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Water Quality Objectives for the Darwin Harbour Region - Background Document

February 2010

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Department of Natural Resources, Environment, The Arts and Sport.

Aquatic Health Unit.

Report: This background document describes the methodology undertaken in the development of locally derived water quality guidelines and objectives for waterways of the Darwin Harbour region. The process of setting the objectives 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.

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

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General Disclaimer: The information contained in this report comprises general statements based on scientific research and monitoring. The reader is advised that some information may be incomplete or unable to be applied in areas outside the Darwin Harbour region. Some information may be superseded by future scientific studies, new technology and/or industry practices.

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1. OVERVIEW

Continued growth of urban and rural activities around Darwin Harbour will place increasing pressure on the general health of the region's waterways. Currently, the assimilative capacity of the Harbour and waterways to receive pollutants from point and non-point sources and other understandings about key ecological processes and their vulnerabilities are poorly known. An efficient and effective monitoring and reporting effort and a staged knowledge acquisition program is required to better ensure that the recreational, social, environmental and economic values of our waterways are sustained .

To that end a Water Quality Protection Plan (WQPP) for the Harbour and catchment is being developed to provide a strategic framework in which information, research, monitoring and condition reporting can be better coordinated and ultimately communicated to the wider stakeholder community. This Plan follows the national *Framework for Marine and Estuarine Water Quality Protection* which in turn is a conduit for implementation of the *National Water Quality Management Strategy* (NWQMS).

As a key component of the WQPP a suite of Water Quality Objectives that relate to the beneficial uses and environmental values of the waterways has been developed to provide some preliminary benchmarks against which various attributes of the health and condition of these waterways can be measured and reported.

This document describes the approach and methodology undertaken in the development of these Water Quality Objectives. Key steps in preparing the Objectives included:

- identification of water quality issues and management goals to address them (Section 2);
- identification of environmental values or uses of waterways in various parts of the catchment (Section 4);
- identification of priority water quality indicators to be monitored (Section 4);
- identification of water types such as groundwater, freshwater or estuary systems to which the objectives will apply (Section 4);
- a rationale for determining water types in the context of seasonal variation experienced in the region (Section 4 & Appendix C) ; and
- freshwater and estuarine Water Quality Objectives for various waterways in the Darwin Harbour catchment based on local water quality data and relevant national water quality guidelines (Section 6).

Section 7 offers some guiding principles to be applied when implementing the Water Quality Objectives in the catchment with particular focus on their use in land use planning and condition assessments.

2. INTRODUCTION

2.1 Developing Water Quality Objectives for the Darwin region.

The natural resources of the Darwin Harbour region are experiencing an increasing demand and impact pressure from the growing human population in the area.

Australian Bureau of Statistics Population projections show that by 2026, more than half of the NT population (around 165,000 people) will live in the Darwin Harbour region (ABS, 10 September 2008) up from 120,652 currently in the region. It is therefore inevitable that the pressure on the Harbour and its waterways will intensify.

At present, water resources 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 has for its ecological diversity and high quality recreational amenities such as fishing and mud-crabbing.

There are, however, areas of concern, especially around some urbanised areas where sewage outfalls and urban stormwater can impact on the quality of the receiving waters. It is important to recognise that sustaining the high environmental quality of these waters will strongly depend on the planning decisions we make now.

Government and non-government organisations involved in coastal planning and management have made commitments to address the pressures experienced in the catchment (Darwin Harbour Regional Plan of Management and Living Rivers). The introduction of Water Quality Objectives for natural waters in the catchment builds on this work and provides a mechanism for a more consistent and strategic approach to the protection of the region's water quality.

3. BACKGROUND

3.1 NT legislative and policy background

The Water Act is the primary piece of legislation that governs water resource regulation and management in the Northern Territory. The objective of the Act is "to provide for the investigation, allocation, use, control, protection, management and administration of water resources". The Act is administered by the Minister for Environment through the Controller of Water Resources who resides in the Department of Natural Resources, Environment, The Arts and Sport (NRETAS). The Controller of Water Resources is under a general obligation to monitor water resources including water quality under S34 of the Water Act.

The responsibility for ensuring water is suitable for public water supply is described in the Water Supply and Sewerage Services Act and is administered by the Department of Health and Families.

NRETAS also administers and implements a number of other Acts that relate directly and indirectly (through land based activities) to water resources. These include:

- Waste Management and Pollution Control Act;
- Soil Conservation and Land Utilisation Act;
- Pastoral Land Act;
- Weeds Management Act; and
- Bushfire Act.

Legislation not administered by NRETAS that relate to water resources includes:

- Water Supply and Sewerage Services Act;
- Mining Management Act;

- Agricultural and Veterinary Chemicals (Control of Use) Act; and
- Planning Act.

The principal legislative basis for water quality management in the NT is the *Water Act*. The legislation includes a process for:

- Identifying and declaring beneficial uses or environmental values. These include environment, cultural and human use values; and
- Establishing corresponding water quality objectives or water quality standards to protect identified beneficial uses.

Water Quality Objectives can be declared under section 73 of the *Water Act*. This declaration allows natural resource managers and regulators to use Water Quality Objectives as benchmarks for regulation to protect beneficial uses and for their use as performance measures for monitoring and reporting.

3.2 National Framework approach to water quality management

The process for setting marine and freshwater quality objectives is based on the national framework outlined in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000). The national document provides a framework that allows the user to move beyond a single-number conservative value, to guidelines and objectives that can be refined according to local environmental conditions. It is within this context that the Darwin Harbour region guidelines and objectives have been initiated and will be progressively enhanced.

The National Water Quality Management Strategy (NWQMS) was introduced in 1992 in response to growing community concern about the condition of the nation's water resources and the need to manage them in an environmentally sustainable way. Key NWQMS documents have been added and/or revised over the period to 2009 and the strategy was confirmed and further endorsed under the COAG National Water Initiative (NWI) in 2005 and is currently undergoing a comprehensive review.

The Strategy aims to ensure a nationally consistent and best practice approach to water quality management. It currently comprises some 21 guideline papers (see http://www.environment.gov.au/water/policy-programs/nwqms/index.html) covering key elements of the water cycle and sets out a conceptual structure to solve and address complex issues often encountered in water quality management. In particular, document #3 of the NWQMS provides guidance on implementation of the Strategy and was a key reference for the process outlined in this paper.

Locally derived guidelines and objectives are the priority preferred ambient quality benchmarks as envisaged by the NWQMS. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (document #4 of the NWQMS) provide default values for a range of water quality parameters in the absence of locally or regionally derived reference values.

Water Quality Objectives described in this document apply to all ground, surface, marine and freshwaters within the Darwin Harbour catchment. It is intended that future information on the region's waterways will be incorporated into the document, so that it will be both expanded to include biological and habitat benchmarks and current in that it incorporates new data from on-going monitoring programs.

Unlike many other regions around Australia, especially the highly altered landscapes and waterways of the southern and eastern states, the ecological health of Darwin Harbour and its tributaries is in good condition, although localised impacts have been detected in some areas. This is recognised by the Water Quality Protection Plan which is being developed and will aim to maintain and protect the regions enviable condition, unlike Water Quality Improvement Plans developed elsewhere in Australia where systems are heavily degraded and significant management intervention is required to retrieve the health of water systems.

3.3 Water Quality Objectives

The Water Quality Objectives describe the water quality needed to protect and sustain each of the environmental values and beneficial uses identified, as per the NWQMS guidelines. These uses and values and water quality objectives can be declared under S73 of the *Water Act* and these can then act as statutory guideline levels and/or reference levels to help guide planning and management to achieve and protect each of the values over time. Under S18 of the Waste Management and Pollution Control Act a S73 Water Act declaration is automatically recognised as an Environment Protection Objective under that Act. The Water Quality Objectives are:

- aimed at protecting human health and the health of the aquatic ecosystems;
- for regions of relative homogeneity in water quality;
- not for heavily urbanised areas;
- applied to perennial rivers and streams;
- not developed for intermittent/episodic streams, lakes, wetlands (base-flow only); and
- not to be used as a value to 'pollute up to' but instead be used to limit the amount and type of discharge flushed into waterways or a particular body of water.

3.4 Application of Water Quality Objectives

Water Quality Objectives for the Darwin Harbour catchment are intended for the community, local councils and government agencies to use in catchment management and land use planning activities. They are a tool for strategic planning and development assessment processes. For example, they will provide local planners, managers and developers with water quality guideline levels to be sustained or achieved when considering or assessing coastal developments.

The Objectives can assist in the above processes by providing:

- values and uses of waters agreed to by the community;
- relevant indicators and guideline levels for assessing water quality impacts;
- a framework for decision making that is consistent and transparent; and
- a better community understanding of water quality and the potential impacts on it.

Section 7 provides an example of how Water Quality Objectives can be of practical help in decision-making.

4. METHODOLOGY

4.1 Darwin Harbour Catchment

Darwin Harbour and its catchment has a total area of 3230 km^2 and a land area of 2010 km^2. Approximately 20% of the catchment is currently (2008) developed for urban and rural land uses.

Urban stormwater and discharges from activities such as wastewater treatment plants have been estimated to double the total annual load of nitrogen and increase by six-fold the annual load of phosphorus discharged to the Harbour from land based activities by wet season runoff (Water Monitoring Branch, 2005). These additional nutrients enter Darwin Harbour in the vicinity of urban areas of Darwin and Palmerston. Nutrient loads derived from rural living areas of the catchment are similar to loads from relatively undisturbed parts of the catchment (Skinner *et al* 2008).

The water quality of Darwin Harbour waters is regarded as being in a near-pristine or slightly modified condition, depending on the definition of these terms. Hydrodynamic modelling, supported by water quality studies, indicate that significant tidal movement in the Harbour does not, on a time scale of weeks or even months, transport diffuse and point source nutrients out of the Harbour, but rather assists in their dispersal within the Harbour precinct.

The impacts of urban and point source discharge are therefore likely to be localized, and, in the case of urban stormwater runoff, highly variable.

Despite these findings, the only area where water quality was clearly demonstrated to be significantly impacted by nutrients is Buffalo Creek. Here, high nutrient loads are discharged into a small tidal creek from the Leanyer Sanderson sewage treatment facility that services an estimated 40,000 people and grossly exceed the creek's nutrient assimilative capacity.

4.2 Development Process

The process of developing management goals, locally appropriate water quality guidelines and objectives through understanding the pressures on our waterways in the region, their water quality and associated beneficial uses is illustrated in Figure 2.

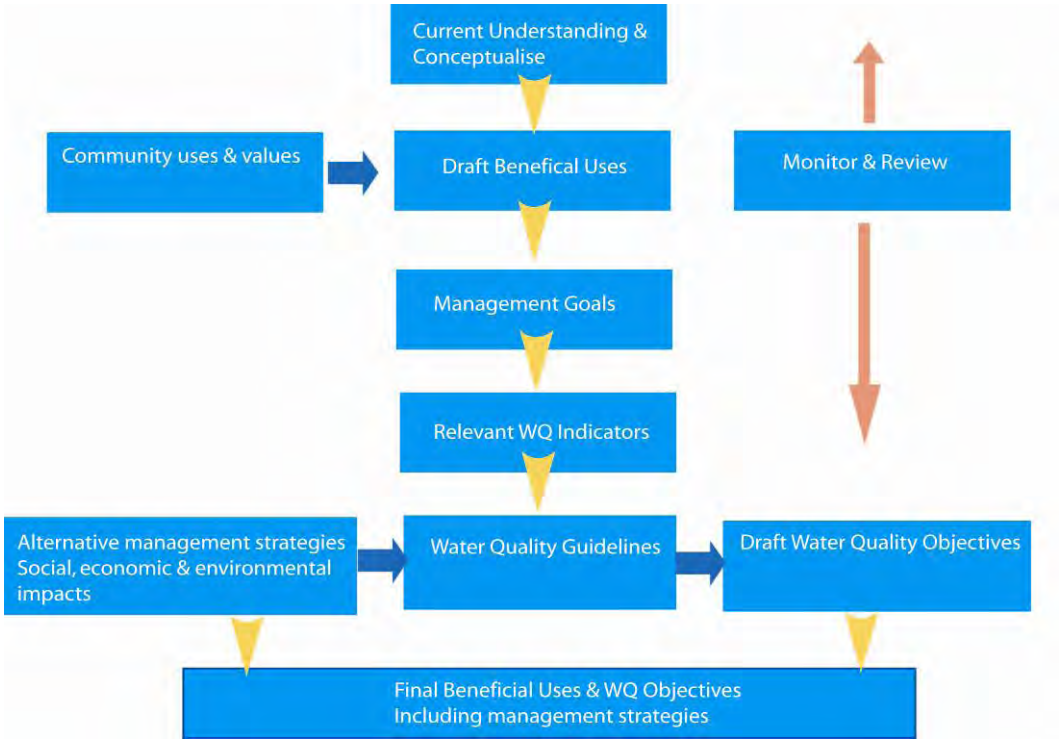
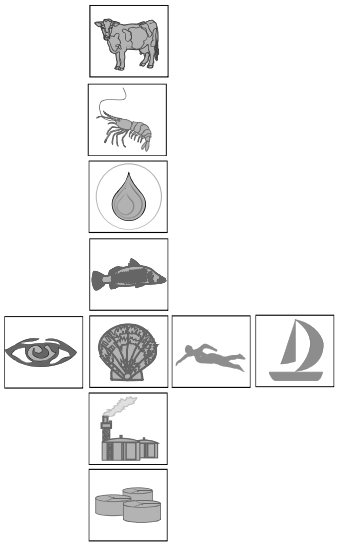


Figure 1: Process for deriving guideline values and Water Quality Objectives.

4.2.1 Environmental values of regional waters and consultation

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 1992* defines these values or uses as Beneficial Uses and 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

In April and May 2007, as a first step in the development of the WQPP, NRETAS undertook a public consultation process to evaluate Beneficial Use declarations originally gazetted in 1996 with respect to significant water bodies in the Harbour catchment. 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 Harbour. For a full description of community preferred uses for respective water resources see Table 1 of Appendix A.

A number of public fora were held across the catchment to gauge public views on what they valued about the harbour and its waterways. A website was developed to provide the public with an opportunity to provide feedback on important beneficial uses through nominating values and specifying regions and waterways of importance. Advertisements and targeted stakeholder forums were also held to allow interest groups to provide direct input into the determination of beneficial uses. This process was undertaken in conjunction with the Darwin Harbour Advisory Committee (DHAC), a community based advisory committee in the region (see http://www.nt.gov.au/nreta/water/dhac/index.html

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 documentation of an 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 Larrakia representatives.

4.2.2 Priority indicators for declared values

Increasing nutrient and suspended sediment contribution to the Harbour's waterways from increasing development pressures has been identified as a broader management issue in the region and the subject of management goals (Darwin Harbour Advisory Committee, 2003). Key water quality characteristics (indicators) for management identified in work to date include nitrogen, phosphorus and total suspended sediment.

4.2.3 Water quality criteria for priority indicators

The *Framework for Marine and Estuarine Water Quality Protection* recommends that reference values (called guidelines) for each indicator should be based on locally derived data so as to reflect local (ambient) conditions. Where derivation of guidelines based on local monitoring is not possible NWQMS recommends that default figures (national guidelines) for tropical Australia are used instead. Detailed procedures for applying the national guidelines are described in the *ANZECC Water Quality Guidelines* (ANZECC & ARMCANZ 2000a).

In the case of Darwin Harbour the most stringent water quality criterion is the environmental Beneficial Use category because the intent of environmental beneficial use is to maintain the health of aquatic ecosystems and a water body that meets an environmental beneficial use will in almost all circumstances also meet the requirements for all other beneficial uses. Human health related guidelines are also provided to protect recreational and cultural values in the region.

4.2.4 Other important indicators for assessment

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 ecological habitat retention. Any assessment of ecosystem health needs to have direct measurement of biological indicators as well as the indirect assessment of system modifiers or potential stressors such as water quality. Measurement of these modifiers is important in determining causes of any changes to biological health attributes. In the case of ecosystem protection there is a plethora of possible indicators to choose from. Monitoring all potential indicators and/or stressors is impractical and a process to select the most appropriate indicators was undertaken.

Priority indicators have been identified for the Darwin Harbour region by an expert panel in conjunction with a review of currently available data. These consist of a limited set of physico-chemical indicators (Table 1-3) for Ecosystem Protection. It is anticipated that a wider range of indicators will be developed over time including a more comprehensive assessment of biological and habitat indicators.

Local guidelines in this document have been derived for physico-chemical indicators and potential stressors, and do not address toxicants (such as heavy metals). Guideline values for toxicant indicators in water and sediment will continue to be sourced from ANZECC (2000) Guidelines. Health related indicators presented in this document are sourced from the NT Department of Health and Families recreational guidelines and/or relevant National guideline values.

Key criteria used in the selection of physico-chemical water quality indicators include ecological significance, relevance to the WQPP, efficiency of indicator suite (avoid indicators which are correlated) and consideration of efficient monitoring methodology. These water quality indicators may be classified as either stressors (e.g. nutrients, turbidity), or ecological indicators that respond to the stressor (e.g. phytoplankton).

Water quality guideline indicators proposed for each major water body type are shown in Tables 2-3. The indicators monitored however, may be broader than those proposed to provide contextual information about the guideline indicator value (e.g. salinity, temperature).

Table 1: Physico-chemical guideline indicators.

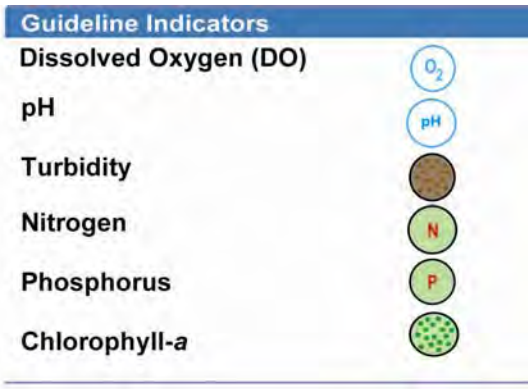


Table 2: Priority indicators for freshwater systems.

Attribute	Indicators	Desirable
Water Quality	Conductivity Temp pH DO NOx, FRP TN, TP Turbidity Chlorophyll-*a*	 Temp maxima and minima DO diel cycle
Habitat	To be determined	
Flow	Refer to Flow Objectives for the Darwin Harbour region.	
Biota*	Aquatic Macroinvertebrates (AusRivAS) Others to be determined.	Fish – richness/diversity Aquatic Macrophytes Diatoms Amphibians

Table 3: Priority indicators for estuary/coastal systems.

Attribute	Indicators	Desirable
Water Quality	Conductivity Temp pH DO NOx, FRP Turbidity Chlorophyll-*a* TN, TP	 Temp maxima and minima DO diel cycle
Habitat	To be determined	Coral Extent/Health, Seagrass or other benthic habitat extent.
Flow	N/A	
Biota*	Phytoplankton Others to be determined	Mangrove health/intactness. Polychaete community assemblage or other species.

*Further investigation to identify a suite of biological indicators for freshwater and estuarine monitoring is required.

4.2.5 Seasonal impact on water quality

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 (NASY 2009), relatively little perennial water exists in this region.

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 creek beds for most of the year only flowing during the wet season. Therefore, seasonal variation across the water types in the Darwin region is highly variable.

Accounting for seasonal variability in the determination of Water Quality Objectives can be complex. Thus the number of water types nominated has attempted to be a compromise between usability and variability. In many cases the interim guideline values provided will be annotated with a range of limitations for its use. For example guidelines for freshwater systems in the Darwin region have been drawn from the determination of dry season resource condition targets (Fukuda & Townsend, 2006).

Only two systems (Howard River and Berry Creek) in the Darwin region persist during the dry season and these are fed by a spring discharge from a deep dolomite aquifer. The determination of guidelines for all other ephemeral systems will necessitate that values are based on early dry season recessional flow conditions. Biological sampling, namely aquatic macro-invertebrate monitoring and more recently some limited fish survey effort is also typically undertaken during these recessional flows. Aquatic ecosystem protection in these systems also requires that environmental flows are maintained. The development of a Water Allocation Plan (WAP) in the region will identify environmental flow provisions for these important perennial systems and the ecosystems they support.

4.2.6 Water types in the Darwin Harbour region

A number of water types have been selected across the Darwin region each requiring a determination of relevant water quality guidelines. There is a considerable natural variation in water quality across the harbour and its tributaries and variation within major water types, for example stream water quality is likely to vary between upper and low reaches.

An approach to take is to aim to define water types where the water quality is reasonably consistent. This allows the setting of a single guideline value that can be applied across all sites within the defined water type. If there is too much variation within a defined water type then a single guideline value may be inappropriate. The risks are minimised by establishing more water types but this can become unwieldy.

In the case of Darwin Harbour catchment and its sub-catchments (Figure 3) the first step was to determine natural variation in water quality. From this process the catchment was divided into water types that best represent the range of natural variation. Current subdivisions are based on:

- Existing data;
- Delineation of marine and estuarine zones through the use of residence times and flushing index derived from the Darwin harbour hydrodynamic model;
- Flow regime – perennial and seasonal systems (freshwater systems);
- Effect of geology on water quality (aquifer fed systems); and
- Spatial effects - Upper and lower reaches (freshwater and estuarine systems).

The estuarine water type within Darwin Harbour was divided into 3 sub-categories which delineate between systems which are similar in their water quality and mean residence times. The rationale for this categorisation is further examined in Appendix B.

There are a number of regions for which appropriate water types have not been defined and for which there is little or no local data. Where no guideline values can be provided the alternative for users will be to default to the ANZECC (2000) guidelines or progress work to developing those which are locally appropriate.

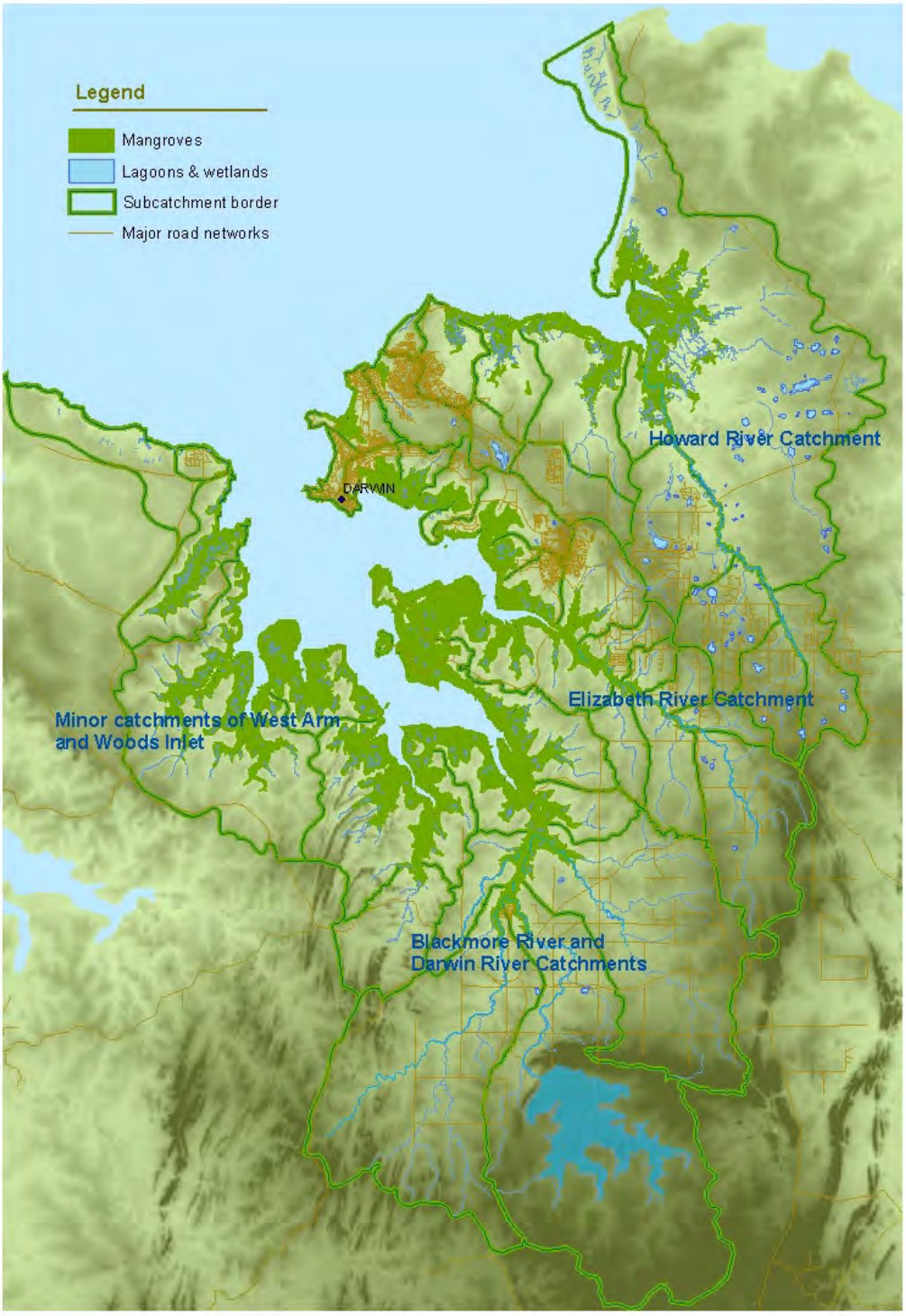


Figure 2: Major Catchments of the Darwin Harbour Region.

Ideally, each water type with a corresponding guideline should have reasonably homogenous water quality and be readily discernable in terms of its physical attributes, such as flow, depth and/or flushing.

Water Types identified for guidelines in the Darwin region are presented in Table 4 and are analogous with those defined in ANZECC (2000) Guidelines.

Table 4: Broad Water Types covered by these guidelines.

ANZECC Water Type	WQPP Water Type	Description	Criteria
Lowland Rivers Altitude <150m above sea level (ANZECC 2000) – Upland streams not applicable in the Darwin region.	**Freshwater streams/rivers**	All rivers and streams. Gradient very slight. The water quality of rivers and streams in the Darwin region is highly variable during the wet season, but relatively constant during seasonal recessional flow in the dry season. Some rivers (e.g. Howard River) have extensive floodplains. In the dry season most streams cease flowing, with the exception of a few that are supplied by deep aquifers (e.g. the lower reaches of Berry Creek). Wet season water quality is broadly dependent on catchment characteristics and the relative proportion and total volumes of surface runoff and base flow. For each storm runoff event, water quality varies over the rising and falling stage of the hydrograph, and the timing of the runoff event with respect to the commencement of wet season flow and antecedent runoff events.	• Highly variable during the wet season, but relatively constant during seasonal recessional flow in the dry season. • Typically ceases to flow during the dry season. • Guidelines applicable only to dry season recessional flow.
No water type defined.	**Aquifer fed freshwater streams/rivers**	Usually upper catchment streams and rivers. Dry season flow maintained by deep aquifer which is usually recharged during the wet season. A dolomitic aquifer lies beneath the Darwin Rural Area. This deep aquifer discharges water to a small number of streams (e.g. Berry Creek downstream of Berry Springs, Howard Springs) during the dry season, and provides rural residents with water for potable use. A shallow aquifer also exists, in the lateritic surface layer which is saturated in the wet season, and supplies wet season recessional flow.	• Dolomitic aquifer fed stream/river/spring systems. • Usually characterised by higher conductivity and continued flows during the dry season.
Wetlands	**Lagoons**	The lagoons in the Darwin region are natural depressions that fill in the wet season by surface runoff, and become hydrologically connected to the surface drainage system. In the dry season the lagoons become isolated and reduce in depth due to evaporation, with some drying completely. The water quality of the lagoons is less variable than the region's rivers during the wet season, but can change significantly as their volume reduces late in the dry season.	• Perched lagoon systems within Darwin rural region • Defined as natural shallow (<4 m deep) depressions that fill each wet season to become part of the drainage network, then become isolated water bodies.
Freshwater lakes & Reservoirs	**Reservoirs**	Darwin River Reservoir is the only reservoir of significant size in the catchment. The reservoir supplies water for potable use to Darwin, Palmerston and those rural residents supplied by reticulated water.	• Significant potable water supply for domestic use.
Estuary	**Estuary** Upper Estuary	Upper most reaches of the estuary where hypersaline conditions may persist for short periods during the dry season and significant freshwater pulses prevail during the wet season where stratification (or saltwater wedges) may occur. Includes a series of tidally influenced creeks branching from the main body of the harbour and its estuarine arms. Significant flushing during the wet season and during tidal movement is experienced by these systems which in most cases are the first sites where catchment disturbance is detected.	This water type has been determined based on flushing index or residence time determined from modelling and knowledge of salinity gradients within Darwin Harbour. • Residence time >32 days. (Appendix B)
	Mid Estuary	Majority of the length of the estuary from below the upper estuary to near the mouth. Excludes smaller well flushed reach at mouth which typically has marine water quality.	• Broad spatial extent from Mandorah to the mouth of east and middle arms of Darwin Harbour and Shoal Bay. • Residence time between 32-14 days (Appendix B)
	Outer Estuary	Coastal waters with some broader marine or ocean exchange. It includes shallower costal waters or embayments. It also includes most downstream reaches of estuaries.	• Indicative of marine waters (80th percentile of seasonal salinity values >35ppt). • Residence time < 14 days (Appendix B).

5 DARWIN HARBOUR REGION - AMBIENT GUIDELINE VALUES

Interim guidelines have been derived for the base set of physico-chemical indicators. For each defined segment and water type where good reference data is available, the guideline values have been derived using methods recommended by ANZECC (2000) Guidelines and the approach taken by Queensland EPA in developing Water Quality Guidelines (Queensland EPA, 2006). Where good local reference data is not available, guidelines should be drawn from default values described in the ANZECC (2000) Guideline values relevant to tropical Australia.

The general approach adopted in deriving guideline values are based on an acceptable departure from a natural or reference condition. This is based on the premise that the reference condition is not fixed but dynamic within certain bounds. This approach requires a sound knowledge of the reference condition and an informed judgement on the extent of an acceptable departure.

5.1 Methodology for deriving local water quality guidelines from reference data

ANZECC (2000) Guidelines recommend that guidelines are developed on the basis of biological effects data. Such data is not commonly available, particularly sub-lethal or chronic effects. The alternative approach is to base guidelines for physico-chemical class indicators on the 80th and/or 20th percentiles of data from reference sites (Appendix E), which is the approach adopted for the Darwin Harbour region.

Monitoring data for each water type was assimilated and reference sites determined. To protect and maintain environmental beneficial use reference sites were required to meet the following criteria:

(a) representative of the water type;
(b) not impacted by point source discharge; and
(c) not impaired by nearby land-uses.

Reference sites in the region were identified for freshwater rivers and streams, estuary and lagoon water types. Data from these sites was then used to determine locally derived guidelines and subsequently Water Quality Objectives.

The availability of data across the region is highly variable. Some segments and water types of the region have a reasonable number of data points to substantiate percentiles. In most cases sample size exceeded the ANZECC (2000) Guidelines recommendation of 24 data values, however the timeframe from which this data has been collected spans periods in excess of 10 years in some cases. Values derived for the Queensland Water Quality Guidelines (Qld EPA 2006) were initially drawn from a range of 15-20 data values for most indicators.

5.2 Levels of protection

These guideline values are designed for application to slightly disturbed waters. For high conservation value waters, the guideline value is taken to be no change in existing water quality. For highly disturbed waters, ANZECC 2000 recommends the application of a less stringent guideline based on (a) different reference data percentiles e.g. 90th and 10th, (b) reference data from more impacted sites to (c) other local information.

Table 5: Basis for determining Darwin region guideline values for waters of different levels of protection.

Level of protection	Basis for guideline value
High Conservation Value (HCV)	No change to natural values
Slightly to Moderately Disturbed (SMD)	Guideline based on 20th and/or 80th percentiles of reference data from good quality reference sites
Highly Disturbed (HD)	Guideline locally derived based on: 1. A less stringent percentile e.g. 10th/90th or 2. Reference data from more impacted but still acceptable reference site.

Sourced Queensland Water Quality Guidelines 2006.

The Darwin Region Water Quality Guidelines and objectives have adopted the ANZECC (2000) approach for physico-chemical indicators as indicated in Table 5 for slightly to moderately disturbed (SMD) systems. The ANZECC guidelines have defined acceptable effect sizes for each level of protection for different indicator types. These are summarised below in Table 6.

Table 6: ANZECC (2000) default effect size for varying levels of protection.

Indicator Class	Effect Size or Departure from reference		
	HCV systems	**SMD systems**	**HD systems**
Toxicants in Water	No change to natural values	95% spp protected	80-90% spp protected
Toxicants in sediments	No change to natural values	>90% individuals protected	
Physico-chemical*	No change to natural values	Median lies within $20^{th}/80^{th}$ percentile of reference range*	Locally determined ($10^{th}/90^{th}$ percentile of range)
Biological	No change to natural values	Median lies within $20^{th}/80^{th}$ percentile of reference range	Locally determined ($10^{th}/90^{th}$ percentile of range)

* Applicable to the approach taken with WQOs for the Darwin Harbour region.

ANZECC (2000) guidelines suggest that use of the 95 percent protection level. This approach is the most commonly applied protection level to ecosystems that could be classified as slightly to moderately disturbed. While for those chemicals that have the potential to bioaccumulate (and in the absence of local data) a higher level of 99% protection is recommended for slightly–moderately disturbed systems.

A number of sites in a region may attract a higher level of protection by virtue of their conservational significance. A list of such sites is listed below (Table 7). In the case of high conservation value systems in the region such as those listed an expectation of no change to natural values for ecosystem protection is recommended.

Table 7: Land uses and conventions that may attract default environmental values.

Environmental value	Designated land use/convention
Aquatic ecosystems	World Heritage Areas Ramsar Wetlands National Parks Treaty/convention Conservation Reserves Areas of National Environmental Significance Sanctuaries (e.g. Whale) Threatened or protected species
Primary industry	Gazetted fishing zone
Recreation and aesthetics (primary and secondary contact)	Designated recreation areas (swimming holes, beaches, pools etc) Designated scenic lookouts and trails
Drinking water	Designated drinking water source (aquifer or surface)

Source: Environment Australia (2002).

5.3 The application of guidelines for Ecosystem Protection

For the purpose of assessing water quality at a test site guidelines are applied as trigger values. Exceedance of guideline values is initially viewed as a trigger for further investigation rather than a failure. Further investigation would be designed to assess the site and its particular local characteristics in more detail leading to a better informed assessment of its true condition (Queensland EPA 2006). The ANZECC (2000) Guidelines definition of an exceedance is:

*An exceedance will be deemed to have occurred when the **median concentration** of n independent samples taken at a test site exceeds the eightieth percentile (i.e. the derived guideline) of the same indicator at a suitably chosen reference site.*

Figure 3: Potential outcomes for test sites.

6 WATER QUALITY OBJECTIVES FOR DARWIN HARBOUR REGION

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 most of the 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 and corresponding mixing zone prevails, the conditions and terms of the waste discharge licence (WDL) will administer requirements for water quality.

These interim objectives should be used in conjunction with the supporting information provided by the ANZECC Guidelines (ANZECC & ARMCANZ 2000). Tables 8-10 indicate Water Quality Objectives for water types relevant to beneficial uses of environment use, recreational and cultural use.

6.1 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 any exceedance indicates a potential risk of adverse ecological effects. Exceedance of the objective indicates the requirement for further investigation or management action (Figure 3).

The risk based approach is based on the NWQMS guidelines 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 when impact is uncertain, this triggers a decision framework for further investigation that leads to an informed assessment of the potential risk (Fig 4).

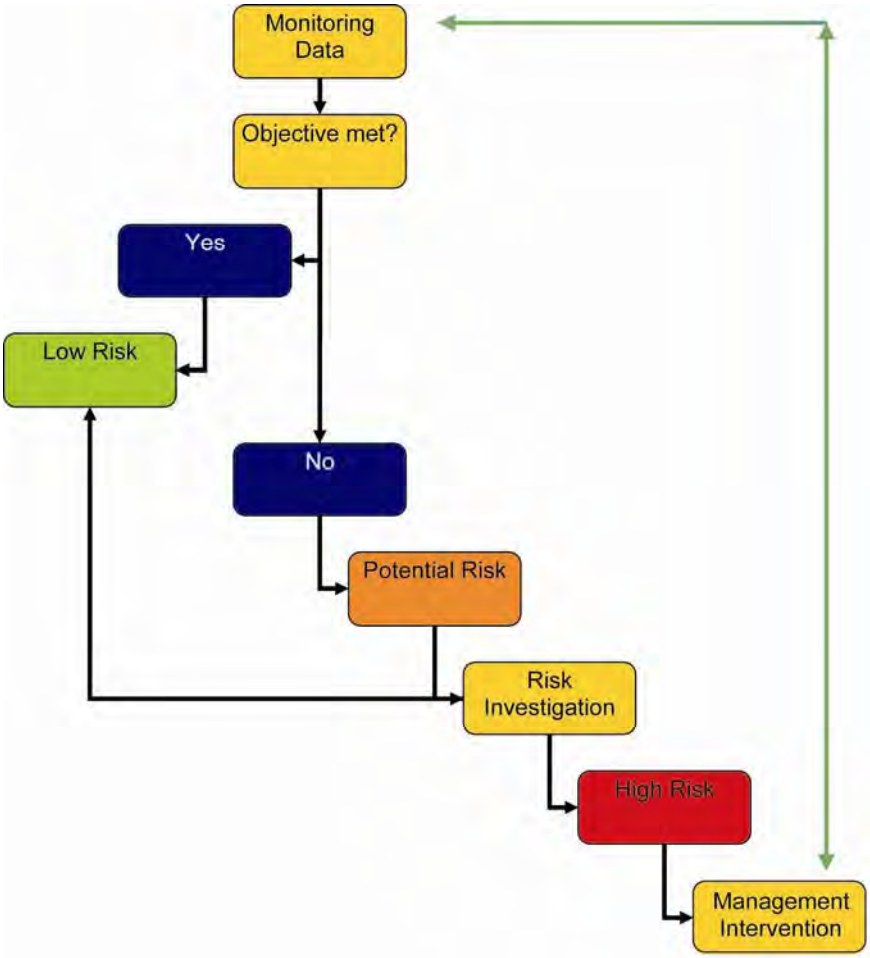


Figure 4: Risk Based Decision Framework.

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.

6.2 Using the Water Quality Objectives for monitoring programs.

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.

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 values when applied as triggers for risk assessment enable the development of water type specific objectives. A review of the level of protection for individual waterways would need to be carried out for areas beyond the Darwin region and the objectives as detailed in this paper should only be used for evaluating ambient water quality in the Darwin region.

Periodic review of the Objectives will be undertaken at least every 5 years with QA and QC programs developed to assess data integrity throughout the monitoring and assessment process.

Table 8: Interim ambient guideline values and Water Quality Objectives for priority water quality indicators of the Darwin Harbour Region (Based on 80th and/or 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		-
Upper			100	100	100	100		100	
Lower			80	80	75	54		37	
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	-	Maintain DO between 35-100% saturation	-
pH	Refer ANZECC (2000)	Refer ANZECC (2000)							
Upper			8.5	8.5	8.5	7.5	8.0	6.0	8.0
Lower			7.0	7.0	6.0	6.0	7.0	5.0	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 5.0-6.0	Maintain pH between 7.0-8.5
Turbidity (NTU)	Refer ANZECC (2000)	Refer ANZECC (2000)	-	-	-	1-20	To be determined	1-2.5	-
Water Quality Objective	-	-	-	-	-	Maintain Turbidity <20 NTU	-	Maintain Turbidity <3 NTU	-
Conductivity (µS/cm)	Refer ANZECC (2000)	Refer ANZECC (2000)	-	-	-	20-200	320-390	13-22	350
Water Quality Objective	-	-	-	-	-	Maintain Conductivity <200 µS/cm	Maintain Natural Conductivity range	Maintain Conductivity <25 µS/cm -	Maintain conductivity to < 400 µS/cm
Nutrients (µg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)					To be determined		-
Total N (µg N/L)			440[a]	270	300	80-225		550	
Water Quality Objective	-	-	Maintain TN<440µg/L	Maintain TN <270 µg/L	Maintain TN <300µg/L	Maintain TN <230 µg/L	-	Maintain TN <550µg/L	-
NOx (µg N/L)			10	17	20	8	nd	8	nd
Water Quality Objective	-	-	Maintain NOx <10 µg/L	Maintain NOx <20µg/L	Maintain NOx <20 µg/L	Maintain NOx <8 µg/L	-	Maintain NOx <8 µg/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
NH_3-N (μg/L)			20	20	20			nd	
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		18	
Water Quality Objective	-	-	Maintain TP <20 μg/L	Maintain TP <20 μg/L	Maintain TP <30μg/L	Maintain TP <10μg/L	-	Maintain TP <20 μg/L	-
FRP (μg P/L)			8[a]	5	9	5	To be determined	1	
Water Quality Objective	-	-	Maintain FRP <10μg/L	Maintain FRP <5μg/L	Maintain FRP <10μg/L	Maintain FRP <5 μg/L	-	Maintain FRP <5 μg/L	-
Chlorophyll a (μg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)	1	2	4	2	-	6	-
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* <6 μg/L	-
TSS (mg/L)	-	-	6[a]	6[a]	10[a]	5[a]	-	-	-
Water Quality Objective	-	-	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <5mg//L	-	-	-
Toxicants	Refer to ANZECC & ARMCANZ Guidelines (2000) or relevant national guidelines								
Possible Biological Indicators – Objectives yet to be determined									
Aquatic Macroinvertebrates (AusRivAS)						X	X	X	-
Fish diversity, abundance						X	X	X	-
Algal biomass (Chlorophyll-a see above)	X	X	X	X	X	X	X	X	-
Polychaete/shellfish or other estuarine species				X	X				-
Macrophyte/aquatic flora							X	X	-
Amphibians						X	X	X	

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
River Metabolism						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 are toxic to some fish species.

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

Note D: Lower trigger values for DO in upper estuarine and freshwater water types are lower than the agreed WQO. The objective was determined based on expert opinion and comparison with ANZECC and other guidelines relevant to northern Australia.

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

Note G: 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.

Note H: Note that guidelines and water quality objectives for freshwater lagoons should only be applied during the high water phase of lagoons. This is usually between January and August but may vary according to lagoon size and annual variation in rainfall. Water quality deteriorates naturally as lagoons water levels fall in the late dry season.

Table 9: 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	

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 form of 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 10: 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 for water in shell fish growth harvest areas									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.

7 PRACTICAL HELP FOR DECISION MAKING

This section gives a broad overview of how the Water Quality Objectives can provide practical help in decision making and planning for activities affecting water quality. The section outlines the key principles underpinning Water Quality Objectives and identifies their applications in catchment and strategic planning and in development assessment activities.

The proposed Water Quality Objectives can be used as a tool for monitoring water quality and supporting decision making on the management of activities affecting coastal marine waters in the Darwin Harbour Catchment. They apply to ambient waters (i.e. the receiving waters) and should not be regarded as individual discharge criteria. They should be used to:

- identify the community's values for marine waters and the water quality
- support those values – these values include protection of aquatic ecosystems and recreational activities associated with the use of marine waters such as swimming, boating and fishing;
- provide guideline levels and goals to assess water quality;
- help protect our waterways – the areas where the objectives are being met should be protected. Where they are not being met, planning and management of these areas should move towards achieving the objectives over time;
- assist the community to understand water quality and the impacts upon it;
- consider marine water quality and manage potential pressures – the framework that is used is nationally recognised and provides transparency;
- support decision making, but not determine development proposals – to be considered as a factor in any decision making process along with other environmental, social and economic considerations; and
- encourage good practice and innovation in planning and design.

7.1 The application of Water Quality Objectives for planning and assessment

7.1.1 Catchment and strategic planning

The estuarine Water Quality Objectives can be used as a tool to assist in the various strategic planning processes influencing coastal water quality. Such plans include:

1. Natural Resource Plans, such as Catchment Actions Plans, Coastal and Estuary Management Plans
2. Council Management Plans, i.e. Stormwater Management Plans
3. regional strategies
4. land-use planning instruments (i.e. Local Environment Plans and Development Control Plans).

Using the Water Quality Objectives can assist in strategic planning by:

- defining community values for water quality
- providing indicators and guideline levels of the water quality that supports those values
- helping planners to identify priority pollutants and their likely sources
- providing a framework for developing priority actions that address water quality.

7.1.2 Assessing impacts of individual activities

Consent and approval authorities (such as councils) already make decisions about activities and development proposals in terms of their impact on water quality (along with other environmental impacts). The Water Quality Objectives provide practical help for these decisions such as:

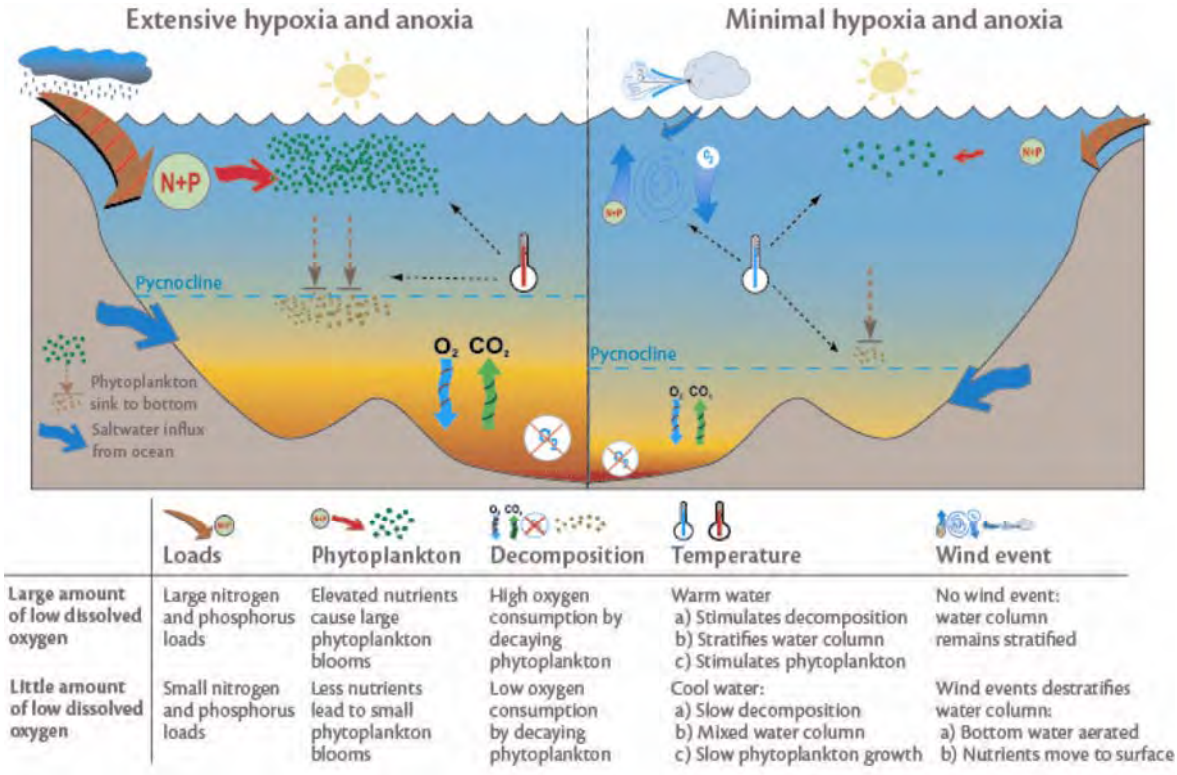
- councils can assess the activity against agreed water quality guideline levels;
- communities can better understand the impacts on water quality in terms of their agreed values and uses; and
- proponents can transparently present their case for their preferred options or development in terms of impact on or contribution to agreed objectives.

8 ENVIRONMENTAL MONITORING AND REPORTING

Environmental monitoring and reporting enables water quality managers to assess whether management actions in a particular area are achieving, or moving towards, the Water Quality Objectives.

The Water Quality Objectives and the ANZECC Guidelines (2000) can be used to provide guidance to those undertaking water quality monitoring programs by providing key water quality indicators that can be monitored over time. Measured water quality can be compared with the criteria to determine whether management goals are being achieved or where management action is required.

For example, if the management goal is to protect aquatic ecosystems from nuisance algal blooms then a potential risk is that excessive nutrient loads could stimulate prolific algal growth. Such events might clog waterways and degrade the aesthetic appearance of the waterway in addition to causing fish kill events as a consequence of oxygen depletion (Fig 5). Management goals, actions and decisions must therefore aim to maintain or improve water quality and keep nutrient concentrations in the water column below the specific criteria indicated by local guidelines and objectives or relevant ANZECC guidelines.



	Loads	Phytoplankton	Decomposition	Temperature	Wind event
Large amount of low dissolved oxygen	Large nitrogen and phosphorus loads	Elevated nutrients cause large phytoplankton blooms	High oxygen consumption by decaying phytoplankton	Warm water a) Stimulates decomposition b) Stratifies water column c) Stimulates phytoplankton	No wind event: water column remains stratified
Little amount of low dissolved oxygen	Small nitrogen and phosphorus loads	Less nutrients lead to small phytoplankton blooms	Low oxygen consumption by decaying phytoplankton	Cool water: a) Slow decomposition b) Mixed water column c) Slow phytoplankton growth	Wind events destratifies water column: a) Bottom water aerated b) Nutrients move to surface

Figure 5: Relationship between nutrient loading, algal blooms and oxygen depletion.

9. CONCLUSION

Currently the waterways in the Darwin Harbour region are in excellent condition. There are, however, areas where localised impacts are notable and these are typically associated with urban areas where sewage outfalls or stormwater influence water quality.

The development of Water Quality Objectives informed by community values will provide a benchmark for the protection of our waterways and aid in the development of management actions to maintain current water quality condition.

Ambient Water Quality Objectives presented in this document may be subject to change as further data becomes available. Future monitoring effort in the region will be undertaken to provide further support to the Objectives and utilise these as performance measures for the ecological health of waterways in the Darwin region.

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11. GLOSSARY

Chlorophyll-*a*: Chlorophyll-*a* is the green photosynthetic pigment found in all plants including phytoplanktonic algae. The concentration of chlorophyll-*a* in estuarine, coastal or marine waters (water column) is used as an indicator of photosynthetic plankton biomass.

Chlorophyll-*a* concentration is a commonly used measure of water quality (as a surrogate of nutrient availability); with low levels suggesting good condition. However, high levels are not necessarily bad and it is the long-term persistence of elevated levels that is a problem. As the long-term levels are important, the annual median chlorophyll-*a* concentration is used as an indicator in State of the Environment reporting (Ward *et al*., 1998).

Conductivity: The conductivity of a solution of water is highly dependent on its concentration of dissolved salts and sometimes other chemical species which tend to ionize in the solution. Electrical conductivity of water samples is used as an indicator of how salt-free or impurity-free the sample is; the purer the water, the lower the conductivity.

Dissolved Oxygen (DO): The majority of aquatic animals need oxygen to survive, and, with the exception of air-breathing animals like marine reptiles and mammals, most use oxygen dissolved in the water. DO concentrations are a result of the interaction between oxygen production (i.e. photosynthesis) and oxygen consumption (i.e. aerobic respiration, nitrification and chemical oxidation) within the water environment and the exchange of oxygen with the atmosphere. Natural processes (e.g. weather, tides and currents) and human pollution (particularly, organic matter) can result in severe reductions in dissolved oxygen levels. Both anoxia (no oxygen) and hypoxia (very low oxygen) are harmful to most marine animals. Anoxia and hypoxia can cause animal kills, a decrease in the available habitat and limit animal movements. Low DO can also result in reducing conditions occurring within the sediments which may cause previously bound nutrients and toxicants to be released into the water column.

Indicator: The recommended indicators to monitor related to a change in ecosystem condition. Many indicators are typically listed under four main categories:

- Indicators of stressor sources;
- Indicators of direct pressures;
- Physical-chemical condition indicators; and,
- Biological condition indicators.

Nutrients: Nitrogen & Phosphorus

The nutrients nitrogen (N) and phosphorus (P) are elements, and are essential building blocks for plant and animal growth. Nitrogen is an integral component of organic compounds such as amino acids, proteins, DNA and RNA. Phosphorus is found in nucleic acids and certain fats (phospholipids). Chemical and biological processes transfer nitrogen and phosphorus through the lithosphere, atmosphere, hydrosphere and biosphere. This is called nitrogen and phosphorus cycling. Nitrogen-fixing bacteria convert di-nitrogen gas into organic nitrogen species that can enter the hydrological cycle and food webs. Phosphorus is made biologically available through the weathering of rocks.

Nutrients exist both as organic and inorganic species, and in dissolved and particulate forms. Total nutrients are the total amount of nutrient present in all its forms (e.g. total nitrogen (TN) is the sum of the nitrogen present in all nitrogen-containing components). Dissolved nutrients occur as dissolved organic and inorganic forms (e.g. total dissolved nitrogen (TDN) is the sum of the dissolved organic nitrogen (DON) (e.g. proteins, amino acids, and urea) and dissolved inorganic nitrogen (DIN) (e.g. nitrate, nitrite and ammonia)). Dissolved nutrients are readily available for plant uptake. Determining the amounts of both total and dissolved nutrients present within the water column will give an indication of the amount of bioavailable nutrients present.

Likewise the Phosphorus pool comprises dissolved (FRP – Filterable Reactive Phosphorus) and particulate forms (PP – Particulate Phosphorus). Total phosphorus (TP) is the sum of the phosphorus present.

Nutrient concentrations within the water column are important as nutrients are taken up by phytoplankton which may then form blooms if excess nutrients are present.

pH: pH is a measure of acidity or alkalinity of water on a log scale from 1 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline).

Most aquatic organisms and some bacterial processes require that pH be in a specified range. For example, the activity of nitrifying bacteria is optimal over a narrow pH range from 7 to 8.5 (Henriksen and Kemp, 1988). If pH changes to beyond the preferred range of an organism (including microbes), physiological processes may be adversely affected (ANZECC/ARMCANZ, 2000a). This is especially true for most organisms if the ambient pH is <~7 or > 9. Physical damage to the gills, skin and eyes of can also occur when pH is sub-optimal for fish, and skin damage increases susceptibility to fungal infections such as red spot disease.

Total Suspended Solids: Total suspended solids are a measure of the total weight of particles in the water column, and is analysed in the lab from field samples. Suspended sediments reduce the amount of light penetration through the water column. This can impact on the photosynthesis of plants such as seagrass and result in plant death

Turbidity: "Turbidity is a measure of water clarity or murkiness. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles. Turbidity results from soluble coloured organic compounds and suspended particulate matter in the water column. Suspended particulate matter may include clay and silt (e.g. suspended sediment), and detritus and organisms" (OzEstuaries, http://www.ozestuaries.org/indicators/turbidity.jsp).

Water Quality Guideline: a parameter concentration (e.g. nitrate) or narrative statement (e.g. no algal blooms) used to assess whether a declared water value is being sustained. If the guideline is not being met, the water maybe under threat and investigation is warranted to ascertain whether the cause is anthropogenic (e.g. nutrient pollution) or due to natural phenomena (e.g. *Trichodesmium* algal blooms that originate from outside Darwin Harbour).

Water Quality Objective: a management objective for a specific water type agreed by stakeholders (NWQMS).

APPENDIX A: Beneficial Use Declarations Review – Distribution of Nominations

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

APPENDIX B: Example of how guideline values were derived from reference data.

Upper Estuary - Selected Physical Parameter of Dissolved Oxygen Only.

Statistic	Dissolved Oxygen (DO)	Dissolved Oxygen (DO)
Units	%sat	% sat
Percentile	20th	80th
Max and Min of reference values	38 (min)	106 (max)
	75	100
ANZECC (Tropical Australia)*	90	120
Proposed Guideline	**75**	**100**
Proposed WQO	**80**	**100**

**ANZECC guideline values and other guidelines for tropical estuaries used for comparison.*

A range of statistics were assimilated to determine the most appropriate guideline and/or corresponding objective value for a range of physical parameters. This information was also peer reviewed by the Ecosystem Monitoring Group, a technical expert group to the Darwin Harbour Advisory Committee with recommendations for the use of 80th and 20th percentiles for guidelines supported by all key stakeholders.

APPENDIX C: Classification of Water Types.

An estuary is:

a) the mouth of a river where tidal effects are evident and where freshwater and seawater mix; and/or
b) the part of a tidal river that widens out as it approaches the coastline; and/or
c) a body of water semi-enclosed by land with sporadic access to water from the open ocean, and where ocean water is at least occasionally diluted by freshwater run-off from land; and/or
d) a body of water where salinity is periodically increased by evaporation to a level above that of the open ocean (such a waterbody is termed a reverse estuary).

This definition is open to some degree of interpretation and therefore some more precise delineation of the boundaries is explored below.

For estuaries, there is sufficient local water quality data in some regions to distinguish multiple water types within the ANZECC 2000 Guidelines base estuary type. These include upper estuary, middle estuary and outer estuary. These types and their respective boundaries within Darwin Harbour estuary are discussed below.

Upper estuary

This is the most upstream of all estuarine waters with a residence time as estimated by a hydrodynamic model >32 days (Williams, 2007). In the uppermost reaches of some estuaries, there is a zone that experiences limited flushing from freshwater inflows (during the dry season) or tidal exchange. Water in this zone typically has a long residence time, moving backwards and forwards in much the same place with successive tides. Water quality in this zone is naturally different, as a result of limited flushing. Comparison of water quality in these upstream zones would often fail guideline values appropriate to the main body of the estuary.

To address this issue an upper estuary water type has been created. This allows the derivation of guidelines that are more appropriate to the natural water quality of this type of zone.

Middle estuary

The middle-estuary water type covers the majority of the length of Darwin Harbour and has a residence time between 32-14 days. The middle estuary begins below the upper estuary. The mid-estuarine zone extends downstream to near the mouth of the estuary at the coast. It excludes the small section just up from and including the mouth that is well flushed each tide with incoming marine waters. The middle estuary has a moderate amount of water movement and salt and fresh water mixing.

Shoal Bay is a region not included in the current hydrodynamic model for Darwin Harbour. In the absence of information relevant to flushing index an examination of available water quality data was undertaken to determine the most appropriate estuarine category. On this basis the region was categorised as mid-estuarine for the purposes of the Water Quality Objectives.

Outer Estuary

Outer estuarine waters or also enclosed coastal waters lie at or near the mouth of an estuary channel, and are frequently subject to some degree of residual mixing with inflowing fresh water. As such, they fall within the broad definition of an estuary. They include shallow coastal waters in straits or enclosed bays adjacent to the mouth of inflowing streams or estuaries. This zone includes the most downstream reach of the main channel of the Darwin Harbour estuary, which exchanges with coastal waters on every tide. The indicative residence time for this segment is <14 days.

Marine waters

Marine waters are part of the ocean, which covers almost three-quarters of the earth's surface. They extend out from, or near, the coastline. They have a uniform salinity of about 34-36 parts per thousand (52-54 mS/cm conductivity), and are not influenced by terrestrial freshwater inputs, except during large flood events.

Open coastal waters also include all coastal waters except those with some residual freshwater influence from inflowing streams (enclosed coastal waters). Therefore open coastal waters extend outwards from the outer limit of enclosed coastal waters, or directly out from the coastline if there are no estuaries nearby, to the 3 nautical mile limit of the NT.

It must also be noted that these categories are not hydrodynamically discrete and for this reason residence times (flushing) offer a sound basis at this time for zonation, although their limits may be arbitrary. The limit and extent of these interactive boundaries may be complex in some areas of the harbour, particularly when deciding on what guideline to apply. However, the flushing index provides a sound basis with which to determine whether a test or reference site is contained within an upper, mid or outer estuarine category. Water quality of reference sites within each estuarine segment is largely agreeable with the broadly defined categories.

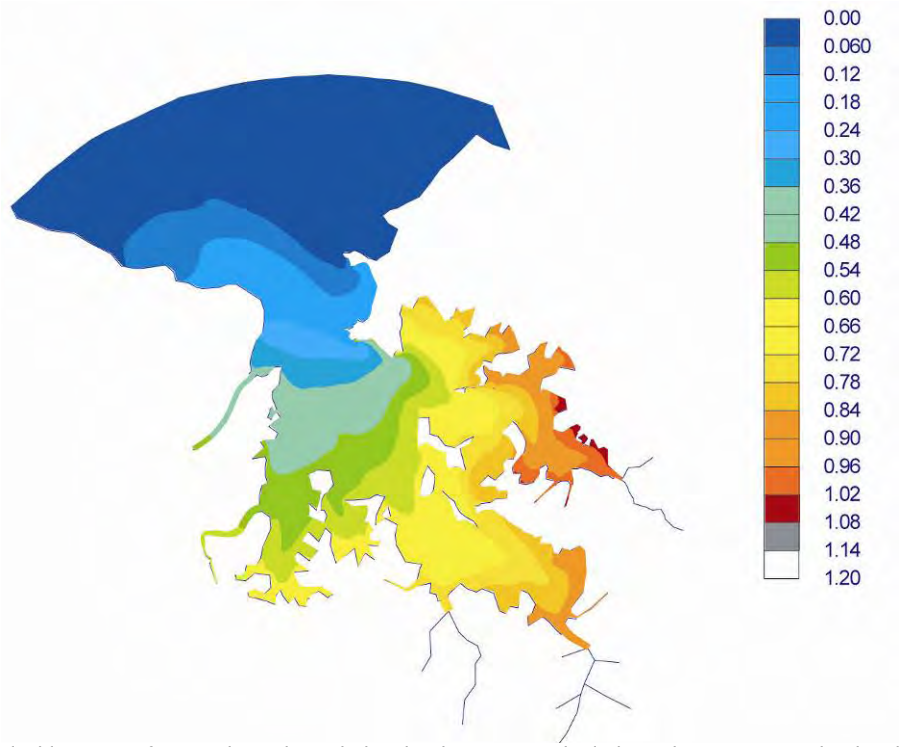

Figure 6: Flushing zones for Darwin Harbour during the dry season. The index values represent the time in days it takes for a conservative constituent to be removed from the harbour by advection / diffusion. Multiply the index values by 60 for the time in days. (*Source: David Williams, in 'Water Quality Guidelines for the Protection of Environmental Beneficial Use of the water resources of the Darwin Region': EMG Paper 1, Dec 2007*).

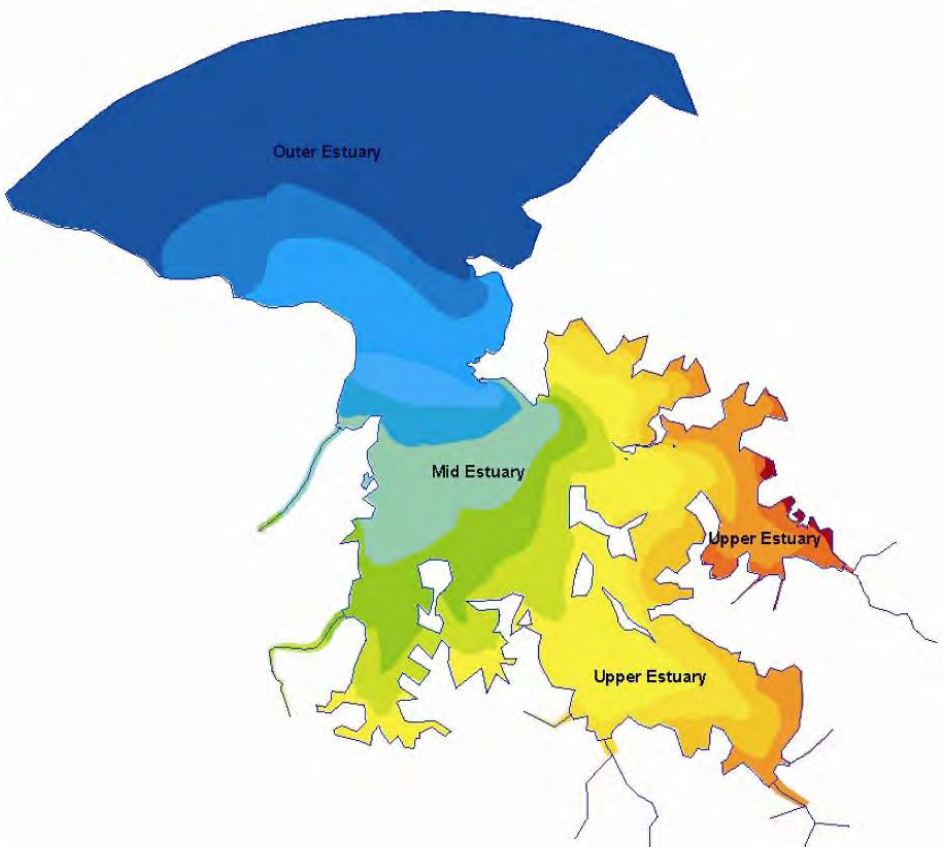

Figure 7: Broad Estuary zonation based on flushing index.

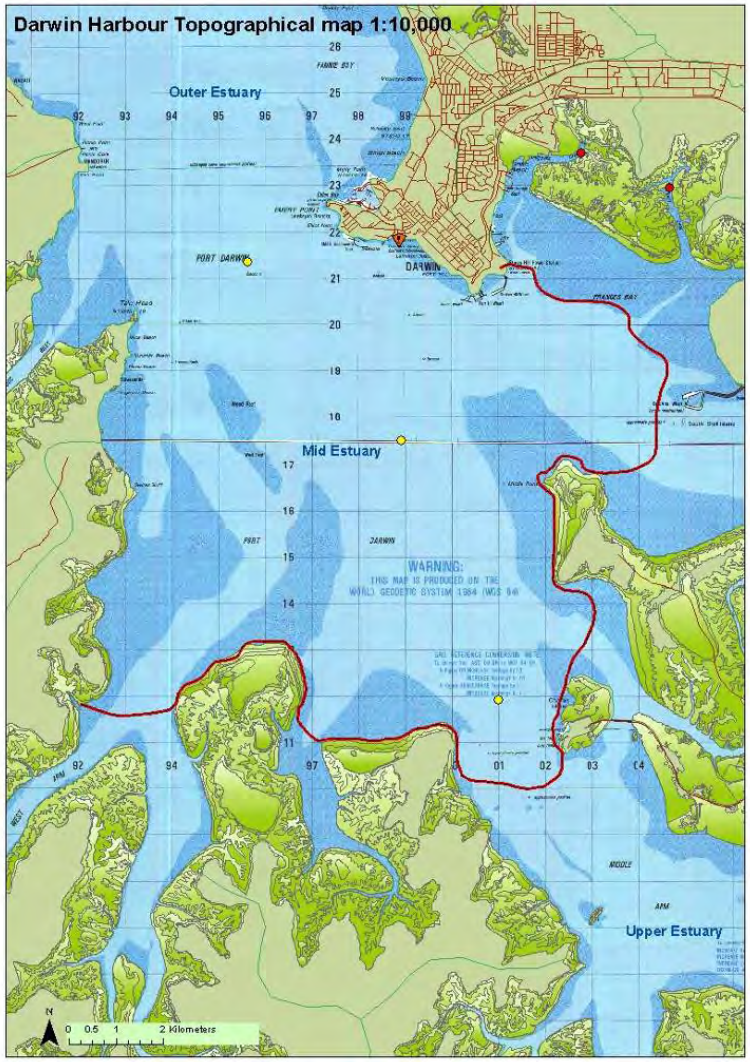

Figure 8: Approximate upper extent of Mid Estuary and lower extent of upper Estuary.
The outer estuary water type approximately extends beyond Mandorah and Emery Point of Darwin Harbour.

Other water Types:

Rivers and streams.

The water quality of rivers and streams in the Darwin region is highly variable during the wet season, but relatively constant during seasonal recessional flow in the dry season. Some rivers (e.g Howard River) have extensive floodplains. In the dry season most streams cease flowing, with the exception of a few that are supplied by deep aquifers (e.g. the lower reaches of Berry Creek). Wet season water quality is broadly dependent on catchment characteristics and the relative proportion and total volumes of surface runoff and baseflow. For each storm runoff event, water quality varies over the rising and falling stage of the hydrograph, and the timing of the runoff event with respect to the commencement of wet season flow and antecedent runoff events.

Lagoons

The lagoons in the Darwin region are natural depressions that fill in the wet season by surface runoff, and become hydrologically connected to the surface drainage system. In the dry season the lagoons become isolated and reduce in depth due to evaporation, with some drying completely. The water quality of the lagoons is less variable than the region's rivers during the wet season, but can change significantly as their volume reduces late in the dry season.

Reservoirs

Darwin River Reservoir is the only reservoir of significant size in the catchment. The reservoir supplies water for potable use to Darwin, Palmerston and those rural residents supplied by reticulated water.

Groundwater.

A dolomitic aquifer lies beneath the Darwin Rural Area. This deep aquifer discharges water to a small number of streams (e.g. Berry Creek downstream of Berry Springs, Howard Springs) during the dry season, and provides rural residents with deep bores with water for potable use. A shallow aquifer also exists, in the lateritic surface layer which is saturated in the wet season, and supplies wet season recessional flow.

APPENDIX D: Water Quality Data Source Sites.

Figure 9: **Estuarine Water Quality Sites.**

Figure 10: **Lagoon Water Quality Sites** (Note: Only 9 reference sites were utilised for the derivation of Water Quality Objectives).

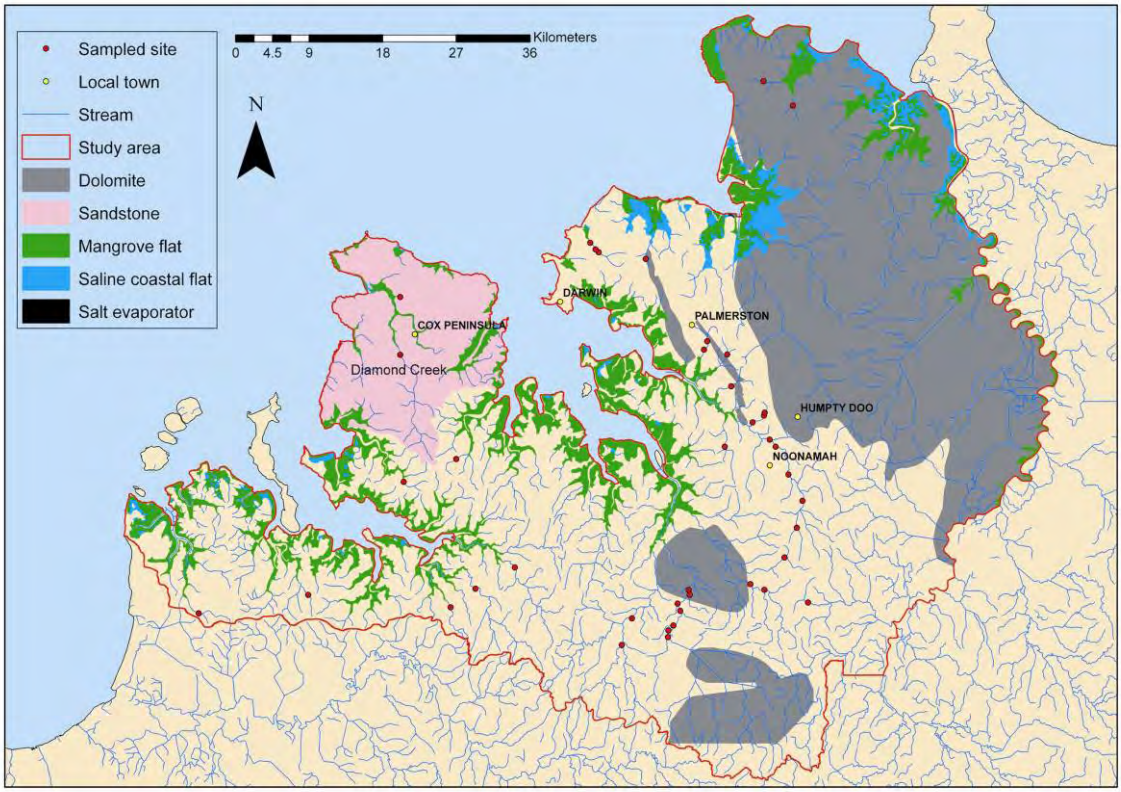

Figure 11: **Sampling sites for the derivation of dry season freshwater rivers and streams water quality guidelines in the Darwin Region. (Source: Fukuda & Townsend 2006)**

APPENDIX E: List of Monitoring Locations

OUTER ESTUARY SITES

Code	Name	Aus grid Northing	Aus Grid Easting
G8155541	DHM 8a	691058.2	8626979
G8155133	DHM Pt 9	699129.9	8631459.9
G8155134	Dwn Harbour @ Pt 8	685120	8636009.9
G8155135	Dwn Harbour @ Pt 7	694430	8626460
G8155132	Dwn Harbour @ Pt 10	706129.9	8639559.9
G8155133	Dwn Harbour @ Pt 9	699129.9	8631459.9
No G code allocated	B1	683810	8637390
No G code allocated	B2	681170	8636210
No G code allocated	B3	685740	8638460
No G code allocated	B4	675990	8631930
No G code allocated	B5	678630	8634390
No G code allocated	B6	690350	8639600
No G code allocated	B7	698290	8640060
No G code allocated	B8	705190	8638630
No G code allocated	B9	694401.2	8640038.6
No G code allocated	B10	701987.1	8639532.9

MID ESTUARY SITES

Code	Name	Aus grid Northing	Aus Grid Easting
G8155136	Dwn Harbour @ Pt 6	695630	8621360
G8150029	Darwin Harbour Tide	701197.9	8621296
G8155136	DHM 6	695630	8621360
G8155467	DHM 13	698913	8617511
G8155130	Dwn Harbour @ Pt 12	695580	8613960
G8155137	Dwn Harbour @ Pt 4	701030	8612360.1

UPPER ESTUARY SITES

Code	Name	Aus grid Northing	Aus Grid Easting
G8155131	Dwn Harbour @ Pt 11	711379.9	8611960.1
G8155140	Dwn Harbour @ Pt 1 & B	714139.9	8613110.1
G8155139	Dwn Harbour @ Pt 2	707429.9	8617860
G8155523	DHM Daly Ck	711357	8596156
G8155487	DHM Creek 1 - 3	700695	8603856
G8155515	DHM Creek2 - 3	702067	8603801
G8155518	DHM CTC	712226	8600354
G8155526	Mid Arm Dalys Ck S4	712928	8597222
G8155527	Mid Arm\044 Blacriv-1	714105	8599642
G8155524	Mid Arm Dalys Ck S2	712053	8596461
G8155525	Mid Arm Dalys Ck S3	712374	8596790
G8155519	Mid Arm CTC S3	712739	8600345

G8155520	Mid Arm CTC S4	713326	8600422
G8155517	Mid Arm CTC S1	711912	8599906
G8155514	Mid Arm Ck 2 S2	702324	8603256
G8155488	Mid Arm Ck 1 S4	701046	8604260
G8155516	Mid Arm Ck 2 S4	701765	8604261
G8155513	Mid Arm Ck2 S1	702005	8603226
G8155486	Mid Arm Ck 1 S2	701056	8603649
G8155093	Daly's Ck @ Pt G6	712229.9	8596360.2
G8155485	Mid Arm Ck 1 S1	700849.6	8603094.9
G8155138	Dwn Harbour @ Pt 3	705520	8607160.1
G8155117	Blackmore R. @ Pt F1	713229.9	8600760.2
G8155118	Middle Arm @ Pt F14	706030	8607660.1
G8155099	Blackmore R. @ Pt G1	711129.9	8604160.1
G8155100	Darwin R. @ Pt G13	712130	8593360.2
G8155102	Channel Is @ Pt. G15	702330	8610460.1
G8155116	Darwin R. @ Pt F12	712230	8593360.2
G8155464	BLACK 10	713867	8600359
G8155465	BLACK 11	712729.9	8601225.1
G8155462	BLACK 08	715431.9	8600008.2
G8155463	BLACK 09	715454	8599356
G8155461	BLACK 07	713903.9	8599223.2
G8155459	BLACK 05	713341.9	8597805.2
G8155460	BLACK 06	715552.9	8597000.2
G8155457	BLACK 03	712465	8595039.2
G8155458	BLACK 04	712345.9	8596464.2
G8155455	BLACK 01	711203	8593047.2
G8155456	BLACK 02	712346	8592862.2
G8155545	DHM E	708680.6	8606364
G8155544	DHM D	714356	8599653
G8155543	DHM C	711424	8593670
No G code allocated	Brooking Ck	716878	8613069
No G code allocated	Mitchell Ck	716271	8613338
No G code allocated	EDW	717036	8610372

FRESHWATER RIVERS AND STREAMS

Code	Name	Aus grid Northing	Aus Grid Easting
G8155553	Leaders Ck west branch	724493	8648806
G8155554	Leaders Ck south branch	728093	8645848
G8150127	Rapid Creek	703304	8629307
G8155182	Airport drain	703941	8628520
G8155142	Rapid Ck Yankee Pool	704334	8628168
G8155621	Palm Ck (Mcmillans Rd)	710088	8627376
G8155607	Mitchell Ck	717606	8617429
G8155468	Mitchell Ck (ds Stuart Hwy)	717215	8616423
G8155474	Brooking Ck	720061	8615827
G8155510	Wells Ck	720547	8612001
G8155511	Bennett Ck	719756	8604710

G8155618	Bees Ck Gulnare Rd	724648	8608819
G8150106	Bees Ck ds	724546	8608461
G8150102	Bees Ck Horne Rd	723169	8607648
G8150018	Elizabeth R	725257	8605565
G8155473	Elizabeth U/S Hwy	725991	8604714
G8155472	Elizabeth R Eliz Valley Rd	727542	8601353
G8155476	Elizabeth R Alverly Rd	729267	8598187
G8155624	Elizabeth R us Townend rd	728575	8594925
G8155626	Acacia Ck	729944	8585911
G8155629	Berry Ck	727068	8591349
G8155478	Fly Ck	722890	8588137
G8155628	Ella Ck	724611	8587454
G8155479	Darwin R	715341	8587433
G8155640	Darwin R (S2)	715469	8586852
G8155639	Darwin R (S3)	713980	8585779
G8155638	Darwin R (S4)	714309	8584911
G8155637	Darwin R control site	713466	8583146
G8155636	Darwin R (dam Xing)	712861	8582551
G8155635	Darwin R u/s control 1	712808	8581747
G8155469	Blackmore R	708402	8584001
G8155470	Peel Ck u/s	707156	8580787
G8150190	Charlotte R	694082	8590142
G8150191	Annie R	689268	8587580
G8155619	Stephens Ck	686903	8603224
G8155610	Leviathan Ck	686220	8585340
G8155620	Pt Stuart Spring	680054	8622776
G8155655	Diamond Ck	680050	8615802
G8155615	Turnbull Bay Ck	680483	8600472
G8155609	Pt Ceylon Rd Ck	668793	8586838
G8155608	Fog Bay Rd Ck	655401	8584610

LAGOONS

No.	Name	Aus grid Northing	Aus Grid Easting
1	Benham's Lagoon	736197	8614384
2	Darren Onn's=Edwin Ck1	735364	8608103
3	Leaning Tree Lagoon		
4	Girraween Lagoon	726009	8615113
5	Herbert 1	732324	8610837
6	Koolpinyah 1	737171	8630672
7	Korebum Lagoon	734030	8631950
8	Waterlily Lagoon	724512	8621796
9	Woodfords Lagoon	713563	8587131