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.

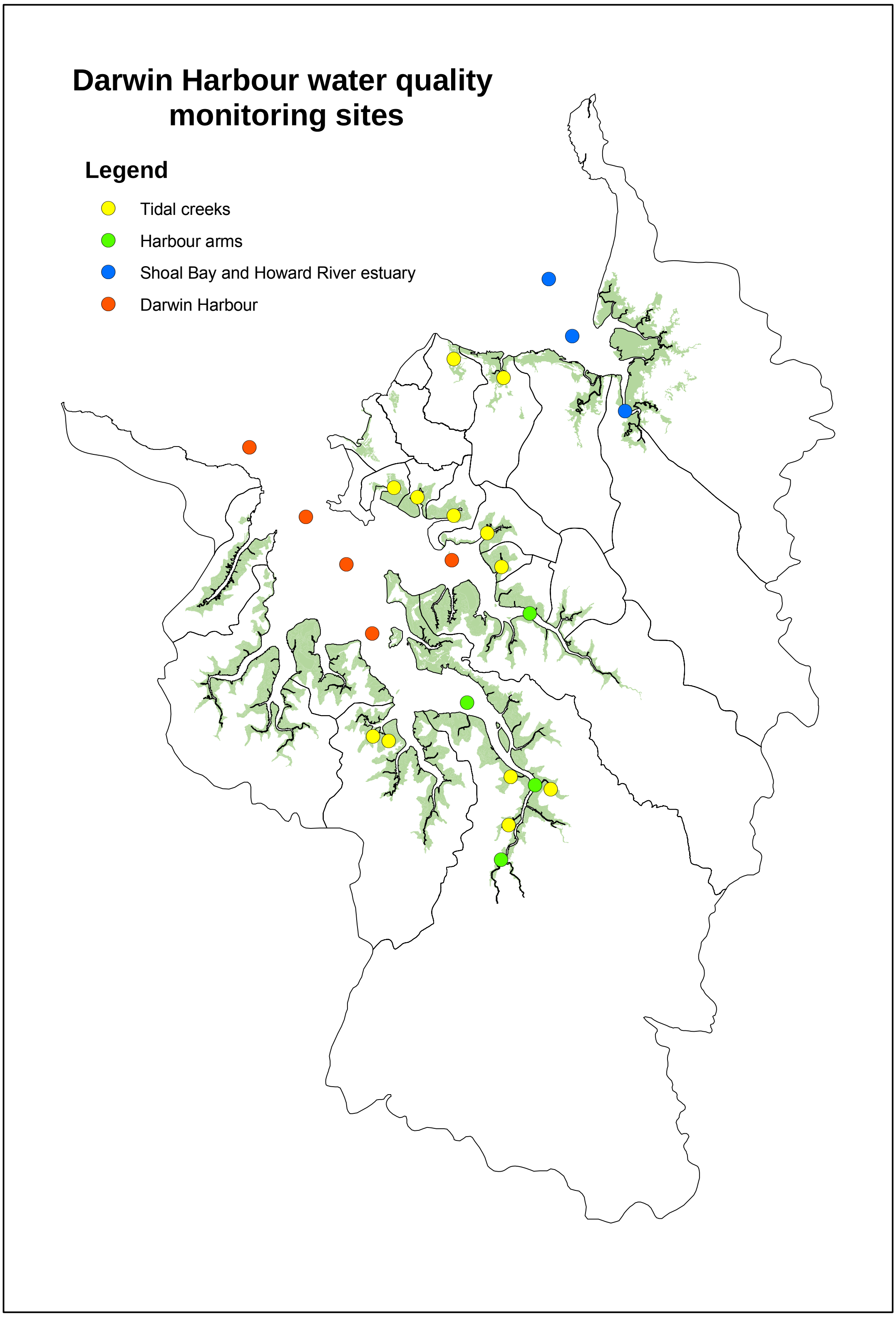


Figure 2.1: Ambient estuarine monitoring sites.

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.

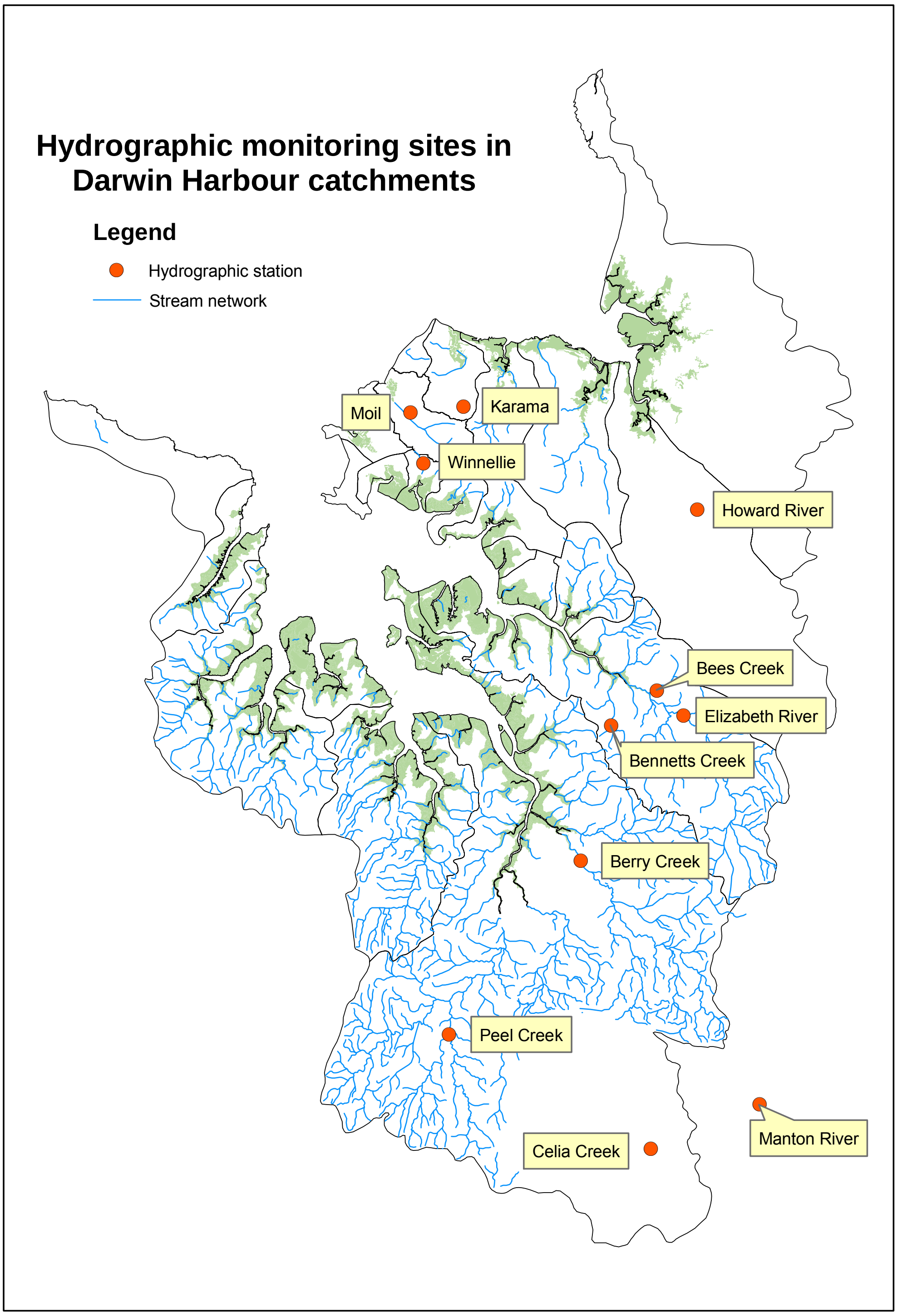


Figure 2.2: Hydrographic monitoring sites in the Darwin region catchment.

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.

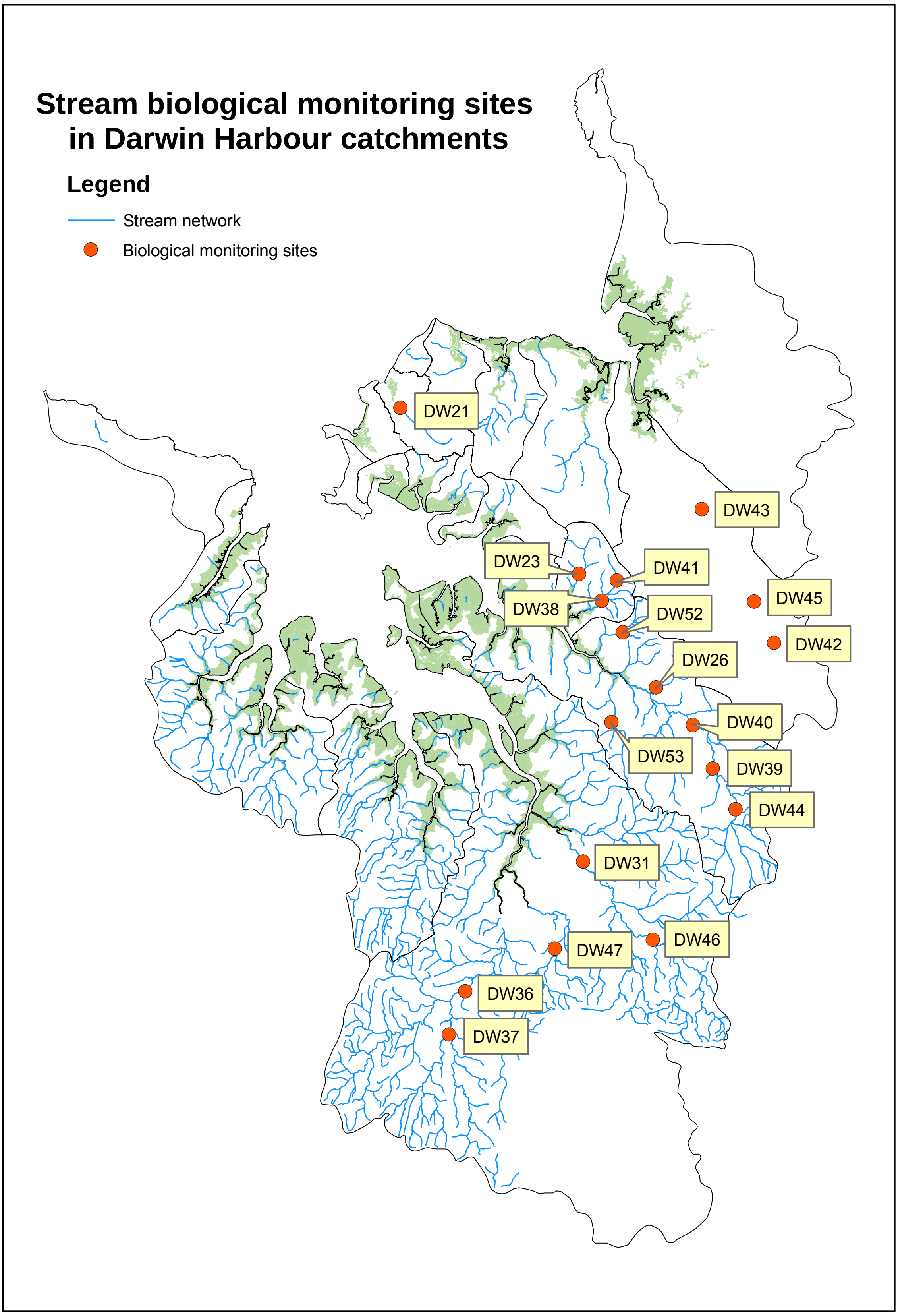


Figure 2.3: Biological Monitoring Sites in the Darwin Region.

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).

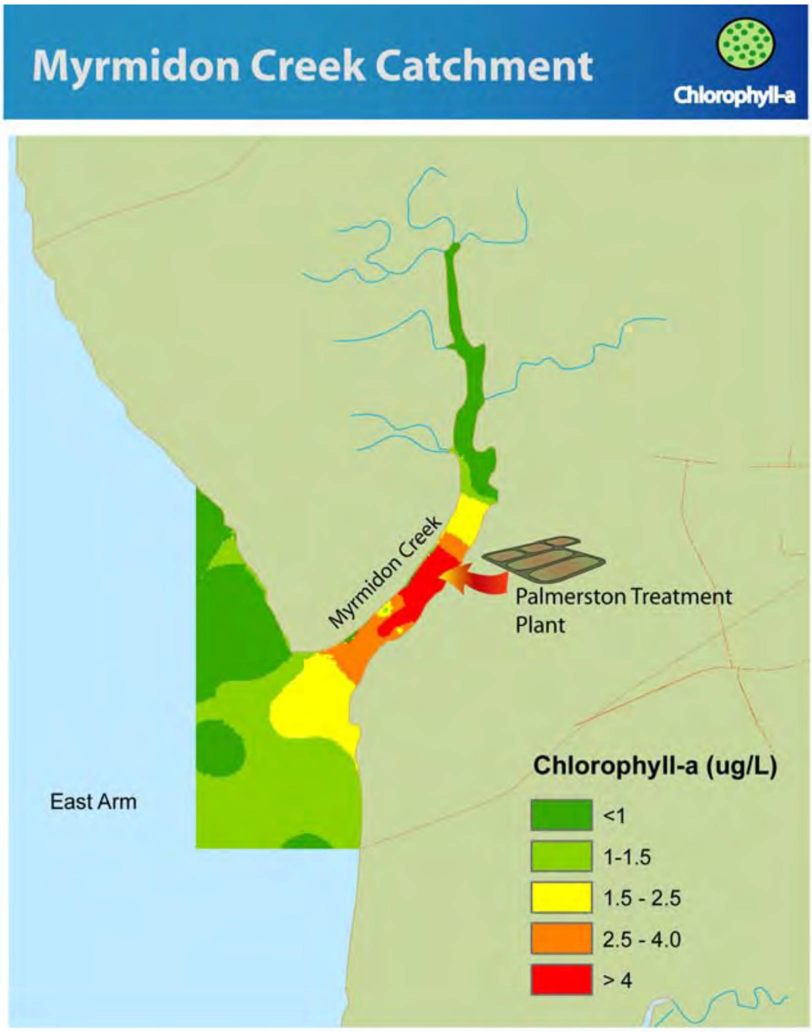


Figure 2.4: Use of spatial interpolation for Chlorophyll-a monitoring data of Myrmidon Creek.

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>

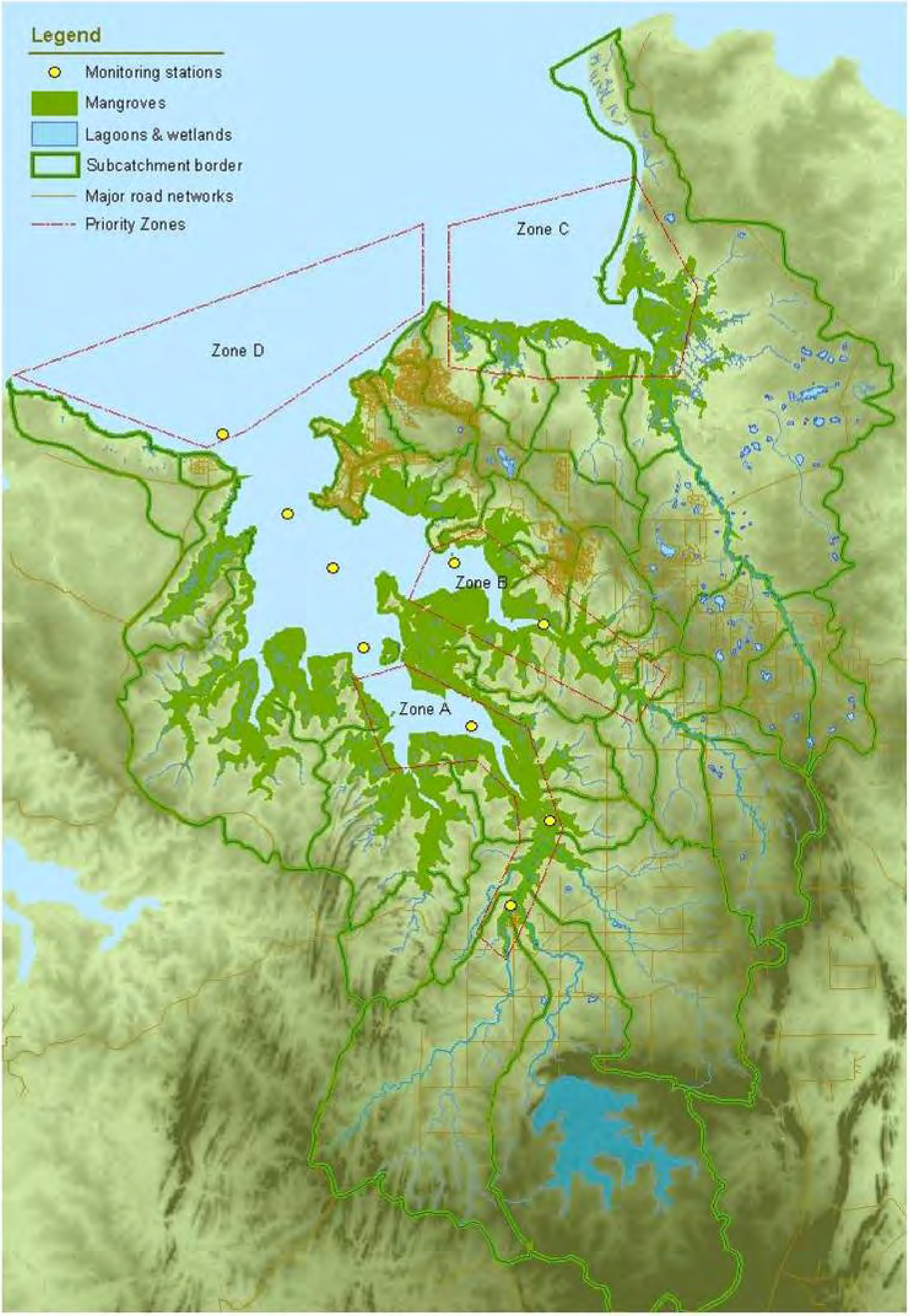


Figure 2.5: Priority zones for future monitoring and modelling effort.

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

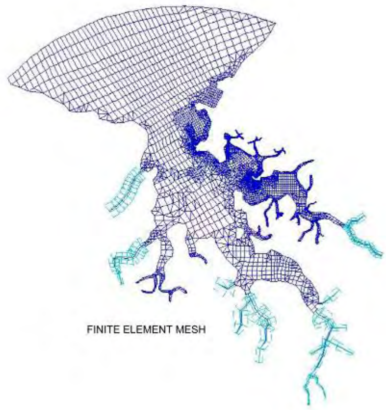
Zone C: Shoal Bay and its tributaries

- 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.