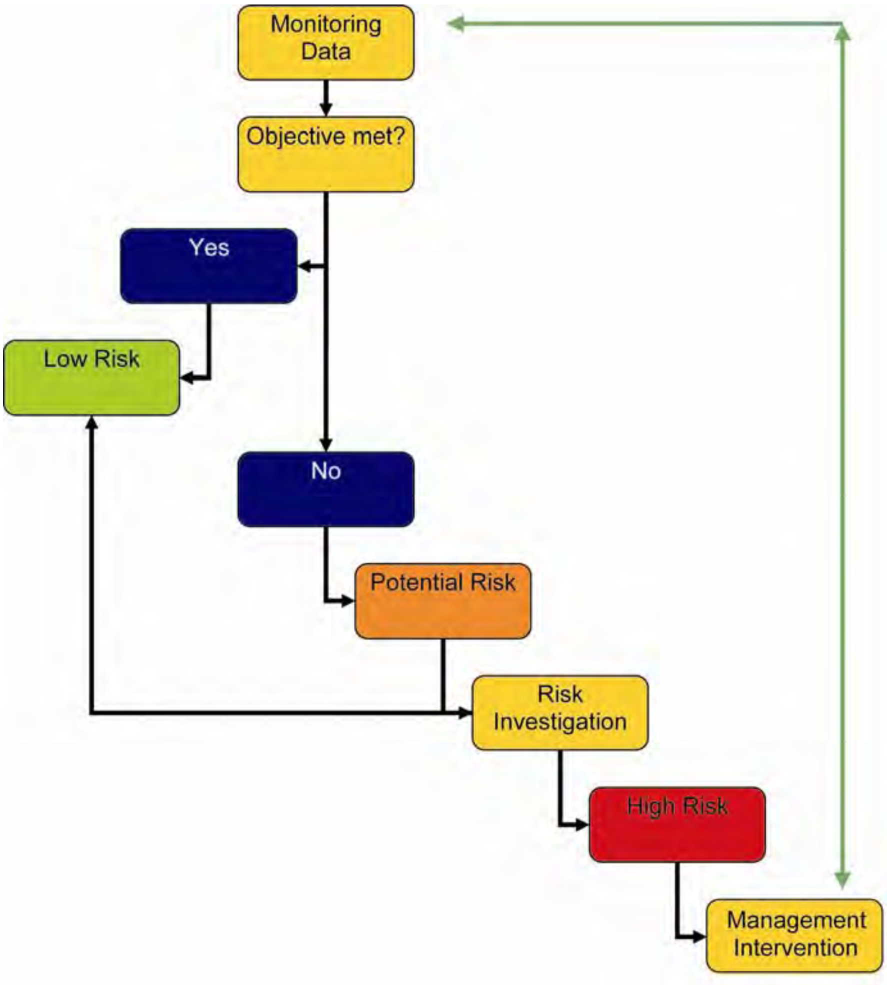


Figure 3.4: Risk Based Decision Framework and adaptive management.

In some environments the objectives may not be achievable in the short term. In these areas, regional targets and management actions should aim to provide realistic goals that accommodate the constraints of the waterway and the aspirations of the community. Management actions aim for progressive improvements towards maintaining Water Quality Objectives where a departure from the objectives may have occurred.

3.4 Application of the Water Quality Objectives.

For recommended Objectives to provide effective protection of water quality, a number of conditions need to be met in their application. A full assessment of water quality requires measurement of all relevant indicators and comparison to Objectives. It is not intended that the attainment of an objective should be evaluated based on 'one-off' samples but rather a longer term monitoring program. Further, these Objectives should only be used for evaluating ambient water quality in the Darwin region.

The paucity of data to characterise the condition of estuaries and other waterways in the region and across the NT is a key knowledge gap. The use of the NWQMS trigger values when applied as triggers for risk assessment will enable the development of water type specific objectives however a review of the level of protection for individual waterways would need to be carried out for areas beyond the Darwin region.

Section 4. Pollutant Load Assessment and Targets

4.0 Pollutant Load Assessment in the Darwin Region

It is vital to understand how the harbour's ecosystem works and how catchment loads emanating from a range of land uses impact ecosystem condition and other environmental values. Catchment loads have been estimated (Skinner *et al* 2008) and in conjunction with the development of a receiving water quality model for Darwin Harbour, will enable resource management agencies to determine the fate of nutrients and other pollutants in Darwin Harbour and set pollutant load targets which protect and maintain important beneficial uses.

Annual load determinations for the region were estimated using an empirical based approach where water quality and hydrographic data from gauged catchments were available. Using resultant export coefficients for urban and non-urban land-uses, loads were forecasted for a number of scenarios which were generated for a series of land-use developments. These loading scenarios were also applied to the Darwin Harbour Receiving Water Quality Model (DHRWQM) with results compared to the Water Quality Objectives determined for estuarine water types in the Darwin region.

It has been determined that the process of urban development on the landscape approximately doubles the volume of runoff in any given wet season compared to an undisturbed landscape. In addition pollutant loads increase with rainfall due to the increased runoff volume across all catchment land-uses; hence more runoff results in more pollutant transport. Riparian vegetation, the prevalence of lagoons and the general low relief of the rural area most probably act to retain a significant proportion of sediment bound pollutants, mitigating the impact potential of the more intensive rural land-uses from otherwise higher pollutant loads to Darwin Harbour.

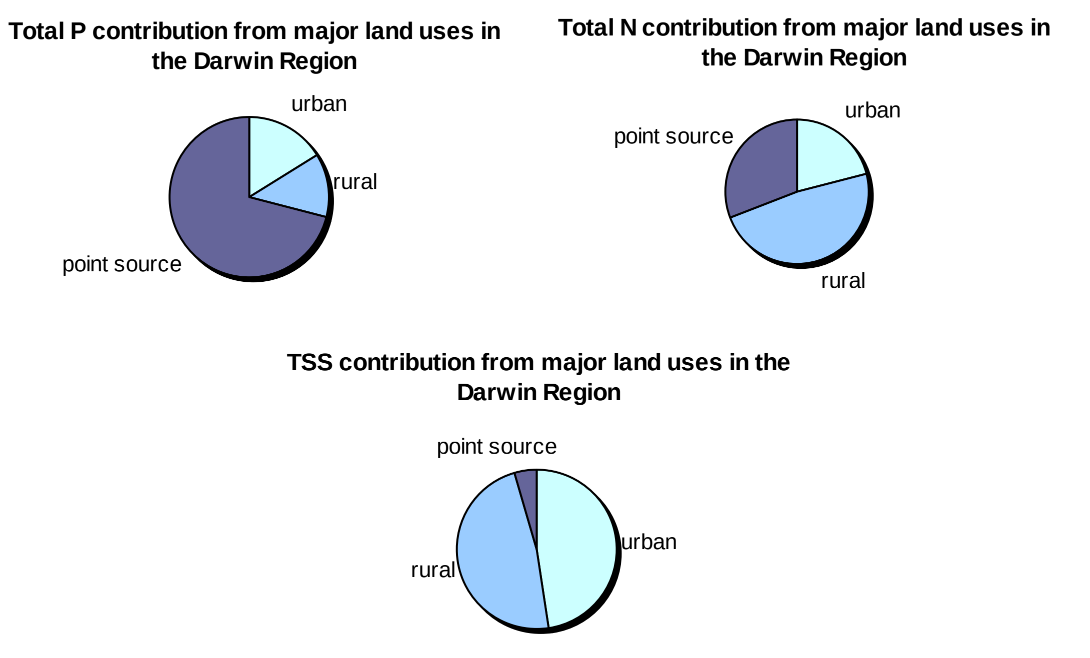


Figure 4.1: Contribution of diffuse and point sources to Darwin Harbour.

Estimated pollutant loads from urban land-use were higher than rural and undeveloped catchments when expressed as an export coefficient (mass/area/wet season) and standardised for rainfall. Nitrogen and phosphorus export coefficients were, respectively, 3 and 12 fold higher from urban areas. Sediment coefficients were 8 fold higher, while urban metal loads were more than 10 fold higher for lead, zinc and copper, and 3 – 7 fold higher for the other metals when compared to non-urban values. Although urban land-use represents only a small proportion of the catchment of Darwin Harbour, this land-use contributes a disproportionate load of pollutants to the harbour.

4.1 Point Source and Diffuse Loads

As well as diffuse source pollution loads, point source loads enter Darwin Harbour, mainly from wastewater treatment plants. At close to average wet season rainfall, diffuse loads were the main source of sediment to Darwin Harbour. More significantly, however was the estimated contribution from point sources with up to 71% of phosphorus input from wastewater point sources (Table 4.1). A substantial proportion of nitrogen entering Darwin Harbour, where algal growth is most likely to be nitrogen limited, is also from wastewater discharge. Wastewater nitrogen load was estimated to contribute up to 31% of the overall annual load to the Harbour.

Table 4.1. Annual pollutant load discharges from wastewater treatment plants (Power Water Corporation 2006) and comparison to 2006/07 catchment loads.

Wastewater treatment plant	Pollutant Load (tonnes)		
	TSS	N	P
Berrimah	25	4	1.4
Larrakeyah	275	58	12
Leanyer/Sanderson	717	79	43
Ludmilla	482	112	28
Palmerston	181	69	18
Wastewater contribution to loads	1680	321	102
Wastewater (% of grand total)	***5***	***31***	***71***
Urban	17528	217	23
Rural	17595	505	19
Catchment contribution to loads	35123	722	42.0
Catchment (% of grand total)	***95***	***69***	***29***
Grand Total	**36803**	**1043**	**144**

The highest loads entering Darwin Harbour emanated from the Blackmore and Howard Rivers due to their large catchment areas (Fig 4.2). Urban areas contributed a disproportionate pollutant load to Darwin Harbour particularly for the soluble fraction nutrients such as filterable reactive phosphorus and nitrate. Diffuse sediment loads were significantly greater than loads from wastewater treatment plants. In contrast, wastewater nitrogen and phosphorus loads, relative to catchment loads, were a significant source of nutrients to Darwin Harbour, particularly for their phosphorus contribution.

On a whole of harbour scale, the contributions from diffuse runoff and point source sewage discharges to the overall nutrient status of the harbour are relatively moderate when compared to recent data which suggests a net import of nutrient from oceanic sources (Burford *et al* 2008). However, current research suggests that the effects of point and diffuse sources of nutrients may be significant at more local scales such as in the tidal creeks or the upper reaches of the estuary where point source nutrient are discharged. Point source contribution is significant, particularly for Phosphorus. A doubling of the population could result in a substantial increase in annual nutrient loads. Consequently point source contribution of phosphorus could assume up to 80% of the annual load and up to 50% of nitrogen load to the Harbour.

4.2 Load Scenarios for Future Development

Further development of Darwin Harbour catchment for urban and industrial land-use in a 'business as usual' mode will increase nutrient, metal and sediment loads to Darwin Harbour. The Lyons, Muirhead and Bellamack-Rosebery developments are, based on existing export coefficients, predicted to increase pollutant loads to the harbour by between 0.2-1.2%. At a local scale, the increase of pollutant loads for the Buffalo Creek catchment is predicted to be 4 - 8% and 7 - 20% from the Mitchell Creek catchment. The projected longer term and larger urban developments have the potential for a more significant impact, with a predicted increase of 31 – 107 % increase in pollutant loads to the Harbour based on the 'business-as-usual' approach. However, water sensitive urban design, the implementation of stormwater management measures, best practice management and other intervention actions can combine to reduce this otherwise extrapolated load to Darwin Harbour.

4.3 Seasonal Variation in Pollutant Loads

Flood events can transport a large proportion of the annual load over a wet season and the 'first flush' events are significant. Storms and localised flooding events occur throughout the wet season, typically between January and March. In excess of 70% of the annual loads of TN and TP can be attributed to these large events (Kernohan & Townsend 2000; Eyre & Pont 2003). As a consequence 75% of the annual nutrient load in the catchment is transported in less than 20% of the time. This contrasts with typical temperate systems where it takes 50% or more of the time to deliver 75% of the annual load (Eyre & Pont 2003). Rainfall intensity and duration of storm events plays a significant role in the delivery of pollutants and their availability in ensuing events.

The predicted annual pollutant loads entering Darwin Harbour are directly proportional to the annual rainfall due to the methodology employed. There can be an almost three fold increase in the load of pollutants entering Darwin Harbour over the range of wet season rainfalls (Table 4.2). The loads calculated for typical wet season rainfall have been adopted for the annual load targets.

Table 4.2. Predicted pollutant loads entering Darwin Harbour during below average, average and above average wet season rainfall.

Pollutant	Low rainfall (1.0 m)	Average rainfall (1. 7 m)	High rainfall (2.7 m)
Rainfall (m)	1.01	1.67	2.67
N (t)	413	722	1150
P (t)	22.7	42.0	67.1
TSS (t)	20500	35100	56200

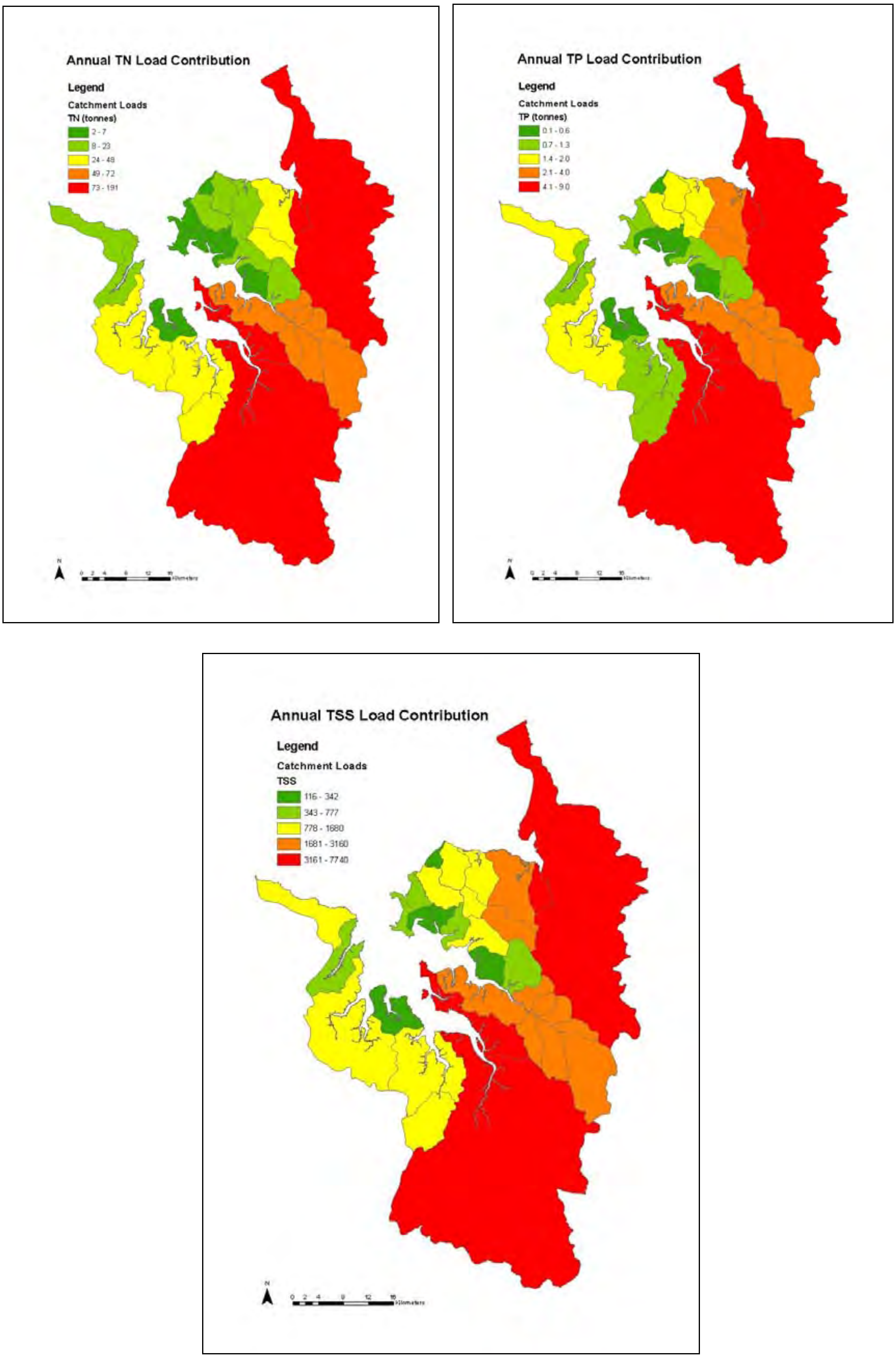


Figure 4.2: Catchment zone contribution to Annual Loads for Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS).

4.4 End of Catchment and Subcatchment Loads

End of catchment loads for 2007 as 'current condition' will be used as part of deriving future targets. Annual load reductions or in this case maintaining a 'business as usual' target is more appropriate in the region than daily reductions or limits such Total Daily Maximum Loads – TDML. The significant variation in flow experienced between wet and dry seasons make the use of this approach invariably difficult. Large daily flows associated with specific events also occur within a wet season.

4.5 Interim Catchment Targets and Uncertainty.

A summary of the diffuse end of sub-catchment loads for Water Quality Objectives (WQOs) are presented in Table 4.3. Future event monitoring in the catchment and modelling data will be compared against these targets.

The end of subcatchment loads presented include diffuse and point source pollutant loads. Subcatchments of Myrmidon, Ludmilla, Darwin CBD, Buffalo and Blesser all include point sources associated with wastewater treatment plants which add significantly to typical diffuse loads from these areas.

Contributions from internal loadings, particularly for phosphorus are difficult to quantify at this stage. As a consequence of material budget research recently undertaken some estimation for nitrogen loadings have been made and these appear to be significant in the case of Darwin Harbour (See Section 7, Figure 1). In the interim, focus on the assessment of loads will be on those from diffuse and point sources. As more data is available on the additional contribution of internal loads this will be incorporated to revised load targets for the region.

Table 4.3. Darwin Harbour region end of subcatchment loads (TN & TP, TSS tonnes/yr) for Water Quality Objectives.

Catchment/Drainage Basin	N tonnes	P tonnes	TSS tonnes
Blackmore	191	9	7740
Bleeser	11	2	498
Buffalo	98	45	2187
Charles Point	23	2	1340
Creek A (Middle Arm)	4	0.1	122
Darwin CBD	64	13	721
Elizabeth East Arm	72	4	3100
Howard	174	9	7720
Hudson	14	1	1010
Kings	48	4	3160
Ludmilla	124	29	1413
Micket	20	2	1220
Mitchell	14	1	737
Myrmidon	71	18	297
Palmerston Sth	5	0.4	339
Pioneer Ck Middle Arm	35	1	1240
Rapid	22	2	1680
Reichardt	4	0.4	310
Sadgroves	5	0.4	342
Sandy	4	0.4	282
West Arm	39	2	1500
Woods Inlet	14	1	777
Total	**1055**	**146**	**37735**

4.6 Annual Load Targets and Current Condition

To account for uncertainty in estimating pollutant loads particularly ecosystem processes and at times a lack of monitoring data it has been determined that a reasonable interim margin of safety (MOS) might be 25%. It should be noted that this is a conservative assumption applied only to the cumulative diffuse and point source contributions. Errors associated with determining internal loads are difficult to quantify. However based on current research the large tidal movements into the harbour bring ocean bound nutrients which in contrast to land-based diffuse or point source is significant. However the effect of point sources of nutrient may be significant at smaller scales such as in tidal creeks where effort is continuing to understand this. Table 4.4 indicates proposed total annual pollutant load targets for the region with the omission of internal loading contribution. Comparison of current loads and targets for pollutant sources is provided in Table 4.5.

Table 4.4. The annual regional load targets with for end of catchment sediment and nutrients loads to Darwin Harbour.

Pollutant	Maximum Pollutant Load Targets (tonnes)*
TN	**1304**
TP	**180**
TSS	**47169**

**Point and diffuse sources only with MOS*

Table 4.5. Current condition and end of catchment load targets for pollutant sources (tonnes).

Pollutant	Source	Current Condition	Maximum Pollutant Load Target
TN	Diffuse	722	903
	Point	321	401
TP	Diffuse	42	52
	Point	102	128
TSS	Diffuse	36055	45069
	Point	1680	2100

Current loads are within the upper targets determined for major pollutants. Maintaining this ‘Business as Usual’ or current condition target should be adopted with catchment load targets representing the uppermost trigger for pollutant loads.

Section 5. Flow Objectives for the Darwin Region

5.0 Summary

This section examines the determination of environmental flow objectives for waterways of the Darwin Harbour region and their role in the water quality management process which recognises that environmental flows are important in maintaining and restoring ecological processes and biodiversity of aquatic ecosystems. Further information on flow objectives are detailed in the document 'Towards Flow Objectives for the Darwin Harbour Region' (Fortune, 2008).

Currently there is no surface water extraction from either seasonal or perennial systems (Howard River and Berry Creek). However groundwater associated with the Howard aquifer system is being utilised for urban and rural domestic supply.

Interim flow objectives have been recommended and are detailed within this section. These broader qualitative objectives are suggested on an interim basis until the Water Allocation process currently taking place in the region is complete. A natural flow regime is recommended for all naturally seasonal and perennial streams. The exceptions are urban streams and the lower reaches of the Darwin River which is modified by Darwin River Dam and dry season releases from the reservoir.

5.1 Introduction

Despite the fact that Australia's tropical rivers and groundwater systems are estimated to contain roughly 70% of Australia's fresh water resources (Land and Water Australia 2005), and even though almost 50% of Australia's average annual run-off enters the Gulf of Carpentaria and the Timor Sea (ABS 2003), relatively little perennial water exists in this region.

Part of the reason for this is that rainfall in the region is highly seasonal, though the seasonal distribution of rainfall is predictable. Parts of the tropical rivers region, including Darwin, receive on average more than 1200mm of rain each year. Other areas of the country receive less than 650mm per year. The majority of this rainfall normally occurs during the wet season and many areas of the north go without any rain for months at a time during the dry.

Clearly the amount of water that is available for human use is not solely dependent upon annual rainfall. Temperature, solar radiation and vegetation also affect the amount of water that subsequently flows into surface water resources and replenishes groundwater sources. Nonetheless, highly variable rainfall leads to highly variable river flows and Australian river systems, notably in arid Australia, are the most variable in the world (Puckridge *et al* 1998). As indicated in Figure 1, regions such as Darwin with wet season rainfall have few perennial rivers. A large proportion of the rivers in the Top End region are essentially dry sandy creek beds for most of the year only flowing during the wet season.

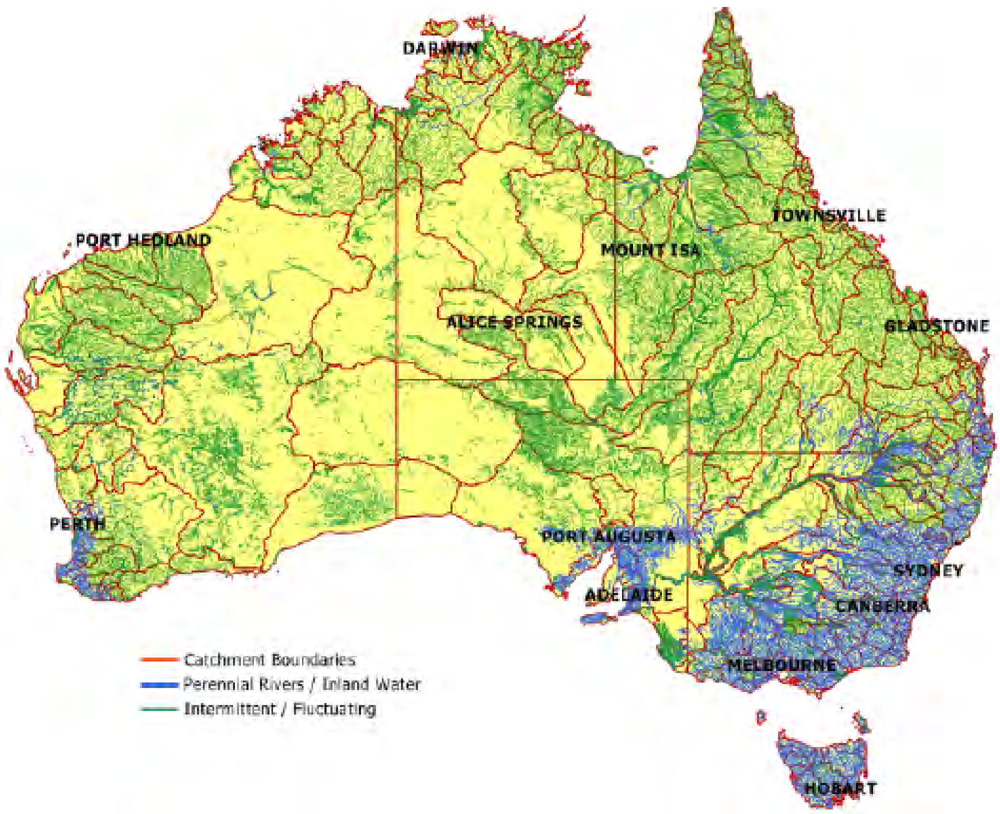


Figure 5.1: Intermittent and Perennial Water in Australia. (Data Copyright Commonwealth of Australia – available from Geoscience Australia).

Perennial surface water is relatively scarce across vast tracts of the Top End. It is not surprising that there is a close correlation between the presence of perennial river systems and the concentration of population within Australia. Therefore, striking the balance between the water resource needs of the population and environment remains a fundamental issue particularly in the south east of the continent (Fig 5.2). However, this is also a growing concern in the tropical rivers region with increasing interest in future development and population pressures that this will bring. For the most part however the rivers in the region are largely unmodified and the hydrological changes that have occurred in the region are generally considered as either minor or moderate.

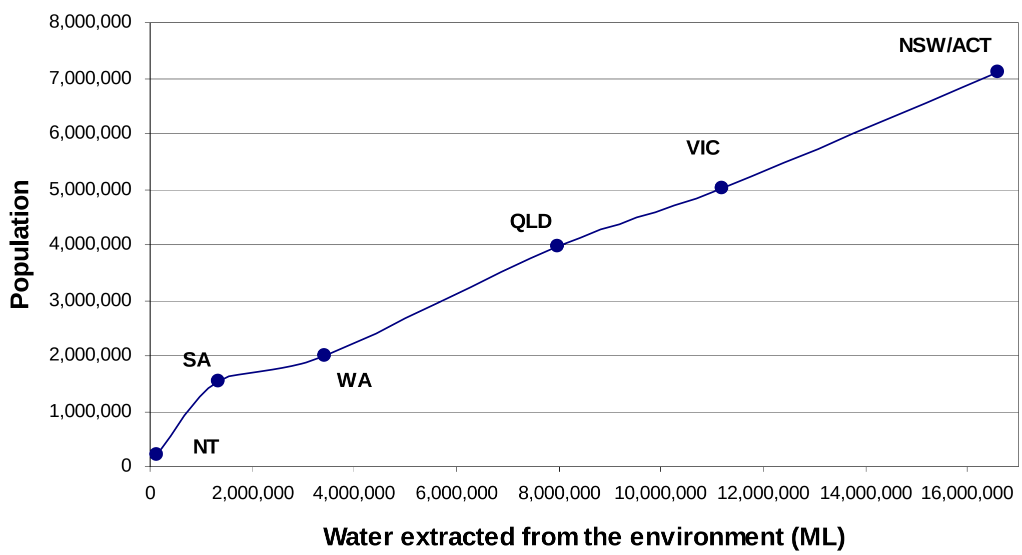


Figure 5.2: Water extraction and population – mainland states 2004-5. (Source: ABS 2004)

5.2 Aquifer Productivity in the Top End

There are many aquifers throughout Australia – some of which are highly productive and many of which are accessible by those living in the Top End. Many of the aquifers in the tropical north are highly productive and offer a viable alternative to surface water and are often used as such (eg. for urban irrigation, stock or human consumption). Water resources in the region are not solely comprised of rivers, wetlands and estuaries. Aquifers can and are used to supplement surface water supplies and are an important part of the region's total water resources.

Aquifer productivity and surface water supply is highly variable across the Northern Territory (Fig 5.3). Catchments across the north vary in size, some like Darwin Harbour are quite small, whilst others are large. The extent of perennial flowing surface waters varies considerably and many basins have highly productive aquifers whilst others are moderate to low. Despite the presence of some highly productive aquifers in the region, their existence does not indicate an unlimited supply of water. Many aquifers although highly productive have been assessed as 'fully exploited' (NGIS Australia 2004), this is particularly the case in the Queensland Gulf area. Therefore the absence of significant quantities of perennial surface water may well continue to serve as a binding constraint for future development in the region despite the presence of aquifers.

A key characteristic of most river systems in the tropical north is that flows are largely 'seasonal'. While there is an abundance of water supply during the wet season there is a significant restraint in the dry, and aquifer supplies do not always offer viable alternatives particularly if they are fully exploited.

The very nature of waterways in the Northern Territory poses a number of restrictions and questions as to how we mange river systems and determine environmental flows. The ability to cope with scarcity and with extremely variable water supplies both geographic and temporal will require ongoing responsiveness. Further characterisation and understanding of these highly variable river networks and the interaction of ground and surface water systems is required to meet the needs of water users and the environment.

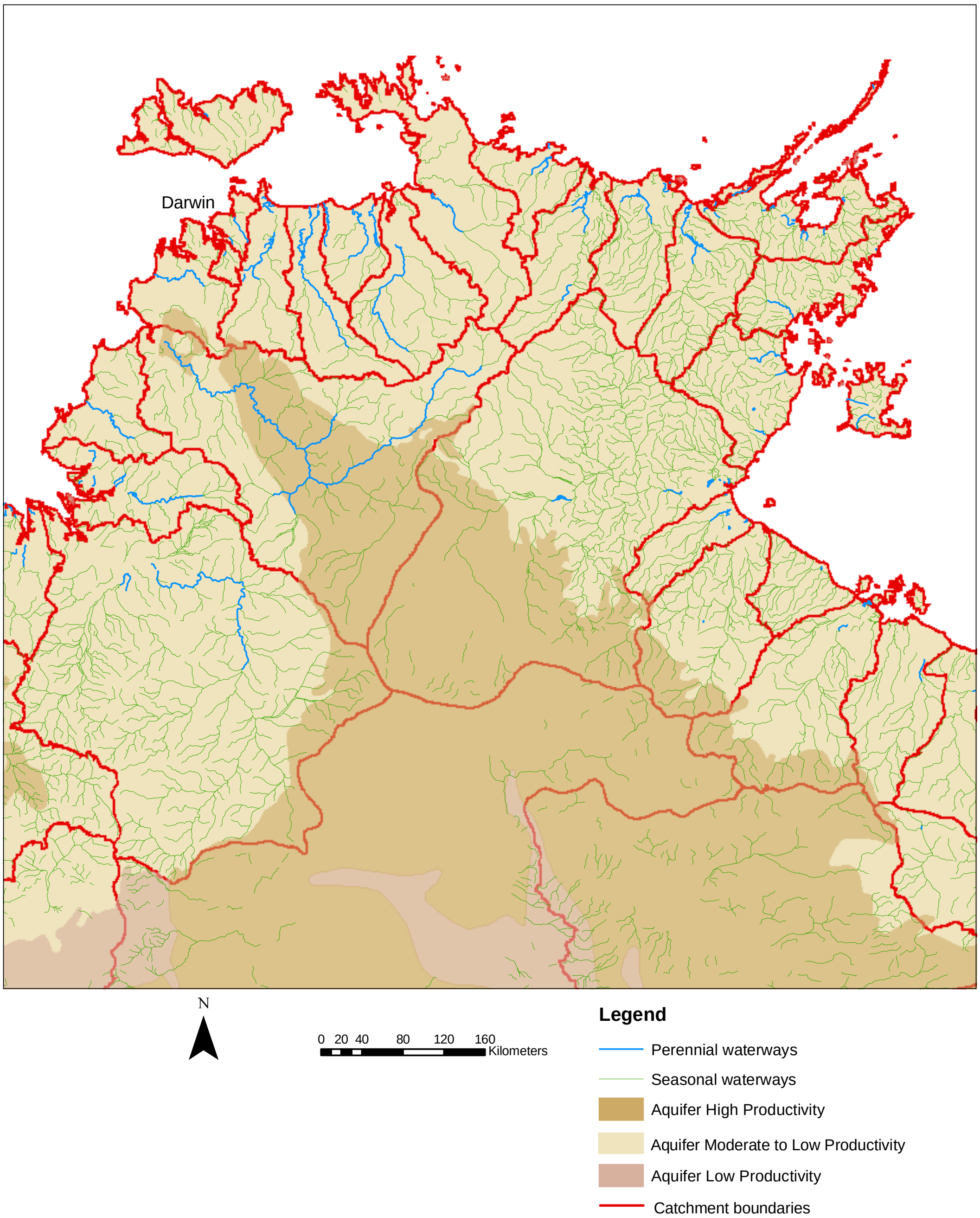


Figure 5.3: Aquifer productivity, perennial and seasonal river networks in the NT.

5.3 Surface Water in the Darwin Region

5.3.1 Rainfall & Climate

The Darwin Region has a monsoonal climate with rainfall occurring primarily between the months of November and March. Following the wet season is a period of up to 7 months with little or no rain. The most continuous rainfall record available is from Darwin Airport where recorded daily rainfall data is available from 1870 to the present. The average annual rainfall at Darwin Airport is 1,700 mm and ranges from about 1,000 to 2,600 mm per year. Mean monthly rainfall ranges from 410 mm in January to less than 5 mm in the months of June, July and August (Cook *et al* 1998). The total annual rainfall in the Darwin Region for the period from 1965 to 2005 is shown below in Figure 5.4. The dates shown are for the rain year from September to August.

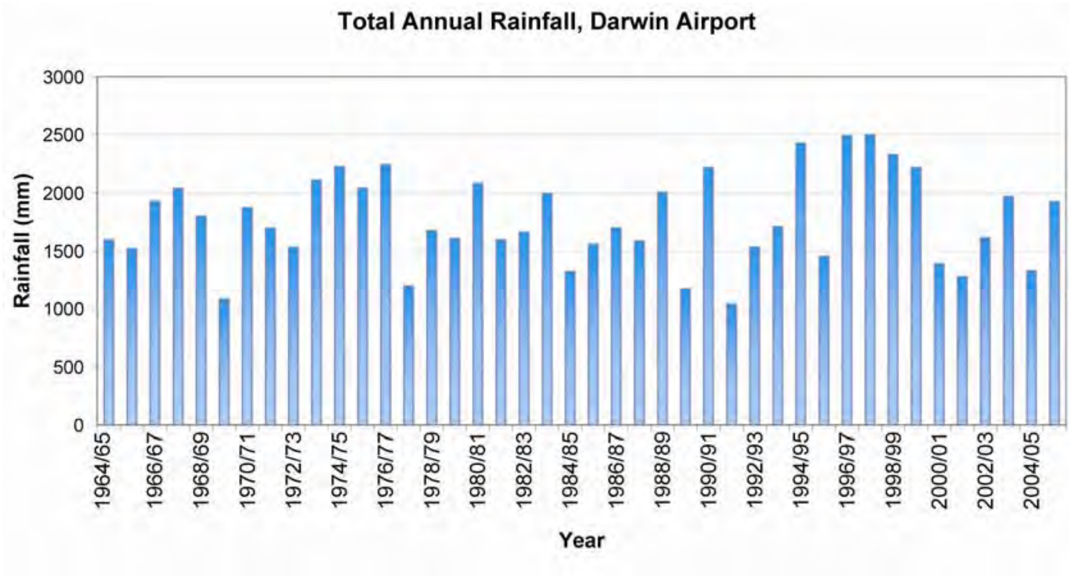


Figure 5.4: Total annual rainfall from Darwin Airport, 1965 to 2005.

5.3.2 Seasonal Runoff Pattern

The majority of river flow in the Darwin Harbour catchment is seasonal. Flow typically commences in December or January, peaks over the wet season, then declines during the early dry season months, ceasing to flow in the middle of the year (typically June). Wet season flow is principally supplied by surface runoff, whilst the remainder originates from groundwater. At this time of year, approximately 50% of the soils in the catchment become moderately to severely waterlogged, with low lying areas prone to flooding. As a result of waterlogging, up to 80% of rainfall during wet season months can be attributed to surface runoff (Hatton *et al* 1997).

In the early part of the dry season, when storm activity becomes infrequent, surface runoff ceases, and flow in the rivers is supplied predominantly from groundwater in shallow laterite and cretaceous sandstone aquifers.

As the groundwater table declines, so too does river flow, such that by the end of June, most rivers and streams have ceased flowing, reduced to a series of pools or a dry river bed. Some notable exceptions, however, are the lower Howard River and Berry Creek, downstream of the Berry Springs, which continue to flow throughout the dry season supplied from a deep dolomitic aquifer. Berry Springs supplies Berry Creek during the dry season, and is valued for its distinctive monsoon rainforest and spring fed pools. In some years, when the groundwater table is low, these same perennial rivers and streams may cease flowing for a short period at the end of the dry season.

The seasonal nature of intermittent streams in the catchment is further highlighted in Figure 5.5(a) and 5.5(b). Peel creek is like most ephemeral systems in the catchment ceasing to flow by June most years.

Figure 5.5(a). Peel Creek crossing Dry season. **Figure 5.5 (b).**Peel Creek crossing Wet season.

5.3.3 Impacts of surface runoff

The volume of runoff not only increases with wet season rainfall, but also catchment development, notably urbanisation, due to the increased area of impervious surfaces and greater hydraulic efficiency of the drainage system. In these cases, the runoff coefficient can more than double. For example, when annual rainfall was 1730 mm, runoff in the urban catchment of Karama was 78% (Townsend 1992), more than double the average for the more rural catchments of the Howard River (33%, Hatton *et al 1*997) and the Elizabeth River (37% Townsend 1992). Urban land-use in the Darwin Harbour catchment, however, is only minor (2.7%, Water Monitoring Branch 2005), and the impact on the Harbour's waters and mangroves appears to be localised.

Another impact of urbanisation is the increased frequency of storm runoff events, especially small storms, and the higher rates of river rise during the storms. This is of particular ecological significance, because storm runoff events scour the river channel, thereby modifying the physical habitat of the river, and remove flora (eg. attached algae) and fauna (eg. macroinvertebrates) from the river.

An inventory of culverts in the rural region has revealed a significant number of structures which could present potential barriers to fish passage and altered stream habitat and flow (Lamche, 2005). No information is currently available on the impact of culverts and floodways on surface hydrology or local fish populations. A study to investigate fish migration is of some importance and such work would be paramount in the development of any guidelines for fish passage.

Late dry season fires, that reduce canopy and ground cover, have been shown to indirectly affect catchment hydrology by increasing the frequency of episodic runoff events prior to seasonal stream flow (Townsend and Douglas 2000). These events are characterised by poor water quality, and could have a detrimental impact on receiving waters such as river pools and estuaries. The reduction of ground and canopy cover, by modification of the land-use in the Harbour's catchment, may result in a similar hydrologic impact to late dry season burning. The hydrographic records for the Elizabeth and Howard Rivers, however, indicate that this is not occurring at a large catchment scale (eg. 100 km^2), but the phenomenon may be occurring at a smaller catchment scale (eg. 10 km^2).

5.3.4 Regulated Systems in the Region

Darwin River Dam, which supplies potable water for the Darwin, Palmerston and part of the rural area, is the only reservoir in the catchment area. The dam's catchment constitutes 23 % of the Blackmore River catchment, and by storing and diverting water, reduces freshwater runoff into the River's estuary. Between 1974 and 2003 Darwin River flowed over the dam's spillway during 14 of 29 wet seasons (Haig & Townsend 2003). Overflow typically commences in February, and lasts for 3 months. Between 1985 and 1996, a period that included several below average rainfall wet seasons, the reservoir did not flow over the spillway. During the dry season, a small volume of water is released to maintain a minimum flow of 40 litres/sec in Darwin River downstream of the dam, otherwise river flow would be seasonal.

5.3.5 Stream Gauge Monitoring

There are a total of 43 hydrographic sites in the catchment where stream flow measurements have been recorded, however only a subset of these is water quality enabled (Section 2, Figure 2.2). Seven of the sites are currently equipped with time series data loggers which provide a continuous record of water level (and indirectly flow) measurements. Gauging of major waterways within the catchment will allow the ongoing monitoring of flow for environmental flow requirements.

5.3.6 Lagoons of the Darwin region

At the end of the dry season, there are areas of wetland that persist after the surrounding region has been drained of shallow groundwater. This phenomenon is often seen as the formation of a "perched lagoon" in areas where depressions in the ground surface has caused the impounding of wet season rainfall. The base of the wetland has a layer of organic mud that acts as a semi-impermeable boundary. The rate of evaporation of the lagoons is approximately 2 metres per year. In comparison, the regional water table drops from 8 to 10 metres from the peak of the wet season to the end of the dry season. As a result, the shallow depressions, which form the "perched lagoons", are left above the water table. There are numerous examples of this phenomenon throughout the Howard River region. Some of the better know occurrences are Knuckey's, McMinns, Lambells and Girraween lagoons (Fig 5.6a -5.6b). Whether all lagoons in the region are "perched" has not been assessed.

Over 137 lagoons have been identified in the Darwin region (Schult 2004). The water levels of lagoons surveyed in 2004 to 2005 indicated distinct seasonal changes. Generally water levels declined at a similar rate to evaporation, although some declined faster or slower due to the differences in vegetation and the localised influences of shallow groundwater aquifers (Schult & Welch 2006).

These wetland systems across the region are also important 'break-out' features which can connect waterways during the wet season and play a distinct ecological role in the environment. These lagoons support an array of fauna and flora and are a haven for visiting water birds from adjacent woodlands and coastal environments. This network of lagoons provides important feeding and breeding grounds across the landscape. Evaluation of their extent and dependence on flow, from both sources of surface and groundwater are the focus of further study which will assist the determination of appropriate environmental flows.

Figure 5.6(a): McMinns Lagoon.

Figure 5.6(b): Girraween Lagoon.

A project is underway in the Darwin region to trial the National Framework for the assessment of River and Wetland Health (FARWH) and indicators for wetland extent, distribution and condition. Lagoons in the region have been chosen as the subject of this assessment.

The framework proposes 6 themes for assessment: catchment disturbance; hydrological disturbance, water and soil quality; physical form; fringing vegetation; and biota. The methodology proposed includes the use of indicators, reference condition, range standardisation, integration and spatial aggregation of indices and sensitivity analysis.

Domestic water extraction from lagoons is not licensed and there is limited knowledge on current or historical unlicensed lagoon water extraction on few lagoons (Lamche, 2008). Data available on lagoon water extraction is based on license data only which is limited. The public water supply in the rural region is largely from deep bores that enter aquifers. These are lower (15m depth and below) than the depth of the perched lagoons and it is generally accepted that this supply does not directly impact on the hydrology of the lagoons (Schult & Welch 2006, Haig & Townsend 2003).

5.4 Groundwater

5.4.1 Regional aquifers

Weathered sediments make up a regional unconfined aquifer system that is recharged by direct infiltration during the wet season. Recharge occurs during the wet season through direct infiltration of the weathered profile. In some areas, the overlying cretaceous sediments provide a source of recharge and storage to the deeper bedrock aquifers (Haig & Townsend 2003).

The ability of the different bedrock units to act as groundwater aquifers is dependent upon the degree of primary or secondary permeability. In the eastern portion of the catchment that extends from Gunn Point to Darwin River Dam, there are a series of highly convoluted, steeply dipping dolomite, siltstone, shales and schist (Haig & Townsend 2003). The best producing deep aquifers in this area are found in the weathered horizon above fractured dolomite and carbonate rocks.

The major aquifer in this area is the Koolpinyah dolomite, which lies beneath most of the Howard River Catchment. The bore field at McMinns and the proposed Howard East extension is located on this aquifer. The Koolpinyah dolomite is considered to be a high yielding aquifer with typical production rates of greater than 5 litres per second. Lower yielding groundwater supplies of 0.5 to 5 litres per second are found in the fractured and weathered siltstone, shale and schist. Most regional aquifers typically yield water of good quality.

5.4.2 Groundwater level changes due to development

Lowering of groundwater levels as a result of development has been identified in the rural catchments of the region. Figure 5.7 is a hydrograph of monitoring bore RN004221, which is located in the centre of concentrated development in the Howard Region. During the period of drier wet seasons from 1983 to 1992, the water level dropped a total of 10 metres. Compared to the undeveloped area, end of dry season water levels have dropped an additional 8 metres. The additional lowering of groundwater levels can be attributed to the increased development in the rural area since 1980. Figure 5.8 is a plot of drawdown contours from the combined effects of the domestic, agricultural and municipal bores in the area around McMinns and Girraween Lagoons.

The Department of Natural Resources, Environment, the Arts and Sport is currently developing a groundwater model of the aquifer system in the Howard River catchment. The purpose of the model is to develop a better understanding of the dynamics of the aquifer regime. The model can also be used to predict various impacts to the aquifer as a result of rural development. This planning tool will be an integral part of the Water Allocation Planning process currently underway in the region and will allows us to better understand natural flow requirements of the Howard system and the pressures of resource use.

The estimates from the model are consistent with the measurements from monitoring bore RN004221 (Figure 5.7), where the end of dry season water levels has dropped by 8 to 10 metres. It should also be noted that although at the end of dry season water levels have been lowered, the aquifer system has usually recharged fully subsequent to periods of above average rainfall.

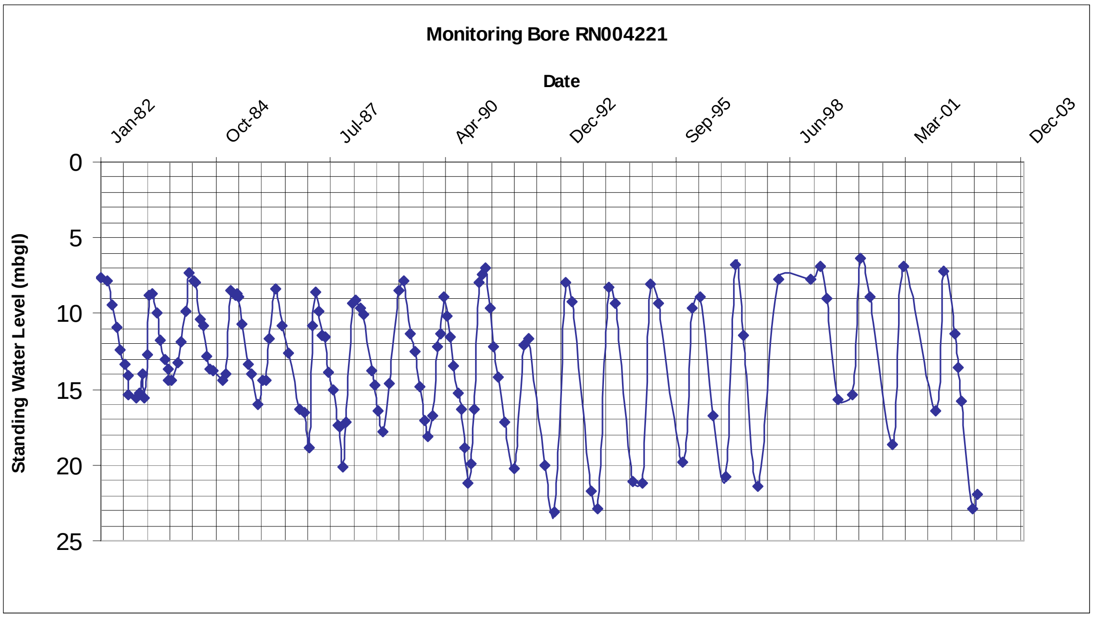


Figure 5.7. Hydrograph of monitoring bore inside the area of rural development (1982-2002).

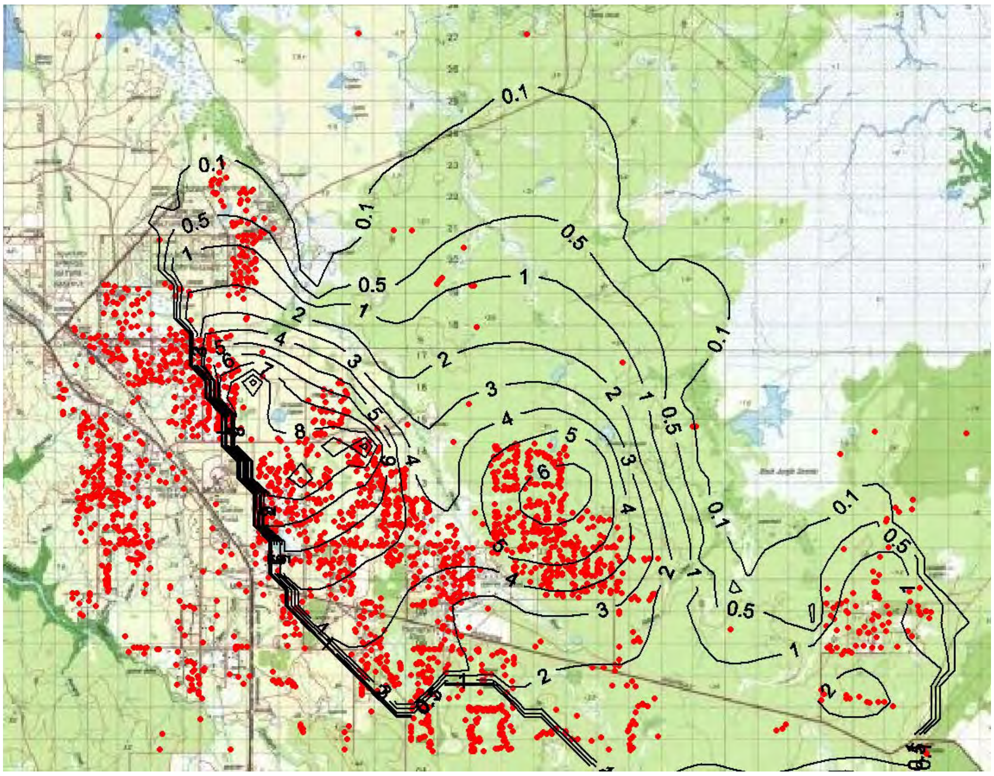


Figure 5.8. Drawdown contours due to rural development (Source: Haig & Townsend 2003).

5.5 Environmental Flow Determination in the Darwin Region

Due to the limited impact of development in the Darwin region, where there is only one major dam, the approach to environmental flow is one of ‘passive’ management. This constitutes the maintenance of flows as they occur. Currently there is no surface water extraction from either seasonal or perennial systems (Howard River and Berry Creek) however productive groundwater aquifer’s associated with the Howard system may be approaching the point of full exploitation.

A ‘Water Allocation Planning’ process is currently underway in the Darwin-Rural region and will explore the impact of groundwater use in the Howard Bore field through groundwater modelling and metering. These projects are vital to quantifying current demands and future supply needs. It is expected that this process will be completed in 2010, when outcomes of the planning process, modelling and groundwater dependent ecosystem research are finalised. This process in conjunction with a NHT funded project to determine the environmental and cultural water requirements of the Howard River is expected to present a sound approach to the determination of environmental flows for perennial river systems in the region.

Water requirements will be determined for fish in the Howard River with findings contributing to the determination of flow requirements and derivation of appropriate performance indicators. The project has recently document the use and importance of water resources to various Indigenous and non-Indigenous groups and assessed the impacts to social and cultural values of increased water use and other threats in the Howard River region (Woodward et al 2008).

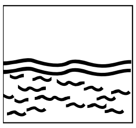
Once the environmental water requirements are known, environmental water provisions can be identified in the water allocation plan so that the environmental water requirements for the groundwater dependent ecosystem are protected. It is only when these provisions are formally adopted that the groundwater dependent ecosystem will be protected by the Water Allocation Plan.

The need to further characterise the complex ground and surface water interactions in this region in the face of growing population pressures is pertinent. The determination of flow requirements which meet ecological targets will follow research and monitoring projects in the area in 2010 and be integrated into the future Water Quality Protection Plan (WQPP).

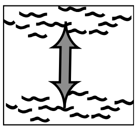
5.6 Interim Flows Objectives

Based on current knowledge of both perennial and seasonal systems within the Darwin region catchment and recognising the highly variable nature of flow in the region a set of generally accepted qualitative flow objectives can be drawn.

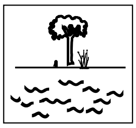
General interim objectives:



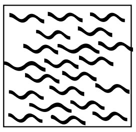
1. Protect natural flow regimes (Dry and wet season flow regimes).



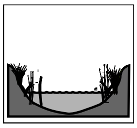
2. Maintain natural variability (A system should retain its perennial or seasonal nature).



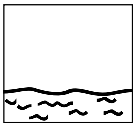
3. Manage groundwater for ecosystems.



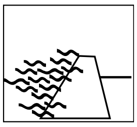
4. Protect important rises in water levels – important wet season flows.



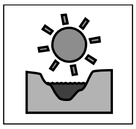
5. Maintain seasonal wetland/floodplain inundation.



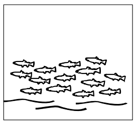
6. Protect natural low flows (perennial systems).



7. Minimise the effect of weirs/dams or other structures on flow



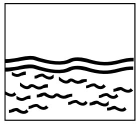
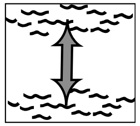
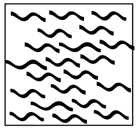
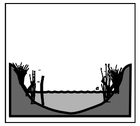
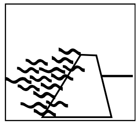
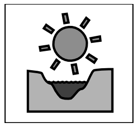
8. Emulate natural drying in seasonal waterways.

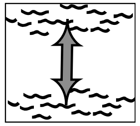
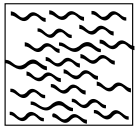
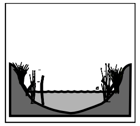
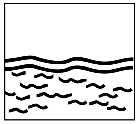
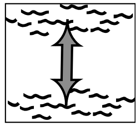
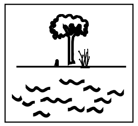


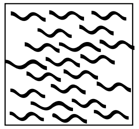
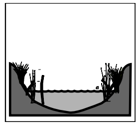
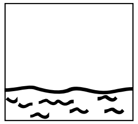
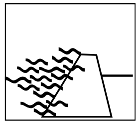
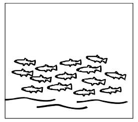
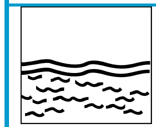
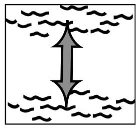
9. Maintain flow requirements for aquatic biota.

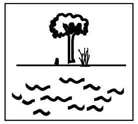
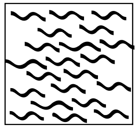
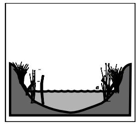
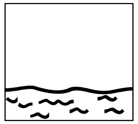
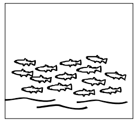
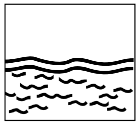
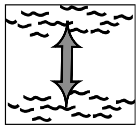
Specific flow objectives will follow research currently underway on the Howard River to assess specific ecological flow requirements of this perennial system of significance. The perennial stretch of Berry Creek is located within Berry Springs Nature Reserve and by virtue of its conservation status is protected. However, production bores in the vicinity of the springs will need to be managed to ensure that aquifers are not exploited.

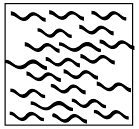
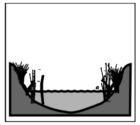
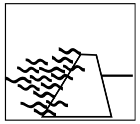
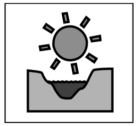
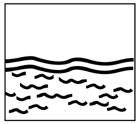
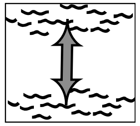
Table 5.1. Interim Flow Objectives for Darwin Harbour Region waterways.

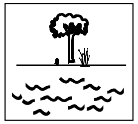
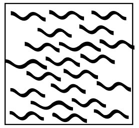
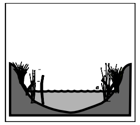
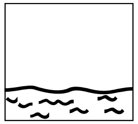
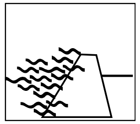
RIVER FLOW OBJECTIVE	SEGMENT OF WATERWAY	PROPOSED FLOW REGIME
 Protect natural flow regimes: (Wet season flow regime)	All seasonal streams and waterways (All are currently not regulated). Eg. Elizabeth River, Bees Creek, Bennett and Peel Creeks.	Maintain near-natural flow regime, not modified.
 Maintain Natural variability		
 Protect important rises in water levels		
 Maintain seasonal wetland/floodplain inundation		
 Minimise the effect of weirs/dams or other structures on flow		
 Emulate natural drying in seasonal waterways		

 Maintain Natural variability  Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation	**Darwin River** – downstream of dam structure/spillway.	Maintain minimum flow of 40L/sec as required by licence. (Allocation currently under review). Modified system
 Protect natural flow regimes (Dry and Wet season flow regimes)  Maintain Natural variability  Manage groundwater for ecosystems	**Berry Creek** (Berry Springs – downstream of creek refer Fig 5.9).	Maintain near-natural, not modified Environmental flow requirements for biota to be assessed.

 Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation  Protect natural low flows (perennial systems)  Minimise the effect of weirs/dams or other structures on flow  Maintain flow requirements for aquatic biota.		
 Protect natural flow regimes (Dry and Wet season flow regimes)  Maintain Natural variability	Howard River perennial segment (Refer Fig 5.9)	Near-natural, not modified Environmental flow requirements for fish will be met by current research to be completed in 2009.

 Manage groundwater for ecosystems  Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation  Protect natural low flows (perennial systems)  Maintain flow requirements for aquatic biota.		
 Protect natural flow regimes (Wet season flow regime)  Maintain Natural variability	Urban Streams Rapid Creek – modified (2 weir structures within freshwater section) Mitchell Creek - drainage modification due to development	Maintain near-natural flow regime

 Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation  Minimise the effect of weirs/dams or other structures on flow  Emulate natural drying in seasonal waterways		
 Protect natural flow regimes (Dry season flow regime and Wet season flow regime).  Maintain natural variability	Springs in Darwin region Palm Creek at Holmes Jungle Hudson Creek Howard Springs Berry Springs Melacca Creek Spring – Koolpinyah Banka Spring Black Jungle Spring Elizabeth River Catchment springs Litchfield Creek spring Parsons Springs Acacia Springs (Tien, 2006)	Maintain near-natural flow regime, not modified.

 Manage groundwater for ecosystems.  Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation.  Protect natural low flows (perennial systems).  Minimise the effect of weirs/dams or other structures on flow		

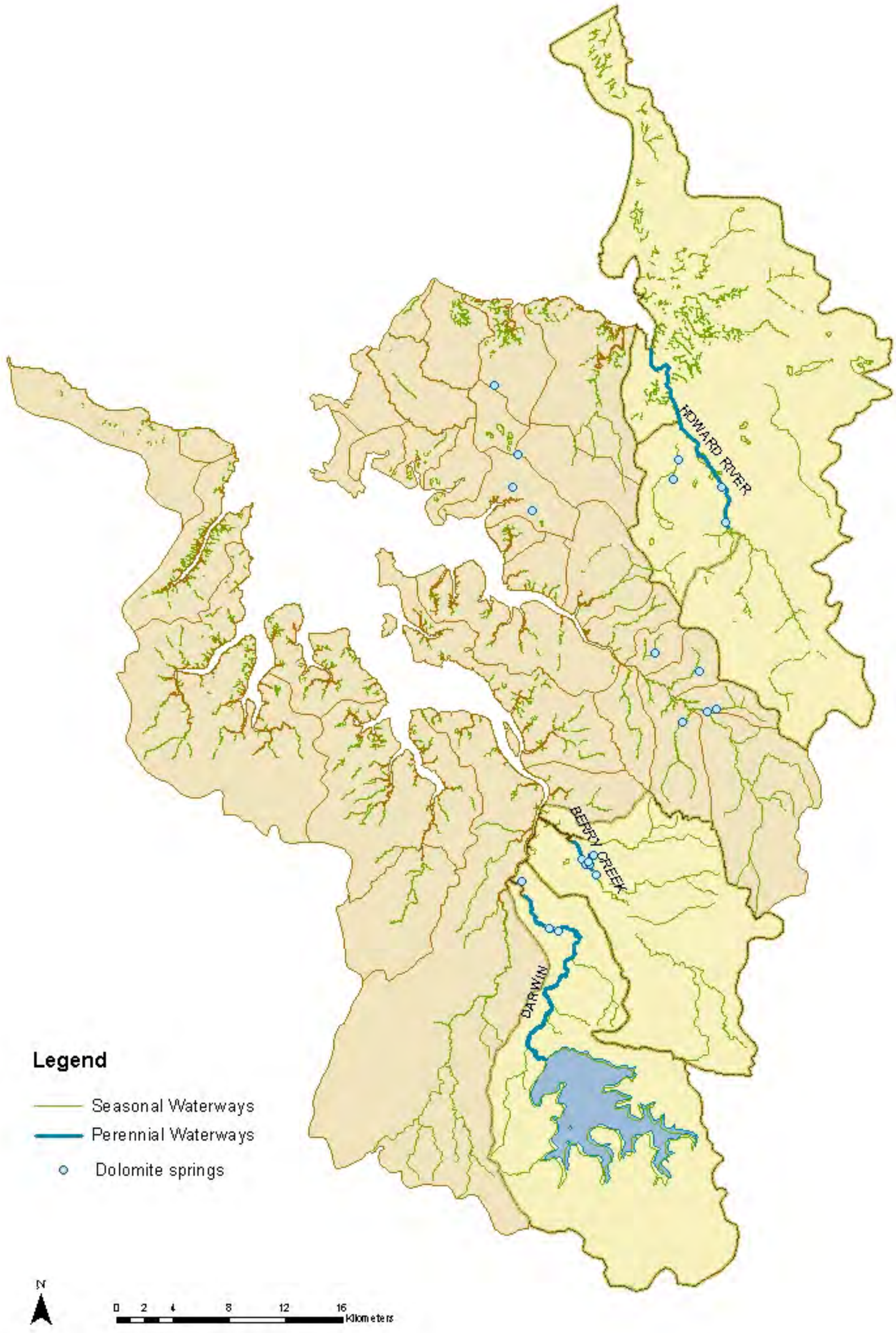


Figure 5.9: Major perennial systems in the Darwin region. The Howard River Catchment and the Berry Creek Catchment delineated from other seasonal systems.

6.0 Introduction

Northern Territory's Department of Natural Resources, Environment, the Arts and Sport (NRETAS) engaged the Water Research Laboratory (WRL) at the University of New South Wales to develop a water quality model for Darwin Harbour. The concentration of nitrogen and phosphorus in the harbour, as a result of catchment runoff and Sewerage Treatment Plant (STP) discharge, was simulated to estimate the total maximum pollutant loads to achieve water quality objectives.

A RMA-2 finite element mesh of Darwin Harbour had been previously established by WRL and developed further by NRETAS for assessing the fate of dredge spoil for construction of the East Arm Port. As part of this current study the model mesh, presented in Figure 6.1, was refined around East Arm and Elizabeth Estuary to provide greater detail of the water quality in these areas where effluent discharge occurs and future development is predicted. Additionally, the model was refined around West Arm, Middle Arm and Blackmore Estuary to enhance the water quality predictions throughout the harbour.

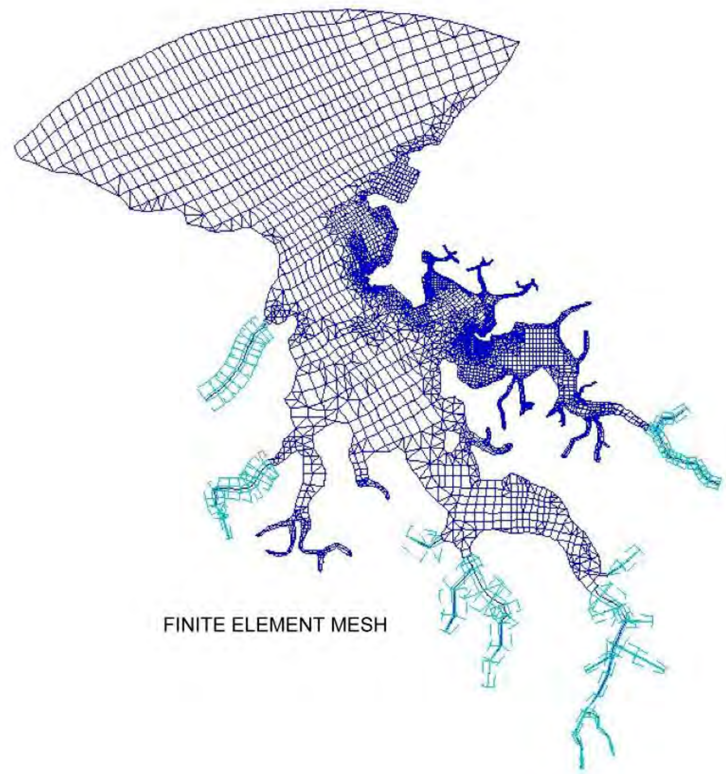


Figure 6.1: Enhanced Finite Element Mesh for the Darwin Harbour Receiving Water Quality Model.

RMA-11 was used to establish a two constituent water quality model of Darwin Harbour. A literature review was undertaken to determine suitable decay rates for nitrogen and phosphorus in the water quality model. Bulk nitrogen and phosphorus were simulated with a single decay rate and were modelled to disperse and diffuse with the tidal currents, catchment runoff, and STP discharge from the RMA-2 hydrodynamic model. Catchment loads were assessed using the methods outlined in the draft report, "The Impact of Urban Land-use on

Total Pollutant Loads Entering Darwin Harbour" (Skinner *et al*., 2008), with STP loads supplied by Power Water Corporation.

6.1 Catchment and STP Loads

The RMA-2 model of Darwin Harbour requires discharges into the harbour from the surrounding catchments and STPs in order to define its boundary conditions. The RMA-11 model boundary conditions require load concentrations to be applied to the RMA-2 inflows to simulate the water quality in the harbour. In this section the data and methods used to calculate these inputs are described.

6.1.1 STP Method

Inflows into the harbour at monthly and daily time periods for each STP were supplied from NRETAS. The discharge of nitrogen and phosphorus into the harbour from each STP was provided by NRETAS in the form of monthly discharge concentrations for the year 2005. As concentrations were provided at monthly time periods, both the RMA-2 and RMA-11 boundary conditions were both specified on a monthly period.

6.1.2 Catchment Method

Hydrographs for Elizabeth River and Blackmore River were supplied. Scaling these hydrographs for the other catchment discharging into the harbour is possible using hydrologic modelling, however the use of these methods was beyond the scope of this study. As no hydrographic data was available for the other catchments discharging into the harbour the following method was applied to estimate discharges. Skinner *et al*. (2008) presents runoff coefficients for selected catchments. Runoff coefficients for Elizabeth and Blackmore were taken as being representative of non-urban catchments with the runoff coefficients for the Karama and Moil catchments taken as being representative of urban catchments. For all the remaining catchments, runoff coefficients were linearly interpolated between these values based on the proportions of area in each catchment, which was classified as urban and non-urban as presented in the following equation:

$$C=C_{urban} x\ U + C_{non\text{-}urban}\ x\ (1 - U)$$

where:

C = runoff coefficient
C urban = representative coefficient for an entirely urban catchment
C non-urban = representative coefficient for an entirely urban catchment
U = percentage of catchment area classified as urban.

6.1.3 Pollutant Load Scenarios

Five scenarios were simulated by the Darwin Harbour Receiving Water Quality Model (DHRWQM). These were as follows:

1. A base case representing the condition for the year 2005-06 (Average rainfall year).
2. A doubled STP discharge scenario, in which the discharge for each STP is doubled to simulate an increase in population.
3. An increased urbanisation scenario, in which the catchments surrounding the Elizabeth Estuary had their fraction of urban area increased to simulate urbanisation
4. An increased urbanisation and doubled STP discharge scenario, in which the discharge from each STP is doubled and catchments surrounding the Elizabeth estuary had their fraction of urban area increased

5. A 100% urbanised and five times STP discharge scenario.

Each scenario was simulated for 12 weeks, for both the wet season (January, February, and March) and dry season (June, July, August). Bulk nitrogen and bulk phosphorus were simulated for each scenario. The bulk concentration of each pollutant is the sum of the pollutant mass regardless of its organic or inorganic form before it is lost to the atmosphere.

The nitrogen and phosphorus concentrations entering the harbour through catchment runoff were calculated by adapting the method outlined in Skinner *et al* (2008). In this report export coefficients are derived for each pollutant allowing the total nitrogen and phosphorus load for each catchment to be calculated.

The results of all simulations were analysed at the Darwin Harbour Marine Monitoring sampling points in the East Arm of Darwin Harbour extending out towards the ocean boundary. The sampling sites are presented in Figure 6.2 and their chainages, measured from the finite element mesh are presented in Table 6.1.

Table 6.1. Chainage of Darwin Harbour Monitoring Locations.

Monitoring Site	Chainage (km)
DHM B	8
DHM 2	15
DHM 13	23
DHM 6	28
DHM 8a	35

Results for the base case or 'business as usual' and other scenarios are presented in Table 6.2 - 6.6 for each monitoring station as a mean pollutant concentration, a maximum pollutant concentration and a minimum pollutant concentration within the given tidal range. Comparison of modelled results to Water Quality Objectives for upper, mid and outer estuarine water types show little derivation from the benchmark with all mean values below the upper trigger value. Highlighted values indicate where water quality objectives have been exceeded and are typically representative of pollutant maximums. It should be noted that comparison of modelled water quality with Water Quality Objectives is constrained by the absence of set boundary conditions and modelled data is likely to be significantly underestimated.

Figure 6.2: Sampling stations used for modelling scenarios.

Table 6.2. Comparison of modelled base or 'business as usual' with Water Quality Objectives. *(Highlighted values indicate exceedance)*

		Wet Season								Dry Season							
		Spring Tide				Neap Tide				Spring Tide				Neap Tide			
Monitored sites	Chainage (km)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)
Bulk Nitrogen																	
Site B	8	0.110	0.260	0.040	0.300	0.110	0.213	0.070	0.300	0.020	0.020	0.014	0.300	0.020	0.020	0.010	0.300
Site 2	15	0.020	0.030	0.010	0.300	0.015	0.030	0.010	0.300	0.010	0.010	0.002	0.300	0.000	0.010	0.000	0.300
Site 13	23	0.000	0.010	0.000	0.270	0.000	0.010	0.000	0.270	0.000	0.000	0.001	0.270	0.000	0.000	0.000	0.270
Site 6	28	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.001	0.270	0.000	0.000	0.000	0.270
Site 8a	35	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440
Bulk Phosphorus																	
Site B	8	0.009	0.015	0.005	0.026	0.008	0.012	0.007	0.026	0.004	0.005	0.002	0.026	0.004	0.005	0.003	0.026
Site 2	15	0.002	0.004	0.001	0.026	0.002	0.003	0.001	0.026	0.001	0.003	0.001	0.026	0.001	0.002	0.001	0.026
Site 13	23	0.000	0.001	0.000	0.020	0.000	0.001	0.000	0.020	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020
Site 6	28	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020
Site 8a	35	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.016

The base case scenario for wet and dry seasons represents the discharges from each STP for the year 2005, and the estimated runoff from each catchment for an average year of rainfall for Darwin. Table 2 presents the results of the Base Case simulations.

Water quality varies significantly with the tide cycle in Darwin Harbour. For the wet season spring tide, nitrogen concentration can vary from 0.04 mg/L to six and a half times that value of 0.26 mg/L. Water quality fluctuates inversely to the tide, so that when the water depth is low, the pollutant concentration is high.

Table 6.3. Comparison of modelled scenario for doubled STP discharge with Water Quality Objectives.

		Wet Season								Dry Season							
		Spring Tide				Neap Tide				Spring Tide				Neap Tide			
Monitored sites	Chainage (km)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)
Bulk Nitrogen																	
Site B	8	0.010	0.000	0.010	0.300	0.010	0.010	0.020	0.300	0.010	0.020	0.012	0.300	0.010	0.020	0.010	0.300
Site 2	15	0.000	0.010	0.000	0.300	0.000	0.010	0.000	0.300	0.000	0.011	0.002	0.300	0.000	0.010	0.000	0.300
Site 13	23	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270
Site 6	28	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.001	0.270	0.000	0.000	0.000	0.270
Site 8a	35	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440
Bulk Phosphorus																	
Site B	8	0.003	0.001	0.004	0.026	0.003	0.002	0.003	0.026	0.004	0.006	0.002	0.026	0.004	0.005	0.002	0.026
Site 2	15	0.001	0.002	0.000	0.026	0.001	0.002	0.001	0.026	0.001	0.003	0.001	0.026	0.001	0.002	0.000	0.026
Site 13	23	0.001	0.000	0.000	0.020	0.001	0.000	0.001	0.020	0.001	0.001	0.000	0.020	0.001	0.001	0.000	0.020
Site 6	28	0.001	0.001	0.000	0.020	0.001	0.001	0.001	0.020	0.001	0.001	0.000	0.020	0.001	0.001	0.001	0.020
Site 8a	35	0.000	0.001	0.000	0.016	0.001	0.001	0.000	0.016	0.001	0.001	0.000	0.016	0.000	0.001	0.000	0.016

For the doubled STP discharge scenario, the discharge from each STP is doubled to model an increase in the population of Darwin. Nonetheless all catchment parameters remain identical to those in the base case scenario. In this simulation only the impact of an increased STP discharge on water quality in Darwin Harbour is assessed.

Doubling STP discharge has little affect on the concentration on nitrogen, with the mean increasing only by 0.01 mg/L at DHM 2 and DHM B, both of which are in the upper reaches of the Elizabeth River estuary. The relative impact on phosphorus concentration is marginally larger with an increase of 0.003 mg/L in the mean phosphorus concentration in the wet season at DHM B, and 0.004 mg/L in the dry season. This represents a doubling of the phosphorus concentration in the wet season at this monitoring station. Phosphorus concentration decrease seawards and is almost undetectable beyond DHM 13 within the main body of Darwin Harbour.

Table 6.4. Comparison of modelled scenario for increased urbanisation with Water Quality Objectives.

		Wet Season								Dry Season							
		Spring Tide				Neap Tide				Spring Tide				Neap Tide			
Monitored sites	Chainage (km)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)
Bulk Nitrogen																	
Site B	8	0.070	0.170	0.020	0.300	0.070	0.150	0.040	0.300	0.0000	0.0010	0.0010	0.300	0.0010	0.0000	0.0020	0.300
Site 2	15	0.010	0.020	0.000	0.300	0.010	0.010	0.000	0.300	0.0001	0.0000	0.0000	0.300	0.0001	0.0010	0.0000	0.300
Site 13	23	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	-0.0006	-0.0010	0.0000	0.270	0.0000	0.0000	0.0000	0.270
Site 6	28	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	-0.0006	-0.0010	0.0000	0.270	0.0000	0.0000	0.0000	0.270
Site 8a	35	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	-0.0005	-0.0010	0.0000	0.440	0.0000	0.0000	0.0000	0.440
Bulk Phosphorus																	
Site B	8	0.010	0.024	0.003	0.026	0.010	0.021	0.006	0.026	0.000	0.001	-0.001	0.026	0.0000	0.0000	0.0000	0.026
Site 2	15	0.001	0.002	0.000	0.026	0.001	0.002	0.001	0.026	0.000	0.002	0.000	0.026	0.0000	0.0000	0.0000	0.026
Site 13	23	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.020	0.0000	0.0000	0.0000	0.020
Site 6	28	0.000	0.001	0.000	0.020	0.001	0.001	0.000	0.020	0.000	0.000	0.000	0.020	0.0000	0.0000	0.0000	0.020
Site 8a	35	0.000	0.001	0.000	0.016	0.000	0.001	0.000	0.016	0.000	0.000	0.000	0.016	0.0000	0.0000	0.0000	0.016

In the increased urbanisation scenario the catchments surrounding East Arm had the percentage of their catchment classified as urban increased. The Hudson Creek, Myrmidon Creek, Palmerston South, Mitchell Creek and Elizabeth Arm catchments all had their percentages of urbanised land increased by approximately 40-50%. The purpose of this was to simulate the effects of urbanisation on water quality in Darwin Harbour, while isolating the increases in urbanisation from increases in STP discharge due to an increased population.

The results in this case are appreciably different from those observed when the STP discharge was doubled. There is almost no change during the dry season for the any of the pollutant concentrations. This is likely to be as a consequence of negligible flow occurring during the dry season, so increasing urbanisation does not increase pollutant loads enough to cause an increase in the concentration in the harbour. There is one parameter where the minimum recorded phosphorus concentration at DHM B actually decreases. This is most likely a result of the increase in flow outweighing the effects of an increase in the pollutant load (Wasko & Miller, 2008). The trends for the wet season are in contrast to those in the dry season. Generally, there is a doubling of phosphorus concentrations in the upper reaches of Elizabeth estuary, and a 60 % increase in the mean nitrogen concentration recorded at DHM B. Seaward of Wickham Point the changes in nitrogen and phosphorus concentrations are insignificant.

Table 6.5. Comparison of modelled scenario for increased urbanisation and doubled STP discharge with Water Quality Objectives.

		Wet Season								Dry Season							
		Spring Tide				Neap Tide				Spring Tide				Neap Tide			
Monitored sites	Chainage (km)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)
Bulk Nitrogen																	
Site B	8	0.080	0.170	0.040	0.300	0.080	0.150	0.060	0.300	0.020	0.020	0.010	0.300	0.010	0.020	0.010	0.300
Site 2	15	0.010	0.030	0.000	0.300	0.010	0.020	0.010	0.300	0.010	0.010	0.000	0.300	0.000	0.010	0.000	0.300
Site 13	23	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270
Site 6	28	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270	0.000	0.000	0.000	0.270
Site 8a	35	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440	0.000	0.000	0.000	0.440
Bulk Phosphorus																	
Site B	8	0.013	0.025	0.007	0.026	0.013	0.022	0.009	0.026	0.004	0.006	0.003	0.026	0.004	0.005	0.002	0.026
Site 2	15	0.002	0.004	0.000	0.026	0.002	0.003	0.002	0.026	0.001	0.003	0.001	0.026	0.001	0.002	0.000	0.026
Site 13	23	0.001	0.000	0.001	0.020	0.001	0.000	0.001	0.020	0.001	0.001	0.000	0.020	0.001	0.001	0.000	0.020
Site 6	28	0.001	0.001	0.001	0.020	0.001	0.001	0.001	0.020	0.001	0.001	0.000	0.020	0.001	0.001	0.001	0.020
Site 8a	35	0.000	0.001	0.000	0.016	0.001	0.001	0.000	0.016	0.001	0.001	0.000	0.016	0.000	0.001	0.000	0.016

The increased urbanisation and doubled STP discharge scenario is a combination of both the increased urbanisation scenario (Table 4) and the doubled STP discharge scenario (Table 3). The Hudson Creek, Myrmidon Creek, Palmerston South, Mitchell Creek and Elizabeth Arm catchments all had their percentages of urban land increased by approximately 40-50%. In addition all the STP's had their volume of discharge for each month doubled, while the concentration of total nitrogen and phosphorus exiting the plants was unchanged. The purpose of this was to simulate the effects of urbanisation on water quality in Darwin Harbour.

Relative to the base case, mean nitrogen concentrations for the dry season have doubled, and for the wet season increased by 70 %. Phosphorus concentrations are also doubled for the dry season, however for the wet season, the increase in mean phosphorus concentration at DHM B is 150 %. The increases in concentration are less pronounced seaward and at DHM 13 the change in both contaminant concentration is slight. The increase in the maximum pollutant concentration observed over the tidal cycle is similar in magnitude to that observed for the average concentrations.

Table 6.6. Comparison of modelled scenario for 100% urbanised catchments and five times the STP discharge with Water Quality Objectives.

		Wet Season								Dry Season							
		Spring Tide				Neap Tide				Spring Tide				Neap Tide			
Monitored sites	Chainage (km)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	WQOb (mg/L)
Bulk Nitrogen																	
Site B	8	0.21	0.37	0.11	0.300	0.21	0.34	0.16	0.300	0.06	0.08	0.05	0.300	0.06	0.07	0.04	0.300
Site 2	15	0.04	0.07	0.02	0.300	0.03	0.06	0.03	0.300	0.02	0.04	0.01	0.300	0.02	0.03	0.01	0.300
Site 13	23	0.01	0.02	0.01	0.270	0.01	0.01	0.01	0.270	0.01	0.01	0.00	0.270	0.01	0.01	0.00	0.270
Site 6	28	0.01	0.01	0.00	0.270	0.01	0.01	0.01	0.270	0.01	0.01	0.00	0.270	0.01	0.01	0.01	0.270
Site 8a	35	0.01	0.01	0.00	0.440	0.01	0.01	0.00	0.440	0.00	0.01	0.00	0.440	0.00	0.01	0.00	0.440
Bulk Phosphorus																	
Site B	8	0.034	0.055	0.020	0.026	0.034	0.050	0.028	0.026	0.016	0.022	0.010	0.026	0.016	0.021	0.010	0.026
Site 2	15	0.007	0.014	0.003	0.026	0.007	0.011	0.005	0.026	0.005	0.012	0.002	0.026	0.004	0.008	0.003	0.026
Site 13	23	0.002	0.002	0.002	0.020	0.002	0.002	0.002	0.020	0.002	0.002	0.001	0.020	0.002	0.002	0.001	0.020
Site 6	28	0.002	0.002	0.001	0.020	0.002	0.002	0.002	0.020	0.002	0.002	0.001	0.020	0.002	0.002	0.002	0.020
Site 8a	35	0.001	0.002	0.000	0.016	0.001	0.002	0.001	0.016	0.001	0.002	0.000	0.016	0.001	0.002	0.001	0.016

In the 100% urbanised and five times STP discharge scenario all the catchments surrounding Darwin Harbour have their percentage of urbanised land set to 100%. STP discharges are magnified five fold from the base case, however the concentration of pollutants remains unchanged.

At DHM B mean nitrogen concentrations for the dry season quadruple, however they are still less than those of the base case in the wet season. Mean wet season nitrogen concentrations at DHM B triple, with the maximum nitrogen concentration observed increasing by 140 % as compared to the base case. Mean phosphorus concentrations at DHM B are approximately 5 times that recorded for the base case. Although the modelled phosphorus concentration is quadrupled at DHM 2, it is still similar to that at DHM B for the base case. Similar trends are observed for phosphorus concentrations in the dry season.

6.2 Modelled Loads and Receiving Water Quality

As a result of the forecasted increase in population and urbanisation of Darwin, the nitrogen and phosphorus loads entering the harbour from catchment runoff and STP discharge will increase.

Scenarios simulated illustrate that urbanising the catchments surrounding the Elizabeth River estuary have a much greater impact on the overall water quality than doubling all STP discharges. In approximate terms, the cumulative effect of these two changes resulted in a doubling of the mean nitrogen concentration in the upper reaches of the Elizabeth River estuary (DHM B). However, the magnitude of this change was less than the tidal variation for the base case wet season spring tide. Mean phosphorus concentrations at the same location increased by 150%. The magnitude of this change was greater than the tidal variation of phosphorus for the base case wet season spring tide. For the extreme scenario of all catchments 100% urbanised and STP discharge increased five fold, mean nutrient concentration levels for the wet season spring tide at DHM 2 did not exceed the mean base case levels at DHM B. Further towards the mouth of the harbour, the change in the concentration of pollutants decreases to levels similar to that of the detection limit for normal laboratory nitrogen and phosphorus analyses. Although increasing urbanisation appeared to have greater impacts on broader modelled water quality this does not negate the potential for localised impacts around point discharges in the harbour, particularly where they emanate into smaller tidal systems.

In order to accurately simulate the concentration of nitrogen and phosphorus in Darwin Harbour and compare modelled results with water quality guidelines, regular water quality sampling is required with knowledge of the level of the tide at the time of sampling. Water quality in the harbour is highly influenced by tides, and the amount of water entering from surrounding catchments. Higher inflows into the harbour result not only in pollutants being dispersed more, but the pollutant loads also increasing. To accurately calibrate the water quality model decay rates for nitrogen and phosphorus also need to be experimentally determined, as both the nitrogen and phosphorus water quality cycles are highly dependent on the local aquatic environment (Wasko and Miller, 2008).

6.3 DHRWQM Toolbox

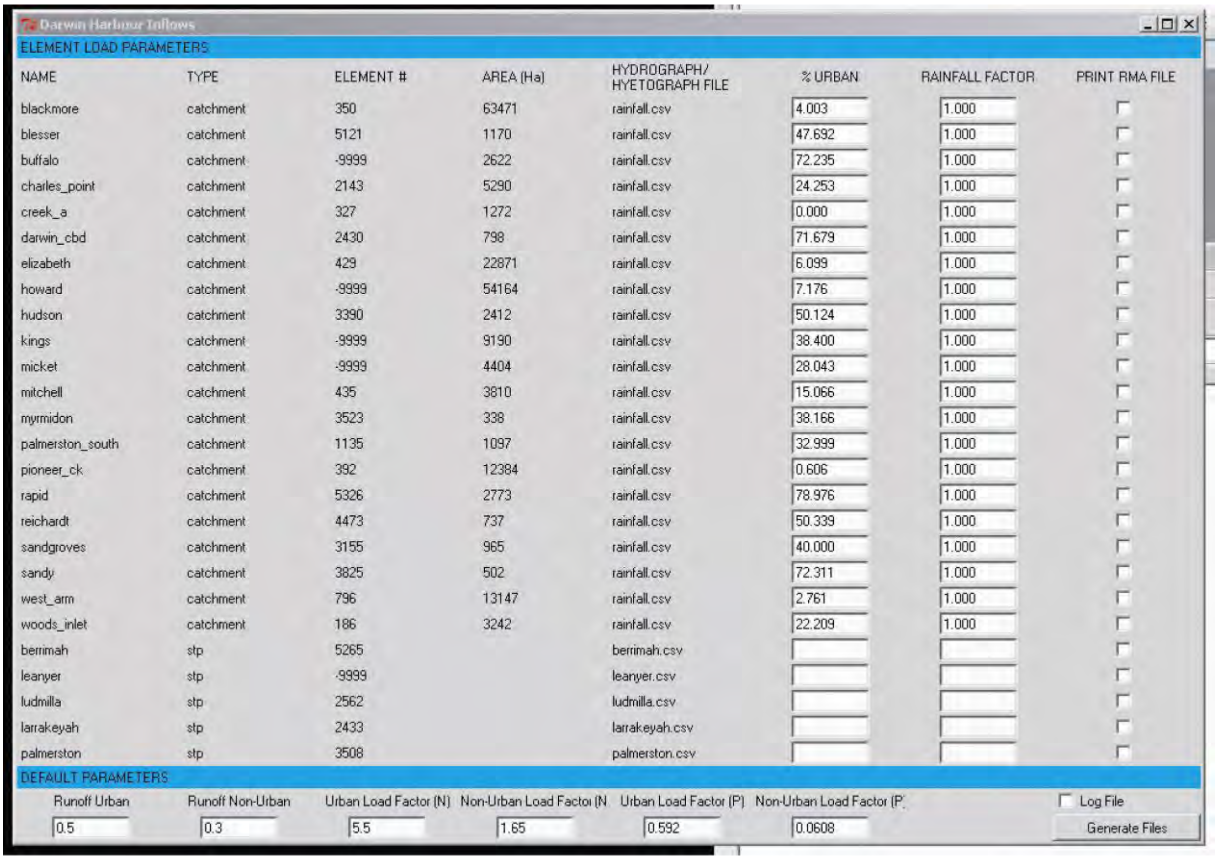
For each scenario tested the boundary conditions must be established. The methods described in WRL technical report 2008/22 for land use and STP changes are repeated for each scenario, and as flows differ in the dry and wet season, these inflows must also be recalculated. The methods described in these sections lend themselves to be implemented using a computer algorithm, hence a toolbox was developed to create the RMA-2 and RMA-11 input files for each of the scenarios simulated. Figure 6.3 presents the Graphical User Interface (GUI) of the RMA inflow toolbox.

The toolbox requires the following user inputs:

- A rainfall hyetograph in csv format;
- STP hydrographs and pollutant concentrations in csv format; and
- A data file with catchment areas and the relevant inflow nodes in the RMA finite element mesh in csv format.

Each of these files has a ready-to-use template which is easily modified. The hydrographs and hyetograph were formatted on a monthly time period, however any time period can be used in the toolbox.

In the graphical interface a number of parameters can be modified so different scenarios can be modelled without the need for updating the input files. The percentage of area in each catchment which is urbanised can be modified, as well as the rainfall factor. Runoff coefficients as well as export coefficients, termed load factors in the toolbox, can also be updated.



Darwin Harbour Inflows

ELEMENT LOAD PARAMETERS

NAME	TYPE	ELEMENT #	AREA (Ha)	HYDROGRAPH/ HYETOGRAPH FILE	% URBAN	RAINFALL FACTOR	PRINT RMA FILE
blackmore	catchment	350	63471	rainfall.csv	4.003	1.000	
blesser	catchment	5121	1170	rainfall.csv	47.692	1.000	
buffalo	catchment	-9999	2622	rainfall.csv	72.235	1.000	
charles_point	catchment	2143	5290	rainfall.csv	24.253	1.000	
creek_a	catchment	327	1272	rainfall.csv	0.000	1.000	
darwin_cbd	catchment	2430	798	rainfall.csv	71.679	1.000	
elizabeth	catchment	429	22871	rainfall.csv	6.099	1.000	
howard	catchment	-9999	54164	rainfall.csv	7.176	1.000	
hudson	catchment	3390	2412	rainfall.csv	50.124	1.000	
kings	catchment	-9999	9190	rainfall.csv	38.400	1.000	
micket	catchment	-9999	4404	rainfall.csv	28.043	1.000	
mitchell	catchment	435	3810	rainfall.csv	15.066	1.000	
myrmidon	catchment	3523	338	rainfall.csv	38.166	1.000	
palmerston_south	catchment	1135	1097	rainfall.csv	32.999	1.000	
pioneer_ck	catchment	392	12384	rainfall.csv	0.606	1.000	
rapid	catchment	5326	2773	rainfall.csv	78.976	1.000	
reichardt	catchment	4473	737	rainfall.csv	50.339	1.000	
sandgroves	catchment	3155	965	rainfall.csv	40.000	1.000	
sandy	catchment	3825	502	rainfall.csv	72.311	1.000	
west_arm	catchment	796	13147	rainfall.csv	2.761	1.000	
woods_inlet	catchment	186	3242	rainfall.csv	22.209	1.000	
berrimah	stp	5265		berrimah.csv			
leanyer	stp	-9999		leanyer.csv			
ludmilla	stp	2562		ludmilla.csv			
larrakeyah	stp	2433		larrakeyah.csv			
palmerston	stp	3508		palmerston.csv			

DEFAULT PARAMETERS

Runoff Urban	Runoff Non-Urban	Urban Load Factor (N)	Non-Urban Load Factor (N	Urban Load Factor (P)	Non-Urban Load Factor (P
0.5	0.3	5.5	1.65	0.592	0.0608

Log File

Generate Files

Figure 6.3: Graphical User Interface of DHRWQM Toolbox.

6.4 Model Simulations and Uncertainty

6.4.1 Enhanced finite element mesh.

The finite element mesh for Darwin Harbour is shown in Figure 6.1. The mesh was previously established by the Water Resources Laboratory (WRL) and has been improved by NRETAS in conjunction with the need to model port developments in the Harbour. For the purposes of the WQPP the mesh has been further refined throughout the East Arm of Darwin Harbour and the upper reaches of Elizabeth estuary. The resolution was particularly refined around the areas of Sadgroves Creek, Reichardt Creek, Blesser Creek, Hudson Creek and Myrmidon Creek to allow modelling of water quality in these estuarine reaches with the provision of wetting and drying for the estuary with tidal cycle. STP discharge is also associated with two of these tidal tributaries, Blesser Creek and Myrmidon Creek, and as a consequence these creeks were refined for suitable predictions in the vicinity of the point discharges. However, the upper reaches of the Harbour Arms require further bathymetry to adequately reflect hydrodynamic processes in these reaches. Currently these reaches exist as 1D elements until further data is available and refinement possible.

6.4.2 Decay Rate

Water quality was simulated in Darwin Harbour using a two constituent RMA-11 model (King 2006). Bulk nitrogen and phosphorus were modelled as arbitrary constituents within the RMA-11 model with a single decay rate applied to each constituent.

It was deemed appropriate to use a single decay rate to encompass all the individual processes for both the nitrogen and phosphorus cycles as site specific data for each is unavailable. A more detailed study including all the sub processes within the N and P cycles including the settlement of particles as well as temperature were not appropriate given the paucity of data. Single decay rates for both wet and dry seasons were chosen as the level of uncertainty in the chosen decay rate was larger than the potential change in the decay rate due to temperature effects.

The rationale for choosing a decay rate was to select a key step in the nutrient cycle and use its decay rate. Ammonification was chosen with a typical value of 0.1/day. Similar decay rates for phosphorus are published with a similar degree of variability. The use of a single rate enabled concentrations for each pollutant to be independently calculated.

6.4.3 Boundary Conditions

Two boundary conditions are required for the RMA-11 water quality model. The first is the ocean boundary, which corresponds to the initial concentration in the harbour. The second is the N and P loads which are discharged into the harbour from surrounding catchments as diffuse sources and other point sources such as STP's.

A zero boundary condition has been adopted for the scenario modelling. This allows the direct comparison of different loading scenarios on water quality. It is recognised that as a consequence of adopting this approach that the results of the water quality simulations cannot be directly compared to sampled values. Although comparison is made in the above tables the values modelled are likely to be underestimated.

Priority research undertaken in conjunction with TRaCK (Tropical Rivers and Coastal Knowledge Consortium) has found that oceanic sources entering the harbour are significant and likely to represent a net import of nutrient. Although limited, data collected in the outer estuary region suggests reasonably high organic Nitrogen concentrations which support current research on sediment and nutrient sources in the harbour. Future simulations with appropriate boundary condition settings may result in more comparable simulations for water quality.

6.5 Sensitivity Testing

The sensitivity of the DHRWQM to decay rate is presented in Figure 6.4. A time series of the concentration of Nitrogen at monitoring station DHM 2 in East Arm is plotted for two different decay rates, 0.1/day and 0.05/day. The concentration of Nitrogen in the harbour is inversely proportional to the decay rate, with the magnitude of the change in decay rate being equal to the magnitude of change in the concentration of N at the station. The concentration of P is identically sensitive to the decay rate. Due to the absence of data, a rate of 0.1/day is adopted based on available literature.

Comparison of modelled water quality in the absence of data to inform complex nutrient processing, particularly for phosphorus and modelling runs without boundary condition have resulted in an under-estimate of resultant receiving water quality. However simulations have broadly provided a better appreciation for the resultant water quality for modelled scenarios and their magnitude.

Flushing rates and the diffusivity parameter were also tested. An absolute diffusion was chosen over the use of scaled diffusion as both East and Middle arms have similar flushing rates.

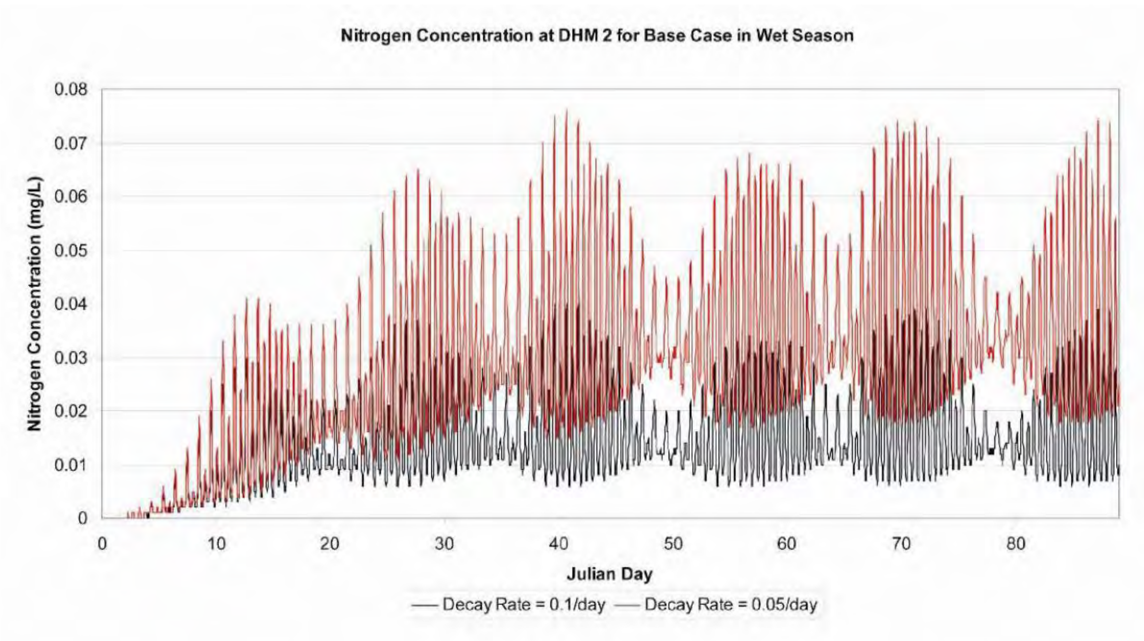


Figure 6.4. Sensitivity testing of decay rates for nitrogen at DHM site 2.

Flushing index was also produced to estimate the relative residence times of a pollutant or constituent within the harbour over time. The index values represent the time in days it takes for a conservative constituent to be removed from the harbour by advection and/or diffusion. The comparison of the flushing index with available water quality data is reasonably analogous and supports the categorisation of estuarine water types (Fig 6.5).

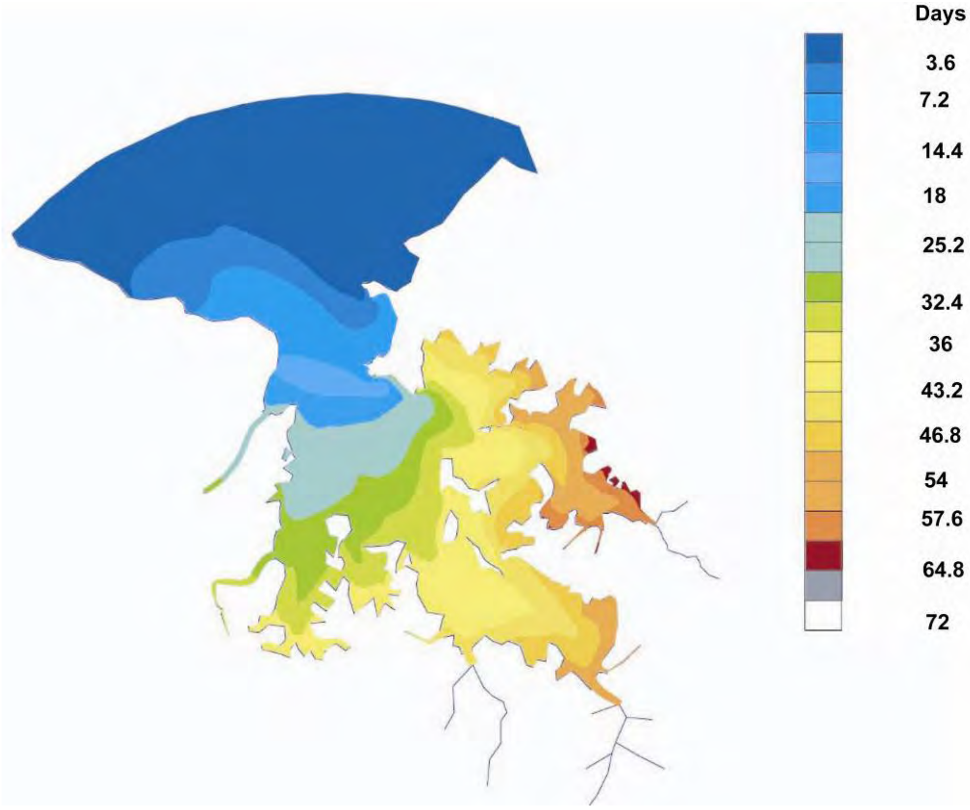


Figure 6.5: Flushing zones for Darwin Harbour during the dry season. The index values represent the time in days it takes for a conservative constituent to be removed from the harbour by advection / diffusion.

Sensitivity of model results to the initial concentration of nitrogen in the harbour was also tested (Wasko & Miller, 2008). For an initial elevated concentration scenario the nitrogen in the system quickly decays back to levels similar to those of the simulation where a zero initial concentration was specified. The increase in concentration between these scenarios ranged from 2-50% depending on tide highlighting the variability associated with tidal cycle in Darwin Harbour.

6.6 Improving Model Predictions

Refinement of models will continue as monitoring data is collected and specific research addresses critical parameter inputs. Given the specialised nature of model development and enhancement ongoing expertise will need to be sought. The ongoing costs associated with such expertise will necessitate the dedication of funds and resources on an 'as needs' or priority basis.

Further coding of the RMA model has been sought to allow the model to better simulate the complex water and sediment quality interactions and processes broadly addressed above. Future iterations of the model will provide enhanced sensitivity to better reflect water quality conditions making use of the priority research outcomes.

Section 7. Priority Research

7.0 Receiving Water Quality Model

Although a range of values for modelling parameters have been produced, the appropriateness of these will require further research given the unique nature of Darwin Harbour and its catchment. Focus on the following elements to inform and calibrate the receiving water quality model was recommended by the Water Quality Modelling Program (WQMP):

- Chlorophyll a and algae growth and settling rates
- Algal nutrient relationships
- Nitrogen Cycle
- Phosphorus Cycle
  - Understand nutrient dynamics their biogeochemical role, important oxidation-reduction reactions and the affect on other variables such as oxygen.
  - Key processes: Ammonification – release of ammonia due to decay processes, nitrification oxidation of ammonia to nitrate (NO_3) directly or to nitrite (NO_2).
  - Uptake – accumulation of inorganic nitrogen by plants during photosynthetic growth. Nitrogen fixation – reduction of N_2 to ammoniated compounds.
- Sediment, nutrient and algae cycling and interaction.

A series of research projects have been initiated to provide insight into key water quality processes in Darwin Harbour and inform model parameters. Outcomes of these projects are detailed below. It should be noted that not all of the research undertaken to date will necessarily inform all requirements of the receiving water quality model. Ongoing refinement of models and investment in future monitoring and research effort will be required.

7.1 Key outcomes of priority research, model calibrations and verification.

7.1.1 Sampling for bulk stable isotopes, lipid markers and pigments was undertaken to allow for a direct comparison of organic matter sources and algal species between the "impacted" and un-impacted sites. (TRaCK Project, Leader: Michele Burford) Results found that:

- Phytoplankton biomass, as indicated by chl-a concentration, covers a range from about 1.3 mg m^{-3} to about 2.9 mg m^{-3}. Biomass was similar at the reference creek and Frances Bay sites with 2.34 and 2.40 mg m^{-3} respectively, and slightly lower at Myrmidon Ck sites with 1.87 mg m^{-3}. At all sites, the pigment composition is similar indicating similar phytoplankton communities. Diatoms as indicated by fucoxanthin are the dominant algal group with green algae (chl-b), possibly euglenophytes or type 2 prasinophytes; cyanophytes (zeaxanthin) and cryptophytes (alloxanthin) present at all sites.

- Microphytobenthos biomass, as indicated by chl-a concentration, covers a range from about 0.76 $\mu g\ g^{-1}$ wet wt. to about 5.14 $\mu g\ g^{-1}$ wet wt. Biomass at Myrmidon Ck and the reference creek sites were 3.41 and 3.78 $\mu g\ g^{-1}$ wet wt. respectively, with lower average biomass at the Frances Bay sites with 1.07 $\mu g\ g^{-1}$ wet wt. The average biomass at the sewage discharge site, was approximately 2 – 2.5 times less than the biomass at the other sites at the same impacted tidal creek. The pigment composition at all sites was dominated by fucoxanthin indicating that benthic diatoms dominated the MPB community.

7.1.2 Determination of water column respiration, benthic nutrient fluxes, denitrification, nitrogen fixation and phosphorus retention in the sediments was undertaken. (TRaCK Project, Leader: Michele Burford). Results reveal that:

- A comparison between wet and dry season revealed differences in the benthic fluxes in the un-impacted creek with higher respiration rates (115 mmol C m^{-2} d^{-1}) and net nutrient influxes in the wet season compared to lower respiration rates (67 mmol C m^{-2} d^{-1}) and net nutrient effluxes in the dry season (under dark conditions). The water column nitrogen concentrations were significantly higher in the wet season (2.5 uM) than the dry season (0.4 uM) but there was no difference in the P concentrations. However, these concentrations are still low compared to the nutrient concentrations measured at the sewage outfall of Myrmidon Creek (34 uM N and 25 uM P).

- At the sewage outfall site, benthic fluxes in the wet season were similar to those measured in the dry season (both measured under high tide conditions) with low respiration rates (69 and 86 mmol C m^{-2} d^{-1} in the wet and dry season respectively) and a net efflux of nutrients. Benthic fluxes were also measured at this site in the wet season at low tide when the water column nitrogen and phosphorus concentrations were over 100 and 25 times higher respectively, with the N and P most likely sourced from the sewage outfall. At low tide, sediment respiration rates were much higher (236 mmol C m^{-2} d^{-1}) and there was a net influx of NOx-N and P.

- Measured nitrogen fixation rates were insignificant in the intertidal sediments.

- Denitrification (measured as net N_2 fluxes) appears to be an important process for removing nitrogen from the system, accounting for approx. 90% of the DIN flux from the sediments. At the sewage outfall site, there was no difference in denitrification between the wet and dry seasons under high tide conditions (approx 7 mmol N m^{-2} d^{-1}) but there was net N_2 uptake (-1.4 mmol N m^{-2} d^{-1}) under low tide conditions.

7.1.3 Primary productivity studies were also undertaken to compare productivity between impacted and un-impacted sites. (TRaCK Project, Leader: Michele Burford) Preliminary results reveal that:

- Primary productivity, standardised to chlorophyll *a,* was higher overall in February 2008 (wet season) than in October 2007 (dry season). This coincided with higher ammonium concentrations and lower salinities in both creeks. Water temperatures did not vary substantially between sampling occasions. It should also be noted that there were substantial differences in primary productivity at the sewage outfall site (Ma) on different stages of the tide (one week apart). High tide productivity values were lower than those on the outgoing tide.

- The depth-integrated areal primary productivity values were similar between wet and dry seasons, and between the creek receiving sewage and the reference creek. The exception was the second day of sampling on the outgoing tide at the sewage discharge site which was substantially higher than the other sites and times.

- Primary productivity rates were highly variable for the microphytobenthos within sites reflecting the greater heterogeneity of sediments compared with the water column. In February 2008 (wet season), primary productivity rates appeared to be higher in Myrmidon creek than the reference creek, but the high variability within sites make it difficult to draw clear conclusions.

7.1.4 Algal bioassays were used to determine whether phytoplankton and microphytobenthos were nutrient limited, and whether sewage inputs affect this. (TRaCK Project, Leader: Michele Burford).

- In October 2007, phytoplankton responded to nitrogen addition. In February 2007, phytoplankton also responded to nitrogen addition at all sites except the sewage discharge site. The response at this site was variable. On the first occasion there was a response to nitrogen and phosphorus, on the second occasion there was only a response to nitrogen. This probably reflects changes across the tidal cycle.

- Bioassays for the microphytobenthos showed a different response to the water column. There was no evidence of a response to nutrient additions, with much greater variability between replicates that that seen in the water column. This reflects the heterogeneous nature of the sediment.

7.1.5 AIMS and Griffith University synthesised previously collected data to establish estimates on net ecosystem production and biogeochemical fluxes in Darwin Harbour. (TRaCK Project, Leader: Michele Burford)

- This study examined a tropical macrotidal estuary, Darwin Harbour, in northern Australia to identify the key sources of production and characterize the biogeochemical processes in the subtidal water column and sediment (Burford *et al*, 2008).

- Production and nutrient cycling in the mangroves and intertidal mudflats surrounding the harbour were estimated based on more limited data. Darwin Harbour is adjacent to the city of Darwin, a rapidly growing urban area. During the two year study, material fluxes were dominated by tidal exchange with net import of C, nitrogen (N) and phosphorus (P).

- The main source of primary production was the extensive area of mangroves and resulted in a net autotrophic system (P_G:R = 2.1). This ratio is considerably higher than temperate estuaries throughout the world, but comparable with other tropical, mangrove-dominated estuaries. The system is likely to be more nitrogen than P-limited, based on low N:P ratios, low dissolved bioavailable N concentrations (ammonium (NH_4^+), nitrate (NO_3^-), urea), high particulate carbon (C):N ratios and evidence that phytoplankton growth in bioassays was stimulated by NH_4^+ addition.

- The largest source of new N input to the system was the dissolved oceanic source, with N fixation on the intertidal mudflats and subtidal sediments of less significance, and river and sewage being minor inputs (Fig 7.1).

- Primary productivity in the water column was relatively high and coupled with low dissolved bioavailable N resulted in high rates of N recycling in the water column.

- Nutrient inputs from urban development are unlikely to have major effects on water quality in the short term. However, this study highlights the importance of maintaining mangrove and mudflat intertidal zones in supporting productivity and biogeochemical cycling in the harbour.

- On a whole-of-harbour basis is it unlikely that increases in human impacts, i.e. sewage and river inputs, will substantially affect biogeochemical processes in the short term, given that loads are relatively small compared with oceanic inputs.

- Localised effects in less flushed areas of Darwin Harbour adjacent to urban inputs are possible. Additionally, this work suggests that mangroves are the major source of productivity and provide an important habitat for many fish and other aquatic species.

- Recreational fishing is an important activity in this region, and protecting key habitats for fish and crustaceans, as well as protecting water quality and aesthetics is central to ensuring the future sustainability of Darwin Harbour.

7.1.6. Sources of sediments and sediment inputs to Darwin Harbour and sediment transport. (TRaCK Project, Leader: Prof David Parry)

- Parry *et al* (unpublished) suggested that 40 % of the fine sediment in the harbour emanates from the catchment. This approximation has been questioned on three grounds i.e. small number of samples, representativeness of the entire catchment area and Darwin Harbour and the limited geochemical tracers in data analysis.

- Wasson *et al* (2007) reported that the topsoil tracers ^{210}Pb (excess) and ^{137}Cs show that most fine sediment being transported in the creeks and rivers that flow into the Harbour comes from the channels rather than from sheet erosion of hillslopes. This is an important conclusion for land managers, but needs to be verified by taking additional samples which will also be used for the sediment input study.

- Further work will aim to collect a greater range of sediment inputs from the catchments as end members for mixing models; quantify lead isotope ratios and metals for the additional samples to add to the REE (Rare Earth Element) profiles and quantify sediment sources in the catchment.

- Preliminary research supports work undertaken on net ecosystem production and biogeochemical fluxes (Burford *et al*, 2008) in Darwin Harbour where significant nutrient (Carbon & Nitrogen) loads may be emanating from the oceanic boundary.

7.1.7 Nutrient absorption to suspended sediment (Charles Darwin University, Leader: Prof David Parry).

- The rate at which nutrients are absorbed to sediments is an important parameter for the DHRWQM and little information on such rates for tropical estuarine systems exists. The relationship between sediment and nutrients of Darwin Harbour and just how much is absorbed is a question which requires laboratory investigation.

- Charles Darwin University has been engaged to undertake a series of experiments to ascertain maximum absorption rates of nutrients to suspended sediment.

- Given the inherently turbid macrotidal waters of Darwin Harbour and its associated wet season flood events suspended sediment is expected to play a chief role in the export of particulate bound nutrients.

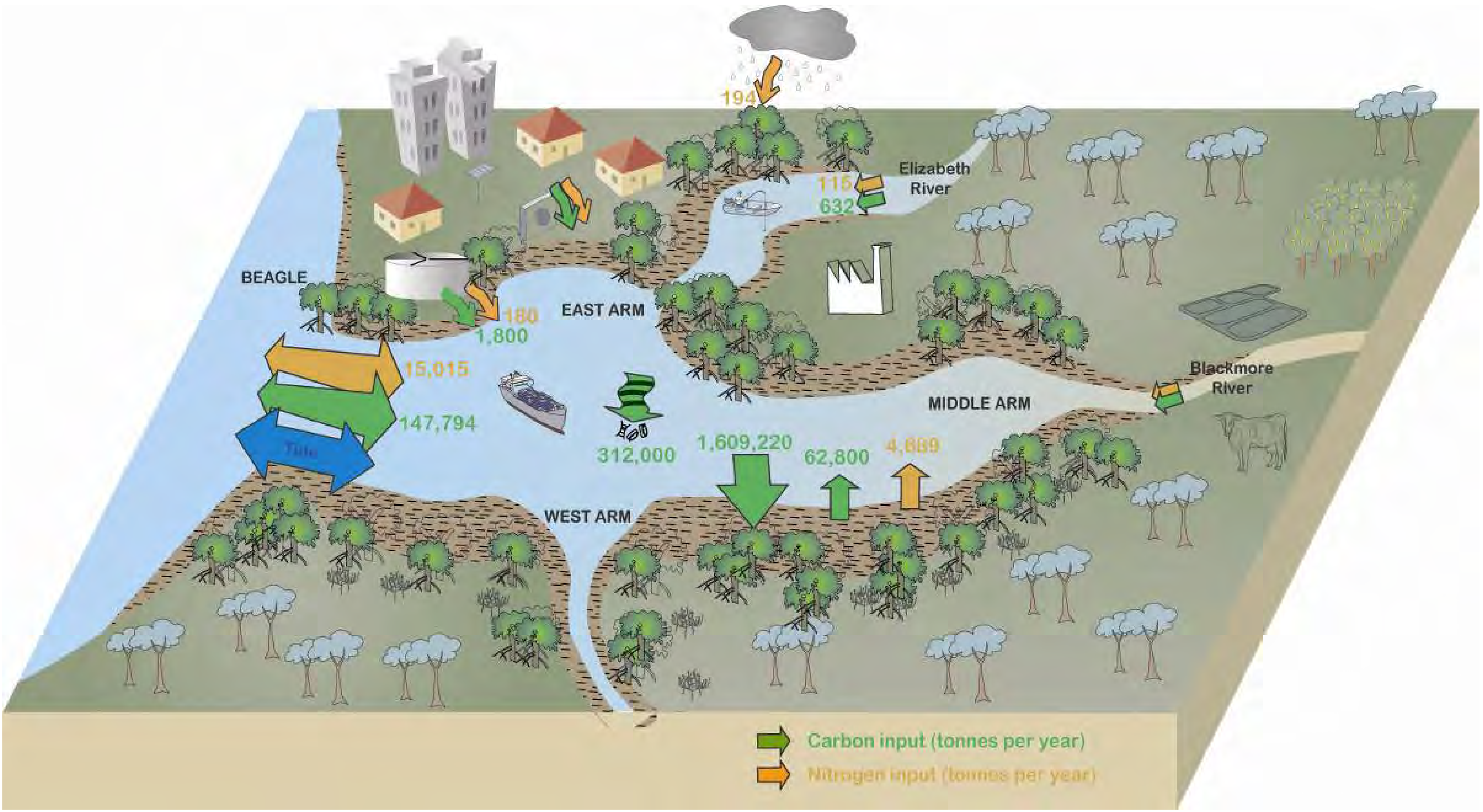


Figure 7.1: Conceptual diagram of estimated load contribution drawn from priority research activities (AIMS and Griffith University)

7.1.8 Development and calibration of a water quality model for Buffalo Creek to enable comparison with the broader receiving water quality model for Darwin Harbour (Charles Darwin University, Leader: Prof Eric Valentine).

Buffalo Creek is a tidal creek receiving wastewater discharge from nearby Leanyer-Sanderson Sewage Ponds. This creek is on occasion subject to minimal tidal flushing and as a consequence experiences regular events of eutrophication.

Little is known about the assimilation of excess nutrients to this creek or the hydrodynamic nature of Shoal Bay, the terminus of Buffalo Creek. To aid our understanding of the fate of nutrients entering the creek and its capacity to assimilate excess nutrients a water quality model will be developed. This tool will also build on our ability to determine locally derived guidelines and objectives where there is a paucity of data.

Additionally, the comparison of this model with that of the broader harbour will be valuable given the likely disparity of these systems based on spatial location and hydrology.

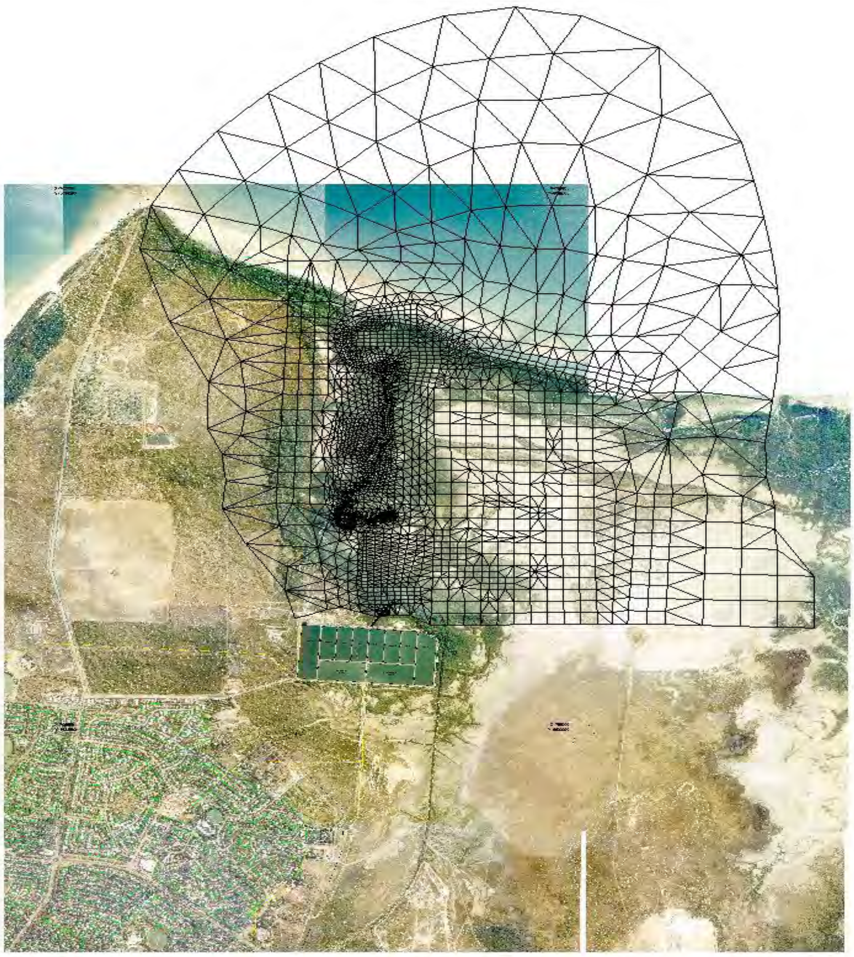


Figure 7.2: Finite element mesh of the Buffalo Creek Water Quality Model.

Outcomes of this priority research and model development include:

- The development of a basic hydrodynamic model which has been constructed for the creek, salt flats and coastal waters. The model uses the Research Management Associates RMA10 software. The mesh for the model is shown in Figure 7.2. The model is a combination of one-dimensional and two-dimensional representations. Most of the area modelled is described in two dimensions.

- Initial testing and calibration. Further work will improve the topographical and hydraulic roughness description and develop the verification of the outputs.

- Preliminary testing for conservative constituents. Calibration will be based on existing field measurements. Future work will develop the model description for pathogens and nutrients which will be informed by other work being carried out for this project in December 2008 as an extension to the TRaCK estuarine research on Darwin Harbour.

7.1.9 Power Water Corporation investment in monitoring effort at STP discharge sites (PWC, Leader: Alex Donald).

In July 2008 the Power Water Corporation funded a series of water quality surveys with a focus on wastewater discharge points associated with the Larrakeyah and East Point outfalls in Darwin Harbour. This data will contribute to improving model calibration and validation in the vicinity of these outfall discharges and extend our understanding of the hydrodynamic influences on mixing zones and constituent decay.

7.2 Catchment Event Monitoring & Improving Loads Assessment

Continued monitoring effort in key tributaries representative of core land uses in the catchment will be important to verify modelled loads. In particular some attention to soluble fraction nutrients, continuous flow time-series data and establishing sound empirical relationships particularly for suspended sediment are necessary.

However, the consistency of this sampling regime has been intermittent due to difficulties associated with equipment failure and availability, inadequate infrastructure (stations), inappropriate stage-flow ratings and inadequate resources have constrained attempts to maintain an annual wet season sampling regime.

Regardless of shortcomings available data and current commitments to ongoing event based monitoring is proposed to aid the development of event based water quality objectives.

Event-based WQOs will be based on similar approaches undertaken in the wet-dry tropics of Queensland. These have been typically derived from several years of data, where flow and water quality data are available. Similar to the methodology used to derive ambient water quality objectives, event-based WQOs are based on the following:

- An appropriate level of protection for a catchment or catchments is determined (HCV, SMD, HD or other);
- Event mean concentrations (EMC) where flow data is available; or
- 80^{th} percentiles of data where flow data is not available.

There is likely to be some uncertainty associated with the use of event mean concentrations (EMC) given the variation in sediment and pollutant supply over the course of an event, the extremes in seasonality and antecedent conditions. Data collected over several years in a number of catchments in the Darwin Region will be used to derive these interim objectives. Further refinement of these objectives would be expected as more data becomes available.

7.2.1 Importance of Event Sampling.

An important feature of freshwater inflows from catchments in Australia is that the variance in rainfall in Australia is high, and for many catchments the majority of the water, nutrient and sediment exports occur for a few days of the year (Webster and Harris, 2004). In tropical Australian catchments such as Darwin, 50% of the annual discharge can occur in 3% of the time (Letcher *et al*., 1999). Capturing these events is vital to quantifying catchment loads as most variation in sediment and nutrient concentration occurs during this period. Kernohan and Townsend 2000 found that a large proportion of nitrogen was transported early in the wet season, owing to high base flow concentrations. More recent work (unpubl) has also found high proportions of suspended sediment also entrained with the first flush and more generally the mass of contaminants transported throughout the wet season is generally dependent on the volume of water rather than contaminant concentration. Particular focus on these sampling events is required to ensure loads are captured and data input to any catchment model is representative of stream flow and constituent characteristics.

7.2.2 Performance of Rating Curve and discharge measurements.

A rating curve for a specific stream location is developed by making discharge measurements at many different stream stages to define and maintain a stage-discharge relation. Discharge can be measured based on a cross sectional assessment using velocity meters or can be determined using a boat-mounted doppler techniques. Once this relationship is developed, it is possible to obtain estimates of discharge simply by obtaining stream depth data. At most gauged sites long term ratings have been determined. However, for more recently established gauge stations such as Peel and Bennett Creek additional gauging is needed to determine rating curves with some confidence. The industrialised catchment of Winnelle also requires additional attention. Discharge at sites where lined drains terminate large urban and industrial subcatchments such as Winnellie and Moil are usually transient. Obtaining sound discharge measurements at these sites is difficult and further assessment using a doppler velocity technique is warranted to improve the existing rating curve.

7.2.3 Sampling Regime Improvements.

The cost of analysis for catchment loads is substantial. Discrete sampling regimes provide improved precision of load estimates however the ongoing costs of such a regime is far more substantial than composite or flow proportional sampling. In order to reduce unnecessary sampling datalogger programs will require further refinement of stage height parameters. The highly variable wet season flows can make this task difficult particularly at newly established stations where only a few seasons have been experienced. Alternatively where over sampling might have occurred samples can be selected based on stage height fluctuations and time, however ideally datalogger programs will need to be revised to alleviate excessive sampling.

7.2.4 Priority Stations for monitoring focus.

Stations at Peel and Bennett Creek's have only recently collected hydrological and water quality data. Therefore, characterising stream flow and load contaminant behaviour at these sites is still underway. Establishing a sound rating curve via an adequate gauging regime for these sites in conjunction with water quality data will enable better load estimation and parameterisation of the model.

A number of stations have recently been improved to enable water quality sampling and remote telemetry. The performance of new dataloggers at these stations will require ongoing review to ensure consistent data collection.

7.2.5 Opportunities to Extend Monitoring Networks.

A number of stations in the catchment do not have water quality capacity. More often than not the infrastructure does not allow the installation of samplers or the existing logger configuration is unable to accommodate samplers. In some cases access during the wet season is significantly restricted posing issues for servicing, sample preservation and safety.

As far as practicable, station placement is based on representative land use in the region and the main tributaries entering Darwin Harbour. A number of existing hydrographic stations in the catchment may further contribute to the current water quality monitoring network. Opportunities to extend water quality capabilities of stations in the catchment, particularly where load estimations and models might identify significant load sources should be examined.

Due to the undeveloped nature of western side of the harbour and absence of major stream networks, gauge stations have not been dedicated to this region. However, historical and current data for undisturbed catchments have allowed estimates from this region through appropriate export coefficients. Catchments to the west and south of Darwin are relatively large and uniform in the land uses they represent.

Historical loads assessment from the industrial catchment of Winnellie has provided limited insight into export coefficients for loads assessment. A more contemporary examination of the catchment is required given the degree of additional development in the largely industrial and commercial estate.

8.0 Introduction

Water quality monitoring data is reasonably agreeable with WQO's, however a number of areas show localised deviations from benchmark values. In some areas data is limited and further monitoring effort will be directed to these areas to validate the objectives and inform modelling simulations.

To maintain Water Quality Objectives and load targets a number of initiatives will be progressed in addition to the formulation of an Implementation and Adaptation Strategy which will attempt to facilitate protection and improvement in water quality. Many of these initiatives are broadly described below (Table 8.1 & 8.2), however further negotiation with relevant partner agencies and organisations are necessary to achieve adoption and define timeframes.

8.1 Point Source Discharge Management Actions/Interventions.

The primary supply of point source loads enters Darwin Harbour from wastewater treatment plants. At close to average wet season rainfall, diffuse loads were the main source of sediment to Darwin Harbour, and contributed about two-thirds of the phosphorus to Darwin Harbour. By contrast the greater proportion of nitrogen entering Darwin Harbour, where algal growth is most likely to be nitrogen limited, is input from wastewater discharges. However more significant is the contribution of phosphorus from these point sources.

Discharge from wastewater treatment plants in Berrimah, Leanyer and Palmerston flow to tidal creeks systems within the Darwin Harbour. The impact of high nutrient inflows to these receiving waterways is the subject of current research under the TRaCK consortium. Understanding the assimilative capacity of these ecosystems will be vital in developing the underpinning parameterisation of the water quality model for Darwin Harbour and for assessing the fate of nutrients.

Other point sources include a number of aquaculture operations which extend along Middle Arm to the upper reaches of the Blackmore River. An assessment of the impact that these point discharges may have on receiving waterways is yet to be explored as data is limited.

Based on preliminary data some estuarine zones of the Harbour will not be able to maintain water quality objectives in the near future without significant investment in intervention activities. Many of these zones are subject to waste discharge licence.

Table 8.1. Minor and Major Point Sources – Broader Management Interventions.

Recommended activities for implementation:	Lead Agency	Support Agency/Group
Ambient monitoring and modelling of mixing zones for point discharge.	Licensee's/ NRETAS	DAC
Implement Industry Best Practice Environmental Management.	Industry/NRETAS	DPI
Environmental Management Plans (EMP) for discharge licensees/point source dischargers.	NRETAS/ Licensees	

Explore upgrades to tertiary treated wastewater or reuse options (prioritisation of point sources).	PWC	NRETAS/DHAC
Examine other regulatory mechanisms to limit loads including licence limits	NRETAS	DHAC
Incorporate works to reduce pollutant loads.	DPI/NRETAS	Industry/DHAC
Initiate collaborative monitoring/intervention activities to improve water quality and reduce loads.	NRETA	Industry/Community Groups/Indigenous Rangers/PWC/DCC/ DHAC
Public Information – Health of the Harbour reports including point source contribution to receiving waterways	NRETAS	PWC/DHAC
Establish WQOs under the *Water Act 1992* to protect declared Beneficial uses.	NRETAS	Industry/PWC/Councils/ DHAC

8.2 Diffuse Pollutant Load Management Action/Interventions

The chief diffuse pollutants associated with new developments are sediment and nutrients. The primary pollutants of concern for existing urban developments are dissolved nutrients, suspended solids and toxicants.

Table 8.2. Diffuse Urban and Rural Sources – Broader Management Interventions.

Recommended activities for implementation:	Lead Agency	Support Agency/Group
WSUD principles – grey water reuse options, landscape design, treatment systems, water saving fittings/appliances.	DPI	NRETAS
Implement and assess compliance with Erosion & sediment control guidelines.	DPI/NRETAS	DRDPIFR
Implement and audit local/ regional erosion and sediment control plans, including those for specific developments.	NRETAS	DPI
Education and community information/awareness.	NRETAS/DPI	Greening Australia, Local Landcare groups DHAC
Industry best practice management – soil, nutrient, pesticide, herbicide use/application practises.	NRETAS DRDPIFR	Horticulture Industry
Protection of riparian zones and employ adequate buffer zones.	NRETAS/DPI	
Implement Clearing guidelines.	NRETAS	DPI
Litter and gross sediment traps /stormwater	DCC	DPI

management-maintenance.		
Community education/awareness: Litter abatement, minimising water use.	NRETAS/DPI	Community based groups/DHAC
Implement Stormwater Management Plan.	NRETAS	DPI/DCC/Industry/DHAC
Monitor loads and the effectives of management measures including treatments system associated with WSUD.	NRETAS/DPI	DHAC

Incorporation of WSUD in new developments or 'Greenfield's' will enable the capture, treatment and release of water to mimic natural flows and reduce loads to receiving waterways.

Stormwater management planning has been undertaken with a focus on the proposed subdivision of Bellamack in Palmerston. Recommendations for sound contingency planning and treatment systems have been examined. Strategies for monitoring the effectiveness of treatment systems are underway. The wet-dry tropics of the Darwin region present a number of challenges to more traditional WSUD approaches elsewhere in Australia. Trialling the usefulness of treatment systems will establish a robust set of design systems adapted for the region which are effective in ameliorating the effects of suspended sediment and nutrients.

Where feasible 'Brownfield' approaches should attempt to examine and implement options for WSUD (retrofit), attempt to incorporate WSUD into any redevelopment opportunities, minimise impervious surfaces and resulting conveyance of surface flow in addition to identifying options for effective gross pollutant traps. Community education and engagement will be another vital component of any implementation and adoption strategy particularly when promoting total water cycle management where private premises are encouraged to adopt water saving opportunities.

8.3 Implementation activities for achieving urban targets – Bellamack Case Study.

The new urban development of Bellamack will be a showcase of WSUD in the wet dry tropics. Design of treatments systems will aim to achieve 80% reduction in TSS loads and a 45% and 60% reduction in TN and TP respectively.

To ensure the protection of Mitchell Creek and Darwin Harbour, stormwater quality objectives have been established for the operational phase of Bellamack. These objectives require specific reductions in pollutant load based on best practice stormwater treatment. The numerical values of the load-based targets are based on achievable load reductions from current best practice stormwater management infrastructure operating in Darwin climatic and pollutant export conditions and operating near the limit of its economic performance. This means that higher load reductions could potentially be achieved, but substantial extra cost would be incurred to obtain a very small additional water quality benefit.

The specific stormwater quality management objectives that apply to Bellamack were established through desk top analysis and discussion of the results at the WSUD Objectives Workshop held on the 14th June 2007 (Table 8.3).

Table 8.3. Stormwater quality objectives for Bellamack (Operational Phase)

Constituent	Discharge Criteria
Total phosphorus (TP)	60% reduction in post development mean annual load
Total nitrogen (TN)	45% reduction in post development mean annual load
Total suspended solids (TSS)	80% reduction in post development mean annual load
Gross pollutants	90% reduction in post development mean annual load

Because there will be limited commercial and no industrial land uses within Bellamack, other pollutants such as hydrocarbons, metals and anthropogenic litter are not expected to be generated in significant loads and therefore the WSUD management strategy does not specifically focus on these pollutants. However, each of these pollutants would be managed appropriately by the proposed WSUD stormwater treatment systems.

Treatments systems will incorporate bioretention and wetland systems into the subdivision landscape to ameliorate loads entering the nearby Mitchell Creek and Elizabeth River systems (Fig 8.1 and 8.2). Monitoring of these treatment systems will focus on measuring TN, TP and TSS loads via a series of gauge stations located up and downstream of the treatment systems. These stations will be engaged over several wet seasons to assess the effectiveness of these systems and guide WSUD options for future developments.

The implementation of WSUD in the region is a significant intervention action in the protection and maintenance of water quality.

8.3.1 Wetland Systems

Ephemeral wetlands with deep water zones, as described in 'Water Sensitive Urban Design Strategy for Bellamack' is the preferred option for this subdivision (Fig 1). This option is the most sympathetic to the climate, location and ecology of Bellamack, in particular the hydrology and high evapotranspiration during the dry season which favours ephemeral waterbodies.

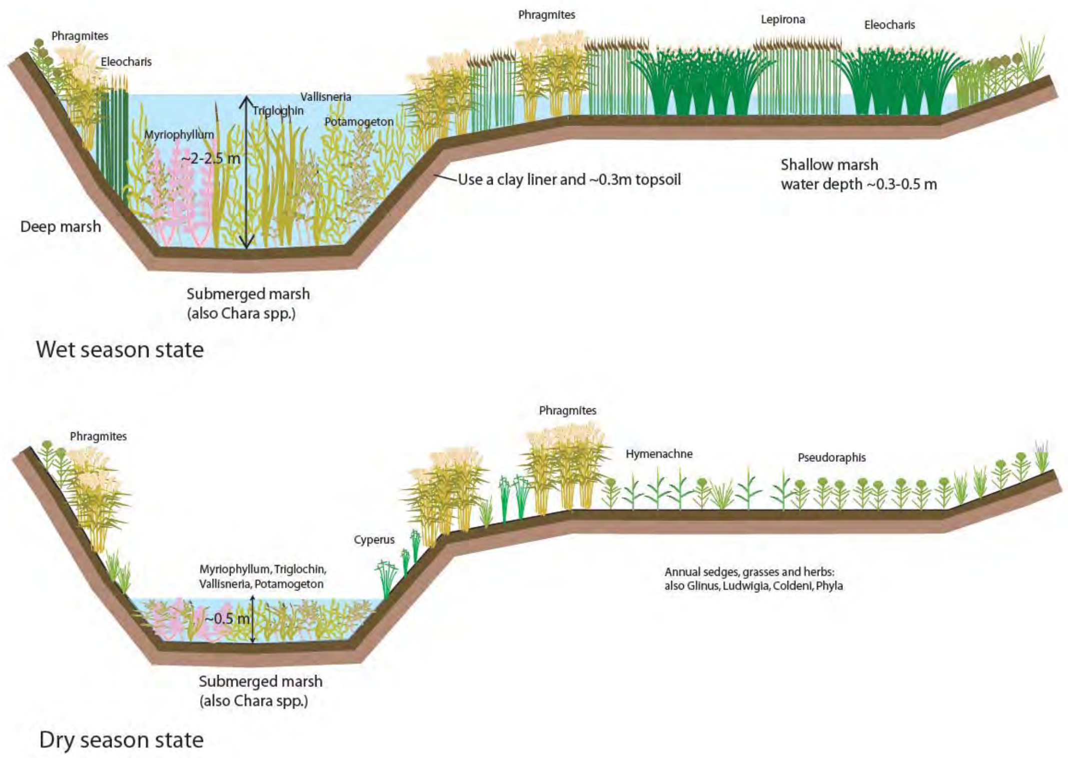


Figure 8.1: Conceptual diagram of an ephemeral wet/dry wetland.

8.3.2 Bioretention Basins (Raingardens)

Bioretention basins are vegetated areas where stormwater runoff is filtered through a soil layer (e.g. sandy loam) as it percolates downwards. It is then collected in a drainage layer via perforated under-drains and flows to downstream waterways or storages for reuse.

Bioretention basins typically use temporary ponding of 0.2-0.4 m depth above the filter media surface to increase the volume of runoff treated through the filter media. The nature of the bioretention basins, being planted soil profiles, means there is a reasonable amount of flexibility regarding the size, shape and location of the systems. As such, there are opportunities to integrate the bioretention basins as landscape features within the overall development layout. Some examples of bioretention systems are shown in Figure 2.

Figure 8.2: Examples of Bioretention systems to be used within the Bellamack subdivision to reduce loads entering nearby waterways.

8.4 Climate Change in the Region

The speed and extent of human induced climate change may have unprecedented impacts on aquatic ecosystems and their vigour in the region. Several of these impacts can be predicted with some confidence and others can be minimised with anticipatory activities.

The most likely consequences of climate change for the NT are:

- Loss of extensive coastal floodplain systems through seas level rise. Floodplain systems are susceptible given their low elevation and proximity to the coast. Changes in salinity can result in marked changes in vegetation and correspondingly the ecological communities they support.
- Loss or retraction of Territory islands.
- Reduced viability of coral reef systems with elevated water temperature and potentially increases in acidity.
- The tolerance thresholds for some species will be exceeded, particularly reptiles such as turtles and crocodiles for which temperature determines the sex of hatchlings.
- The severity of fires may degrade catchments and increase conveyance of surface overflows or runoff bringing with increased nutrient and suspended sediment load.
- Change or loss of suitable habitat for some species or environments.
- Likelihood of new disease, weeds and pests or increased incidence of existing disease, weeds and pests that may impose increasing strain on the regions ecosystems.
- Increase in the intensity and frequency of severe weather events. Increasing runoff events will result in higher than average load contribution, increased erosion and scouring of river and stream channels. All of these processes have the propensity to degrade water quality and undermine set Water Quality Objectives.

Factoring in the potential impacts of climate change to future monitoring and modelling efforts will be sought through the development of monitoring and modelling strategies. Regular review of the implementation and adaptation strategy will allow the consequences of climate change to be recognised and actions undertaken to minimise their effect.

Section 9. Progressing a program of Water Quality Modelling & Monitoring

9.0 Priority Investment Review

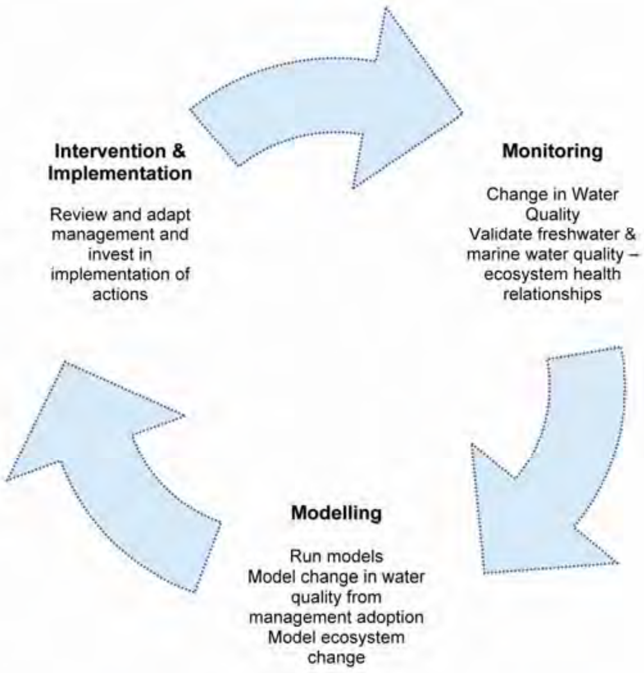
Table 9.1 has been adapted from the document entitled 'Water Quality Modelling Program for Darwin Harbour'. The revised table addresses investment in priority monitoring and modelling activities undertaken as part of the preparation phase of a WQPP for Darwin Harbour.

A large proportion of the proposed activities has been completed or is currently underway. Some of the monitoring and modelling tasks are subject to further funding bids either through Commonwealth and/or NT Government funding streams. The implementation of priority activities will be reviewed annually to ensure research and monitoring activities continue to inform modelling and management in the region.

Refinement of models will continue as monitoring data is collected and specific research addresses critical parameter inputs. Given the specialised nature of model development and enhancement ongoing expertise will need to be sought. The costs associated with such expertise will necessitate the dedication of funds and resources on an 'as needs' basis and will be further addressed in the development of subsequent monitoring and modelling strategies as part of the WQPP.

9.1 Integrated Monitoring and Modelling

It is proposed that modelling and monitoring activities are integrated to determine the effectives of management interventions. Monitoring and models will continue to inform planning and management in the region to ensure the protection of beneficial uses and water quality.



Future monitoring and modelling effort will require ongoing partnership arrangements with research institutions and other stakeholders. Opportunities for collaborative effort will be examined as part of the future development of monitoring and modelling strategies for the region and their implementation.

Table 9.1: Priority Investment Review.

Monitoring/Research Actions	Implementation Status (Nov 2008)
1. Synthesis of existing information Synthesis of historical data and studies will involve a workshop with researchers and agencies previously conducting research in Darwin Harbour to develop a report on the findings. (TRaCK, NRETA and others)	Completed and resulting data made available to modellers.
1.1 Estimate historic rates of sediment and nutrient loads to Darwin Harbour based on sediment cores.	Complete as part of Catchment loads reporting.
2. Intensive field campaigns during the wet season/dry season to quantify the effect of key catchment inputs, e.g. sewage outfalls, on primary and secondary production, and key nutrient and carbon processes on adjacent mudflats and the water column.	Complete in conjunction with TRaCK consortium. An extension to this program of work was funded in June 2008 with Buffalo Creek the subject of study. Field work was undertaken in December 2008 and the results of this work will be reported by March 2009 in conjunction with TRaCK milestone reporting requirements.
3. Examination of potential bioindicators of land based inputs, e.g. fish, crustaceans, molluscs.	To be undertaken – subject to current funding bid.
4. Develop tracing methods for sources of pollutants.	Trialled as part of TRaCK collaborative research.
5. Sediment dynamics (sedimentation, resuspension, transport, bioturbation, sources.	To be undertaken – subject to current funding bid.
6. Algae population dynamics (algal growth / die-off/ biomass). – determined as part of AIMS research in 2004 – synthesis of sediment data required to complete this.	Partially met by AIMS/TRaCK research.
7. Nutrient inputs and availability – budget.	Estimates complete via empirical modeling and research undertaken by AIMS/Griffith University. A conceptual diagram was produced to describe major nutrient pathways (Nitrogen and Carbon).
8. Catchment runoff loads Catchment water budget, notably runoff.	Completed as part of Catchment loads report. The development of a more process orientated model is underway.
9. Development of a conceptual model of the effect of nutrient and sediment loads on the health of mudflats and mangroves.	Conceptual diagram/model completed – to be used with scientific and other communications material.

10. Hydrology Currents Density stratification Exchange with outer Harbour Mixing by wave action Tides Surface water discharge volume Surface water flow rate (Hydrodynamic model improvements)	Partially completed – hydrodynamic model (finite mesh) improvements have been undertaken. Further monitoring of currents and sediment has been undertaken in specific areas of the Harbour subject to dredging.
11. Boundary Conditions – profile nutrient, algae and physical conditions. Spring tide conditions required.	Limited work has been undertaken in the outer estuary. Future work is planned in 2009 to intensify monitoring effort and extend monitoring stations to adequately cater for boundary condition assessment.
12. GIS layers – spatial data requirements for catchment model - Land use (lumped accordingly dependent on model requirements) - Soil types/geology - Stream/drainage networks - DEM - Floodplain extent - Gully density - Hillslope erosion - Annex data/nutrient datasets - Gully Density, Riparian Vegetation, Annual Rainfall, RKLS Factors, Soil Clay %, N in surface Soil, P in surface soil, Air temp, DIN, DON, DIP, FRP. - Time-series flow data	ANNEX datasets are to be compiled and catchment model development pursued in 2009 building on existing empirical approaches. Most of the spatial data requirements for modeling have been met but will require additional preparation.
13. Develop a catchment model which can provide loads data for the receiving water quality model with some confidence and a sound tool for planning and policy formulation purposes.	A more process orientated model such as SedNet will be pursued in 2009. Comparison with empirical based approaches and data already gathered as part of this approach will be used to verify future modelling work.
14. Catchment model development should enable the identification of 'hotspots', which can be examined with finer resolution models if required. i.e. Sediment sources in	The use of Sednet or similar will enable the identification of 'hot spots'. Current data and other research on sediment sources in the catchment suggest that 'in-stream' sources are more significant than hillslope sources. Generally low relief in the region coupled with the extensive lagoon/wetland and dambo type systems in the

catchment.	landscape effectively ameliorate sediment runoff providing natural sediment traps.
15. Focus loads on sampling events at a number of sites and first flush events when most of the variation in sediment and nutrient concentrations occurs.	Intensive sampling will be biennial based on the level of development and/or changes in the catchment.
16. Improve rating curve through more frequent gaugings at Winnellie, Bennett and Peel stations to enable better stage-discharge relationships.	Currently underway.
17. Further development of sound empirical relationships between parameters such as TSS and Turbidity	Data collected to establish these relationships at key sites.
18. Examine collected data for structure and insight into the processes that are operating so that the sampling regime can continue to be improved.	Currently underway.
19. Reduce unnecessary over-sampling caused by fluctuations around sample height by employing minimum time interval before sampling re-occurs at the same height trigger.	Included as part of sampling rationale at each site where discrete sampling is undertaken.
20. Focus sampling on newer stations to build a better understanding of stream discharge and water quality relationships.	Currently Underway and the focus on ongoing loads assessment.
21. Evaluate opportunities to extend water quality capabilities of existing hydrological stations.	Currently reviewing opportunities for other relevant partners within Govt.
22. Engage expertise for catchment model development	Recently appointed staff with relevant expertise.
23. Benthic Habitat Mapping. This task will better define the spatial context of habitats and characteristic ecosystem processes. This whole-system approach will thus support the development and calibration of the water quality model.	To be undertaken – subject to current funding bid

Model Verification and Calibration	**Implementation Status (Nov 2008)**
1. Ambient monitoring– nutrients (NO2, NO3, TKN, TP, FRP…)	Currently underway with intentions to intensify effort in priority zones.
2. Ambient monitoring – Physical water quality conditions (Temp, pH, EC, salinity, DO, Turbidity, PAR)	Currently underway with intentions to intensify effort in priority zones.
3. Ambient monitoring – (Selected sites to minimize cost/time). Phytoplankton/ zooplankton	Under review given costs and resource restrictions
4. Ambient monitoring – Suspended Sediment (TSS/VSS)	Currently underway with intentions to intensify effort in priority zones.
5. Sediment characteristics and mapping (grain size, fall velocity, density, bulk density, shear stress of erosion and deposition & determine diffusion parameters for model)	Under review given costs and resource restrictions. Some recent work undertaken by CDU/TRaCK may inform this work. Further sediment quality is proposed as part of a current funding bid.

10. Conclusion

The Darwin Harbour Region Water Quality Protection Plan aims to maintain water quality suitable for aquatic ecosystem protection and human uses. This first phase of the plan has developed water quality objectives and pollutant load targets consistent with beneficial uses.

A receiving water quality model has been developed which will provide a valuable tool in the assessment of development pressures in Darwin Harbour. A number of proposed management actions including the incorporation of water sensitive urban design have been identified as important intervention measures to ensure diffuse and point sources do not degrade the aquatic ecosystems of the Darwin region.

Significant investment will be required for successful outcomes and implementation will focus on progressing priority actions to maintain water quality and enable aquatic ecosystem assessment to inform ongoing management actions.

The future development of phase two of the plan will integrate monitoring, modelling and implementation strategies and identify opportunities to incorporate legislation and planning. It is expected that these core strategies will be developed by 2010 in conjunction with a comprehensive consultation program.

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Appendix A: Distribution of preferences for Beneficial Uses as part of the Public Consultation Phase.

Beneficial Use / Water body	Agricultural	Cultural				Aquaculture	Public Water Supply		Environment	Riparian	Industry
	irrigation water	food source	spiritual values	recreation (e.g. swimming or fishing)	aesthetics (visual amenity)	aquaculture (both in water or on land)	drinking water source	domestic purposes (not drinking)	habitat for plants and animals	water for stock	industrial (cooling water)
Darwin Harbour and its marine reaches	7	43	25	44	44	26	6	6	52	19	19
Rapid Creek freshwater reaches	4	23	25	40	38	5	4	3	44	21	5
Elizabeth & Howard Rivers Region – surface water	20	28	18	34	34	11	14	19	47	28	6
Elizabeth & Howard Rivers Region – groundwater	30	13	10	14	14	6	36	23	31	18	13
Darwin & Blackmore Rivers Catchment- surface water	34	33	21	34	33	20	24	15	46	29	11
Darwin & Blackmore Rivers Catchment- groundwater	35	15	13	13	15	10	34	27	33	15	14
Shoal Bay & Vernon Islands	2	35	22	36	35	15	3	2	45	18	2
Hudson Creek and Tributaries	3	30	20	29	29	8	5	1	40	15	18

Indicates Beneficial Uses currently declared under the Water Act