Section 3. Water Quality Objectives for the region

3.0 Introduction

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

3.1 Water Quality Indicators

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

Table 3.1: Physico-chemical Guideline indicators.

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

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

3.2 Guidelines and Objectives

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

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

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

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

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

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

Indicator for Environmental Use: Aquatic Ecosystem Protection 	Marine and Estuarine Systems					Freshwater Systems			
	Offshore Marine	Inshore marine	Outer Estuary	Mid Estuary	Upper Estuary	Freshwater Rivers & streams[b]	Aquifer Fed Springs	Lagoons	Groundwater
Nutrients (μg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)					To be determined	To be determined	-
Total N (μg N/L)			440[a]	270	300	80-225			
Water Quality Objective	-	-	Maintain TN<440μg/L	Maintain TN <270 μg/L	Maintain TN <300μg/L	Maintain TN <230 μg/L	-	-	-
NOx (μg N/L)			10	17	20	8	nd		nd
Water Quality Objective	-	-	Maintain NOx <10 μg/L	Maintain NOx <20μg/L	Maintain NOx <20 μg/L	Maintain NOx <8 μg/L	-	-	-
NH3-N (μg/L)			20	20	20				
Water Quality Objective	-	-	Maintain Ammonia <20 μg/L	Maintain Ammonia <20 μg/L	Maintain Ammonia <20 μg/L	-	-	-	-
Total P (μg P/L)			16	20	26	10			
Water Quality Objective	-	-	Maintain TP <20 μg/L	Maintain TP <20 μg/L	Maintain TP <30μg/L	Maintain TP <10μg/L	-	-	-
FRP (μg P/L)			8[a]	5	9	5	To be determined	To be determined	
Water Quality Objective	-	-	Maintain FRP <10 μg/L	Maintain FRP <5 μg/L	Maintain FRP <10 μg/L	Maintain FRP <5 μg/L	-	-	-
Chla (μg/L)	Refer ANZECC (2000)	Refer ANZECC (2000)	1	2	4	2	-	10	-
Water Quality Objective	-	-	Maintain Chl *a* <1 μg/L	Maintain Chl *a* <2 μg/L	Maintain Chl *a* <4 μg/L	Maintain Chl *a* <2 μg/L	-	Maintain Chl *a* <10 μg/L	-
TSS (mg/L)	-	-	6	6	10	5	-	-	-
Water Quality Objective	-	-	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <10mg//L	Maintain TSS <5mg//L	-	-	-

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

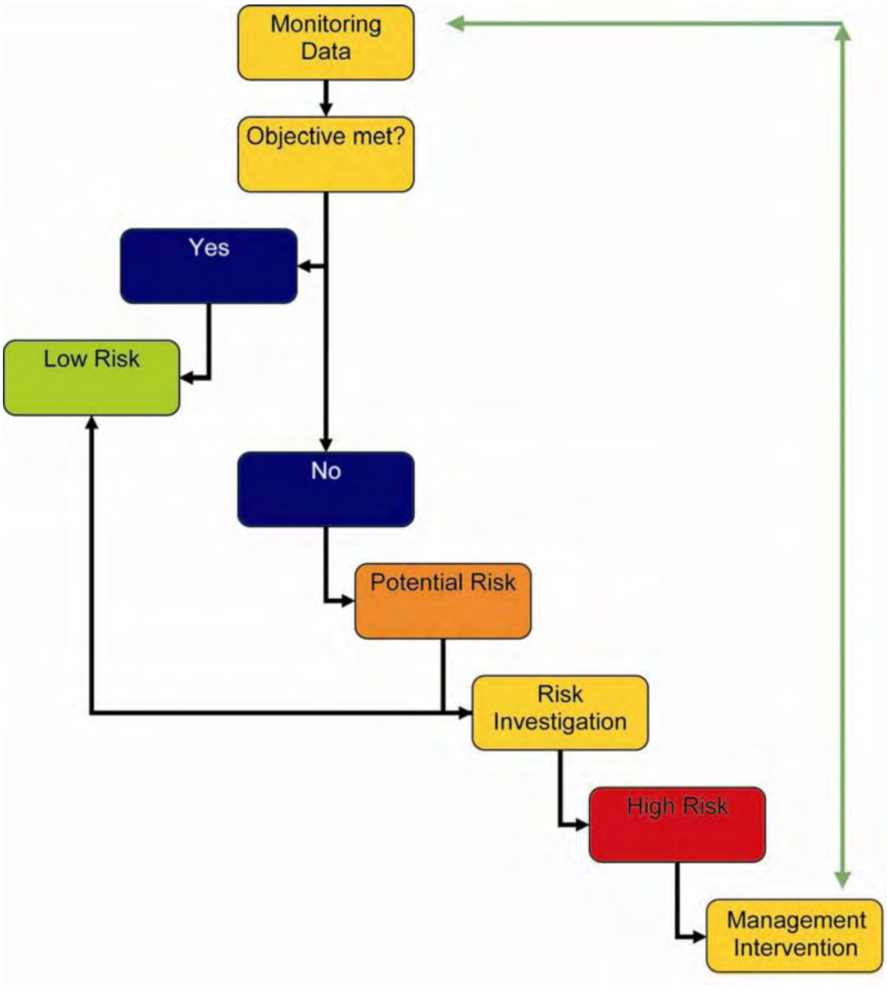


Figure 3.4: Risk Based Decision Framework and adaptive management.

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

3.4 Application of the Water Quality Objectives.

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

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

Section 4. Pollutant Load Assessment and Targets

4.0 Pollutant Load Assessment in the Darwin Region

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

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

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

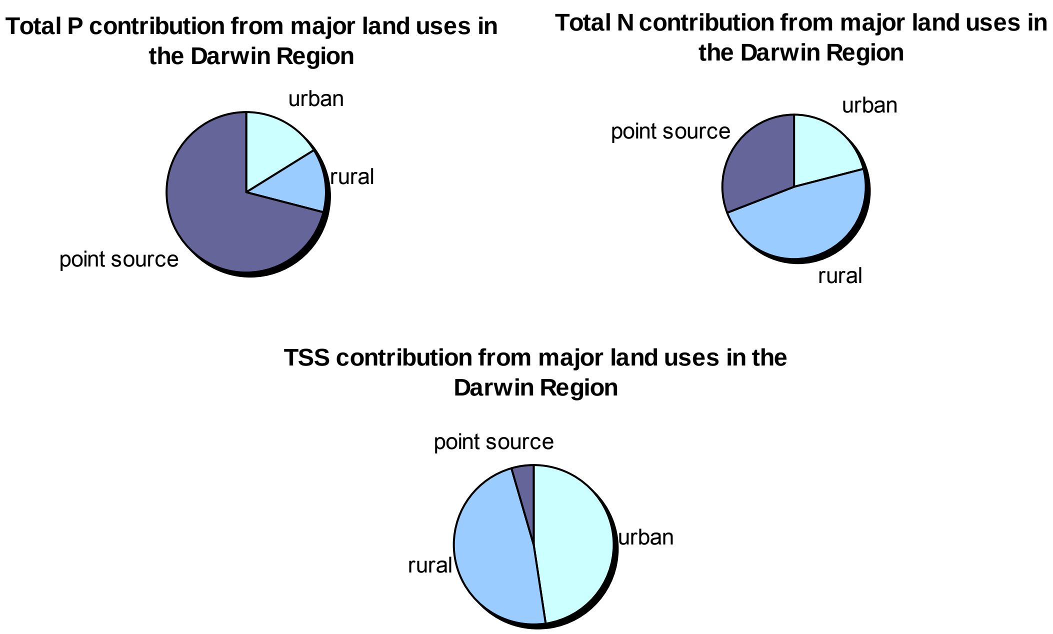


Figure 4.1: Contribution of diffuse and point sources to Darwin Harbour.

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

4.1 Point Source and Diffuse Loads

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

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

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

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

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

4.2 Load Scenarios for Future Development

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

4.3 Seasonal Variation in Pollutant Loads

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

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

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

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

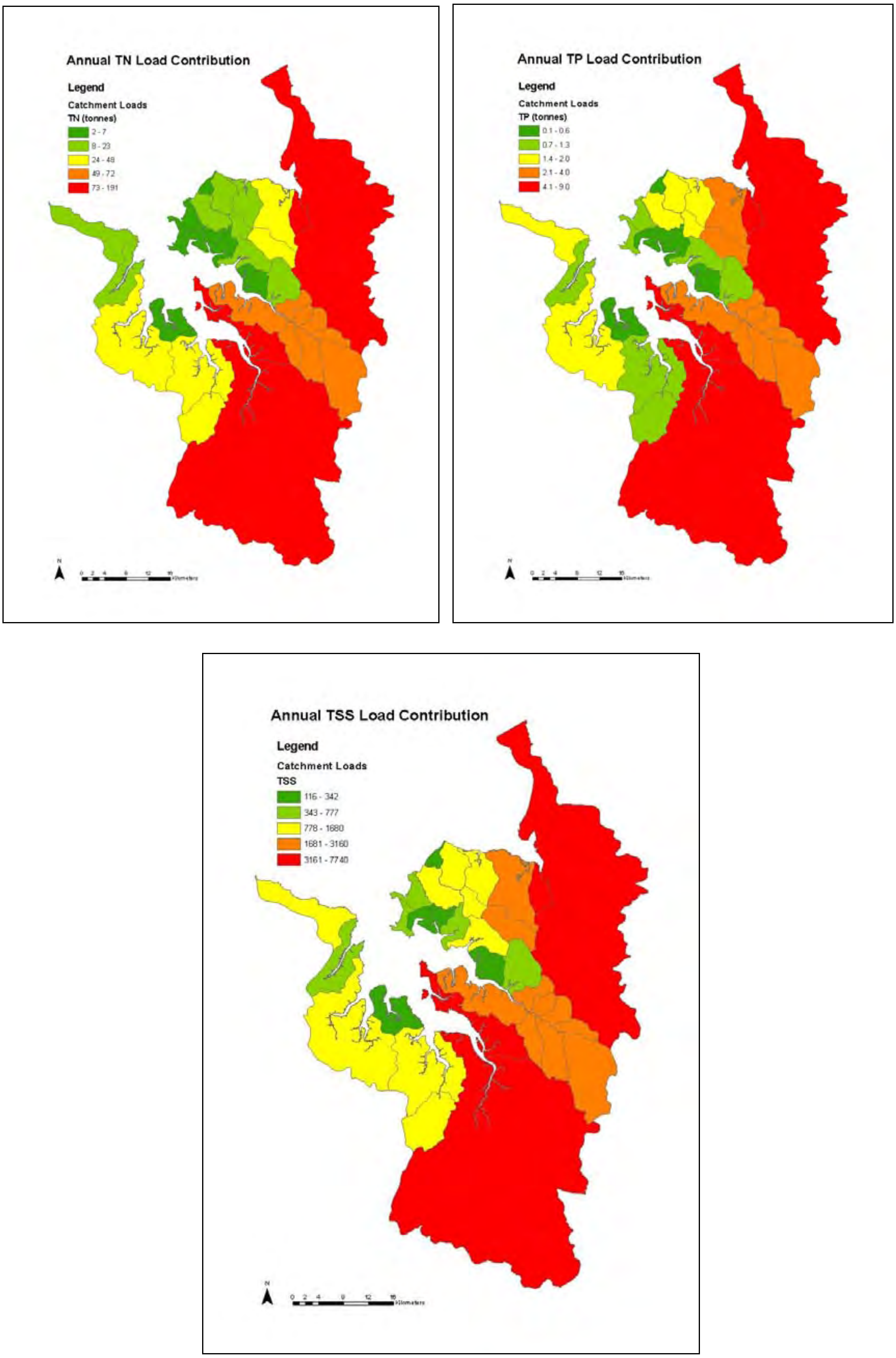


Figure 4.2: Catchment zone contribution to Annual Loads for Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS).

4.4 End of Catchment and Subcatchment Loads

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

4.5 Interim Catchment Targets and Uncertainty.

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

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

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

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

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

4.6 Annual Load Targets and Current Condition

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

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

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

**Point and diffuse sources only with MOS*

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

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

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

Section 5. Flow Objectives for the Darwin Region

5.0 Summary

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

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

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

5.1 Introduction

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

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

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

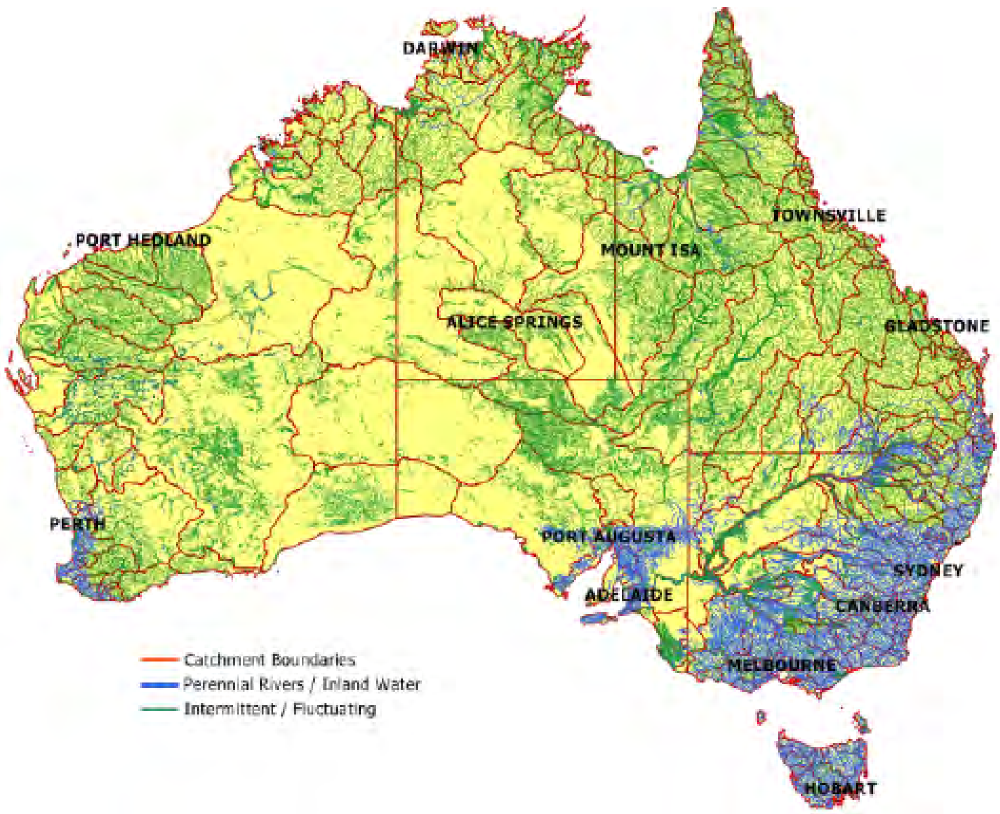


Figure 5.1: Intermittent and Perennial Water in Australia. (Data Copyright Commonwealth of Australia – available from Geoscience Australia).

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

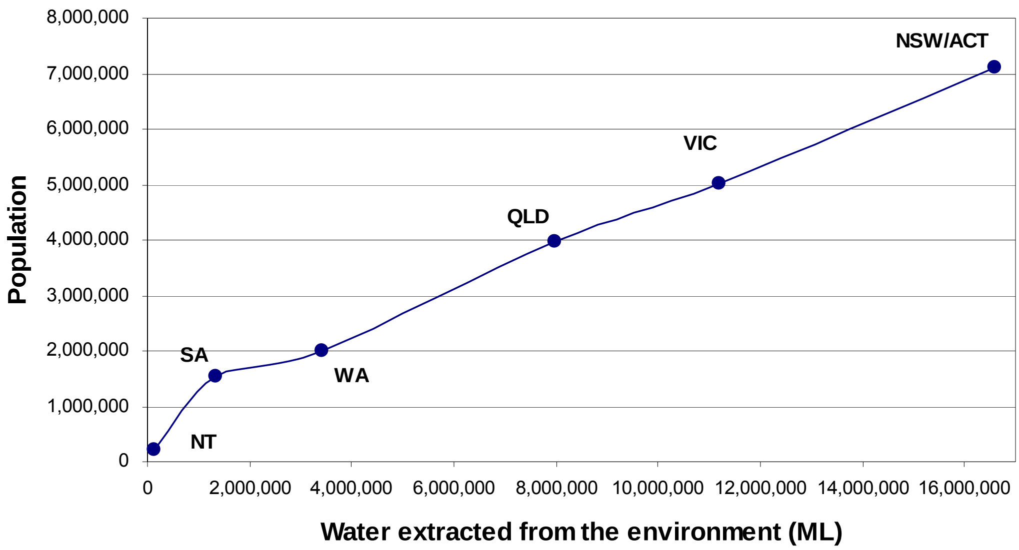


Figure 5.2: Water extraction and population – mainland states 2004-5. (Source: ABS 2004)

5.2 Aquifer Productivity in the Top End

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

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

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

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

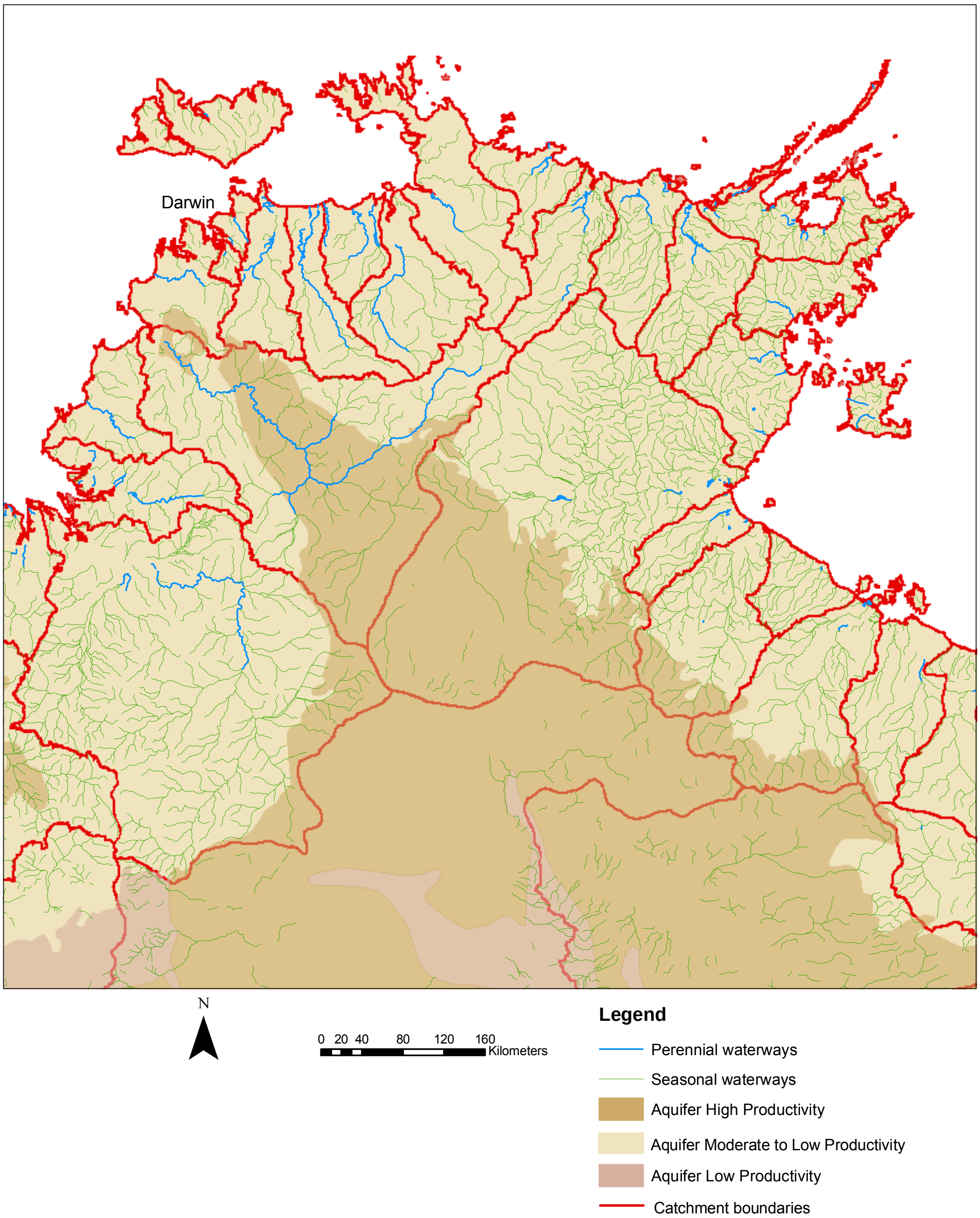


Figure 5.3: Aquifer productivity, perennial and seasonal river networks in the NT.

5.3 Surface Water in the Darwin Region

5.3.1 Rainfall & Climate

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

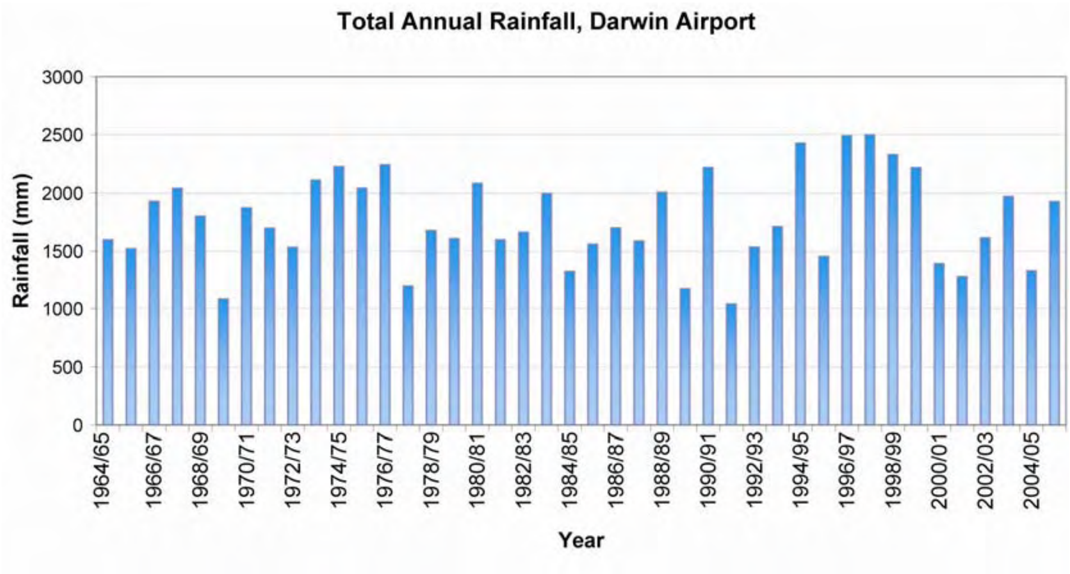


Figure 5.4: Total annual rainfall from Darwin Airport, 1965 to 2005.

5.3.2 Seasonal Runoff Pattern

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

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

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

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

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

5.3.3 Impacts of surface runoff

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

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

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

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

5.3.4 Regulated Systems in the Region

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

5.3.5 Stream Gauge Monitoring

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

5.3.6 Lagoons of the Darwin region

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

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

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

Figure 5.6(a): McMinns Lagoon.

Figure 5.6(b): Girraween Lagoon.

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

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

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

5.4 Groundwater

5.4.1 Regional aquifers

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

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

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

5.4.2 Groundwater level changes due to development

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

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

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

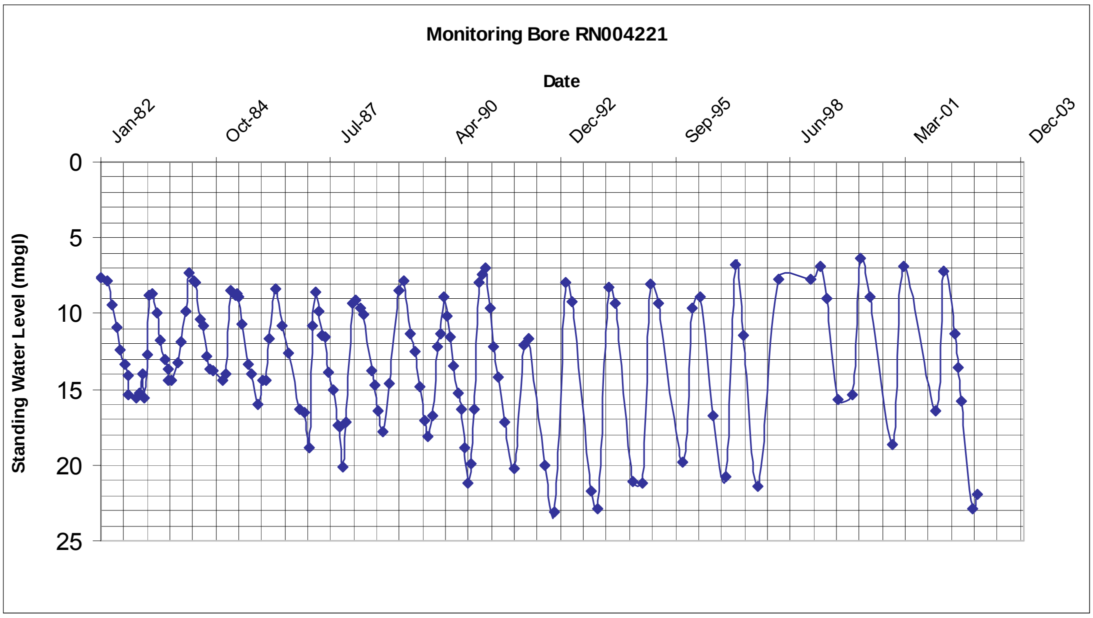


Figure 5.7. Hydrograph of monitoring bore inside the area of rural development (1982-2002).

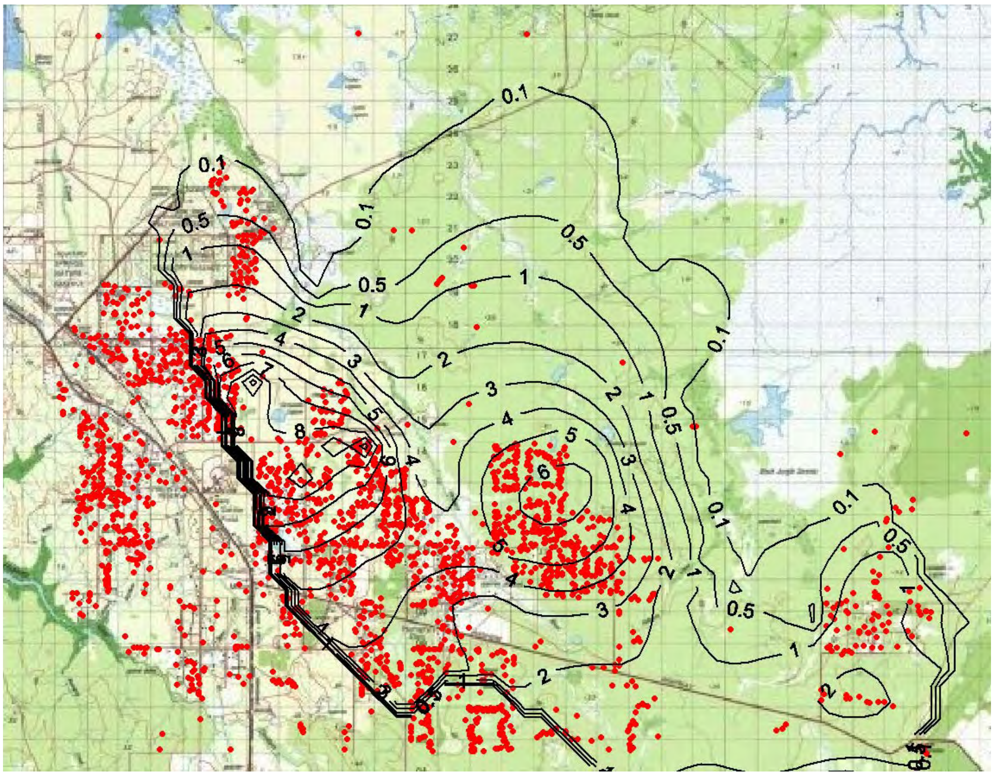


Figure 5.8. Drawdown contours due to rural development (Source: Haig & Townsend 2003).

5.5 Environmental Flow Determination in the Darwin Region

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

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

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

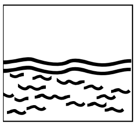
Once the environmental water requirements are known, environmental water provisions can be identified in the water allocation plan so that the environmental water requirements for the groundwater dependent ecosystem are protected. It is only when these provisions are formally adopted that the groundwater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

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

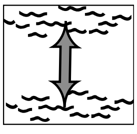
5.6 Interim Flows Objectives

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

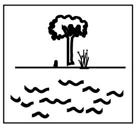
General interim objectives:

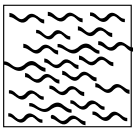


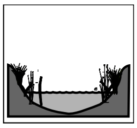
1. Protect natural flow regimes (Dry and wet season flow regimes).

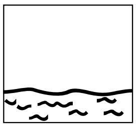


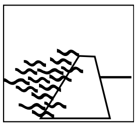
2. Maintain natural variability (A system should retain its perennial or seasonal nature).

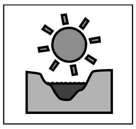

3. Manage groundwater for ecosystems.

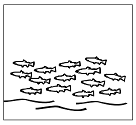

4. Protect important rises in water levels – important wet season flows.


5. Maintain seasonal wetland/floodplain inundation.


6. Protect natural low flows (perennial systems).

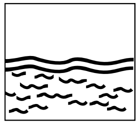
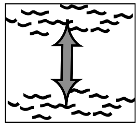
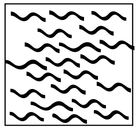
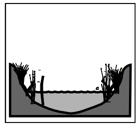
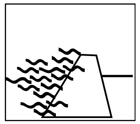
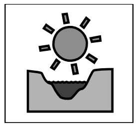

7. Minimise the effect of weirs/dams or other structures on flow

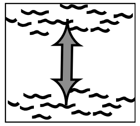
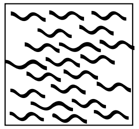
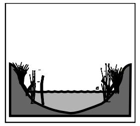
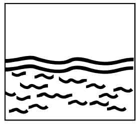
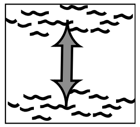
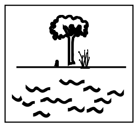

8. Emulate natural drying in seasonal waterways.

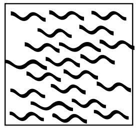
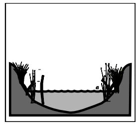
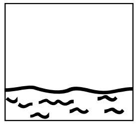
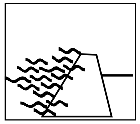
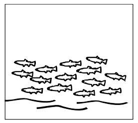
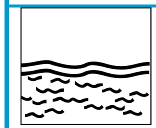
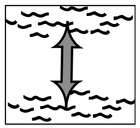

9. Maintain flow requirements for aquatic biota.

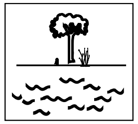
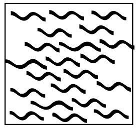
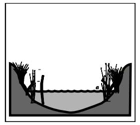
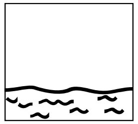
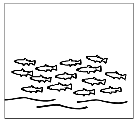
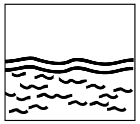
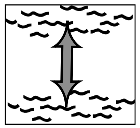
Specific flow objectives will follow research currently underway on the Howard River to assess specific ecological flow requirements of this perennial system of significance. The perennial stretch of Berry Creek is located within Berry Springs Nature Reserve and by virtue of its conservation status is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

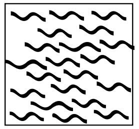
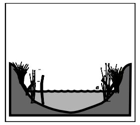
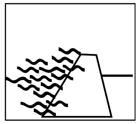
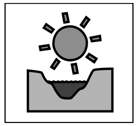
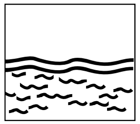
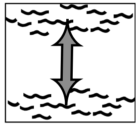
Table 5.1. Interim Flow Objectives for Darwin Harbour Region waterways.

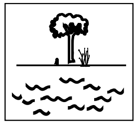
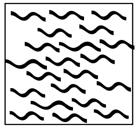
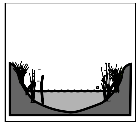
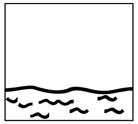
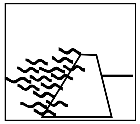
RIVER FLOW OBJECTIVE	SEGMENT OF WATERWAY	PROPOSED FLOW REGIME
 Protect natural flow regimes: (Wet season flow regime)  Maintain Natural variability  Protect important rises in water levels  Maintain seasonal wetland/floodplain inundation  Minimise the effect of weirs/dams or other structures on flow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

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

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

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

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

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

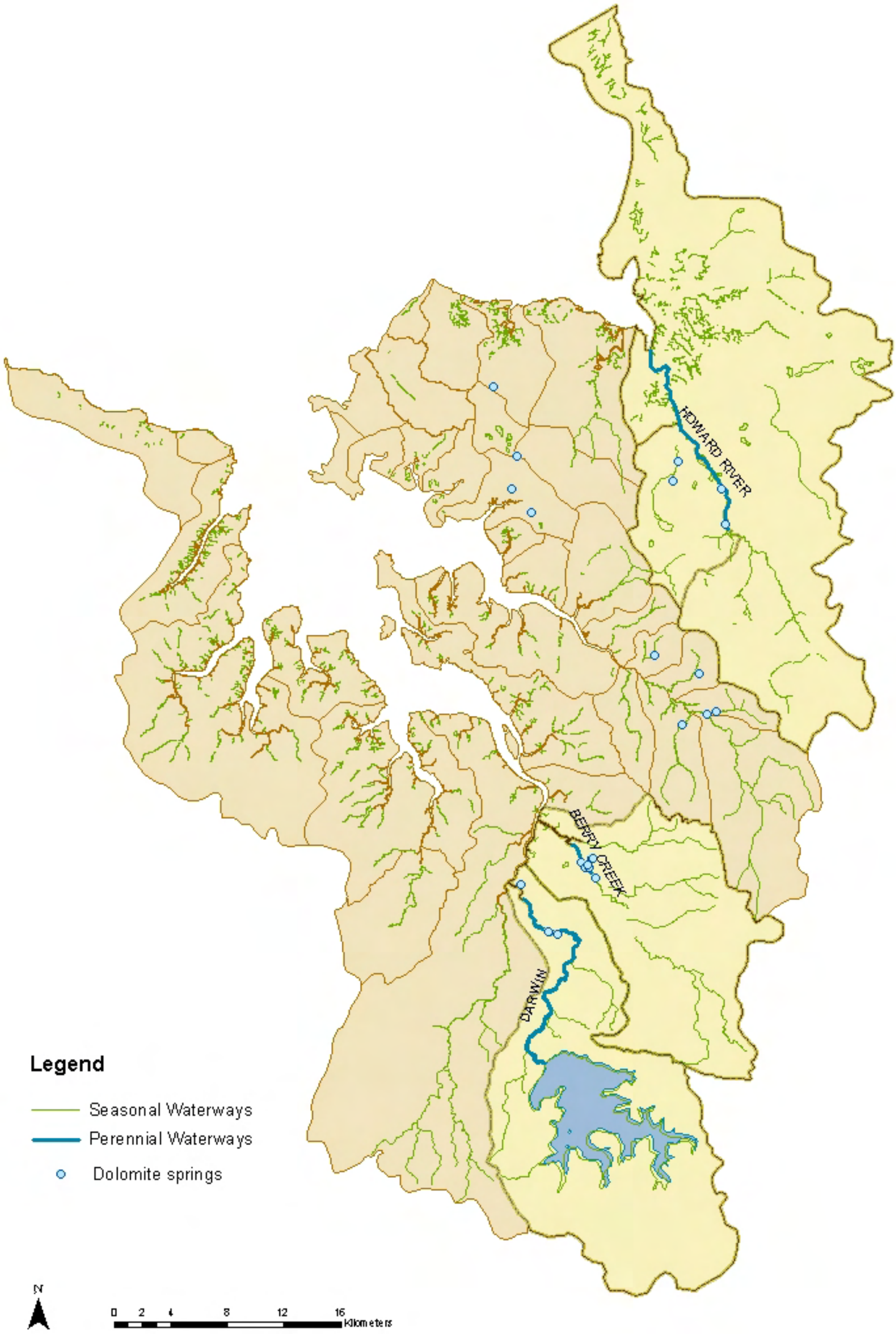


Figure 5.9: Major perennial systems in the Darwin region. The Howard River Catchment and the Berry Creek Catchment delineated from other seasonal systems.