The Impact of Urban Land-use on Total Pollutant Loads Entering Darwin Harbour

Lizzy Skinner, Simon Townsend and Julia Fortune

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Summary

The catchment of Darwin Harbour, between Gunn and Charles Points covers an area of 2010 km^2 of land. Most of the catchment, about 80%, is not developed and comprises savanna woodland, though not in pristine state due to, for example, high fire frequency and access tracks. Urban land-uses, which include residential living, manufacturing and industrial uses, roads and defence facilities, comprise about 11% of the catchment, predominately in Darwin and Palmerston whilst other land uses are rural.

Land-use influences the water quality and flow volumes that enter Darwin Harbour, and consequently influences the water quality of Darwin Harbour. To manage the water quality of Darwin Harbour, the water quality of rivers and streams entering the harbour needs to be well managed. Estimated annual load inputs from diffuse sources to the harbour for the nutrients, nitrogen and phosphorus, total and volatile sediment, and the following metals: aluminium, arsenic, cadmium, chromium, copper, nickel, lead and zinc were determined for rural and urban land uses. Estimated annual load assessment in this report considers only land-based diffuse and point source loads from licensed wastewater treatment plants. It does not include the contribution of other sources such as atmospheric or oceanic pollutants to Darwin Harbour, which is subject to further research.

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 the Darwin Harbour.

Estimated diffuse 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 than for rural or undisturbed 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 disproportionately high load of pollutants.

Further development of Darwin Harbour catchment for urban and industrial land-use in a ‘business as usual’ mode could see increases in 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 5-11%. At a local scale, the increase of pollutant loads for the Buffalo Creek catchment is predicted to be between 4 - 8% and 5 - 26% from the Mitchell Creek catchment. The projected longer term and larger urban developments collectively have the potential for a more significant impact, with a predicted increase

of 31 – 107 % in pollutant loads to the Harbour based on a 'business-as-usual' approach.

The estimated contribution of nutrients from treated wastewater is significant, particularly for phosphorus which assumes up to 71% of the estimated current annual load. The contribution from future developments coupled with a growing population may result in increasing pollutant loads and pose mounting pressure on receiving waterways.

However, water sensitive urban design, the implementation of stormwater codes of practice for various industry sectors, water reuse, recycling and other management actions can combine to reduce this otherwise predicted load to Darwin Harbour.

Contents

Introduction

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

This report collates pollutant and hydrographic data for the Darwin Harbour catchment, with a focus on monitoring of loads undertaken in the 2006/07 wet season. It extrapolates monitoring undertaken for specific catchments to the wider Darwin Harbour catchment, and predicts the impact of future development on the pollutant loads entering Darwin Harbour based on a 'business as usual' approach.

Objectives

The report's objectives are to:

1. Estimate the catchment loads of sediment, nutrients and metals to Darwin Harbour from diffuse sources.
2. Evaluate the inter-annual variability of these loads.
3. Compare diffuse source loads with point source loads.
4. Estimate the impact of further catchment development and increased population on annual loads to Darwin Harbour based on a 'business as usual' approach.

Section 1. The Darwin Region Catchment

1.0 General Description

For the purposes of this study the extent of Darwin Harbour and its catchment is defined by a line between Gunn and Charles Point, and includes Port Darwin and Shoal Bay (Figure 1). The 2010 km^2 terrestrial catchment, that being the land above the harbour's high water mark, comprises the cities of Darwin and Palmerston, a predominately rural hinterland, and undeveloped areas. The major rivers flowing into the harbour are the Howard, Elizabeth and Blackmore Rivers.

Figure 1. Darwin Harbour, defined by an imaginary line between Gunn and Charles Points.

1.1 Climate

The Darwin Region has a tropical climate with distinct wet and dry seasons. The wet season, between October and April, features monsoon rains, convective thunderstorms and cyclones. Darwin's average annual rainfall is 1717mm, with two-thirds falling between January and March.

River flows reflect the region's rainfall, with flows typically commencing during December and January, and reaching maxima during periods of heavy rainfall between January and March. By June most rivers have ceased to flow with the exception of Darwin and Howard Rivers, and the spring fed Berry Creek (Fukuda and Townsend 2006). These latter systems are supplied by aquifer fed groundwater during the dry season (Tien 2006) with the exception of the Darwin River where flows are maintained by regulated discharge from Darwin River Dam for riparian users.

1.2 Land-use in the catchment

Darwin Harbour catchment is not intensively developed. By 2005 approximately 18% of the catchment had been cleared of native vegetation for mainly urban and rural residential living, horticulture, agriculture, infrastructure, defence facilities and manufacturing.

The catchment carried a population of approximately 120,900 in 2006 with most people living in Darwin and Palmerston. These urban areas make up 3% of the catchment. Industry constitutes a smaller proportion of the catchment (0.15%) and is located at Winnellie, East Arm Point, Berrimah, Pinelands and Wickham Point.

1.3 Geology and soils

Darwin Harbour's catchment is ancient, highly weathered and eroded, with most soils relatively infertile. The catchment has low relief, and is low lying with the bulk of the catchment less than 50m above sea level and the maximum elevation around 140m (Nott 2003, McKinnon *et al*. 2006).

The principal geomorphic units of the Darwin Harbour region are the alluvial plains, coastal plains, the Koolpinyah Surface and dissected foothills. The alluvial plains associated with the middle reaches of the Elizabeth River, Howard River and Berry Creek have shallow yellow and mottled soils. These plains are developed on Proterozoic and Tertiary geology and are seasonally inundated. The coastal plains consist of flat, poorly drained saline mud and clay plains which are a significant feature of the low-lying coastal strip of Shoal Bay.

The Koolpinyah Surface dominates the Cox and Gunn Point peninsulas, and underlies Darwin and Palmerston. This geomorphic unit consists of gravels, sands, silts and clays that have been repeatedly weathered and redeposited. Since being deposited during the Tertiary period, sediments have undergone intense weathering to produce a lateritic mantle that contains ironstone and high aluminium levels. The soils of the Koolpinyah Surface range from massive red and yellow earths to shallow lithosols.

South of Darwin Harbour dissected foothills rise above the Koolpinyah Surface in the form of rocky hills, boulder covered strike ridges, stony hillocks and occasional granite tors. Soils of the dissected foothills are typically shallow and include extensive areas of surface stone. Most of the region is covered by 20-50 m of more recent sandstone, siltstone and claystone with a 5-10 m thick layer of laterite that forms a capping layer over the area. The bedrock consists of dolomite, carbonate rocks, sandstone, shale, siltstone, schist, granite and metamorphic rocks. The dolomite and carbonate rocks, which are found in the Darwin rural area, contain high yielding aquifers compared to the fractured sandstone and siltstone.

1.4 Vegetation

Approximately 80% of the Darwin Harbour catchment remains uncleared. The dominant vegetation communities are savanna woodlands and forests. About 60% of the region is made up of eucalypt woodlands, with the most common trees being stringybark, woolybutt, cycad, sand palm and pandanus (DHAC 2003). Extensive growth, especially of grasses, occurs during the wet season compared to the dry season when there is little growth. Dry season fires clear the understorey of grasses, which have become more frequent, more intense and more extensive. Invasive weeds such as gamba and mission grass increase the frequency and intensity of fires (DHAC 2003).

Rainforest patches, paperbark forests, grasslands and heath make up the lowland vegetation. Freshwater lagoons, grassy swamps, paperbark woodlands, floodplains and monsoon forest approximate 6% of the catchment (DHAC 2003). Extensive tracts of mangroves fringe Darwin Harbour and are a dominant feature of the coastal zone. The area of mangroves in Darwin Harbour is approximately 27,350 ha, which represents about five percent of the total mangrove area of the NT.

The riparian zone plays an important role in the health of rivers and creeks providing a buffer from adjacent land-uses (Price 2003). The ecological condition of riparian vegetation remains mainly intact with approximately 11% cleared of native vegetation in 2005.

Section 2. Catchment Runoff

The different land-uses within the catchment influence the timing and volume of runoff that reaches rivers and creeks. Land clearing and urbanisation alters overland flow paths, reduces the volume of water that infiltrates to groundwater, and reduces the time runoff takes to enter the rivers and creeks.

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

The runoff coefficient is a useful measure to assist in the assessment of the actual and also the potential impact of catchment development. The runoff coefficient is defined as the volume of runoff per unit area divided by the total rainfall for a nominated period, and describes the proportion of rain that flows into rivers and creeks relative to total rainfall. Runoff coefficients are always less than 1, and for this study refer to the water year from September to August; thereby including a single wet season. Runoff coefficients are influenced by, inter alia, soil infiltration rates, vegetation cover and rainfall intensity.

Runoff volumes and runoff rates play an important part in determining the health of rivers and creeks and the ultimate harbour receiving waters. Higher runoff leads to a greater potential for scouring of channels and transportation of pollutant loads via the rivers and creeks to the harbour.

This section of the report examines how the runoff concepts discussed above apply to four sub-catchments within the greater Darwin Harbour catchment.

2.0 Study Catchments

In the Darwin Harbour region and the adjacent Manton River catchment, runoff and water quality have been monitored at 11 hydrographic stations (Figure 2) to compute catchment pollutant loads. The period of runoff monitoring for these stations varies from 2 to 44 years, and far exceeds the number of wet seasons monitored for water quality. To examine the impact of land-use on catchment runoff, the Blackmore and Elizabeth Rivers have been selected as examples of predominantly undeveloped catchments (Table 2), and the Moil and Karama suburban stations as examples of urban catchments because they have the longest and most accurate hydrographic data.

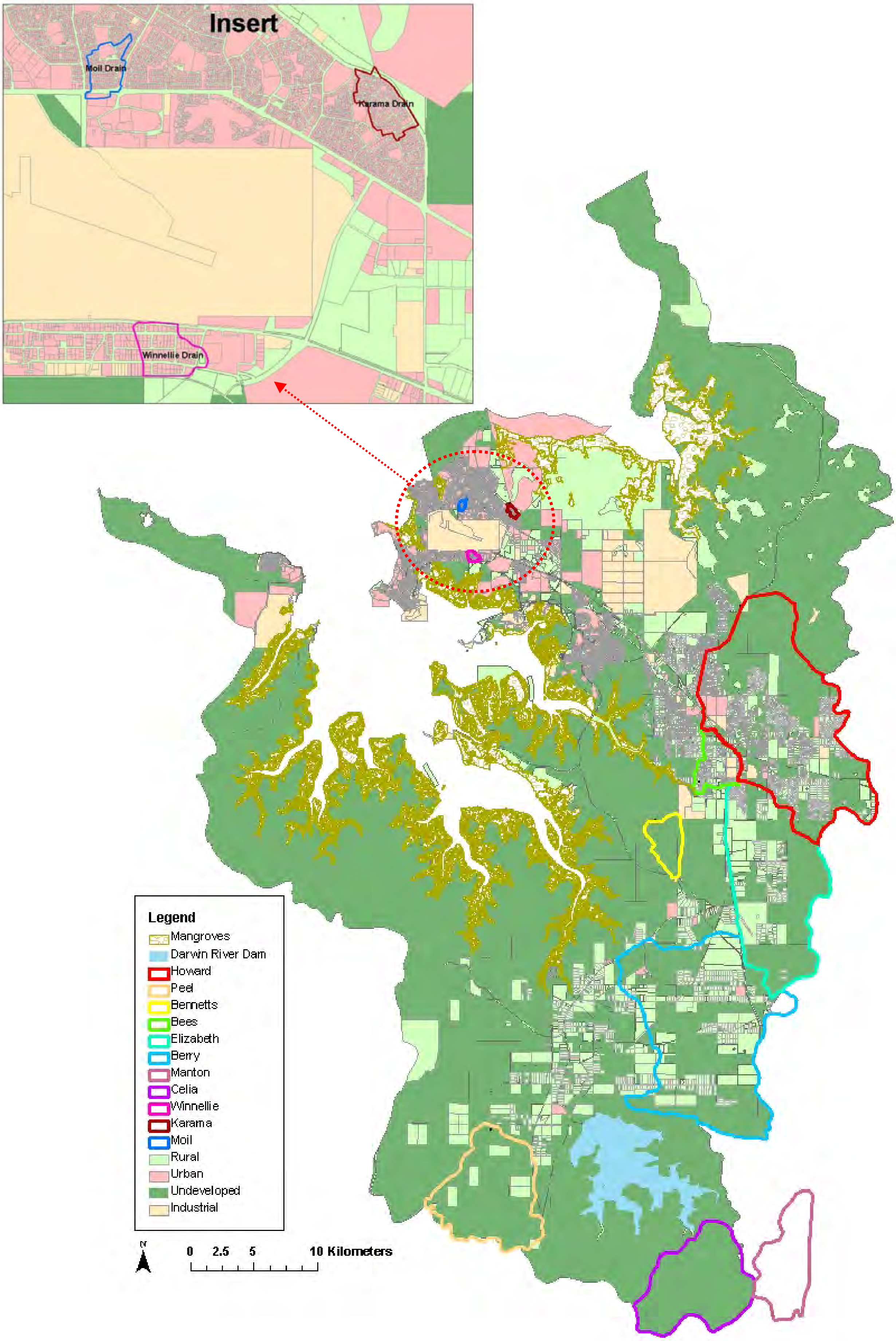

Figure 2. Catchments of hydrographic stations and their respective land uses that have monitored water quality for wet season load calculations.

Rainfall data was provided by the Bureau of Meteorology for the most relevant rain gauge to the catchments shown in Figure 2, whilst runoff data was provided by the Department of Natural Resources, Environment the Arts and Sport (NRETAS). Details of the rainfall and runoff data used are shown in Table 1.

Table 1. Hydrographic and rainfall data sets used to calculate runoff coefficients.

Catchment	HYDSTRA* hydrographic station number	Period of hydrographic data	BoM** Rainfall gauge name and number
Blackmore	G8150098	1961-2007	Darwin River Dam (14183)
Elizabeth	G8150018	1959-2007	Noonamah/Elizabeth Valley (14080/14222)
Karama	G8150232	1988-1994	Karama (14227)
Moil	G8150231	1987-2007	Darwin Airport (14015)

*HYDSTRA, NRETA water resource database.
** BoM: Bureau of Meteorology.

Table 2 outlines the land-uses within the study catchments. The Moil and Karama catchments consist mainly of urban and industrial land-uses, with only 23% and 4% respectively being rural or defence land. By contrast, the Blackmore and Elizabeth catchments are made up of less than 5% urban or industrial areas, with the majority of land undeveloped.

Table 2. Land-use within the Blackmore, Elizabeth, Howard, Moil and Karama catchments (2004).

Catchment	Land-use category from ACLUMP* data		
	Undeveloped	Rural/Defence	Urban/Industrial
Blackmore	68%	28%	4%
Elizabeth	58%	39%	2%
Moil	0%	23%	77%
Karama	0%	4%	96%

*ACLUMP is Australian Collaborative Land Use Mapping Programme.

2.1 Hydrographic station rating tables

At each hydrographic station, water level is monitored at a rate such that sufficient change is recorded to accurately generate a stage hydrograph reflecting true water levels over time. This height is then converted to a flow through a rating table. The accuracy of the rating tables is developed and validated by measuring stream flows by standard hydrographic gauging techniques. Gaugings for the last ten years have been compared to predicted flows to assess the accuracy of the rating table. Earlier data were not used because the cross-section and hydraulic control of the river at the hydrographic station may have changed over time. The comparison is presented in Appendix 1.

Gauging to validate the rating table for each site were carried out at low to moderate flows, and agree with the rating table over these ranges. However, no gaugings have been conducted for very high flows. The rating table for the high flows greater than the highest gauged flow relies on the surveyed cross-section and theoretical calculations. These high flows are infrequent (Appendix 2), and would only in occasional years contribute substantially to the total volume of river flow. The estimation of the pollutant loads and extrapolated predicted loads in this study assumes the validity of the rating table at high river flows.

2.2 Rainfall - runoff coefficients

Runoff will (generally) occur when rainfall intensity is greater than the soil infiltration rate. For periods of higher rainfall, especially when soils are close to saturation, higher rates of runoff will result.

Runoff coefficients for catchments within the Darwin Harbour region calculated on an annual basis generally increase with an increase in the total annual rainfall (Appendix 2). Variation in the total rainfall measure accounted for about 25% of inter-annual variability determined in the runoff coefficients. In the Blackmore and Elizabeth River catchments, which have the longest periods of hydrographic and rainfall record, the coefficients ranged from 0.1 in very low rainfall years to 0.9 in high rainfall years when the catchment was saturated for lengthy periods.

2.3 Land-use and runoff

Urban land-use with a high proportion of impervious areas will have higher runoff coefficients than rural and undeveloped catchments. The savanna woodlands of the catchment will have lower runoff coefficients as water is intercepted by vegetation, transpired to the atmosphere or retained by leaf litter, grass and soil. This trend is apparent when years of common data are compared between the rural and urban catchments (Figure 3).

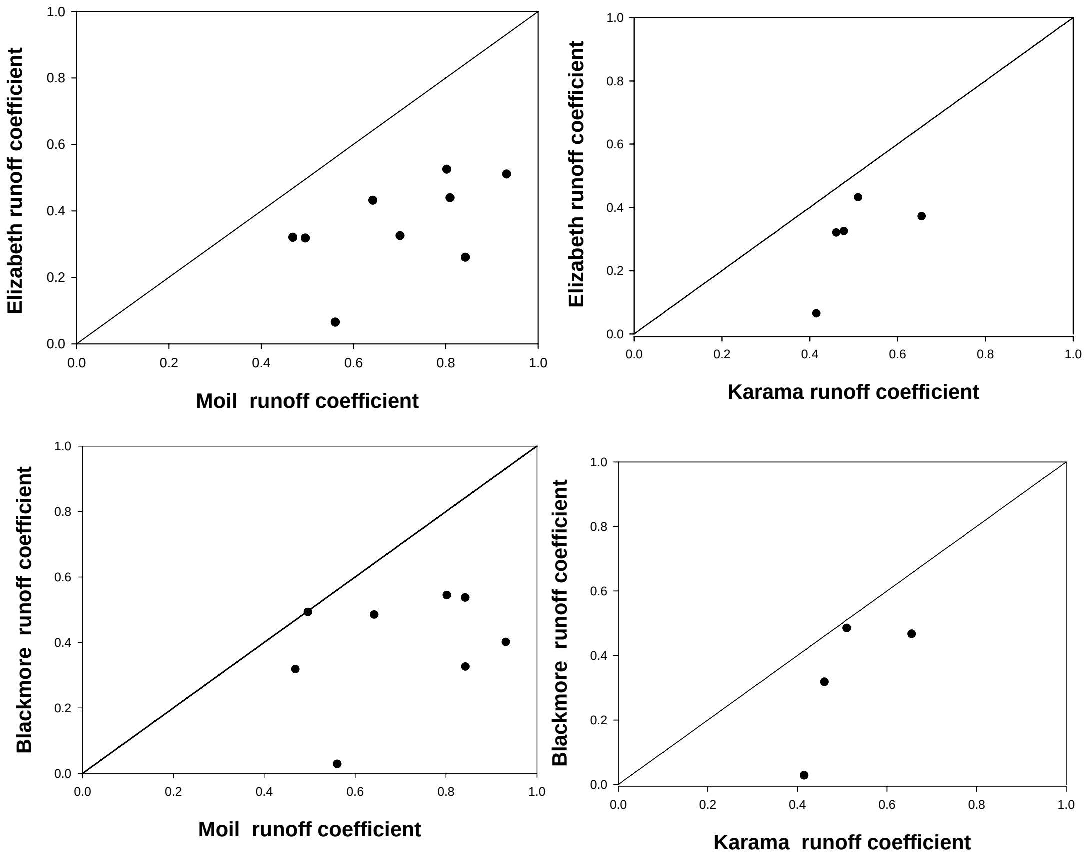

Figure 3. Runoff coefficients for urban Karama and Moil, and rural Elizabeth and Blackmore catchments for common years of data. The diagonal line represents the 1:1 ratio of runoff coefficients.

Figure 3 shows runoff coefficients for the urban catchments are consistently higher than those of the less developed Elizabeth and Blackmore catchments. Runoff coefficients averaged 0.38 and 0.35 for the Blackmore and Elizabeth River catchments respectively, and averaged 0.78 for the Moil catchment for years of common data collection. The runoff coefficient averaged 0.5 in the Karama catchment. These coefficients agree with other estimates of runoff coefficients for the region. Hatton *et al*. (1997) found the average rural wet season runoff coefficient to be 0.33. The results of a study by Townsend (1992) also concur with the above findings, which noted that the urban runoff coefficient can be more than double rural coefficients. Urban land-use approximately doubles runoff coefficients compared to rural land-uses, but the individual coefficients vary with the annual rainfall total.

The runoff coefficient for the urban area of Moil is consistent with those runoff coefficients found in other urban centres of Australia which typically range between 0.5-0.8 (Barry *et al* 2004).

2.4 Conclusion

Rainfall and hydrographic data were examined in four sub-catchments within the Darwin Harbour catchment and revealed the following trends:

- The runoff coefficient increases as annual rainfall increases.
- Urban catchments have higher runoff coefficients relative to rural catchments.

Consequently, there is, for any given rainfall, a greater proportion of runoff from an urban catchment than from an undeveloped catchment and that this proportion increases for both land use categories as total rainfall increases. This runoff is, in turn, the principal agent to transport pollutants from the catchment to the receiving waters.

Urban land use approximately doubles the annual runoff coefficient which varies with annual total rainfall. The proportion of impervious surface attributable to urban and industrial development exacerbates run-off and consequently affects pollutant loads to Darwin Harbour.

Section 3. Pollutant export rates and land-use

Rivers and streams carry nutrients, sediments and metals. The sources for these constituents include the atmosphere (deposited in rain or as dust and ash), decaying of natural organic material, the natural weathering and erosion of soil and anthropogenic (human induced) pollution.

Human activity can increase the concentration of nutrients, sediment and metals in rivers and streams from diffuse and point sources. A point source is a discharge from an identifiable location, such as a sewerage treatment effluent or industrial outlet. Diffuse source pollution originates from the general catchment. This report focuses on the latter.

Pollution levels can be expressed as the load or mass of the pollutant. The load is equal to the runoff volume multiplied by the concentration of the particular pollutant for a nominated period. A pollutant export coefficient is the load per unit area exported from the catchment for a nominated period.

In this section, we draw upon on the results of previous Darwin Harbour load studies (Table 3), and analyse pollutant load data for the 2006-07 wet season. We examine the influence of land-use on pollutant export coefficients, and then apply the loads from each sub-catchment entering Darwin Harbour to determine the overall annual loads. In a later section of the report, scenario modelling then draws on these results to predict the 'business as usual' outcomes of proposed future development on the pollutant loads entering Darwin Harbour. The report examines nutrients, metals, and suspended sediment. It does not examine all pollutants; such as pesticides, grease, oil, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Pesticide pollution of the rivers and streams in the Darwin region has been reported by Waugh and Padovan (2004).

3.0 Pollutant sampling method

Pollutant loads have been monitored at 10 hydrographic stations (Figure 1, Table 3) in the catchment of Darwin Harbour since 1990. The Manton River, upstream of Manton Dam, and adjacent to the Darwin Harbour catchment, was also monitored to provide information about runoff water quality from a relatively undeveloped catchment. Pollutant loads have been determined for the total amounts of nitrogen (N), phosphorus (P), aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn) and total (TSS) and volatile (VSS) suspended sediment. Nearly all rivers and streams cease to flow in the dry season, with the exception of the lower reaches of the Howard River and Berry Creek. The proportion of dry season flow that contributes to the annual inflow of freshwater to the harbour is negligible (<0.001%), and was not monitored for water quality. Consequently, the loads presented here are calculated for the wet season, but equate to an annual load.

During the 2006/07 wet season, water samples were collected at the Moil, Howard, Elizabeth, Bennett, Peel and Berry hydrographic stations. At Moil, discrete water samples were collected, automatically refrigerated on site, and analysed for nitrate, nitrite, ammonia and filterable reactive phosphate to provide information about the proportion of these nutrients in soluble form in an urban catchment and are reported in Appendix 3.

A datalogger was used to continuously record flow at all sampling sites, and was programmed to activate an automatic sampler after a pre-determined volume of water flowed past the gauge station. Sampling was therefore volume proportional and representative of all flow regimes (base flow and storm events). Samplers were engaged prior to the commencement of the wet season to capture first flush events from each site.

At each station, pumped aliquots were combined in a 20L polyethylene container to give a single composite sample. There were typically about 20 to >100 pumped aliquot samples which made up each composite sample for laboratory analysis, depending on event magnitude. At one to two week intervals, composite samples were well mixed and sub-sampled for the chemical analysis of total nitrogen (as the sum of total Kjeldahl nitrogen (TKN), nitrate and nitrite), total phosphorus, and total and volatile suspended sediment. The samples were also analysed for total metal concentrations (Al, Cd, Cr, Cu, Pb, Ni, Zn) and arsenic. Suspended solids were analysed at the DPIFM laboratory using Standard Methods (APHA, 1998). Nutrients and metals were analysed at the NTEL laboratory in Darwin.

The water quality of flow periods not sampled due to equipment failure were estimated as the average of the concentration determined for the periods immediately before and after the period of nil sample collection. The load was determined by summing the product of concentration and flow for each period of water sample collection.

3.1 Impact of land-use on pollutant loads

This section of the report will use the 2006/07 pollutant data to develop an understanding of how land-use impacts on water quality. The export coefficient is a widely used tool for comparing catchment pollutant loads and will be examined first. Following this, an export coefficient standardised for rainfall will be developed to remove the impact of rainfall variability between catchments on the export coefficient, and for use when developing catchment loads later in the report. This is necessary due to the effect of rainfall on runoff volume, a determinant of catchment load.

3.2 Catchments studied

The land-use in the catchments of the hydrographic stations on Bennett, Peel and Berry Creeks, Elizabeth and Howard Rivers, and Moil Drain varied from predominantly undeveloped through to urban and industrial land-uses. The catchments were divided into three categories: undeveloped, rural and urban. This division was based on the percentage of land-use types in each catchment which was assessed using the Australian Collaborative Land Use Mapping Program (ACLUMP) data.

Table 3. History of Loads Monitoring for the Darwin Harbour Catchment.

Catchment	Hydrographic station number	Wet seasons monitored.	Reference
Karama	G8150232	1990/91, 1991/92	Townsend, S.A. (1992), Kernohan, A. K and Townsend, S.A. (2000).
Moil	G8150231	1995/96, 1996/97, 2006/07	Padovan, A.V. (2001b).
Berry	G8150028	1999/00, 2000/01, 2001/02, 2006/07	Padovan, A.V. (2001a), Padovan, A.V. (2001b), Padovan, A.V. (2002).
Howard	G8150179	2005/06, 2006/07	
Elizabeth	G8150018	1990/91, 1995/96, 1996/97, 1997/98, 2001/02, 2002/03, 2005/06, 2006/07	Townsend, S.A. (1992), Padovan, A.V. (2002), Padovan, A.V. (2001b).
Peel	G8150321	2005/06, 2006/07	Padovan, A.V. (2001b).
Bennett	G8150322	2005/06, 2006/07	Padovan, A.V. (2001b).
Bees	G8150036	2001/02, 2002/03, 2003/04. Pollutant loads for Bees Creek have not been used in this report due to an inaccurate rating table.	Padovan, A.V. (2001b), Padovan, A.V. (2002).
Winnellie	G8150016	1995/96, 1996/97, 1999/00, 2000/01. Pollutant loads for Winnellie Drain over-estimate actual loads due to an inaccurate rating table, and have not been used in this report.	Padovan, A.V. (2001a), Padovan, A.V. (2001b).
Celia	G8150151	1995/96, 1996/97	Padovan, A.V. (2001b)
Manton	G8170033	1996/97. Catchment bordering to the Darwin Harbour catchment (Figure 1).	Padovan, A.V. (2001b)

ACLUMP maps land-use across Australia. There are many ACLUMP land-use classifications so they were aggregated into the three land-use categories of Level 1, Level 2 and Level 3 as shown in Appendix 4. Level 1 development is land-use with minimal disturbance such as remnant vegetation and national park. Level 2 development is defined by typically rural types of land-uses such irrigated crops or rural living. Level 3 development is urban and industrial land-uses. The percentage area of each level was calculated using Arc Map for each catchment with the results shown in Table 4. These percentages were then used to classify each catchment as undeveloped, rural or urban.

Bennett and Peel Creek catchments have been classified as undeveloped. Both have predominantly Level 1 development with Peel having 12% of its catchment classified as Level 2 development. A majority of Berry, Elizabeth and Howard River catchments are Level 1 development and approximately 40% are Level 2 development with a diverse range of land-uses. Given the similarities in land-use they have been put into the same classification referred to as rural. Finally, Moil catchment has been classified as urban with greater than 77% of the catchment comprising Level 3 development. This approach was necessary because the stations did not drain any single land-use based on ACLUMP criteria.

Table 4. Land-use categories, based on ACLUMP, data for catchments of hydrographic stations.

Catchment Category	Catchment	Land-use category from ACLUMP data			Total (ha)
		Level 1	Level 2	Level 3	
Undeveloped	Bennett	97%	0%	2%	938
	Peel	86%	12%	1%	5668
	Celia	100%	0%	0%	5281
	Manton	96%	4%	0%	2997
Rural	Berry	56%	40%	4%	13618
	Elizabeth	58%	39%	2%	9006
	Howard	53%	41%	6%	14614
Urban	Moil	0%	23%	77%	36
	Karama	0%	4%	96%	49

3.3 Export coefficients

Pollutant loads discharged from a catchment are dependent on the area of the catchment area. The export coefficient (kg/ha) standardises the pollutant load across catchments of different sizes. The export coefficient allows the amount of pollutant exported per unit area to be directly compared across catchments.

The average coefficients for the 2006/07 wet season for each catchment land-use category are presented in Table 5, and were derived from data presented in Appendix 5. Rainfall, which affects the runoff volume, was similar for each catchment based on the closest gauge station to each (Table 6). The historical range of export coefficient values is shown in Table 7.

Table 5. Average export coefficients for catchment categories in Darwin Harbour during the 2006/07 wet season. (The 'undeveloped' class is the average of the Peel and Bennett catchments, the rural is the average of the Elizabeth River, Berry and Howard catchments, the urban class is represented by Moil catchment). Coefficients are rounded to 2 significant figures.

Pollutant	Catchment categories		
	Undeveloped	Rural	Urban
TN (kg/ha)	4.7	2.6	14
TP (kg/ha)	0.06	0.08	1.5
Al (g/ha)	7500	6600	50000
As (g/ha)	3.0	2.2	13
Cd (g/ha)	1.4	0.13	1.2
Cr (g/ha)	5.8	5.9	36
Cu (g/ha)	36	15	830
Ni (g/ha)	6.3	4.1	25
Pb (g/ha)	5.9	3.6	130
Zn (g/ha)	130	44	1000
TSS (kg/ha)	85	73	930
VSS (kg/ha)	31	25	230

Table 6. Wet season rainfall over hydrographic station catchments

Catchment	2006/07 rainfall (m)	Rainfall station
Bennett	1.81	Hydrographic station data (G8150322)
Peel	1.46	Hydrographic station data (G8150321)
Elizabeth	1.64	Noonamah/Elizabeth Valley (RN14080/14222)
Howard	1.80	McMinns Lagoon (RN14219)
Berry	1.68	Territory Wildlife Park (RN14264)
Moil	1.64	Darwin Airport (RN14015)

Table 7. Minimum, average (bold type) and maximum export coefficients for all wet seasons sampled (including 2006/07) for each catchment class in Darwin Harbour catchment and Manton River. The number of years of wet season data is shown in parentheses. For some metals, only a single year of data was collected. (Coefficients expressed to 2 significant figures).

Pollutant	Catchment Classification		
	Undeveloped	Rural	Urban
TN (kg/ha)	0.69, **4.2**, 6.6 (2)	0.80, **2.5**, 5.2 (12)	4.6, **9.9**, 17 (5)
TP (kg/ha)	0.038, **0.19** 0.51 (2)	0.040, **0.080**, 0.29 (12)	0.40, **1.0**, 2.3 (5)
Al (g/ha)	910, **5000**, 9800 (2)	910, **3500**, 8200 (10)	**50000** (1)
As (g/ha)	0.470, **2.1**, 4.8 (2)	0.69, **1.9**, 4.8 (12)	5.4, **11**, 15 (3)
Cd (g/ha)	0.13, **2.3**, 7.5 (2)	0.07, **0.24**, 0.72 (12)	1.2, **1.9**, 2.9 (3)
Cr (g/ha)	2.2, **17**, 58 (2)	0.29, **4.1**, 7.6 (12)	7.1, **44**, 81 (5)
Cu (g/ha)	6.0, **25**, 41 (2)	2.50, **8.4**, 20 (12)	38, **200**, 830 (5)
Ni (g/ha)	1.5, **6.1**, 9.8 (2)	0.9, **3.0**, 6.2 (12)	4.3, **13**, 25 (3)
Pb (g/ha)	1.3, **6.4**, 12 (2)	1.2, **2.7**, 5.0 (12)	110, **270**, 360 (5)
Zn (g/ha)	2.8, **130**, 350 (2)	6.7, **37**, 120 (12)	300, **890**, 1900 (5)
TSS (kg/ha)	47, **150**, 290 (4)	33, **80**, 200 (12)	300, **730**, 960 (12)
VSS (kg/ha)	8.3, **44**, 80 (4)	8.7, **24**, 55 (12)	87, **200**, 230 (4)

3.3.3 Impact of rainfall of export coefficients

Rainfall affects the export coefficient by increasing discharge and the mobilisation of pollutants, similar to its influence on the runoff coefficient. This trend is shown for the Elizabeth catchment (Figure 4). Rainfall intensity is also important, particularly in urban zones.

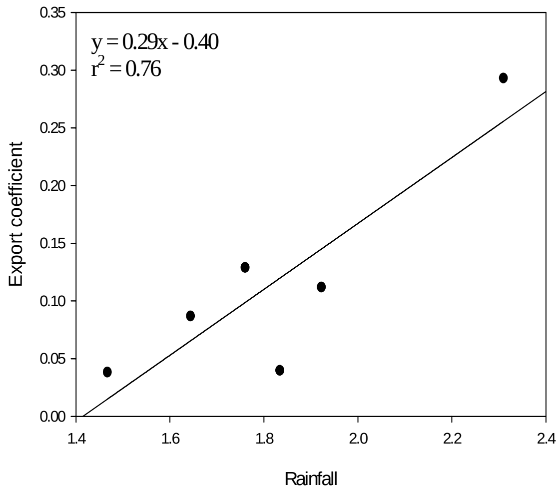

Figure 4 Impact of rainfall on the total phosphorus export coefficient in the Elizabeth catchment (P<0.01).

Flood events can transport a large proportion of the annual load over a wet season. Storms and localised flooding events occur throughout the wet season, typically between January and March. In excess of 70% of annual nutrient load from the Karama catchment occurred during these large events (Kernohan & Townsend 2000; Eyre & Pont 2003). As a consequence 75% of the annual nutrient load in the catchment was 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.

3.3.4 Impact of land-use of export coefficients

The urban catchment had significantly higher export coefficients for all water quality variables relative to undeveloped and rural catchments, except cadmium (Table 7), assuming land-use to be the prime determinant. There is a 2-100 fold increase in average export values.

Of the nutrients, urban phosphorus export coefficients were, respectively, 5 and 13 times greater than the undeveloped and rural values. Urban nitrogen export coefficients were approximately three times higher. Total and volatile suspended sediments were also greater from urban catchments than rural and undeveloped catchments.

Of the heavy metals, aluminium, copper, lead and zinc had the greatest difference between urban and rural. Schult (2004) found a similar trend when comparing heavy metal concentrations in the light industrial catchment of Winnellie with the rural Berry Creek catchment. Concentrations of heavy metals were higher in the Winnellie Drain compared to Berry Creek in 90% of the samples.

The undeveloped and rural land-use categories had similar export coefficients compared to the urban land-use category. Average coefficients were higher from the undeveloped catchments relative to the rural catchment, despite the presumed greater catchment disturbance and anthropogenic activity in the rural area land-use category. A likely explanation may lie in their different topography.

The rural catchments have very low catchment slopes, compared to the undeveloped Manton, Celia and Peel catchments which feature hills that are vulnerable to erosion and streams with greater slopes. The higher drainage stream velocities caused by the higher slopes of the undeveloped catchments may cause greater bank erosion and increased sediment transport and other loadings. This is supported by a study that found 80% of fine grain sediment originated from stream banks in the catchment (Ecosystem Research Group, 2006) rather than from the broader catchment. The riparian land and floodplains of the rural catchments may be more effective at trapping sediment bound pollutants than the riparian land of undeveloped hill slopes. Moreover, the Howard River catchment has several lagoons which will act as traps for sediment bound pollutants.

The nutrient and sediment export coefficient for the savanna lowlands of Kakadu National Park (Townsend and Douglas 2000, Townsend and Douglas 2004, Townsend *et al*. 2004) provide additional data on undeveloped land-use. These catchments have low slopes and are dominated by the Koopinyah surface similar to the Darwin region. Wet season export coefficients from these catchments were 0.3 - 1.0 kg/ha for nitrogen, 0.02 – 0.1 kg/ha for phosphorus, 10 – 90 kg/ha for total suspended sediment, and 5 – 20 kg/ha for volatile suspended sediment. These coefficients are generally lower than the Manton, Celia and Peel catchments, and are similar to the low lying Bennett catchment (with the exception of nitrogen), and overlap with the lower range of the rural catchment export coefficients. This comparison supports the contention that Manton, Celia and Peel export coefficients are relatively high due to their topography.

Given the magnitude of difference in export coefficients between the urban areas compared to the undeveloped and rural catchments, the undeveloped and rural catchments are treated in this study as one catchment classification, referred to as non-urban. Table 8 details the export coefficients for the new catchment categories.

Table 8. Average wet season export coefficients for urban and non-urban land-uses, Darwin Harbour catchment.

Pollutant	Catchment classification	
	Non-urban	Urban
TN (kg/ha)	3.2	9.9
TP (kg/ha)	0.12	1.0
Al (g/ha)	3800	50000
As (g/ha)	2.2	11
Cd (g/ha)	0.93	1.9
Cr (g/ha)	8.5	44
Cu (g/ha)	13	200
Ni (g/ha)	4.3	13
Pb (g/ha)	4.1	270
Zn (g/ha)	71	890
TSS (kg/ha)	110	730
VSS (kg/ha)	32	200

3.4 Conclusion

Export coefficients of nutrients, metals and sediment were higher for urban catchments than undeveloped and rural catchments, assuming similar landform and geology. There did not appear to be a significant difference between undeveloped and rural catchments. Consequently, for the purpose of this study these land-use classifications were aggregated as ‘non-urban’ catchments.

Section 4. Pollutant Loads Entering Darwin Harbour

The pollutant loads entering Darwin Harbour from each catchment can be predicted by using the average export coefficients, as calculated in the previous section, the catchment land-use areas and the relevant rainfall data. This section of the report will predict catchment loads entering Darwin Harbour during below average, average and above average rainfall years.

4.0 Darwin Harbour sub-catchments

To determine the total catchment loads to Darwin Harbour, the export coefficients as derived in Table 8 have been applied to the whole of the Darwin Harbour catchment. The catchment was divided into sub-catchments (Figure 5) which are aggregations of several smaller catchments based on drainage boundaries. The catchments are defined for those areas above the highest astronomical tide, and do not include the inter-tidal zone of mangroves and saltflats.

Major river systems in the catchment include the Howard, Elizabeth and Blackmore Rivers; only minor streams and creeks feed West arm and Woods inlet. These major systems also correspond with the largest subcatchments in the region assuming 54,100 ha, 22,870 ha and 63,470 ha respectively and include the largest proportion of rural type land uses.

Catchments with the largest area of light industrial land use are the Sadgroves Creek (351 ha), Hudson Creek (229 ha) and Reichardt Creek (157 ha) catchments. Hudson Creek is an area subject to expanding industrial activity in association with the nearby East Arm Port.

Rapid Creek catchment includes the largest urban area (1,216 ha). Extensive urban areas are also found in the catchments of Buffalo Creek, Ludmilla Creek and the Darwin CDB.

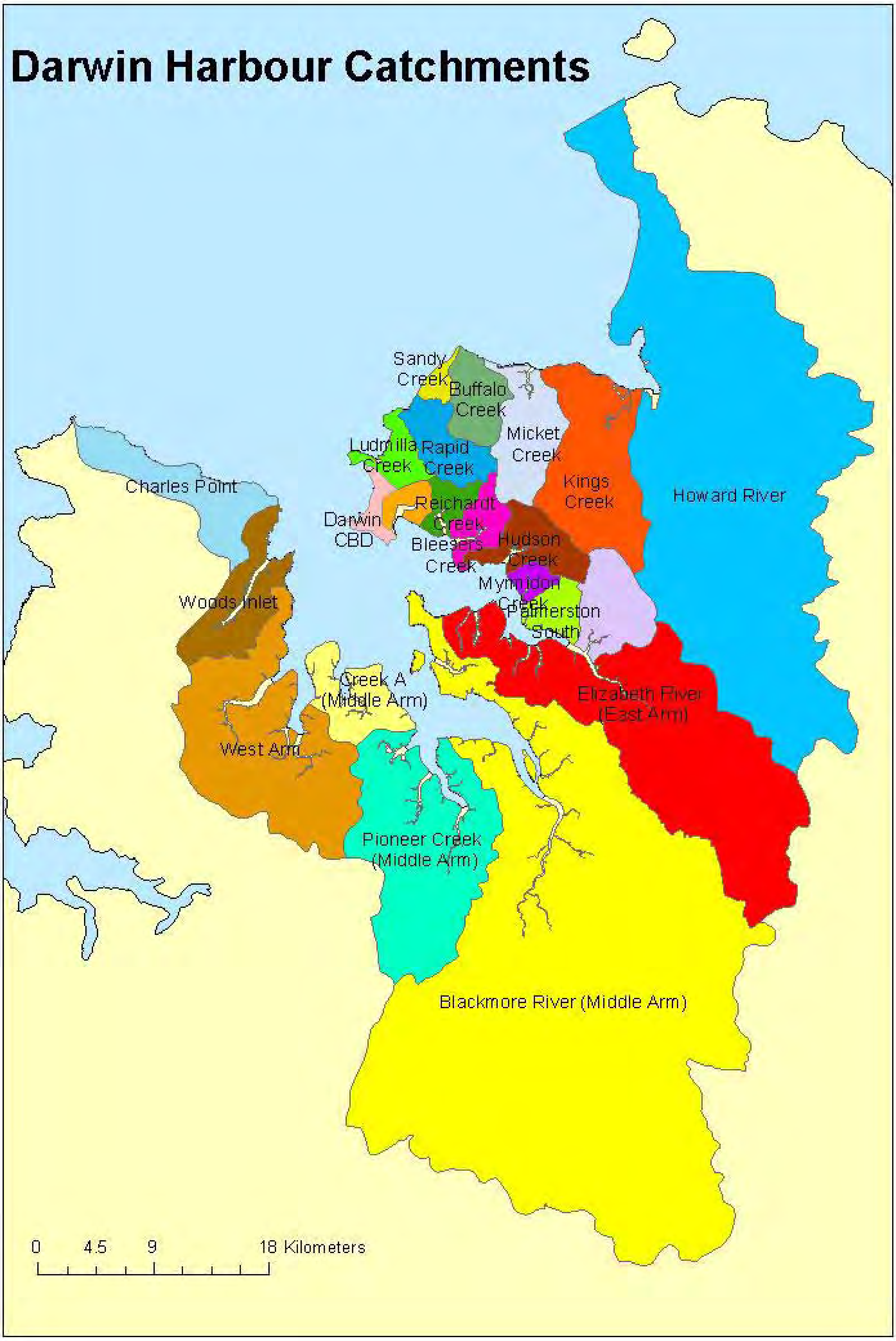

Figure 5. Sub-catchments used to calculate the total catchment loadings to Darwin Harbour.

The ACLUMP land-use classifications in Appendix 4 were used to determine the urban and non-urban areas in each sub-catchment (Table 9). The larger sub-catchments such as the Blackmore, Howard and Elizabeth, are predominantly non-urban. By contrast, the smaller sub-catchments such as those around central Darwin are predominantly urban.

Table 9. Land-use classifications for each Darwin Harbour sub-catchment

Darwin Harbour sub-catchment	Catchment area (ha)		
	Non-urban (Level 1 & 2)	Urban (Level 3)	Total
Blackmore *	60930	2541	63471
Bleeser	612	558	1170
Buffalo	728	1894	2623
Charles Point	4007	1283	5291
Creek A (middle arm)	1272	0	1272
Darwin CBD	226	572	797
Elizabeth East Arm	21476	1395	22871
Howard	50277	3887	54163
Hudson	1203	1209	2412
Kings	5661	3529	9190
Micket	3169	1235	4405
Mitchell	3236	574	3811
Myrmidon	209	129	338
Palmerston Sth	735	362	1097
Pioneer Ck Middle Arm	12309	75	12384
Rapid	583	2190	2773
Reichardt	366	371	737
Sadgroves	579	386	965
Sandy	139	363	501
West arm	12784	363	13147
Woods Inlet	2522	720	3242
Total **	183023	23636	206659
Percentage of total	89%	11%	

* The Blackmore River catchment area excludes the catchment of Darwin River Dam because water from the reservoir is diverted to supply Darwin, Palmerston and the rural area with potable water, though in some high rainfall wet seasons the dam overflows.
** Computation of the catchment areas by this method produced a total area of 2059 km^2, marginally higher but not significantly different from the area computed by DHAC (2003) of 2010 km^2.

4.1 Catchment loads

To calculate the catchment loads for a particular rainfall year from each sub-catchment (Figure 5) the following steps were taken:

1. Calculation of the average export coefficient for urban and non-urban catchments and standardise for rainfall.
2. Computation of the urban and non-urban areas for each sub-catchment.
3. Multiply the non-urban and urban areas for each sub-catchment by the relevant rainfall standardised export coefficient (explained below) by the rainfall for the nominated wet season.
4. Sum the sub-catchment loads for urban and non-urban areas to give a total catchment load.

4.2 Rainfall standardised export coefficients

The standardised rainfall export coefficient is a useful tool when examining the predicted export loads from the catchments during wet seasons of substantially different rainfall. By standardising the coefficient, we are seeking to decrease the variability of export coefficients attributable to rainfall in order to better determine the export coefficient associated with land-use.

The rainfall standardised export coefficient is calculated by dividing the export coefficient by the annual rainfall (September to August). For example, the Karama rainfall standardised export coefficient for phosphorus in 1990/01 was calculated by dividing the 1990/91 phosphorus export coefficient (0.70 kg/ha) by the 1990/91 Karama rainfall (2.29 m). This gives a rainfall standardised export coefficient of 0.304 kg/ha/m. Rainfall data was provided by the Bureau of Meteorology and NRETA (Table 10). Appendix 6 presents the rainfall standardised export coefficients for each pollutant for each year of data for hydrographic station's catchment.

Table 10. Rainfall data used for each catchment to calculate rainfall standardised export coefficient.

Catchment	Station
Karama	NRETA Karama (RN14227)
Manton	Darwin River Dam (RN14183)
Moil	Darwin Airport (RN14015)
Berry	Territory Wildlife Park (RN14264)
Howard	McMinns Lagoon (RN14219)
Elizabeth	Noonamah/Elizabeth Valley (RN14080/14222)
Peel	NRETA Hydrographic station data (G8150321)
Bennett	NRETA Hydrographic station data (G8150322)
Celia	Darwin River Dam (RN14183)

The rainfall standardised export coefficients presented in Appendix 6 were used to calculate an average rainfall standardised export coefficient, for urban and non-urban catchments (Table 11).

Table 11. Average rainfall standardised export coefficients (mass/area/rainfall) for urban and non-urban catchments, and the difference between exports coefficients.

Pollutant	Catchment classification		
	Non-urban	Urban	Difference between non-urban and urban
TN (kg/ha/m)	1.65	5.50	3x
TP (kg/ha/m)	0.0608	0.592	10x
Al (g/ha/m)	1978	30600	15x
As (g/ha/m)	1.14	5.80	5x
Cd (g/ha/m)	0.445	1.13	3x
Cr (g/ha/m)	4.11	23.6	6x
Cu (g/ha/m)	7.29	135	19x
Ni (g/ha/m)	2.29	7.23	3x
Pb (g/ha/m)	2.15	151	70x
Zn (g/ha/m)	35.1	445	13x
TSS (kg/ha/m)	57.6	444	8x
VSS (kg/ha/m)	17.1	98.1	6x

The rainfall standardised export coefficients in Table 11 were used to calculate pollutant loads for wet seasons of high, low and typical rainfall. The rainfall standardised export coefficients were compared with the measured export coefficients to test their predictive capacity.

Predicted export coefficients differed by up to a factor of 2 compared with the measured export coefficients. The deviations both over-estimated and under-estimated measured export coefficients, however there was no systematic bias. Given the almost order of magnitude difference between urban and non-urban export coefficients, the error associated with the rainfall standardised export coefficients is acceptable.

4.3 Load calculations

The following equation was applied to each sub-catchment to determine its load:

Catchment load = [Urban area × EX(urban) + non-urban area × EX(non-urban)] × wet season rainfall.

Where: EX(urban) = urban rainfall standardised export coefficient
EX(non-urban) = non- urban rainfall standardised export coefficient

Catchment pollutant loads for a wet season of typical rainfall year (1.67m in 2006/07) across Darwin Harbour are shown in Table 12, whilst low and high rainfall wet season loads are shown in Appendices 7 and 8. Corresponding sub-catchment sediment and nutrient load contribution maps for a typical wet season are also shown in Appendix 9.

Table 12. 'Business as usual' - pollutant loads into Darwin Harbour in a typical wet season rainfall (1.67m), 2006/07.

Catchment	N	P	Al	As	Cd	Cr	Cu	Ni	Pb	Zn	TSS	VSS
	tonnes	tonnes	tonnes	kg	kg	kg	kg	kg	kg	kg	tonnes	tonnes
Blackmore	191	8.70	331	140	50.0	518	1310	263	858	5460	7740	2160
Bleeser	6.82	0.610	30.5	6.56	1.51	26.2	133	9.08	143	451	473	109
Buffalo	19.4	1.95	99.2	19.7	4.11	79.6	436	25.7	479	1450	1470	331
Charles Point	22.8	1.68	78.8	20.0	5.40	78.1	338	30.8	337	1190	1340	325
Creek A (Middle Arm)	3.51	0.130	4.20	2.41	0.940	8.73	15.5	4.86	4.58	74.6	122	36.4
Darwin CBD	5.87	0.590	30.0	5.96	1.25	24.1	132	7.77	145	438	446	100.0
Elizabeth East Arm	72.0	3.56	142	54.2	18.6	202	576	98.8	428	2300	3100	843
Howard	174	8.95	365	133	44.7	498	1490	239	1160	5840	7720	2070
Hudson	14.4	1.32	65.8	14.0	3.17	55.9	287	19.2	308	969	1010	232
Kings	48.0	4.07	199	44.9	10.90	178	864	64.2	908	2950	3160	740
Micket	20.1	1.54	73.6	18.0	4.68	70.4	317	27.0	322	1100	1220	293
Mitchell	14.2	0.90	40.0	11.7	3.49	44.8	169	19.3	156	616	737	187
Myrmidon	1.76	0.150	7.28	1.64	0.400	6.51	31.6	2.35	33.2	108	116	27.1
Palmerston Sth	5.36	0.430	20.9	4.90	1.23	19.3	90.6	7.18	93.7	312	339	80.4
Pioneer Ck Middle Arm	34.6	1.32	44.5	24.1	9.28	87.4	167	47.9	63.1	778	1240	364
Rapid	21.7	2.23	114.0	22.3	4.56	90.3	501	28.7	553	1660	1680	375
Reichardt	4.42	0.400	20.2	4.29	0.97	17.1	88.1	5.88	94.6	297	310	71.3
Sadgroves	5.14	0.440	21.6	4.83	1.16	19.2	94.0	6.87	99.1	321	342	79.8
Sandy	3.71	0.370	19.0	3.77	0.79	15.2	83.4	4.91	91.7	278	282	63.4
West Arm	38.6	1.66	60.8	27.8	10.20	102.0	237	53.2	137	1020	1500	425
Woods Inlet	13.6	0.970	45.2	11.8	3.23	45.7	193	18.3	190	683	777	190
Total	722	42.0	1810	576	180	2190	7560	984	6600	28300	35100	9110

4.3.1 Diffuse load contribution from the Darwin region catchment

Although the Blackmore and Howard River catchments are predominantly undeveloped, and have low export coefficients, their sheer size means they contribute the greatest proportion of the overall pollutant load. By contrast, the Darwin CBD has a higher export coefficient but is a small catchment (0.39% of the catchment), and contributes between 1 and 2% of the total pollutant loads.

Pollutant loads were calculated for three rainfall scenarios across the Darwin Harbour catchment. The first was a typical wet season, based on an average rainfall at Darwin Airport between 1941 and 2008 of 1.7m. It is noteworthy that the 2006/07 wet season had a rainfall total of 1.67 m, close to the long term average rainfall. Low rainfall (1.0 m) and high rainfall (2.7 m) wet seasons, which approximate extreme annual rainfall totals, were also calculated. Pollutant loads to Darwin Harbour for the three rainfall scenarios are presented in Table 13. Loads from individual catchments are presented in Appendices 7 and 8, and Table 12.

Table 13. Predicted pollutant loads entering Darwin Harbour during below average, average and above average wet season rainfall. Rainfall was assumed to be the same over the catchment.

Year	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
Al (t)	757	1810	2900
As (kg)	364	576	921
Cd (kg)	72.6	180	289
Cr (kg)	1030	2190	3500
Cu (kg)	4580	7560	12100
Ni (g)	572	984	1570
Pb (kg)	3950	6600	10600
Zn (kg)	16100	28300	45200
TSS (t)	20500	35100	56200
VSS (t)	5440	9110	14600

The predicted annual pollutant loads entering Darwin Harbour (Table 13) are directly proportional to the annual rainfall due to the methodology employed. The values give an indication of the pollutant loads that could be expected in years of different rainfall, and the range of pollutant loads. There can be an almost three fold increase in the load of pollutants entering Darwin Harbour over the range of wet season rainfalls.

4.3.2 Point Source contribution to loads

As well as diffuse source pollution loads, point source loads enter Darwin Harbour, mainly from wastewater treatment plants (Figure 6). The estimation of loads from wastewater treatment plants was based on available discharge data and pollutant concentrations collected at licensed discharge points (Power Water Corporation 2006).

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 total land based diffuse and point source loads for phosphorus from wastewater treatment plants (Table 14). A substantial proportion of nitrogen entering Darwin Harbour, where algal growth is most likely to be nitrogen limited, is also from wastewater discharge. Nitrogen load from wastewater treatment plant data was estimated to contribute up to 31% of the estimated land based annual load to the Harbour.

Table 14. 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	**VSS**	**N**	**P**
Berrimah	25	23	4	1.4
Larrakeyah	275	253	58	12
Leanyer/Sanderson	717	599	79	43
Ludmilla	482	332	112	28
Palmerston	181	170	69	18
Wastewater contribution to loads	1680	1377	321	102
Treated Wastewater (% of grand total)	***5***	***13***	***31***	***71***
Urban (Diffuse)	17528	3871	217	23
Rural (Diffuse)*	17595	5236	505	19
Catchment contribution to loads	35123	9107	722	42.0
Catchment (% of grand total)	***95***	***87***	***69***	***29***
Grand Total	**36803**	**10487**	**1043**	**144**

*Rural category = non-urban aggregation (Refer Table 9)

A doubling of the population in the region without measures for improved point source treatment and/or wastewater recycling options could result in significant increases in loads attributable to point sources.

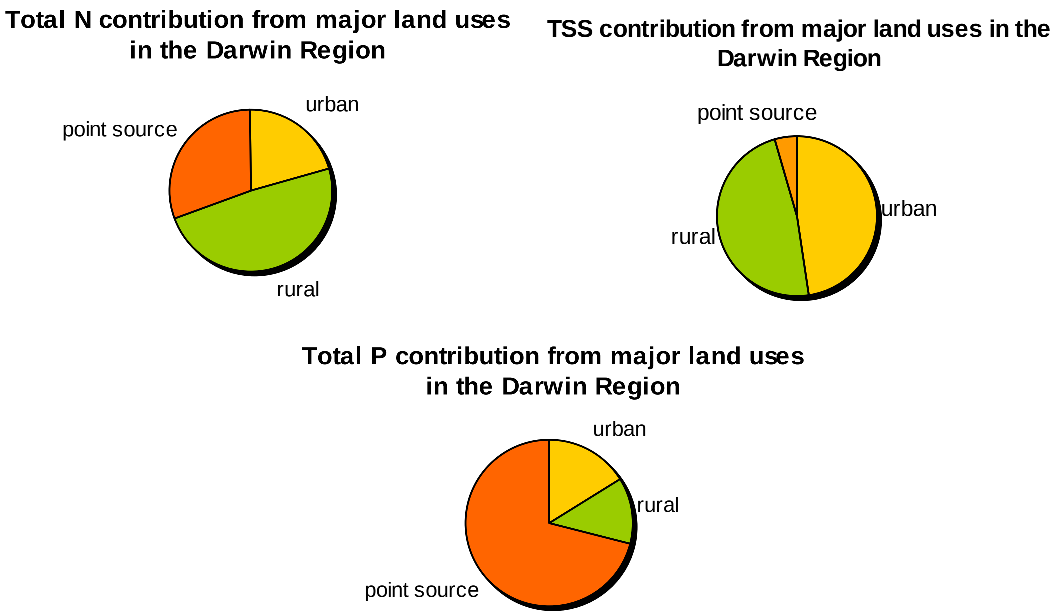

Figure 6. Relative Load Contribution from Major Land Uses.

Discharge from wastewater treatment plants in Berrimah, Leanyer and Palmerston flow into tidal creeks systems within Darwin Harbour (Figure 7). The impact of high nutrient inflows to these receiving waterways is the subject of current research under the Tropical Rivers and Coastal Knowledge consortium (TRaCK). Understanding the assimilative capacity of these ecosystems will be vital for the parameterisation of a water quality model for Darwin Harbour and assessing the fate of nutrients.

In conjunction with their wastewater discharge licenses Power and Water Corporation intend on diverting sewage from the Larrakeyah macerator to Ludmilla WWTP to undergo enhanced treatment prior to disposal at East Point. Demand management, effluent reuse, recycling and higher treatment technologies are being considered as part of a suite of strategies to reduce pollutant loads to the harbour in the future.

4.4 Conclusion

Diffuse source loads to the Harbour increase with wet season rainfall, with the higher proportion of the loads contributed from the Blackmore and Howard Rivers. This is a function of the large areas that these two catchments encompass. Urban areas, although representing only a small proportion of the total catchment, contributed a disproportionately high diffuse pollutant load to Darwin Harbour. Diffuse source sediment loads were significantly greater than sediment loads from wastewater treatment plant loads. In contrast, point source inputs from wastewater treatment plant discharges contributed a relatively high proportion of the nitrogen and phosphorus loads to Darwin Harbour. This analysis has not considered other non-licensed point source discharges. Further research is required to quantify these.

Figure 7. Location of wastewater treatment plants discharging to Darwin Harbour.

Section 5. Scenarios and Analysis

The population of the Darwin region in 2006 was 120,900, with current projections by Australian Bureau of Statistics of the region's population to be between 126,500 and 184,500 by 2021. Further projections have predicted the population of Darwin to increase to 335,000 by 2056 (Australian Bureau of Statistics, 2006). To accommodate this growth, new areas for urban and industrial land-use are planned. This section of the report makes an assessment on the impact of some of the proposed developments planned in the catchment to the pollutant loads entering Darwin Harbour. It looks at the short term impact of pending developments that are currently planned or under construction. It will then investigate the impact of land-use changes proposed in the Northern Territory Government's planning scheme. Underlying the scenario predictions is the assumption that the export coefficients developed thus far are applicable to future land-uses – that is a 'business-as-usual' scenario. This may not be the case if diffuse urban pollutant reduction measures and management practices are effective in reducing urban pollutant loads.

Simulated diffuse loads for a range of scenarios have been undertaken (Table 15). All scenarios assume a change in land use from rural or undisturbed to urban type land uses. The application of these scenarios was undertaken without regard to point source pollutant loads. It is likely that for scenario 4, which projects extensive development in the southern area of the Darwin Harbour catchment, would necessitate additional wastewater treatment plants to accommodate population demands.

Table 15. Description of Model Scenarios.

Scenario	Description	Estimated Population (year)	Estimated Population	Area (ha)
1	Lyons-Muirhead developments (Buffalo Creek subcatchment, see Figure 8)	Current	120,900	155.6
2	Bellamack-Rosebery developments (Mitchell subcatchment, see Figure 8)	2010	126,500	160
3	Lyons-Muirhead & Bellamack-Rosebery developments (Scenario 1+ 2)	2015	184,200	315.60
4	Future Development (Middle Arm development, Figure 9)	2050	335,000	25,365

5.0 Pending developments

5.1 Lyons, Muirhead and Bellamack/Rosebery

The Lyons and Muirhead developments are located in the northern suburban precinct of Darwin in the Lee Point area in the Buffalo Creek catchment (Figure 8). The Lyons development is a joint venture between the Defence Housing Authority and the Canberra Investment Corporation Ltd. The proposed 690 dwelling development is currently under construction. For the purpose of this scenario, it is assumed that there will be an additional 40 ha of development.

Figure 8. Lyons, Muirhead, Bellamack and Rosebery developments.

In 2006 the Defence Housing Authority purchased 152.6 ha of land adjacent to the Lyons development for residential development in the next five to ten years and is now called Muirhead. Muirhead has potential for 1000 new residential dwellings. There are still negotiations regarding the extent of development that will take place. For the purpose of this scenario it is assumed that 75% of the area (115 ha) will be developed.

For the purpose of this report, the Muirhead and Lyons developments will be combined and treated as one development of 155.6 ha. The Lyons and Muirhead sites are described by the ACLUMP data as Defence Land prior to development. Defence land is classified as Level 2 development (see Appendix 4), placing them in the non-urban classification.

Another development is the Bellamack/Rosebery suburbs that are either planned to, or in the process now, of actually extending the Palmerston (Figure 7) urban footprint. Palmerston has been the mainstay of Darwin's suburban growth over the last 15 years. The 160 ha development site is currently described by the ACLUMP data as Remnant Native cover, and hence the area forms a non-urban catchment classification. The proposed development is urban residential with parks and open space, a shopping village and a community hub which will change the classification to urban. The development is in the Mitchell Creek catchment.

To estimate the increase in pollutant loads from the urban development, projected pollutant loads were calculated, first calculating the non-urban loads, and then using the urban export coefficients with the latter as a 'business-as-usual' estimate. This will not be the case, however, for the Bellamack suburb because the suburban design incorporates "water sensitive urban design" principles which will reduce pollutant export coefficients.

The increase in diffuse pollutant loads for scenarios 1-2 (Tables 16 and 17), expressed as a percentage, approximated TSS load increases of up to 7% from the Buffalo Creek subcatchment, and 14% from the Mitchell sub-catchment. The average increase in diffuse TSS loads for the combined proposed developments to Darwin Harbour is approximately 8% (Table 18).

The predicted percentage increase in diffuse nutrient loads for the combined developments of Lyons-Muirhead and Bellamack-Rosebery could see a 6% increase in TN and a 9% increase for TP. These increases are a function of the area of urban development, relative to the total sub-catchment area, as well as the effect of urbanisation on pollutant loads.

The additional loads attributable to the proposed Bellamack subdivision could be effectively reduced with the implementation of water sensitive urban design strategies.

Table 16. Predicted diffuse pollutant loads from the Darwin Harbour Buffalo Creek sub-catchment resulting from the proposed Lyons and Muirhead developments (assuming average rainfall).

Pollutant	Scenario 1		
	Pre development	Post development	Percentage increase
TN (t)	19.4	20.4	5%
TP (t)	1.95	2.09	7%
Al (t)	99.2	107	8%
As (kg)	19.7	20.9	6%
Cd (kg)	4.11	4.29	4%
Cr (kg)	79.6	84.6	6%
Cu (kg)	436	469	8%
Ni (kg)	25.7	27.0	5%
Pb (kg)	479	517	8%
Zn (kg)	1450	1560	8%
TSS (t)	1470	1570	7%
VSS (t)	331	352	6%

Table 17. Predicted diffuse pollutant loads from the Darwin Harbour Mitchell sub-catchment resulting from the proposed Bellamack and Rosebery developments (assuming average rainfall).

Pollutant	Scenario 2		
	Pre development	Post development	Percentage increase
TN (t)	14.2	15.2	7%
TP (t)	0.90	1.04	16%
Al (t)	40.0	48	20%
As (kg)	11.7	12.9	10%
Cd (kg)	3.49	3.67	5%
Cr (kg)	44.8	50.0	12%
Cu (kg)	169	203	20%
Ni (kg)	19.3	20.6	7%
Pb (kg)	156	196	26%
Zn (kg)	616	725	18%
TSS (t)	737	840	14%
VSS (t)	187	209	12%

Table 18. Predicted diffuse pollutant loads from combined Mitchell and Buffalo Creek subcatchments for proposed Muirhead-Lyons and Bellamack-Rosebery developments (assuming average rainfall).

Pollutant	Scenario 3		
	Pre development	Post developments	Percentage increase
TN (t)	33.6	35.6	6%
TP (t)	2.85	3.13	9%
Al (t)	139.2	155	10%
As (kg)	31.4	33.8	7%
Cd (kg)	7.6	7.96	5%
Cr (kg)	124.4	135	8%
Cu (kg)	605	672	10%
Ni (kg)	45	47.6	5%
Pb (kg)	635	713	11%
Zn (kg)	2066	2,285	10%
TSS (t)	2207	2,410	8%
VSS (t)	518	561	8%

5.2 Long-term planned developments

The current population of the Darwin Harbour region is projected to double by 2050. An area of 25,365 ha is currently planned for urban development in catchments of Middle Arm (Figure 9) and includes the proposed City of Weddell. The current urban area of Darwin city is approximately 11,200 ha and Palmerston City is approximately 5,500 ha.

Glyde Point on the upper eastern border of the harbour catchment has been included in the longer term development scenario. However, the light industrial development of this area will now take place in Middle Arm.

Under this scenario, the urban development of 25,365 ha will significantly increase pollutant loads entering Darwin Harbour using business-as-usual projections. For diffuse sources it is predicted that total nitrogen and phosphorus loads would increase by 233% and 877% respectively for this area, with total and volatile suspended solid loads increasing by 670% and 472% respectively. The metal load increases range from 154% for cadmium through to approximately 6800% for lead (Table 19). In addition to the projected catchment load, increased point source pollutant loads are likely in order to accommodate the increasing needs of a growing population. Once again, it is anticipated that overall best practice urban water design and planning, inclusive of effluent reuse, could result in significant mitigation of the projected load increases.

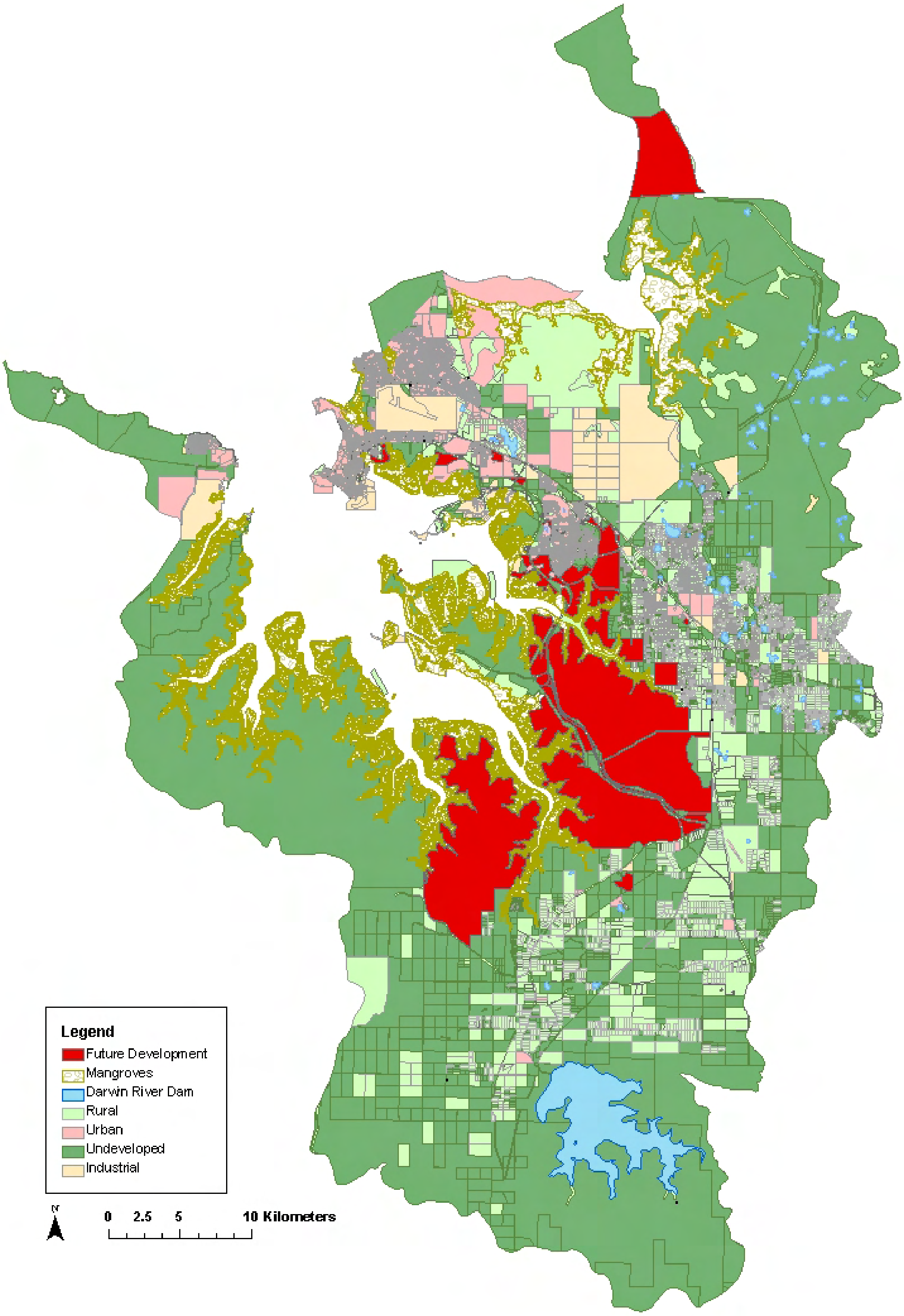

Figure 9. Current planning zones for the Darwin Region. Source: NTG Integrated Land Information System (ILIS).

Table 19. Predicted diffuse pollutant loads resulting from the proposed 25,365 ha urban land-use (Middle Arm) in Darwin Harbour catchment (assuming the average rainfall).

Pollutant	Scenario 4		
	Pre development	Post development	Percentage increase
TN (t)	69.9	233	233%
TP (t)	2.57	25.1	877%
Al (t)	83.8	1300	1451%
As (kg)	48.1	246	411%
Cd (kg)	18.8	47.8	154%
Cr (kg)	174	999	474%
Cu (kg)	309	5720	1751%
Ni (kg)	96.8	306	216%
Pb (kg)	91.3	6380	6888%
Zn (kg)	1490	18800	1162%
TSS (t)	2440	18800	670%
VSS (t)	726	4150	472%

Table 20. Predicted increase in diffuse pollutant loads from all projected developments for the entire Darwin Harbour region (assuming the average rainfall).

Pollutant	Current Loads	Projected Loads	Percentage increase
TN (t)	722	991	37%
TP (t)	42	70	67%
Al (t)	1810	3262	80%
As (kg)	576	855	48%
Cd (kg)	180	236	31%
Cr (kg)	2190	3324	52%
Cu (kg)	7560	13948	84%
Ni (kg)	984	1338	36%
Pb (kg)	6600	13691	107%
Zn (kg)	28300	49430	75%
TSS (t)	35100	56319	60%
VSS (t)	9110	13825	52%

Scenario 4 assumes the development of a substantive area of Middle Arm. Estimated loads attributable to the projected development of the 25,365 ha area could result in substantial increases in loads. Comparison of current loads with those of the combined scenarios 3 and 4 (Table 20) indicate increases of up to 107% for some pollutants (Figures 10-16). Assuming the development of subdivisions Lyons, Bellamack and Middle Arm, annual loads could result in increases of up to 37% in TN, 67% for TP and 60% of TSS.

Figure 10 indicates increases in total loads for metals and TSS for current and projected development scenarios. Scenario 4 indicates a greater departure from current diffuse loads for the metals of Cu, Pb, Zn and TSS/VSS (Figure 10, 15 and 16). However, loads estimated for scenario 3 do not illustrate a large departure from current annual loads or 'business as usual', particularly for TN and TP.

The implementation of WSUD type principles could effectively reduce loads for Scenario 3 to those akin to current condition. However estimates predict that Scenario 4 and the cumulative effect of all proposed developments would continue to exceed current load conditions in the absence of mitigation actions.

It has been demonstrated that through water sensitive urban design that load reductions of up to 80% for TSS, 60% of TP and 45% of TN are possible (EDAW 2007). Should future developments embrace these urban design principles, diffuse nutrient loads could be adequately ameliorated. However the assumption of load reduction for WSUD in the wet/dry tropics needs to be validated by further research.

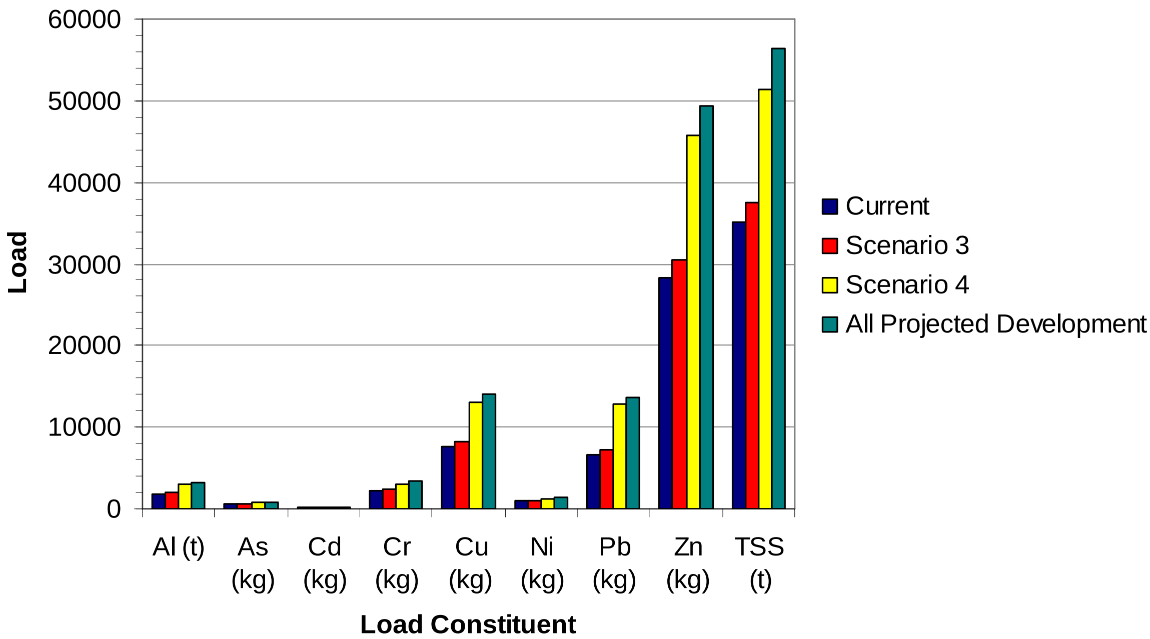

Figure 10. Comparison of current annual catchment loads to those of scenarios for future development for metals and suspended sediment.

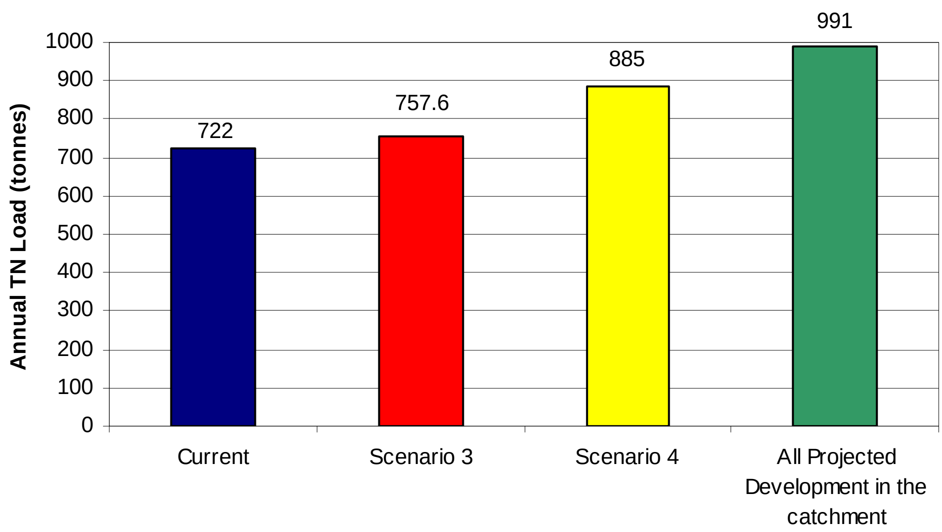

Figure 11. TN loads for Scenarios versus current loads.

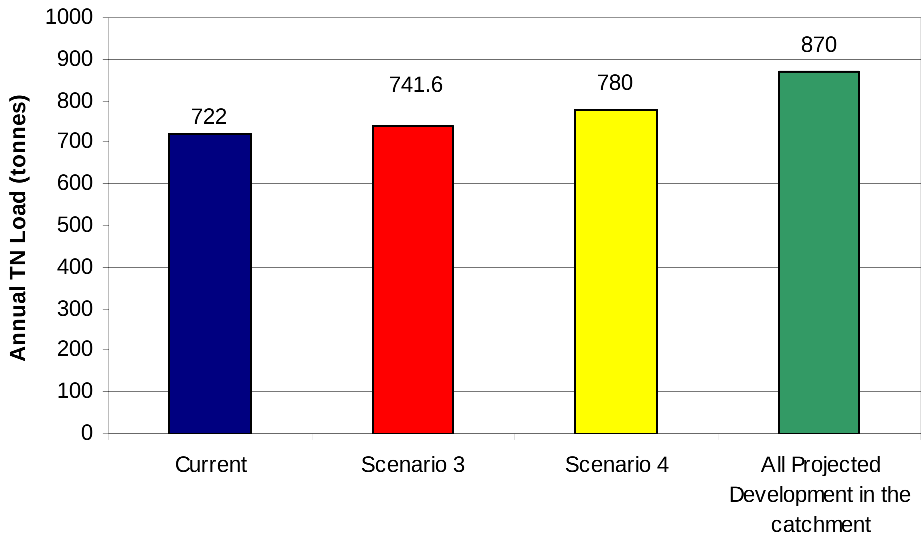

Figure 12. Resultant TN loads with the implementation of WSUD.

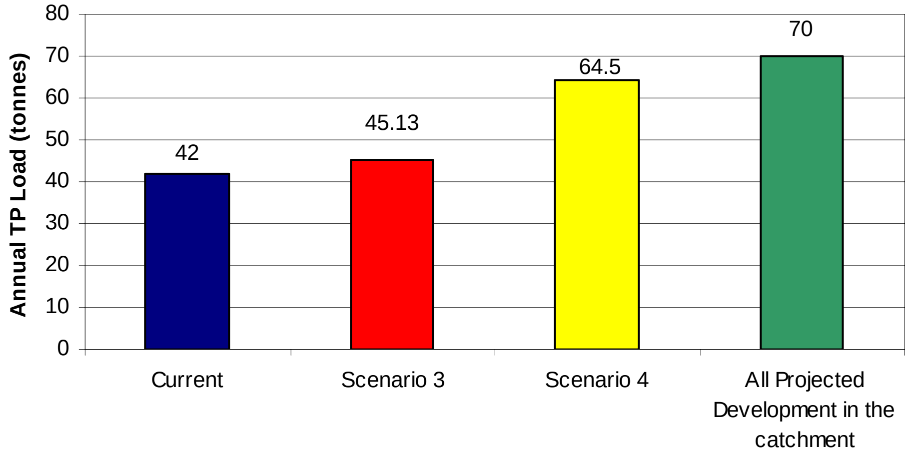

Figure 13. TP loads for Scenarios versus current loads.

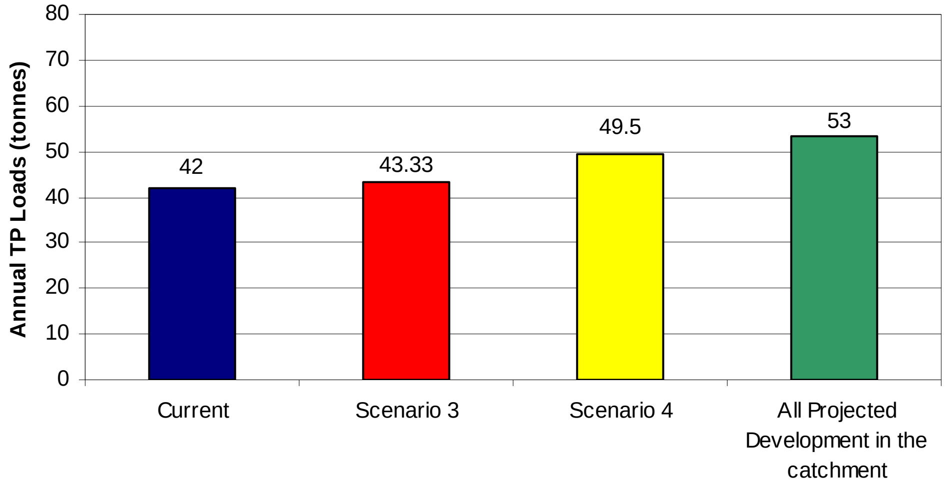

Figure 14. Resultant TP loads with the implementation of WSUD.

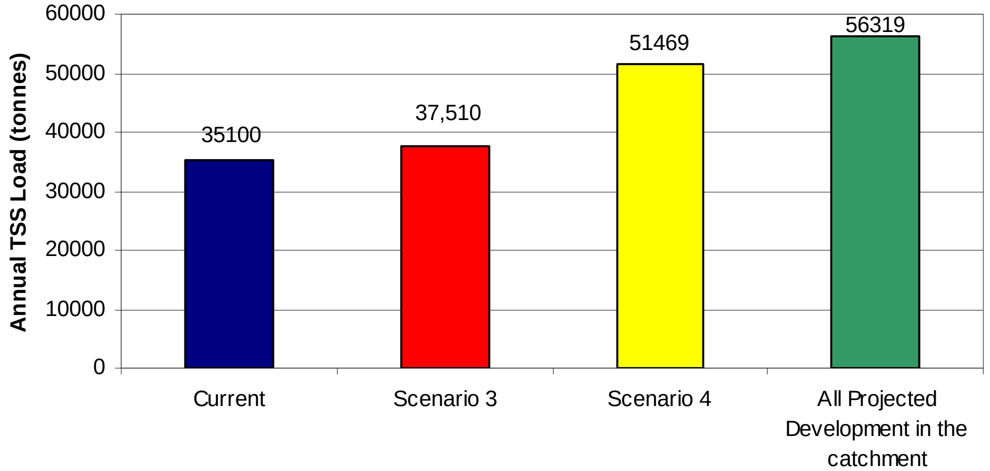

Figure 15. TSS loads for Scenarios versus current loads.

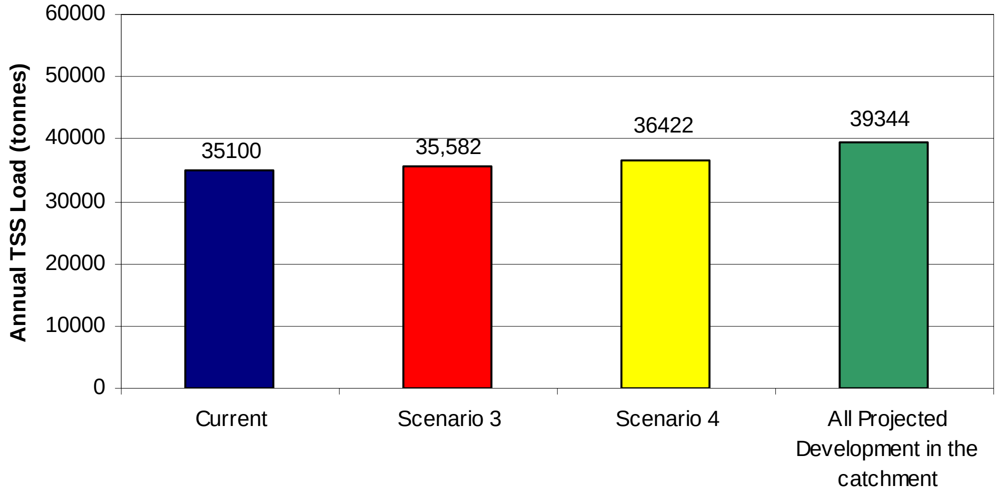

Figure 16. Resultant TSS Loads with the implementation of WSUD.

5.3 Certainty of Predictions

The empirical model used to determine load estimates are based on simple, time based, flow and pollutant concentrations. The following general assumptions and limitations should be noted:

- Given the "lumped" nature of land uses, it provides a limited degree of spatial resolution. Due to this aggregation it is likely that for highly developed catchments such as Winnellie that estimated loads could be under estimated.

- Modelled scenarios provide a preliminary total maximum load for diffuse loads only. Point sources such as those from wastewater treatment plants operate under waste discharge licences. Load-based limits/targets for these discharges are yet to be evaluated. However, such an option might be considered suitable as one of a number of possible management strategies to maintain pollutant load targets.

- Current or 'business as usual' loads have been estimated based on an average rainfall year. It has been demonstrated that variation of inter annual rainfall can have significant bearing on annual loads. Consequently rainfall has been utilised to standardise export rates from catchments during wet seasons of substantially different rainfall.

- On the completion of the Darwin Harbour Receiving Water Quality Model (DHRWQM), an evaluation of pollutant load targets to achieve water quality objectives will be undertaken. It is anticipated that pollutant load targets will be developed in conjunction with the model and data from this report.

Preliminary modelling of current loads suggests that the mean concentration of suspended sediment and nutrients (TN and TP) in the harbour is approximately 6mg/L and 0.2mg/L respectively (Williams, 2006). However, this initial modelling effort has assumed no settling or decay for nutrient constituents as rates are unknown. Additionally, these modelling runs (Williams, 2006) were undertaken with both TN and TP combined as arbitrary total nutrient constituents; therefore the accuracy of these values can be improved with future research. Nevertheless, preliminary values are in line with the current draft water quality objectives for the estuarine waters of Darwin Harbour.

5.4 Conclusion

The medium and long-term planned urban development for the Darwin harbour catchment will potentially increase pollutant loads entering Darwin Harbour, assuming current urban export coefficients. The increased loads for the Buffalo Creek and Mitchell Creek sub-catchments approximate 10%, and are minor on a whole of catchment scale, but maybe significant at a local scale. Longer term urban developments, again assuming current urban export coefficients, coupled with increasing population pressures and the ensuing increase in point source discharge could result in substantial increases in pollutant loads.

Section 6. Conclusion

Darwin Harbour is a unique asset for the people of Darwin. It is a complex ecosystem with extensive mangrove forests, macro-tides and diverse assemblages of flora and fauna. The water quality of aquatic systems in the region could be described as largely near pristine except where urbanisation occurs, however the harbour faces growing pressures from urban, commercial and industrial development. This will present the community with ongoing challenges in maintaining this enviable state and managing potential impact to water quality.

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 estimated from this report, in conjunction with the development of a receiving water quality model for the Darwin Harbour, will help resource management agencies to determine the fate and impact of nutrients and other pollutants in Darwin Harbour and set pollutant load targets which protect and maintain important beneficial uses. However, further research is required to understand these how nutrients are assimilated in the receiving estuary.

The annual diffuse loads for sediment and nutrients to Darwin Harbour for a typical wet season using average wet season rainfall, and export coefficients adjusted for rainfall in this report are as follows:

Pollutant	Total Annual Load (tonnes)	FWMC Urban (mg/L)*	FWMC Rural/Undisturbed (mg/L)
TN	722	0.82	0.41
TP	42	0.09	0.01
TSS	35,123	56.1	17.9

FWMC = Flow weighted Mean Concentration.
*Based on 2006-07 data for Moil Drain – Rapid Creek Catchment.

Analysis of historical data indicates that export coefficients vary with annual rainfall. There can be an almost three fold increase in the load of diffuse source pollutants entering Darwin Harbour over the range of wet season rainfalls. Variation in rainfall coupled with increased urbanisation can result in a greater proportion of pollutants entering Darwin Harbour.

Export coefficients for nutrients, metals and sediment were higher for urban catchments than undeveloped and rural catchments, assuming similar landform and geology. There was no significant difference between undeveloped and rural catchments. Consequently, these land-use classifications were aggregated as non-urban catchments.

This report has quantified land-based diffuse and point source loads from wastewater treatment plants only. Further work is required to better quantify annual variation for some diffuse and other point sources to help determine maximum pollutant load targets for the region, and harbour related impacts. The modelling in the latter section of the report has omitted all point source contributions in the simulated scenarios.

The highest loads entering Darwin Harbour were from the Blackmore and Howard Rivers due to their large catchment areas. Urban areas contributed a disproportionate pollutant load to Darwin Harbour particularly for soluble fraction nutrients such as filterable reactive phosphorus and nitrate. Diffuse source sediment loads were significantly greater than sediment 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 phosphorus contribution.

Proposed future developments in the catchment have the potential to greatly increase catchment loads to the Harbour. The longer term scenario presented in this report assumes the development of Middle Arm. This projected setting would see land straddling the Elizabeth and Blackmore Estuaries developed with a range of urban and commercial estates. The cumulative effect of all proposed future developments, based on an average rainfall year, could result in total nitrogen and phosphorus loads increasing by 37% and 67% respectively, and total and volatile suspended solid loads increasing by 60% and 52% respectively. The projected annual metal loads could result in increases which range from 31% for cadmium and 36% for nickel through to 107% for lead.

Not included in this forecast are the additional loads attributable to a number of point sources inevitably required to support increasing population demands. A doubling of the population could result in a substantial increase in annual nutrient loads. Consequently point source contribution of phosphorus from wastewater treatment plants could assume up to 80% of the estimated annual load and up to 50% of nitrogen load to Darwin Harbour. Future diffuse loads coupled with point source contribution are likely to be greater, and may have significant impact at a local scale.

On a whole of harbour scale, it is unlikely that increases in human impacts, such as sewage and river inputs, will substantially affect biogeochemical processes in the short term, given loads are relatively minor compared with oceanic input. However, current research suggests that the effects of point and diffuse sources of nutrients may be significant at more local scales such as in tidal creeks or the upper reaches of the estuary where point source nutrients are discharged.

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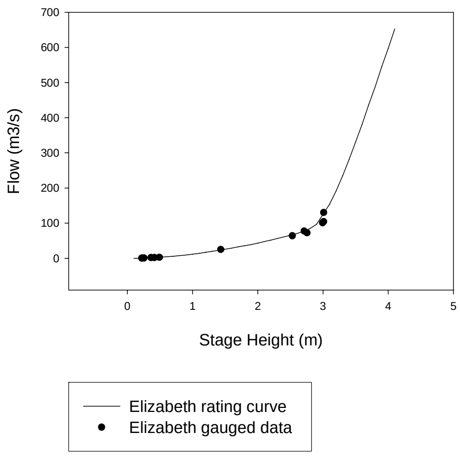
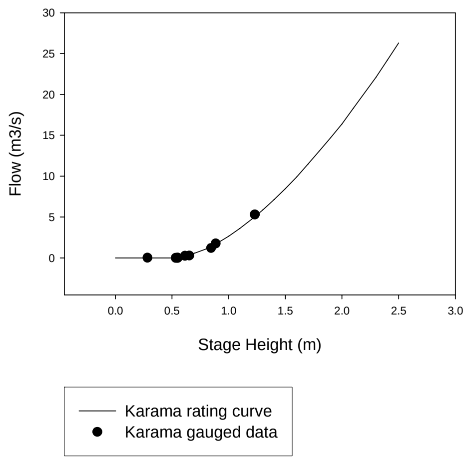
Appendices

Appendix 1: Comparison of gauged flows (filled circles) and rating table (line).

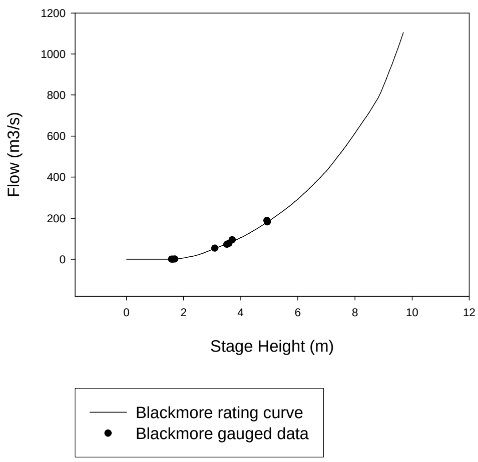
Elizabeth River Catchment



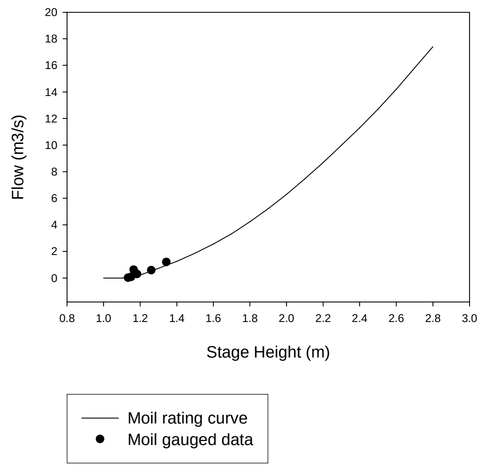
Karama Drain Catchment



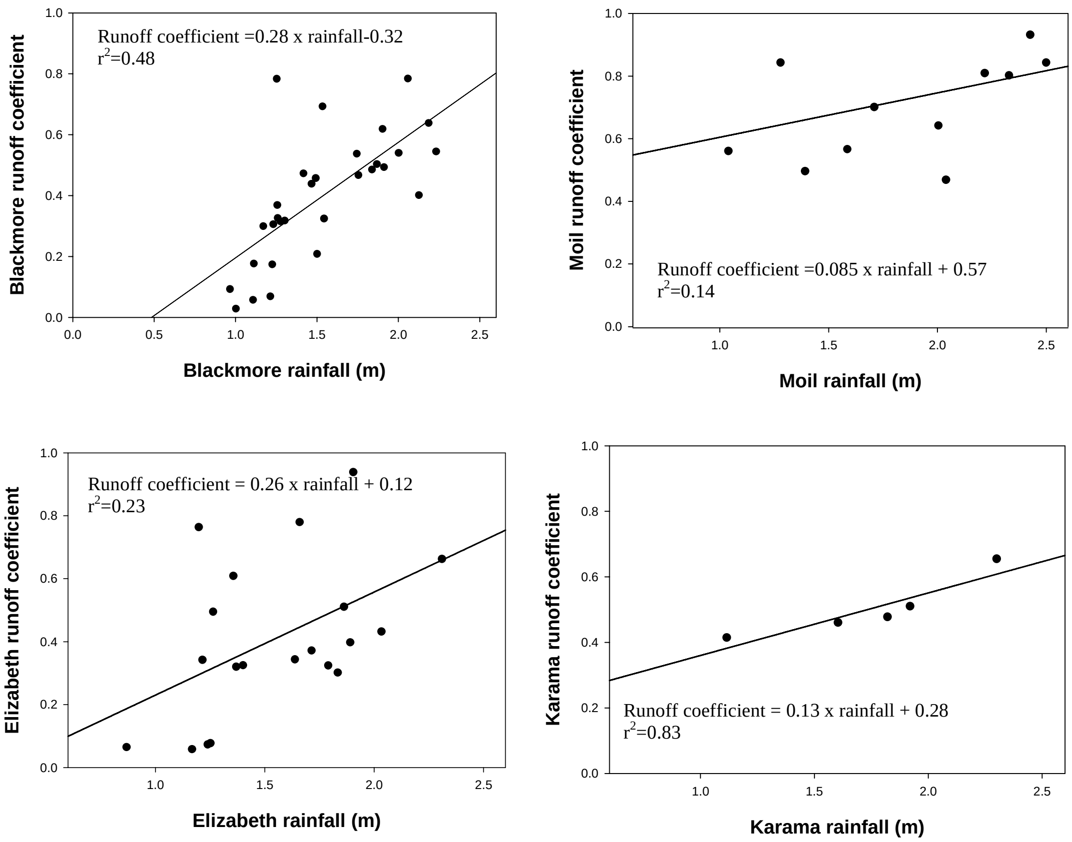
Blackmore River Catchment



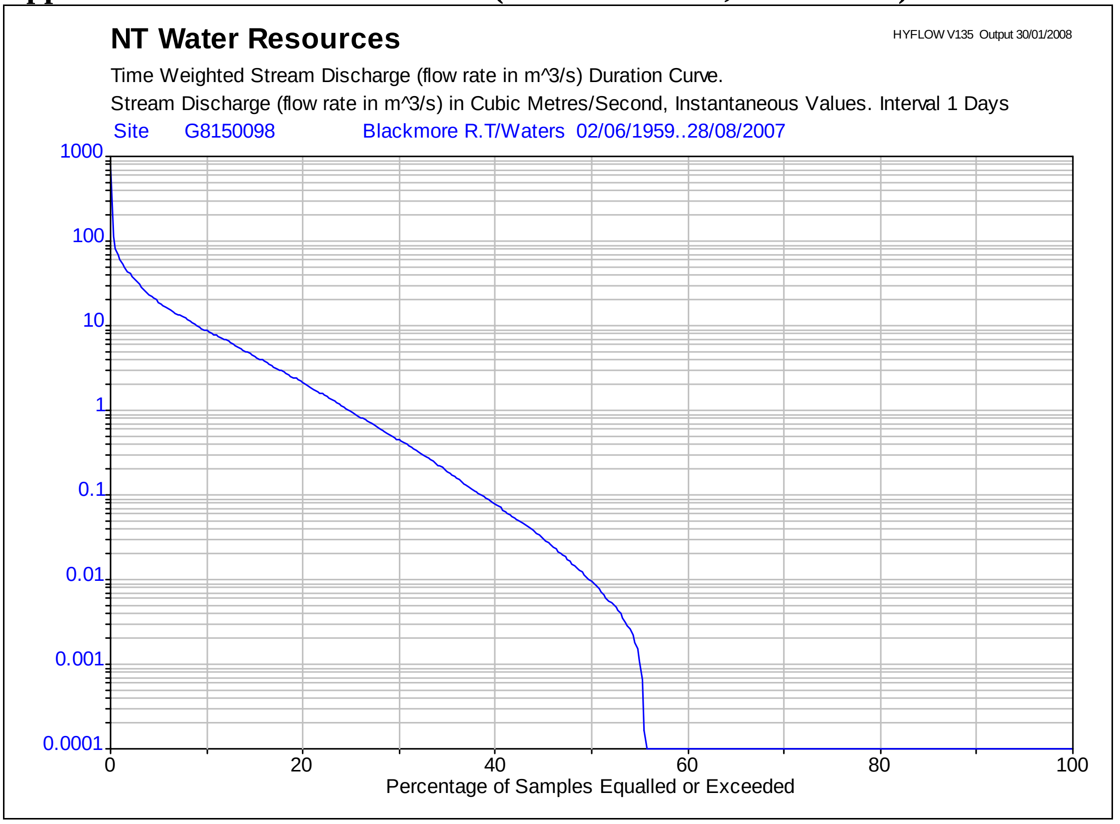
Moil Drain Catchment



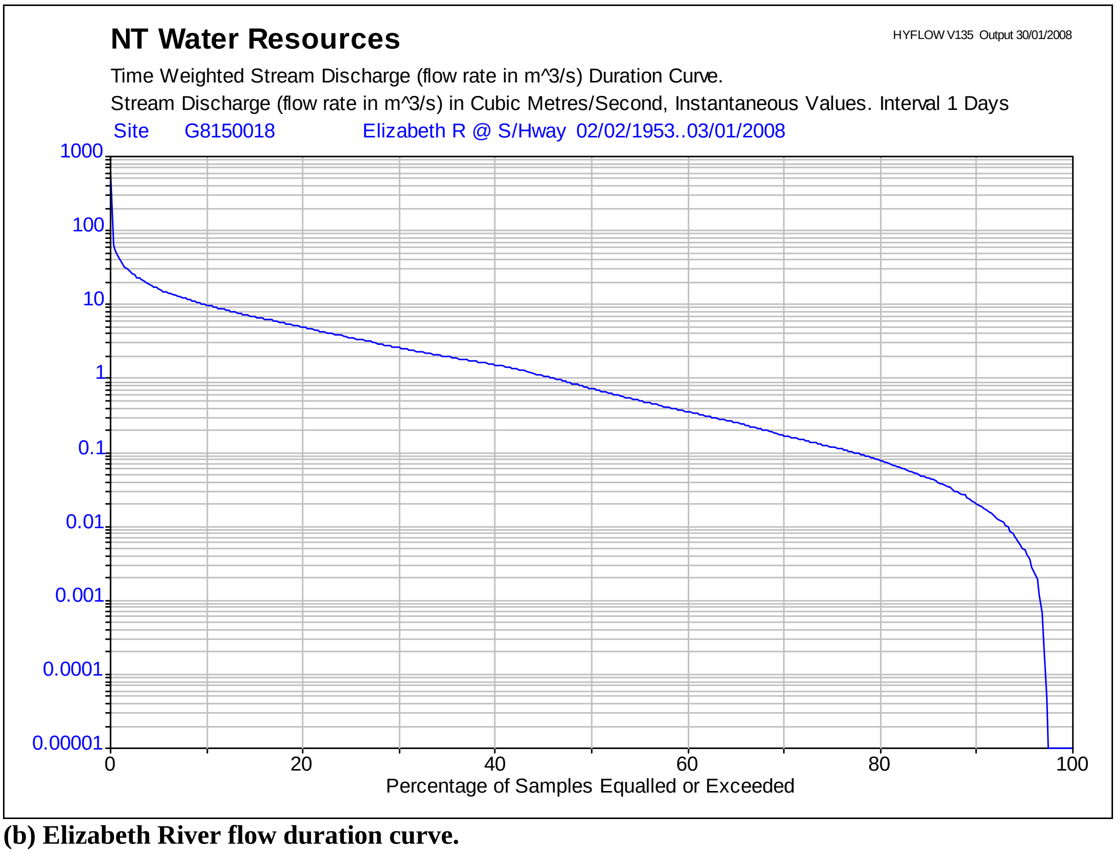
Regression plots of runoff coefficient versus rainfall based on total annual runoff and rainfall data.



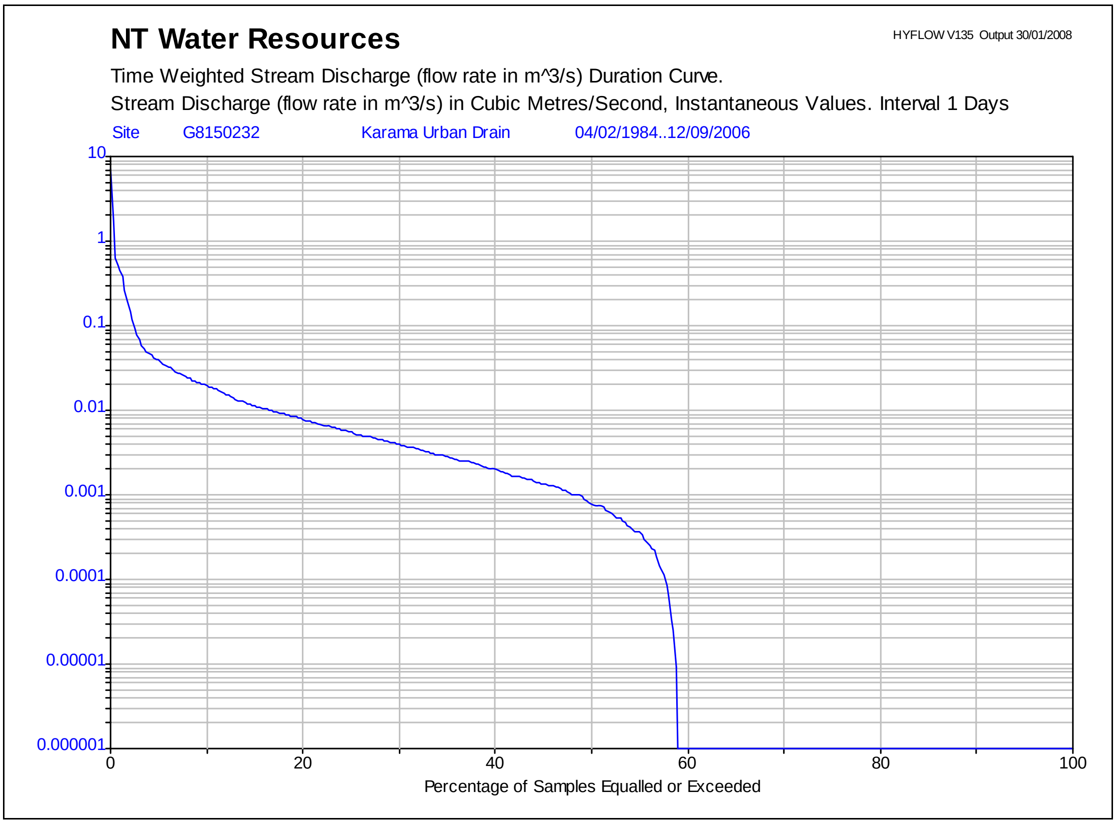
Appendix 2: Flow Duration Curves (source: NRETA; HYDSTRA).



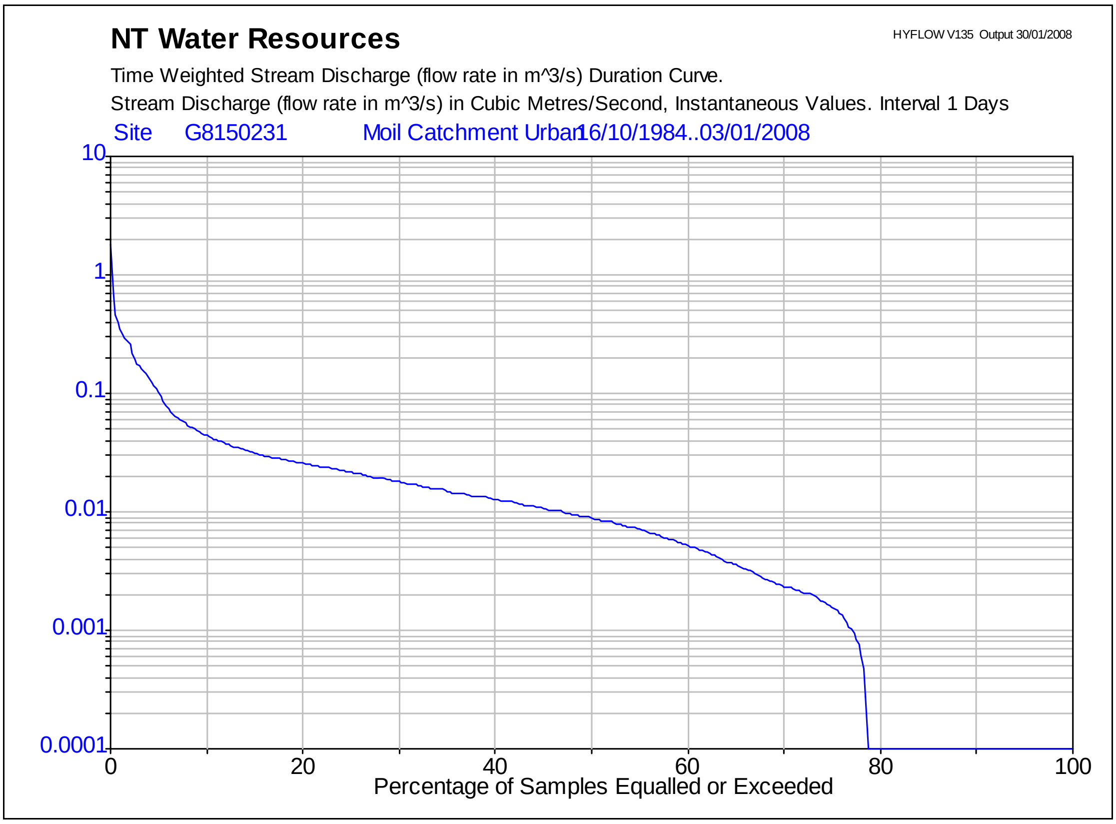
(a) Blackmore River flow duration curve.



(b) Elizabeth River flow duration curve.



(c) Karama Drain flow duration curve.



(d) Moil Drain flow duration curve

Appendix 3: Soluble Nitrogen and Phosphorus.

The chemical form of a nutrient will determine the level of impact it will have on the environment. Soluble forms of nutrients are available for immediate uptake by algae, and are more likely to have an immediate impact of the receiving environment.

The most soluble forms of nitrogen are ammonium and nitrate ions with ammonium tending to readily bonded to soil particles. These forms of nitrogen are also preferentially utilised by algae and typically assimilated rapidly in the nitrogen limited aquatic ecosystems of Darwin Harbour.

Phosphorus is categorised as either dissolved or particulate. Inorganic dissolved phosphorus occurs as orthophosphate (PO_4). Particulate phosphorus includes phosphorus incorporated into mineral structures, adsorbed on to surfaces and bound to organic matter.

The table below outlines the nutrient concentrations during the 2006/07 wet season in the Moil catchment.

Table A1: Flow weighted mean concentration and export coefficients for nitrogen and phosphorus species of Moil Catchment (2006/07).

	PO_4 as P	**TP as P**	**NO_2 as N**	**NO_3 as N**	**TKN**	**NH_3 as N**	**TN**
Flow Weighted Mean Concentration (mg/L)	0.053	0.088	0.002	0.36	0.466	0.094	0.82
Export coefficient (kg/ha)	0.88	1.4	0.037	5.91	7.65	1.55	13.6

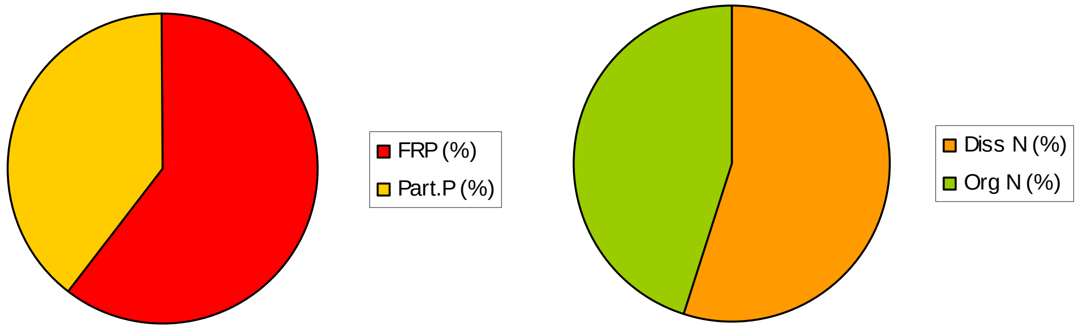
N and P Pool Contribution from an Urban Catchment

The contribution of soluble P to the phosphorus pool for the Moil station is approximates 60%, with particulate P constituting the remaining 40%, as shown in the following figure A1. Organic N assumes the largest proportion of the N pool. Dissolved N comprised 55% of the N pool with nitrate the most significant contributor. The remaining 45% was in the form of organic nitrogen (Figure A1). Comparison with the industrial catchment of Winnellie and other rural catchments is presented in Figure A1.

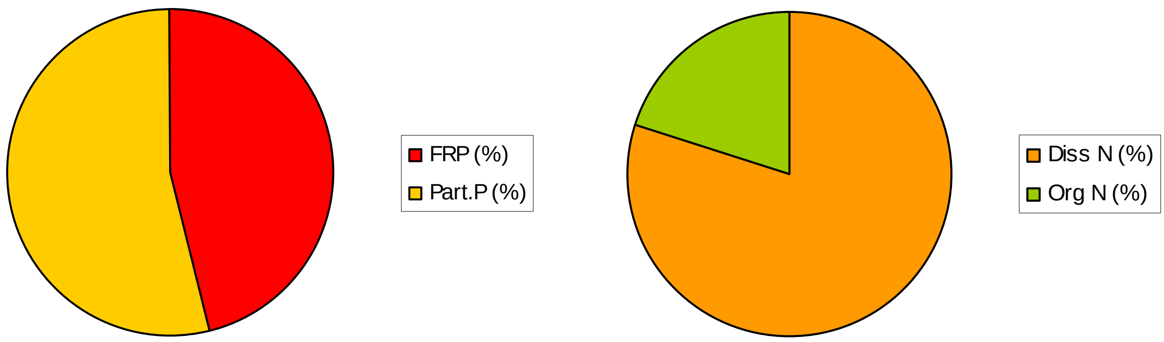
Land-use and Nutrient Fractionation

Schult (2004) found that nutrient concentrations for rural catchments were markedly lower than those of the industrial catchment of Winnellie. A large proportion of nutrients in rural catchments are present in particulate form. In contrast, nitrogen and phosphorus in the industrial and urban subcatchments are predominantly in soluble form with the industrial catchment of Winnellie delivering loads with up to 80% in the dissolved nitrogen form, predominantly nitrate.

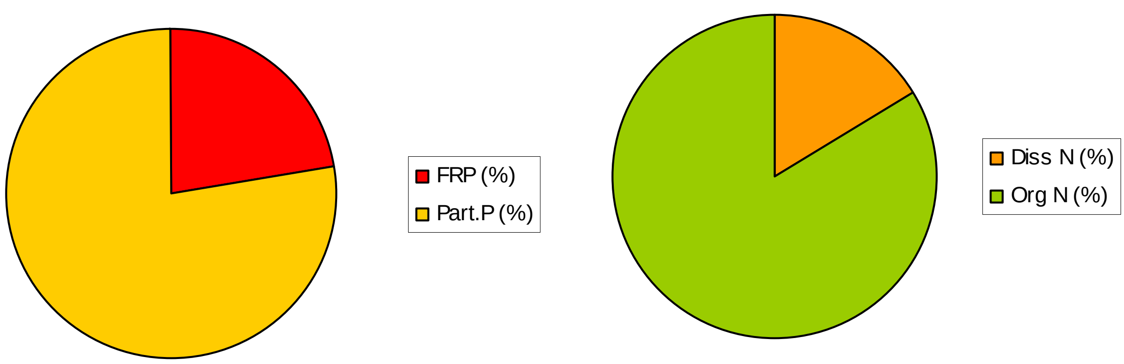
Figure A1: Percentage proportion of N and P species from urban, industrial and rural catchments.



(a) Moil (Urban) Catchment P and N Pool (%)



(b) Winnellie (Industrial) Catchment P and N Pool (Source: Schult 2004)



(c)Rural Catchments P and N Pool (Source: Schult 2004)

The Winnellie catchment consists primarily of large tracts of impervious surface and contains little vegetation that would typically take up nitrate. Run-off from the industrial properties in the Winnellie subcatchment conveys higher amounts of dissolved N than rural streams. Similarly the urban catchments appear to contribute a greater proportion of dissolved N in comparison to the rural catchments. Receiving waterways of these industrial and urban systems are likely to receive nutrients in a more bioavailable form.

Seasonal trends in nutrient levels and fractionation are apparent in rural catchments (Schult, 2004). Elevated nitrogen and phosphorus are typically detected in the early part of the wet season indicating that nutrients are flushed from the catchment with the onset of early rains. The subcatchments with principally urban land-use contribute a disproportionate amount of the soluble fraction of nutrients to the harbour compared to non-urban catchments.

Appendix 4: ACLUMP land-use classification

1 = Level 1, 2 = Level 2, 3 = Level 3

ACLUMP category	Land-use Classification	ACLUMP category	Land-use Classification	ACLUMP category	Land-use Classification
Airports/aerodromes	3	Landscape	1	Rehabilitation	2
Aquaculture	2	Legume/grass mixtures	2	Remnant native cover	1
Cattle	2	Manufacturing and industrial	3	Research facilities	2
Channel/aqueduct	3	Marsh/wetland	1	Reservoir - intensive use	2
Cleared	2	Marsh/wetland - conservation	1	Reservoir/dam	2
Commercial services	3	National park	1	River	1
Cropping	2	Native/exotic pasture mosaic	2	Roads	3
Defence	2	Natural feature protection	1	Rural residential	2
Defence facilities	3	Nature conservation	1	Seasonal horticulture	2
Drainage channel/aqueduct	3	Navigation and communication	3	Services	3
Effluent pond	3	NT rural	2	Shadehouses	2
Electricity generation/transmission	3	Other conserved area	1	Softwood production	2
Estuary/coastal waters	1	Perennial horticulture	2	Solid garbage	3
Gas treatment, storage & trans	3	Pigs	2	Sown grasses	2
Grazing modified pastures	2	Ports and water transport	3	Stormwater	3
Habitat/species management area	1	Poultry	2	Supply channel - water pipe	3
Hay & silage	2	Protected landscape	1	Surface water supply	1
Intensive horticulture	2	Public services	3	Traditional indigenous uses	1
Irrigated perennial horticulture	2	Quarries	3	Urban residential	3
Irrigated sown grasses	2	Railways	3	Utilities	3
Irrigated tree fruits	2	Recreation and culture	2	Water	1
Lake - conservation	1	Recreation and culture - church	3	Water storage	1
Lake - production	2	Recreation and culture - parks	2		

Appendix 5: Export Coefficients *(Note: Data is not presented for the Winnellie or Bees Creek catchments due to their inaccurate rating tables).*

Catchment	Wet Season	TP kg/ha	TN kg/ha	Al g/ha	As g/ha	Cd g/ha	Cr g/ha	Cu g/ha	Ni g/ha	Pb g/ha	Zn g/ha	TSS kg/ha	VSS kg/ha
Karama	90/91	0.7	11				81	110		320	1900	610	
	91/92	0.4	5				55	38		361	331	956	228
Manton	96/97	0.301	4.35	9.34	0.483	7.46	58.3		6.76	7.02	39.9	154	49.0
Moil	95/96	0.730	4.59		5.38	2.88	7.13	98.1	4.28	106	300	295	86.6
	96/97	2.27	16.9		14.3	1.74	16.9	52.5	8.95	350	670	820	218
	06/07	1.45	13.6	50300	13.1	1.15	35.6	828	24.9	125	1027	928	227
Berry	99/00	0.0758	2.17	1390	1.76	0.445	3.63	4.97	1.81	2.45	24.1	69.8	18.3
	00/01	0.0510	1.03	2240	1.23	0.246	3.84	6.27	3.08	2.86	28.9	79.2	12.5
	01/02	0.0361	0.802	915	0.689	0.138	0.289	2.50	0.900	1.59	6.66	58.0	12.4
	06/07	0.0769	1.73	8230	2.52	0.132	6.00	13.8	4.52	4.76	30.9	71.1	23.4
Howard	05/06	0.0563	2.98	2120	1.43	0.074	3.11	2.72	2.14	1.70	12.7	62.3	24.9
	06/07	0.0621	2.80	4670	1.39	0.171	4.39	14.6	2.40	2.41	56.3	59.9	23.1
Elizabeth	95/96	0.0399	1.46		1.42	0.633	2.54	20.8	2.10	1.85	116	60.1	16.2
	96/97	0.2931	5.20		4.82	0.716	7.56	4.69	4.69	4.95	104	204	54.5
	01/02	0.0383	1.38	997	0.956	0.191	0.425	2.86	1.58	1.24	7.86	32.5	8.67
	02/03	0.1290	3.12	3690	2.03	0.406	6.10	5.55	5.33	3.54	16.7	112	26.5
	05/06	0.1120	5.05	3370	3.54	0.126	6.68	6.73	6.23	3.89	25.6	163	54.1
	06/07	0.0870	3.27	7020	2.77	0.093	7.14	16.2	5.41	3.53	46.1	89.3	28.7
Peel	05/06											189	80.0
	06/07	0.0775	4.78	9800	3.72	1.15	6.77	40.8	7.58	8.53	121	122	34.4
Bennett	05/06											156	54.3
	06/07	0.0378	4.69	5130	2.21	1.54	4.84	30.8	4.91	3.35	146	46.6	26.8
Celia	95/96	0.0422	0.691		0.469	0.134	2.23	5.97	1.54	1.34	2.77	47.9	8.32
	96/97	0.505	6.58		3.71	1.31	13.83	21.9	9.81	11.9	346	288	63.6

Appendix 6: Rainfall standardised export coefficients.

Catchment	Wet Season	Rainfall (m)	TP kg/ha/m	TN kg/ha/m	Al g/ha/m	As g/ha/m	Cd g/ha/m	Cr g/ha/m	Cu g/ha/m	Ni g/ha/m	Pb g/ha/m	Zn g/ha/m	TSS kg/ha/m	VSS kg/ha/m
Karama	90/91	2.30	0.304	4.78	-	-	-	35.2	47.8	-	139	826	265	0
	91/92	1.11	0.359	4.48	-	-	-	49.3	34.1	-	324	297	857	204
Moil	95/96	1.45	0.502	3.16	-	3.70	1.98	4.91	67.5	2.94	72.9	206	203	59.6
	96/97	2.49	0.911	6.78	-	5.74	0.698	6.78	21.1	3.59	140	269	329	87.5
	06/07	1.64	0.883	8.28	30600	7.98	0.700	21.7	504	15.2	76.1	626	565	138
Urban average			0.59	5.50	30600	5.81	1.13	23.6	135	7.24	150	444	444	97.82
Manton	96/97	2.19	0.138	1.99	4.27	0.221	3.41	26.7	-	3.09	3.21	18.3	70.5	22.4
Berry	99/00	2.14	0.0354	1.01	649	0.822	0.208	1.70	2.32	0.846	1.14	11.3	32.6	8.55
	00/01	1.62	0.0315	0.637	1380	0.760	0.152	2.37	3.88	1.90	1.77	17.9	48.9	7.73
	01/02	1.27	0.0284	0.631	720	0.542	0.109	0.227	1.97	0.708	1.25	5.24	45.6	9.75
	06/07	1.68	0.0457	1.03	4890	1.50	0.0785	3.57	8.20	2.69	2.83	18.4	42.3	13.9
Howard	05/07	1.99	0.0283	1.50	1070	0.720	0.0373	1.57	1.37	1.08	0.856	6.39	31.4	12.5
	06/07	1.80	0.0345	1.56	2600	0.773	0.0951	2.44	8.12	1.33	1.34	31.3	33.3	12.8
Elizabeth	95/96	1.83	0.0218	0.796	-	0.774	0.345	1.39	11.3	1.15	1.01	63.3	32.8	8.83
	96/97	2.31	0.127	2.25	-	2.09	0.310	3.27	2.03	2.03	2.14	45.0	88.3	23.6
	01/02	1.47	0.0261	0.941	680	0.652	0.130	0.290	1.95	1.08	0.845	5.36	22.2	5.91
	02/03	1.76	0.0733	1.77	2100	1.15	0.231	3.47	3.15	3.03	2.01	9.49	63.6	15.1
	05/06	1.92	0.0583	2.63	1750	1.84	0.0655	3.48	3.50	3.24	2.02	13.3	84.8	28.1
	06/07	1.64	0.0529	1.99	4270	1.69	0.0566	4.34	9.86	3.29	2.15	28.0	54.3	17.5
Peel	05/06	2.17	-	-	-	-	-	-	-	-	-	-	87.0	36.8
	06/07	1.46	0.0532	3.28	6730	2.55	0.789	4.65	28.0	5.20	5.85	83.0	83.7	23.6
Bennett	05/06	1.88	-	-	-	-	-	-	-	-	-	-	83.2	28.9
	06/07	1.81	0.0209	2.59	2830	1.22	0.851	2.67	17.0	2.71	1.85	80.7	25.7	14.8
Celia	95/96	1.54	0.0273	0.448	0	0.304	0.087	1.45	3.87	0.998	0.868	1.79	31.0	5.39
	96/97	2.19	0.231	3.01	0	1.70	0.599	6.33	10.0	4.49	5.44	158	132	29.1
Non-urban average			0.061	1.65	1978	1.14	0.444	4.11	7.28	2.29	2.15	35.1	57.6	17.1

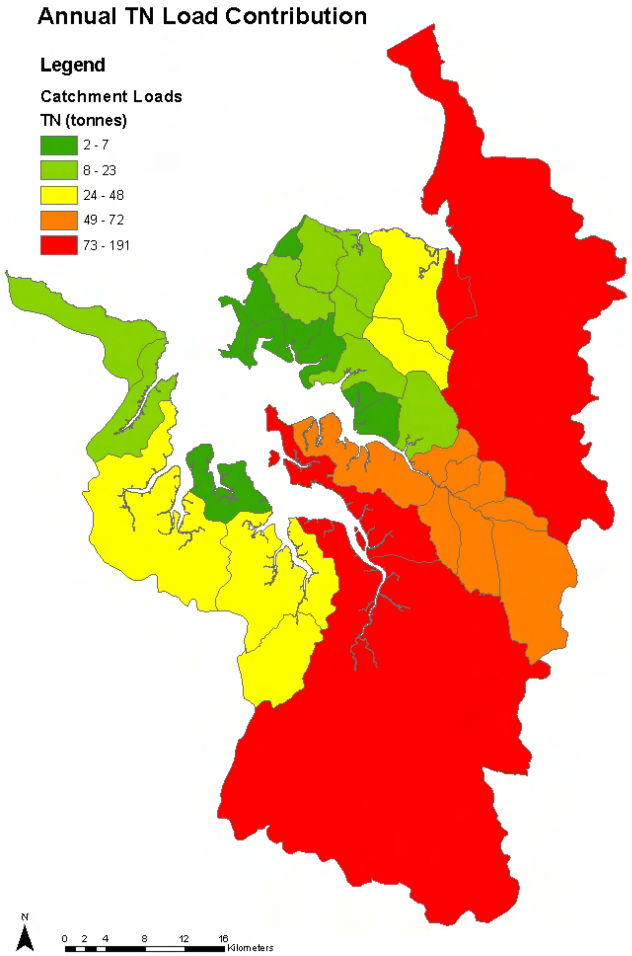
Appendix 7: Predicted pollutant loads to Darwin Harbour for a below average wet season rainfall (1.01m), 1991/92.

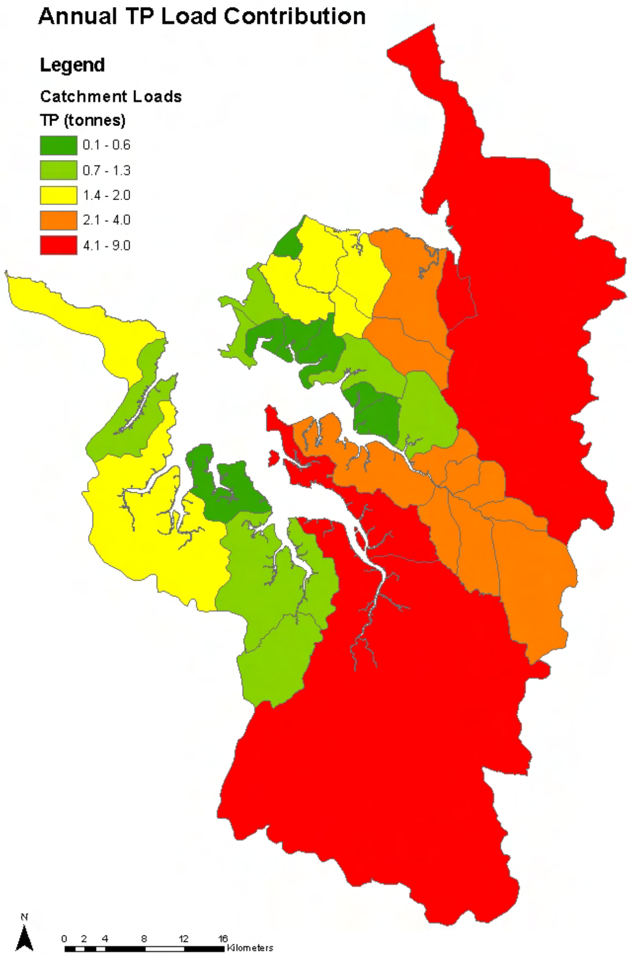
Catchment	TN	TP	Al	As	Cd	Cr	Cu	Ni	Pb	Zn	TSS	VSS
	t	t	t	kg	kg	kg	kg	kg	kg	kg	t	t
Blackmore	112	4.37	170	90.0	18.1	216	798	152	505	2980	4450	1280
Bleeser	3.69	0.360	9.94	4.02	0.790	14.9	80.6	5.41	86.1	269	284	65.6
Buffalo	10.3	1.17	30.8	12.0	2.340	47.0	264	15.4	290	873	889	200
Charles Point	12.7	0.960	28.4	12.5	2.460	40.8	205	18.1	203	698	793	195.0
Creek A (middle arm)	2.08	0.060	2.72	1.57	0.320	3.250	9.43	2.78	2.48	38.4	69.1	21.6
Darwin CBD	3.13	0.350	9.32	3.62	0.710	14.2	79.6	4.67	87.4	264	269	60.4
Elizabeth East Arm	41.8	1.84	67.5	34.6	6.95	88.1	349	57.1	254	1280	1790	502
Howard	101	4.68	168	84.7	17.0	221	902	138	689	3260	4470	1240.0
Hudson	7.81	0.780	21.3	8.56	1.68	31.9	174	11.5	186	580	608	140.0
Kings	26.3	2.38	66.7	27.6	5.44	98.6	523	38.1	548	1760	1890	445.0
Micket	11.1	0.890	25.9	11.1	2.20	37.5	192	15.9	194	651	726	176
Mitchell	8.060	0.500	15.8	7.35	1.46	22.0	102	11.3	93.6	356	433	112
Myrmidon	0.960	0.090	2.440	1.01	0.200	3.61	19.1	1.40	20.0	64.2	69.2	16.3
Palmerston Sth	2.95	0.250	7.17	3.03	0.600	10.5	54.8	4.25	56.5	185	202	48.3
Pioneer Ck middle arm	20.5	0.620	27.5	15.6	3.16	33.2	101	27.4	35.4	405	702	216
Rapid	11.5	1.34	35.1	13.5	2.64	53.7	303	17.3	334	1000	1010	227
Reichardt	2.39	0.240	6.52	2.62	0.510	9.78	53.3	3.51	57.2	178	186	43.0
Sadgroves	2.81	0.260	7.20	2.97	0.580	10.7	56.9	4.08	59.8	191	205	48.0
Sandy	1.98	0.220	5.90	2.29	0.450	9.00	50.5	2.95	55.4	167	170	38.3
West arm	22.6	0.820	33	17.9	3.60	41.3	144	30.6	80.1	549	857	253
Woods Inlet	7.60	0.550	16.5	7.33	1.45	23.6	117	10.8	114	400	460	114
Total	413	22.7	757	364	72.6	1030	4580	572	3950	16100	20500	5440

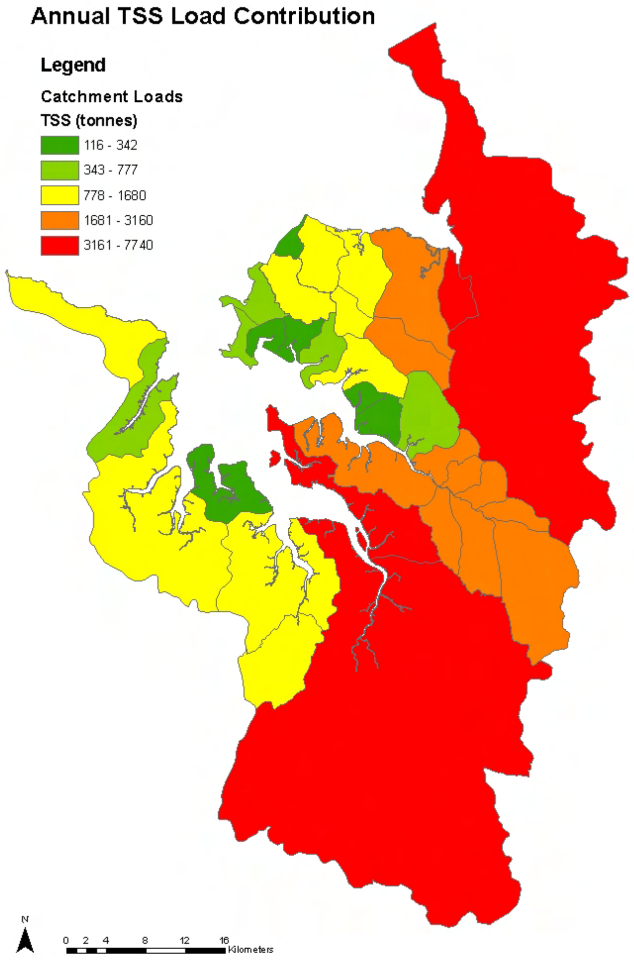
Appendix 8: Predicted pollutant loads to Darwin Harbour for an above average wet season rainfall (2.67), 1998/99.

Catchment	TN	TP	Al	As	Cd	Cr	Cu	Ni	Pb	Zn	TSS	VSS
	t	t	t	kg	kg	kg	kg	kg	kg	kg	t	t
Blackmore	306	13.9	529	224	80.0	829	2100	421	1370	8730	12400	3450
Bleeser	10.90	0.980	48.8	10.5	2.41	41.9	213	14.5	228	720	756	174
Buffalo	31.0	3.11	159.0	31.5	6.58	127	697	41.0	766	2320	2360	529
Charles Point	36.5	2.68	126.0	32.0	8.63	125	540	49.2	539	1900	2140	519
Creek A (middle arm)	5.61	0.210	6.72	3.86	1.51	14.0	24.8	7.76	7.32	119	196	58.2
Darwin CBD	9.39	0.940	47.9	9.53	1.99	38.5	210	12.4	231	700	712	160
Elizabeth East Arm	115	5.69	227	86.7	29.7	323	921	158	684	3670	4950	1350
Howard	279	14.3	583	213	71.4	796	2380	382	1850	9330	12300	3320
Hudson	23.1	2.11	105.0	22.4	5.07	89.4	459	30.7	493	1550	1620	372
Kings	76.8	6.50	318	71.8	17.4	284	1380	103	1450	4720	5050	1180
Micket	32.1	2.47	118.0	28.7	7.49	113.0	507	43.2	515	1760	1950	468
Mitchell	22.7	1.43	64.0	18.7	5.57	71.7	270	30.8	249	985	1180	298
Myrmidon	2.81	0.240	11.60	2.63	0.640	10.40	50.5	3.76	53.0	173	185	43.3
Palmerston Sth	8.56	0.690	33.5	7.84	1.96	30.9	145	11.5	150	499	542	128
Pioneer Ck middle arm	55.4	2.12	71.1	38.5	14.8	140.0	267	76.6	101.0	1240	1980	583
Rapid	34.7	3.56	182.0	35.7	7.29	144	800	45.8	884	2660	2690	600
Reichardt	7.07	0.650	32.3	6.86	1.55	27.4	141	9.40	151	475	496	114
Sadgroves	8.22	0.700	34.6	7.73	1.85	30.7	150	11.0	158	513	546	128
Sandy	5.94	0.600	30.4	6.03	1.26	24.4	133	7.85	147	444	451	101
West arm	61.7	2.65	97.2	44.4	16.3	163	380	85.0	219	1630	2390	680
Woods Inlet	21.7	1.55	72.2	18.8	5.17	73.0	309	29.3	304	1090	1240	304
Total	1150	67.1	2900	921	289	3500	12100	1570	10600	45200	56200	14600

Appendix 9: Catchment Zone contribution to Annual Loads for Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS).







Annual TSS Load Contribution
Legend
Catchment Loads
TSS (tonnes)
116 - 342
343 - 777
778 - 1680
1681 - 3160
3161 - 7740
N
0 2 4 8 12 16
Kilometers